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COMPARATIVE ASSESSMENT OF PARTICULATE MATTER USING LOW COST SENSOR: A CASE STUDY OF ABUJA AND KANO, NIGERIA

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ABSTRACT

Inhaling excessive amounts of Particulate Matter (PM) which can be blown over great distances by the wind and then settle in the ground, water, or in the air we breathe, can be hazardous to both sensitive and non-sensitive persons. The study investigates the mass concentration of particulate matter (PM) in Kano and Abuja. Utilizing a purple air sensor, $PM_{1.0}$, $PM_{2.5}$, and $PM_{10.0}$ were all examined along with some climatic variables including temperature and relative humidity. In Kano and Abuja, monitoring took place between January 2021 and December 2021. Results indicate that the monthly PM exceeds the WHO 24-hour limit for the two locations. When the standard limit of the Air Quality Index (AQI) is taken into consideration, the mean value of $PM_{2.5}$ shows that the air quality in both locations is dangerous for sensitive persons, such as those who have respiratory ailments while the mean value of $PM_{10.0}$ shows that the air quality in both locations was moderate for both sensitive and non- sensitive person. The results in this study suggests that government should enhance its current air quality regulations and install new air quality sensors in sufficient locations in Nigeria so that additional research may be done on such regions. The results of a Pearson correlation analysis show that PMs and relative humidity have substantial negative correlations indicating that as relative humidity rises in either locations, PMs mass concentration would decrease as well. A relatively high correlation existed between PMs and temperature for both locations.

Keywords: Air Quality Index (AQI), Correlation coefficient, Kurtosis, Particulate Matter (PM), Purple Air, Skewness

INTRODUCTION

The introduction of dangerous items into the environment is referred to as pollution. Pollutants are the name given to these dangerous substances which have negative consequences on the quality of the air, water, and land (West *et al.*, 2020). The release of pollutants into the atmosphere is classified as air pollution, these pollutants are damaging human health and the environment as a whole (Abulude & Abulude, 2021).

The Smog (also known as ground-level ozone) and Soot (also known as particulate matter) are the two most common forms of air pollution. The gaseous combination of solid and liquid particles suspended in air is known as Particulate matter (PM) (Dockery *et al.*, 1997; WHO, 2013; Adams *et al.*, 2015; Istiqomah *et al.*, 2020). It is also a complex mixture of liquid droplets made up of acids (such as nitrates and sulfates), ammonium, water, black carbon, organic compounds, metals, soil debris, and airborne particles (EPA, 2020). The concentration of PM differs according to but not limited to the following factors wind speed, precipitation, weather conditions and relative humidity (Ghim, 2001). It appears in a variety of sizes and forms which are made up of different chemicals (US-EPA, 2017).

Duan et al. (2015) has pointed out that PM is divided into three size fractions: Ultrafine, Fine, and Coarse, each with its own set of physiologic and source features. $PM_{1.0}$ or Ultrafine particle, with aerodynamic diameter (Di) less than 0.1 μm, $PM_{2.5}$ or Fine particle (Di $\leq$ 2.5 μm) and $PM_{10.0}$ or Coarse particle (Di$<$ 10 μm). The particles size distribution and its content are determined by their production processes, which include their source, which has been studied extensively (Tsai *et al.*, 2015).

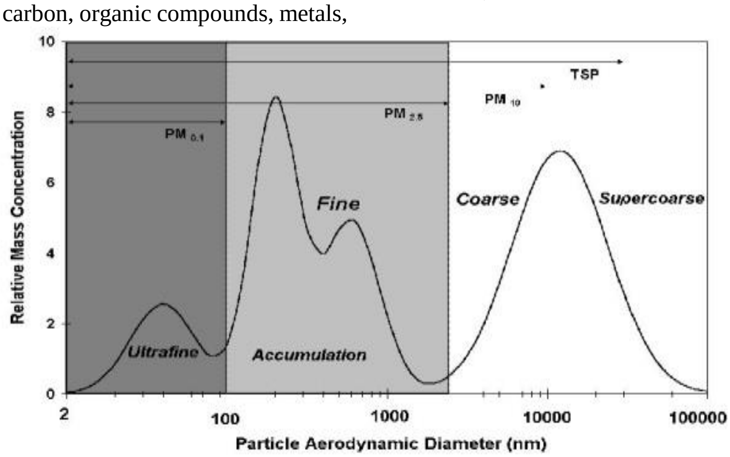

Figure 1: Types of PM Source: (Slezakova *et al.*, 2013)

