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ASSESSMENT OF AIR QUALITY CONDITIONS IN AN AREA IN THE GULF OF GUINEA, IBADAN, USING LOW-COST SENSORS

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Abstract
Air quality monitoring is essential for the determination of the potential negative impacts of air pollution on humans and the environment. This study investigated the contribution of particulate matter (PM 2.5 and 10) to air quality in an area in the Gulf of Guinea, far south of Sahara. The study used the hourly data of PM 2.5 and 10 concentrations and other auxiliary data in 2021 from the PurpleAir sensors. These PM concentration data were first converted into Air Quality Index (AQI) using appropriate method of aggregation. Subsequently, the AQI was used to categorize the ambient air into six classes that range between “Good" to "Severe" conditions. Results indicated higher prevalence of "Good “to “Satisfactory" AQI conditions during the peak of the rainy season (June, July and August), characterized by low PM concentrations, whereas the harmattan season (December, January and February) exhibited a higher prevalence of "Very Poor" to "Severe" conditions, characterized by high PM concentrations. High AQI and PM concentrations were attributable to organic PM Saharan dust in the harmattan season, while low AQI and PM concentrations in the rainy season were associated with localized anthropogenic sources. Thus, the low-cost sensor PurpleAir was able to capture the expected seasonal patterns peculiar to the study region.

INTRODUCTION

Air quality refers to the cleanliness and sanctity of air, encompassing pollutants and contaminants that can negatively impact ecosystems, human health, and the environment. It has been reported that air pollution levels worldwide are rising because of the current global economic expansion, industrialization, urbanization, population growth, increased energy consumption, transportation, and motorization. The combined effects of environmental ambient air and household air pollution is associated with 6.7 million premature deaths annually.

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Ambient (outdoor) air pollution alone was estimated to have caused 4.2 million premature deaths worldwide in 2019, and about 89% of these occurred in low- and middle-income countries, with the greatest part situated in the Southeast Asia and Western Pacific Regions (WHO, 2022). Quality air is crucial for maintaining good health because it has a direct impact on the cardiovascular and respiratory systems. Poor air quality can lead to respiratory conditions such as asthma, chronic obstructive pulmonary disease (COPD), and respiratory infections. According to the World Health Organization (WHO), the pollutants that pose the greatest risk to the public's health are particulate matter (PM), carbon monoxide (CO), ozone (O3), nitrogen dioxide (NO2), and sulfur dioxide (SO2). Particulate matter (PM) is a mixture of solid particles and liquid droplets containing various chemicals in the air (US EPA, 2017). The common components of PM include organic compounds, sulfates, nitrates, metals, and black carbon. The PM is classified based on aerodynamic diameters as PMx, where x represents the diameter in microns. PM10 and PM2.5 are the size fractions most commonly monitored. Fine particles, such as PM2.5, are of particular concern because of their ability to penetrate deep into the lungs and potentially enter the bloodstream. PM2.5 and PM10 have been linked to many severe health effects (US EPA, 2017, Pope III *et al., 2004*). High concentrations of nitrogen dioxide and sulfur dioxide also worsen asthma symptoms in vulnerable individuals (Brook *et al.,* 2010). According to Dockery et al., 1993, health effects associated with exposure to PM include respiratory and cardiovascular issues, such as aggravated asthma, bronchitis, reduced lung function, and increased risk of heart attacks and premature death. In addition, PM can have harmful effects on the environment. Fine particles can impair visibility, resulting in haze and reduced air clarity. Besides, PM can contribute to the formation of smog and acid rain and, have adverse effects on ecosystems, including damage to plants, reduced crop yields, and impacts on biodiversity (Galloway et al., 2004). Thus, the health of people and ecosystems is significantly at risk from air pollution, which is characterized by the presence of toxic compounds in the atmosphere. By reducing the level of pollutants in the atmosphere, countries can reduce the burden of disease from stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases, including asthma (WHO, 2022).

Understanding the possible health and environmental impacts of atmospheric pollutants heavily depends on air quality monitoring and evaluation. Nigeria, the most populous African nation, is located south of the Sahara, and similar to Southeast Asian countries, is bedeviled by problems associated with urbanization, industrialization, transportation emissions, and biomass burning, which could directly impact air quality. Afore-mentioned studies had already established that air quality impacts the environment, human health, and sustainable development.

