Research Article

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Geospatial Evaluation of Ambient Air Quality in Akure South Local Government Area, Ondo State, Nigeria

Victor Ayodele Ijaware*

Funsho Solomon Ajibare

Department of Surveying and Geoinformatics,
School of Environmental Technology,
Federal University of Technology,
Akure, Ondo State, Nigeria
**Corresponding Author*

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Abstract

The study evaluates the ambient air quality in Akure South Local Government Area, Ondo State, Nigeria, focusing on particulate matter (PM2.5 and PM10) and its health implications on residents. Primary data were collected using Purple Air Monitor devices at 28 ground stations and structured questionnaires, base maps. The study utilized QGIS for mapping, SPSS for statistical analysis and WHO's AirQ software for health risk assessment. Findings indicated exceedances of WHO and USEPA recommended limits for PM2.5 and PM10, with areas near major highways showing elevated PM levels. The health risk assessment revealed potential increases in hospitalizations and mortality due to air pollution. This research contributes uniquely by applying geospatial evaluation and health risk assessment tools for comprehensive air quality analysis. It highlights the urgent need for effective air quality management strategies, including the deployment of air quality monitoring stations and public education campaigns. The study provides crucial insights for policy makers, emphasizing the importance of mitigating air pollution's adverse effects on urban settings.

Keywords: *Ambient Air Quality (AAQ); Geospatial Mapping (GM); Particulate Matter (PM); MODIS Aerosol Optical Depth (AOD)*

1. Introduction

The 21st century has seen the urbanization rate increase meteorically and is also regarded to be an urban century, while it was also said that by 2050, the majority of humanity will live in cities, towns, and other urban areas (Lim, *et al.,* 2010). Correlatively, the increasing population of the world has led to an increasing rate of anthropogenic activities in urban centers, which in most cases have affected to an increase in the release of some harmful pollutants, due to the dependence of mankind on fossil fuels for sources of energy (Avis and Bartington 2020). W.H.O (2014) has it that pollution from anthropogenic activities (vehicular and industrial emissions), has been linked to the cause of increased morbidity and mortality rates. In recent times, there has been increasing concern about the ambient quality of air, and its chemical compositions have become one of the major important topics in environmental studies (Balarabe *et al.,* 2015). The atmospheric element is a summation of gases (oxides of carbon, nitrogen, Sulphur); particulates (fumes, aerosol); radioactive materials (Aliyu, 2018a). The increasing rate of urbanization experienced in Nigeria is yet to be coordinated with proper environmental planning, causing serious air quality concerns (Owode *et al*., 2013). Predominantly in the cities, there exist high vehicular and industrial activities thus elevating outdoor atmospheric pollution levels. Globally, there has been concern about air quality because of its direct impact on man and his environmental components. Nigeria is ranked 152nd out of 180 countries on the Environmental Performance Index for Air Quality, so there is reason to be concerned about its air quality (Abulude *et al.,* 2021, WHO, 2016). industrial cities like Lagos, Kano, and Port Harcourt have all been the subject of the problem of impaired air quality challenge in Nigeria (Umunnakwe and Njoku, 2017). It was stated by HEI (2019) that over 72 percent of the household population in places across Nigeria is exposed to the dangers of household air pollution; next to Nigeria on the list in Africa is Ethiopia with 89% exposure to the dangers of air pollution. Akure is Ondo state's capital where there exists the peak of a high rate of commercial activities and it is also one of the fastest-growing cities in Nigeria. Domestic, industrial and transportation activities have all increased in Akure, Nigeria, thereby increasing the release of pollutants. Previous efforts made by the government to curtail the deleterious effect of air pollution include the establishment of 5 observation stations by NIMET for monitoring the air quality index in locations across the nation (UNEP, 2015).

Some identified challenges of ambient air quality include: i) high levels of localized pollution from vehicular activities, industrial and domestic emissions, which can significantly affect population health and the ozone layer; ii) degredation of air quality due to anthropogenic activities such as mining from quarry sites, use of kerosene, charcoal, firewood for cooking and lighting; iii) health risks from poor ventilation and dust exposure, particularly during the dry season, leading to skin infections and respiratory diseases; iv) a lack of air quality monitoring and public awareness, with an absence of a comprehensive network of air quality monitoring stations and insufficient efforts to inform the public about the dangers of air pollution. Addressing these issues is essential for protecting public health, the environment, and ensuring a healthier future for all.

