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Spatiotemporal Assessment of Urban Particulate Matter Air Quality Index and its Implication on Human Health in the Kano Metropolis, Nigeria

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Abstract

Rapid urbanization in Kano Metropolis, Nigeria, has led to significant air quality challenges, particularly concerning particulate matter (PM) concentrations. This paper examined the spatiotemporal variations of the air quality of $PM_{2.5}$ and PM_{10} in the Kano metropolis and their implications for public health. Data on the pollutants were collected from 34 sampled locations across four distinct seasons hot and dry (Bazara), warm and wet (Rainy), warm and dry (Kaka), and cold and dry (Harmattan) using HoldPeak Laser PM2.5-5800D Digital Meter from March 2017 to February 2018. The data collected were subjected to Air Quality Index (AQI) computation, the outputs of which were used to spatially predict the concentrations of the unsampled areas through interpolation with the Inverse Distance Weighted (IDW) model. Also, Analysis of Variance (ANOVA) was used to assess the spatial and temporal significance of the variation of the AQIs over the metropolis. The results indicated no significant differences in the variation of $PM_{2.5}$ AQI across seasons or locations [F(3, 135) = 0.453, p=0.0716] but with a significant difference in PM_{10} AQI [F(3, 132) = 5.360, p=0.002], with high pollutant concentrations exceeding permissible guidelines in nearly all cases. This persistent pollution was attributed to the transboundary diffusion of emissions, leading to a consistently poor AQI throughout the metropolis. The findings highlighted that all residents of the Kano metropolis are exposed to dangerous levels of air pollutants, posing serious health risks. The paper concludes that air quality was poor across the study area all year round. It recommends both local and regional monitoring of emission sources, to mitigate the adverse health impacts of pollution and improve air quality for the urban populace.

Keywords: Particulate Matter, Air Quality Index, Health, Inverse Distance Weighted, Kano Metropolis

INTRODUCTION

Clean air is a vital necessity for human health and overall well-being (Bhat & Andrabi, 2017). On average, a person inhales approximately 12 kg of air daily, which is 12 to 15 times more than the amount of food consumed (Omole *et al.,* 2020). While humans can endure several

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days without food or water, they cannot survive without air for even an hour. In its natural state, the atmosphere provides organisms with the needed clean air and protects them by absorbing dangerous ultraviolet radiation, warming the surface, and regulating temperature (Gul, 2021). However, the atmosphere's vital functions can be threatened by the emission of chemicals and other substances in a process called air pollution.

Air pollution is one of the most conspicuous environmental challenges and the greatest threat to human health that accompanies urbanisation which needs drastic measures to comprehend and mitigate (Manisalidis *et al.,* 2020; WHO, 2024). To achieve this, the understanding of Air Quality is critical. Air quality is the degree to which the air is suitable or clean enough for humans, animals, or plants to remain healthy and it can also be defined as a measure of how much pollutants are in the air, which includes particulates and gaseous pollutants (Pryor *et al*, 2015; Lee, 2024). In other words, air quality is the description of the level or magnitude of pollution or how polluted the air of a geographical location is at a given period. It is measured using an index called the Air Quality Index (AQI) (Gupta *et al.,* 2023).

The Air Quality Index (AQI) is a straightforward, colour-coded (Table 1), and dimensionless scale that effectively represents air pollution levels. It operates as a piecewise linear function, meaning it is a real-valued function defined over real numbers, and its value depends on the concentration of specific pollutants (United States of America Environmental Protection Agency [USEPA], 2023a). While various countries have developed their own AQI systems aligned with their national air quality standards, Nigeria currently lacks an official air quality index. Air quality, much like the weather, can fluctuate rapidly, sometimes within just a few hours (Lee, 2024). The AQI is determined by evaluating the levels of the six Critical Air Pollutants (CAPs) and assigning a score on a scale from "Good" to "Hazardous," resulting in an overall AQI value ranging from 0 to 500 (USEPA, 2023a). Different countries worldwide apply varying thresholds for "good" air quality, often based on which pollutants their system monitors (Fowler *et al.,* 2020; Zhang & Srinivasan, 2020). Good air quality is defined by USEPA as having an AQI of 50 or lower, and moderate air quality is defined as having readings between 51 and 100. For sensitive groups, readings between 100 and 150 are deemed harmful; greater values signify deteriorating conditions (Table 1). Any number above 300 is considered harmful, and when the AQI surpasses 200, a health alert is activated (USEPA, 2023a).

