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Assessment of Atmospheric Pollutants (NO_2, CO, and Aerosols) in Kano State, Northwestern Nigeria, from 2019 - 2023

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ABSTRACT: Air pollution is a serious environmental concern, with evidence showing that both short and long-term exposure to gaseous pollutants negatively impacts the environment and human health. Kano State, one of Nigeria's largest industrial hubs, has experienced rapid population growth, deforestation, and industrialization, all of which have the potential to impact air quality. Therefore, this paper aims to evaluate air quality in Kano State, Northwestern Nigeria, by analyzing atmospheric pollutants such as nitrogen dioxide (NO_2), carbon monoxide (CO), and aerosols from 2019 - 2023. The study utilizes secondary data accessed through Google Earth Engine, primarily sourced from the Sentinel-5 Precursor (S5P) satellite equipped with the Tropospheric Monitoring Instrument (TROPOMI). Results indicate annual mean NO_2 concentrations of 0.0000535 mol/m² (2019), 0.0000539 mol/m² (2021), and 0.0000592 mol/m² (2023). The mean CO concentrations for these years were 0.0373 mol/m², 0.0369 mol/m², and 0.0364 mol/m², respectively, while mean aerosol concentrations were -0.364, -0.060, and 0.596. Statistical analysis revealed no significant changes ($p > 0.05$) in NO_2 and CO levels over the study period, whereas aerosol concentrations increased significantly ($p < 0.001$) from 2019 - 2023. These findings underscore the need for continuous air quality monitoring in Kano State to track pollutant trends and guide regulatory actions aimed at mitigating health and environmental impact.

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Air pollution is a major environmental challenge globally, affecting both developed and developing countries (Mannucci and Franchini, 2017). The problem has worsened due to rapid population growth, urbanization, and the overexploitation of natural resources, making air pollution a pressing global concern (Wassie, 2020). Research shows that both short- and long-term exposure to gaseous pollutants such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and aerosols have adverse effects on the environment and human health (Sharma *et al*., 2013). These pollutants not only pose serious health risks but also contribute to climate change, which threatens local and international communities (Kaur and Pandey, 2021). Urban and suburban areas, particularly in growing cities, experience higher concentrations of these pollutants, leading to dangerous air quality conditions that often exceed World Health Organization (WHO) standards (WHO, 2023). The WHO reported that in 2019, outdoor air pollution caused approximately 4.2 million premature deaths globally, largely due to exposure to fine

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particulate matter linked to cardiovascular and respiratory diseases, as well as cancer. Developing countries face higher exposure to harmful pollutants, resulting in more premature deaths and health issues like respiratory and cardiovascular diseases (Bruce *et al*., 2000). Nigeria, one of Africa's growing economies, faces serious air pollution challenges, especially in its urban and industrial cities (Amaechi and Biose, 2016). Kano State, the second-largest industrial state and the second most populous state in Nigeria after Lagos, with a population of over fifteen million, has experienced significant urbanization, industrialization, and deforestation, all of which contribute to rising levels of air pollution (Ohwo and Abotutu, 2023). The state's large population and industrial activities make it vulnerable to pollutants like CO, NO_2, and aerosols. Kano's role as a leading industrial hub in northern Nigeria, combined with its large population, makes it an important case study for understanding the impact of air pollution in developing countries. The aim of this study is to assess the air quality in Kano State, focusing on pollutants such as CO, NO_2, and aerosols. The objectives include identifying key air quality parameters to be measured, determining the trend and spatial patterns of these pollutants over time, and analyzing any significant differences in their concentrations during the study period. By understanding the temporal and spatial distribution of these pollutants, this study will provide critical data for developing effective pollution control strategies. Despite growing concerns about air pollution in Nigeria, there is insufficient research on the temporal and spatial distribution of pollutants in Kano State. A lack of comprehensive data on the spatiotemporal variations of key air pollutants like NO_2, CO, and aerosols hampers the development and implementation of effective air quality management strategies, which are crucial for protecting public health and the environment. Therefore, this paper aims to evaluate the air quality in Kano State, Northwestern Nigeria, by analyzing atmospheric pollutants (NO_2, CO, and aerosol) from 2019 - 2023.

