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Spatiotemporal comparison of particulate matter pollution in Port Harcourt and Kano using clarity Node-S measurements

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ABSTRACT: This study presents a spatiotemporal comparative analysis of particulate matter (PM) pollution in two cities in Nigeria, Port Harcourt and Kano, using high-resolution data from Clarity Node-S sensors. The research investigates the concentrations of $PM_{1.0}$, $PM_{2.5}$, and PM_{10} across both cities, focusing on seasonal variations and their consequences for public health and the environment. The results of the analysis show that Port Harcourt exhibits significantly higher mean PM concentrations ($PM_{2.5}$: 64.06 µg/m³; PM_{10}: 65.19 µg/m³) compared to Kano ($PM_{2.5}$: 20.80 µg/m³; PM_{10}: 34.22 µg/m³), with both cities exceeding WHO guidelines. The dry season consistently recorded elevated PM levels, which can be attributed to dust, harmattan winds and biomass burning. Statistical analyses reveal greater variability of this particulate matter concentration in Port Harcourt; this might also be linked to the influence of localised industrial activities and artisanal activities in the city. The risk assessment reveals that Port Harcourt has significantly higher $PM_{2.5}$ and PM_{10} pollution than Kano, with AQI levels reaching "Unhealthy". Kano's air quality fluctuates from "Good" to "Unhealthy" but remains less severe than Port Harcourt. Both cities face public health risks from prolonged PM exposure, especially in Port Harcourt, where pollution consistently exceeds WHO guidelines. The study presents an urgent need for targeted air quality interventions, including emission controls and real-time monitoring, to mitigate the adverse health and environmental impacts of PM pollution in these urban centres. These findings help address key gaps in local air quality studies and provide data to guide policies for cleaner air in Nigerian cities.

Keywords: Air pollution, Clarity Node-S, particulate matter, spatiotemporal analysis.

INTRODUCTION

Particulate matter (PM), including fine ($PM_{2.5}$) and coarse (PM_{10}) particles, is a critical global air pollutant with significant health and environmental impacts. Globally, PM pollution contributes to approximately 7 million premature deaths annually, particularly in urban regions of Africa and Asia, where concentrations often exceed the World Health Organisation's guideline of 5 µg/m³ for $PM_{2.5}$ (World Health Organisation [WHO], 2021). In Nigeria, PM pollution is a growing concern due to increasing industrial activities, vehicular emissions, and reliance on biomass fuels, with urban centres like Port Harcourt and Kano experiencing elevated levels influenced by regional and seasonal factors (Yakubu, 2018, 2021; Taiwo *et al.*, 2015).

In Port Harcourt, a major oil and gas hub in Nigeria's Niger Delta, PM pollution is predominantly driven by gas flaring, refinery emissions, and vehicular exhaust, which release fine particulates, including black carbon and sulfates (Fakinle *et al.*, 2020). In contrast, Kano, a commercial centre in northern Nigeria, faces PM pollution from seasonal Harmattan dust storms, biomass burning for cooking, and emissions from local industries like textile and leather production (Abdullahi *et al.,* 2013). Both cities experience distinct spatiotemporal PM patterns due to differences in climate and economic activities. The adverse effects of PM pollution are profound, impacting both human health and the environment. $PM_{2.5}$, due to its ability to penetrate deep into the lungs and bloodstream, is linked to respiratory and cardiovascular diseases, including asthma and heart attacks, which affect vulnerable groups like children and the elderly (Cohen *et al.*, 2017; Abulude *et al.*,2024). Environmentally, PM contributes to haze, reduced visibility, and ecosystem degradation through deposition, with Port Harcourt experiencing acid rain from oil-related PM and Kano facing reduced crop yields due to dust deposition (Akpoghelie *et al.*, 2021; Owoade *et al.,* 2021).

Research shows that PM10 concentrations in Port Harcourt often surpass local limits of 150 µg/m³ (Akinfolarin *et al.*, 2017), with industrial sites recording higher levels than residential areas. Gas flaring and refinery operations release fine particles and volatile organic compounds, contributing to poor air quality. Similarly, Studies reveal that PM2.5 levels in Kano's urban areas, particularly near traffic and industrial sites, are alarmingly high, with 51.7% of particles classified as fine. (Sadiq *et al.,* 2022). These particles contain heavy metals like lead and manganese, posing severe health risks, including neurological damage. These emissions stem from heavy reliance on diesel-powered vehicles and inadequate vehicle maintenance, releasing soot and fine particles into the atmosphere.

Another critical issue is industrial activities, which are particularly pronounced in Port Harcourt due to its role as a hub for oil and gas operations. Industrial sites in Port Harcourt exhibit higher PM concentrations compared to control areas, with activities like flaring and refinery operations releasing fine particles and volatile organic compounds (Akinfolarin *et al.,* 2017). In Kano, small-scale industries and artisanal activities release PM laden with heavy metals, contributing to chronic health conditions. Elemental analyses reveal particles containing heavy metals like lead and manganese, posing severe health risks (Sadiq *et al.,* 2022; Ezeh *et al.,* 2018).

A third problem is the influence of seasonal meteorological conditions, which worsen PM concentrations, particularly during the dry season. In both cities, studies show higher PM levels in the dry season due to reduced rainfall and increased dust resuspension from unpaved roads and construction activities (Akinfolarin *et al.,* 2017; Sadiq *et al.,* 2022). In Kano, windblown dust and biomass burning further elevate PM levels, while in Port Harcourt, low humidity and stagnant air trap pollutants. The lack of stringent air quality regulations and limited monitoring infrastructure further compounds the problem, leaving populations vulnerable to PM-related health risks (Yahaya *et al.,* 2023).

