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ORIGINAL RESEARCH ARTICLE

Spatial assessment of ambient CO_2 concentrations along Maiduguri Road, Kano Metropolis, Nigeria

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ABSTRACT

Vehicular traffic is an important source of carbon dioxide (CO_2) in rapidly urbanising Nigerian cities. However, spatially referenced empirical data on ambient CO_2 concentrations along specific urban road corridors remain limited. This study assessed the spatial distribution and statistical differences in ambient CO_2 concentrations along Maiduguri Road in Kano Metropolis, Nigeria, using field measurements and Geographic Information System (GIS) techniques. CO_2 concentrations were measured with a calibrated portable CO_2 meter at five sampling stations: Gadar Lado, Kwanar Tarauni, Aliko Junction, Kwanar Sabo, and Hotoro Roundabout during morning, afternoon, and evening periods. Descriptive statistics and one-way analysis of variance (ANOVA) were used to evaluate differences in mean CO_2 concentrations among the sampling locations, while Inverse Distance Weighting (IDW) was employed to generate a continuous spatial distribution surface. All stations recorded mean CO_2 concentrations above the 2026 global atmospheric baseline of approximately 430 ppm. Kwanar Sabo and Hotoro Roundabout recorded the highest mean concentrations of 594.00 and 590.33 ppm, respectively, whereas Kwanar Tarauni recorded the lowest mean concentration (526.67 ppm). The overall mean concentration was 561.33 ppm. One-way ANOVA: $F(4,10) = 0.980$, $p = 0.461$; therefore, mean CO_2 concentrations did not differ significantly among the five sampling stations. The IDW interpolation revealed moderate-to-high CO_2 concentration zones along the Kwanar Sabo–Hotoro Roundabout section, whereas comparatively low concentrations were observed around Kwanar Tarauni and Aliko Junction. The concentrations were higher than the reported Lagos average of 450.1 ± 31.2 ppm but substantially lower than peak concentrations reported in Benin City (up to 1,767 ppm). The findings demonstrate spatial variability in ambient CO_2 concentrations along the corridor and highlight the need for targeted traffic management and continued monitoring of areas with elevated concentrations.

Keywords: Ambient CO_2 concentrations; Traffic congestion; Spatial distribution; Geographic Information System (GIS); Inverse Distance Weighting (IDW); One-way ANOVA.

Introduction

Transportation plays a fundamental role in economic development, urban mobility, and social interaction. However, the rapid expansion of road transport has increased greenhouse gas and other atmospheric pollutants from fuel combustion. CO_2 is the largest contributor to anthropogenic greenhouse gas emissions and a major driver of global climate change, primarily through fossil-fuel combustion (Sims et al., 2014; IPCC, 2021). The transport sector is a major source of energy-related CO_2 emissions globally, with road transport accounting for the largest share (International Energy Agency, 2022; Barth & Boriboonsomsin, 2008). In

urban environments, areas with intensive human activities and high traffic volumes may experience elevated ambient CO_2 concentrations, particularly along major road corridors. The spatial distribution of CO_2 in such environments can therefore provide useful information on local atmospheric conditions and the influence of urban activities.

In developing countries, rapid urbanisation and rising transportation demand have contributed to growing environmental concerns about urban atmospheric pollution (Zhang & Batterman, 2013). Nigeria is undergoing significant urban expansion, leading to increasing reliance on road transportation. In many cities, this mode of transport remains the primary means of mobility, largely due to the limited availability of viable alternatives. Ajayi et al. (2023) highlighted the challenges with such dependence and emphasised the need to diversify urban transport systems by promoting alternatives such as public buses, rail transit, cycling, and pedestrian infrastructure to accommodate growing urban populations. As a major commercial and transportation centre in northern Nigeria, Kano Metropolis is characterized by intensive human activities and high vehicular traffic along its major road corridors. Maiduguri Road is one of the transportation routes and accommodates considerable traffic and commercial activities throughout the day. These activities may influence local ambient CO_2 concentrations, making spatial monitoring important for understanding variations in atmospheric CO_2 within the corridor.