MATERIAL AND METHODS

Study area: Kano State (Figure 1) was selected as the study area for this research because it serves as a leading industrial hub in northern Nigeria, and its high population density may result in public health risks posed by air pollution. This makes it a relevant case study for understanding the impact of air pollution in developing nations. Its geographical size, with a land mass of about 20,131 km² (Oseni, 2012), and its 44 local government areas (Mpyet *et al*., 2017) provide a diverse landscape for environmental analysis. Geographically, Kano is located between latitudes 12°00'N and longitudes 8°52'E within the Sudan Savanna biome (Garba, 2009). This region is characterized by distinct wet and dry seasons (Butu and Emeribe, 2019), which could influence the dispersal and concentration of air pollutants throughout the year. In this research, CO, NO_2, and aerosols have been chosen as the primary pollutants for investigation due to their significant impact on both environmental quality and public health, as well as their prevalence in industrialized and urbanized areas like Kano State, Nigeria.

Data type and data source: The data type used for this study is a secondary data type, obtained directly from Google Earth Engine (GEE) through a source script. GEE offers an extensive collection of remote sensing data, including raster data from a range of satellite missions like Landsat, Sentinel, and MODIS, among others (Tamiminia *et al.,* 2020). This research depends on the secondary data type, which is obtained from the Sentinel 5P satellite, enabled with the Tropospheric Monitoring Instrument (TROPOMI). The Sentinel-5P carries the TROPOMI, which is a spectrometer capable of measuring a wide range of atmospheric pollutants with high spatial resolution (Kaplan and Avdan, 2020). The TROPOMI has a sampling size of 7x7 km^2 and a swath width of 2,600 km. It has 4 spectrometers, each electronically split in two bands (2 in UV, 2 in VIS, 2 in NIR, and 2 in SWIR) with a radiometric accuracy of 1.6% (SWIR) to 1.9% (UV) of the measured earth spectral reflectance, which makes it good for monitoring air quality and pollution (Zhao *et al*., 2020). It operates by observing sunlight reflected or scattered by the Earth's surface and atmosphere, allowing for detailed monitoring of air quality. It can detect pollutants such as NO_2, ozone (O_3), SO_2, CO, aerosols (Butz *et al.,* 2012), etc.

Method of data collection: With the application of Google Earth Pro, a temporal-spatial survey across various locations in Nigeria was conducted. The aim was to identify potential study areas for further analysis. The study area was selected based on the preparatory spatial survey. GEE was used to download raster imagery of the selected study area (Kano State). Java script was developed within GEE in order to generate raster datasets. By employing a rectangle geometry tool from the GEE and also within the Java script, the study area was defined. Data was collected on an annual basis. Which allowed for the assessment of temporal changes in the atmospheric pollutants (NO_2, CO, and aerosol). The script was executed within GEE to obtain the tropospheric vertical column density of offline levels of NO_2, CO, and aerosol. The script ran to generate raster datasets correlating with the specified study areas. The generated raster was downloaded from GEE to Google Drive for storage.

After this, the downloaded raster datasets were taken into ArcGIS software for further processing and analysis.

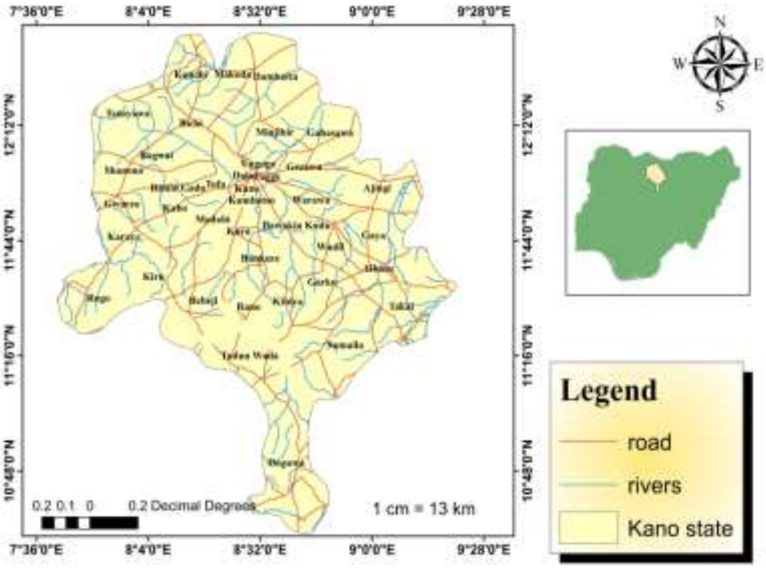

Fig. 1: Study area map (Kano State)
Source: Researcher's work, 2024

Method of analysis: The temporal trends and spatial distribution of the tropospheric vertical column density of offline levels of NO_2, CO, and aerosol within the selected study areas were analyzed using ArcGIS software. The result was then compiled, organized, and processed in Microsoft Excel for interpretation and visualization. The result was interpreted regarding the spatial and temporal variations of the pollutant levels within the study area.

