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Assessment of Particulate Matter ($PM_{2.5}$) and Air Quality Index (AQI) in Eight Locations of Lagos State, Nigeria

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Abstract

Air pollution, particularly fine particulate matter ($PM_{2.5}$), poses a significant threat to public health, especially in rapidly urbanizing areas like Lagos State, Nigeria. Despite the severity of the issue, there is a lack of comprehensive data on $PM_{2.5}$ levels and the Air Quality Index (AQI) in Lagos. This study leverages data from AirQo, an innovative air quality monitoring network using low-cost sensors, to provide a detailed assessment of $PM_{2.5}$ concentrations and AQI across eight locations in Lagos State. This approach offers real-time, continuous monitoring, filling a critical data gap in the region's air quality management efforts. This study uses AirQo data to assess the concentration levels and spatial distribution of $PM_{2.5}$ and AQI across the selected eight locations. Data on $PM_{2.5}$ concentrations were obtained from AirQo sensors deployed across the eight strategic locations in Lagos. The spatial distribution of $PM_{2.5}$ levels and AQI were analyzed, and the results were compared with national and international air quality standards. The findings revealed that $PM_{2.5}$ levels (minimum - 6.28 µg/m^3 (Ikeja) and maximum - 204.68 µg/m^3 (Banana Island) in many areas of Lagos exceed annual WHO and national air quality guidelines, indicating significant health risks. The spatial analysis identified pollution hotspots, particularly in densely populated and industrial regions. The data suggested vehicular emissions and industrial activities as major contributors to high $PM_{2.5}$ levels. This study underscores the severe air quality issues in Lagos State, emphasizing the need for immediate and targeted interventions to mitigate $PM_{2.5}$ pollution. The use of AirQo sensors proved effective in providing accurate and timely data for air quality assessment. It is recommended that Lagos State implements stricter emission controls, promotes cleaner technologies, and enhances public transportation systems to reduce traffic-related pollution. Additionally, expanding the air quality monitoring network and incorporating more environmental data will provide a more comprehensive understanding of air pollution impacts, thereby facilitating better policy and public health decisions.

1 Introduction

Air pollution is a global pervasive environmental health issue with significant implications for public health, particularly in urban areas. Particulate matter (PM), especially fine particles with a diameter of less than 2.5 micrometers ($PM_{2.5}$), poses serious health risks as it can penetrate deep into the respiratory system and enter the bloodstream, leading to cardiovascular, respiratory, and other systemic health problems [1-5]. There are several associated problems regarding air quality problems in low-income, low GDP, underdeveloped and developing countries across the Africa regions. Notable factors that contributed to these poor air quality - both indoor and outdoor include industrialization and urbanization activities – ranging from road construction, factories effluents and wastes, overpopulation in some cities such as Lagos, occasion natural disaster, poor waste and environmental management policies, low standard of living of the citizens, expensive or non-readily available and affordable waste management facilities across cities, very poor funding of concern enforcing agencies, poor or no funding of research project in line with air quality, instability of government ideology, urban development, including climate change, etc. All these factors summed together contributed in one way or the other to the poor outdoor and indoor air quality in Africa but not limited to Africa counties alone. It is important to note that air pollution can occur as a result of natural and or artificial reasons but more to the human factor (anthropogenic). Some of these air pollutants include particulate matter ($PM_{2.5}$ and $PM_{10.0}$), various gases such as oxygen (O_2), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NOx), sulphur dioxide (SO_2), and ozone (O_3). Others are volatile organic compounds (VOC), and persistent organic pollutants (POPs) in the atmosphere (PAHs, OCPs, PCBs, etc.) [6-13]. Nigeria is one of the countries in Africa with the highest population density with several urban cities across the six geopolitical zones. One of such cities is Lagos with rapid urbanization, industrial activities, and high traffic density contributing significantly to air pollution, making the assessment of $PM_{2.5}$ levels and the Air Quality Index (AQI) crucial for effective air quality management and public health protection [11,14-15].

The assessment of $PM_{2.5}$ concentrations involves a combination of methods. Gravimetric analysis, a traditional approach, collects air samples on filters and measures the particulate mass by weighing these filters before and after sampling [16]. Advancements in technology have facilitated the use of low-cost sensors for real-time monitoring, providing continuous and immediate data on $PM_{2.5}$ levels and other variables. These sensors are calibrated against standard reference instruments to ensure accuracy and reliability [5,17-19]. The AQI is a standardized tool that communicates the current or forecasted air quality and its potential health effects. The AQI ranges are divided into categories that correspond to different levels of health concern. These health concerns are classified according to AQI six categories. These categories are color-coded so that they can be easily understood with value ranges. The categories are: good - green (0-50), moderate - yellow (51-100), unhealthy for sensitive groups - orange (101-150), unhealthy – red (151-200), very unhealthy – purple (201-300), and hazardous – maroon (301-500) [11,20-22]; https://www.epa.gov/outdoor-air-quality-data/air-data-basic-information).