Assessing air quality is essential for understanding the extent and nature of pollution levels in different provinces and regions of the world. Through comprehensive monitoring, policymakers and environmental agencies can gain insights into the spatial and temporal patterns of air pollution, identify pollution hotspots, evaluate the effectiveness of emission control measures, and establish guidelines and standards to protect public health and the environment (EEA, 2020). Fuwape *et al.* (2020) studied the impact of COVID-19 lockdowns on air pollution in Lagos, Port Harcourt, and Kaduna using Ozone Monitoring Instrument (OMI) data and historical records to determine changes due to restricted mobility. Odediran *et al.* (2022) studied air pollution trends at 25 traffic intersections in Ibadan, Nigeria, before and during the COVID-19 lockdown, analyzing climatic parameters, vehicular counts, and ten pollutants. Ana *et al*. (2009) assessed air pollution sources in an urban center, Ibadan, Nigeria, and their adverse health effects on students. This study aimed to fill the knowledge gaps on air quality and its impact on school-age children in Africa, thereby contributing to the understanding of the potential health risks of pollutants.

The paucity of air quality data has been identified as a problem in many regions. The recent publicly available data from low-cost PurpleAir monitoring sensors provide an enormous opportunity to assess the air quality in

Ibadan, a densely populated city located in the Gulf of Guinea, Nigeria. This study aims to assess the air quality at selected locations in Ibadan.

2 Materials and Methods

2.1 PurpleAir Air Quality Monitoring Data

The recent proliferation of low-cost air quality monitoring sensors offers extraordinary opportunities for air quality and exposure measurements by the public and researchers, though, attention must be paid to data quality assurance (Snik et al., 2014). PurpleAir air quality monitoring sensor (PurpleAir, Draper, Utah) is one of the large numbers of inexpensive, commercially available air quality monitoring sensors used by people and researchers worldwide. These sensors can be deployed indoors or outdoors to measure PM concentrations, humidity, temperature, and pressure in real-time for home, commercial, or industrial applications. The sensor has an in-built Wi-Fi that enables real-time data transmission to the PurpleAir database, which is then made accessible to any smart device.

Hourly data for the year 2021 from the PurpleAir sensors deployed by citizen groups in the study area were downloaded (*https://community.purpleair.com/t/download-sensor-data/100*) and used. The dataset consists of air pressure, temperature, humidity, PM1.0, PM2.5, and PM10 measurements.

2.2 Study Location

The densely populated second largest indigenous African city of Ibadan (lat. 7º 23' to 7º 55' N; lon. 3º 5' to 4º 36'E) was selected for this study. It has an area of approximately 3,200 km^2. The PurpleAir sensors that were picked and used in this study clustered around two sub-urban areas of the city: Ona-Ara and Egbeda, with a population of over a million as of the 2006 census. The study locations are home to various small-to-medium-sized industries and have heavily used highways, which could be factors that impact the air quality of the area. Hourly data of air temperature, relative humidity, PM2.5, and PM10 measurements that were available for 2021 were downloaded for the study locations and used in this study (Table 1)

Table 1: Geographical coordinates and average values of Air Temperature and Relative Humidity of the locations of study in 2021.

Location	Latitude(°N)	Longitude(°E)	Air Temperature(°	Rel. Humidity(%)
Ogbere-tioya	7.350419	3.953661	30.6	52
Ogbere-tioya	7.349429	3.953799	30.6	53
Alawaye	7.340042	3.950384	30.2	52
Awodele Olorunsc	7.354617	3.94582	30.8	51
Ifewunmi	7.37122	3.954707	-	-
Alakia	7.40223	3.978691	-	-
Olaogun	7.384663	3.94529	32.9	49
Olubadan Estate	7.378107	3.954845	31.2	45
Ogbere-oloba	7.378437	3.953661	32.5	43
Adekola-olode	7.370136	3.993421	30.8	44
Oremeji-Agagu	7.382587	3.932735	31	46
Sawmill	7.389509	3.944217	29.5	50
Akingbade	7.383283	3.950495	28.6	47