Ambient CO_2 concentrations reflect inputs from multiple sources, including traffic, fossil-fuel combustion, commercial and domestic activities, human respiration, and atmospheric dispersion. Portable CO_2 meters measure ambient CO_2 concentrations at the sampling locations rather than directly quantifying emissions from vehicles. The measured concentrations therefore reflect the combined influence of multiple CO_2 sources and atmospheric processes, rather than traffic emissions alone. Consequently, the observed spatial variations are differences in ambient CO_2 concentrations associated with traffic activity and local environmental conditions, rather than direct measurements of vehicular emission rates.

Spatial assessment of these concentrations can provide valuable information on areas where relatively elevated CO_2 levels occur and their relationship to the surrounding urban environment. Such information is particularly relevant in densely developed areas where traffic activity, commercial activities, and pedestrian movement occur simultaneously.

Although monitoring urban atmospheric conditions is vital, empirical data on the spatial distribution of ambient CO_2 concentrations along major road corridors in Kano Metropolis remains scarce. In Nigeria, existing environmental studies typically address conventional pollutants and broad urban air-quality conditions, leaving spatial assessments of ambient CO_2 at the corridor level relatively underexplored. The absence of spatially referenced measurements makes it difficult to identify areas with relatively elevated CO_2 concentrations and to understand their distribution across urban environments.

Recent advances in environmental monitoring and GIS have enhanced the ability to collect, analyse, and visualise spatial variations in environmental parameters (Hoang Tu et al., 2023). When field measurements are integrated with GIS-based spatial interpolation techniques, such as Inverse Distance Weighting (IDW), the distribution of measured environmental variables can be represented spatially, and areas of relatively higher or lower concentrations

can be identified (Jerrett et al., 2005). This approach provides a useful framework for examining the spatial characteristics of ambient CO_2 concentrations along urban road corridors.

Therefore, this study aims to assess the spatial distribution of ambient CO_2 concentrations along Maiduguri Road, Kano Metropolis, Nigeria, using field measurements obtained with a calibrated portable CO_2 meter and GIS-based spatial interpolation. Specifically, the study seeks to (i) measure ambient CO_2 concentrations at selected locations along Maiduguri Road and (ii) analyse and map their spatial distribution using GIS-based Inverse Distance Weighting (IDW) interpolation. The findings are expected to provide spatially explicit information on ambient CO_2 conditions along the study corridor and support urban environmental monitoring and management.

Study area

The study was conducted along Maiduguri Road, a major transportation corridor traversing Tarauni and Nassarawa Local Government Areas (LGAs) of Kano Metropolis, Kano State, Nigeria (Figure 1). Kano Metropolis is one of the largest and most economically active urban centres in northern Nigeria, serving as a major commercial and transportation hub connecting different parts of the region and neighbouring countries. The study corridor is characterized by high vehicular activity, dense commercial development, pedestrian movement, and other urban activities, which contribute to variations in ambient CO_2 concentrations. The sustained traffic flow along the corridor, particularly during periods of high activity, makes it an appropriate setting for examining the spatial distribution of ambient CO_2 concentrations in relation to urban and traffic conditions.

Five sampling stations were strategically chosen along the corridor to reflect a variety of traffic patterns, land-use types, and road-environment conditions. This selection aims to ensure a comprehensive analysis of the area's dynamics, allowing for a better understanding of how these factors interact and influence one another. These included Gadar Lado, located near a flyover; Kwanar Tarauni and Aliko Junction, characterised by major road intersections; Kwanar Sabo, a highly active commercial area; and Hotoro, located around a major roundabout. However, less busy and less congested areas were excluded from the study because they did not meet the criteria for selecting high-traffic locations. The variation in traffic movement, commercial activity, road configuration, and surrounding land uses across these locations provides a basis for assessing spatial differences in ambient CO_2 concentrations and identifying areas of relatively elevated or lower concentrations along the corridor.