Table 1: Air Quality Index

Air Quality Index (AQI) Values	Levels of Health Concern	Colours
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

Source: USEPA (2023b)

Generating urban air quality maps is a complex process that requires the application of mapping techniques. This is because the spatial and temporal concentrations of the pollutant vary with topographic and meteorological features such as altitude, local wind speed and direction. Numerous models and algorithms for spatial mapping of air pollution have been developed over the years (Karroum *et al.,* 2020) and these spatial models, otherwise known as spatial prediction or spatial interpolation models, provide means of describing different responses over contrasting spatial scales (Schloeder *et al.,* 2001). Spatial prediction techniques aim to obtain a value for a variable at an unsampled location based on surrounding measurements (Idir *et al.,* 2021). The most common interpolation method calculates the estimates for a property at any given point by averaging nearby data. Weighting for each averaged given value is assigned either through deterministic or statistical (spatial covariance) criteria. The statistical criterion is used when a random process is involved, and the optimality of the averaging method estimates the variance. When a deterministic approach is used, the measures of optimality are random (Idir *et al.,* 2021). Among statistical techniques, geostatistical kriging-based methods, including Simple and Ordinary Kriging, Universal Kriging, and Simple Kriging (Pyrcz & Deutsch, 2014) have often been used for spatial analysis. However, among deterministic methods, the Inverse Distance Weighted (IDW) interpolation and its modifications (Wong *et al.,* 2004) are the most often applied.

The Kano metropolis has the second largest concentration of industries in Nigeria after Lagos (Koko *et al.,* 2023). Serving as the commercial hub of Northern Nigeria, it is also the country's second most populous city (Abubakar *et al.,* 2023). Consequently, the metropolis emits a large volume of pollutants from industries, automobiles and several anthropogenic activities (Garba & Yunusa, 2016; Ladan, 2013). Hence, its consequent declaration as the most polluted city in Africa based on particulate matter (PM) emission (IQ AirVisual, 2019). Recent studies highlight a growing connection between PM exposure and cardiovascular conditions, such as strokes and ischemic heart disease, as well as cancer (Henning, 2024; Li et al., 2024; Liang et al., 2023; Moradi et al., 2023). However, most residents remain unaware of the risks associated with PM pollution. This paper therefore aims to assess the spatiotemporal variability of urban particulate matter AQI and its implication on human health in the Kano metropolis, Nigeria.

MATERIALS AND METHODS

The Study Area

The Kano metropolis is situated in the central-western region of Kano State, within latitude 11.99988° to 12.04433°N and longitude 8.52214° to 8.55547°E (Figure 1). It lies in the North-west region of Nigeria and is located some 840km away from the edge of the Sahara Desert and 1,140km from the Atlantic Ocean. The Kano Urban area covers 499 sq. km (Okunola et al, 2012).