2.3 Air quality index (AQI)

The air quality index (AQI) is usually calculated based on pollutant criteria, where the concentration of an individual pollutant is transformed into a sole index using an appropriate aggregation method (Ott, 1978). Each pollutant category is given an index value once the pollutant concentrations are compared to particular threshold values or standards. Using the formula developed by the Central Pollution Control Board of India (CPCB,2016), the AQI sub-index of PM2.5 and PM10, I_p, was calculated for each location based on the data set obtained from PurpleAir sensors.

$$I_p = \frac{J_{Hi} - J_{Lo}}{BP_{Hi} - BP_{Lo}}(C_p - BP_{Lo}) + J_{Lo}$$

Where, I_p= sub-index of pollutant p, C_p = averaged concentration of pollutant p for each day, and BP_{Hi} is the concentration breakpoint with value greater than or equal to C_p while BP_{Lo} is the concentration breakpoint with value less than or equal to C_p. J_{Hi} is the AQI with a value corresponding to BP_{Hi} and J_{Lo} is the AQI with a value corresponding to BP_{Lo}. The highest sub-index was chosen as the AQI following the calculation of the sub-indices for each pollutant. Depending on the AQI score given in Table 2, these values were then classified as "good," "satisfactory," "moderately polluted," "poor," "very poor," or "severe."

After calculating the Air Quality Indices (AQI), the results were further divided into three sub-categories for ease of analysis. This was done by categorizing the standard AQI in the "good" and "satisfactory" categories as "good to satisfactory" category, the "moderately polluted" and "poor" categories as "moderate to poor" category and finally, the "very poor" and "severe" category were categorized as "very-poor to severe" category. The number of days in each category was further sorted into the harmattan season (DJF), comprising December, January, and February, and the peak of the rainy season (JJA), comprising June, July, and August in the study area. The total number of days in each season was then normalized to 90 days to account for missing data and differences in the number of days for the months.

Table 2: Air Quality Index (AQI) Category Adapted from the Central Pollution Control Board of India (2016)

AQI Category		Concentration Range	
	AQI	PM10	PM2.5
Good	0-50	0-50	0-30
Satisfactory	51-100	51-100	31-60
Moderately Polluted	101-200	101-250	61-90
Poor	201- 300	251-350	91-120
Very Poor	301-400	351-430	121-250
Severe	401 – 500	430+	250+

3. Results and Discussion

The harmattan season had the highest number of severities across all 13 locations. The air quality in all the 13 locations during this season was found to be predominantly in the "moderate to poor" and "very poor to severe" categories. This indicates a significant deterioration in air quality and the presence of air pollutants that pose severe health risks. The highest number of days in terms of exposure to very poor/severe conditions was at Alakia (66), with Sawmill (51) experiencing the least number of such days, as shown in Figure 1. Figures 2-4 showed the spatial distribution of the number of days corresponding to the various categorizations (i.e. "good to satisfactory", "moderate to poor", and "very poor to severe") in the harmattan season. Only 3% of the 90 days of the harmattan season correspond to "good to satisfactory" air quality condition, while 33% are in "moderate to poor" condition and the largest chunk of 66% of the 90 days corresponds to "very poor to severe" air condition. Proximity to ambient anthropogenic sources of pollutants, such as roads and highways, seemed to play a lesser role in the air quality when comparing locations such as Oremeji-Agugu, Alakia, and Sawmill with other locations (Figures 3 and 4). The Saharan dust transport, which is prevalent during the DJF months, has been shown to have clear seasonality and is associated with elevated concentrations of suspended PM in the West Africa region, especially when rainfall is low (Querol *et al.*, 2009). The main source of global mineral dust is Saharan dust, and 60% of this dust is transported to the Gulf of Guinea, where our study locations are situated during the harmattan season (Engelstaedter *et al.*, 2006, Okeahialam, 2016).