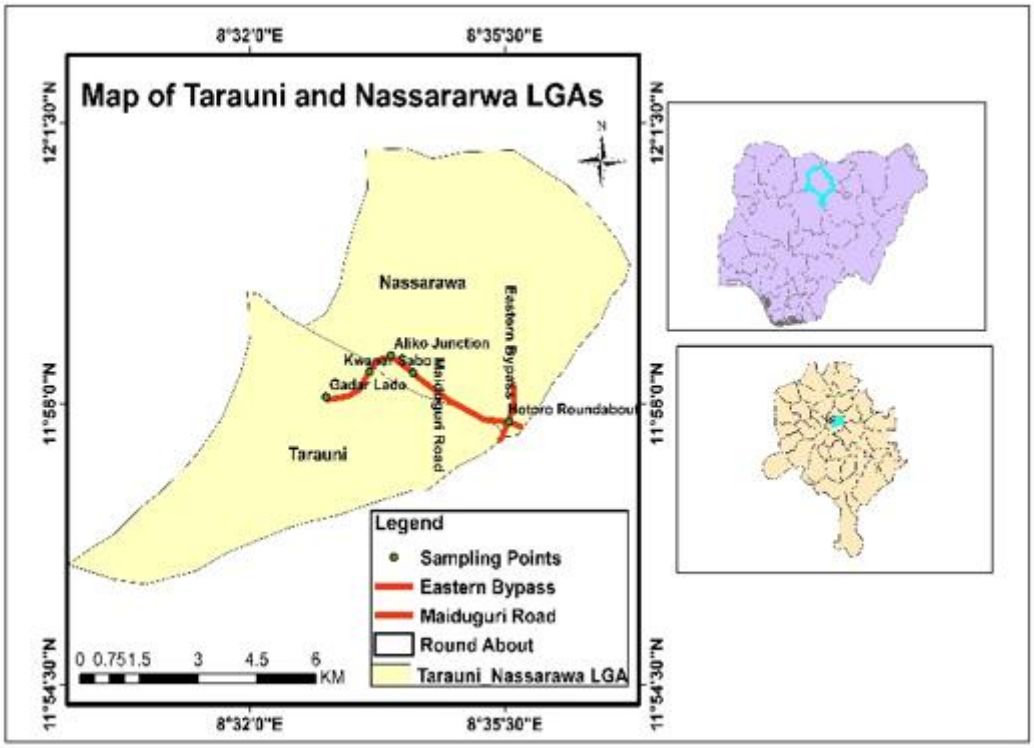


Figure 1. Location Map of Tarauni and Nassarawa Local Government Areas Showing the Study Area

Methodology

Sampling design and data collection

A quantitative field-monitoring approach was used to assess the spatial and diurnal variation of ambient CO_2 concentrations along Maiduguri Road, Kano Metropolis. Five sampling stations were strategically selected to represent different traffic conditions, road configurations, and surrounding urban activities along the study corridor. Ambient CO_2 concentrations were measured at each station utilizing a calibrated portable meter, following appropriate quality-assurance procedures for ambient air monitoring (U.S. EPA, 2023). Measurements were conducted during three periods of the day: morning, afternoon, and evening to capture variations in CO_2 concentrations associated with changes in traffic activity and other human activities. Geographic coordinates for each sampling station were accurately recorded using a GPS device, which is essential for conducting spatial analysis. The mean CO_2 concentration at each station was determined by averaging three measurements taken during specific periods, ensuring a reliable representation of the data collected at each location.

GIS-based spatial analysis

The station-level mean CO_2 concentrations and corresponding geographic coordinates were imported into ArcGIS 10.8 to assess their spatial distribution along Maiduguri Road. Inverse Distance Weighting (IDW) interpolation was applied to estimate CO_2 concentrations at unsampled sites, drawing on measured values from nearby sampling stations. The method assumes that the influence of a sampled location decreases with increasing distance, thereby giving greater weight to nearby observations (Watson & Philip, 1985; Esri, 2024). The

interpolated CO_2 concentration surface was classified into five categories: very low, low, moderate, high, and very high, to facilitate interpretation of spatial patterns and identification of areas with relatively elevated CO_2 concentrations. The resulting spatial distribution was overlaid with the Tarauni and Nassarawa LGA boundaries and sampling locations to produce the final map of ambient CO_2 concentration distribution along the study corridor.