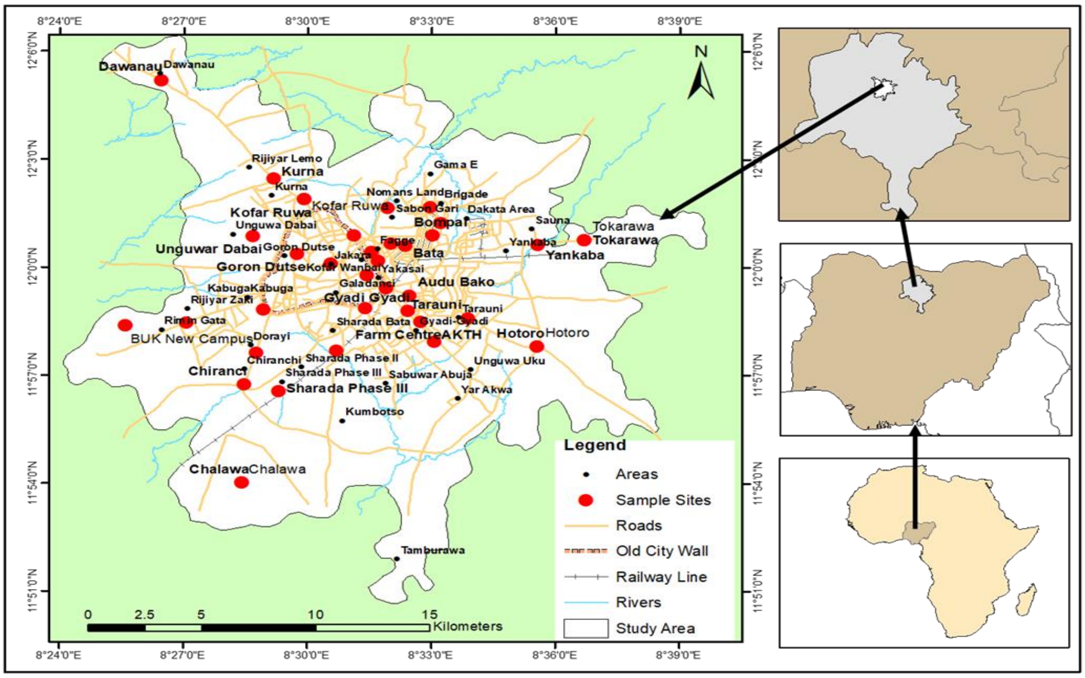


Figure 1: The Study Area

The Kano metropolis is the largest city in Northern Nigeria. According to the 2006 population census, it has a population of 2,828,861 (NPC, 2006), and when projected, by 2024 the population is expected to reach 4,670,069.

The metropolis falls within the Tropical Savanna climate. It experiences four climatic seasons which include; the dry and cool season (December to February), the dry and hot season (March to May), the wet and warm season (June to August), and the dry and warm (September to November) (Abdulhamed *et al.*, 2015). It has the second-largest concentration of industries in Nigeria after Lagos. It also has the highest number of automobiles and going by the 2006 population census, it has one of the highest population concentrations. All these put together suggest that the metropolis emits a large volume of not only solid waste but also gaseous chemicals from industries, automobiles and several human activities such as the use of fuelwood.

Methods of Data Collection

HoldPeak Laser PM2.5-5800D Digital Meter was used to measure Suspended Particulate Matter ($PM_{2.5}$ and PM_{10}). The data was collected from 34 sampled points (Figure 1) within twelve (12) calendar months from March 2017 to February 2018. The data collection period was divided into four distinct seasons: cold and dry (*Harmattan*), hot and dry (*Bazara*), warm and wet (Rainy), and warm and dry (*Kaka*). Geographic coordinates of the sampled locations were recorded using Global Positioning System (GPS) receivers.

Methods of Data Analysis

The data collected were subjected to AQI computation, which was used to spatially predict the concentration of the unsampled areas through interpolation with the IDW model. The computation of AQI requires the average concentration of an air pollutant over a specified period which is usually obtained from an air monitor. The level of contaminants and time represent the dose of the air pollutant. Hence, when computed, the AQI shows the possible health effects corresponding to a given dose of the contaminants.

The AQIs of the Criteria Air Pollutants (CAPs) for the metropolis were computed using the following formula adapted from USEPA (2023a):

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}} (C - C_{low}) + I_{low} \qquad (1)$$

where:

I = the (Air Quality) index,
C = the pollutant concentration,
C_{low}= the concentration breakpoint that is ≤ C,
C_{high}= the concentration breakpoint that is ≥ C,
I_{low}= the index breakpoint corresponding to I,
I_{high}= the index breakpoint corresponding to I.

Since Nigeria has not developed any air quality standard (Mbow-Diokhane, 2019), the USEPA AQI procedures (Table 2) are adopted in computing the AQIs in this paper.

Table 2: CAPs Concentration and Index Breakpoints

Concentration Breakpoints ($C_{high} - C_{low}$)		Index Breakpoints ($I_{high} - I_{low}$)	Level of Health Concern	Colours
PM$_{2.5}$ (µg/m^3)	PM$_{10}$ (µg/m^3)			
0 - 12	0-54	0-50	Good	Green
12.1 - 35.4	55-154	51-100	Moderate	Yellow
35.5 - 55.4	155-254	101-150	Unhealthy for Sensitive Groups	Orange
55.5 - 150.4	255-354	151-200	Unhealthy	Red
150.5 - 250.4	355-424	201-300	Very Unhealthy	Purple
250.5 - 500.4	425-604	301-500	Hazardous	Maroon