RESULTS AND DISCUSSION

The concentration of air pollutants in this study was analyzed and measured in mol/m^2 except for aerosol which has no unit. The mean of each air quality parameter, the p values, and the chi-square goodness of fit are given in Table 1. The superscripts "a", "b", and "c" next to the mean values for aerosol concentration appeared in cases when there was a significant difference. The study area was classified into three categories based on their concentration levels: low, moderate, and high for each pollutant (NO_2, CO, and aerosol). These classifications enabled a spatial understanding of pollutant distribution across Kano State over the study period.

Table 1: Air Quality Concentration

	Air Quality Concentration		
Years	**NO_2 (mol/m^2)**		
	Mean	**Max**	**Min**
2019	0.000053496	0.00009004	0.00004628
2021	0.000053875	0.000096057	0.00004462
2023	0.000059204	0.000106669	0.00004901
p-Values	$p>0.05$		
Chi-square values	0.939		
	CO (mol/m^2)		
	Mean	**Max**	**Min**
2019	0.037261722	0.039621975	0.03517626
2021	0.036934466	0.040280115	0.0341275
2023	0.036447386	0.0387563	0.03436781
p-Values	$p>0.05$		
Chi-square values	0.991		
	Aerosol		
	Mean	**Max**	**Min**
	-	-	
2019	0.364553104^b	0.063746512	-0.7516808
2021	-0.06049543^c	0.242580593	-0.5053628
2023	0.596068513^a	0.876553893	0.16472328
p-Values	$p<0.001$		
Chi-square values	0.000		

*Min-Max = minimum and maximum values for each parameter per year: post hoc = values with different superscripts (a > b > c) are significantly different ($p < 0.05$). *$p < 0.01$ (high significant difference) *$p < 0.001$ (very high significant difference).*

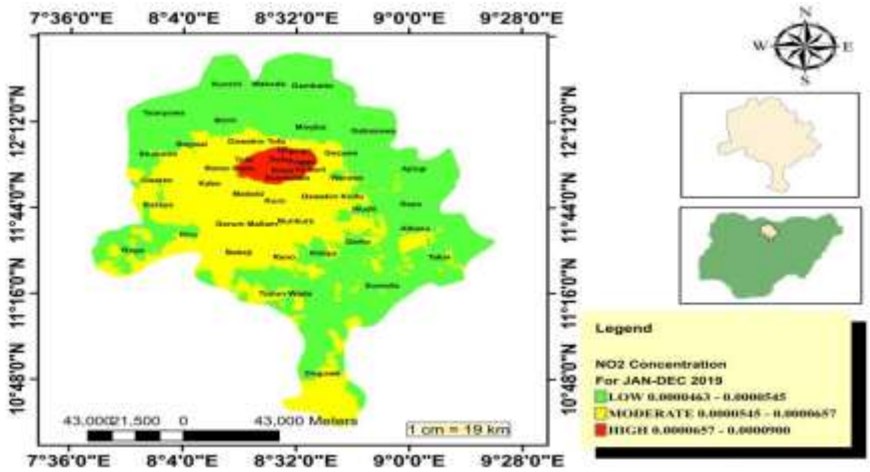

Fig. 2: Distribution of NO_2 concentrations in Kano State
Source: Researchers work, 2024