Therefore, the goal of this research is to geospatially determine the ambient air quality index in Akure South Local Government Area (LGA), Ondo state, Nigeria, with a view to assess the contributory effect of air pollutants on residents' health. The following research questions provide the impetus that enable the research aim to be achieved: (i) what is the spatial distribution of particulate matter in the study area? (ii) what is the compliance of air quality standard in the study area? (iii) what is the impact of exposure of the residents to the hazards of air pollution in the study area?

2. Literature Review

The compendium of research explored in this study underscores notable progress and existing gaps within the domain of air quality index evaluation, with a particular emphasis on the geographical locale of this investigation. Bael and Sample, (2015), investigated the impact of air pollution on public health in twin cities region of Minnesota, and examined the relationship between urban air quality of each 165 zip codes that lie entirely or partly within the seven county twin cities. While Yuanyu, *et al.,* (2015) developed a robust mixed effects model aimed at deriving daily estimates of surface PM2.5 levels in Beijing by employing hinges on harnessing the daily-calibrated 3km resolution satellite aerosol optical depth (AOD) data, synergized with newly available high-density surface measurements. Khaniabadi *et al.,* (2016) focused on the association between health impacts such as mortality rate of cardiovascular diseases and common air pollutants for the year 2014 and 2015 in the city of Kermanshah, Iran by employing Air-Q World Health Organization (WHO) software. At a global, regional and country levels, Cohen *et al.,* (2017) explored spatial and temporal trends in mortality and burden of disease attributable to ambient air pollution from 1990 to 2015. Their study estimated global population-weighted mean concentrations of particle mass with aerodynamic diameter less than 2.5 μm (PM2·5) and ozone at an approximate 11 km × 11 km resolution with satellite-based estimates, chemical transport models, and ground-level measurements. While previous research in the study area shows that Abulude *et al.,* (2018), Modinah *et al.,* (2019) and Isworo *et al.,* (2019) highlighted the effectiveness of portable sensors in determining particulate matter concentrations.

Collectively, these studies provide a rich tapestry of methodologies, findings, and insights. However, a crucial aspect remained unexplored which is the demonstration of the utility of air quality monitor, and the examination of the potential exposure effect on the residents. This approach not only delineate the state of the art but also situates the current inquiry within a broader scholarly milieu, highlighting the nuanced contributions and challenges that define the field.

3. Materials and Method

3.1 Study Area

Akure South local government which is the study location of this research lies approximately at latitude 7° 5′ 0 "N & 7° 19′ 0 " N and longitude 5° 6′ 0 " E & 5° 20′ 0 " E of the Greenwich Meridian. it is bonded on the northeast by Akure North Local Government Area, North West by Ifedore Local Government Area, and Idanre Local Government Area in its southern part. Akure South is one of the six (6) Local Government Areas classified as the Ondo central senatorial district and one of the eighteen (18) LGAs in Ondo State. Akure which is the largest city and capital of Ondo State became the capital of Ondo state in 1976 within the jurisdiction of the city are two local governments, namely; Akure North and the south local government area. The localities under the Akure South Local Government Area are; Adofure, Ita-Oniyan Camp, Araromi-Adofure, Oda, Orisaye, Aiyeboro, Ipinsa, Akure Township, Italepo, Adejubu, Ijojo, Babasale and Egbeda. The sample sites were selected from communities distributed across the research locations, namely; Akure Township, Emiloro Oda, Oda Town, Adofure, and Ita-Oniyan. These communities spread across a landmass of about 331km² and it's about 250m above the sea level. The average weather temperatures range from 65 °F to 88 °F and it is rarely below 5°F or above 93°F during the year while the precipitation consists of about 0.04 inches during the wet day. According to the figure presented by National Population Census in 2006, it was recorded that about 360,268 was estimated to hit 744,000 in the year 2023, with a 3.76% annual rate compared to 2021 (Macrotrends, 2023). The increase in annual growth of the population has been tied to the administrative role of the town and its long-standing role as a center of economic activities attracting a large spectrum of immigrants into it. The research location is characterized by various commercial buildings, institutions, and other public infrastructures. The main occupation of the people in the local government area is farming and trading. Ondo state is known for oil production and agricultural produce. Frequently, there exist high vehicular activities across the major roads in the study area, ranging from heavy-duty vehicles and commercial cars plying road.