The air conditions during the peak of rainy season were predominantly good and satisfactory (Figure 5). During the rainy season, the air quality in all 13 locations displayed remarkable improvement over that of the harmattan season, with the onset of the rainy season in April at Ibadan triggering the processes of aerosols rained out and washed out of the old suspended PM in the air. Of the 90 days of the JJA months, 59% corresponded to "good to satisfactory" air quality conditions, while 39% were in "moderate to severe" condition. Locations such as Oremeji, Alakia, and Sawmill were situated close to major roads and have elevated concentrations of pollutants that may have different chemical compositions from the organic PM that characterized the harmattan season (Figures 7 and 8). The elevated concentration of pollutants in other locations, such as Akingbade, Ifewumi, Ogbere-tioya, and Olaogun, may be due to refuge burning, which is a common practice in the study region, or it may also be due to artifacts of the air quality monitoring sensors. This should be further investigated (Figures 7 and 8).

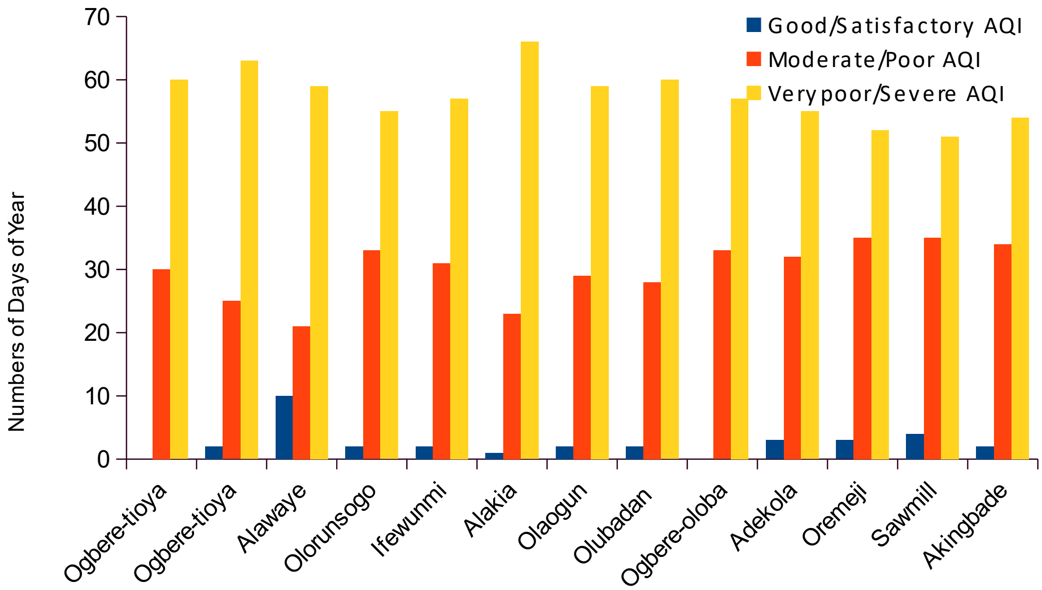

Figure 1: Air Quality Index conditions for all PurpleAir sensor's locations during the 2021 harmattan season