The ArcMap tools were used to interpolate (using the IDW model) the AQIs into air quality maps. IDW was calculated using the IDW model formula (Jasim & Walli, 2023):

$$Z*(\boldsymbol{u}) = \sum_{i=1}^{n} \lambda_i Z\,(U_i)$$

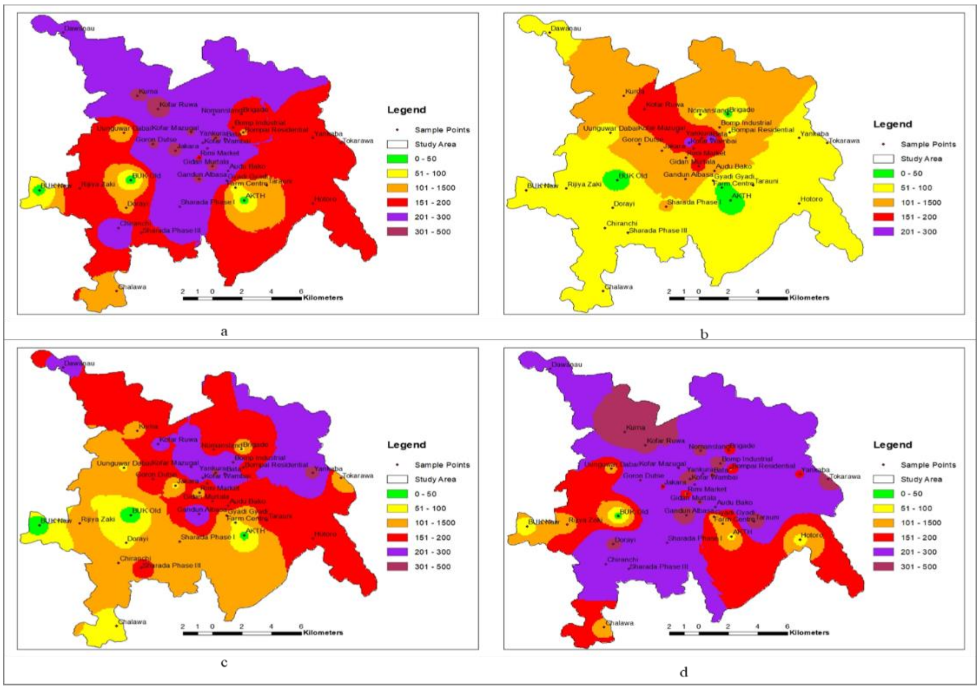
where: u is the estimation location, U$_i$, i= 1…, n, are the locations of the sample points within the search neighbourhood, Z *(u) is the inverse distance estimate at the estimation location, n is the number of sample points, λ$_i$, i= 1, …, n, are the weights assigned to each sample point, and Z(U$_i$), i= 1… , n, are the conditioning data at sample points.

Also, the Analysis of Variance (ANOVA) was used to assess the temporal and spatial significance of the variation of the AQIs over the metropolis (Mahmud *et al.*, 2023).

RESULTS AND DISCUSSION

Particulate matter (PM$_{2.5}$) AQI

The particulate matter (PM$_{2.5}$) Air Quality Index (AQI) Computation was carried out using the concentration breakpoints in Table 2. These breakpoints were calculated using the microgram per cubic metre unit of measurement (µg/m3). The AQI computation is presented in Figure 2.



(2)

Figure 2: Particulate matter (PM$_{2.5}$) AQI for a. the hot-dry season, b. warm-wet season, c. warm-dry season, d. cold-dry season

In the hot-dry season (Figure 2a), it is only the areas around BUK old and new campuses, AKTH, Unguwar Dabai, Dorayi, Farm Centre, Chalawa and Tarauni that recorded good air quality. The other locations ranged from unhealthy to sensitive groups to hazardous. The air quality of the metropolis based on the AQI of $PM_{2.5}$ is at its best during the warm-wet season (Figure 2a). Rainfall during this season might be responsible for washing or reducing dust particles from the atmosphere. However, areas around Kofar Ruwa up to Bata had unhealthy air quality despite the rains. The ongoing construction of the Kofar Ruwa underpass and the Bata-Yankura overhead bridge at the time of the data collection for this study must have contributed immensely to the high concentration of dust in these areas. In the warm-dry season (Figure 2c), most sites had good air quality except for the commercial areas. While in the cold-dry season (Figure 2d), a few spots were found to be AQI-healthy. This season coincides with the harmattan season which is predominantly characterized by dust.

Similar air quality indexes were reported in Nigerian cities. Shittu *et al.* (2019) recorded hazardous AQIs in both dry and wet seasons in Ogun and Lagos states and Akinfolarin *et al.* (2017) reported the same in the dry season in Port Harcourt. However, Osimobi *et al.,* (2019) recorded PM2.5 AQI within the 'unhealthy for sensitive group' category at the University of Port Harcourt, Nigeria. Also, Osaiyuwu & Ugbebor (2019) reported very unhealthy $PM_{2.5}$ air quality in some host communities of oil facilities of Rivers State.