Fine particles contain secondary produced aerosols, combustion particles, recompensed organic and metallic vapor (Amato *et al.*, 2016), while coarse particles generally contain components from the earth's crust, dust from cars and industrial facilities (Akpan, & William, 2014) whereas ultrafine particles is made up of a variety of hazardous chemicals produced as primary emissions, such as trace metals and diesel black carbon [BC] or as secondary aerosols formed by deposition on existing particles from gaseous progenitors (E.S.T, 2021), because it reduces interference from natural sources.

The $PM_{2.5}$ has been recognized to have lesser indication for automotive emissions occurring in roadside than the $PM_{1.0}$ (E.S.T., 2021). PM is discharged into the air by a variety of natural (lower ratio) and man-made sources (higher ratio) (Miranda & Tomaz, 2008). They are released from smoke, dirt, dust or construction sites, while others are formed in the atmosphere due to complicated chemical reactions, such as nitrogen oxides and sulfur (iv) oxide—pollutants produced by factories and power plants. PM emissions are stated to be causing increasing issue around the globe due to its tremendous influence on man and the environment (Duan *et al.,* 2015). $PM_{10.0}$ (smaller than one tenth the breadth of a human hair) has health implications since it generates noise and throat discomfort when inhaled, which might result in high blood pressure (HBP), stroke, lung cancer, heart attack, bronchitis, and other health problems (Zhao *et al.,* 2020). $PM_{2.5}$ enters the blood as well as the lungs. It causes inflammation and harm, such as respiratory sickness, a lowered immune response, congenital defects, and diabetes, among other things (Feng *et al.,* 2016). Scientists have yet to discover any health implications for $PM_{1.0}$, but it is thought to have a larger impact (WHO, 2006; Polichetti *et al.*, 2009, U.S. EPA, 2012; Health Effects Institute, 2020).

Statistics from the World Health Organization showed that, each year over seven million people die as a result of air pollution, 70% of people breathe air with PM levels that are higher than the guidelines of Air quality recommended by WHO ($PM_{2.5}$ should not exceed 10 $\mu g/m^3$ annual mean and 25 $\mu g/m^3$ 24 hours mean: $PM_{10.0}$ should not exceed 20 $\mu g/m^3$ annual mean and 50 $\mu g/m^3$ 24 hours mean) (WHO, 2021). Several research reveals those who live in areas with poor air quality are more prone to develop respiratory disorders, as well as cardiovascular and circulation problem.

Owoade et al. (2012); Nwaogazie and Zagha, (2015); Akin-folarin et al. (2017); Osimobi et al. (2019); Abulude et al. (2021); Falaiye et al. (2021) are some of Nigeria researchers out of many researchers who have carried out studies in Nigeria on the evaluation of air quality using instrument, while many others have not due to the cost of these instruments, the time required, and the work required in executing the study hence it has limited certain study due to a lack of $PM_{1.0}$, $PM_{2.5}$, and $PM_{10.0}$ monitoring sites. To address the issue, less expensive air quality instrument that measure PM are made readily available, making it simple to provide safety information on the air we breathe in.

Williams et al. (2014) and US EPA (2017) have noted that regions like Asia and the United States, the use of low-cost air quality sensors that directly send PM concentrations to the internet is increasing rapidly. A lot of enterprises are developing tiny electronic sensors for the purpose of monitoring, which use lasers to scatter light off the particles into detectors. The scattered light during this process are studied to measure number, particle size, and mass concentration using Mie scattering theory (Wallace *et al.,* 2021). With over 16,000 devices in use, Purple Air is one of the most widely utilized monitors.

In Sub-Saharan Africa (SSA), the viability and applicability of measuring air quality for $PM_{2.5}$ using a low-cost sensor (purpleair), with the goal of evaluating the effectiveness of its data recovery rate and identification of difficulties faced by users in each region has been determined (Awokola *et al*., 2020). Their investigation showed that, despite certain operational difficulties, it is rationally practicable and possible to set up a network of low cost devices to provide data on local $PM_{2.5}$ concentrations in SSA nations. Such information is essential for increasing public awareness of air pollution throughout SSA.