Particulate matter ($PM_{2.5}$) is a critical component of the AQI due to its severe health impacts. Prolonged exposure to high levels of $PM_{2.5}$ can cause chronic respiratory and cardiovascular diseases, decreased lung function, and increased mortality rates [23,24]. Lagos was one of the megacities reported to be with the highest $PM_{2.5}$ according to a World Bank project (Figure 1) [25]. This has several implications on all levels or categories of human - children, women, and men. A research study conducted by Kalisa et al. [26] reported negative implications on children arising from the pollution of the atmosphere by particulate matter [27,28]. The pollution of the atmosphere by either fine particles or other atmospheric pollutants will cause poor outdoor and indoor air quality and the deterioration of buildings and other facilities depending on the quality and structures of such facilities [5,23,24,29].

AirQo is an initiative by Makerere University in Uganda aimed at improving air quality monitoring across Africa. Utilizing a network of low-cost sensors, AirQo provides real-time data on air pollution, with a particular focus on $PM_{2.5}$ concentrations. This project supports the development of informed policies and raises public awareness about air quality issues [30]. Previous studies [25,30-45] on $PM_{2.5}$ in Lagos have highlighted the severe air quality issues facing the city. Awopeju [30] documented elevated levels of $PM_{2.5}$ across various parts of Lagos, attributing these high concentrations to vehicular emissions and industrial activities. Similarly, Akinfolarin et al. [31] found that $PM_{2.5}$ levels frequently exceed WHO's recommended limits, underscoring the significant health risks posed to residents. A study conducted by Iroegbulem et al. [32] on some air quality parameters such as total particulate matter, CO, and CO_2 reported that air quality was poor throughout the year of study in Lagos when compared with WHO limit including a world bank project on air quality carried out by Croitoru et al. [25] in Lagos.

The significance of this study lies in its potential to inform all the stakeholders on the public health status of the area, this will assist in workout strategies and policy-making in Lagos State. By providing comprehensive data on $PM_{2.5}$ levels and AQI across multiple locations, this study aims to identify pollution hotspots and temporal patterns, thereby enabling targeted interventions to mitigate health risks and improve air quality. Lagos State faces significant air pollution challenges due to its dense population, high traffic volumes, and extensive industrial activities. Despite the severity of these issues, there is limited data on the spatial distribution and levels of $PM_{2.5}$ and AQI, hindering effective air quality management and mitigation efforts. This study seeks to address this critical data gap by assessing $PM_{2.5}$ concentrations and AQI in eight locations across Lagos State. Assessing $PM_{2.5}$ levels and AQI are crucial for several reasons. It helps understand the extent of air pollution and its health impacts, supports the formulation of local air quality standards, and aids in evaluating the effectiveness of current pollution control measures (Kumar, Gulia et al. [33]. Moreover, it raises public awareness and encourages community action towards improving air quality. One of the biggest environmental health dangers around the globe is air pollution hence the need for adequate monitoring. In 2019, 99% of people on Earth lived in areas where the WHO's recommended air quality criteria were unmet. Ambient (outside) air pollution is predicted to have contributed to 4.2 million premature deaths globally in 2019. The effects of ambient and residential air pollution are linked to 6.7 million premature deaths annually [28].

This study acknowledges several limitations. The accuracy of low-cost sensors, although improving, can vary compared to standard monitoring equipment. Additionally, the study's spatial coverage is limited to eight locations, which does not fully represent the entire state's air quality. Seasonal variations and specific local factors could also influence $PM_{2.5}$ levels and AQI, potentially affecting the comprehensiveness of the study. The aim of this study is to utilize data from AirQo to assess the concentration levels and spatial distribution of $PM_{2.5}$ and AQI across the selected eight locations in Lagos State, Nigeria. The objectives are to:

1. Analyze $PM_{2.5}$ concentrations in eight locations in Lagos State using data obtained from AirQo sensors,
2. Evaluate the spatial distribution of $PM_{2.5}$ levels and AQI across these locations,
3. Compare the measured $PM_{2.5}$ levels and AQI with national and international air quality standards,
4. Provide recommendations for improving air quality based on the findings from the AirQo data.

2 Materials and Methods

2.1 Description of the locations

Lagos State, located in the southwestern region of Nigeria, is the most populous state in the country and the economic hub of West Africa. It spans an area of approximately 3,577 square kilometers and is home to over 20 million people. The state is characterized by a diverse economy that includes industries such as finance, manufacturing, oil and gas, and telecommunications (Lagos State Government, https://lagosstate.gov.ng/about-lagos/). Lagos State is divided into five administrative divisions, which are further subdivided into 20 local government areas. The state's rapid urbanization and economic activities have made it a critical area for studying air quality and environmental impacts [35-37].