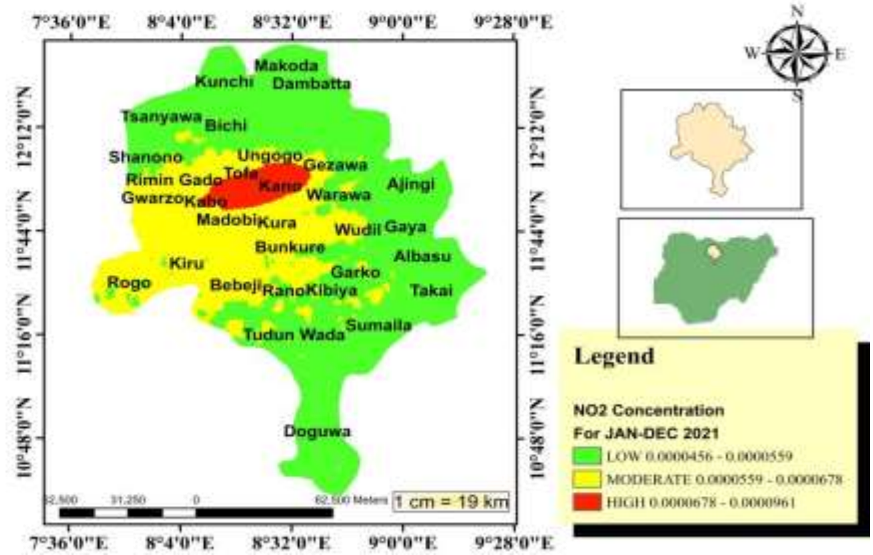

Fig. 3: Distribution of NO_2 concentration in Kano State
Source: Researchers work, 2024

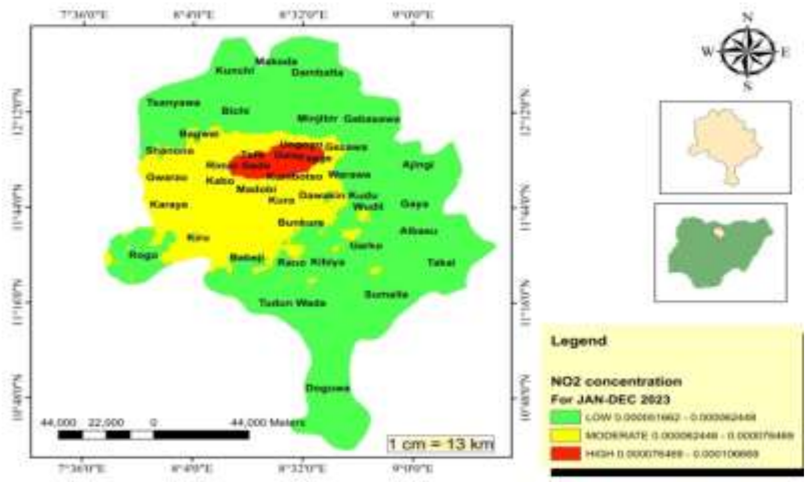

Fig. 4: Distribution of NO_2 concentrations in Kano State
Source: Researchers work, 2024

NO_2 Concentration (2019, 2021, and 2023): The distribution of NO_2 (Figures 2-4, Table 2) showed that 58.32% of the area had low concentrations, 38.74% had moderate concentrations, and 2.95% had high concentrations. The minimum, maximum, and mean values of NO_2 concentrations were 0.0000434 mol/m², 0.0000535 mol/m², and 0.0000535 mol/m², respectively (Table 1). By 2021, the low concentration areas had increased to 64.11%, moderate areas decreased to 32.16%, and high concentration areas rose to 3.72% (Table 2), with a mean concentration of 0.0000539 mol/m² (Table 1). In 2023, the low concentration areas increased to 71.59%, moderate areas reduced to 25.39%, and high concentration areas remained relatively stable at 3.02% (Table 2), with a mean concentration of 0.0000592 mol/m² (Table 1). Areas with lower concentrations of NO_2 are likely to be less populated, with lower traffic density and fewer industrial facilities. Meanwhile, areas with moderate NO_2 concentration tend to have a mix of residential and commercial zones. High NO_2 concentrations are linked to higher traffic density, industrial processes, and power generation activities.

Table 2: Air Quality Percentage Cover

	Percentage Cover of Air Quality Parameters		
Years	**NO_2 (%)**		
	High	**Moderate**	**Low**
2019	2.948	38.735	58.317
2021	3.724	32.164	64.112
2023	3.016	25.392	71.591
	CO (%)		
	High	**Moderate**	**Low**
2019	40.264	40.586	19.15
2021	27.758	49.817	22.425
2023	39.719	38.5	21.781
	Aerosol (%)		
	High	**Moderate**	**Low**
2019	65.053	25.86	9.087
2021	39.061	50.293	10.646
2023	51.712	39.141	9.146