Despite the availability of air quality studies, there remains a critical gap in comparative analyses that leverage advanced, low-cost sensor technologies like Clarity Node-S to provide real-time, high-resolution data on PM pollution across these regions. Most studies rely on traditional monitoring methods, such as gravimetric sampling, which lack the temporal and spatial granularity needed for city settings (Osimobi *et al.*, 2019). Furthermore, there is a scarcity of comparative studies between cities like Port Harcourt and Kano, which differ in their industrial and climatic profiles, limiting the ability to tailor interventions to regional contexts. The lack of comprehensive spatiotemporal data also limits the understanding of seasonal and spatial differences in PM concentrations, which is crucial for addressing the uneven health burdens faced by residents in these cities.

The use of Clarity Node-S sensors enables high-resolution monitoring of these variations, provides important measurements for understanding local pollution and its dynamics. This study, therefore, aims to investigate the spatiotemporal variations of PM pollution in these two distinct Nigerian cities, using high-resolution Clarity Node-S measurements to assess the extent, sources, and impacts of PM pollution. The result will be useful for targeted interventions to mitigate its health and environmental impact. Studies highlight the need for comprehensive monitoring and mitigation strategies to address the health and environmental impacts of PM pollution in these regions.

MATERIALS AND METHODS

Study area

Port Harcourt is the capital city of Rivers State in the Niger Delta region of Nigeria (Ayotamuno and Gobo, 2004; Echendu and George, 2021). Port Harcourt metropolis, partly situated in a wetland ecosystem between latitudes 4.55°N and longitudes 6.55°E to 7.05°E, the city sits approximately 15.83 meters above sea level within a coastal wetland ecosystem characterised by flat topography and tropical climatic conditions (Yakubu, 2018). As the hub of Nigeria's oil and gas industry, Port Harcourt experiences severe particulate matter pollution primarily from industrial emissions, gas flaring, and vehicular exhaust, creating a complex air quality challenge that demands scientific investigation (Fakinle *et al.,* 2020). The city's rapid development and industrial growth over the past five decades have transformed its atmospheric environment, with studies showing a consistent exceeds of World Health Organisation air quality guidelines for particulate matter (Akinfolarin *et al.,* 2017; Ezeh *et al.*, 2018). Port Harcourt's tropical monsoon climate creates distinct seasonal air quality patterns, with dry season conditions (November-March) causing pollutant accumulation and $PM_{2.5}$ levels frequently exceeding 150 µg/m³ due to atmospheric stability and occasional Harmattan dust intrusions (Anjorin *et al.*, 2020; Yakubu and Sonibare, 2021). While the wet season (April-October) provides some pollution reduction through rainfall. Baseline PM levels remain high year-round due to continuous emissions from industries and vehicles (Akinfolarin *et al.*, 2017).

Kano, the largest city in northern Nigeria and the capital of Kano State, presents a compelling case study for air pollution research due to its unique combination of geographical, climatic, and anthropogenic factors. Situated at 12.00°N latitude and 8.52°E longitude in the Sudanian Savanna ecoregion, the city's air quality is profoundly influenced by its position at the southern edge of the Sahara Desert (Abdullahi *et al.,* 2013). Unlike the industrial pollution dominating Port Harcourt, Kano's particulate matter (PM) profile reflects an interaction between natural dust sources and urban emissions, creating distinctive air quality challenges that require specialised mitigation approaches.

The Harmattan season from December to February affects the air quality in Kano, as northeast trade winds transport massive quantities of mineral dust from the Sahara Desert, elevating PM_{10} concentrations to hazardous levels exceeding 500 µg/m³ during severe episodes (Yakubu, 2018).

Meteorological conditions in Kano create distinct seasonal pollution patterns that differ markedly from southern Nigerian cities. During the rainy season, atmospheric cleansing through wet deposition reduces PM_{10} levels to 30-50 µg/m³, though still above WHO guidelines. However, the prolonged dry season brings progressively deteriorating air quality as diminishing humidity and increasing temperatures contribute to the suspension of dust.

Sources of data

The particulate matter (PM1.0, PM2.5 and PM10.0) measurements were obtained from Air clarity sensors (Node S) stations mounted at Rivers State University, Port Harcourt and at the Centre for Atmospheric Research, Bayero University Campus, Kano State. The data spans from January 2022 to February 2023. The measurements of $PM_{1.0}$, $PM_{2.5}$, and $PM_{10.0}$ were obtained at 60 minutes intervals and downloaded online from the "https://www.clarity.io" website. The raw data were scrutinised in order to eliminate the effect of errors from replicated datasets and other possible errors. Furthermore, the $PM_{1.0}$, $PM_{2.5}$, and $PM_{10.0}$ measurements were reduced to the daily mean.

Measurements from Air clarity sensors strategically positioned in different parts of Nigeria are used to monitor the potential risks of Particulate matter ($\mu g/m^3$). Clarity employs OPC technology and a proprietary calibration method to accurately measure $PM_{1.0}$, $PM_{2.5}$, and PM_{10}. at the local level, helping to paint a complete picture of the particulate matter pollution in a given location. 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:// https://www.clarity.io/). 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. 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} in μg/m3 (microgram of gaseous pollutant per cubic meter of ambient air) for standard indoor and outdoor particles (for Atmospheric conditions).

Data analysis

The Pearson Correlation Coefficient (PCC) was also used as a comparison to determine the correlation of the Particulate matter at different locations. It is defined as:

$$r = \Sigma\{(xi - \bar{x}) \times (yi - \bar{y})\}\sqrt{\Sigma\{(xi - \bar{x})2 \times (yi - \bar{y})2\}} \quad (1)$$

Where: r is $correlation\ coefficient$, xi is $values\ of\ the\ x\text{–}variable$, $\bar{x}$ is $mean\ values\ of\ x\text{–}variable$, yi is $values\ of\ the\ y\text{–}variable$, $\bar{y}$ is $mean\ values\ of\ y\text{–}variable$

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

Standard deviation was used to measure the dispersion of PM concentrations around the mean, indicating variability in the data. The equation for the sample standard deviation is:

$$s = \sqrt{(\Sigma(x_i - \bar{x})^2 / (n - 1))} \quad (2)$$

Where: x_i is each PM concentration value, x̄ is the mean, and n is the number of observations.

This equation quantifies the consistency of PM levels, with higher values indicating greater variability due to factors like seasonal changes.

