KADUNA JOURNAL OF GEOGRAPHY
2025, VOL. 7, No. 1, 441-448
https://doi.org/10.47514/kjg.2025.07.01.047

SPECIAL ISSUE: CELEBRATING 20 YEARS OF GEOGRAPHY IN KADUNA STATE UNIVERSITY - ADVANCES AND FRONTIERS IN GEOGRAPHY

Assessment of Dry Season Ground Level Vehicular Air Pollution in Minna Metropolis, Niger State, Nigeria

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ABSTRACT

Vehicular emissions are one primary contributor to air pollution, especially in the dry season, when environmental conditions favour the accumulation of pollutants in the atmosphere. Thus, commuters and inhabitants along roadways are vulnerable to respiratory irritation, coughing, asthma, and long-term exposure, which can result in chronic respiratory diseases. Therefore, this study assessed ground-level vehicular air pollution during the dry season in Minna metropolis, Niger State, Nigeria. The Testo 350XL gas analyser was used to measure NOx and CO levels, and a 5-in-1 multifunction laser sensor, the BRV8 detector, was used to analyse the PM_{10} and $PM_{2.5}$ concentrations. Additionally, a geographic positioning system (GPS) device was used to pinpoint the locations of the sampled intersections and roundabouts. A total of 45 junctions and roundabouts were sampled for their air quality conditions. The results revealed that the PM_{10} concentrations significantly exceeded the $PM_{2.5}$ concentrations across the various locations, with Minna-Bida Road and Eastern Bypass having the highest PM_{10} concentrations at 560.2 μg/m³ and 495 μg/m³, respectively, thereby exceeding the WHO standard of 150 μg/m³. Notably, the Gurara Junction recorded the highest $PM_{2.5}$ (621 μg/m³) and PM_{10} (773 μg/m³) concentrations, surpassing the WHO limits of 75 μg/m³ and 150 μg/m³, respectively. In addition, CO_x had the highest occurrence at Mechanic Road, with a value of 2.064 mg/m³, followed by Chanchaga-Mekunkele Road, with a value of 1.836 mg/m³, which falls below the 30 mg/m³ WHO standard. NOx concentrations were relatively low across the assessed locations, ranging from 0.738 mg/m³ to 0.250 mg/m³, which were below the 0.5 mg/m³ for the one-hour exposure guideline set by the WHO. This study has, among other goals, recommended the promotion of green infrastructure, such as planting trees and increasing green spaces around these roads, junctions, and roundabouts, to help absorb pollutants and improve air quality in Minna metropolis, Niger State, Nigeria.

ARTICLE HISTORY
Submitted 29 October 2025
Accepted 20 December 2025
Published 01 January 2026

GUEST EDITOR
A. M. Ahmed

KEYWORDS
Air Pollution, Dry Season, Minna Metropolis, Vehicular Pollution, Global Positioning System

1 Introduction

Air pollution, mainly from fossil fuel combustion, transport, industry, and agriculture, causes approximately 4.2 million premature deaths annually. Nearly 90% of these cases occur in low-income and middle-income countries. In 2019, 99% of people worldwide breathed unsafe air (World Health Organization [WHO], 2025). According to Fu et al. (2024), air pollution, particularly in developing countries, has emerged as a critical environmental and public health concern. In Africa, air pollution is still one of the largest issues and is responsible for approximately 600,000 deaths every year (United Nations Environmental Program [UNEP], 2025). Ambient air pollution from human activities in Nigeria has caused more than 21,100 premature deaths from exposure to $PM_{2.5}$. Among these, 13.5% were caused by fossil fuel use and vehicle emissions, and 51% were caused by biomass burning. Economic estimates of these premature deaths are $5.65 billion. Air pollution is a major driver of increased mortality from respiratory and cardiovascular diseases in Nigeria (Romanello et al., 2024). The Minna metropolis, which serves as the capital of Niger State, is not protected from this devastating air pollution (Nwaerema et al., 2024). Vehicular emission is a major source of air pollution, particularly during the dry season, when atmospheric conditions promote the concentration of pollutants (Glory et al., 2022). Understanding the extent of ground-level vehicular air pollution in Minna is essential for formulating effective policies to mitigate its impact on public health and the environment.