Data analysis

The CO_2 concentrations were systematically categorized by sampling stations and the timeframes during which the measurements were taken. This organization facilitated clearer data analysis and enabled comparisons across different locations and time periods. To summarize the measured concentrations and examine spatial and diurnal variations, descriptive statistics were applied. Mean CO_2 concentrations and standard deviations were calculated for each sampling station and compared to identify locations with relatively higher and lower ambient concentrations.

To determine whether the observed differences in mean CO_2 concentrations among the five sampling locations were statistically significant, a one-way analysis of variance (ANOVA) was performed. Sampling location was treated as the independent categorical variable, while measured CO_2 concentration (ppm) was treated as the dependent variable. A total of 15 observations were analyzed from five sampling stations, comprising three observations (morning, afternoon, and evening) at each station. The null hypothesis was that there was no significant difference in mean CO_2 concentration among the five sampling locations, while the alternative hypothesis was that at least one location differed significantly from the others. Statistical significance was evaluated at the 5% significance level ($\alpha = 0.05$). The ANOVA result was reported using the F-statistic, degrees of freedom, and p-value.

The observed spatial patterns were interpreted in relation to traffic intensity, road configuration, commercial activities, and surrounding land-use characteristics at the sampling locations. The measured concentrations were also compared with the global atmospheric CO_2 background concentration to provide context for the degree of local CO_2 enrichment (WMO, 2025). This approach enabled the study to characterize the spatial distribution and temporal variation of ambient CO_2 concentrations along Maiduguri Road.

Results and discussion

CO_2 concentrations across sampling stations

Table 1 summarises the CO_2 concentrations recorded at the five sampling stations across the three measurement periods.

Table 1. Mean CO_2 concentration (ppm) across sampling stations along Maiduguri Road

Station	Morning (ppm)	Afternoon (ppm)	Evening (ppm)	Mean ± SD (ppm)
Gadar Lado	578	530	590	566.00 ± 31.75
Kwanar Tarauni	504	518	558	526.67 ± 28.02
Aliko Junction	568	619	402	529.67 ± 113.47
Hotoro Roundabout	604	577	590	590.33 ± 13.50
Kwanar Sabo	614	610	558	594.00 ± 31.24

All five sampling stations (Table 1) recorded mean CO_2 concentrations above the reported global atmospheric background concentration of approximately 430 ppm (NOAA Global Monitoring Laboratory & Scripps Institution of Oceanography, 2026), indicating localized CO_2 enrichment along Maiduguri Road. Mean concentrations varied from 526.67 ppm at Kwanar Tarauni to 594.00 ppm at Kwanar Sabo, indicating descriptive spatial variation in ambient CO_2 levels along the corridor. However, one-way ANOVA showed that the differences in mean CO_2 concentrations among the five sampling locations were not statistically significant, $F(4, 10) = 0.980$, $p = 0.461$. Since $p > 0.05$, the null hypothesis was not rejected, indicating that the observed differences among station means represent descriptive spatial variation rather than statistically significant differences. Therefore, the differences in mean concentrations should be interpreted cautiously and not regarded as evidence of statistically distinct CO_2 levels among the sampling stations.

Kwanar Sabo recorded the highest mean CO_2 concentration (594.00 ppm), followed closely by Hotoro Roundabout (590.33 ppm) and Gadar Lado (566.00 ppm). The relatively higher concentration observed at Kwanar Sabo may be associated with intense commercial activity and frequent stop-and-go traffic, which can contribute to local CO_2 accumulation. Similarly, the relatively high concentration at Hotoro Roundabout may reflect traffic volumes and congestion associated with the intersection. Previous studies suggest that traffic-related emissions at urban intersections are influenced by both congestion conditions and traffic management strategies, which can affect the magnitude of emissions generated at these locations (Meneguzzer et al., 2018). Moreover, studies in African urban environments have documented elevated and temporally variable pollutant concentrations around major traffic intersections and roundabouts (Codjo-Seignon et al., 2021).