Ogunjo et al. (2022) conducted a study to analyze PMs with a view to establish the places with the strongest connections among COVID-19 cases, In their study they utilized low-cost air quality monitors (Purple Air sensor) across seven administrative states in Nigeria. According to them, strong positive correlation values exits between COVID-19 cases and PMs. They believe that the considerable positive correlation between PMs and COVID-19 cases and fatalities will help control and mitigate pandemic spread within a group of people.

The purpose of this study is to investigate the variability of PMs over Abuja and Kano with a view to assess the environmental impacts.

Study Area

Nigeria's climate is tropical, with variation of rainy and dry seasons based on location. For the most part, the south is damp, whilst the north is usually dry. The rainy season in th e south lasts from March to November, but only from mid-May to September in the far north. The dry season is referred to as the harmattan season. Harmattan is a cool, dry breeze that sweeps from the northeast or east across the Western Sahara. Up to half of the world's substantial dust emissions come from the Sahara Desert (Ogunjo *et al.*, 2022). Generally it has been reported that in Nigeria the rainy season falls between the months of April through October and the dry season in between November through March (Akpootu *et al*., 2017; Akpootu *et al*., 2019a)

Kano state (Latitude: $12°\ 40'$ and $10°\ 30'$N, and longitude: $7°\ 40'$ and $9°\ 30'$ E). The climate is divided into two seasons: dry and wet. The dry season usually start in November and lasts until March, with the rainy season beginning in May and ending in September. The average annual rainfall is approximately 690 mm, and the average annual temperature swings between a maximum of 33°C and a minimum of 19°C. The vegetation is primarily Savanna, which is classified climatically as Northern Guinea savanna and Sudan savanna (Wakawa *et al.*, 2016). Having a population of more than 15 million people Kano State is consider as the second-largest industrial center in Nigeria, after Lagos State, and the largest in Northern Nigeria, with industries including textile, tanning, footwear, cosmetics, plastics, enamelware, pharmaceuticals, ceramics, and furniture. Other commodities include agricultural instruments, soft drinks, food and beverages, dairy products, vegetable oil, animal feeds and it has an altitude of 360 m

Abuja is an administrative territory central Nigeria. It is bordered by the states of Niger to the west and northwest Kaduna to the northeast Nassarawa to the east and south and Kogi to the southwest. It is located between latitude 9.0765° N and longitude 7.3986° E. Guinea Savannah is the predominant vegetation type in Abuja, and it is made up of tall grasses that are sprinkled with various species (Ahmad *et al.,* 2017). With an altitude of 456m and a population of about

3,564,126. Agriculture is one of the economic foundations. Millet, corn (maize), yams, sorghum and beans are produced in this region. Mineral resources include clay, tin, feldspar, gold, iron ore, lead, marble, and talc. Abuja and Kano were chosen because they have comparable vegetation and weather features.

MATERIALS AND METHOD

Low-cost air quality stations (called Purple Air stations) were established in Nigeria to address the absence of PM concentrations. The stations are strategically positioned in some states in Nigeria. This information can be used to assess the potential links between Particulate matter ($\mu g/m^3$), temperature (°F), and relative humidity (%). Ardon-Dryer et al. (2020) and Liu et al. (2020) have evaluated data from Plantower sensors' low-cost optical devices for monitoring particulate matter.

Purple air stations were assess to acquire PM readings in this investigation. The program is linked to a sensor, which communicates with the particle counter via an ESP8266 microcontroller chip, which also provides complete capabilities, including connecting to a WiFi network and sending data to the cloud (https://www.purpleair.com/). The sensor uses PMS5003 and PMS1003 laser counters to detect particle matter in real time, with each laser counter alternating 5-second readings averaged over 120 seconds (http://www.plantower.com/en/). It measures the size of particles suspended in increments of 0.3, 0.5, 1.0, 2.5, 5.0, and 10 μm (Plantower User Manual, 2016).The sensor processes these particle counts using a complicated algorithm to compute the mass concentrations of $PM_{1.0}$, $PM_{2.5}$, and $PM_{10.0}$ in μg/m^3 (microgram of gaseous pollutant per cubic meter of ambient air) for standard indoor (CF-1 i.e for laboratory use) and outdoor particles (ATM i.e for Atmospheric condition) (Plantower User Manual, 2016). PurpleAir's website displays real-time data in the color-coded air quality index (AQI) form and actual PM concentrations (PurpleAir, 2019).The Purple Air-II-SD has an in-built when connected to the internet, a Real-Time Clock (RTC) sets itself.

