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Spatial and Temporal Distribution of Outdoor Particulate Matter ($PM_{2.5}$) Levels for Locations within Two Local Government Areas in Edo State, Southern Nigeria

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ABSTRACT

Particulate matter (PM) are airborne microscopic sized particles of solid or liquid matter. This study investigated the spatial distribution of $PM_{2.5}$ concentrations and assessed $PM_{2.5}$ related air quality in both Egor and Oredo Local Government Areas (LGAs) of Edo State. Twenty outdoor locations were monitored once monthly from June to July 2023 using Biaoling™ air quality monitor. The values obtained were subjected to unpaired t test analyses which were conducted at 95% probability level. For sampled areas in Oredo LGA, mean $PM_{2.5}$ values ranged from 10.3 µg/m^3 ± 0.1 to 45.3 µg/m^3 ± 0.2 whilst a range of $PM_{2.5}$ values; 12 µg/m3 ± 0.2 to 42 µg/m3 ± 0.1 was recorded for locations in Egor LGA. Statistical analysis revealed an insignificant difference in $PM_{2.5}$ mean data between the two months ($p > 0.05$) in both LGAs. There was an insignificant difference between the $PM_{2.5}$ for June and July, 2023 in both LGAs ($p>0.05$). The drawn spatial maps for both LGAs revealed that the $PM_{2.5}$ related air quality index (AQI) values was good in majority of the sampled areas with the exception of New Benin in Oredo LGA and Orovbie sampling point in Egor LGA. More studies should be conducted with focus on the evaluation of outdoor air quality in more areas within these LGAs as well as well likely and implementable cost effective abatement measures that can lower the magnitude of PM pollution in the respective study areas.

INTRODUCTION

Outdoor air pollution has been described as a pressing global environmental issue that poses significant risks to human health and the environment (Manisalidis et al., 2020; Rentschler and Leonova, 2023). It is caused primarily by the release of pollutants into the atmosphere from various anthropogenic activities, including industrial processes, transportation, energy production and residential combustion (Yin et al., 2015; Singh et al., 2020; Fuller et al., 2023).

Particulate matter (PM) is a major component of outdoor air pollution. It has been described as a complex mixture of solid particles and liquid droplets suspended in the air (Zhang et al., 2021). PM is classified on the basis of its size, with PM10 referring to particles with a diameter of 10 micrometres or less and $PM_{2.5}$ referring to particles with a diameter of 2.5 micrometres or less (Araujo & Nel, 2009). These fine particles are of particular concern due to their ability to penetrate deep into the human respiratory system (USEPA, 2016; Smith, 2020).

Exposure to elevated PM concentrations has been linked to a range of adverse health effects (Sacks et al., 2011). Scientific studies have consistently demonstrated the associations between PM exposure and respiratory and cardiovascular diseases, including asthma, chronic obstructive pulmonary disease (COPD), lung cancer, and cardiovascular events (Li et al., 2018; Lelieveld et al., 2019; Alexeeff et al., 2021; Eghomwanre et al, 2022; Yang et al., 2022). PM can have detrimental effects on the respiratory system by triggering inflammation, impairing lung function, and exacerbating existing respiratory conditions (Xing et al., 2016; Mack et al., 2019; Lee et al., 2021). Fine particles can penetrate the lungs and enter the bloodstream, leading to systemic inflammation and oxidative stress, which can contribute to the development of cardiovascular diseases such as heart attack, stroke, and high blood pressure (Snider et al., 2016; Du et al., 2016; Wu et al., 2018; Hamanaka & Mutlu, 2018; Basith et al., 2022). Vulnerable populations, including children, elderly individuals, and individuals with pre-existing respiratory and cardiovascular conditions, are particularly susceptible to the health impacts of PM pollution (Esposito et al., 2014; Simoni et al., 2015; Maung et al., 2022). Additionally, long-term exposure to elevated PM concentrations has been associated with reduced life expectancy (Cohen et al., 2017; Pothirat et al., 2019; Elbarbary et al., 2020; Amnuaylojaroen & Parasin, 2024).

The World Health Organization (WHO) has recognized outdoor air pollution as a leading environmental health risk, suggesting that it contributes to millions of premature deaths annually worldwide (WHO, 2018). Consequently, there is a growing emphasis on monitoring and mitigating PM pollution to protect public health and improve air quality (Kelly & Fussell, 2015; Chen et al., 2020). In the course of effectively addressing the issue of PM pollution, understanding its spatial distribution within specific geographic areas is crucial (Pappa and Kioutsioukis, 2021; Yang et al., 2023; Lee et al., 2024).