Risk assessments

The average concentrations of $PM_{2.5}$ and PM_{10} were calculated and evaluated against the WHO air quality standards [WHO, 2021]. These averaged measurements served as the basis for determining the Air Quality Index (AQI) values (Table 1). The AQI estimation for each pollutant (derived from averaged measurements across all sampling locations) followed the established mathematical formula presented below (US EPA, 2014):

$$AQI_{pollutant} = \frac{Pollutant\ Concentration}{WHO\ standard} \times 100 \quad (3)$$

Table 1. Air Quality Index (AQI) levels of health concern (US EPA, 2014).

AQI value of index	Levels of health concern	PM2.5 Conc. (g/m^3)	PM10 Conc. (g/m^3)	Daily AQI colour	Air pollution level
0-50	Good	0–12	0-54	Green	Level 1
51-100	Moderate	2.1–35.4	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

"Good" (0–50): Air quality is at safe levels, presenting minimal or no health risk. **"Moderate" (51–100):** Air quality is generally acceptable, though a small portion of particularly sensitive individuals may experience mild health effects. **"Unhealthy for Sensitive Groups" (101–150):** People with high sensitivity—due to medical conditions, prolonged exposure, or natural susceptibility—may experience adverse health effects during outdoor activities. The general population, however, is unlikely to be affected. **"Unhealthy" (151–200):** At this level, anyone spending time outdoors may encounter respiratory issues, with more pronounced effects among sensitive individuals. According to EPA risk assessments, this range poses a significant health concern for vulnerable groups.

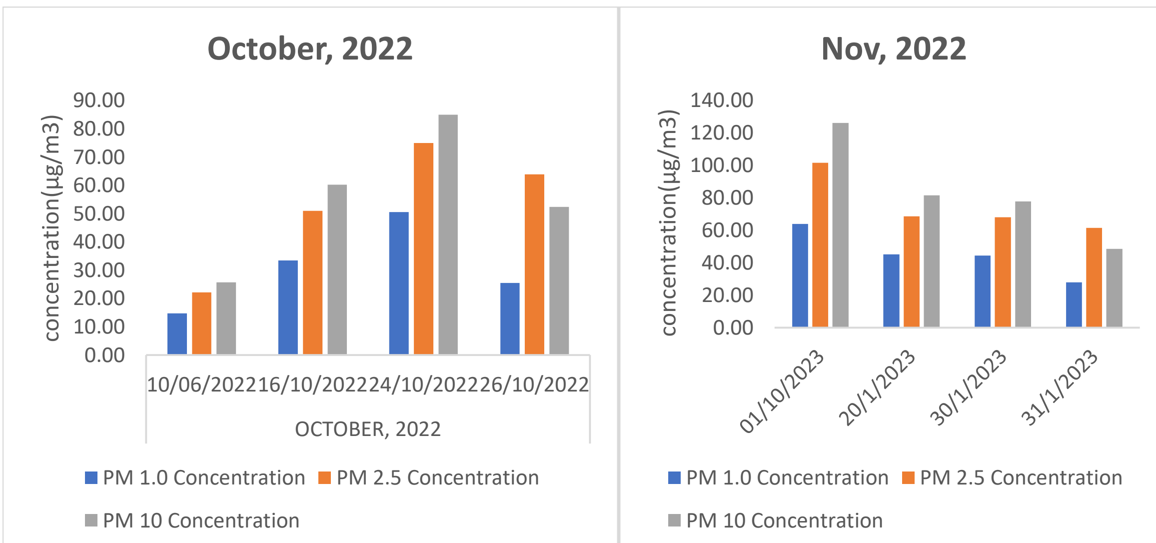

Figure 1. Concentration levels of PM $_{1.0}$, PM $_{2.5}$ and PM $_{10.0}$ in Oct and November 2022 (Port Harcourt).

RESULTS

Particulate matter concentration in Port Harcourt

The results of the measurements of the concentration level of PM $_{1.0}$, PM $_{2.5}$, and PM_{10} for Port Harcourt stations (both in the wet seasons and dry seasons) are given in Figures 1 to 4. The results reveal that PM $_{1.0}$, PM $_{2.5}$, and PM $_{10}$ concentrations are generally higher in the months from December 2022 to February 2023 (Dry season) compared to other months in the wet season. December 2022 shows the highest concentrations across all sizes, with the $PM_{2.5}$ concentration reaching 123.46 µg/m³ and PM_{10} peaking at 158.48 µg/m³ in December. These levels are well above the recommended air quality standards set by the World Health Organisation (WHO), which suggests that $PM_{2.5}$ should be below 25 µg/m³ and PM 10 should not exceed 45 µg/m³ (24-hour average). Similarly, January 2023 continues with relatively high concentrations, especially for PM2.5 (101.68 µg/m³ on January 1), further indicating poor air quality during this period. Lower concentrations of $PM_{2.5}$ and $PM_{10.0}$ were recorded in September, with values as low as 12.46 and 30.79 µg/m³, respectively.

The concentration of $PM_{1.0}$ was observed to be relatively low compared to the other particulate matters ($PM_{2.5}$ and $PM_{10.0}$). It had a minimum of 7.68 µg/m³ in September, and a peak of 75.40 µg/m³ in December, indicating less pollution in these months.