Gadar Lado recorded a mean concentration of 566.00 ppm (Table 1), representing the third-highest value among the five stations. Its relatively elevated concentration may be related to surrounding traffic activity and the local built environment, including the flyover structure, which could influence air movement and pollutant dispersion. In contrast, Kwanar Tarauni recorded the lowest mean CO_2 concentration (526.67 ppm), although it remained above the global atmospheric background level. The comparatively lower concentration may reflect differences in traffic intensity, vehicle accumulation, and atmospheric dispersion at the station. Nevertheless, because the ANOVA did not detect a statistically significant difference among stations, these site-specific explanations should be regarded as plausible interpretations of the observed pattern rather than statistically demonstrated causal relationships.

Table 2, Aliko junction recorded a mean concentration of 529.67 ppm, slightly higher than Kwanar Tarauni. However, diurnal variation was observed at this location, with concentrations increasing from 568 ppm in the morning to 619 ppm in the afternoon, before declining sharply to 402 ppm in the evening. The evening value was the only measurement below the reported global background concentration. This substantial decline is linked to traffic activity and short-term atmospheric conditions, including increased atmospheric mixing and dispersion. Therefore, the evening observation likely reflects a temporary fluctuation in CO_2 levels rather than a sustained decrease in atmospheric CO_2 concentration.

The diurnal results further demonstrate that CO_2 concentrations varied considerably across the sampling stations (Table 1). Morning concentrations ranged from 504 to 614 ppm, afternoon concentrations from 518 to 619 ppm, and evening concentrations from 402 to 590 ppm. The highest individual measurement was recorded at Aliko Junction in the afternoon (619 ppm), while the lowest was recorded at the same station in the evening (402 ppm). At Kwanar Sabo, concentrations remained consistently high during the morning (614 ppm) and afternoon (610 ppm), before declining to 558 ppm in the evening. These patterns indicate that the relationship between CO_2 concentration and time of day was not uniform across the corridor and was likely influenced by variations in traffic activity and local dispersion conditions.

Table 2. Spatial ranking of mean CO_2

Rank	Station	Mean CO_2 (ppm)
1	Kwanar Sabo	594
2	Hotoro Roundabout	590.33
3	Gadar Lado	566
4	Aliko Junction	529.67
5	Kwanar Tarauni	526.67

Therefore, the findings (Tables 1 & 2) reveal significant spatial and diurnal variability in ambient CO_2 concentrations along Maiduguri Road in Kano Metropolis. The highest average CO_2 concentrations were recorded at Kwanar Sabo and Hotoro Roundabout. Conversely, Kwanar Tarauni and Aliko Junction recorded the lowest mean concentrations, at 526.67 ppm and 529.67 ppm, respectively. These spatial variations across sampling stations highlight how traffic density, congestion, and local environmental factors influence localized CO_2 levels along the corridor. This pattern aligns with earlier studies documenting traffic-related fluctuations in CO_2 and other air pollutants in Nigerian urban environments.

Spatial distribution of ambient CO_2 concentrations

The IDW-interpolated spatial surface (Figure 2) reveals a non-uniform spatial distribution of ambient CO_2 concentrations along Maiduguri Road, Kano Metropolis. A moderate-to-high concentration zone extends across the Kwanar Sabo–Hotoro Roundabout section in the eastern part of the study area, corresponding with the relatively high mean CO_2 concentrations recorded at these sampling stations. The elevated concentrations in this corridor may be associated with high traffic volume, vehicle idling, congestion, and intense commercial activity, which can increase local CO_2. In contrast, Kwanar Tarauni and Aliko Junction exhibit low-to-very-low interpolated CO_2 concentrations, consistent with their lower recorded mean values. The relatively lower concentrations at these locations may reflect better traffic flow, reduced vehicle congestion, and more effective atmospheric dispersion.