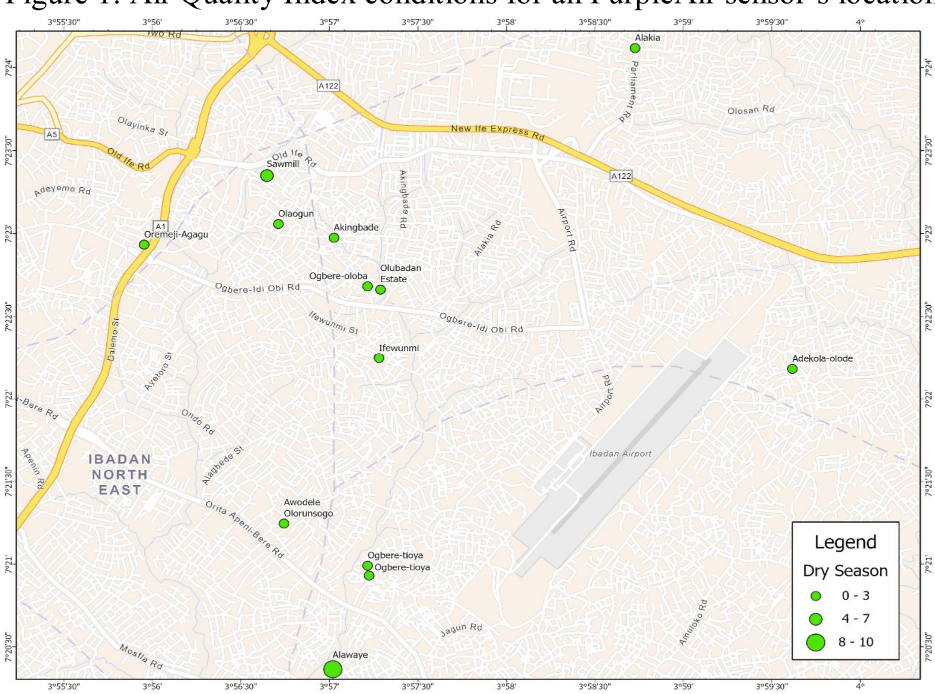

Figure 2: Spatial distribution of "Good to Satisfactory" air quality conditions in all study locations for 2021 harmattan season

Figure 3: Spatial distribution of "Moderate to Poor" air quality conditions in all study locations for 2021 harmattan season.

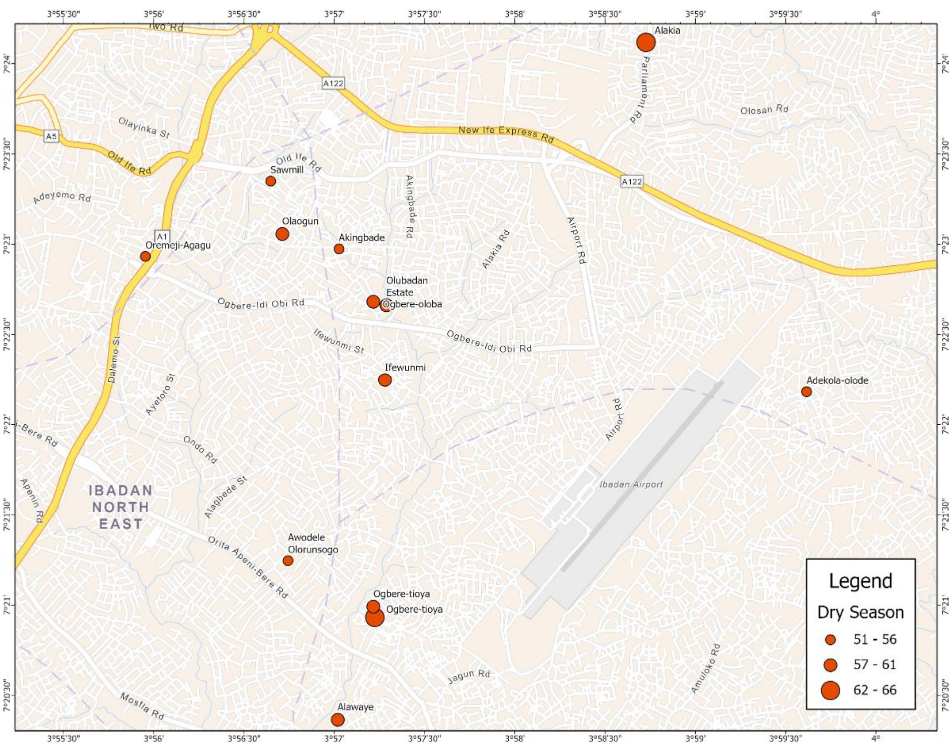

Figure 4: Spatial distribution of "Very poor to Severe" air quality conditions in all study locations for 2021 harmattan season.