Akoka (6.5261° N, 3.3921° E) is a residential area located in the Yaba district of Lagos (Table 1). It is known

for housing the University of Lagos, one of Nigeria's leading academic institutions. The presence of the university contributes to a relatively high population density and significant vehicular traffic in the area. Akoka's air quality is influenced by both residential and educational activities [38]). Banana Island (6.4667° N, 3.4500° E) is an affluent neighborhood in Lagos, known for its exclusivity and luxury real estate. Situated off the coast of Ikoyi, Banana Island hosts high-end residential and commercial properties. The area is characterized by lower population density and controlled environmental standards, which generally result in better air quality compared to more industrial or densely populated areas [39].

Egbeda (6.59160 ° N, 3.29110 ° E) is a bustling suburb located in the Alimosho Local Government Area of Lagos. It is a densely populated area with a mix of residential, commercial, and industrial activities. The high traffic congestion and numerous small-scale industries contribute to significant air pollution in Egbeda [40]. Ikeja (6.6018° N, 3.3515° E), the capital of Lagos State, is a major commercial and administrative center. It is home to the Murtala Muhammed International Airport, numerous businesses, and government offices. Ikeja experiences heavy traffic congestion and industrial emissions, which significantly impact its air quality [41].

Ikotun (6.5631° N, 3.2506° E) is a residential and commercial area in the Alimosho Local Government Area. It is known for its busy markets and high population density. The air quality in Ikotun is affected by traffic emissions and the activities of numerous small businesses and vendors [42]. Lagos Island (6.4549° N, 3.4246° E) is the historic and commercial heart of Lagos State. It is the headquarter of many of the financial institutions, corporate headquarters, and major markets, such as Balogun international Market. The high concentration of commercial activities and traffic congestion contribute to significant air pollution on Lagos Island [43].

Lagos Port, also known as Apapa Port (6.4413° N, 3.3799° E), is the largest and busiest port in Nigeria. It handles a significant portion of the country's maritime trade, leading to heavy truck traffic and industrial activities in the area (Table 1). The port's operations are a major source of air pollution, including emissions from ships, trucks, and industrial activities [44].The Lagos State Property Development Corporation (LSPDC - 6.5576° N, 3.3653° E) is involved in real estate development across Lagos State. LSPDC-managed estates and developments are spread throughout the city, providing housing and commercial spaces. These developments vary in terms of population density and environmental impact, but they generally aim to implement sustainable building practices (Lagos State Government, n.d.).

Table 1: The coordinates and the activities within the monitored locations.

Station ID	**Location**	**Latitude**	**Longitude**	**Region**	**Activities/Land Use**
1	Akoka	6.5261°N	3.3921° E	Southwest	Residential area. High population density and significant vehicular traffic
2	Banana Island	6.4667° N	3.4500° E	Southwest	Residential and commercial properties
3	Egbeda	6.5916° N	3.2911° E	Southwest	Residential, commercial, and industrial activities
4	Ikeja	6.6018°N	3.3515°E	Southwest	Commercial and administrative center
5	Ikotun	6.5631° N	3.2506° E	Southwest	Busy markets and high population density
6	Lagos Island	6.4549° N	3.4246° E	Southwest	Commercial activities and traffic congestion
7	Lagos Port	6.4413° N	3.3799° E	Southwest	Emissions from ships, trucks, port and industrial activities
8	LSPDC	6.5576° N	3.3653° E	Southwest	Housing and commercial activities. High population density

The methods employed in this study for assessing $PM_{2.5}$ concentrations and Air Quality Index (AQI) in eight locations across Lagos State, Nigeria, primarily involved the utilization of data from AirQo sensors. These sensors provide real-time, continuous monitoring of air quality, offering a robust and cost-effective means of gathering data on particulate matter. To perform this study, the steps summarized in the following subsections were undertaken.

2.2 Sensor Deployment and Data Collection

AirQo Project an air quality initiative from Makerere University, Uganda collaborated with Air Quality Monitoring Research Group (AQMRG), University of Lagos, Lagos, Nigeria with the a shared vision for cleaner air for cities. AirQo $PM_{2.5}$ sensors were strategically deployed across eight locations in Lagos State, selected based on factors such as population density, traffic volume, and proximity to industrial activities in other to determine the hotspots [45]. At each of the locations the sensors were mounted between 1.5 –

2 meters above the ground. These sensors continuously monitored $PM_{2.5}$ levels, capturing data at regular intervals for three months (January to March 2024). AirQo's sensors are known for their reliability and have been calibrated against reference-grade monitoring equipment to ensure accuracy [45].