Spatial mapping of PM concentrations is known to provide valuable insights into the localized patterns of pollution, identification of hotspots with elevated levels with the consequent planning and implementation of targeted interventions and policies aimed at reducing exposure to and mitigation of associated anthropogenic health risks (Burns et al., 2019; Kamruzzaman et al., 2020; Okimiji et al., 2021; Abecasis et al., 2022; Hossain et al., 2023). Spatial mapping of the PM concentration is crucial for the identification of pollution hotspots, understanding pollution sources, assessing exposure and health risks, guiding urban planning decisions, and monitoring the effectiveness of pollution control measures (Abdel-Salam, 2015; Cummings et al., 2021). In providing detailed and geographically specific data, spatial mapping enables evidence-based decision-making and targeted interventions to mitigate air pollution, protect public health, and improve the overall environmental quality of a given area (Miranda & Edwards, 2015; Biu et al., 2024).

Oredo and Egor local government areas (LGAs) are third-tier governmental administrative areas covering sections of Benin City, the administrative capital of Edo State, Nigeria. These two LGAs are characterized by a diverse range of land usage patterns and economic activities, including industrial, commercial and residential sectors. The spatial aggregation of these respective land utilization patterns in these LGAs can have negative implications for air quality and public health, requiring a comprehensive understanding of the local context and its associated issues. Few studies have assessed $PM_{2.5}$ concentrations in these urban areas in Edo State. Ojeaga and Okoro (2023) found that $PM_{2.5}$ concentrations in residential areas exceeded WHO and USEPA limits, with higher levels during the dry season. Eghomwanre et al. (2022a) reported indoor $PM_{2.5}$ levels ranging from 27.4 to 59.6 µg/m³, correlating with increased asthma cases in children. Vehicular emissions have been linked to elevated $PM_{2.5}$ levels at traffic hotspots in Oredo LGA, with evening peaks showing the highest concentrations. Furthermore, Eghomwanre et al. (2022b) reported that $PM_{2.5}$ levels in residential areas in Benin city were above WHO limits, with seasonal variations influenced by local activities. This study aimed to determine the spatial distributions of $PM_{2.5}$-derived AQI concentrations across several outdoor locations in Oredo and Egor LGAs.

MATERIALS AND METHODS

Study Area Description

Both LGAs, Oredo and Egor are located in Edo State, Southern Nigeria and cover different sections of Benin city, the administrative headquarters of Edo State. Egor LGA is characterized by mostly flat terrain and busy marketplaces, including both Oliha Market and New Benin Market respectively. With a population of 339,899 as documented in the national census conducted in 2006 and a land area of approximately 93 square kilometres, the economy of Egor is centred on commerce, agriculture, industry, and educational endeavours. Egor is an area with two distinct seasons: the rainy season, which runs from

April to October, and the dry season, which runs from November to March. The average temperature is 28°C, and the humidity is approximately 68%. On the other hand, Oredo LGA, which covers extensive areas of Benin City, the state capital, is a prime example of rapidly increasing urbanization and population expansion. Particulate matter (PM) pollution dynamics can be closely examined against the intriguing backdrop of its landscape, which is a tapestry of urban and peri-urban habitats. Variations in $PM_{2.5}$ pollution levels are caused by a region's industrial activity as well as a variety of land uses, including residential, commercial and industrial uses/applications.

Data Collection

The collection points were generated by using ARCGIS 10.8 to generate random sampling points within both LGAs. These points were visited once monthly for a 2-month period (June and July 2023), and the $PM_{2.5}$ data were collected in the morning period (9am to 11am) at each visited sampling point. Duplicate steady readings were collected at the visited locations. The mean $PM_{2.5}$ values were collected with the aid of a PM meter (Biaoling TM air quality monitor, produced by Biaoling manufacturers at Dijin Rd, Haidian District, Beijing, China). The PM monitor is capable of detecting airborne PM_{10}, PM_5 and $PM_{2.5}$ levels respectively. Figure 1 shows a map of the study area with sampling points for Oredo LGA, and Figure 2 shows a map of the study area with sampling points for Egor LGA. All the sampling points were located in the urbanized areas of the respective LGAs. The observed anthropogenic activities which occurred on a daily basis at the vicinities of these sampling points varied from transportation activities, educational services, commercial activities, religious practices and recreational activities.