Data were collected for particulate matter ($PM_{1.0}$, $PM_{2.5}$ and $PM_{10.0}$) from two PurpleAir sensors: Sensor 1 Space Weather and Atmospheric Physics Laboratory, Center for Atmospheric Research Bayero University Campus, Kano State and Sensor 2 Space Environment Research Laboratory, Centre for Atmospheric Research, Abuja. Measurements of particulate matter concentrations, temperature and relative humidity were collected for 1 year (1st January, 2021 to 31st December 2021).

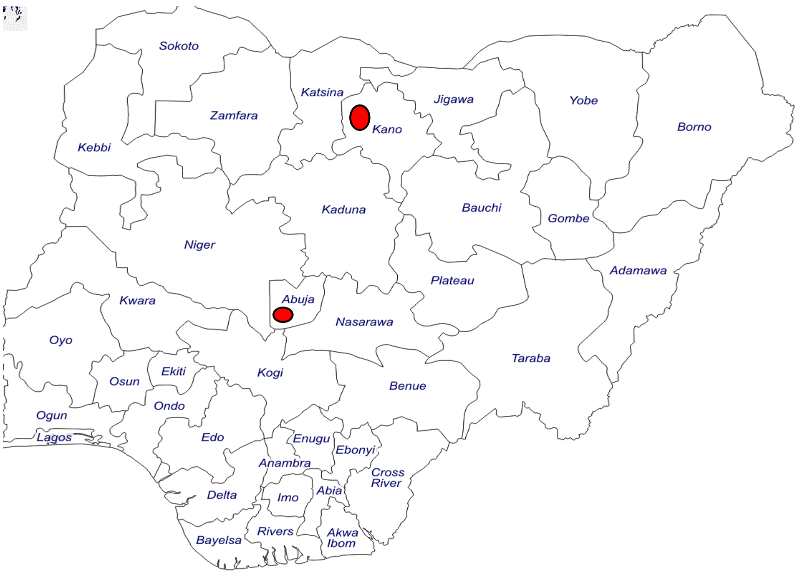

Figure 2: Map of Nigeria showing the states where data were obtained

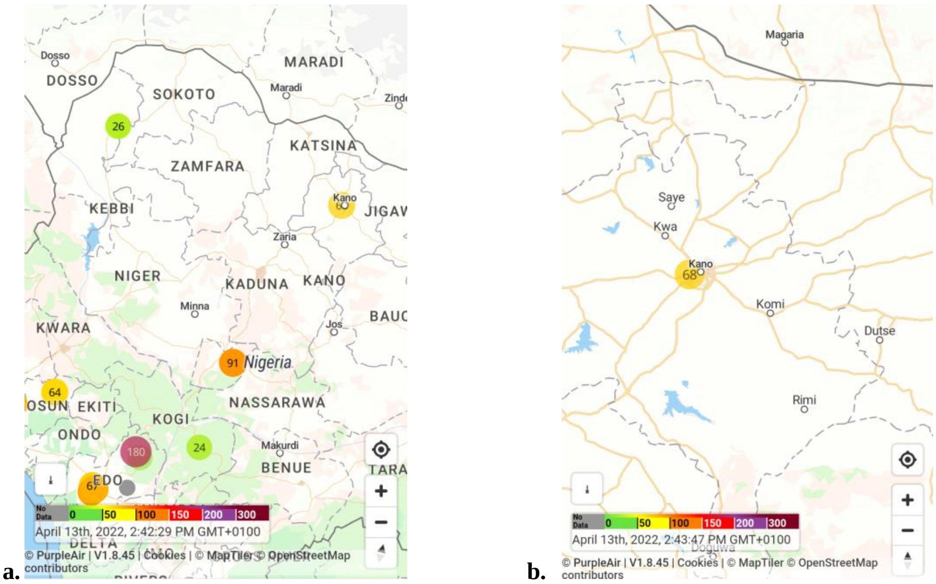

Figure 3: **a.** Showing various PurpleAir sensors in Nigeria **b.** Sensor in Bayero University, Kano

The study relied on $PM_{1.0}$, $PM_{2.5}$, $PM_{10.0}$, temperature, and relative humidity measurements, the data were obtained at 60 minutes intervals. A thorough data check on the raw data is undertaken to limit the effect of problematic data points such as duplicated datasets, incomplete measurements, odd zeros, and so on. Following the data quality check, measurement data for $PM_{1.0}$, $PM_{2.5}$, $PM_{10.0}$, temperature, and relative humidity were combined into one average. The data was downloaded as a CSV file, and Excel was used to run statistical analyses (version 2013).