2.3 Data Validation and Calibration

To ensure the accuracy and reliability of the data, the AirQo sensors underwent rigorous calibration procedures [45,46]. The calibration involved comparing the sensor readings with those from standard reference monitors in controlled settings of the AirQo based in Makerere University, Uganda. This process helped to adjust the sensor outputs, ensuring that they provide accurate $PM_{2.5}$ measurements [23].

2.4 Spatial Analysis

The collected data were analyzed to understand the spatial distribution variations of $PM_{2.5}$ levels across the eight locations for the three months periods. Geographic Information System (GIS) tools were used to map the spatial distribution of $PM_{2.5}$ concentrations, highlighting areas with high pollution levels [47]. The analysis involved examining the variations in $PM_{2.5}$ levels over different times of the day and months, identifying patterns and trends [48].

2.5 Air Quality Index (AQI) Calculation

The AQI for each location was calculated using the $PM_{2.5}$ concentration data (https://www.airnow.gov/aqi/aqi-calculator/). The AQI is a standardized index that converts $PM_{2.5}$ levels into a single number representing the overall air quality, categorized into different health impact levels. The calculation followed the guidelines set by the U.S. Environmental Protection Agency [16], which provide a clear framework for interpreting $PM_{2.5}$ data in terms of health risks.

2.6 Data Analysis and Interpretation

The data analysis included statistical methods using Excel and Minitab software to determine the basic distributions and contributions. Comparative analysis was conducted against national and international air quality standards, including WHO [1,49] guidelines, to evaluate the severity of pollution in Lagos.

3 Results

Table 2 depicts the levels across various locations with mean values and standard deviations indicating both the average pollution levels and their variability. The high coefficient of variation in percent (58.23-104.40) shows wide variability, which are confirmed by the minimum and maximum values. Akoka (65.51 ± 47.13µg/m^3) and Banana (46.51 ± 48.56 µg/m^3) show the highest pollution levels and variability, suggesting severe and fluctuating pollution, likely due to intermittent industrial activities and traffic. Egbeda (39.27 ± 28.68µg/m^3) and Ikotun (36.84 ± 28.01µg/m^3) have moderate pollution levels with considerable variability, indicating a mix of constant and sporadic pollution sources. Also, Ikeja (28.26 ± 21.35µg/m^3) and Lagos Island (35.04 ± 22.99µg/m^3) show lower pollution levels with more stability, suggesting effective pollution control and fewer extreme pollution events, and Lagos port (19.12 ± 11.84 µg/m^3) and LSPDC (15.63 ± 9.11µg/m^3) exhibit the lowest pollution levels and variability, indicating successful pollution management and a cleaner environment. The implications of these results include: high and variable pollution significant health risks, including respiratory and cardiovascular diseases, degradation of air and water quality, impacting biodiversity and soil health, increased healthcare expenses, reduced productivity, and lower property values which may be tagged economic consequences of high pollution. On this premise, there is a need for stricter pollution control regulations, effective monitoring, enforcement of policies, particularly in high-pollution areas, and enhancing community awareness and promoting green initiatives to reducing the pollution levels.

Table 2: Basic Description of the data in the different locations.

Parameter	Akoka	Banana Island	Egbeda	Ikeja	Ikotun	Lagos Island	Lagos Port	LSPDC
Mean (µg/m^3)	65.61	46.51	39.27	28.26	36.84	35.04	19.12	15.63
SE Mean	1.19	1.63	0.78	0.62	0.69	0.82	0.31	0.42
Stdev	47.13	48.56	28.68	21.35	28.01	22.99	11.84	9.11
CoefVar (%)	71.84	104.40	73.02	75.55	76.02	94.18	61.90	58.23
Minimum (µg/m^3)	7.39	7.15	6.97	6.28	6.37	6.51	6.46	6.74
Q1	20.86	14.97	15.39	12.51	14.27	12.57	12.76	10.08
Median	53.62	22.54	31.42	20.01	28.21	21.10	15.42	13.47
Q3	114.41	56.03	55.71	36.42	52.64	46.61	200.78	16.92
Maximum (µg/m^3)	196.77	204.68	144.05	111.48	149.17	178.81	115.21	65.14
IQR	93.54	41.05	40.32	23.91	38.38	34.03	8.02	6.84
Skewness	0.47	1.50	1.10	1.24	1.11	1.74	2.53	2.59
Kurtosis	-1.12	0.85	0.56	0.55s	0.52	2.85	8.35	8.28

Figure 1 shows the air quality results concerning $PM_{2.5}$ levels in Lagos. Akoka has the worst air quality, exceeding (annual) WHO (15 μg/m^3) standards. Banana Island, Egbeda, Ikeja, and Ikotun also surpass WHO recommendations but fall within the national limit of NESREA (150 μg/m^3). Only LSPDC meets both safety standards. These results highlight potential health risks for residents due to chronic exposure to $PM_{2.5}$. Stricter regulations aligned with WHO guidelines and targeted interventions in high-pollution areas like Akoka are crucial. Continuous air quality monitoring is necessary to track progress in improving Lagos' air quality. The percentage contribution of $PM_{2.5}$ across the eight locations studied can be expressed in this order: Akoka>Banana>Egbeda>Ikotun>Lagos Island>Ikeja>Lagos Port>LSPDC.