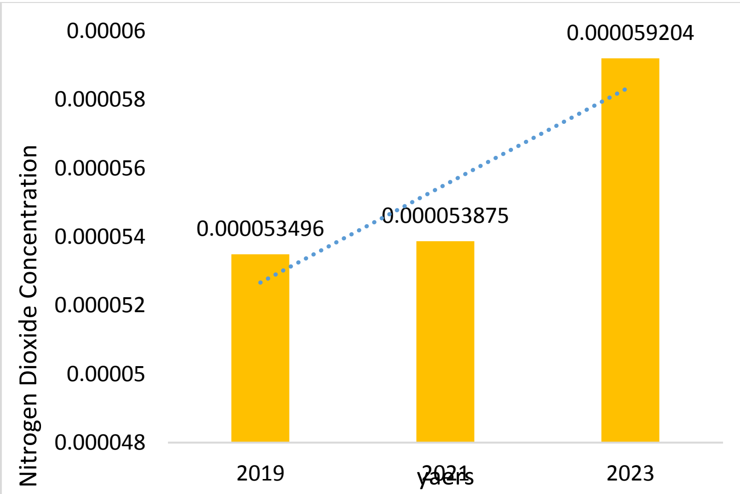

Fig. 5: The annual mean trend of NO_2 concentration over the years (2019, 2021, 2023)
Source: Researchers work, 2024

Figure 5 shows the mean trend of NO_2 concentration over a five-year period. The trends observed across the years were different in 2019, 2021, and 2023. The trend line indicated that NO_2 slightly increased from 2019 to 2021 and then a further increase in 2023. Using the chi-square goodness of fit, there was no significant difference ($p>0.05$) between NO_2 concentration over the five years. According to Kahadija and Ibrahim (2019), NO_2 concentrations in Kano state are mostly concentrated in industrial zones which aligns with my findings in this study.

CO Concentration (2019, 2021, and 2023): In 2019, the percentage of areas with low CO concentrations was 19.15%, moderate concentrations covered 40.59%, and high concentrations covered 40.26% (Table 2). The mean CO concentration was 0.0373 mol/m² (Table 1). By 2021, the low concentration areas increased to 22.43%, moderate areas expanded to 49.82%, while high concentration areas decreased to 27.76%, with a mean concentration of 0.0369 mol/m² (Table 1). In 2023, the low concentration areas covered 21.78%, moderate areas covered 38.50%, and high concentration areas slightly increased to 39.72% (Table 2), with a mean concentration of 0.0364 mol/m² (Table 1). Lower CO concentrations were found in areas with fewer vehicles and industries. Urban areas with high population density and intense industrial activity were more likely to experience elevated CO levels. The spatial distribution of CO is presented in Figures 6 - 8.

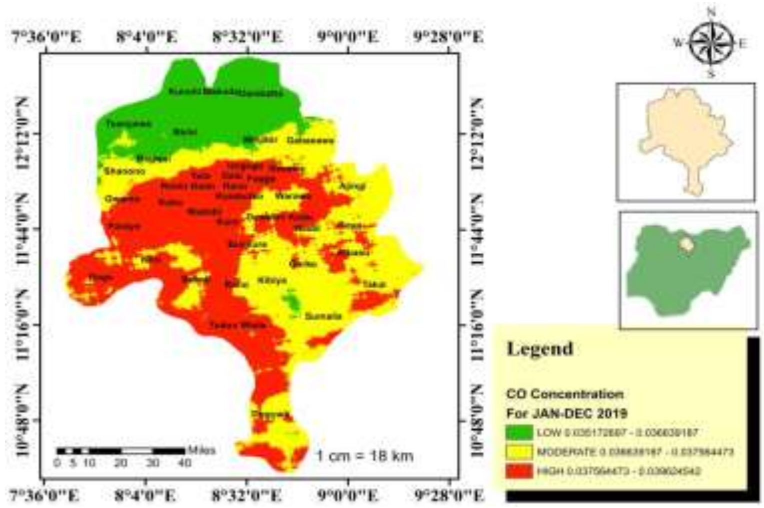

Fig. 6: Classified Distribution of CO concentrations in Kano State.
Source: Researchers work, 2024