Air Quality Index (AQI)

The Air Quality Index, or AQI, is the system used to monitor air pollution by telling the general public how clean or polluted the air we breathe and how the air we breathe can be dangerous to both sensitive and non sensitive people. The AQI tracks ozone (smog) and particle pollution (tiny particles from ash, power plants and factories, vehicle exhaust, soil dust, pollen, and other pollution). The table below shows the standard limit for air quality set aside by the US, informations are available for $PM_{2.5}$ and $PM_{10.0}$. From the table below, we can deduce that the lower the values of PM the better the air quality for both sensitive and non sensitive people.

Table 1: Air quality index and health effects (Nathaniel and Xiaoli, 2020)

AQI Value Of Index	Levels of Health Concern	$PM_{2.5}$ Conc. (μg/m³)	PM_{10} Conc. (μg/m³)	Daily AQI Color	Air Pollution Level
0–50	Good	0–12	0–54	green	Level 1
51–100	Moderate	12.1–35.4	55–154	yellow	Level 2
101–150	Unhealthy for sensitive groups	35.5–55.4	155–254	orange	Level 3
151–200	unhealthy	55.5–150.4	255–354	Red	Level 4
201–300	Very unhealthy	150.5–250.4	355–424	Purple	Level 5
301 and Higher	Hazardous	250.5–Higher	425–Higher	Maroon	Level 6

Correlation Analysis

The Pearson Coefficient Correlation (PCC) was used as a comparison. It is defined as

$$r = \frac{\sum\{(x_i - \bar{x}) \times (y_i - \bar{y})\}}{\sqrt{\sum\{(x_i - \bar{x})^2 \times (y_i - \bar{y})^2\}}} \quad (1)$$

where

r represent correlation coefficient

x_i represent values of the $x-variable$

$\bar{x}$ represent the mean values of $x-variable$

y_i represent values of the $y-variable$

$\bar{y}$ represent the mean values of $y-variable$

The correlation coefficient values lies between -1 and + 1. The + sign indicate positive linear correlation while the – signs indicate negative linear correlation (Akpootu and Iliyasu, 2017).

Descriptive Statistics

The key components that are looked at in the descriptive statistical analysis are Skewness and Kurtosis. The asymmetry in the data surrounding the mean value of the independent meteorological parameters is measured and the direction of variation in the dataset is revealed using the skewness tests. If the data have a Gaussian distribution, this implies normal distribution; if the data are spread out more to the left of the mean value than to its right, it means negatively skewed and if the data are spread out more to the right than to its left, this implies positively skewed. The Kurtosis test measures a distribution's relative peak or flatness in relation to the normal distribution, which illustrates the general form of a random variable. It measures the consistency of each climate parameter for the research locations (Hejase and Assi, 2011; Akpootu *et al.*, 2019b).

RESULTS AND DISCUSSION

Monthly Variation

The monthly variations of PM are shown for one year (January 2021- December 2021) as depicted in Figure 4a and 4b. It can be seen that the PM concentrations were relatively high from January, February, March, and gradually decrease from May to October then it start to rise again as we get into the dry season from November to December for both Kano and Abuja. The increase in the PM values during Harmattan season can be attributed to anthropogenic sources which bring about the formation of fog/haze and the dust from the Sahara desert since Kano and Abuja has a close proximity with it. The increase in PM from January to March can be associated with tiling of land, bush burning as farmer will be getting their land ready for farming as we approach rainy season and this is in line with the study reported by Abulude & Abulude (2021) and Ogunjo et al. (2022). The decrease in PM from May to October can be trace to wet season as precipitation helps to lower the amount of PM in the atmosphere as the particles drop together with rain to the ground. The PM concentrations are generally higher in the dry season than that of the rainy season.