Elsewhere, hazardous $PM_{2.5}$ air quality indexes were recorded in Urumqi and Turfan cities in China, and Southwest Taiwan (Lee *et al.,* 2019; Yin *et al.,* 2019). Also, unhealthy categories were reported in Delhi, Bengaluru, Chennai and Jaipur which are megacities of India (Dadhich *et al.,* 2018; Sharma *et al.,* 2019).

Continuous exposure to $PM_{2.5}$ may penetrate deeply into the lung, irritate and corrode the alveolar wall, and consequently impair lung function (Xing *et al.,* 2016). It can also result in enhanced susceptibility to bacterial and respiratory infection (Kleinman *et al.,* 2007; Chen *et al.,* 2018; Kalisa *et al.,* 2019), asthma, wheezing, rhinitis and eczema (Deng *et al.,* 2019), cardiac sympathetic hyperactivity (Tsai *et al.,* 2019), inflammation in the gastrointestinal tract (Mutlu *et al.,* 2018), hypertension and diabetics (Bai *et al.,* 2018), and chronic stress (Petrowski *et al.,* 2018).

Particulate matter (PM_{10}) AQI

The computation of PM_{10} Air Quality Index (AQI) was carried out using the concentration breakpoint (Table 2), which is also calculated using microgram per cubic metre ($\mu g/m^3$). The results were used to generate the PM_{10} AQI maps as shown in Figure 3.

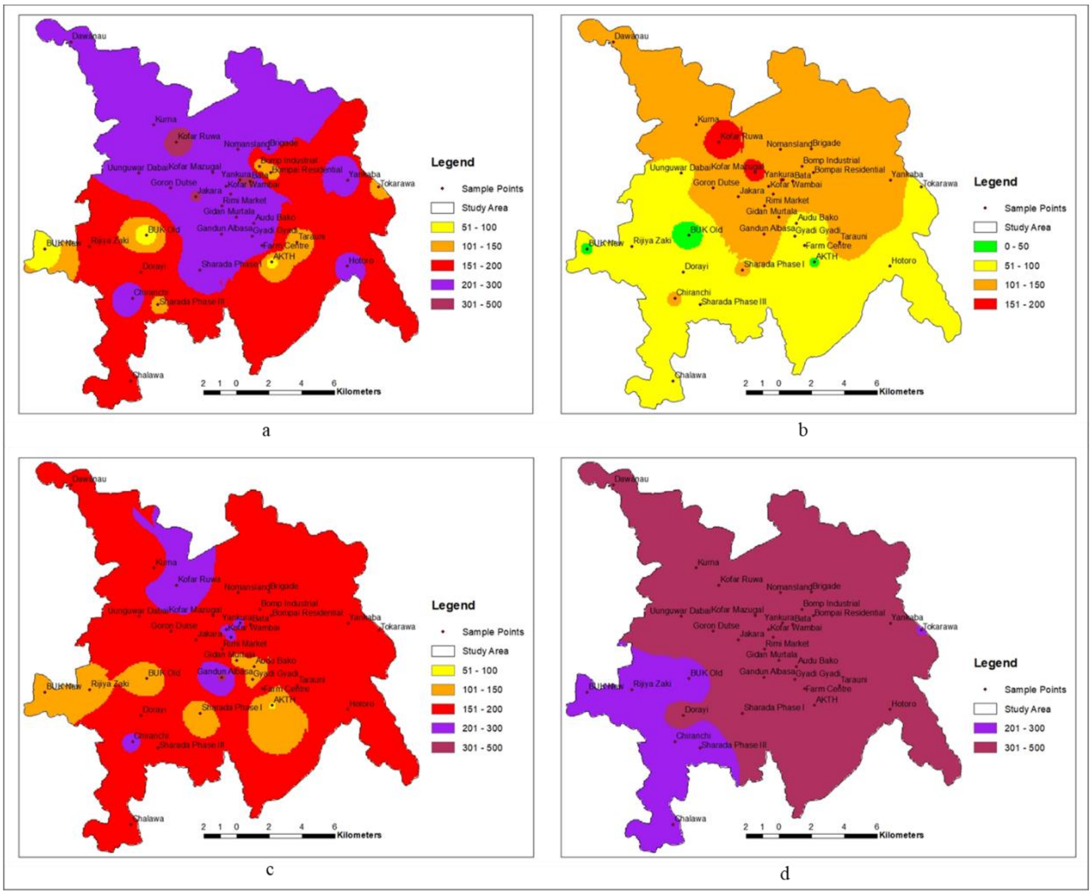


Figure 3: Particulate matter (PM$_{10}$) AQI for a. the hot-dry season, b. warm-wet season, c. warm-dry season, d. cold-dry season