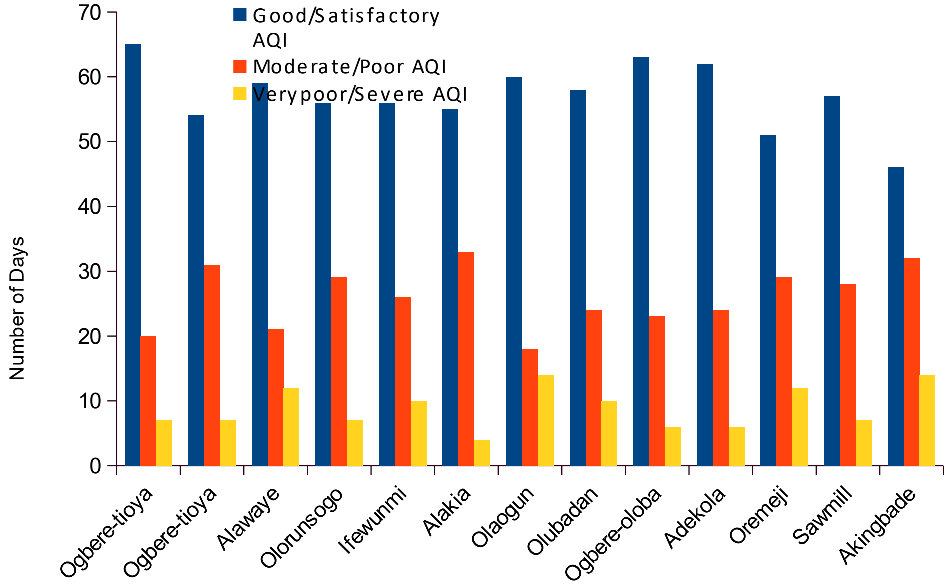

Figure 5: Air Quality Index conditions for all PurpleAir sensor locations during the peak of rainy season in 2021

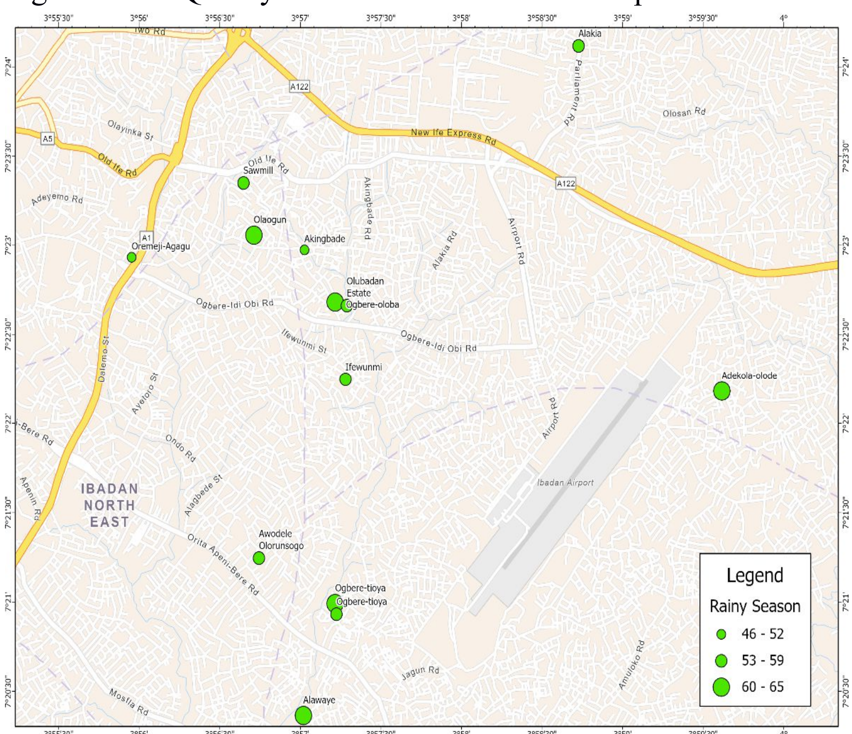

Fig. 6: Spatial distribution of “Good to Satisfactory” air quality conditions for the peak rainy season in 2021

Fig. 7: Spatial distribution of "Moderate to Poor" air quality conditions for the peak of rainy season in 2021.