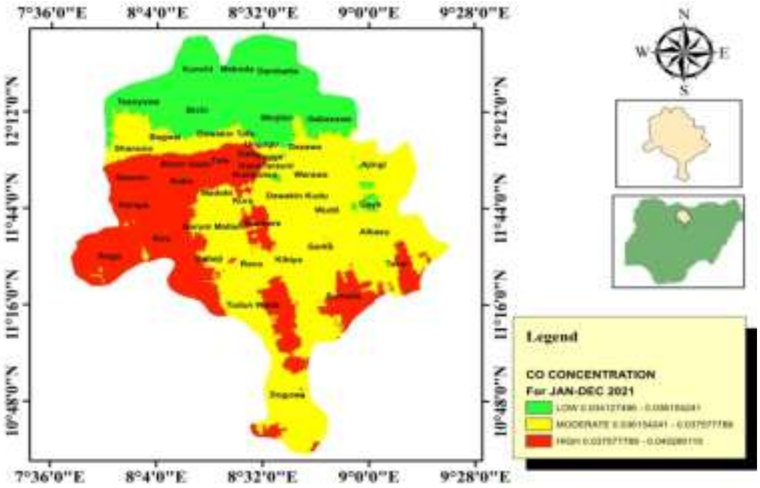

Fig. 7: Classified Distribution of CO concentrations in Kano State
Source: Researchers work, 2024

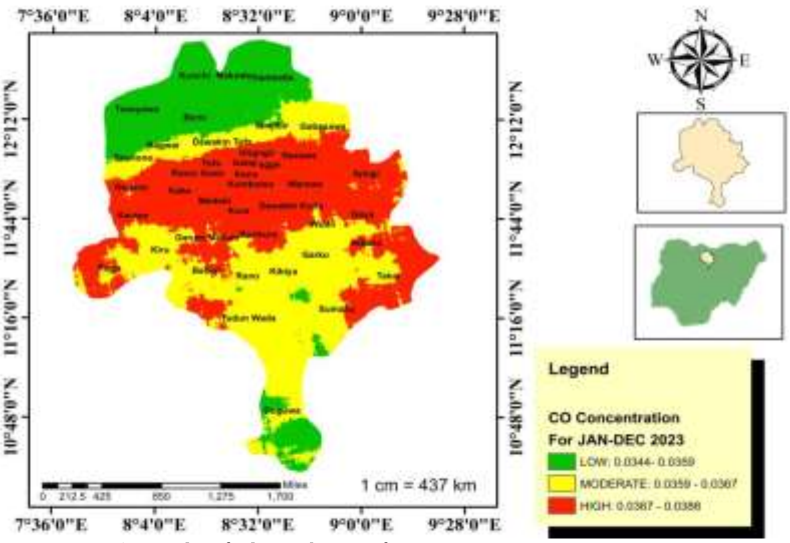

Fig. 8: Classified Distribution of CO concentrations in Kano State
Source: Researchers work, 2024

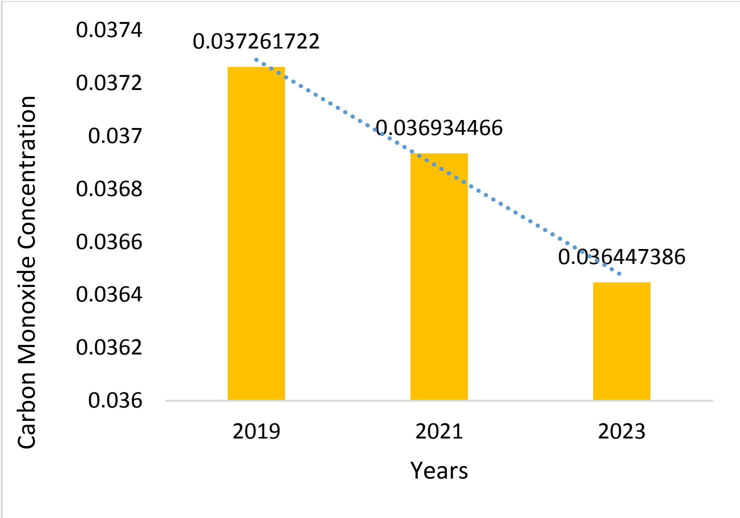

Fig. 9: The mean trend of CO concentration over the years (2019, 2021 and 2023)
Source: Researchers work, 2024

Figure 9 shows the annual mean trend of CO concentration over a five year period. The trends observed across the years were different in 2019, 2021 and 2023. The trend line indicated that CO from 2019 slightly decreases in 2021 and a further decrease occurs in 2023 over the study period. Using the chi-square goodness of fit, there was no significant difference (p>0.05) between CO concentration over the five years period (Table 1). The assessment of CO levels in kano State by Alkasim *et al.*, (2013) shows an important comparison to this study. Their research captures CO pollution from vehicular emissions at key locations. Both studies agree that areas with high traffic and industrial activities experience elevated CO concentrations. In contrast to Alkasim *et al.*, (2013) study, which focuses on a specific time, this study, shows changes in CO levels over time, showing a slight decrease in CO concentrations from 2019 - 2023.