The results suggest that particulate pollution is higher in the dry season months (December through February) than in the wet season. The main spike, which occurred in December 2022, was much higher than in any other month. This could be due to factors such as industrial activities, vehicle emissions, or climatic changes such as

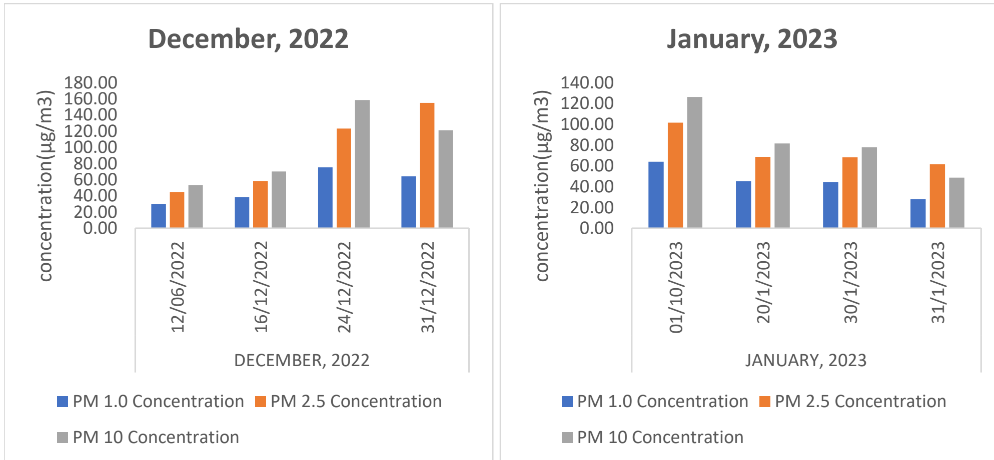

Figure 2. Concentration of PM $_{1.0}$, PM $_{2.5}$ and PM $_{10.0}$ in December 2022 and January 2023 (Port Harcourt).

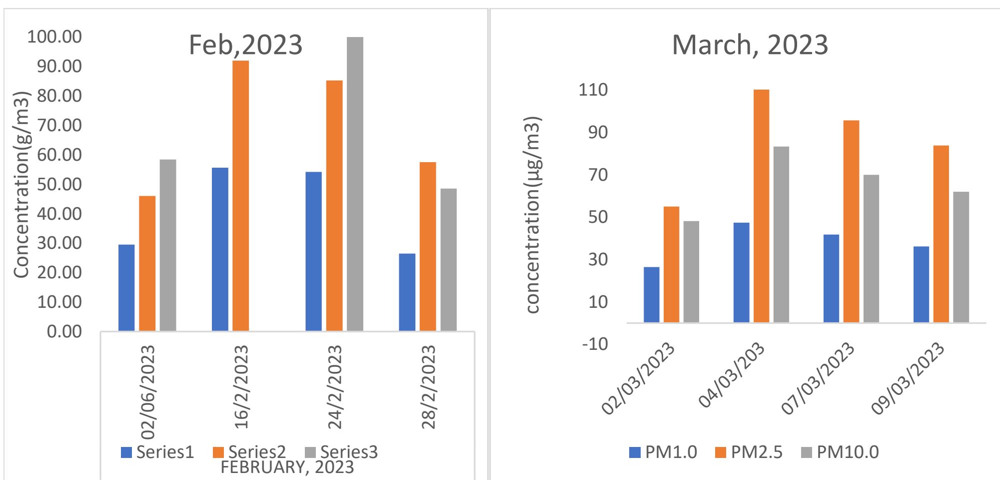

Figure 3. Concentration of PM $_{1.0}$, PM $_{2.5}$ and PM $_{10.0}$ in February and March 2023 (Port Harcourt).

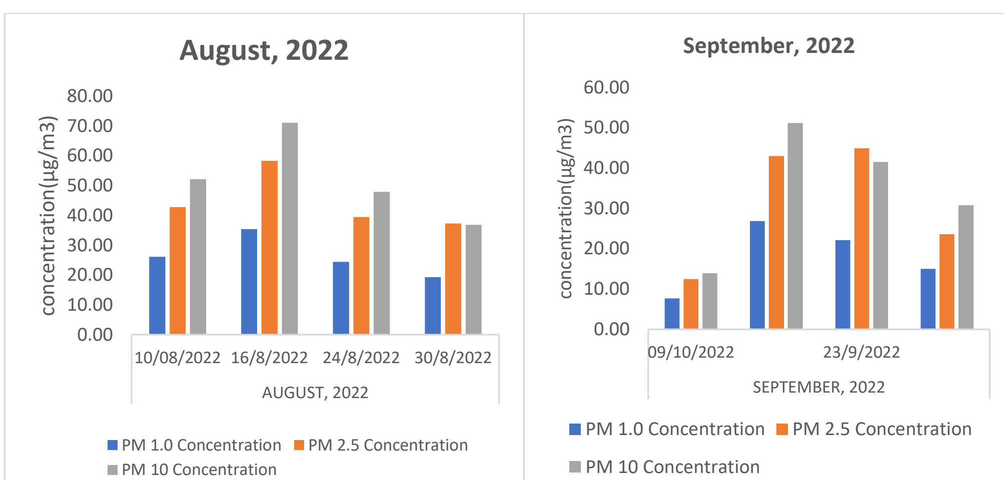

Figure 4. Concentration of PM $_{1.0}$, PM $_{2.5}$ and PM $_{10.0}$ 0 in August and September 2023 (Port Harcourt).

Table 2. Result of the statistical analysis for Port Harcourt Station (dry season).

Statistics	PM1 (µg/m³)	PM2.5 (µg/m³)	PM10 (µg/m³)
Mean	40.46	72.85	72.74
Std Dev	7.80	15.48	16.03
Variance	60.80	239.71	256.92
Maximum	52.06	95.45	100.82
Minimum	31.12	53.07	55.85
Kurtosis	-1.36	-1.36	-1.24
Skewness	0.30	0.30	0.45

Table 3. Result of the Statistical Analysis for Port Harcourt Station (Wet season).

Statistic	PM1 (µg/m³)	PM2.5 (µg/m³)	PM10 (µg/m³)
Mean	22.10	37.72	43.17
Std Dev	5.93	9.52	12.50
Variance	35.15	90.61	156.25
Maximum	26.29	44.46	52.01
Minimum	17.91	30.98	34.33

harmattan winds, which may carry dust particles into the atmosphere. It's worth investigating the specific local sources of pollution and meteorological conditions to understand the spikes in particulate matter concentration during those months.