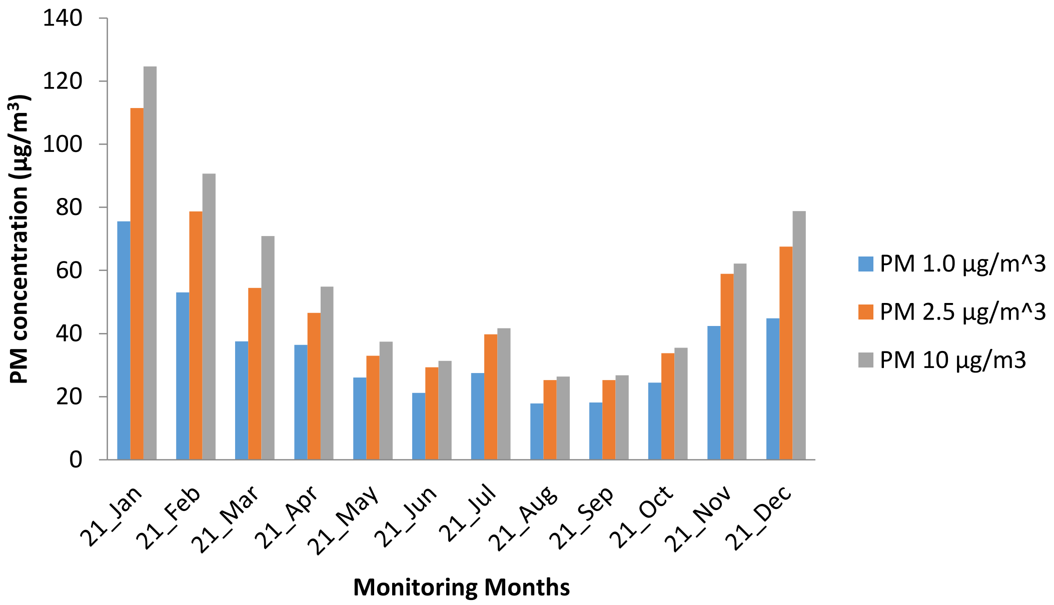

Figure 4a**:** Monthly variation of PM values in Abuja

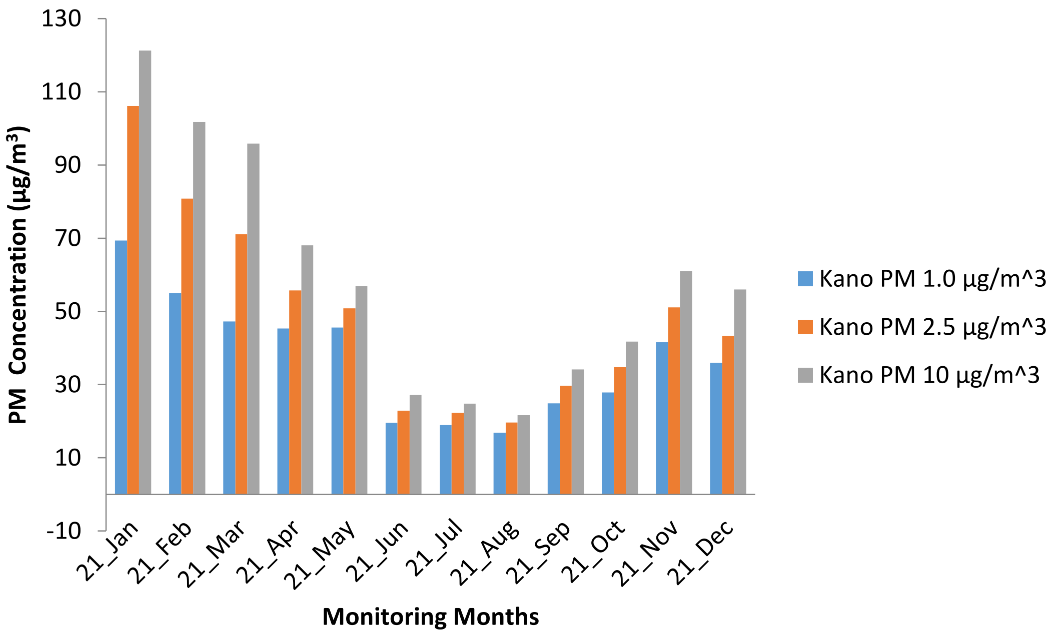

Figure 4b**:** Monthly variation of PM values in Kano State

Coeffient of Correlation

Table 2: Pearson coeficient correlation for Abuja

	$PM_{1.0}$ (µg/m³)	$PM_{2.5}$ (µg/m³)	$PM_{10.0}$ (µg/m³)	Temperature (°F)	Relative humidity (%)
$PM_{1.0}$ (µg/m³)	1				
$PM_{2.5}$ (µg/m³)	0.995843	1			
$PM_{10.0}$ (µg/m³)	0.988614	0.992711	1		
Temperature (°F)	0.498995	0.456857	0.530721	1	
Relative humidity (%)	-0.856120	-0.860940	-0.905240	-0.713630	1

Table 3: Pearson coefficient correlation for Kano state

	$PM_{1.0}$ (µg/m³)	$PM_{2.5}$ (µg/m³)	$PM_{10.0}$ (µg/m³)	Temperature (°F)	Relative humidity (%)
$PM_{1.0}$ (µg/m³)	1				
$PM_{2.5}$ (µg/m³)	0.979472	1			
$PM_{10.0}$ (µg/m³)	0.964921	0.990974	1		
Temperature (°F)	0.606584	0.596786	0.601484	1	
Relative humidity (%)	-0.862820	-0.825460	-0.865330	-0.546041	1

One of the most important elements regulating the change of PM concentration has long been known to be weather conditions. As a result, we looked into the consequences of meteorological conditions on PM concentrations in Tables 2 and 3. Since the PurpleAir sensor also monitors temperature and relative humidity, the Pearson correlation between average PM concentration, temperature, and relative humidity was investigated in this table.

From Table 2 $PM_{1.0}$ has a strongly positive correlation with $PM_{2.5}$ (r = 0.996), strong positively correlation was also found with $PM_{10.0}$ (r = 0.989) while low positive correlation coefficient value with temperature (r = 0.499) and a strong negative correlation with relative humidity (r = -0.856). Meanwhile, $PM_{2.5}$ has a strong positive correlation coefficient value with $PM_{10.0}$, low positive correlation coefficient value with temperature and a strong negative correlation with relative humidity. $PM_{10.0}$ has a positive correlation coefficient value (r = 0.531) with temperature and a strong negative correlation with relative humidity. A negative correlation of 0.714 existed between temperature and relative humidity.

