[Journal of Environmental Science and Sustainable Development](https://scholarhub.ui.ac.id/jessd)

Volume 5
Issue 1 *July* Article 6

7-31-2022

# ARE RESIDENTS IN URBAN AREAS OF NIGERIA EXPOSED TO HEALTH-IMPACTING LEVELS OF NOISE POLLUTION?

Obinna C.D. Anejionu
*Department of Geoinformatics and Surveying, University of Nigeria Enugu Campus, Uyo, Nigeria*, Obinna.anejionu@unn.edu.ng

Elijah S. Ebinne
*Department of Geoinformatics and Surveying, University of Nigeria Enugu Campus, Uyo, Nigeria*, elijah.ebinne@unn.edu.ng

Kelechi I. Nwosu
*Department of Geoinformatics and Surveying, University of Nigeria Enugu Campus, Uyo, Nigeria*, kelechi.nwosu@unn.edu.ng

Miriam G. U. Anejinou
*Department of Pharmaceutical Microbiology and Biotechnology, Nnamdi Azikiwe University, Awka, Nigeria*, gu.anejionu@unizik.edu.ng

*See next page for additional authors*



## Recommended Citation

Anejionu, Obinna C.D.; Ebinne, Elijah S.; Nwosu, Kelechi I.; Anejinou, Miriam G. U.; and Ndukwu, Raphael I. (2022). ARE RESIDENTS IN URBAN AREAS OF NIGERIA EXPOSED TO HEALTH-IMPACTING LEVELS OF NOISE POLLUTION?. *Journal of Environmental Science and Sustainable Development*, 5(1), 85-108.
Available at: https://doi.org/10.7454/jessd.v5i1.1096

# ARE RESIDENTS IN URBAN AREAS OF NIGERIA EXPOSED TO HEALTH-IMPACTING LEVELS OF NOISE POLLUTION?

Authors

Obinna C.D. Anejionu, Elijah S. Ebinne, Kelechi I. Nwosu, Miriam G. U. Anejinou, and Raphael I. Ndukwu

Journal of Environmental Science and Sustainable Development
Volume 5, Issue 1, Page 85-108
ISSN: 2655-6847
Homepage: http://scholarhub.ui.ac.id/jessd

# ARE RESIDENTS IN URBAN AREAS OF NIGERIA EXPOSED TO HEALTH-IMPACTING LEVELS OF NOISE POLLUTION?

**Obinna C. D. Anejionu[1*], Elijah S. Ebinne[1], Kelechi I. Nwosu[1], Miriam G. U. Anejinou[2], Raphael I. Ndukwu[1]**

[1]Department of Geoinformatics and Surveying, University of Nigeria Enugu Campus, Uyo, Nigeria

[2]Department of Pharmaceutical Microbiology and Biotechnology, Nnamdi Azikiwe University, Awka, Nigeria

[*]Corresponding author: obinna.anejionu@unn.edu.ng

(Received: 25 April 2021; Accepted: 5 July 2022; Publish: 31 July 2022)

## Abstract

Across the world urban dwellers are facing increasing risks of exposure to noise pollution. The World Health Organization (WHO) described noise pollution as an underestimated threat that can cause various health problems to humans and wildlife. In Nigeria, urban areas are experiencing increasing levels of noise pollution. In this study, a combination of low-cost noise sensors and GIS modelling were used to conduct a preliminary investigation of the spatiotemporal patterns of noise pollution in a prominent urban area in Nigeria. This was to ascertain whether residents are exposed to dangerous noise levels that could affect their health as well as to demonstrate the potentials of deploying network of sensors for real-time monitoring of noise pollution in urban areas of developing countries. We observed noise levels at 5 seconds intervals, over a period of 24 hours, at different strategic locations (e.g. Achara Layout, Abakpa, and Independence Layout) across the city. Using GIS analytics techniques, data obtained from field were used to produce noise maps of the city. We found that night-time noise levels ranged between 32 and 35dBA, which are below recommended limits by the Nigerian government and WHO. Daytime noise levels ranged between 44 and 66dBA, slightly exceeding recommended limits. This contradicts general perceptions that noise levels in the city are dangerously high. This study has given the first insight into the spatiotemporal patterns of noise levels across Enugu Metropolis. It is the first time a spatiotemporal study of noise pollution was conducted in the city, revealing noise footprints of various parts of the city.

**Keywords**: Environmental Management; Nigerian Cities; Noise Pollution; Urban Area Management; Urban Area Noise.

## 1. Introduction

Cities are facing enormous social, environmental, and economic challenges that have intensified in the past decade. Increasing population of cities across the world is expected to exacerbate these challenges. Noise pollution is a key environmental issue that many urban areas are facing. The deleterious effects of noise pollution on public health have continued to generate great concern across the world. Long-term exposure to high levels of noise has been found harmful to humans and wildlife (Clark et al., 2020; Hegewald et al., 2020; Thompson et al., 2022; UNEP, 2022; WHO, 2022a). Hence, the World Health Organization (WHO) has set an annual average night exposure limit of 40 decibels (dB) (WHO, 2022b). People sleeping at noise levels above the limit for over a year could suffer health effects ranging from sleep disturbance and insomnia that could lead to mental disorders, to elevated blood pressure and heart attacks (long-term average night exposure to noise levels above 55dB) (Basner & McGuire, 2018; Kim & van den Berg, 2010; WHO, 2009a). Noise pollution could also trigger premature illness and death (WHO, 2009a; 2009b). This is especially critical in developing countries with poor environmental regulation policies.

Owing to increasing population, poor environmental regulatory framework and policy enforcement, urban areas in Nigeria like in other developing countries are experiencing increasing levels of noise pollution (Egbenta et al., 2021; Omubo-Pepple et al., 2010; This Day Newspaper, 2021; Wokekoro, 2020). Despite the attention pollution has generated globally, industrializing countries such as Nigeria are facing increasing high levels of pollution, as they continue to push for economic growth (Bearak, 2016; Laake, 2017). Businesses and industries do not strictly adhere to existing laws and policies. In many developing countries, where local industries are rapidly developing such as India, Kenya, Pakistan, China, Bangladesh, and Madagascar, up to one in four deaths can be attributable to pollution (Stockholm Resilience Centre, 2017).

Whereas there has been some considerable level of awareness of air pollution in developing countries such as Nigeria, the negative impacts of noise pollution are often overlooked or underestimated by the governments and people. This is especially the case with urban residents in Nigeria, where noise pollution is greatest. Environmental policy makers in the country also fail to enforce strict regulations and monitoring mechanism to curtail environmental noise (Maduemezia 2002; Omubo-Pepple et al., 2010). This lackluster attitude towards noise pollution abatement in the country is largely attributable to the failure of the science and research community to clearly demonstrate the magnitude and extent of exposure to noise (how noise affects the public health), and effectively communicate findings to the general public in a way they could easily appreciate. For instance, in the study area, no research has been undertaken to investigate the spatial extent and magnitude of noise pollution in the area and possible exposure of residents to it. As a result, people are to a large extent oblivious of the dangers of increased levels of noise pollution on their wellbeing.

Therefore, this research firstly, undertook a spatiotemporal investigation and mapping of noise pollution in Enugu metropolis as means to ascertain residents' exposure levels to noise pollution. Secondly, the research was conducted to demonstrate potential benefits of deploying multiple low-cost sensors across cities in a developing country such as Nigeria for monitoring and mapping noise pollution in real-life for effective management and mitigation. Maps are about the most effective and scientific way of communicating environmental and spatial information to a wide range of audience. It aids the visualization and understanding of spatial relationships, patterns, and trends between environmental features and processes.

Due to the recognition of the importance of understanding the extent, magnitude (levels) and impacts of noise pollution in European cities, the European Union directed (as a matter of policy) that noise pollution maps be produced for all urban areas (with population above 250,000) across the continent on a regular basis (Directive, 2002; Guardian, 2014). Despite this recognition and consequent extensive study and mapping of noise pollution by many developed countries, empirical studies comprehensively investigating the spatial distribution, levels and associated impacts of noise pollution are lacking in developing countries. Consequently, the findings are lacking in providing adequate strategic information and key deliverables capable of driving or supporting policy changes and appropriate response from the government and the public.