The statistical analysis of the particulate matter (PM) concentrations for Port Harcourt Station is summarised in Tables 2 and 3. The mean concentration for $PM_{2.5}$ is 64.06 µg/m³, which is considerably higher than PM 1.0. and exceeds the WHO safe limits. The mean concentration of PM_{10} is 65.19 µg/m³, almost the same as $PM_{2.5}$, which suggests a relatively high level of suspended particles larger than 2.5 microns but still small enough to be harmful to human health.

The standard deviation for is 15.42, 30.25, 30.06 µg/m³ for pm 1.0, PM $_{2.5}$ and $PM_{10.0}$, respectively. This indicates significant fluctuations, indicating a considerable level of variation in the data. The variance for $PM_{1.0}$ is 237.85 (µg/m³)², which, when squared, provides a measure of the spread or variability of the $PM_{1.0}$ data. The variance for $PM_{2.5}$ is 915.10 (µg/m³)², suggesting that $PM_{2.5}$ concentrations exhibit higher dispersion from the mean, which is a sign of more irregular or erratic air quality in terms of particulate matter. The variance for PM_{10} is 903.58 (µg/m³)², showing that PM 10 concentrations also exhibit considerable dispersion similar to $PM_{2.5}$, pointing to notable fluctuation in air quality.

The maximum concentration for PM_{10} is 158.48 µg/m³, and the minimum is 13.89 µg/m³, indicating high variability in particulate matter levels for larger particles (PM_{10}).

The kurtosis value of 0.33 for $PM_{1.0}$ indicates a relatively flat distribution, signifying that most values are near the mean. The kurtosis value of 1.59 for $PM_{2.5}$ suggests a moderately peaked distribution with a higher number of extreme values.

The skewness values indicate that there are generally more occurrences of higher concentrations, which could mean that at certain times, the air quality may reach harmful levels.

These results show the need for continuous monitoring of air quality, especially for fine particulates ($PM_{2.5}$ and PM_{10}), which are associated with serious health risks. The variability in the data suggests that pollution can reach unsafe levels, demanding public health measures to reduce particulate matter in these locations.

Particulate matter concentration in Kano

The results presented in sections Figures 5 to 10 show the particulate matter (PM) concentration measurements for $PM_{1.0}$, $PM_{2.5}$, and PM_{10} in Kano, Nigeria, from January to December 2022. The results show that $PM_{1.0}$ has its highest concentration (30.97 µg/m³) in December, while this is a lower level compared to $PM_{2.5}$ and PM_{10}, it still shows a significant presence of ultra-fine particles in the air. The highest concentration of $PM_{2.5}$ (58.63 µg/m³) and PM_{10} (83.36 µg/m³) were also recorded in December. These values are well above the World Health Organisation's (WHO) recommended annual limit for $PM_{2.5}$. This suggests poor air quality, especially in December, which could be linked to weather conditions, increased traffic, or industrial activities.

Notably, the measurements during the wet season were low; for example, in July 2021, PM concentrations were relatively low, with $PM_{2.5}$ concentrations ranging from 3.50 to 11.71 µg/m³. This fluctuation indicates that the dry season is more prone to pollution, possibly due to no

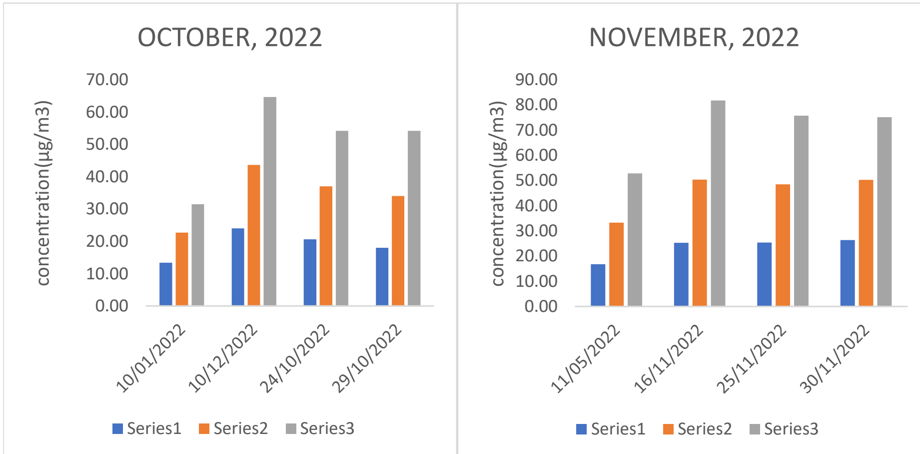

Figure 5. Concentration levels of PM $_{1.0}$, PM $_{2.5}$ and PM $_{10.0}$ in October and November 2022 (Kano).

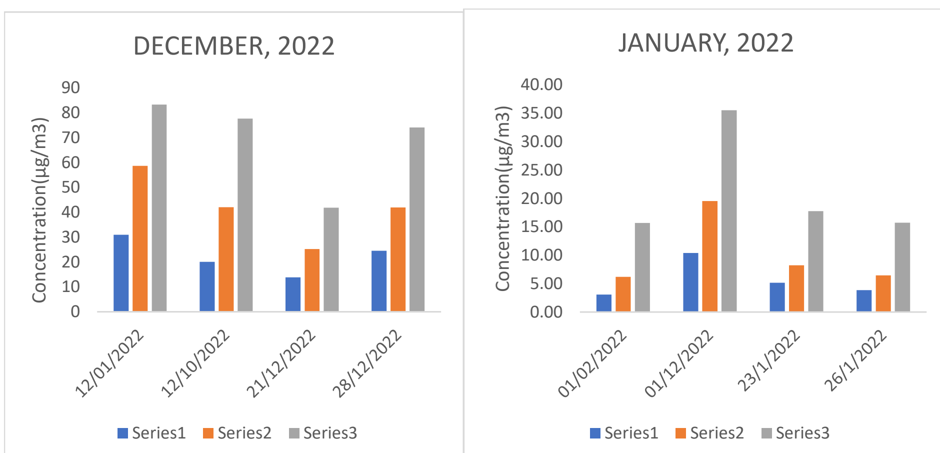

Figure 6. Concentration levels of PM 1.0, PM 2.5 and PM 10.0 in December and January 2022 (Kano).