The air quality of the metropolis based on PM$_{10}$ was moderate around the Bayero University, Kano (BUK) old and new campuses and Aminu Kano Teaching Hospital (AKTH) in the hot-dry season (Figure 3a). The AQI of other locations falls within the 'unhealthy for sensitive groups' and 'hazardous' category. The warm-wet season (Figure 3b) had the best air quality of PM$_{10}$ for the whole year. Except for Kofar Ruwa and Kofar Mazugal, all the other sites were within the 'acceptable' AQI range. Kofar Ruwa suffered from heavy dust pollution due to the ongoing underpass road construction at the time of data collection.

In the warm-dry season (Figure 3c) AQI was poor except for a few locations (including BUK old and new campuses, Rijiyar Zaki, Gyadi-Gyadi and Sharada Phase I), all the other sites recorded AQIs that are not within the acceptable range. The cold-dry season (Figure 3d) had the worst air quality in terms of PM$_{10}$. The entire metropolis recorded only two categories of AQI. The very unhealthy and hazardous. The prevailing meteorological conditions in this season, including harmattan dust and strong winds that are capable of raising dust, played a significant role in the resultant AQI.

Similar air quality indexes were reported in Nigeria and other parts of the world. Hazardous air quality was reported in Ogbomoso, Oyo State Nigeria (Akintunde *et al.*, 2019); unhealthy and hazardous categories in Sapele and Port Harcourt, Nigeria (Obiebi & Oyibo, 2019; Osaiyuwu & Ugbebor, 2019); hazardous in Lagos and Ogun State (Shittu *et al.*, 2019).

Away from Nigeria, hazardous PM$_{10}$ air quality was reported in Nagpur and West Tripura, India (Singh *et al.*, 2019), poor and hazardous in Beijing, Ningbo and Urumqi, China (Tian *et* *al.,* 2019; Tu *et al.,* 2019; Yin *et al.,* 2019) and hazardous in Lima, Peru (Delgado & Aguirre, 2019).

Exposure to unhealthy PM_{10} air quality will, among others, lead to lung function disorders in children (Isiugo *et al.,* 2019) and cardiovascular diseases (Soleimani *et al.,* 2019). It can also lead to cardiac sympathetic hyperactivity (Tsai *et al.,* 2019), cardiopulmonary mortality (Pope *et al.,* 2018), inflammation in the gastrointestinal tract (Mutlu *et al.,* 2018) and mortality (Di *et al.,* 2017).

Table 3: ANOVA Test for $PM_{2.5}$ AQI Variability

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.107	3	0.036	0.453	0.716
Within Groups	10.416	132	0.079		
Total	10.523	135			

The results of the Analysis of Variance (ANOVA) indicated that the variability of the AQIs of $PM_{2.5}$ [F(3, 135) = 0.453, p = 0.0716] is not significantly different over time and across locations($p \geq 0.05$) (Table 3). However, the results of PM_{10} AQIs [F(3, 135) = 5.360, p = 0.002] indicated a significant difference in the variability of the pollutant over space and time (Table 3).

Table 4: ANOVA Test for PM_{10} AQI Variability

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.557	3	0.186	5.360	0.002
Within Groups	4.576	132	0.035		
Total	5.133	135			

CONCLUSION

The spatiotemporal variations of the AQI of $PM_{2.5}$ and PM_{10} and their effects on public health were investigated in the Kano Metropolis. Results reveal that air quality within the Kano metropolis exhibits minimal seasonal and spatial variation, with consistently high pollutant concentrations recorded across nearly all seasons and locations. The elevated levels of pollutants, frequently surpassing established guidelines, are likely driven by transboundary transport of emissions, contributing to the persistently poor Air Quality Index (AQI) observed in the metropolis. These findings indicate that no resident is immune to the harmful effects of air pollution, underscoring the urgent need for comprehensive mitigation strategies. Addressing both local and regional sources of emissions will be critical to improving air quality and protecting public health in the Kano metropolis.

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