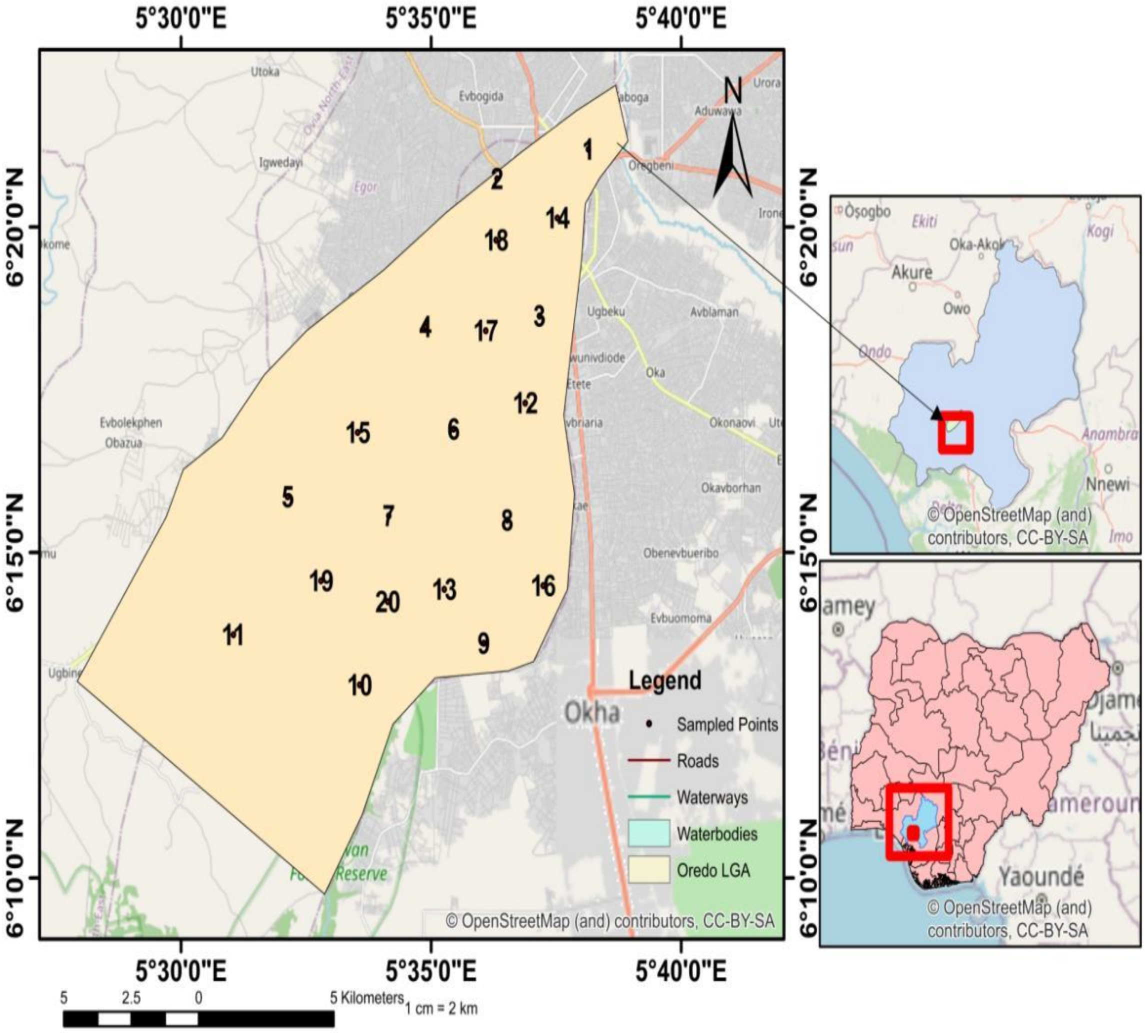

Figure 1. Map of the study area showing the sampling points for Oredo LGA

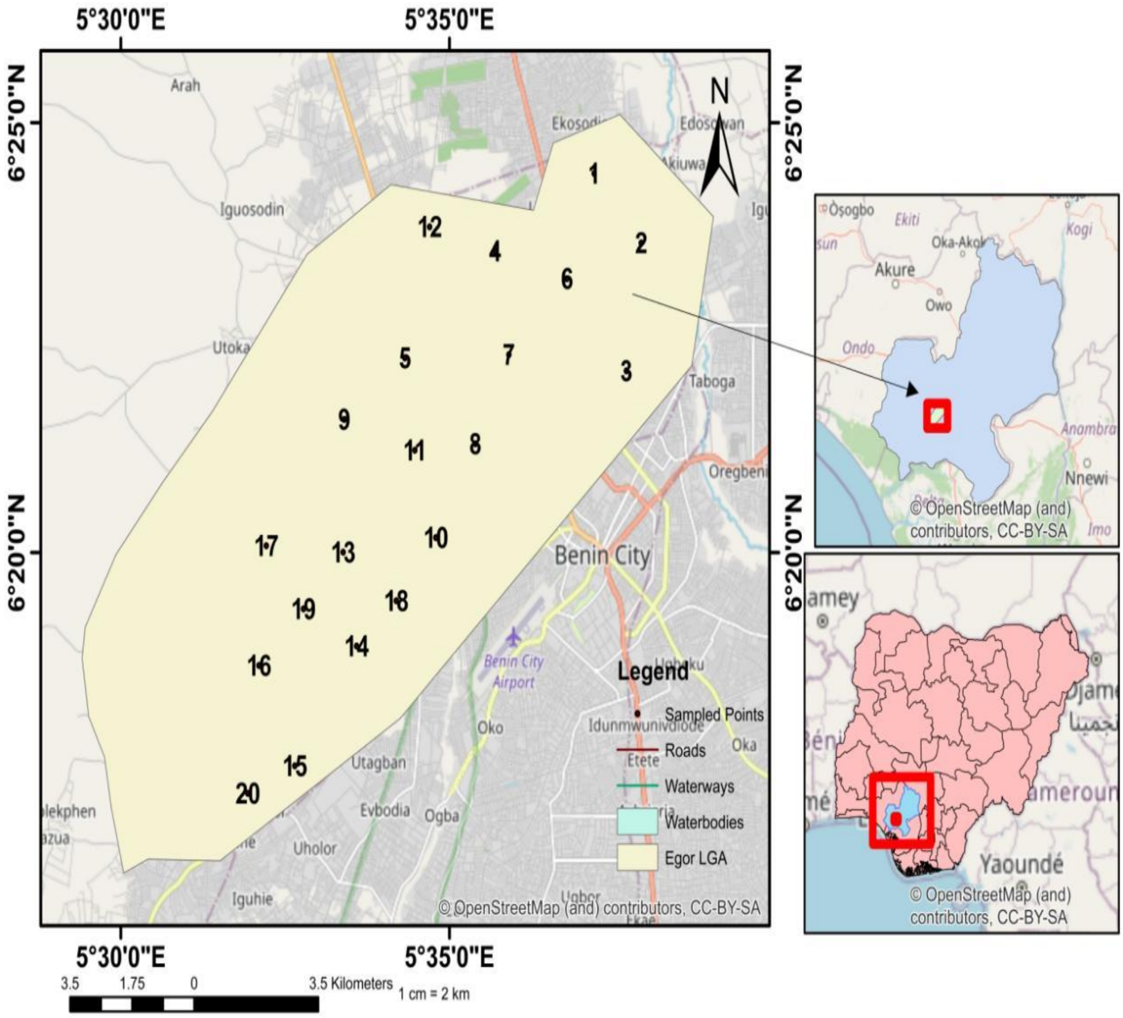

Figure 2. Map of the study AREA showing the sampling points for Egor LGA

Spatial Mapping of AQI Data

To ascertain the spatial patterns of the PM concentrations within Oredo and Egor LGAs, the inverse distance weighting (IDW) interpolation technique in ArcGIS 10.8 was used. The IDW technique serves the purpose of predicting values at locations where measurements were not taken, relying on information from neighbouring sampled locations (Li et al., 2014). This technique operates under the assumption that the impact of PM concentrations at a specific site is primarily determined by its proximity to surrounding locations, as opposed to distant locations. The fundamental principle of IDW lies in the assignment of weights to neighbouring sample points, with the weight assigned to each point being inversely proportional to its distance from the target site. Essentially, the closer a sample point is to the target location, the more significant its influence becomes in determining the estimated value of the PM concentration at that particular site.