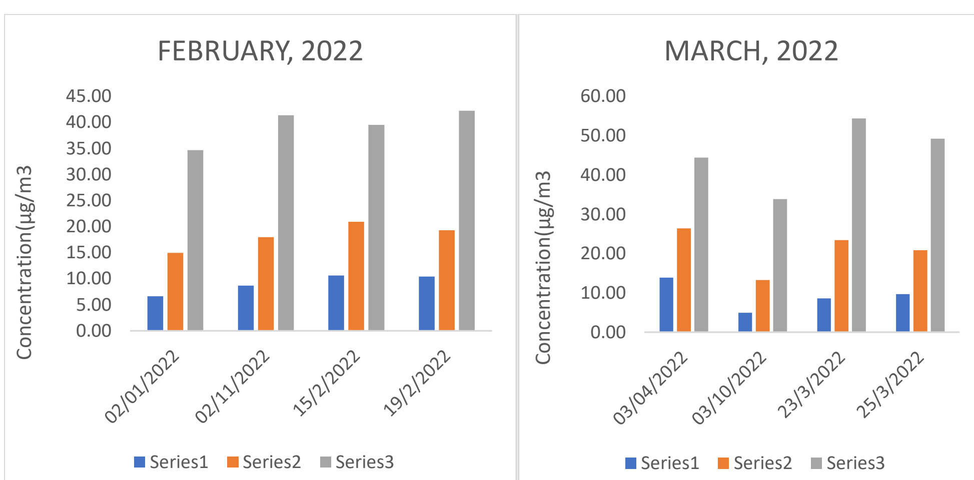

Figure 7. Concentration of PM $_{1.0}$, PM $_{2.5}$ and PM $_{10.0}$ in February and March 2022 (Kano).

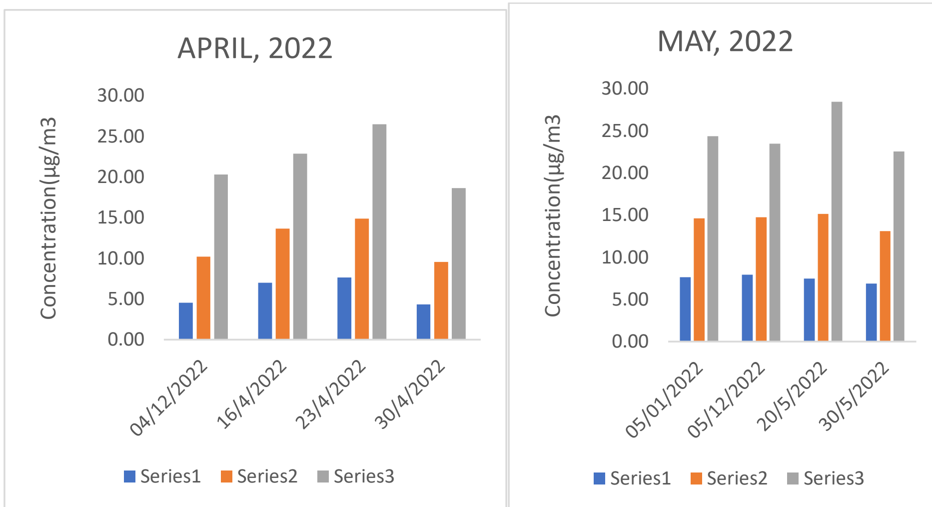

Figure 8. Concentration of PM 1.0, PM 2.5 and PM 10.0 in April and May 2022 (Kano).

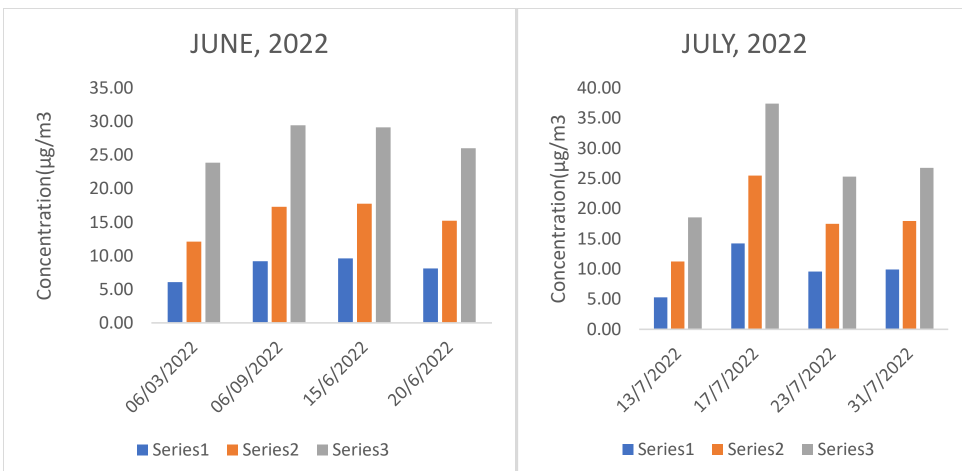

Figure 9. Concentration of PM 1.0, PM 2.5 and PM 10.0 in June and July 2022 (Kano).

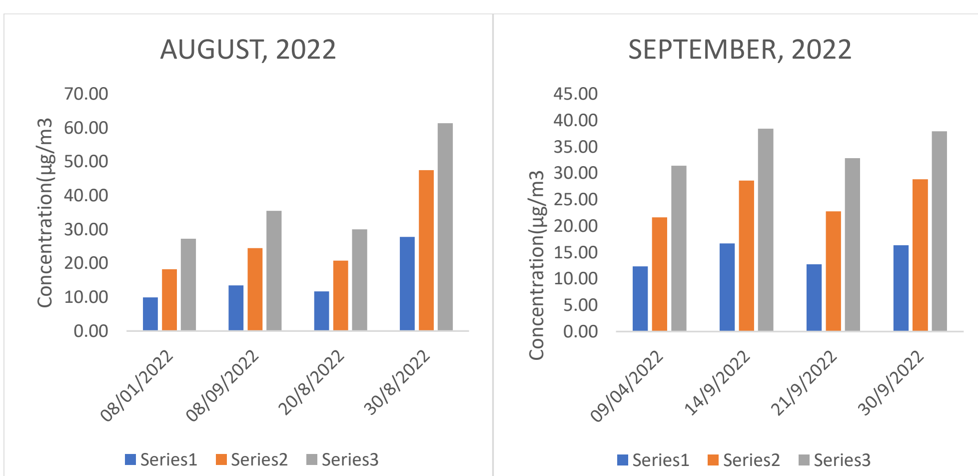

Figure 10. Concentration of PM $_{1.0}$, PM $_{2.5}$ and PM $_{10.0}$ in August and September 2022 (Kano).