Air pollution arises from both primary and secondary sources. Primary pollutants resulting from human activities include harmful metals such as toxic lead, ammonia (NH_3), and mercury. Additionally, other sources include unpleasant odors from waste, sewage, and industrial discharges; effluents from nuclear explosions; and gaseous sulphur oxides (SOx), toxic nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOCs), particulate matter (PM), and persistent free radicals. On the other hand, secondary pollutants are formed from the reactions of primary pollutants. Notably, ozone (O_3) at ground level, which is produced from NOx and VOCs, and photochemical smog are examples of secondary air

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pollution (Mahendra & Vaibhav, 2013; Nwaerema et al., 2020).

Vehicular air pollution in urban areas has been influenced by inadequate planning of roads and buildings, leading to ineffective dispersion of pollutants along streets and greater impacts on public health (Gireesh et al., 2021). Additionally, the problem is worsened by an increase in poorly maintained vehicles and traffic congestion at intersections and roundabouts, particularly at bottleneck roads. Pollution levels can also rise when drivers excessively accelerate their vehicles while in motion (Hamdy et al., 2021). Other contributing factors to increasing vehicular air pollution include poor road conditions, uncontrolled traffic flow, faulty vehicle exhaust systems, and inefficient engines (Gireesh et al., 2021; Hamdy et al., 2021). Consequently, this study examined ground-level vehicular air pollution during the dry season in Minna metropolis, Niger State, Nigeria.

The dry season is characterized by lower rainfall and drier atmospheric conditions, which provide a critical opportunity to examine vehicular air pollution and its effects on human lives. During this period, there is a tendency for temperature inversions to occur, trapping pollutants close to the ground and preventing their dispersion (Das et al., 2021). In Minna, this phenomenon is exacerbated by the increased use of vehicles, especially as economic activities increase. Therefore, a thorough evaluation of air quality during the dry season will reveal vital insights into the nature and extent of vehicular emissions (Bankole et al., 2023). Such insights can guide local authorities in implementing remedial measures and developing sustainable urban transportation policies.

Ground-level air pollution is primarily characterized by increased concentrations of various pollutants, including particulate matter (PM), nitrogen oxides (NOx), carbon monoxide (CO), and volatile organic compounds (VOCs). These pollutants are associated with a range of health issues, from respiratory diseases to cardiovascular illnesses (Nnaemeka, 2020). In urban areas such as Minna, where exposure to air pollutants is often chronic due to dense traffic, the risk factors for these health conditions are considerably high.

The vulnerability of the population, particularly among children and elderly individuals, highlights the need for rigorous studies that can provide a comprehensive understanding of the impact of vehicular emissions on public health and well-being (Ajayi et al., 2023). Studying vehicular pollution during the dry season in Minna town and its environment is crucial because of the absence of comprehensive dry-season air quality data and the limited focus on road vehicle emissions in medium-sized Nigerian cities. Therefore, this study was carried out to address the lack of air quality data and awareness of vehicular emissions during the dry season in Minna, thereby enabling effective pollution management and health protection in the city.

2 Materials and Methods

2.1 Study Area

The Minna study area is located approximately between longitudes 6°26'E and 6°38'E and latitudes 9°34'N and 9°42'N of the GMT (Figure 1). This city serves as the capital of Niger State and is bordered by the Federal Capital Territory (FCT) as well as the states of Kaduna, Kwara, Kebbi, and Zamfara. Minna features several developed neighborhoods, such as Bosso, Maitumbi, Shango, Barikiri Sale, Fadikpe, and Dutsen Kura. Owing to urban growth, Minna has transformed into an integrated metropolitan area. Minna town, in Nigeria's Guinea savanna belt, experiences a temperature average of 33.5°C, with March being the hottest month, with an average of 35.7°C, and has less than 71% humidity, with average rainfall below the national value per annum (Akinsanola & Ogunjobi, 2024). The town has a hilly terrain with undulating landscapes and possesses urban characteristics typical of a growing administrative center of mixed residential, commercial, and industrial areas. Additionally, it has expanded infrastructure development, especially road networks that cross cities.