### 1.1. Noise pollution impacts

Exposure to noise pollution could cause health issues ranging from mild to severe impacts. Noise disrupts sleep, leading to sleeping disorders, and has been found to cause cardiovascular diseases and psychological stress (Basner & McGuire, 2018). High levels of noise severely harm people's health (Hegewald et al., 2020). This is in addition to affecting daily human activities at home, workplace, school, and during recreation (WHO, 2022b). Several studies have found various negative impacts of noise on the wellbeing of children. Noise may also cause impairment in early childhood development that could have lifelong effects on academic achievement and health. Studies have found that chronic exposure of children to aircraft noise could affect cognitive performance, and impacts on blood pressure and catecholamine hormone secretion (Thompson et al., 2022; WHO, 2022a).

DOI: https://doi.org/10.7454/jessd.v5i1.1096 

Prominent impacts include impaired reading comprehension and high levels of noise annoyance (Haines et al., 2002); deficits in language skills (Evans & Maxwell, 1997); and higher mean systolic and diastolic blood pressures and lower mean heart rate (Evans et al., 2001; Regecova and Kellerova,1995). For adults, exposure to ambient noise levels as low as 45dB LAeq could impair speech communication for the elderly (Berglund, 1996). Furthermore, in addition to the impacts on public health, noise pollution has been noted to have hazardous effects on the rural environment biodiversity and wildlife (Kight & Swaddle, 2011; Pepper et al., 2003; Radle, 2007; Sordello et al, 2019). The Interdepartmental Group on Costs and Benefits Noise subject group (IGCB(N)) identified four groups of impacts of noise, which include: amenity, health, productivity, and ecosystems (IGCB-N, 2010).

The WHO noise guidelines recommend less than 30 A-weighted decibels (dB(A)) in bedrooms during the night for a sleep of good quality and less than 35dB(A) in classrooms to allow good teaching and learning conditions (WHO, 2022a). Furthermore, the guidelines stipulate average annual night noise of less than 40 dB(A) outside of bedrooms. It is usually recommended that to minimize hearing risk, exposure to noise should not exceed 90dBA for a maximum limit of eight hours per day, and this should be followed by at least ten hours of recovery time at 65dBA or lower (National Environmental Board, 1976). In addition, maximum noise level near residential area, hospitals and educational establishments should not exceed 65dBA.

Noise pollution poses serious challenge to both developed and developing countries. For instance, one in five Europeans are reported to be regularly exposed to sound levels at night that could significantly damage their health (WHO, 2009a). Traffic noise alone has been found to be harmful to almost one-third of person in the WHO European Region (Guardian, 2014; WHO, 2022b). Urban areas in many developing countries are relatively nosier than those in Europe. Hence, it would be safe to assume that the proportion of people affected by noise in such noisier environments would be higher.

In Nigeria, noise pollution is on the rise particularly in the urban areas due to increasing road traffic, social, and religious activities, and domestic usage of noisy power generators (Ibhadode et al., 2018; Omubo-Pepple et al., 2010). Omubo-Pepple et al. (2010) noted that despite Nigeria acknowledging the importance of monitoring noise levels as far back as the 1990s, by empowering the Federal Environmental Protection Agency (FEPA) with the responsibility of enforcing laws to regulate and control noise levels and impacts, noise pollution is yet to abate.

The recognition by the research community of the potential dangers of noise pollution in Nigeria has attracted the attention of some researchers who have investigated levels of noise pollution in certain cities and towns of the country. Some of the prominent ones include those that studied noise pollution in Enugu, Portharcourt, Owerri Agbor, Ughelli, Sapele, Ozoro, and Warri Calabar, and Yenagoa (Egbenta et al., 2021; Menkiti & Agunwamba, 2015; Nwaogazie & Owate, 2000; Omubo-Pepple et al., 2010). Consequently, three core sources of noise pollution in the country have been identified namely: private power generators, road traffic, and loudspeakers from religious and social activities (Omubo-Pepple et al., 2010). Like in the rest of the world, traffic noise is a leading source of noise pollution in Nigeria. Increasing urban population across the country results to increased road traffic usage. This in turn leads to increased levels of noise pollution as has been witnessed in other parts of the world (Brainard et al., 2003; DEFRA, 2013; DEFRA, 2019; Directive, 2002; Gayathri et al, 2012; Mehdi & Arsalan, 2008; Mishra et al., 2012; Ozdemir et al., 2014; Zannin et al., 2006).

Furthermore, due to poor power generation in Nigeria, many households and businesses use very noisy generators to power their homes and business. This is the case for both cities and some affluent rural areas. The situation is worse in tertiary institutions where various forms of allied small-scale businesses such as cyber cafes business centers thrive. Consequently, noise from these sources often disturbs academic activities and effective learning. In addition, activities of religious organizations competing for attention also result in daytime and night-time noise. Indeed, the proliferation of Pentecostal churches in virtually every nook and cranny of the country (especially in the southern parts) results in significant noise during the night-time. Social events such as marriage, burial ceremonies and festivals also generate considerable level of noise especially in the rural communities.

### 1.2. Mapping noise pollution

Map is an effective tool to communicate findings of research with geographic context to both experts and the public. Noise pollution mapping is essentially used to determine level of exposure of individuals to environmental noise, communicate information on environmental noise and its effects on the public; facilitate adoption of action environmental plans, and continuous monitoring of spatiotemporal variations in environmental noise quality (DEFRA, 2015; 2019; European Commission, 2015). Mapping of noise pollution is also used in identifying environmental equity in the distribution of noise. Environmental equity describes the equal sharing of risks/burden associated with a particular pollution among the various demographic classes and distributions of an area (Brainard et al., 2003; Lavelle, 1994). Where such environmental equity is not in place, environmental justice, which involves remedial actions to correct injustice imposed upon a specific subgroup of society is.

The mapping of noise pollution became imperative at the recognition that to understand and effectively manage and mitigate the impacts of noise, underlying interaction between noise and people (exposure) should properly be investigated and clearly represented. The European Commission (EC) suggested that mapping noise pollution should be undertaken at local levels to aid planning and provoke further debate on public policy (Commission of the European Commission (CEC), 1996[A1][A2][A3]). Subsequently, EC member states were directed to generate noise maps for all European conurbations with populations greater than 250,000 by 2005, with corresponding maps to be drawn up for urban areas with populations over 100,000 by the end of 2009 (Brainard et al., 2003; Directive, 2002).

Geospatial analysis of noise pollution has been found to play key role in the understanding and management of the health and environmental impacts of noise (; Farcaş & Sivertunb, 2010; Hadzi-Nikolova et al., 2012; Kurakula, 2007; Mehdi & Arsalan, 2008; Stoter et al., 2008). This is due to advanced capabilities of GIS that allows the integration, manipulation, and spatial analysis of measured noise levels, with other relevant environmental and demographic data to accurately represent noise distribution and exposure (Gan et al., 2012). In addition, the graphical representation of outputs enables efficient visualization and comprehension. Geospatial technologies also allow for the modeling of noise pollution across every point of a specific area of interest based on levels measured at discrete locations. Strategic maps produced from geospatial analysis of noise levels are in turn used by policy makers to access the overall exposure of the population to high levels of noise and the impacts of noise pollution on the health of the public.

Despite the importance of noise pollution mapping and its application in noise pollution monitoring and management in developed countries, there is a dearth of such maps in Nigeria. This is due to lack of regular and adequate data required to produce such maps. Whereas noise pollution has been investigated to a certain extent in some parts of the country, no published research till date has undertaken a geospatial investigation of noise pollution in Enugu. As a result, residents of the metropolis are unaware of how noise may have affected their wellbeing.

Most of the studies of noise pollution in Nigeria stopped short of spatially analyzing the measured noise pollution levels and investigating their interaction with the environment and the public, as has been conducted in most European, Asian, and other western cities (Brainard et al., 2003; Gan et al., 2012; Kim et al., 2012; Sadr et al, 2014; Tang & Wang, 2007; Vlachokostas et al., 2012). There is therefore need for the extensive investigation and modelling of noise pollution and impacts in the country. This is one of the gaps that this research, is hoping to address, by developing relevant methodologies through which such data could regularly be acquired with low-cost instruments, and noise maps produced on a regular basis.

## 2. Methods

### 2.1. Study area

This research used Enugu Metropolis as a trial site before subsequent rollout of the methods developed for a comprehensive study of noise pollution across cities in the country. Enugu is a key city in southern Nigeria, due to political, academic, and natural resource reasons. It is currently the capital of Enugu State (Figure 1). Enugu Metropolis is made up of 3 out of the 17 LGAs in the state namely: Enugu North, Enugu East and Enugu South. It has a population of over 700,000 as at 2006 national census, and an area of 556Km$^2$ (National Population Commission, 2010). The metropolis rose to geopolitical prominence due to the discovery of coal in commercial quantities in 1909. This brought about the emergence of a permanent cosmopolitan settlement, making it the oldest urban area in the Igbo-speaking southern part of the country (Egbenta et al., 2021). It was therefore natural that it became the administrative capital of the Eastern Region, the Republic of Biafra, and subsequently the East Central State, Anambra State and currently Enugu State.