Table 4. Result of the Statistical Analysis for Kano Station (dry season).

Statistic	PM1 (µg/m³)	PM2.5 (µg/m³)	PM10 (µg/m³)
Mean	9.53	18.25	34.10
STD	2.34	4.84	8.80
VAR	5.46	23.39	77.41
MAX	12.75	23.02	45.49
MIN	5.61	10.11	21.18
Kurtosis	-0.85	-1.24	-0.95
Skewness	-0.22	-0.15	0.18

Table 5. Result of the Statistical Analysis for Kano Station (wet season).

Statistic	PM1 (µg/m³)	PM2.5 (µg/m³)	PM10 (µg/m³)
Mean	6.07	11.96	19.81
STD	1.64	2.85	5.60
VAR	2.69	8.11	31.32
MAX	8.24	15.61	27.10
MIN	3.93	8.32	12.79
Kurtosis	-1.36	-1.36	-1.24
Skewness	0.30	0.30	0.45

rainfall.

Several studies on particulate matter concentration in Kano and similar cities in Nigeria provide valuable comparisons to this study. Research conducted in Kano has consistently shown that particulate matter concentrations in the city exceed the WHO-recommended limits, particularly during certain periods of the year.

The particulate matter measurements as presented in tables 4 and 5 show moderately high pollution levels, with $PM_{2.5}$ concentrations averaging 37.72 µg/m³ (ranging from 30.98 to 44.46 µg/m³) and PM_{10} averaging 43.17 µg/m³ (34.33-52.01 µg/m³), both approaching or exceeding WHO guidelines. $PM_{1.0}$ particles showed slightly lower levels, averaging 22.10 µg/m³ (17.91-26.29 µg/m³). The data reveal PM_{10} had the greatest variability between measurements, while $PM_{1.0}$ concentrations remained more stable. The consistent ratio between $PM_{2.5}$ and $PM_{1.0}$ concentrations suggests combustion sources like vehicle emissions may be contributing significantly to the pollution. Although limited to just two data points, these measurements indicate air quality conditions that could potentially affect respiratory health, especially for vulnerable populations with prolonged exposure. The $PM_{2.5}$ levels in particular, exceeding WHO's 24-hour limit of 15 µg/m³ by 2.5 times, represent a notable health concern that would benefit from additional monitoring.

DISCUSSION

Comparative analyses of the particulate concentration in Port Harcourt and Kano

The comparative analyses of the PM concentration in both cities as presented in Table 6 shows that mean values for $PM_{1.0}$, $PM_{2.5}$, and PM_{10} are significantly higher in Port Harcourt compared to Kano.

Both the standard deviation and variance are higher in Port Harcourt for all particulate matter sizes ($PM_{1.0}$, $PM_{2.5}$, and PM_{10}). This suggests that the air quality in Port Harcourt is more variable and can fluctuate greatly compared to Kano, and is consistent with previous research documenting the severe air pollution burden in Nigeria's Niger Delta region (Fakinle *et al.,* 2020). The elevated standard deviations and variances observed in Port Harcourt's PM levels suggest greater air quality variability than in Kano, mirroring patterns identified in earlier studies that attributed these fluctuations to industrial emissions and gas flaring activities (Akinfolarin *et al*., 2017).

The kurtosis and skewness values in both cities indicate that the distribution of particulate matter concentrations is relatively normal, with slight skewness in both cities. Higher kurtosis in Port Harcourt for $PM_{2.5}$ and PM_{10} suggests occasional extreme values in particulate matter concentration. While both cities exhibit approximately normal distributions of particulate matter concentrations, Port Harcourt's higher kurtosis values for $PM_{2.5}$ and PM_{10} indicate more frequent extreme pollution events, a phenomenon previously linked to industrial activities and gas flaring (Anjorin *et al.,* 2020).

The findings imply that residents of Port Harcourt are exposed to higher health risks due to poor air quality compared to residents of Kano. The significant disparity in air quality between the two cities suggests a need for stricter regulatory measures and pollution control strategies in Port Harcourt. These results validate earlier health risk assessments showing Port Harcourt residents face greater exposure to airborne pollutants than their

Table 6. Comparison between PM concentration in Port Harcourt station and Kano Station.

Parameters	Port Harcourt			Kano		
	PM1.0 (μg/m³)	PM2.5 (μg/m³)	PM10 (μg/m³)	PM 1.0 (μg/m³)	PM 2.5 (μg/m³)	PM 10 (μg/m³)
Mean	35.87	64.06	65.19	11.03	20.8	34.22
STD	15.42	30.25	30.06	5.9	10.81	16.71
VAR	237.85	915.1	903.58	34.78	116.86	279.15
MAX	75.4	155.05	158.48	23.49	45.62	71.41
MIN	7.68	12.46	13.89	3.93	8.32	12.79
Kurtosis	0.33	1.59	2.37	0	0.6	0.72
Skewness	0.68	1.05	1.29	0.94	1.11	1.04

Table 7. Monthly mean concentration of particulate matter with the AQI(kano).