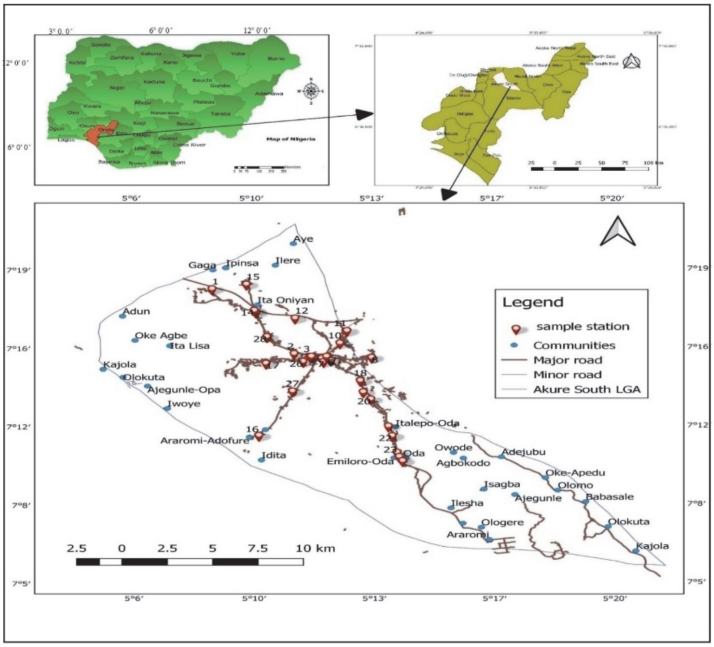

Figure 1: Study Area Map

3.2 Data Collection and Processing

The flowchart of the research methodology is as shown in Figure 2

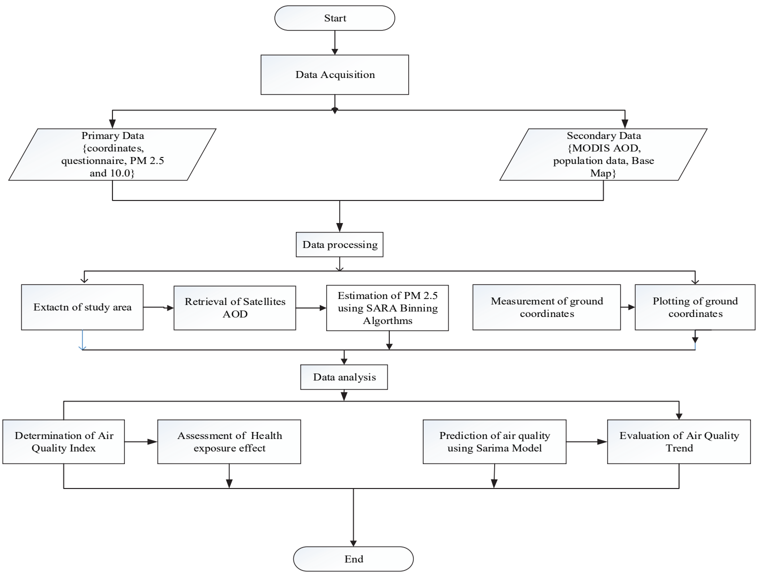

Figure 2: Flowchart framework of research methodology

In this research a comprehensive data collection approach was undertaken, incorporating both primary and secondary sources. The primary data was gathered through field measurements using Purple Air Monitor device across 28 selected locations. These locations were chosen to reflect the diversity of land uses within Akure South, including residential areas, commercial centers, and highways, to capture a broad spectrum of air quality scenarios influenced by different sources of pollution. In parallel, geospatial coordinates of pollution monitoring stations were recorded using a Garmin GPS, enhancing the spatial accuracy of the pollution mapping. Parallel to this measurement is a well-structured questionnaire distributed among the residents of the selected communities and records of diseases and mortality triggered by various air pollution exposures were collected at the hospitals. This was administered in order to quantitatively evaluate the health impact associated with air pollution exposure among residents, which involves analyzing the prevalence of respiratory symptoms and diseases in correlation with particulate matter levels and applying statistical test to explore the significance of the observed relationships. The data acquired was supported by a combination of hardware and software tools. The study was purposively divided into geographical cardinal zones, and sample sites were distributed across the zones, of which five (5) locations were selected using a stratified sampling approach. The population data was projected to 2023 from the 2006 National Population Census (NPC) data. The sample size was determined using the Yamane (1967) formula. Of which population size is 517,746 with a sample size of 400. A multi stage sampling technique was employed to determine sampling points within the settlements in the area, starting from the core areas of Akure metropolis to the smaller less dense areas. This enables air quality data to be obtained across the foci locations within the research study area. The secondary data played a crucial role in the analysis, demographic information from the Nigerian Population Census (NPC), and base maps. This multidimensional dataset enabled a detailed examination of long-term air quality trends and their potential health impacts on the local population.