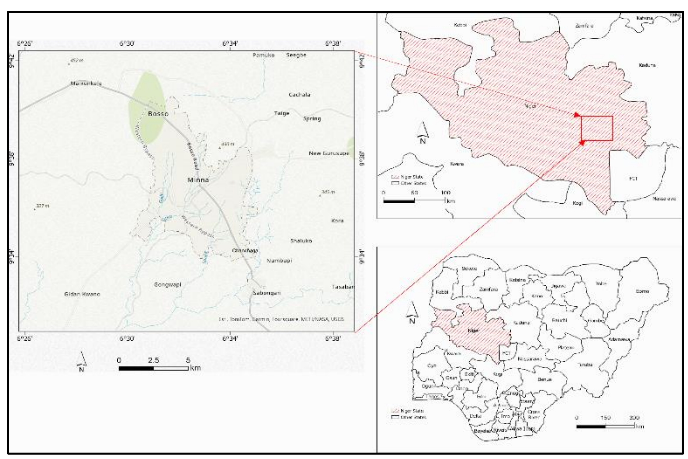


Figure 1: Map of the Minna metropolis

2.2 Data Collection

The selected junctions and roundabouts were purposively chosen on the basis of the amount of vehicular traffic and human activities in those areas. These locations were among the busiest routes, featuring the highest traffic volumes and connecting Minna to other cities within the state. A geographic positioning system (GPS) was used to determine the precise locations of the chosen junctions and roundabouts for mapping purposes. The air pollutants measured included oxides of nitrogen (NOx), carbon monoxide (CO), particulate matter (PM10), and particulate matter ($PM_{2.5}$) via air quality detectors. To analyse NOx and CO, a Testo 350XL gas analyser calibrated in mg/m³ was employed, while PM_{10} and $PM_{2.5}$

measurements were taken with a digital handheld air detector (5-in-1 multifunction sensor of BRV8). Both instruments demonstrated a natural diffusion accuracy of ≤± 5% and had a response time of 5 minutes.

The Testo 350XL gas analyser, with a Testo brand, was a professional instrument designed for accurate emission measurements. It was manufactured by Testo SE & Co. KGaA, which is a German company that is well known for accurate measurement instruments for environmental and industrial gas testing. Additionally, the 5-in-1 multifunction sensor of BRV8 was manufactured by Bosean Electronic Co., Ltd., with a series of BS-5000 and BH-90A models. Before the gas analysers were used, calibrations were performed with certified calibration gases to ensure accurate measurements. The calibration gases were connected to the analyser and adjusted to the device according to the manufacturer's instructions by ensuring that the readings were at zero and span points. The calibrations aided the removal of potential measurement errors that would have occurred and ensured that precise pollutant concentrations were established during the testing process.

The air quality sampling was carried out in March 2025 to assess vehicular air pollution during the dry season. Measurements were conducted in the morning and evening (6–9 am and 4–7 pm), aligning with peak rush hours characterized by higher traffic volumes. The air pollutant measurements were conducted in situ via calibrated instruments. The air quality was captured across various road trunks, such as Trunk A (Federal Roads), Trunk B (State Roads), and Trunk C (Neighborhood Roads). Furthermore, three (3) roads were purposively selected in each road trunk, and five (5) junctions or roundabouts were sampled on each road, totalling forty-five (45) junction and roundabout sample points. Trunk A (federal roads) included Chanchaga-Mekunkele Road, Maitunbi Road, and Minna-Bida Road. Trunk B (state roads) included Western Bypass, Eastern Bypass, and the Government House Road. Trunk C (Neighborhood Road) included Mechanic Road, Brighter Road, and Top Medical Road. The 45 sample locations of road junctions and roundabouts were selected because these intersections were characterized by high traffic volumes and congestion, which made them critical points for assessing peak emission levels and understanding spatial variations in air quality within Minna town.