Month	PM2.5 (μg/m³)	PM10 (μg/m³)	PM2.5 AQI	PM10 AQI	Overall AQI	AQI Category
Jan	10.11	21.18	42	19	42	Good
Feb	18.29	39.46	73	36	73	Moderate
Mar	21.00	45.49	84	41	84	Moderate
Apr	12.07	22.07	51	20	51	Moderate
May	14.43	24.72	59	23	59	Moderate
Jun	15.61	27.10	63	25	63	Moderate
July	18.04	27.00	71	25	71	Moderate
Aug	27.77	38.55	108	35	108	Unhealthy for Sensitive Groups
Sep	25.47	35.16	99	32	99	Moderate
Oct	34.39	51.16	134	46	134	Unhealthy for Sensitive Groups
Nov	45.62	71.41	159	64	159	Unhealthy
Dec	41.97	69.26	151	62	151	Unhealthy for Sensitive Groups

Table 8. Monthly mean concentration of particulate matter with the AQI (Port Harcourt).

Month	PM2.5 (μg/m³)	PM10 (μg/m³)	PM2.5 AQI	PM10 AQI	Overall AQI	AQI Category
August	44.46	52.01	120	47	120	Unhealthy for Sensitive Groups
Sept	30.98	34.33	91	31	91	Moderate
Oct	53.07	55.85	140	50	140	Unhealthy for Sensitive Groups
Nov	56.58	60.16	148	54	148	Unhealthy for Sensitive Groups
Dec	95.45	100.82	188	90	188	Unhealthy
Jan	75.05	83.63	168	75	168	Unhealthy
Feb	70.24	70.05	158	63	158	Unhealthy
Mar	86.68	65.90	178	59	178	Unhealthy

Kano counterparts (Yahaya *et al.,* 2023), reinforcing calls for targeted emission control strategies in southern Nigeria's industrial zones. The persistent air quality disparitybetween these cities, now quantified through comparative statistical analysis, underscores the urgent need for region-specific pollution mitigation approaches, particularly in Port Harcourt, where industrial sources dominate the pollution profile (Echendu *et al*., 2022). These findings align with other studies on urban air quality variations across Nigeria while providing an updated indication of the uneven environmental health problems faced by oil-producing regions (Yakubu, 2018).

Risk assessments of the particulate matter concentration in Port Harcourt and Kano

The risk assessment of particulate matter ($PM_{2.5}$ and PM_{10}) in Kano and Port Harcourt, as presented in Tables 7 and 8, reveals significant variations in air quality across different months, with Port Harcourt exhibiting higher pollution levels compared to Kano. In Kano, the overall AQI ranged from "Good" in January to "Unhealthy" in November and December, with $PM_{2.5}$ concentrations peaking at 45.62 and 41.97 µg/m³, respectively. Port Harcourt, however, recorded more severe pollution, with December and March reaching "Unhealthy" levels (AQI 188 and 178, respectively), driven by $PM_{2.5}$ concentrations as high as 95.45 and 86.68 µg/m³. These findings align with previous studies indicating that urban areas in Nigeria, particularly Port Harcourt, face high air pollution due to industrial activities, vehicular emissions, and seasonal biomass burning (Suriano *et al*., 2024; Owoade *et al.,* 2021). The elevated PM levels in Port Harcourt during the dry season (November to March) are consistent with the findings that harmattan winds worsen the air quality (Giwa *et al*., 2014).

The health implications of these findings are concerning, as prolonged exposure to $PM_{2.5}$ and PM_{10} is associated with respiratory and cardiovascular diseases (World Health Organisation [WHO], 2021). The frequent "Unhealthy" and "Unhealthy for Sensitive Groups" categories in Port Harcourt suggest a higher public health risk compared to Kano, where "Moderate" conditions dominate. This disparity may stem from Port Harcourt's industrial density, including oil refineries and petrochemical plants, which emit significant particulate matter (Nduka and Orisakwe, 2018). Comparatively, Kano's lower pollution levels could be attributed to its reliance on less industrialised emissions, though the "Unhealthy" readings in late months indicate deteriorating air quality, possibly due to seasonal factors. Previous studies in Sub-Saharan Africa have noted similar seasonal trends in PM concentrations rising during dry seasons due to increased combustion sources (Petkova *et al.,* 2013).

The findings stress the urgent need for strong air quality regulations and mitigation strategies in both cities, particularly Port Harcourt, where pollution levels exceed WHO guidelines (WHO, 2021). While Kano's air quality remains relatively better, the rising $PM_{2.5}$ levels in certain months warrant preventive measures to avoid escalation.

Conclusion

The study presents the spatiotemporal comparison concentration of particulate matter in Port Harcourt and Kano. The results show that the mean $PM_{1.0}$, $PM_{2.5}$ & $PM_{10.0}$ concentration in Port Harcourt all exceeds the WHO annual guideline of 5 µg/m³, significantly. This suggests high levels of particulate pollution in the air, which could pose a risk to human health, particularly to the respiratory system.

The mean concentration of particulate matter in Kano is far above the WHO guideline of 5 µg/m³, and the maximum significantly exceeds the 24-hour limit of 15 µg/m³. However, the concentrations in Kano are still lower than those in Port Harcourt.

The findings of this study demonstrate significant seasonal and spatial variations in particulate matter concentrations between Port Harcourt and Kano, with both cities exhibiting pollution levels that frequently exceed WHO guidelines, particularly during dry seasons. Port Harcourt shows consistently higher mean concentrations across all particle sizes ($PM_{1.0}$, $PM_{2.5}$, and PM_{10}) compared to Kano, along with greater variability as evidenced by higher standard deviations and variances, reflecting the strong influence of industrial activities and gas flaring in the Niger Delta region. Kano's pollution level, while generally lower than Port Harcourt's, still presents concerning levels during Harmattan seasons, primarily driven by natural dust sources combined with urban emissions. The health implications of these findings are substantial, as the documented $PM_{2.5}$ and PM_{10} concentrations in both cities, particularly in Port Harcourt, are associated with increased risks of respiratory and cardiovascular diseases.

The continuous gap in the pollution levels between these cities emphasises the environmental health challenges experienced by residents of oil-producing regions and calls for immediate policy interventions and continuous monitoring to protect public health.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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