Due to its prominence, it has continued to draw a lot of people from the rural areas and other parts of the country. There has been recent increase in commercial, academic, and industrial activities that has facilitated this urbanization process. However, this has exacerbated environmental problems in the metropolis and exerted a lot of pressure on local resources. Furthermore, due to poor power generation in Nigeria, many households and businesses in the city like in other cities across the country, use very noisy electric power generators to power their homes and business. The situation is worse in tertiary institutions where various forms of allied small-scale businesses such as cyber cafes, business centers thrive. Consequently, noise from these sources often disturbs academic activities and effective learning.

In addition, activities of religious organizations competing for attention also result in daytime and night-time noise. The proliferation of Pentecostal churches in virtually every nook and cranny of the country results in significant noise during the night-time. Social events such as marriage, burial ceremonies and festivals also generate considerable levels of noise especially in the suburbs and rural communities. These have made most residents to perceive that the noise levels they are exposed to could be harmful to their health (Menkiti & Agunwamba, 2015). Hence, buttressing the necessity for this research.

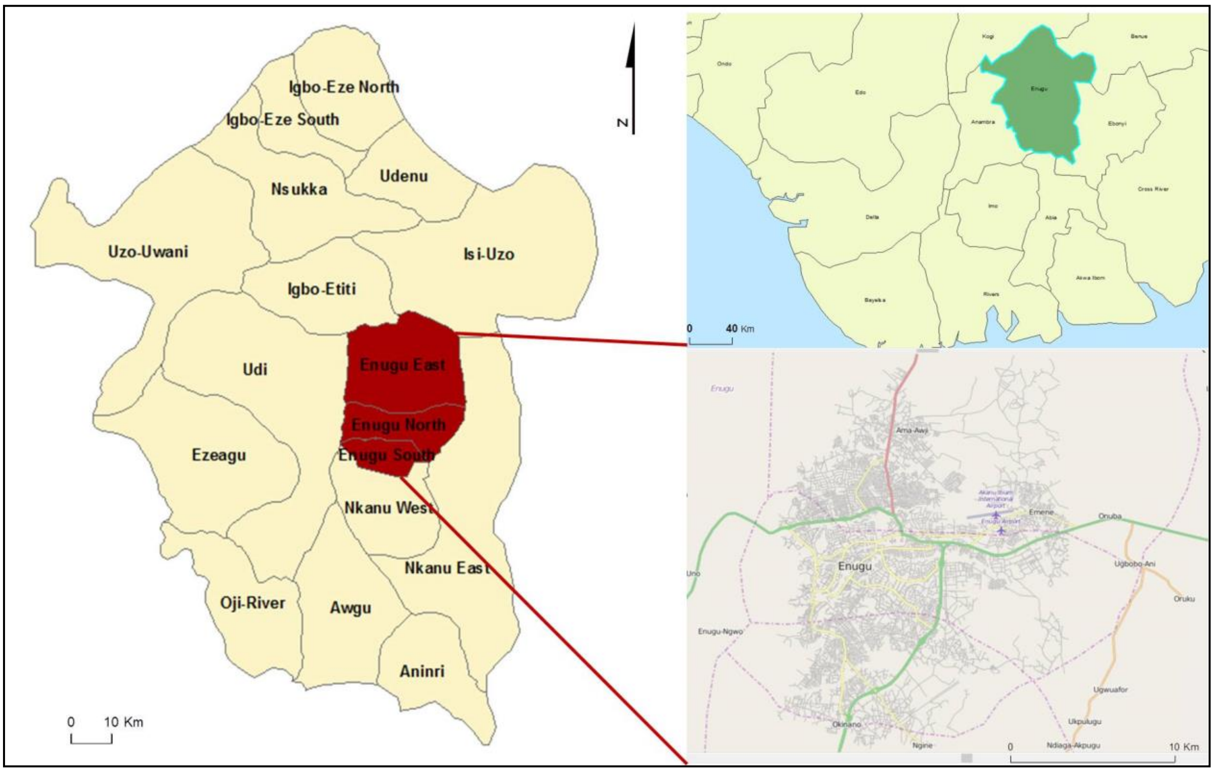


Figure 1. Map of Enugu State showing the locations of the 17 local government areas and the Enugu Metropolis. Street map of the metropolis and map of the neighbouring states are inset.

## 2.2. Data

Key data that used in this research include the following: noise level measurements from key locations across the metropolis, political maps and population distribution data. Measurements were made with a Volcraft sound level meter, that measures sound levels from 30 – 130dBA. Noise levels across the city were observed at 5 seconds interval for a 24-hour period, at strategic locations across the city comprising of high dense residential, commercial, and academic areas that would capture key activity areas, where most people in the city spend their time. Residential areas observed include Independence Layout; Trans Ekulu, Achara Layout, and Abakpa; commercial areas include Holy Ghost (Ogbete Main Market), Old Park, and Gariki; and the academic area include the University of Nigeria Enugu Campus (UNEC). The data used in this research was acquired in September 2017.

### 2.3. Approach

Results obtained from field observation were exported into a PostgreSQL database. Exploratory analysis of the data was conducted with Tableau Data Visualization software, and spatial analysis conducted with ArcGIS. To enhance understanding of noise pollution levels across the city, noise level trajectories for each location were obtained by plotting the noise levels against time over a 24-hour period Figures 3 and 4. These were assumed to be representation of noise level variations within the areas. Relevant statistics levels (maximum, minimum and average noise levels) were subsequently computed from the noise levels for each location (Table 2). The noise levels were subsequently grouped into three periods: day (06:00 to 19:00), evening (19:00 to 23:00), and night (23:00 to 06:00) time periods.

The maximum, minimum and average noise levels from each observed location were used alongside their geographic coordinates to perform spatial interpolation in the GIS platform. Three interpolation techniques (Kriging, IDW and Spline) were tested. To determine the optimal interpolation technique to be adopted for estimating noise across the city, noise level estimates from the techniques were validated with the leave-one-out approach. The validation process involves the estimation of noise level at each target location (with the three interpolation techniques), using observed noise levels at the remaining locations (i.e., observations from 7 out of 8 for each location). Thus, cross validating the results obtained from the spatial interpolation. The difference between the estimated and observed noise levels were noted as the interpolation error. The root mean square error (RMS) for each technique was subsequently computed (IDW = ±2.53, Kriging = ±2.54 and Spline ±3.45 decibels). The IDW technique with the least RMS error was adopted for estimating noise levels across the city.

## 3. Results and discussion

Key results from the research are presented in this section. Table 1 summarizes the relevant noise level statistics from the locations. Average daily noise levels ranged between 39 and 50dBA, while maximum noise levels ranged between 44 and 66dBA. The lowest noise levels ranged between 32 and 35dBA. Highest noise level (65.5dBA) was recorded at Holy Ghost at about midday, while the lowest (32.3dBA) was recorded at Old Park around 11pm.

Table 1. Summary statistics of noise levels obtained from key locations across Enugu

| Location | Long | Lat | Time | Max | Time | Min | Average |
|---|---|---|---|---|---|---|---|
| Abakpa | 7.515 | 6.492 | 20:23:53 | 57.9 | 03:16:38 | 34.2 | 47.39 |

| Location | Long | Lat | Time | Max | Time | Min | Average |
|---|---|---|---|---|---|---|---|
| Achara Layout | 7.502 | 6.410 | 20:00:38 | 60.8 | 01:59:43 | 34.6 | 44.75 |
| Gariki | 7.493 | 6.387 | 11:01:37 | 63.3 | 01:54:27 | 32.5 | 48.15 |
| Holy Ghost | 7.488 | 6.437 | 13:02:58 | 65.5 | 23:04:43 | 32.5 | 49.57 |
| Old Park | 7.482 | 6.438 | 11:59:40 | 65.2 | 22:57:10 | 32.3 | 49.56 |
| Independence Layout | 7.532 | 6.438 | 20:51:08 | 44.0 | 01:17:38 | 33.0 | 39.06 |
| Trans Ekulu | 7.493 | 6.478 | 09:35:46 | 49.6 | 01:21:06 | 33.4 | 40.81 |
| UNEC | 7.506 | 6.424 | 11:14:31 | 60.4 | 00:13:21 | 33.8 | 42.60 |

Figures 2 and 3 show the noise level trajectories for each observed location. The residential areas (Achara Layout, Abakpa, and Independence Layout) were marked by fluctuating noise levels during the day, with peak noise levels recorded during the evening time (between 7 and 10:00pm), except for Trans Ekulu, where peak noise value was observed around 9am (Figure 2). Lowest noise levels were recorded between 1:00am and 4:30 am.