Figure 2 shows the spatial distributions of $PM_{2.5}$ vary significantly across the eight locations used in the study. Akoka has the highest contribution (23%), indicating that within specified locations, $PM_{2.5}$ contributed most of air pollution in that area. Other locations like Banana Island (16%) and Egbeda (14%) also have substantial contributions. While the specific health impacts can vary depending on factors like age, pre-existing health conditions, and duration of exposure, here are some general health concerns associated with $PM_{2.5}$: Exposure to $PM_{2.5}$ can irritate the lungs, leading to respiratory problems like asthma, bronchitis, and difficulty breathing [1,2,4]. This is a concern for all locations in Lagos with $PM_{2.5}$ contributions above 0%. $PM_{2.5}$ can increase the risk of heart disease by affecting the cardiovascular system [2]. All locations with $PM_{2.5}$ contributions in Lagos should be aware of this potential risk. Long-term exposure to $PM_{2.5}$ is linked to an increased risk of lung cancer. Locations with higher contributions, like Akoka (23%), Banana Island (16%), and Egbeda (14%), have a greater potential risk. $PM_{2.5}$ is just one of many air pollutants. The combined effects of various pollutants can be more harmful than individual exposures. Children, older adults, and people with pre-existing health conditions are more susceptible to the negative health effects of $PM_{2.5}$ [2,4].

Table 3 shows the comparisons between our study and previous studies on $PM_{2.5}$ air pollutions. The data provided reveals significant variations in $PM_{2.5}$ concentrations across different Nigerian cities. $PM_{2.5}$ levels range from a low of 4.22 μg/m^3 in Gwagwalada according to Ezeonyejiaku et al. [50] to a high of 236.6 μg/m^3 in Ile-Ife by Abulude et al. [51], showcasing a substantial difference in air quality across these locations. Lagos falls (15.63 – 65.61 μg/m^3) within the range observed in other cities. While some areas in Lagos have concerning levels, others seem comparable to cities like Yenagoa [7,52]) and Abuja [53]. Owerri, Ezihe village [54], Ile-Ife [52], Port Harcourt [31], and Nsukka [55] have particularly concerning $PM_{2.5}$ levels, consistently exceeding WHO guidelines (15μg/m^3).Several factors can contribute to these variations which include, highly urbanized and industrialized cities like Lagos, Kano, and Port Harcourt have higher $PM_{2.5}$ emissions from vehicles, factories, and power plants, cities with heavy traffic congestion, like Lagos, experience increased $PM_{2.5}$ emissions from vehicle exhaust, open waste burning practices could have significantly elevated $PM_{2.5}$ levels, particularly in densely populated areas, the wind patterns and weather