The heart of the methodology lay in the meticulous data processing and analysis, where the datasets underwent rigorous cleaning, filtering, and interpolating processes to ensure the integrity of the findings. Using QGIS tool for spatial analysis and SPSS for statistical testing, the study not only analyzed the spatial distribution of particulate matter but also accessed air quality levels against established health adversaries through the computation of the Air Quality Index (AQI). While interpolation techniques, notably Inverse Distance Weighting (IDW) and Kriging, were employed to estimate PM concentrations across the study area, enabling the creation of detailed pollution maps and the identification of pollution hotspots.

To ensure the accuracy and quality of the collected data, specifically, the Purple Air Monitor, used for measuring particulate matter, was highlighted for its robust performance and reliability, even under varying weather conditions. Additionally, the research questionnaires were pre-tested to ensure clarity and effectiveness in capturing accurate responses, thereby ensuring high quality of data used in the study, enhancing the validity of the research findings.

The integrated approach not only elucidated current air quality conditions and public health risks but set a foundation for informed policy-making and effective air quality management strategies.

3.2.1 Determination of Air Quality Index

The concentration of the pollutant (PM 2.5 and PM 10.0) at designated locations was measured using a portable measuring device for certain number of time interval at identified locations, the air quality index of the study area was determined. Table I shows the Air Quality Index categories.

Table I: AQI and possible health impacts [https://www.lung.org, EPA (2016)]

INDEX VALUE	EPA (2016) breakpoint (µg/m3, 24h average)	NAME	COLOR	ADVISORY
0 to 50	0.0 – 12.0	Good	Green	none
51to 100	12.1 – 35.4	Moderate	Yellow	Unusually Sensitive Individuals should consider limiting prolonged Outdoor exertion.
101 to 150	35.5 – 55.4	Unhealthy for Sensitive Groups	Orange	Children, active adult, and people with respiratory disease, such as asthma, should limit prolong outdoor exertion.
151 to 200	55.5 – 150.4	Unhealthy	Red	Children, active adult, and people with respiratory disease, such as asthma, should avoid outdoor exertion, everyone else should limit prolong outdoor exertion.
201 to 300	150.5 – 250.4	Very Unhealthy	Purple	Children, active adult , and people with respiratory disease , such as asthma , should avoid outdoor exertion, everyone else should limit outdoor exertion
301 to 500	250.5 – 350.4	Hazardous	Maroon	Everyone should avoid all physical activity outdoors

3.2.2 *Air Quality Compliance Standards*

In the pursuit of safeguarding lives and mitigating health risks associated with exposure to air pollutants, various regulatory environmental agencies, such as the World Health Organization (WHO) and the US Environmental Protection Agency (USEPA), have established stringent guidelines to regulate air pollution and monitor air quality. Notably, Nigeria's Federal Environmental Protection Agency (FEPA) does not specify limits for PM2.5 concentrations. Therefore, this research assesses compliance using the standards set forth by USEPA, EPA Victoria and WHO as shown in (Table II).

Table 2: Air quality compliance standards

POLLUTANTS	WHO (24hr)	USEPA (24HR)	EPA ^{b} (I HR)
PM 2.5	25 µgm^{-3}	35.5 µgm^{-3}	50 µgm^{3}
PM 10.0	50 µgm^{-3}	150 µgm-3	150 µgm^{3}

3.2.3 *Assessment of the Exposure of the Residents to the Hazards of Air Pollution.*

The estimates provided are intended to inform the decisions of policy-makers or other stakeholders. Health effects such as respiratory effects, mortality and other diseases attributable to ambient air pollution specific to PM2.5 during the period of the data collection is estimated using the linear exposure-response curve method. For the implementation of the objective, the input data for needed are:

i. Air quality data/ average concentration of PM 2.5 in the study area.
ii. Population data: (estimates or projections)
iii. Area of the study area
iv. Health data retrieved from Questionnaires