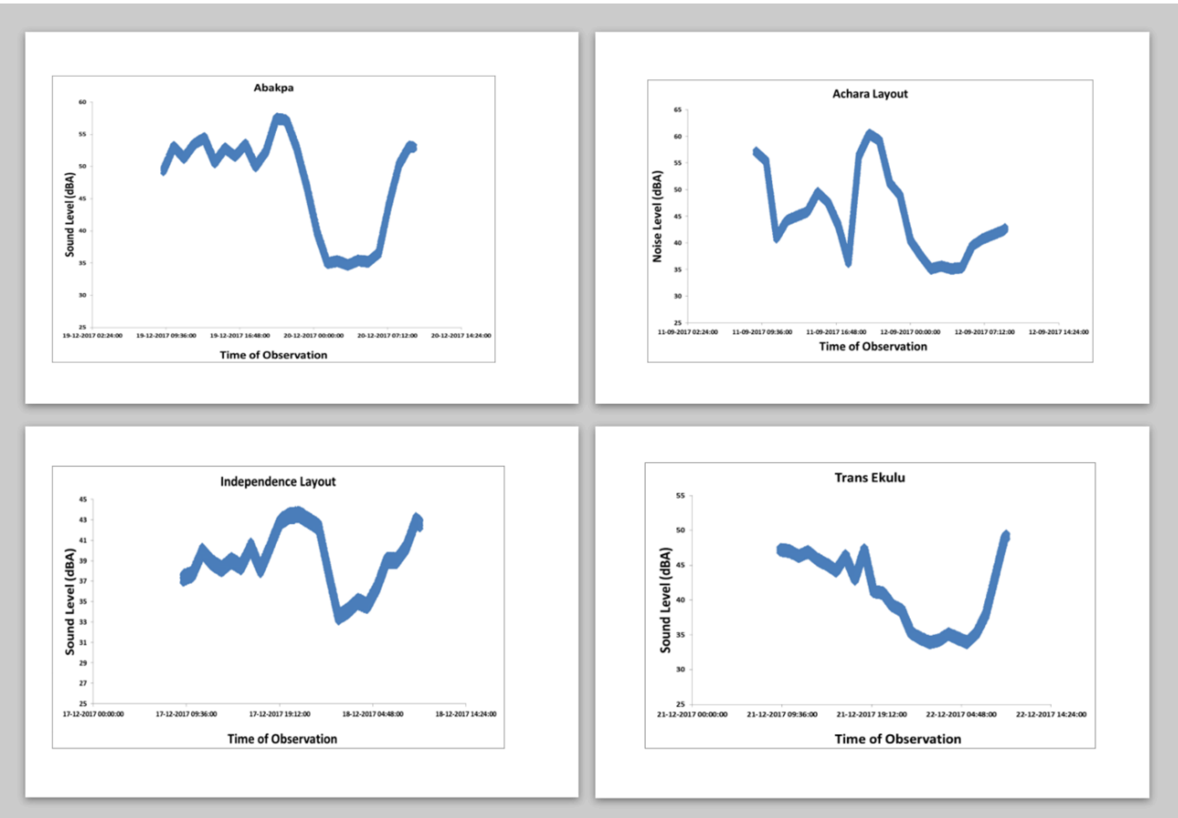


Figure 2. Noise level trajectories measured across key residential areas of Enugu

DOI: https://doi.org/10.7454/jessd.v5i1.1096 

However, for the commercial areas (Holy Ghost, Gariki and Old Park) there were sustained periods of high noise levels (> 60 dBA) during the day (between 8am and 6pm). The noise levels generally peaked for most of the locations between 11am and 1pm. Lowest noise levels were recorded between 9:30pm and 5am. For the academic environment, there are two short periods of sustained high noise levels with observed peaks around 11am and 1pm. However, sustained long periods of low noise levels were observed between 7pm and 6am.

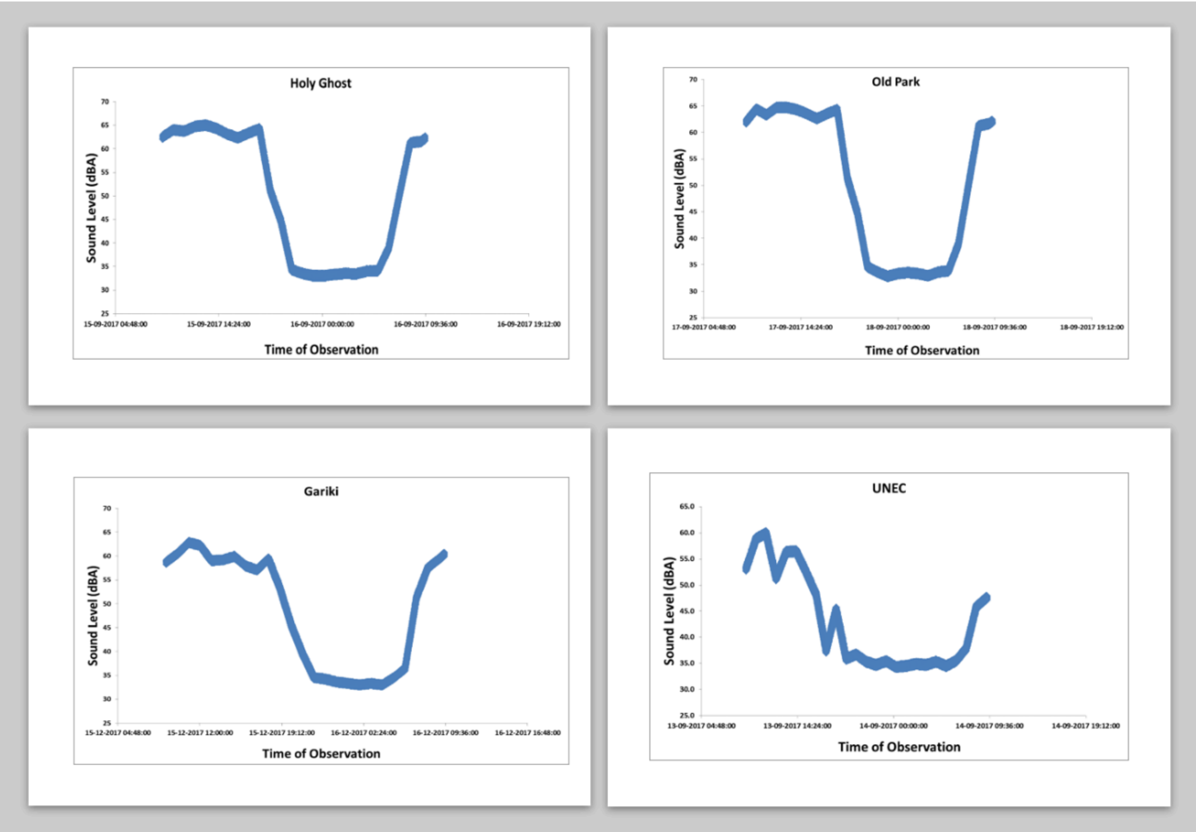


Figure 3. Noise level trajectories from commercial and academic activities

Based on the noise levels observed at the various locations, noise levels at every point in the city was estimated using spatial interpolation (see Section 4.3). Key results from the spatial interpolation are presented in Figure 4. Results show that on the average, people living or working in the western flank of the city are more exposed to high levels of noise than those in the eastern flank. Furthermore, results show that areas around Independence Layout and Trans Ekulu, were the quietest, while areas surrounding Holy Ghost and Gariki were the noisiest.