Table 3 indicate that $PM_{1.0}$ has strongly high positive correlation coefficient value with $PM_{2.5}$ (r = 0.979), strong positively correlation was also found with $PM_{10.0}$ (r = 0.965) while a positive correlation coefficient value with temperature (r = 0.607) and a strong negative correlation with relative humidity (r = -0.863). Similarly, $PM_{2.5}$ is strong positive correlated with $PM_{10.0}$, positive correlation coefficient value with temperature and a strong negative correlation with relative humidity. $PM_{10.0}$ is strongly correlated with the temperature and a strong negative correlation with the relative humidity. A negative correlation of 0.546 existed between the temperature and relative humidity.

Table 2 indicates that temperature have a low correlation with PM concentration ($PM_{1.0,\ 2.5,\ 10}$) while relative humidity has a relatively strong negative correlation in table 2 and 3.We observed a strong positive correlation between the three PM which reveals that an increase in $PM_{1.0}$ directly increase in the remaining PMs ($PM_{1.0,\ 2.5,\ 10}$). The findings in this study are in agreement with those of Obioh, et al (2013), Nathaniel and Xiaoli (2020) and Abulude and Abulude (2021). Generally, the Pearson correlation coefficients analysis shows that PM concentrations are strongly negatively correlated with relative humidity that is as relative humidity increases PM decreases in the atmosphere. Study has shown that as humidity increase PM becomes too large and can no longer remains in the atmosphere hence began to fall a process known as dry deposition of particulate matter (Wang and Ogawa 2015). While a positive correlation of temperature with PMs was recorded indicating that as the temperature increase PM concentration also increases and vice versa.