The AirQ software which is an open source is used to evaluate the attainable risk proportion on the residents of the research location. The WHO stipulated limits for PM 2.5 emissions is employed in the research. The formula for the attributable risk proportion is given as in equation 3 (**Bherwani *et al*, 2022**).

$$AP = \frac{\sum\{[RR(s)-1]\times p(s)\}}{\sum\{RR(s)\times p(s)\}} \quad \text{..........} \quad 3a$$

Where;
RR(s) is the relative risk for the health outcome difference
P(s) is the fraction of population

RR(s) is the relative risk for the health outcome difference

$$RR(s) = \frac{C-T}{\{10\times(RR-1)+1)}$$ 3b

Where;

C is pollutant concentration in air,

T is the WHO stipulated limit for detected pollutant;

RR is the relative risk derived from the exposure-response function for selected health outcomes.

4. Result and Discussion

The analysis of result is categorized into three sections which are: spatial distribution of particulate matter, compliance to air quality standard and regulations, and impact of exposure of the residents to the hazards of air pollution.

4.1 Spatial distribution of Particulate Matter (PM 2.5 and 1.0)

The pollution map, generated through the application of the inverse distance weighting method, offers valuable insights into the spatial distribution of particulate matter 2.5 (PM 2.5) and particulate matter 10.0 (PM 10.0) concentrations within the boundaries of Akure South Local Government. In this analysis, two critical figures, (Figure 3 and Figure 4), showcase the spatial distribution of mean concentrations of PM 2.5 and PM 10.0, respectively. These Maps serve as essential visual representations of air quality patterns in the region. Specifically, attention is drawn to monitoring stations denoted as 1 (located at the North Gate) and 14 (positioned at the Road Block) in both Figure 3 and Figure 4. These stations exhibit notably higher mean concentrations of PM 2.5, falling within the range of 60.5 to 75.0 μg/m³, and PM 10.0, within the range of 70 to 80 μg/m³. These findings signal areas within Akure South Local Government where air quality may be of concern. Factors contributing to these elevated concentrations include increased vehicular traffic, or other local sources of pollution. Residents in the surrounding environments are prone to air pollution hazards. In contrast, it's noteworthy that monitor stations situated at Ita Oniyan, Adofure, and Ijapo Extension display significantly lower concentrations of PM 2.5. This is a positive indication of relatively cleaner air quality in these areas. Lower PM levels can be associated with factors such as reduced traffic volume or limited industrial emissions.