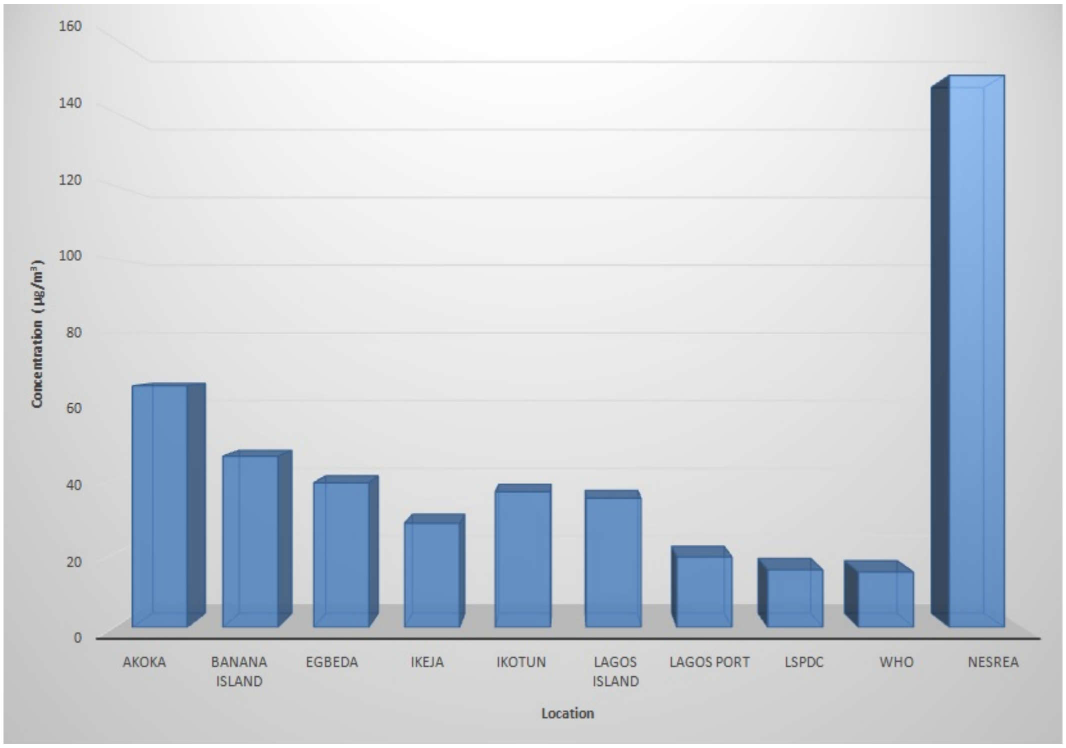

Figure 1: The comparisons of the PM values of each location with the national and international safety standards.

conditions could have affected how $PM_{2.5}$ disperses in the atmosphere in Gwagwalada including industrial effluents. Lastly, variations in data collection methodologies and timeframes across different studies could have contributed to the discrepancies.

The high $PM_{2.5}$ levels in several cities pose significant health risks to residents, including respiratory problems, heart disease, and lung cancer. There is the need to reduce the $PM_{2.5}$ pollution by implementing stricter regulations on industries and vehicles can significantly reduce $PM_{2.5}$ emissions, transitioning to cleaner energy sources like solar and wind power can reduce reliance on fossil fuels and improve air quality, phasing out open waste burning and implementing efficient waste collection systems are crucial, educating the public about the health risks of $PM_{2.5}$ and promoting protective measures like wearing masks can empower residents, and consistent monitoring across cities is essential to track progress and identify areas needing the most attention.

Table 3: Analyzing and contrasting our study's findings with earlier research from different Nigerian cities.

Location	**$PM_{2.5}$ (μg/m³)**	**AQI**	**References**
Lagos, Nigeria	15.63 – 65.61	63 – 157	Our study
Abuja, Nigeria	30.79 - 105.43	205 - 702.86	[53]
Owerri and Ezihe village, Nigeria	99.30-124.70	-	[54]
Yenagoa, Nigeria	11.1-26.2	46-80	[7]
Ile-Ife, Nigeria	9.1 - 236.6	128	[52]
Abuja, Nigeria	18 – 95	4-42	[56]
Ikeja, Nigeria	20 - 123	70 – 188	[51]
Port-Harcourt, Nigeria	>200	-	[31]

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Location	**$PM_{2.5}$ (µg/m^3)**	**AQI**	**References**
Nsukka, Nigeria	57-106	50.00-99.87	[55]
Kano, Nigeria	22-110	19.62- 106.11	[57]
Gwagwalada, Nigeria	4-4.22	17	**[50]**
Ilorin, Nigeria	44.36-60.70	114-154	[58]

Table 4 presents a concerning picture of air quality in various locations across Lagos. All locations, except LSPDC, have $PM_{2.5}$ concentrations exceeding the WHO guideline. Akoka has the highest level (65.61 μg/m^3), followed by Banana Island, Egbeda, Ikotun, and Lagos Island. These areas fall under the "Unhealthy for Sensitive Groups" AQI category (101-150), indicating a risk for people with respiratory or heart conditions, the elderly, and children. Ikeja, Lagos Port, and LSPDC fall under the "Moderate" AQI category (51-100), suggesting less risk but still with potential health effects for sensitive individuals during prolonged exertion. Table 4 also highlights the increased risk of respiratory problems, heart disease aggravation, and premature mortality for sensitive groups across most locations. Even in "Moderate" AQI areas, unusually sensitive people might experience health effects during extended physical activity.

The widespread presence of $PM_{2.5}$ above safe levels poses a significant public health threat to Lagos residents, especially vulnerable populations. Urgent action is required to reduce $PM_{2.5}$ emissions and improve air quality. This could involve, implementing stricter emission controls for vehicles and industries, investing in cleaner energy sources like solar and wind power, phasing out open waste burning and promoting efficient waste collection, educating the public about the risks of $PM_{2.5}$ and promoting protective measures like wearing masks and Akoka, with the highest $PM_{2.5}$ level, needs immediate investigation to identify pollution sources and implement targeted interventions.

Table 4: The PM Concentration, Air Quality Index, AQI Category, Sensitive Groups, and Health effects and Cautionary Statements.