Additionally, stratified sampling was used to ensure coverage of major traffic zones located in residential, commercial, and industrial areas, thereby providing comprehensive data for pollution patterns in Minna Town. The three major types of roadways (Trunks A, B, and C) in Minna Town vary in their traffic volume and design, thereby influencing the vehicular pollution concentration. Thus, Trunk A, characterized by heavy traffic, tends to have more vehicular traffic and pollution levels. Trunk B, with moderate traffic volumes, had intermediate pollutant concentrations, and Trunk C presented the lowest vehicular traffic volumes and pollution levels.

2.3 Data Analysis

The data were organized into structured formats by categorizing pollutant concentrations according to road location and time via Microsoft Excel. The means of the hourly measurements across the day and across different road trunks were calculated and displayed in tabular format. In addition, the measured concentrations were compared against the World Health Organization (WHO) air quality standards to determine the degree of pollution severity.

3 Results and Discussion

Table 1 presents a comprehensive analysis of air quality metrics at various road locations and roundabouts, with a focus on the concentrations of particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen oxides (NOx), and carbon oxides (COx). A comparison against the World Health Organization (WHO) interim targets revealed the environmental health implications of these findings. Each location's measurements revealed distinct trends, with significant implications for public health and urban planning.

From an initial glance at the $PM_{2.5}$ levels, it was evident that all monitored locations exceeded the WHO guideline of 75 μg/m³ for 24-hour exposure, indicating a concerning level of air pollution. The highest concentration was found at Gurara Junction, where $PM_{2.5}$ was measured at 621 μg/m³, which was disturbingly higher than the WHO limit. On the other hand, the lowest $PM_{2.5}$ concentration was recorded at the Three Arm Zone Junction, at 215 μg/m³, which was still above the allowable threshold.

Additionally, the PM_{10} concentration differed. Like $PM_{2.5}$, all recorded values exceeded the WHO recommendation of 150 μg/m³. Thus, the maximum PM_{10} concentration of 773 μg/m³ at the Gurara junction further emphasized the location's critical air quality deterioration. Areas such as the Brighter Junction and Mandella Junction presented the lowest PM_{10} levels and still had a potency that could affect respiratory health. These findings align with the knowledge that particulate matter is linked with both short-term and long-term health effects, particularly in urban settings where vehicular emissions and industrial activities are prominent.

The levels of nitrogen oxides (NO_x) and carbon oxides (CO_x) revealed another level of potential health risk, particularly with respect to respiratory diseases and cardiovascular issues. While NOx concentrations were relatively low across the assessed sites, they were consistently around or below 0.5 mg/m³ for the one-hour exposure guideline set by the WHO. Thus, CO_x levels showed a wider disparity, with most junctions falling below the 30 mg/m³ threshold, indicating that while the CO_x levels were generally acceptable, other pollutants remain a significant concern. The relative stability of NOx and CO_x levels at most locations indicated that traffic congestion and vehicular emissions need to be more closely monitored and managed to reduce air quality hazards.

In terms of urban planning and public health policy implications, the stark contrast between different pollution levels at different sites revealed the necessity of localized approaches. High-pollution areas, particularly the Gurara Junction and City Gate Roundabout, may benefit from targeted enforcement of emission regulations, traffic rerouting, or the introduction of green infrastructure such as urban trees and green spaces to help filter air pollutants. Vulnerable populations, especially children and the elderly living or commuting through these areas, may require additional exposure protection measures, such as improved public transport options, to mitigate vehicular dependency.