DOI: https://doi.org/10.7454/jessd.v5i1.1096 

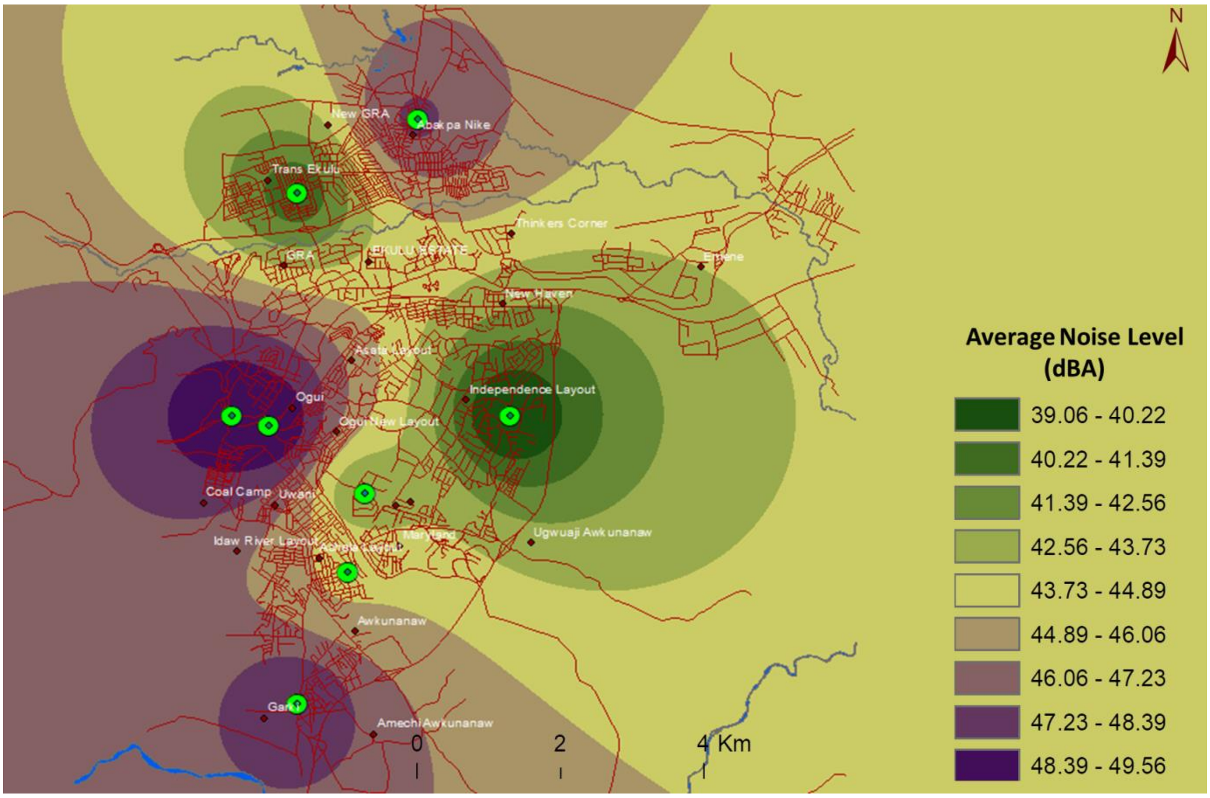


Figure 4. Average noise levels across various parts of Enugu metropolis

This research was undertaken as a preliminary study to investigate the spatial and temporal patterns of noise levels in Enugu metropolis, to ascertain if residents are exposed to unusually high noise levels that could affect their health. In-depth investigation of noise pollution is important due to significant deleterious effects of high levels of noise on children and adults (WHO, 2022a; 2022b). The essence of this study was to generate credible and compelling evidence of the magnitude and extent of noise pollution and exposure levels in the metropolis that could be associated to the health outcomes of the residents. Table 2 shows the permissible environmental noise limits in Nigeria (NESREA, 2009).

Table 2. Maximum permissible noise levels for general environment (First Schedule of National environmental (Noise Standards and Control) Regulation 2009)

| Facility | Maximum Permissible Noise Limits dB (A) (Leq) | |
|---|---|---|
| | Day | Night |
| Any building used as hospital, convalescence home, home for the aged, sanatorium and institutes of higher learning, | 43 | 35 |

| Facility | Maximum Permissible Noise Limits dB (A) (Leq) | |
|---|---|---|
| | Day | Night |
| conference rooms, public library, environmental or recreational sites | | |
| Residential buildings | 50 | 35 |
| Mixed residential (with some commercial and entertainment) | 55 | 45 |
| Residential + industry or small-scale production + commerce | 60 | 50 |
| Industrial (outside perimeter fence) | 70 | 60 |

Note: Above noise levels are weighted average in the facility over the hours defined for night (10:00pm-6:00am) and day (6:00am - 10:00Pm).

Findings from this research show that night-time noise levels from the various locations (Figures 2 and 3) are below permissible noise levels set by the Nigerian Government (Table 2), as well as those set by the World Health Organisation (WHO, 2018). According to WHO 2018 guidelines, annual average night exposure should not exceed 40dB in a residential area. Individuals exposed to night noise levels higher than 40dB over the year can have adverse health outcomes such as sleep disturbance and insomnia, while long-term average night exposure to noise levels above 55dB, can cause elevated blood pressure and heart attacks (WHO, 2019). This study revealed that for both residential and commercial areas, night noise levels are well below 40dB (Figure 5), indicating that residents may not have suffered from any negative health risk. This is particularly important as it contradicts the perception of many residents, as noted in the survey conducted by Menkiti and Agunwamba (2015).

Although earlier studies (Ibhadode et al., 2018; Menkiti & Agunwamba, 2015) have found average noise levels above 90dBA, these were measured within 1m from a power generating set (without accounting for loss as sound propagates), unlike in this study, where what was measured was the propagated noise levels (ambient noise) that reaches individuals in various parts of the city. Daytime noise levels from all the locations except Independence Layout and Trans Ekulu exceeded the stipulated limits of 55dB. With maximum noise level of 66dBA, daytime exposure to noise is not expected to have any significant negative health outcome, unless for those within 1 – 10m of the immediate noise sources (e.g., power generator sets, where noise levels could exceed what we observed. It has been suggested that maximum noise level near residential area, hospitals and educational establishments should not exceed 65dBA.

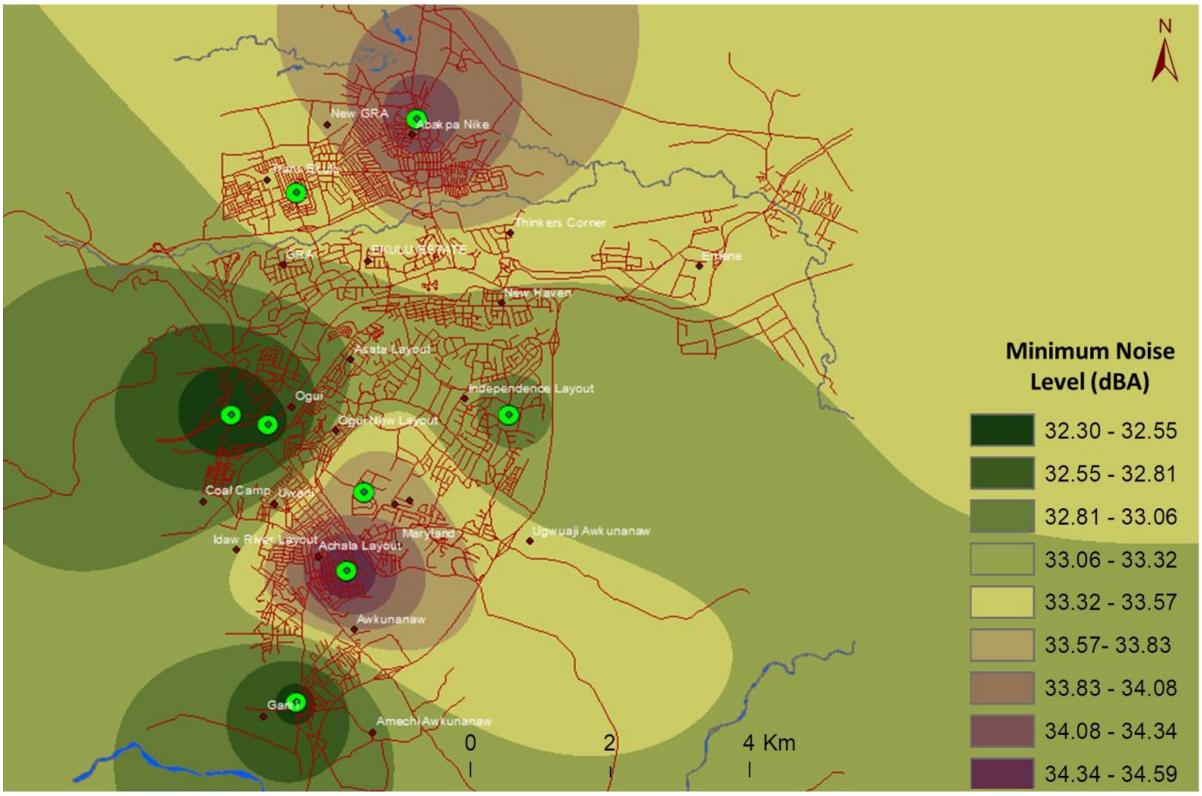


Figure 5. Minimum noise levels across various parts of Enugu metropolis

However, extended, and detailed noise level monitoring is required at more sites (up to 100) than currently used in this study, to verify these preliminary results. The extended study could also reveal daily, weekly/weekend, monthly, seasonal, and annual variations in noise level patterns, that could accurately be used in managing noise pollution and enabling mitigation mechanisms, by relevant government agencies.