Location	**$PM_{2.5}$ Concentration**	**AQI**	**AQI Category**	**Sensitive Groups**	**Health Effects Statements**	**Cautionary Statements**
Akoka	65.61	157	Unhealthy	People with respiratory or heart disease, the elderly and children are the groups most at risk	Elevated respiratory effects in the general population; increased exacerbation of heart or lung disease and early mortality in individuals with cardiopulmonary disease and the elderly.	Extended physical activity should be limited for everyone else, but it should be avoided by those with heart or respiratory conditions, the elderly, and the children.

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Location	**$PM_{2.5}$ Concentration**	**AQI**	**AQI Category**	**Sensitive Groups**	**Health Effects Statements**	**Cautionary Statements**
Banana Island	46.91	129	Unhealthy for sensitive group	People with respiratory or heart disease, the elderly and children are the groups most at risk.	An increased risk of respiratory symptoms in susceptible people, worsening heart or lung illness, and early death in older people and those with cardiopulmonary disease.	Prolonged exercise should be limited in the elderly, children, and those with heart or pulmonary conditions.
Egbeda	39.37	110	Unhealthy for sensitive group	People with respiratory or heart disease, the elderly and children are the groups most at risk.	Increasing likelihood of respiratory symptoms in sensitive individuals, aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly.	People with respiratory or heart disease, the elderly and children should limit prolonged exertion.
Ikeja	28.26	86	Moderate	People with respiratory or heart disease, the elderly and children are the groups most at risk.	Unusually sensitive people should consider reducing prolonged or heavy exertion	Unusually sensitive people should consider reducing prolonged or heavy exertion

Location	$PM_{2.5}$ Concentration	AQI	AQI Category	Sensitive Groups	Health Effects Statements	Cautionary Statements
Ikotun	36.84	103	Unhealthy for sensitive group	People with respiratory or heart disease, the elderly and children are the groups most at risk	Increasing likelihood of respiratory symptoms in sensitive individuals, aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly.	People with respiratory or heart disease, the elderly and children should limit prolonged exertion
Lagos Port	19.12	69	Moderate	People with respiratory or heart disease, the elderly and children are the groups most at risk.	Unusually sensitive people should consider reducing prolonged or heavy exertion.	Unusually sensitive people should consider reducing prolonged or heavy exertion.
LSPDC	15.64	63	Moderate	People with respiratory or heart disease, the elderly and children are the groups most at risk.	Unusually sensitive people should consider reducing prolonged or heavy exertion.	Unusually sensitive people should consider reducing prolonged or heavy exertion.

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Location	$PM_{2.5}$ Concentration	AQI	AQI Category	Sensitive Groups	Health Effects Statements	Cautionary Statements
Lagos Island	35.04	103	Unhealthy for sensitive group	People with respiratory or heart disease, the elderly and children are the groups most at risk	Increasing likelihood of respiratory symptoms in sensitive individuals, aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly.	People with respiratory or heart disease, the elderly and children should limit prolonged exertion

4 Conclusions

This study provides a comprehensive assessment of $PM_{2.5}$ concentrations and AQI across eight locations in Lagos State, Nigeria, utilizing data obtained from AirQo sensors. The findings underscore the critical issue of air pollution in Lagos, revealing that $PM_{2.5}$ levels in many areas exceed both national and international air quality standards. This indicates a significant risk to public health, particularly in densely populated and industrial regions of the state. The spatial analysis of $PM_{2.5}$ and AQI highlights specific pollution hotspots, which can be attributed to factors such as vehicular emissions, industrial activities, and urban development. These insights are crucial for policymakers and public health officials in Lagos State to develop targeted strategies to mitigate air pollution and protect public health.

This study also emphasizes the importance of continuous and real-time air quality monitoring. The use of AirQo array of sensors has proven effective in providing accurate and timely data, which is essential for informed decision-making and public awareness. Despite its limitations, such as the potential variability in sensor accuracy and the limited spatial coverage, this study contributes valuable information to the understanding of air quality in Lagos State. Future research should aim to expand the monitoring network and incorporate additional environmental and health data to provide a more comprehensive picture of the impacts of air pollution.

In all, addressing the high levels of $PM_{2.5}$ in Lagos State is imperative for improving public health outcomes and ensuring a sustainable urban environment. The findings from this study serve as a crucial step towards achieving these goals, highlighting the need for collaborative efforts between government agencies, research institutions, and the community to combat air pollution effectively.

5 Recommendations

Based on the findings from the assessment of $PM_{2.5}$ and AQI in eight locations across Lagos State, the following recommendations are proposed to address the air quality issues and mitigate health risks:

Enforce stricter emissions standards for vehicles, promote regular vehicle maintenance, and encourage the use of cleaner fuels and electric vehicles. Implement stringent regulations for industrial emissions, ensure regular monitoring, and mandate the adoption of cleaner production technologies. Develop and expand public transportation networks to reduce the reliance on private vehicles. This includes investing in buses, trains, and other mass transit systems with the best available practices (bap). Promote the use of non-motorized transport, such as cycling and walking, by creating dedicated lanes and safe pathways.