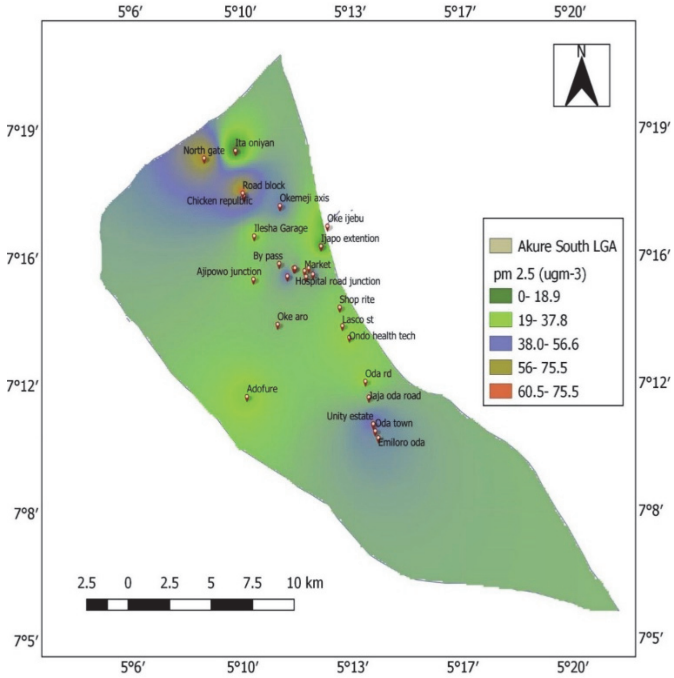

Figure 3: Pollution Map for P.M 2.5

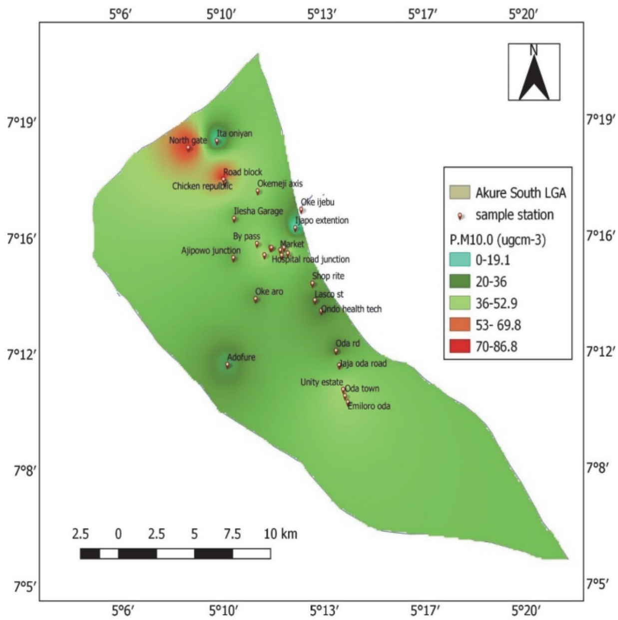

Figure 4: Pollution Map for P.M 10

4.2 Compliance to Air Quality Standards and Regulations

For the 10 monitoring stations from which measurements were taken at 3 epochs in the research locations, when assessing compliance with the 24-hour PM2.5 standards set by WHO (25 μg/m³) and USEPA (35.5 μg/m³). As shown in (Figure 5), findings revealed that 7 stations exceeded the WHO limit the other 3 stations at (STN 10, STN 15, STN 16) were in conformity with the standard. 5 stations exceeded the USEPA limit for PM2.5 concentrations. These exceedances signal areas where air quality may be of significant concern, potentially posing health risks to the local population.

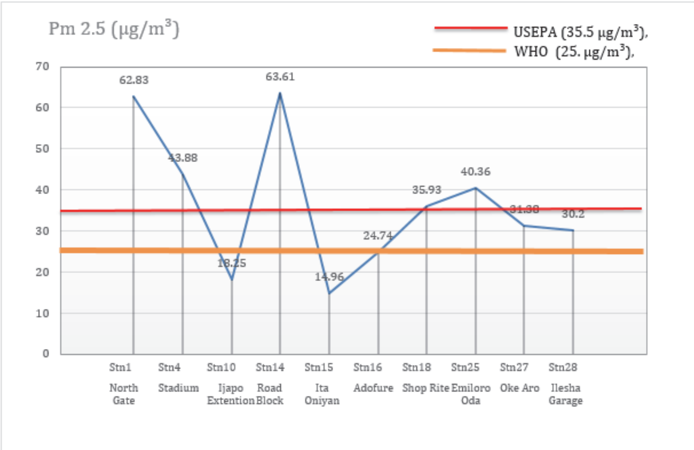

Figure 5: Conformity to standards set by USEPA and WHO for P.M 2.5

Observations regarding PM10.0 concentrations also indicated that 3 stations exceeded the WHO (50 μgm⁻³) standard (see Figure 6). All exceedances were consistent with the stipulated USEPA limit (150 μgm⁻³). This suggests that measures should be taken to address the levels of PM 2.5 and PM10.0 in the areas where there is non- conformity to meet international air quality standards.

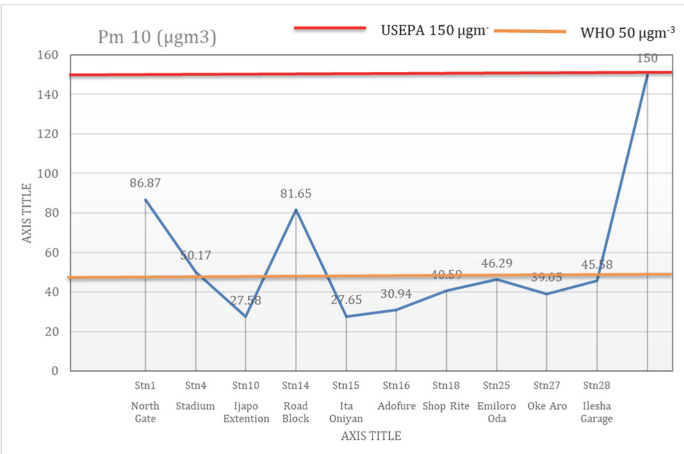

Figure 6: Conformity to standards set by USEPA and WHO for P.M 10.0

In the context of hourly-based observations, it's important to note that no specific standard is defined for particulate matter concentration on an hourly basis. To address this gap, the research utilizes a threshold of 50 µg/m³ and 150 µg/m respectively for PM 2.5 and PM 10.0, which is considered a trigger for categorizing air quality as poor, in line with EPA Victoria's guidelines (2021). Encouragingly, none of the hourly-based sample sites exceeded this threshold. Additionally, no samples exceeded the higher threshold of 50 µg/m³ and 150 µg/m respectively for PM 2.5 and PM 10.0 by EPA Victoria for PM 10.0 (see Figure 7 and Figure 8) .