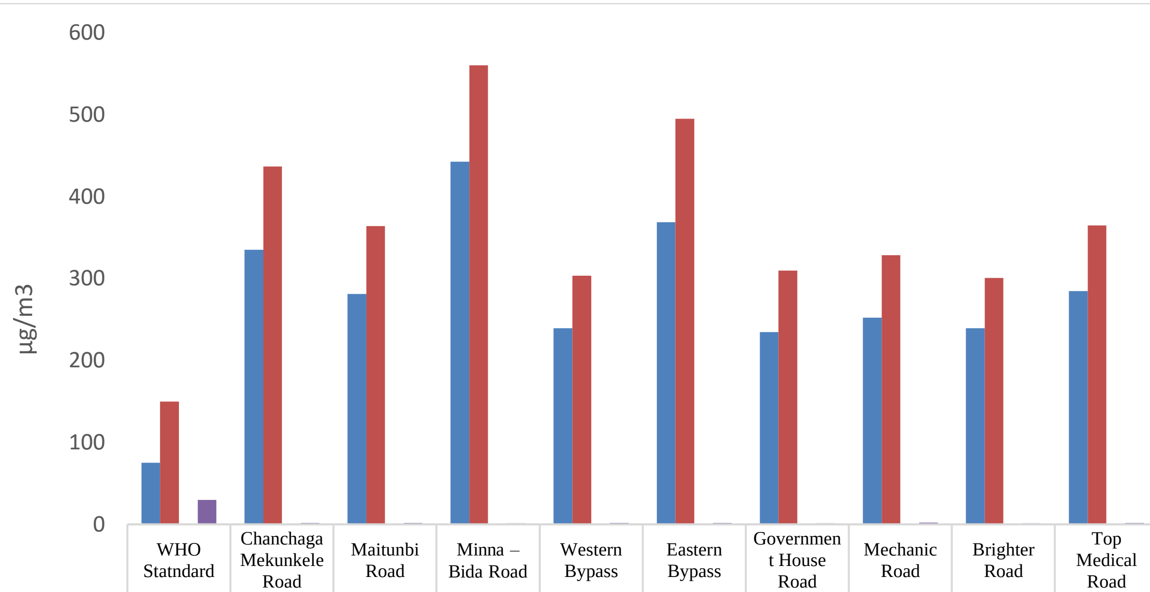
Table 1: Comparison of Vehicular Air Pollution with WHO Standards in the Minna Metropolis during the Dry Season

Location	Name of Roundabout/Junction	Northing Latitude	Easting Longitude	$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)	NO_x (mg/m³)	CO_x (mg/m³)
Trunk A (Federal Roads)							
Chanchaga Mekunkele Road	Water Board Junction	9.536253	6.579345	315	412	0.45	1.16
	City Gate Roundabout	9.581945	6.567873	400	530	0.70	2.29
	Tunga Market Junction	9.602192	6.558278	420	542	0.80	2.29
	Mobile Roundabout	9.614187	6.547215	250	318	0.87	2.29
	Obasanjo Complex Roundabout	9.618848	6.546228	290	382	0.85	1.15
Maitunbi Road	Sabongari Junction	9.619850	6.552888	250	323	0.47	1.15
	New Market Junction	9.622037	6.556655	249	322	0.40	1.15
	Kwari Bega	9.630727	6.563687	251	323	0.55	1.15
	Flymingo	9.631977	6.567623	265	347	0.99	2.29
	Maitunbi Roundabout	9.636152	6.579455	391	504	0.86	2.29
Minna – Bida Road	Gurara Junction	9.591974	6.516010	621	773	0.89	1.15
	Gbeganu Junction	9.593628	6.519977	560	713	0.75	1.15
	Nice Travel Juction	9.596431	6.527790	341	412	0.79	1.15
	Kpakungu Roundabout	9.598233	6.532622	381	503	0.58	1.15
	AP Junction	9.605032	6.530572	310	400	0.68	2.29
Trunk B (State Roads)							
Western Bypass	Three Arm Zone Junction	9.625545	6.580830	215	278	0.58	1.15
	PDP Junction	9.618385	6.579114	227	294	0.49	2.29
	Gwari Block Industry Junction	9.608164	6.575595	268	339	0.29	1.15
	MI Wushishi Junction	9.599859	6.574275	235	306	0.39	1.15
	Galaxy Int'l School Junction	9.58905	6.573529	251	300	0.46	2.29
Eastern Bypass	NNPC Junction	9.580077	6.561743	466	646	0.39	2.29
	Brighter Junction	9.579717	6.556953	397	545	0.19	1.15
	Mandella Junction	9.581452	6.553333	297	394	0.17	2.29
	Imani Roundabout	9.588488	6.541878	404	530	0.29	1.15
	Morris Junction	9.594620	6.537272	279	360	0.23	2.29
Government House Road	Dutse-Kwura Gwari Junction	9.628724	6.522378	280	379	0.36	1.15
	London Street Junction	9.629576	6.525245	228	297	0.19	2.29
	Federal Ministry Junction	9.630355	6.530338	225	293	0.25	1.15
	Government Roundabout	9.631130	6.535366	218	286	0.19	1.15
	Gorit House Lodge Junction	9.631673	6.538068	226	294	0.25	1.15
Trunk C (Neighborhood Road)							
Mechanic Road	Mypa Junction	9.651251	6.533692	241	314	0.27	1.15
	Deeper Life Junction	9.647894	6.529672	235	305	0.29	2.29
	Madarasatu Juction	9.647631	6.527261	267	350	0.35	2.29
	Awal Ibrahi Junction	9.647250	6.526302	262	347	0.19	3.44
	Scorpion Junction	9.646670	6.525324	256	326	0.27	1.15
	Brighter School	9.575134	6.557544	258	320	0.28	1.15