Aerosol Concentration (2019, 2021, 2023): In 2019, areas with low aerosol concentration covered 9.09%, moderate areas covered 25.86%, and high concentration areas covered 65.05% (Table 2), with a mean aerosol concentration of -0.365 (Table 2). By 2021, the percentage of low concentration areas increased to 10.65%, moderate concentration areas covered 50.29%, and high concentration areas decreased to 39.06%, with a mean concentration of -0.0605. By 2023, the high concentration areas expanded to 51.71%, moderate areas covered 39.14%, and low areas remained stable at 9.15%. The mean aerosol concentration for 2023 was 0.596. Statistical analysis indicated a significant ($p < 0.001$) increase in aerosol concentrations over the study period, suggesting changes in emissions or atmospheric conditions in Kano State, Nigeria. The spatial distribution of aerosols is presented in Figures 10–12.

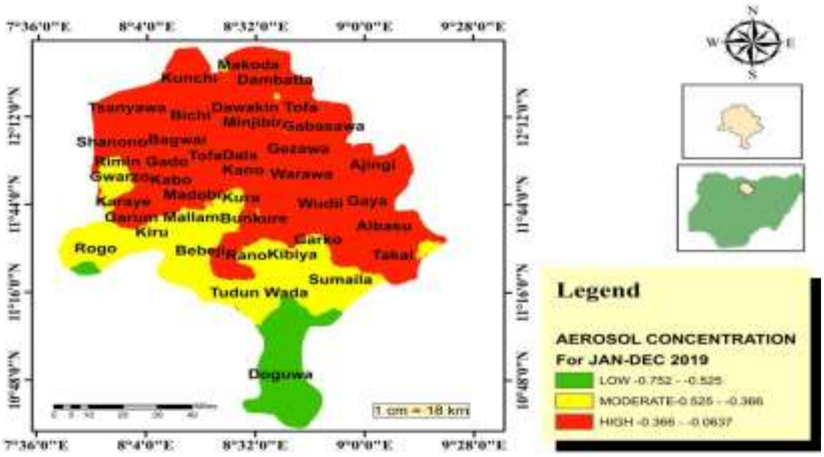

Fig. 10: Classified distribution of aerosol concentrations in Kano State
Source: Researchers work, 2024

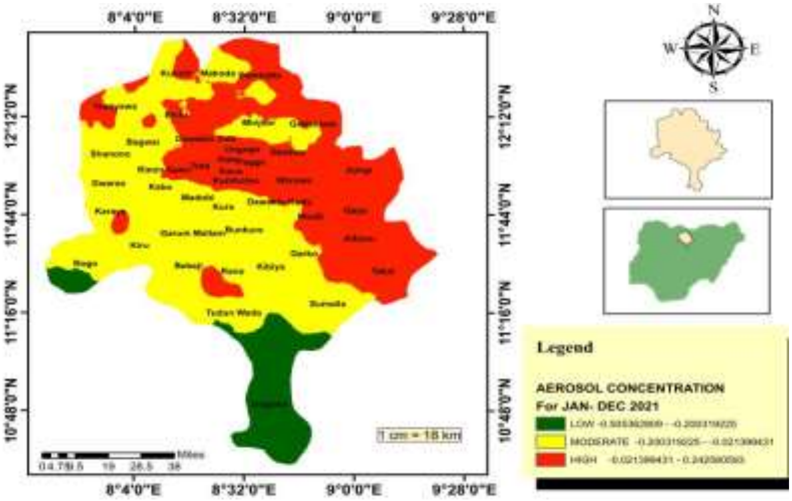

Fig. 11: Classified distribution of aerosol concentrations in Kano State in 2021
Source: Researchers work, 2024