AQI Assessment

The mean $PM_{2.5}$ values collected from June to July at the 20 sampling points in both LGAs were converted to AQI values using the AQI formula given below.

$$IP = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}} (C_p - BP_{Lo}) + I_{Lo}$$

Where Ip = the index for pollutant p; Cp = the truncated concentration of pollutant p; BPHi = the concentration breakpoint that is greater than or equal to Cp; BPLo = the concentration breakpoint that is less than or equal to Cp; IHi = the AQI value corresponding to BPHi; and ILo = the AQI value corresponding to BPLo. Air quality values were rated as shown in Table 1.

Statistical Analysis

The duplicate $PM_{2.5}$ values were converted to mean values and the respective standard deviation values were also derived using Microsoft Excel 2016 software. The mean values were subjected to unpaired t test analysis using Microsoft Excel 2016 software. The analysis was conducted at the 95% probability level.

RESULTS AND DISCUSSION

Table 1 shows the mean $PM_{2.5}$ values obtained at the visited locations within Oredo LGA in June and July. The spatial distributions of the AQI values directly derived from the respective outdoor $PM_{2.5}$ concentrations in Oredo LGA are shown in Figures 3 and 4.

Table 1. AQI level ratings

AQI	Health Concern Level	AQI Daily Colour Code	Air Pollution Level
0 – 50	Good	Green	Level 1
51 – 100	Moderate	Yellow	Level 2
101 – 150	Unhealthy for Sensitive Groups	Orange	Level 3
151 – 200	Unhealthy	Red	Level 4
201 – 300	Very Unhealthy	Purple	Level 5
301 and above	Hazardous	Maroon	Level 6

For the month of June, the lowest mean value (10.3 $\mu g/m^3 \pm 0.1$) was recorded at the Obaizamonwan Primary School sampling point, whereas the highest mean value (45.3 $\mu g/m^3 \pm 0.2$) was recorded at the New Benin sampling point (Table 2). For the month of July, the lowest mean value (10.3 $\mu g/m^3 \pm 0$) was recorded at the Grace of Bethseda Church sampling point (Table 2), whereas the highest mean value (43.3 $\mu g/m^3 \pm 0.2$) was recorded at the New Benin sampling point (Table 2). The difference between the two groups of $PM_{2.5}$ mean data was insignificant (T stat; 0.23896, $p > 0.05$).

Table 2. $PM_{2.5}$ ($\mu g/m^3$) mean values from sampling points in Oredo LGA

Sampling Locations (location number)	June, 2023	July, 2023
Exmond new motor spare parts (1)	[a]22.3± 0.1	24.3 ± 0.1
New Benin (2)	45.3 ± 0.2	43.3 ± 0.2
Jamb Office (3)	14.7± 0.1	13 ± 0.0
Federal Marriage Registry (4)	20.3 ± 0.7	22.3 ± 0.1
Osaro Avenue (5)	15 ± 0.2	16.7 ± 0.1
Wellspring University (6)	13.7± 0.1	16 ± 0.2
Spirit and life bible church Ekehuan (7)	16 ± 0.7	18 ± 0.0
Koosa Hotel (8)	14.7 ± 0.1	15.7 ± 0.3
Choice gate Hotel (9)	21.7 ± 0.1	22 ± 0.0
Victorious mega chicken (10)	17 ± 0.0	17.7 ± 0.1
Omoruyi Street (11)	11.7± 0.1	12.3 ± 0.3
Ontario Park (12)	28.7± 0.2	28.7± 0.1
EBS Global world investment (13)	24 ± 0.1	27 ± 0.0
Airport Road (14)	12.7 ± 0.1	15 ± 0.2
Tasty Buds (15)	11± 0.2	11 ± 0.0
Hui Hui Foods (16)	12 ± 0.7	12.7 ± 0.1
Foundation of God assembly (17)	11.3± 0.0	13.3 ± 0.2
Obaizamonwan Primary School (18)	10.3 ± 0.1	11.7 ± 0.1
Grace of Bethseda Church (19)	10.7± 0.1	10.3 ± 0
Elizabeth Havilah Pharmacy (20)	13± 0.0	14 ± 0.3

KEY: a; values are in overall mean ± std. deviation

The spatial maps for Oredo LGA revealed that the majority of the $PM_{2.5}$ derived AQI values were "good", as the values were between 43 and 56 (Table 1, Figures 3 and 4). However, for both June and July, a small area had AQI values ranging from 69 to 120, which can be regarded as varying from moderate to unhealthy air quality status (Table 1, Figures 3 and 4). As expected, the New Benin sampling point had $PM_{2.5}$ derived AQI values that can be regarded as unhealthy (Table 1, Figures 3 and 4).