Brighter Road	Gwamaja Road Junction	9.572913	6.557988	260	302	0.19	1.15
	Kurmi Moses Kagara Junction	9.457061	6.558463	224	290	0.29	1.15
	Haske Street Junction	9.567500	6.559395	226	295	0.33	1.15
	Ndaiji Nupe Avenue Junction	9.563698	6.560791	229	297	0.28	2.29
Top Medical Road	Top Medical Junction	9.597606	6.561334	265	347	0.23	2.29
	New Facol Hotel Junction	9.598544	6.563739	434	536	0.29	1.15
	NUT Junction	9.598600	6.566131	275	354	0.19	2.29
	NSTV Junction	9.598859	6.568399	233	302	0.28	2.29
	Ideal Royal School Junction	9.599422	6.571057	217	285	0.26	1.15
	WHO Interim Target 1			PM2.5 (75μg/m³ for 24 Hr)	PM_{10} (150μg/m³ for 24Hr)	NOx 0.5 mg/m³ (1Hr)	COx 30 mg/m³ (1Hr)
	Colour Meaning			Below WHO Level		Above WHO Level	

Figure 2 reveals that vehicular air pollution during the dry season in Minna metropolis varies across different roads. This result indicated that the PM_{10} and NO_x concentrations fluctuated notably. For example, Minna-Bida Road recorded the highest PM_{10} concentration at 560.2 μg/m³, significantly exceeding the WHO standard of 150 μg/m³, which revealed critical particulate pollution possibly due to high traffic density and vehicle emissions. Similarly, Minna-Bida Road had the highest NO_x level at 0.738 mg/m³, which was above the recommended standard of 0.5 mg/m³, emphasizing the impact of exhaust emissions. The CO_x levels ranging from 1.378 to 2.064 mg/m³ across the various roads suggested increased carbon monoxide pollution. These figures revealed that roads with high traffic volumes and poor wind speeds were more prone to severe vehicular pollution during the dry season.

Furthermore, the pattern of pollution across the roads suggested that some roads, such as Maitumbi Road and Western Bypass, were hotspots for particulate and gaseous pollutants, which attracted health concerns for residents and commuters. The Eastern Bypass, for example, had a PM_{10} level of 495 μg/m³, which exceeded safe limits, revealing air quality deterioration. On the other hand, roads such as Chanchaga-Mekunkele Road and Top Medical Road presented relatively low pollutant levels but still exceeded the WHO standards for PM_{10} and NOx, respectively. This uneven distribution highlights the influence of traffic flow, road infrastructure, and possible environmental factors such as wind and dust on pollution patterns during the dry season.