The varying noise level patterns observed between commercial and residential areas depict the underlying activities of the areas. Whereas commercial areas had noise peaks between late morning and mid-afternoon, residential areas (except Trans Ekulu) had their peaks in the evening periods. In Nigeria, commercial activities generate considerable level of noise during the day due to various factors: noise from motor parks/transport activities, human traffic around the markets, power generators, megaphones, loudspeakers etc. For residential areas, the high noise levels recorded in the evening is probably due to the use of power generators by various households. Due to inadequate power supply, virtually every household in cities across Nigeria use power generators, which produce a considerable level of noise in the process.

DOI: https://doi.org/10.7454/jessd.v5i1.1096 

These are mostly deployed in the evenings after the day's work. Furthermore, whereas commercial areas have extended periods of high noise levels (daytime) and low noise levels (night-time), residential areas have shorter periods of low noise levels during the night, because of generator usage. Trans Ekulu although is usually classified as a residential area, has several commercial outlets and academic institutions that may have contributed to its behavior (peak noise levels during the day, similar to commercial areas), unlike other residential areas.

These results were to identify parts of the city mostly impacted by noise. Although the western flank of the city where most commercial activities take place is noisier during the day (Figure 6), results obtained from this study reveals that they are quieter during the night (Figure 5). This could be a mitigating factor on negative health impacts on residents, as the day and night noise may compensate for the effects of each other.

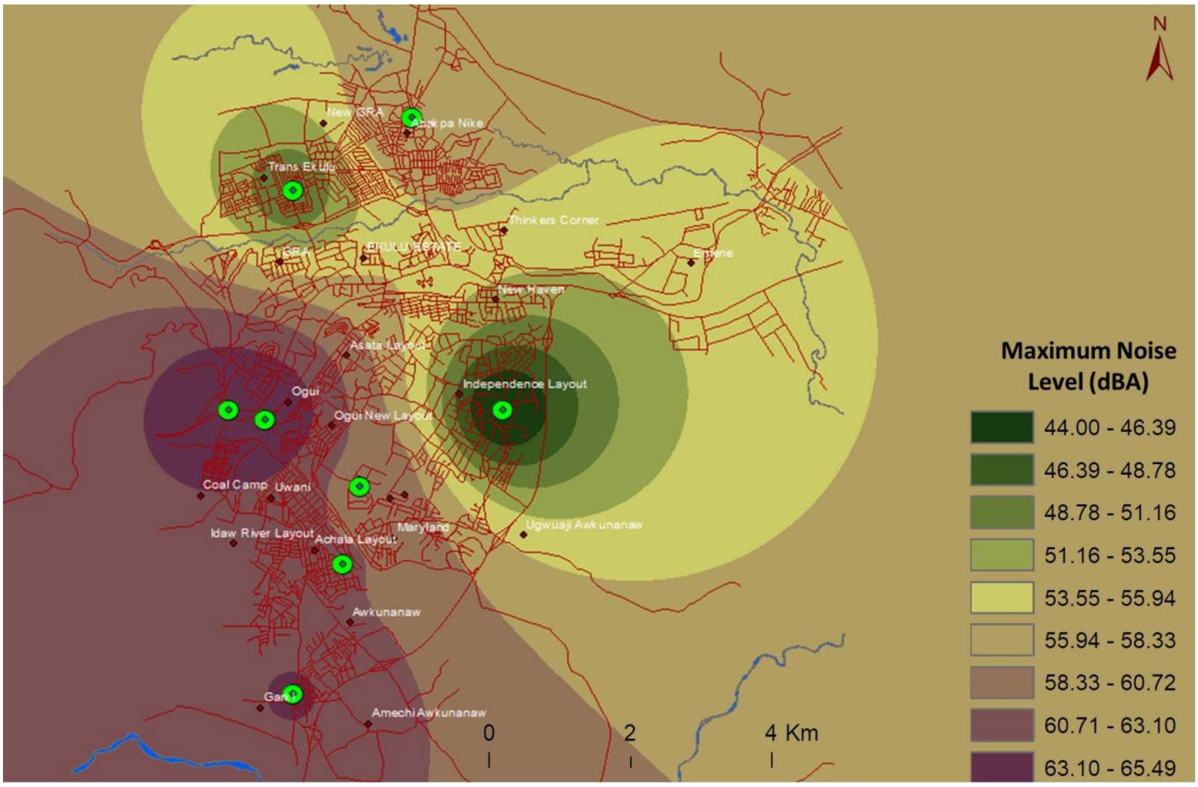

Figure 6. Maximum noise levels across various parts of Enugu metropolis

Findings from this research demonstrate the need for continuous monitoring of noise levels across the city. The monitoring and mapping of noise on a consistent basis will improve city resilience and support city management. This research provides the impetus for conducting further research using network of low-cost sensors – internet of things (IoT), big data analytics and machine learning in monitoring and mitigating impacts of noise pollution across cities in developing countries. City managers can use insights from such research to identify high noise sources and hotspots, areas and population severely impacted and plan for ways to mitigate these issues. Results from this research could stimulate the state government to have stronger justifications for regulating exposure today and night noise and make informed decisions and clear guidance on what these limits should be. Results could also be integrated with other environmental pollution such as air pollution to gain insights into the pollution profile of the metropolis.

Furthermore, results from this study could be used as proxies for important socioeconomic variables that could shed light on lifestyles and various activities across the city at different times. This is particularly important as some of these socioeconomic variables are rarely or difficult to acquire at such high-level detail. For instance, noise levels in the area could be used to identify areas of active nightlife; or unsafe areas at various times of the day/week. Results suggests that commercial areas in the city could be unsafe during the late evening, when activities have ebbed, with few people around.

Significantly, this study has given the first in-depth insight into the spatiotemporal patterns of noise levels across Enugu. This is the first time such a detailed spatial study is being conducted in the city. Results from this research will enable the state's environmental managers and policy makers in the environmental ministry to articulate relevant policies for curbing or minimizing noise across the city. This would support the rationale for subsequent expansion of the investigation to other parts of the region and the country at large, resulting in the comprehensive noise mapping of the region and the country as undertaken in developed countries of the world.

It is expected that by using maps to accurately depict the distribution of noise pollution across various activity sectors (residential, commercial, education etc.) of the metropolis, this research will enhance awareness and general understanding of noise pollution in the metropolis. In addition, environmental policymakers could use the outputs of this study to identify noise hotspots and source sectors generating high levels of noise, for targeted abatement measures. Policymakers, researchers, and other environmentalist are expected to know the level and distribution of noise in a particular area to assess and control its impacts. For example, policymakers in charge of the development of a city are expected to know the area where the equivalent noise level due to road traffic noise is low so that schools and hospitals can be sited there. Therefore, it is expected that the outcome of the research will stimulate adequate noise control measures in the country.

DOI: https://doi.org/10.7454/jessd.v5i1.1096 

## 4. Conclusion

This research was undertaken to investigate spatiotemporal distribution of noise pollution in Enugu Metropolis and attendant exposure of residents to harmful noise levels, using low-cost sensors. The novelty of this research lies in the combination of low-cost noise sensors, Geographic Information System (GIS), and interactive data visualization tools, in modelling and mapping noise pollution in an urban area. This research demonstrates the potential and usefulness of combining modern technologies in a cost-effective way to achieve near-real-time monitoring and visualization of noise pollution in an area. Findings from this research revealed noise footprints of various parts of the city and those associated with various activities. Whereas daytime noise exceeded limits set by both the Nigerian government and World Health Organization, night-time noise levels were well below recommended limits. These results contradict widely held perception among residents that assumes that residents are exposed to dangerous levels of noise pollution during the day and night. These results from Enugu represents the situation in other cities in the country without significant industrial activities.

Results from this study calls for an extended monitoring of the noise levels. Longer periods of observation should be undertaken to account for daily variations and to identify difference in noise levels between days, especially for weekdays and weekends. In addition, the spatial density of observations of noise levels should be increased to ensure an accurate representation of noise pollution at a greater detail. This would require continuous data capturing from a network of noise sensors to simultaneously cover more locations to improve the noise level estimates. We are currently considering the use of mobile phone noise level apps as a low-cost alternative to achieve real-time noise level monitoring and mapping. This would require a spatial big data infrastructure to store, process, analyze, and enable visualizations of noise levels and exposure on a real- or near-real time basis.