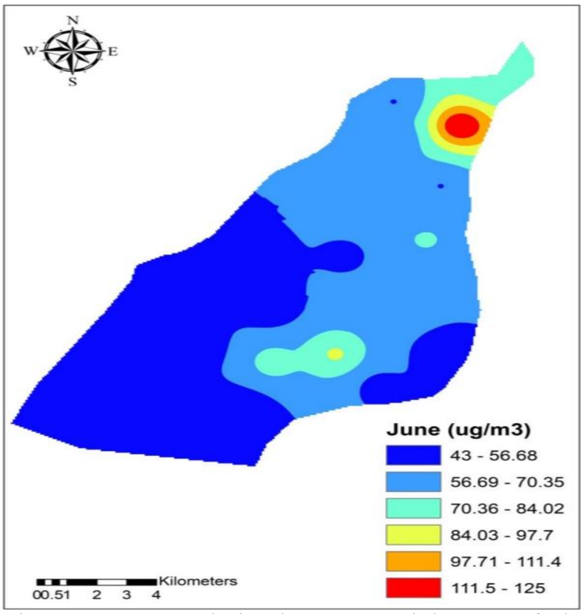

Figure 3. $PM_{2.5}$ derived AQI spatial map of the study area within Oredo LGA sampled in June 2023

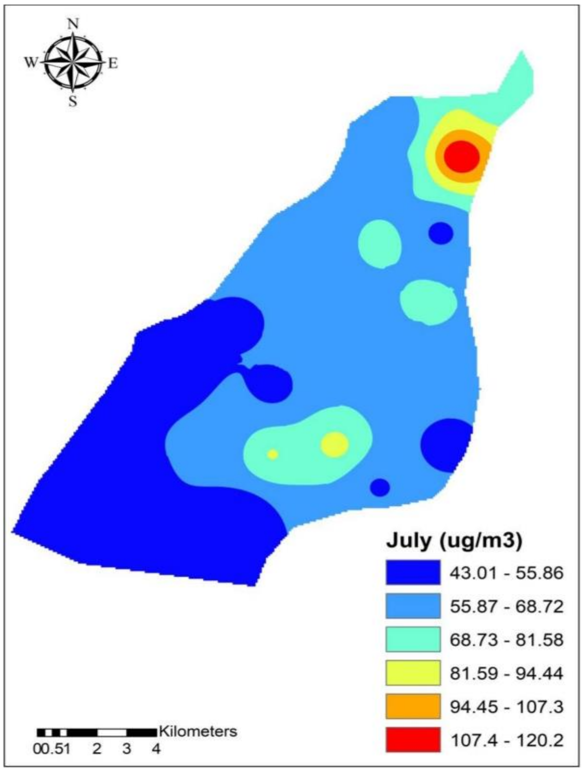

Figure 4. $PM_{2.5}$-derived AQI spatial map of the study area within Oredo LGA sampled in July 2023

Table 3 revealed the $PM_{2.5}$ mean values obtained at the visited outdoor locations within the Egor LGA in June and July. The spatial distributions of the AQI values directly derived from the respective mean $PM_{2.5}$ values in Egor LGA are shown in Figures 5 and 6. For the month of June, the lowest mean value (12 µg/m^3 ± 0.2) was recorded at the Triumphant Baptist church sampling point, whereas the highest mean value (42 µg/m^3 ± 0) was recorded at the Upper Ekenwan sampling point (Table 3). For the month of July, the minimal mean value (12 µg/m^3 ± 0) was recorded at the Oghede primary school sampling point (Table 3), whereas the highest mean value (41 µg/m^3 ± 0.2) was recorded at the Upper Ekenwan sampling point (Table 3). The difference between the two groups of $PM_{2.5}$ mean data was insignificant (T Stat; 0.1787, P >0.05).