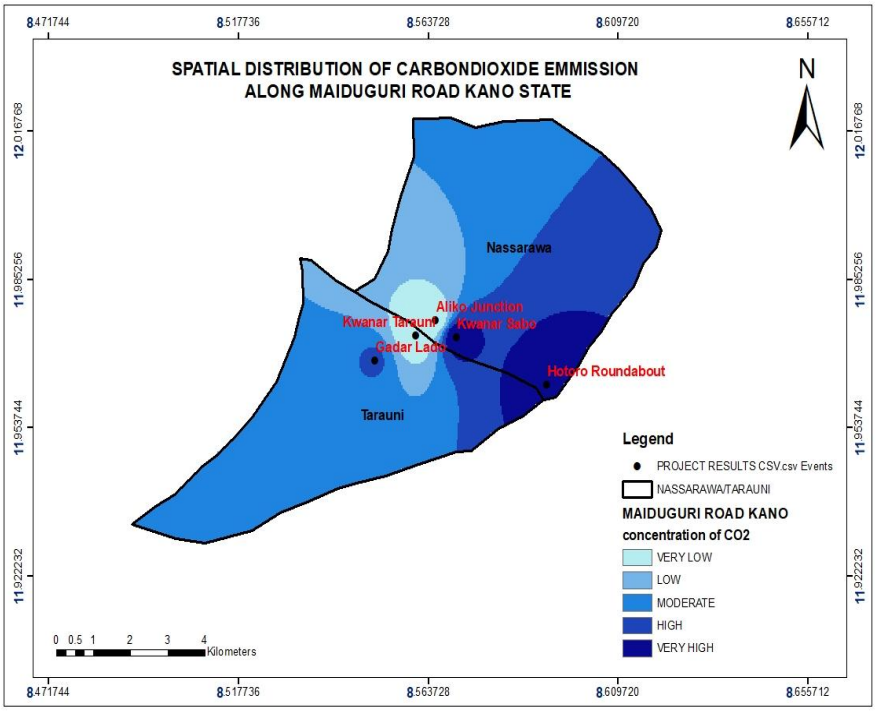


Figure 2. Spatial distribution of ambient CO_2 concentrations along Maiduguri Road, Kano State, using IDW interpolation.

Gadar Lado emerges as an anomalous high-intensity patch on the map, visually more pronounced than its mean concentration of 566.00 ppm suggests. The relatively high concentration observed at Hotoro Roundabout should be interpreted with caution, as the available data do not permit the contribution of individual factors to be isolated. Although vehicular traffic may have contributed to the elevated CO_2 concentration, other site-specific factors, including local elevation, surrounding commercial and human activities, traffic flow characteristics, and the spatial distribution of sampling points, may also have influenced the observed pattern. Furthermore, the use of the IDW interpolation technique may have affected the spatial representation of CO_2 concentrations, particularly where sampling points were unevenly distributed. Therefore, the apparent hotspot at Hotoro Roundabout should not be attributed solely to traffic intensity or to an interpolation artefact. This spatial pattern derived from the available observations should be interpreted as local variability rather than definitive evidence of a single causal factor. However, the actual reading is best interpreted as moderately high, consistent with restricted air circulation beneath the flyover structure. The surrounding dark patch should be interpreted as an interpolation artefact rather than as direct evidence of heightened severity.

Comparison with other studies and broader discussion

Table 2 compares the mean ambient CO_2 concentration recorded along Maiduguri Road with values reported for selected traffic corridors and intersections in Nigeria, as well as the global atmospheric background concentration.

Table 2. Comparison of mean ambient CO_2 concentrations along Maiduguri Road with selected Nigerian studies and the global atmospheric baseline.

Study Location	Mean CO_2 (ppm)	Source
Maiduguri Road corridor, Kano (this study)	561.33	Present study (2026)
Traffic corridors, Lagos megacity	450.1 ± 31.2	Olufemi et al. (2023)
Road intersections, Benin City (peak values)	Up to 1,767	Iwuala & Oriaku (2019)
Global atmospheric baseline (Mauna Loa, 2026 average)	≈430	NOAA/Scripps (2026)

The comparison indicates that the mean ambient CO_2 concentration of 561.33 ppm recorded along Maiduguri Road was higher than the global atmospheric baseline of approximately 430 ppm and the mean value reported for traffic corridors in Lagos (450.1 ± 31.2 ppm). However, it remained substantially below the peak concentration of up to 1,767 ppm reported at road intersections in Benin City. This variation demonstrates that ambient CO_2 concentrations can differ considerably among urban road environments, depending on traffic intensity, congestion, vehicle activity, road configuration, and local atmospheric dispersion conditions. The relatively elevated concentration observed along Maiduguri Road therefore suggests an influence of urban traffic activities on local ambient CO_2 levels, while remaining considerably lower than the extreme values reported at highly congested intersections elsewhere in Nigeria.