Further work will develop a geospatial big data system for the continuous monitoring and mapping of noise pollution across major urban areas in Nigeria. The system will be designed to support the capturing, processing, and modelling of data from sensor data and integration with other relevant environmental and socioeconomic data, in order to evaluate exposure and impacts on residents. Measures of noise pollution from various source sectors and meteorological conditions will be used to model the propagation and spatial distribution of noise across the cities. Results obtained will be integrated with demographic and land use/cover data, to identify exposure levels of different parts of the cities. High risk areas and source sectors contributing high noise pollution will be identified to aid subsequent mitigation strategies. This article expected that results from this study will stimulate intense high-level discussions among environmentalists and the government and provide the basis for the regulation of noise pollution in the metropolis.

**Acknowledgment**

We would like to acknowledge the Tertiary Education Trust Fund (TETFUND) who funded this project under the Institution Based Research (IBR).

**Author Contribution**

Conceptualization: Obinna C. D. Anejionu, Elijah S. Ebinne and Kelechi I. Nwosu; Methodology: Obinna C. D. Anejionu, Elijah S. Ebinne, Kelechi I. Nwosu, Miriam G. U. Anejionu, and Raphael I. Ndukwu; Validation: Obinna C. D. Anejionu, Miriam G. U. Anejionu and Raphael I. Ndukwu; Formal Analysis: Obinna C. D. Anejionu; Investigation: Obinna C. D. Anejionu; Data Curation: Kelechi I. Nwosu.; Writing – Original Draft Preparation: Obinna C. D. Anejionu, Elijah S. Ebinne, Kelechi I. Nwosu, Miriam G. U. Anejionu, and Raphael I. Ndukwu; Review & Editing: Obinna C. D. Anejionu and Miriam G. U. Anejionu; Visualization: Obinna C. D. Anejionu.

**Declaration of conflicting interest**

The authors declare that there are no competing interests. We have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**References**

Basner, M., & McGuire, S. (2018). WHO environmental noise guidelines for the European region: a systematic review on environmental noise and effects on sleep. *International Journal of Environmental Research and Public Health*, *15*(3), 519. https://doi.org/10.3390/ijerph15030519

Bearak, M. (2016). How the world's poorer countries breathe worse air, in charts and maps. *Washington Post*. Accessed on October 13, 2019. https://www.washingtonpost.com/news/worldviews/wp/2016/10/03/cleanish-air-is-increasingly-a-preserve-for-wealthy-nations/?noredirect=on&utm_term=.ee43a4d03c1a

Berglund, B. (1996). Aircraft noise and health. In *The Proceedings of the Second Airport Regions Conference (ARC),* 111-119: Vantaa, Finland.

Brainard, J. S., Jones, A. P., Bateman, I. J., & Lovett, A. A. (2003). *Modelling environmental equity: exposure to environmental urban noise pollution in Birmingham, UK* (No. 03-04). CSERGE Working Paper EDM. https://www.econstor.eu/handle/10419/80295

Clark, C., Crumpler, C., & Notley, H. (2020). Evidence for environmental noise effects on health for the United Kingdom policy context: a systematic review of the effects of environmental noise on mental health, wellbeing, quality of life, cancer, dementia, birth, reproductive outcomes, and cognition. *International Journal of Environmental Research and Public Health*, *17*(2), 393. https://doi.org/10.3390/ijerph17020393

Commission of the European Commission (CEC). (1996). *Future Noise Policy: European Commission Green paper*. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:51996DC0540

DEFRA (Department for Environment, Food and Rural Affairs). (2013). Draft Noise Action Plan: Roads (Including Major Roads). *Environmental Noise (England) Regulations 2006, as amended*. Accessed on May 5, 2022. https://consult.defra.gov.uk/communications/https-consult-defra-gov-uk-environmentalnoise/supporting_documents/Draft%20Roads%20Noise%20Action%20Plan.pdf

DEFRA (Department for Environment Food and Rural Affairs) (2015). *Welcome to the noise mapping England website*. Accessed on April 15, 2015. http://services.defra.gov.uk/wps/portal/noise.

DEFRA (Department for Environment, Food and Rural Affairs). (2019). *Noise Action Plan: Roads (England) Regulations 2006*. Accessed on May 15, 2022. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/813666/noise-action-plan-2019-roads.pdf

Directive, E. U. (2002). Directive 2002/49/EC of the European parliament and the Council of 25 June 2002 relating to the assessment and management of environmental noise. *Official Journal of the European Communities*, *L*, *189*(18.07), 2002.

Egbenta, I. R., Uchegbu, S. N., Ubani, E., & Akalemeaku, O. J. (2021). Effects of noise pollution on residential property value in Enugu urban, Nigeria. *SAGE Open*, *11*(3), 21582440211032167. https://doi.org/10.1177%2F21582440211032167

Evans, G. W., & Maxwell, L. (1997). Chronic noise exposure and reading deficits: The mediating effects of language acquisition. *Environment and Behavior*, *29*(5), 638-656. https://doi.org/10.1177%2F0013916597295003

Evans, G.W., Lercher, P., Meis, M., Ising, H., and Kofler, W.W. (2001). Community noise exposure and stress in children. *Journal of the Acoustic Society of America*, *109*(3), 1023-1027. https://doi.org/10.1121/1.1340642

European Commission. (2015). *Noise: the environmental noise directive (2002/49/EC)*. Accessed on April 15, 2015. http://ec.europa.eu/environment/noise/directive.htm

Farcaş, F., & Sivertunb, Å. (2010). Road traffic noise: GIS tools for noise mapping and a case study for Skåne region. *Sweden: Citeseer*. http://urn.kb.se/resolve?urn=urn%3Anbn%3Ase%3Afhs%3Adiva-3217

Gan, W. Q., McLean, K., Brauer, M., Chiarello, S. A., & Davies, H. W. (2012). Modeling population exposure to community noise and air pollution in a large metropolitan area. *Environmental research*, *116*, 11-16. https://doi.org/10.1016/j.envres.2012.04.001

Gayathri, K., Jaisheeba, A. A., & Sornaraj, R. (2012). Assessment of noise pollution in Thoothukudi city. *International Journal of PharmTech Research*, *4*(3), 1345-1350.

Hadzi-Nikolova, M., Mirakovski, D., Ristova, E., & Stefanovska Ceravolo, L. (2012). Modeling and mapping of urban noise pollution with soundplan software. *International Journal for Science, Technics and Innovations for the Industry MTM (Machines, Tecnologies, Materials)*, *6*(5/2012), 38-42. http://eprints.ugd.edu.mk/796/

Haines, M. M., Stansfeld, S. A., Head, J., & Job, R. F. S. (2002). Multilevel modelling of aircraft noise on performance tests in schools around Heathrow Airport London. *Journal of Epidemiology & Community Health*, *56*(2), 139-144. https://jech.bmj.com/content/56/2/139.short

Hegewald, J., Schubert, M., Freiberg, A., Romero Starke, K., Augustin, F., Riedel-Heller, S. G., ... & Seidler, A. (2020). Traffic noise and mental health: a systematic review and meta-analysis. *International Journal of Environmental Research and Public Health*, *17*(17), 6175. https://doi.org/10.3390/ijerph17176175

Guardian. (2014). *Map some noise: how your smartphone can help tackle city sound pollution*. Accessed on April 15, 2015. http://www.theguardian.com/cities/2014/sep/12/map-noise-how-smartphone-help-tackle-city-sound-pollution-noisetube

Nwaogozie, J. L., & Owate, I. O. (2000). Noise pollution modeling of Port Harcourt refinery part 1&2. *Technical Journal of Nigerian Society of Engineers*, *35*(1), 92-104.

Ibhadode, O., Tenebe, I. T., Emenike, P. C., Adesina, O. S., Okougha, A. F., & Aitanke, F. O. (2018). Assessment of noise-levels of generator-sets in seven cities of South-Southern Nigeria. *African Journal of Science, Technology, Innovation and Development*, *10*(2), 125-135. https://hdl.handle.net/10520/EJC-e461f77ef

IGCB-N (The Interdepartmental Group on Costs and Benefits Noise Subject Group). (2010). Noise and Health – valuing the human health impacts of environmental noise exposure. *The Second Report of the IGCB(N)*.