Table 3. $PM_{2.5}$ (µg/m^3) mean values from sampling points in Egor LGA

Sampling Locations (location number)	June, 2023	July, 2023
Ekosodin road (1)	19.3 ± 0.0	18.6 ± 0.1
Hall 6, UNIBEN (2)	15.3 ± 0.2	16 ± 0.0
Medical store road (3)	16 ± 0.1	15.3 ± 0.1
Adolor college road (4)	19 ± 0.0	18.0 ± 0.2
Ogida barracks (5)	20 ± 0.2	18.3 ± 0.1

Federal Gov. Girls College (6)	13.7 ± 0.1	14.3 ± 0
Uwelu road (7)	19.7 ± 0.1	19.7 ± 0.2
A.A Rano upper Siluoko (8)	20 ± 0.0	19.6 ± 0.1
Mechanic road (9)	14.7 ± 0.1	14 ± 0.0
Asoro (10)	20 ± 0.0	19 ± 0.0
Ojo street after Useh market(11)	25.3 ± 0.3	23.6 ± 0.1
Triumphant Baptist church (12)	12 ± 0.2	12.6 ± 0.2
Evbotubu (13)	17 ± 0.0	15.3 ± 0.1
Iyamu street (14)	12.7 ± 0.1	12.3 ± 0.1
Oghede primary school (15)	12.3 ± 0.1	12 ± 0.0
Upper Ekenwan (16)	42 ± 0.0	41 ± 0.2
Orovie (17)	30.3 ± 0.1	31 ± 0.1
Evbotubu health centre (18)	18.7 ± 0.1	17± 0.0
Ugbiyoko (19)	15 ± 0.0	14 ± 0.1
Ogba road (20)	26 ± 0.0	26.6 ± 0.2

KEY: a; values are presented as the overall mean ± std. deviation

As with the spatial maps constructed for Oredo LGA, the spatial maps generated for Egor LGA revealed that the majority of the $PM_{2.5}$-derived AQI values were "good", as the values were between 50 and 104 or less than 100 (Table 1, Figures 5 and 6). Similar to the Oredo maps, for both June and July, a small area had AQI values ranging from 104 -115, which can be regarded as varying from moderate to unhealthy air quality status (for sensitive groups) (Table 1, Figures 5 and 6). The outermost left region of the sampled area encompassing the Orovie sampling point had $PM_{2.5}$-derived AQI values that can be regarded as unhealthy (Table 1, Figures 5 and 6).

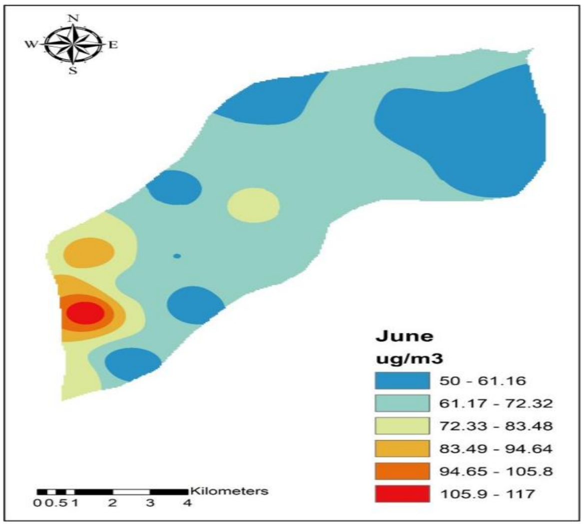

Figure 5. $PM_{2.5}$-derived AQI spatial map of the study area within the Egor LGA sampled in June 2023

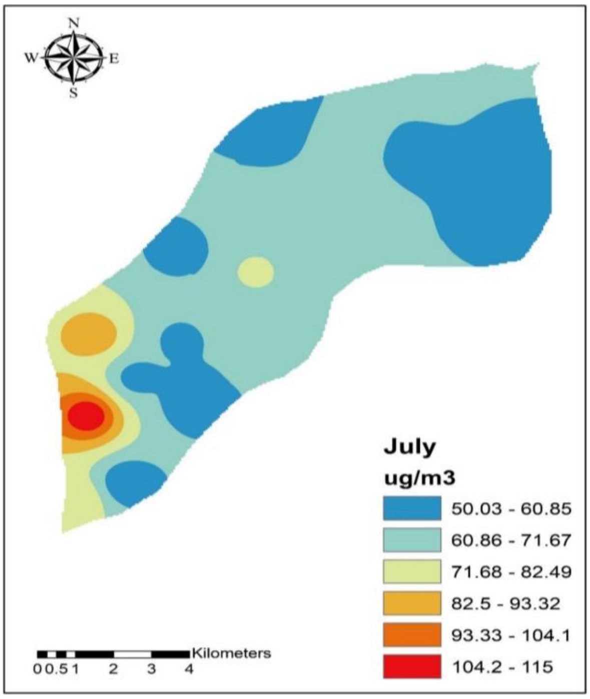

Figure 6: PM2.5-derived AQI spatial map of the study area within the Egor LGA sampled in July 2023