Descriptive Statistical Analysis

Table 4: Descriptive Summary Result

	$PM_{1.0}$ (µg/m³)	$PM_{2.5}$ (µg/m³)	$PM_{10.0}$ (µg/m³)	Temperature (°F)	Relative Humidity (%)
ABUJA					
Mean	35.4042	50.3403	56.7602	91.3346	41.1374
STD	16.9174	25.8333	30.1536	3.7818	17.7118
VAR	286.1993	667.3601	909.2363	14.3023	313.7060
MAX	75.5246	111.5265	124.6871	96.8348	60.3222
MIN	17.7918	25.2221	26.3632	85.4527	12.5083
Kurtosis	1.6436	1.6012	0.8004	-0.7534	-1.3662
Skewness	1.2405	1.3017	1.0909	-0.2150	-0.5542
					KANO
Mean	37.3479	49.0082	59.2021	-69.0990	26.9775
STD	16.2506	26.4256	32.5603	166.8355	11.8250
VAR	264.0827	698.3104	1060.1740	27834.0800	139.8302
MAX	69.3170	106.1048	121.2962	98.2482	43.1590
MIN	16.8333	19.6221	21.6803	-229.0000	12.8028
Kurtosis	-0.4531	0.4238	-0.5438	-2.4369	-1.7877
Skewness	0.4323	0.9264	0.6913	0.0042	0.2150

Table 4 shows the descriptive statistics for both locations. The Air quality index (AQI) standard table in table 1 above was compared with descriptive summary in table 4, AQI provides adequate information about the air we breathe. The result shows that $PM_{2.5}$ concentration for Abuja and Kano is unhealthy for sensitive group and falls under level 3 in air pollution, sensitive people are those people who are suffering from any respiratory and cardiovascular illness while $PM_{10.0}$ concentration for both states falls in the moderate, that is the air in both regions is good for both the sensitive people and the non sensitive people which is in the level 2 category. $PM_{1.0}$, $PM_{2.5}$, and $PM_{10.0}$ concentrations in Kano State were 37.35, 49.01 and 59.20 $\mu g/m^3$ respectively while for Abuja are 35.40, 50. 34 and 56.76 $\mu g/m^3$ respectively. The WHO 24-hour guideline limits of 25 $\mu g/m^3$ and 50 $\mu g/m^3$ were exceeded in Kano and Abuja respectively.

For Abuja, It was observed that the temperature and relative humidity data's spread out more to the left of their mean value (negatively skewed) while $PM_{1.0}$, $PM_{2.5}$ and $PM_{10.0}$ data's spread out more to the right of their mean value (positively skewed) and $PM_{1.0}$, $PM_{2.5}$ and $PM_{10.0}$ data's have positive kurtosis which indicates a relatively peaked distribution and possibility of a leptokurtic distribution while temperature and relative humidity data have negative kurtosis which indicates a relatively flat distribution and possibility of a platykurtic distribution. For Kano, the skewness and kurtosis for Kano is quite lower than that of Abuja, the bottom part of the table show that all PMs, temperature and relative humidity spread out more to the right of their mean value (positively skewed) while for kurtosis only $PM_{2.5}$ has a positive kurtosis indicating a peaked distribution and $PM_{1.0}$, $PM_{10.0}$, temperature and relative humidity has a negative kurtosis indicating a flat distribution.

CONCLUSION

A comparative assessment of PM and the parameters of temperature and relative humidity for Abuja and Kano was investigated. The outcome shows that during the dry season in both locations, the monthly average of $PM_{1.0}$, $PM_{2.5}$ and $PM_{10.0}$ surpasses the WHO 24-hour standard limit. Since both locations are the two major industrious locations in the northern part of Nigeria which causes the population to grow on a regular basis, this can be attributed to excessive pollution and an increase in car emissions. While during the wet season, $PM_{1.0}$, $PM_{2.5}$ and $PM_{10.0}$ are below the WHO 24-hour guideline. When compared to AQI, $PM_{2.5}$ was said to be unhealthy for sensitive individuals. People with respiratory or cardiovascular conditions are advised to be aware of their surroundings through the help of an air quality measures device that may determine whether the air they breathe is beneficial or hazardous for them. In order to achieve the goals of health is wealth and to lower the rate of morbidity caused by air pollution around the globe, air quality sensor manufacturers should also offer portable and less expensive sensors that are affordable for the general public.

ACKNOWLEDGEMENTS

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