	WHO Statndard	Chanchaga Mekunkele Road	Maitunbi Road	Minna – Bida Road	Western Bypass	Eastern Bypass	Government House Road	Mechanic Road	Brighter Road	Top Medical Road
PM2.5 (μg/m3)	75	335	281.2	442.6	239.2	368.6	234.5	252.2	239.4	284.8
PM10 (μg/m3)	150	436.8	363.8	560.2	303.4	495	309.8	328.4	300.8	364.8
NOx(mg/m3)	0.5	0.734	0.654	0.738	0.442	0.254	0.248	0.274	0.274	0.25
COx(mg/m3)	30	1.836	1.606	1.378	1.606	1.834	1.378	2.064	1.378	1.834

Figure 2: Dry Season Pattern of Vehicular Air Pollution across the Various Roads in the Minna Metropolis

This result is similar to the findings of Nwaerema et al. (2024), who evaluated wet-season ground-level vehicular air pollution and the health index of Minna metropolis, Niger State, Nigeria. The results indicated that during the wet season, the average concentration of $PM_{2.5}$ in Minna metropolis was 130.85 μg/m^3, whereas the average PM_{10} concentration was 165.15 μg/m^3. The average concentration of NOx was 0.49 mg/m^3, surpassing the standards set by the World Health Organization (WHO). In contrast, the concentration of COx in Minna metropolis was less than 30 mg/m^3. Additionally, Edokpa et al. (2019) carried out an assessment of ground-level criteria pollutant concentrations in Port Harcourt city, Nigeria. The study revealed that the air quality of NOx and PM_{10} levels exceeded established limits for Nigeria (ranging from 100–370% and 10–60%, respectively) during the dry season, except in the wet season, when PM_{10} levels were below the set limit at most locations because early rains washed away suspended particulates. The $PM_{2.5}$ concentrations were generally within the limits set by Nigeria and the WHO (according to Target 1) across all the sampled sites. In a residential area during morning rush hours, ground-level NOx and CO concentrations surpassed the limits for Nigeria, whereas particulate levels were within acceptable ranges. The air quality was most favourable at Port Harcourt International Airport, where the pollutant concentrations were largely below the established limits.

These results revealed that pollutant concentrations varied across locations and were influenced by the seasons of the year. Furthermore, some junctions presented relatively low pollution levels; the overall data indicated widespread air quality issues that exceeded WHO health recommendations. This prevalent atmospheric challenge calls for a multifaceted response involving local authorities, urban planners, public health officials, and community engagement to develop a comprehensive strategy for air quality improvement. Addressing these environmental health threats is essential for increasing the community's overall livability and reducing the burden of disease associated with air pollution.

The particulate matter (PM) levels in this study were higher than those of other pollutants because of a combination of human and natural atmospheric factors, such as high traffic volume with poorly maintained vehicles that emit excessive pollutants and dry season atmospheric conditions that limit natural dispersion (Meo et al., 2024). According to Gireesh et al. (2021), Road construction and poor vehicle maintenance resulted in the rise of emitted dust, soot, and other particulates through the vehicle exhaust pipes. This was supported by heavy traffic, which increased the general load of pollutants released into the air. Ajayi et al. (2024), in a study conducted in Lagos city, concluded that during the dry season, reduced moisture and increased atmospheric stability hindered the vertical and horizontal dispersion of pollutants, thereby leading to their accumulation near ground level. Meteorological factors such as temperature influence pollutant dispersion by affecting atmospheric stability; higher temperatures promote vertical mixing but lead to thermal inversions if the temperature gradient is stable, thereby trapping pollutants near the surface (Mitra et al., 2025). Wind speed plays a crucial role in dispersing pollutants. For example, low wind speeds resulted in limited dispersion and higher concentrations, and higher wind speeds facilitated the dilution and removal of particulate matter. Humidity can influence particle behavior by promoting the accumulation of particles, which could either increase their size and deposition rate or, in some cases, facilitate secondary particle formation, which further impacts the air quality conditions of the area (He et al., 2024).