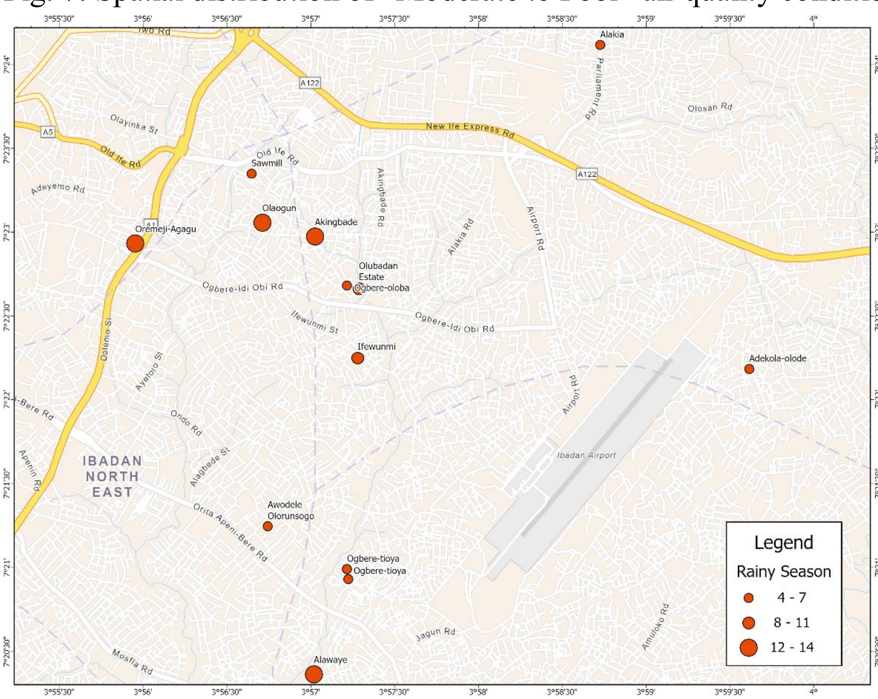

Fig. 8: Spatial distribution of "Very-poor to Severe" air quality conditions for the peak of rainy season in 2021.

4. CONCLUSIONS

This study evaluated the levels of particulate matter concentration in Ibadan, an urban city in the Gulf of Guinea, down south of Sahara, using PurpleAir sensors. Results indicated favorable air quality during the peak of the rainy season, which degraded rapidly during the harmattan season (i.e. DJF months), causing high pollution levels. The results further emphasized how seasonal changes affected the air quality of the study area. Due to precipitation's inherent purifying properties, the rainy season (i.e. JJA months), which was marked by greater amounts of rainfall and humidity, has better air quality. On the other hand, the harmattan season, which was marked by dry and dusty weather, caused an accumulation of particulate matter in the air, resulting in poor and severe air quality.

The particulate pollutants that characterized the harmattan season were mainly from a natural source (i.e. Saharan dust), while the peak of the rainy season was mainly characterized by anthropogenic particulate pollutants from effluents from vehicles, electricity-generating sets, and refuge burning.

Thus, the low-cost sensor, PurpleAir, deployed to measure PM concentrations was able to capture the essential seasonal variations as expected from the climate of the study region. This further confirmed the results of other workers that low-cost sensors could provide both robust and accurate measurements for air quality monitoring when they are well calibrated (Robinson et al. 2023).

Based on the findings, this study suggests educating residents of the study locations about seasonal air quality variations and the need to implement mitigating measures during the harmattan season. In fact, many studies linked the concentration of organic particulate matter in Saharan dust to morbidity. Jiménez *et al*. (2010) found that PM10 concentrations displayed a significant statistical association with daily mortality on days with Saharan dust. While no such effect was attributable to PM10 exposure on non-Sahara dust days. Most studies report on PM2.5–10 (Mallone *et al*., 2011; Pérez *et al*., 2008; Tobías *et al*., 2011a) are in agreement with each other that a strong association exist between PM concentrations' level and daily mortality. Morbidity rates due to West Africa's Saharan dust could be higher than those of other regions of the world, especially in the Gulf of Guinea where harmattan dust accounts for more than 60% of the global mineral dust (Engelstaedter *et al.*, 2006, Okeahialam, 2016). This region, therefore, deserve more scientific investigations in this regard than it is currently getting. Implementation of regulations, emission limits, and prohibition of open burning are crucial. Long-term monitoring and research are advised to identify long-term effects, trends, and the success of implemented mitigation measures.

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Statements and Declarations

The authors declare that there are no competing or conflicting interests associated with the study.

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