The spatial analysis further demonstrates that ambient CO_2 concentrations were not uniformly distributed along the Maiduguri Road corridor. The higher concentrations identified around Kwanar Sabo and Hotoro Roundabout correspond with areas characterised by relatively greater traffic activity; lower concentrations around Kwanar Tarauni and Aliko Junction indicate spatial differences in local atmospheric conditions and traffic movement. These findings support the interpretation that traffic-related activities contribute to localized variations in ambient CO_2 concentrations along the study corridor.

Integrating direct field measurements with GIS-based interpolation provides a more comprehensive spatial representation of ambient CO_2 concentration patterns than relying on individual sampling points alone. The IDW interpolation surface effectively highlights zones of relatively higher and lower concentrations, thereby supporting the identification of locations that warrant targeted environmental monitoring. However, the interpolated results should be interpreted in conjunction with the observed measurements, as the IDW method estimates values at unsampled locations through distance-weighted averaging of neighboring data points. Increasing both the number and spatial density of sampling stations in future studies would strengthen the reliability of the interpolated surface. Moreover, comparative evaluation with alternative geostatistical techniques, such as Kriging, could yield deeper insights into spatial prediction performance and strengthen confidence in representing CO_2 distribution along Maiduguri Road

Conclusion

This study measured and spatially assessed ambient CO_2 concentrations along Maiduguri Road in Kano Metropolis by integrating field-based CO_2 measurements with GIS-based Inverse Distance Weighting (IDW) interpolation. All five sampling stations recorded mean CO_2 concentrations above the global atmospheric baseline, indicating elevated local

ambient CO_2 levels along the study corridor. The observed variations in concentration were associated with differences in traffic activity, congestion, and time of day.

Spatial analysis revealed an uneven distribution of ambient CO_2 concentrations along the corridor, with relatively elevated concentrations at Kwanar Sabo and Hotoro Roundabout, while Kwanar Tarauni and Aliko Junction recorded comparatively lower mean concentrations. However, these spatial variations should be interpreted with caution because the available data do not allow the individual contributions of traffic intensity, congestion, elevation, surrounding commercial and human activities, and other local environmental conditions to be clearly distinguished. Furthermore, the IDW interpolation may have influenced the spatial representation of concentrations, particularly where sampling points were unevenly distributed. Thus, the identified areas of relatively elevated CO_2 should be considered indicative of local spatial variability rather than definitive evidence of a single causal factor.

Both research objectives—measuring ambient CO_2 concentrations at selected traffic locations and assessing their spatial distribution using GIS-based interpolation—were achieved. The findings demonstrate that integrating ground-based CO_2 measurements with GIS-based spatial analysis provides a useful approach for identifying areas of relatively elevated ambient CO_2 concentrations along urban road corridors. The results also underscore the importance of location-specific traffic-management and environmental-monitoring measures, particularly at busy junctions and commercial areas where traffic congestion, prolonged vehicle idling, and surrounding activities may contribute to localised CO_2 accumulation. Accordingly, traffic decongestion, improved junction management, and periodic CO_2 monitoring should be prioritised at locations exhibiting relatively elevated concentrations. Such measures, supported by repeated monitoring across different times, seasons, and environmental conditions, would provide a stronger basis for understanding spatial and temporal variations in urban CO_2 concentrations and for informing sustainable traffic and environmental management along Maiduguri Road and similar urban corridors in Kano Metropolis.

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Data availability: *Not applicable*

Use of AI tools (where applicable): *Not applicable*

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