The increased levels of particulate matter ($PM_{2.5}$ and PM_{10}) and gaseous pollutants such as NOx and COx in the study area pose a significant health risk to residents and commuters, especially in areas that have exceeded the WHO guidelines. Pablo et al. (2020) revealed that short-term exposure to high concentrations of PM could cause respiratory irritation, coughing, and exacerbation of asthma, and long-term exposure increases the risk of chronic respiratory diseases, cardiovascular problems, and premature mortality. The extreme $PM_{2.5}$ levels observed at the Gurara Junction (up to 621 μg/m^3) have drawn attention, as such concentrations are associated with increased hospital admissions for respiratory and cardiovascular conditions. Wang et al. (2025) suggested that high particulate levels can penetrate deep into the lungs and enter the bloodstream, thereby complicating health risks, especially for vulnerable populations such as children, elderly individuals, and those with underlying health conditions.

Furthermore, the presence of increased NOx and COx levels, although generally within some WHO limits, still contributes to adverse health effects. Taha et al. (2025) reported that NOx compounds are linked to respiratory inflammation, reduced lung function, and the formation of ground-level ozone, which can further harm lung tissues. Similarly, Barma et al. (2023) reported that carbon monoxide (COx) resulting from incomplete combustion could impair oxygen transportation in the body, which could lead to symptoms such as dizziness, fatigue, and, in extreme cases, fatalities in highly polluted environments. The spatial variation in pollution levels across different roads indicates that congestion, poor vehicle maintenance, and environmental factors such as limited wind dispersion during the dry season exacerbate these health risks.

4 Conclusion

This study conclusively revealed that PM_{10} concentrations are significantly higher than $PM_{2.5}$ levels across all monitored sites. The Minna-Bida Road and Eastern Bypass locations had the highest concentrations of PM_{10}, 560.2 μg/m³ and 495 μg/m³, respectively. This finding indicates that coarse particulate matter (PM_{10}) is the most common and tends to dominate in these areas, likely because of sources such as road dust, construction activities or increased vehicular emissions. The second most common pollutant is $PM_{2.5}$, which has the highest concentrations at the Minna-Bida Road (442.6 μg/m³) and Eastern Bypass (368.2 μg/m³). Moreover, this study revealed that the concentrations of the gaseous pollutants NOx and COx are relatively lower than those of particulate matter but that some variations exist across roads. Thus, NOx levels are highest at Minna-Bida Road, reaching 0.738 mg/m³, and at Chachanga-Mekunkele Road, reaching 0.734 mg/m³, potentially indicating that vehicular emissions are a common source. In addition, CO_x has the highest occurrence at Mechanic Road, with a value of 2.064 mg/m³, followed by Chanchaga-Mekunkele Road, with a value of 1.836 mg/m³. Notably, COx levels are generally low and remain relatively consistent across sites, indicating uniformity in combustion-related emissions. For the junctions and roundabouts, the Gurara Junction recorded the highest $PM_{2.5}$ level at 621 μg/m³, which is above the WHO limits, and the Three Arm Zone Junction had the lowest at 215 μg/m³, which still exceeds the standards. Additionally, the PM_{10} concentrations are above the WHO guidelines, with the Gurara Junction reaching 773 μg/m³, revealing severe air quality challenges surrounding the area. The consistent increase in PM_{10} and $PM_{2.5}$ concentrations across roads, junctions, and roundabouts suggests that the Minna metropolis is subject to substantial particulate pollution, which could have notable health and environmental implications, especially considering the proximity to busy roads and urban infrastructure. These findings reveal that commuters and inhabitants along these roadways are vulnerable to respiratory irritation, coughing, asthma and long-term exposure, which can result in chronic respiratory diseases.

The following are recommended. First, local authorities should consider implementing traffic management strategies such as congestion pricing to reduce vehicle emissions in high-traffic areas. The basic idea behind congestion pricing is to impose a fee on vehicles that enter high-traffic areas, particularly during peak hours. Second, the promotion of green infrastructure, such as the planting of trees and increasing the amount of green space around these junctions, could help absorb pollutants and improve air quality. Additionally, stricter regulations on vehicle emissions and the encouragement of alternative transportation modes, such as cycling and public transit, should be prioritized. Regular air quality monitoring is also essential for evaluating the effectiveness of these interventions and ensuring that they lead to sustainable improvements in air quality.

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