Furthermore, the hourly-based observations, while not governed by specific standards, demonstrate that air quality in the research area does not exceed the defined threshold for poor air quality

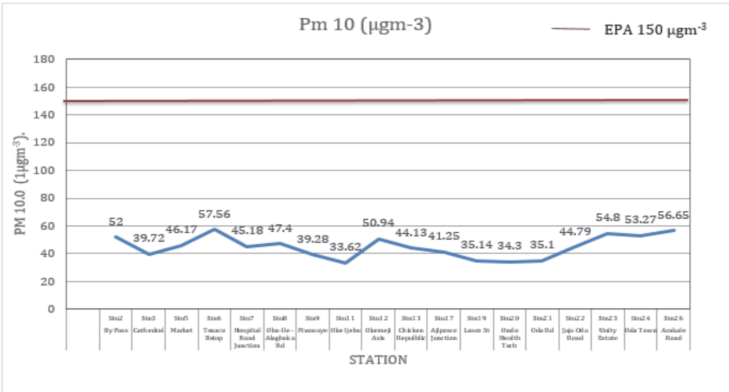

Figure 7: Conformity to standards set by EPA Victoria for 10.0

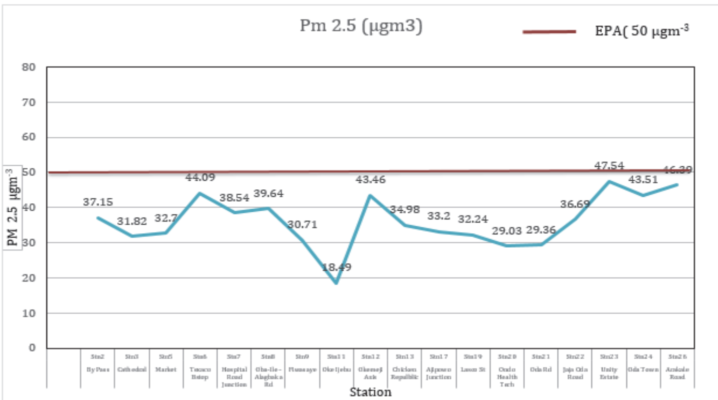

Figure 8: Conformity to standards set by EPA Victoria for P.M 2.5

4.3 Impact of Exposure of the residents to the hazards of air pollution

These responses represent the frequency of household experiencing certain symptoms or conditions among the respondents.

Table 3: Records of those treated for any respiratory ailment in the last 6 months

Variable	Frequency	Percentage
Yes	150	37
No	251	63
Total	401	100

Source: Survey (2023)

150 representing 37% of the respondents indicated they have been treated for respiratory ailments while 251 representing 63% of the respondents indicated they have not been treated for any respiratory ailments.

4.3.1 Data on Attributable Risk Due to Short-Term Exposure Effects

Attributable risk is a crucial metric that quantifies the proportion of individuals who develop a specific disease due to certain risk factors (Laaksonen, 2010). In the context of this study, Aliyu and Botai (2018b) previously employed a theoretical relative risk factor derived from multiple peer-reviewed studies. However, for the present study, the risk factor used in the analysis was obtained from data encoded in the Air software. The fundamental parameters for assessing attributable risk cases include the average concentration of Particulate Matter 2.5 (PM2.5) at 35.5 µg/m³ and a sample population consisting of 401 individuals. To calculate the attributable risk proportion, the analysis relied on the number of survey respondents who reported suffering from respiratory diseases, constituting 37% of the surveyed population. The results of the short-term exposure effect of PM2.5, obtained using the AirQ software with a 95% confidence interval, were based on relative risk factors ranging from 1.019 to 1.0402 for hospital admissions due to respiratory diseases and 1.0073 to 1.0116 for mortality due to respiratory diseases. These results unveiled a significant finding: there were 6 to 12 excess cases of hospital admissions for respiratory diseases and 2 to 3 excess mortality cases attributed to short-term exposure to PM2.5 (See Figure 9 and 10). These findings underscore the impact of air quality on public health, as they indicate that a certain number of hospitalizations and deaths could potentially have been averted with effective preventive measures in place.