Conduct public awareness campaigns to educate residents about the health impacts of air pollution and ways to reduce personal exposure. Encourage community involvement in air quality monitoring and

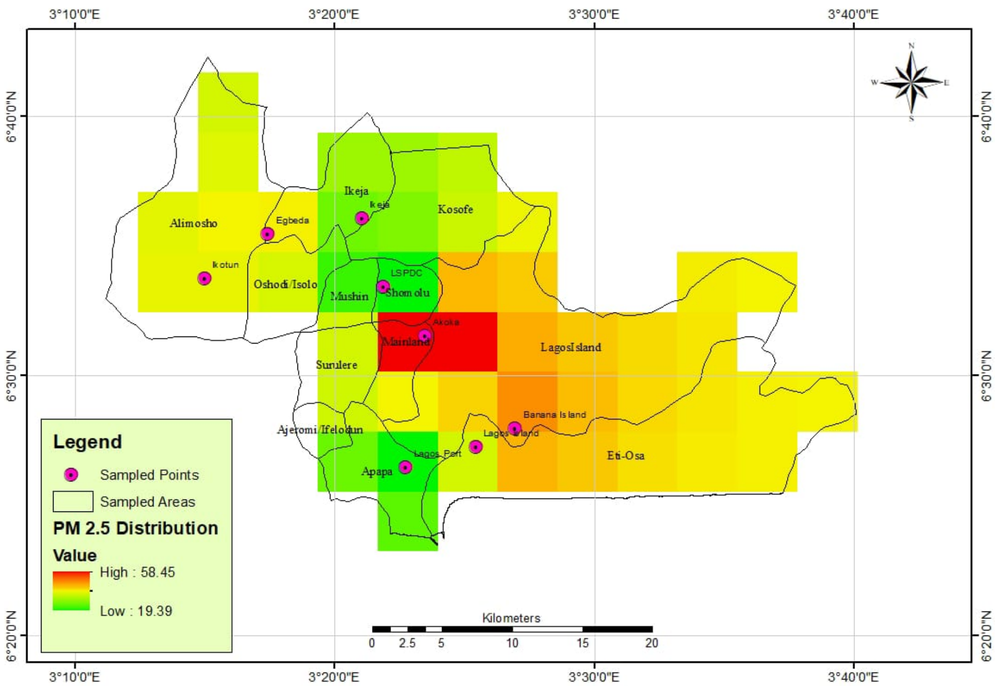

Figure 2: This figure shows the distributions (mean) of $PM_{2.5}$ in each location of the various locations. The different colours show levels of the $PM_{2.5}$ concentrations.

pollution reduction initiatives. Increase the number of monitoring stations across Lagos State to provide more comprehensive coverage and capture local variations in air quality. Utilize advanced monitoring technologies, such as satellite observations and mobile monitoring units, to supplement ground-based sensors. Collaborate with local governments, communities, and stakeholders to develop tailored air quality action plans that address specific pollution sources and local conditions. Set clear targets and timelines for reducing $PM_{2.5}$ levels and improving overall air quality.

Support ongoing research on air pollution sources, dispersion patterns, and health impacts to inform policy decisions. Facilitate the sharing of air quality data among government agencies, research institutions, and the public to enhance transparency and collective action. Integrate green infrastructure, such as parks, green roofs, and urban forests, into city planning to enhance air quality and provide additional environmental benefits. Implement zoning regulations that separate industrial areas from residential neighborhoods to minimize exposure to pollutants.

Lastly, foster collaboration between various government agencies, including environmental, health, transportation, and urban planning departments, to ensure integrated and cohesive air quality management strategies. Align air quality improvement efforts with broader environmental and public health policies to maximize impact and resource efficiency.

6 Supplementary Materials

The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Figure S1: title; Table S1: title; Video S1: title.

7 Author Contributions

Conceptualization, AA, S.D.A., and F.O.A.; methodology, F.O.A.; software, A.A. and F.O.A; validation, A.A.; formal analysis, A.A.; investigation, F.O.A.; resources, F.O.A.; data curation, A.A.; writing—original draft preparation, F.O.A.; writing - review and editing, A.A, S.D.A., D.S. and F.O.A.; visualization, A.A.; project administration, F.O.A.A.A., and S.D.A. Authors have read and agreed to the published version of the manuscript

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11 Data Availability Statement

Data are publicly unavailable due to privacy.

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13 Conflicts of Interest

The authors declare no conflicts of interest.

14 Copyright Notice

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