The spatial distribution of $PM_{2.5}$ within Oredo LGA could highlight the interrelationship of factors influencing air quality in urban environments. To conduct a comparative analysis of the $PM_{2.5}$ related AQI values across twenty sampling points, this study delineates varying levels of $PM_{2.5}$ pollution, revealing significant disparities between residential and commercial areas. Commercial hubs, characterized by intense human activities and vehicular congestion, are characterized by elevated $PM_{2.5}$ concentrations, which poses heightened health risks to inhabitants. These findings resonate with those of global research, highlighting the role of urbanization, industrialization, and traffic-related emissions in exacerbating air pollution (Guo et al., 2020).

Insights from Jincheng, China, also revealed the impact of industrial activities on $PM_{2.5}$ levels, with concentrations peaking in industrial zones and tapering towards residential neighbourhoods (Guo et al., 2020). The authors also reported that in most areas of Jincheng, the range of the highest 24-h $PM_{2.5}$ concentrations was 15–120 μg/m^3 in July and 15–240 μg/m^3 in December. The $PM_{2.5}$ concentrations in December were higher than those in July, mainly because of $PM_{2.5}$ emissions from coal-fired heating equipment in December (Sari & Bayram, 2014). The close proximity of some residential units to commercial and industrial areas can exacerbate exposure risks, as airborne particle matter pollutants from various sources infiltrate these residential spaces.

Moreover, wind patterns are known to play a pivotal role in $PM_{2.5}$ dispersion, influencing the spatial distribution of pollutants. As demonstrated by Pearce et al. (2012), wind speed and direction affect the spread of $PM_{2.5}$ emissions, with concentrations decreasing with increasing distance from emission sources. This trend might reveal the importance of meteorological conditions in shaping air quality profiles and necessitate comprehensive monitoring and modelling efforts.

The $PM_{2.5}$ levels documented in both Egor and Oredo LGAs during June–July 2023 were generally lower than those reported in prior studies. For example, Eghomwanre et al. (2022) described indoor $PM_{2.5}$ levels ranging from 27.4 to 59.6 µg/m³, while Ojeaga and Okoro (2023) reported values consistently above WHO limits (25 µg/m³).

For both Oredo and LGAs, the occurrence of unhealthy $PM_{2.5}$ derived AQI pollution in some of the sampled areas might underscore the urgent need for proactive measures to safeguard public health and mitigate environmental risks. GIS applications have emerged as invaluable tools for spatial analysis and decision-making, facilitating targeted interventions and policy formulation. Collaborative efforts between research institutions, urban planners, and policymakers are imperative to address air quality challenges effectively.

Moreover, the integration of zoning regulations, buffer zones, and sustainable urban planning practices can mitigate $PM_{2.5}$ pollution, fostering healthier and more resilient communities. By prioritizing environmental health and adopting evidence-based strategies, local authorities can pave the way for a cleaner, more sustainable future.

CONCLUSION

THE $PM_{2.5}$ concentrations in the geo-referenced areas in both Oredo and Egor LGA were evaluated via spatial mapping via a GIS application. The findings revealed different distribution patterns of pollutants for different forms of land use. High $PM_{2.5}$ concentrations were observed in different parts of the sampled areas in both LGAs, but the outdoor air quality with reference to $PM_{2.5}$ associated AQI values was generally ‘good’ in the sampled mapped areas in the respective LGAs.

It is necessary to take immediate action to reduce pollution sources and guarantee that the residents reside in a healthy environment. The community, Non-Governmental organizations (NGOs), and Local Government authorities should collaborate and work together to improve air monitoring and enforcement programmes, if there are any in the study areas. In the event of the absence of functional outdoor air monitoring and enforcement programmes, the respective Government tiers; State and Local should prioritize the setting up of outdoor air monitoring schemes and implement modalities in liaison with other stakeholders such as the resident communities and interested NGOs focusing on the effective monitoring of outdoor air quality in these urban areas.

More studies should be conducted focusing on the evaluation of outdoor air quality in more areas within these LGAs as well as well likely and implementable cost effective abatement measures that can lower the magnitude of PM pollution in the respective study areas.

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