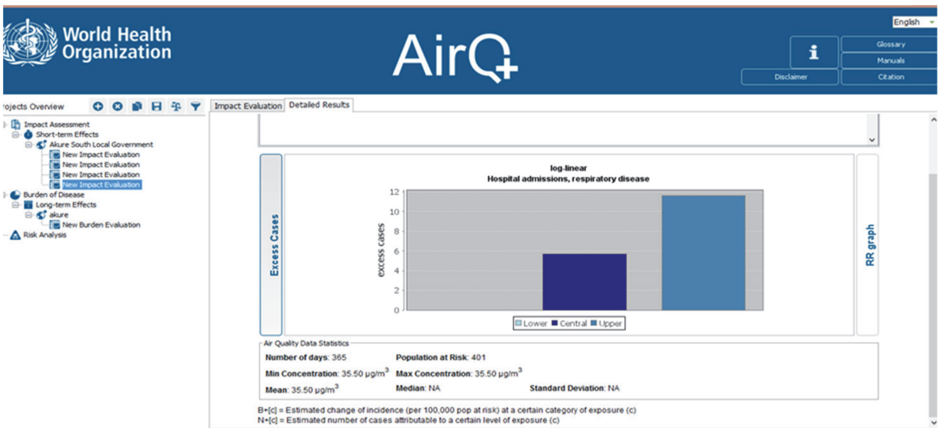

Figure 9: Result from The AirQ Software Showing the Attributable Data of Hospital Cases Respiratory Diseases.

Figure 10: Result from The AirQ Software Showing the Attributable Data of Mortality, Respiratory Diseases.

5. Conclusion

In conclusion, this research illuminates the pressing challenges posed by air pollution in Akure South, Nigeria, against the backdrop of rapid urbanization and increased anthropogenic activities. The study focused on particulate matter (PM 2.5) as a key indicator of air quality and its potential health implications. The findings underscore the significance of addressing air pollution as a critical public health concern. The spatial analysis of PM 2.5 concentrations revealed localized areas of elevated pollution, particularly near major road intersections and commercial zones. This spatial insight is vital for targeted interventions and urban planning to minimize exposure to harmful pollutants. Additionally, the compliance assessment with air quality standards highlighted areas where regulatory measures are urgently needed to ensure the well-being of the local population. The research also utilized flexible monitoring techniques, such as Purple Air Quality Monitors, to provide a comprehensive understanding of air quality dynamics. This technological approach enhances the precision of data collection and contributes to a more accurate representation of pollution levels across strategic locations. Furthermore, the assessment of short-term exposure effects on public health using the AirQ software revealed a concerning number of excess cases of hospital admissions and mortality attributed to PM 2.5. This highlights the immediate impact of air pollution on the well-being of the residents in the study area. As Local government grapples with the challenges of rapid urbanization, it becomes imperative for regulatory agencies and policymakers to implement effective measures to curb air pollution. Strategies may include stringent emission controls, improved urban planning, and the promotion of cleaner energy sources. Additionally, the establishment of real-time air quality monitoring stations and the integration of technology in environmental management can aid in prompt decision-making and response. Ultimately, this research contributes valuable insights to the ongoing discourse on air quality and public health, providing a foundation for evidence-based policies aimed at creating sustainable, healthy urban environments. The urgency to address air pollution in Akure South and similar regions cannot be overstated, as it directly impacts the quality of life and longevity of the residents.

6. Recommendation

The Ondo state government is encouraged to consider these recommendations which is aimed at creating a holistic approach to improving air quality in Akure South Local Government. By addressing pollution sources, raising awareness, and collaborating with stakeholders, the region can move towards cleaner and healthier air for its residents. Also, Advocate for the establishment of air quality standards and regulations at the local level, aligning with international guidelines set by organizations like WHO and USEPA. This will ensure that air quality goals are legally enforceable.

7. Acknowledgement

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7.1 Ethics Approval

This is an observational study. The Federal University of Technology Akure, Graduate School Research Ethics Committee has confirmed that no ethical approval is required.

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