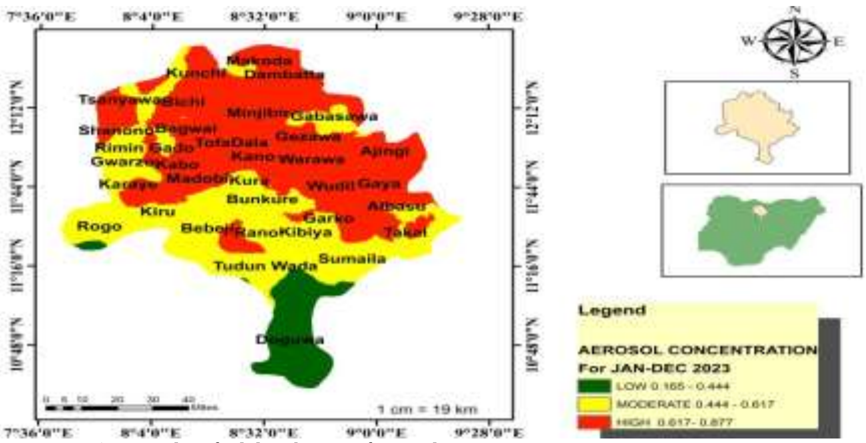

Fig. 12: Classified distribution of aerosol concentrations in Kano State in 2023.
Source: Researchers work, 2024

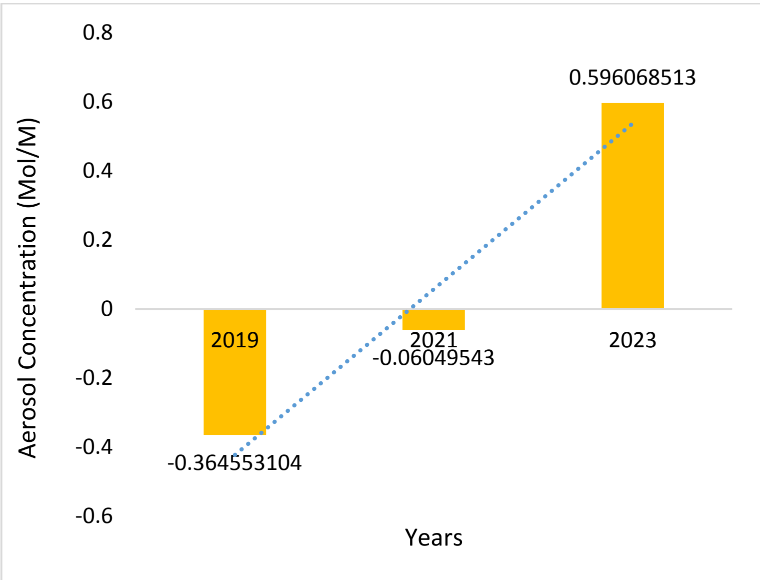

Fig. 13: The mean trend of aerosol concentration over the years (2019, 2021 and 2023)
Source: Researchers work, 2024

Figure 13 shows the annual mean trend of aerosol concentration over five years. The trends observed across the years were different. The trend line indicated that aerosol concentration increased over the study period. Using the chi-square goodness of fit, there was a very high significant difference ($p<0.001$) between aerosol concentrations over the five years. The study's results align with the findings of Wang and Hao (2012), who reported that urbanization and industrialization contribute to serious air quality issues in cities. Urban areas in Kano, particularly Kano Municipal, showed higher concentrations of NO_2, CO, and aerosol due to factors such as transportation, industrial activities, and population growth. Similar conclusions were taken by Abdullahi *et al*. (2020), emphasizing that these human activities in urban regions significantly influence air pollution levels. Across the study period, NO_2 concentrations increased moderately, but statistical analysis revealed that the changes were not significant ($p > 0.05$). This suggests a relatively stable situation regarding NO_2 levels in Kano State. Similarly, while there was a downward trend in CO concentrations, the decrease was not statistically significant ($p > 0.05$), implying that CO levels remained relatively stable. However, aerosol concentrations showed a highly significant increase over the years ($p < 0.001$), suggesting potential environmental or anthropogenic changes influencing aerosol emissions in Kano State, Nigeria. Conclusion: The findings of this study highlight the need for continuous air quality monitoring and the implementation of strategies to mitigate pollution, particularly aerosol emissions, which pose an increasing concern for public health and environmental sustainability in Kano State. There is a need to enforce regulations on industrial emissions and invest in renewable energy sources to help reduce air pollution and promote long-term environmental sustainability in Kano State, Nigeria.

Declaration of Conflict of Interest: The authors declare no conflict of interest.

Data Availability Statement: Data are available upon request from the last author.

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