Kight, C. R., & Swaddle, J. P. (2011). How and why environmental noise impacts animals: an integrative, mechanistic review. *Ecology Letters*, *14*(10), 1052-1061. https://doi.org/10.1111/j.1461-0248.2011.01664.x

Kim, R., & Van den Berg, M. (2010). Summary of night noise guidelines for Europe. *Noise and health*, *12*(47), 61. https://www.noiseandhealth.org/text.asp?2010/12/47/61/63204

Kim, K. H., Ho, D. X., Brown, R. J., Oh, J. M., Park, C. G., & Ryu, I. C. (2012). Some insights into the relationship between urban air pollution and noise levels. *Science of the Total Environment*, *424*, 271-279. https://doi.org/10.1016/j.scitotenv.2012.02.066

Kurakula, V. (2007). A GIS-based approach for 3D noise modelling using 3D city models. *M.Sc. Thesis submitted to the International Institute for Geo-information Science and Earth Observation Enschede*. The Netherlands.

Laake, L. (2017). How to Fight Air Pollution in Developing Countries. *Clean Air Camfil US*. Accessed on August 10, 2019. https://cleanair.camfil.us/2017/10/30/air-pollution-in-developing-countries/

Lavelle, M. (1994). Environmental justice. In: World Resources Institute. *The 1994 information please environmental almanac*, 234-265. Houghton-Mifflin: Boston MA.

Maduemezia A. (2002). Physics, Health and the Environment. *Invited paper presented at the 25th annual conference of the Nigerian Institute of Physics held at the Physics Advanced laboratory*. Sheda Science and Technology Complex, Abuja.

Mehdi, M. R., & Arsalan, M. H. (2008). Exploring spatio-temporal acoustical variations of roadway traffic through geo-informatics. *NUST Journal of Engineering Sciences (NJES)*, *1*(1), 30-39.

Mishra, R. V., Rathore. S., Sharma, N., Johr, D. D., & Mallick, Z. (2012). Effects of road traffic noise on traffic constable in Ghaziabad region. *Proceedings of the National Conference on Trends and Advances in Mechanical Engineering, YMCA University of Science & Technology, Faridabad, Haryana, Oct 19-20*, 765 -773.

National Environmental Board. (1976), Noise standard in the workplace. *Royal Government Gazette USA*, 30.

National Population Commission. (2010). 2006 Population and Housing Census: population distribution by sex, state, LGA and senatorial district. *Priority Table Volume III.*

NESREA - National Environmental Standards and Regulations Enforcement Agency. (2009). *National Environmental (Noise Standards and Control) Regulations 2009*. Government Notice No. 288 Printed and Published by The Federal Government Printer, Lagos, Nigeria FGP 1121102009/1,000 (01 60). Federal Republic of Nigeria Official Gazette. Vol.96, N0.67 Abuja – 19th October, 2009.

Menkiti, N. U., & Agunwamba, J. C. (2015). Assessment of noise pollution from electricity generators in a high-density residential area. *African Journal of Science, Technology, Innovation and Development*, *7*(4), 306-312. https://hdl.handle.net/10520/EJC180818

Omubo-Pepple, V. B., Briggs-Kamara, M. A., & Tamunobereton-ari, I. (2010). Noise pollution in Port Harcourt Metropolis: Sources, effects, and control. *Pacific Journal of Science and Technology*, *11*(2), 592-600. https://scindeks.ceon.rs/article.aspx?artid=0354-804X1001033O

Ozdemir, B., Bayramoglu, E., & Demirel, O. (2014). Noise pollution and human health in Trabzon parks. *Studies on Ethno-Medicine*, *8*(2), 127-134. https://doi.org/10.1080/09735070.2014.11917627

Pepper, C. B., Nascarella, M. A., & Kendall, R. J. (2003). A review of the effects of aircraft noise on wildlife and humans, current control mechanisms, and the need for further study. *Environmental Management*, *32*(4), 418-432. https://doi.org/10.1007/s00267-003-3024-4

Radle, A. L. (2007, March). The effect of noise on wildlife: a literature review. In *World Forum for Acoustic Ecology Online Reader* (Vol. 2, pp. 1-16). https://winapps.umt.edu/winapps/media2/wilderness/toolboxes/documents/sound/radle_effect_noise_wildlife.pdf

Regecová, V., & Kellerová, E. (1995). Effects of urban noise pollution on blood pressure and heart rate in preschool children. *Journal of hypertension*, *13*(4), 405-412. https://europepmc.org/article/med/7629400

Sadr, M. K., Nassiri, P., Hosseini, M., Monavari, M., & Gharagozlou, A. (2014). Assessment of land use compatibility and noise pollution at Imam Khomeini International Airport. *Journal of Air Transport Management*, *34*, 49-56. https://doi.org/10.1016/j.jairtraman.2013.07.009

Sordello, R., Flamerie De Lachapelle, F., Livoreil, B., & Vanpeene, S. (2019). Evidence of the environmental impact of noise pollution on biodiversity: a systematic map protocol. *Environmental Evidence, 8*(1), 1-7. https://hal.archives-ouvertes.fr/hal-02018275/

Stockholm Resilience Centre. (2017). *Pollution and poverty a deadly mix*. Accessed on July 4, 2022. https://www.stockholmresilience.org/research/research-news/2017-10-25-pollution-and-poverty-a-deadly-mix.html

Stoter, J., De Kluijver, H., & Kurakula, V. (2008). 3D noise mapping in urban areas. *International Journal of Geographical Information Science*, *22*(8), 907-924. https://doi.org/10.1080/13658810701739039

Tang, U. W., & Wang, Z. S. (2007). Influences of urban forms on traffic-induced noise and air pollution: Results from a modelling system. *Environmental Modelling & Software*, *22*(12), 1750-1764. https://doi.org/10.1016/j.envsoft.2007.02.003

This Day Newspaper. (2021). Nigeria: Growing Menace of Noise Pollution [Editorial]. Accessed on May 4, 2022. *All Africa*. https://allafrica.com/stories/202102180522.html

Thompson, R., Smith, R. B., Karim, Y. B., Shen, C., Drummond, K., Teng, C., & Toledano, M. B. (2022). Noise pollution and human cognition: An updated systematic review and meta-analysis of recent evidence. *Environment international*, *158*, 106905. https://doi.org/10.1016/j.envint.2021.106905

UNEP. (2022). *Frontiers 2022: Noise, Blazes and Mismatches - emerging issues of environmental concern*. ISBN: 978-92-807-3917-6. Job number: DEW/2415/NA. https://www.unep.org/resources/frontiers-2022-noise-blazes-and-mismatches

Vlachokostas, C., Achillas, C., Michailidou, A. V., & Moussiopoulos, N. (2012). Measuring combined exposure to environmental pressures in urban areas: An air quality and noise pollution assessment approach. *Environment international*, *39*(1), 8-18. https://doi.org/10.1016/j.envint.2011.09.007

Wokekoro, E. (2020). An Examination of Sources of Noise Pollution in Cities in Nigeria. *World Journal of Research and Review (WJRR)*, *11*(1), 01-06. https://www.wjrr.org/download_data/WJRR1101004.pdf

WHO (World Health Organization). (2009a). *One in five Europeans is regularly exposed to sound levels at night that could significantly damage health*. Accessed on April 15, 2015. http://www.euro.who.int/en/media-centre/sections/press-releases/2009/10/one-in-five-europeans-is-regularly-exposed-to-sound-levels-at-night-that-could-significantly-damage-health (Accessed on 15th April 2015).

WHO (World Health Organization). (2009b). *Night noise guidelines for Europe*. http://www.euro.who.int/__data/assets/pdf_file/0017/43316/E92845.pdf

WHO (World Health Organization). (2018). *Environmental Noise Guidelines for the European Region*. http://www.euro.who.int/__data/assets/pdf_file/0008/383921/noise-guidelines-eng.pdf?ua=1. ISBN 978 92 890 5356

WHO (World Health Organization). (2019). *WHO night noise guidelines for Europe*. http://www.euro.who.int/en/health-topics/environment-and-health/noise/policy/who-night-noise-guidelines-for-europe.

WHO (World Health Organization). (2022a). *Data and statistics*. Accessed on May 4, 2022. http://www.euro.who.int/en/health-topics/environment-and-health/noise/data-and-statistics

WHO (World Health Organization). (2022b). *Noise*. Accessed on May 4, 2022 http://www.euro.who.int/en/health-topics/environment-and-health/noise/noise

Zannin, P. H. T., Ferreira, A. M. C., & Szeremetta, B. (2006). Evaluation of noise pollution in urban parks. *Environmental monitoring and assessment*, *118*(1), 423-433. https://doi.org/10.1007/s10661-006-1506-6