

Assessing the Atmospheric Concentrations of Carbon Monoxide (CO) and Carbon Dioxide (CO₂) in the Urban Environment in Maiduguri Metropolis

M. Hussaini¹; U. A. Ibrahim¹; A. M. Gambo²; S. M. Ashigar²; B. S. Abubakar³; L. B. Musami⁴; and A. L. Abdullahi⁵

¹Department of Civil and Water Resources Engineering Department, University of Maiduguri, Maiduguri, Nigeria. ²Final Year UG students, Department of Civil and Water Resources Engineering Department, University of Maiduguri, Maiduguri, Nigeria. ³PhD student, Department of Civil and Water Resources Engineering Department, University of Maiduguri, Maiduguri, Nigeria. ⁴MSc student, Department of Civil and Water Resources Engineering Department, University of Maiduguri, Maiduguri, Nigeria. ⁵Department of Architecture, Faculty of Environmental Sciences, University of Abuja, Abuja Nigeria.

Corresponding author: m.hussaini@unimaid.edu.ng

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Abstract

This paper assessed the outdoor atmospheric concentration levels of Carbon Monoxide (CO) and Carbon Dioxide (CO₂) emissions in Maiduguri Metropolis, Borno State, North-Eastern Nigeria. The study was conducted using a multi-gas air quality monitor (S360 Multi-gas Analyzer) in year 2025, across fourteen (14) Emissions Monitoring Stations (EMSs). Data were collected at every EMS for multiple 24-hour periods, from 6am to 3am, at 3-hour intervals, over a period of 2-3 months. Average data were considered for all the EMSs (by point) and at the 3-hour intervals (by time) across the 24-hour periods. Also, maximum data were considered (by time) across the 24-hour period for the city. The results show that average concentrations for CO and CO₂ at the 14 EMSs range between 0.00-3.75 ppm (with a city average of 1.81 ppm) and between 334-671 ppm (with a city average of 575 ppm) respectively. The average daily trends show that CO and CO₂ levels range between 0.00-3.14 ppm and between 523-623 ppm respectively. Similarly, maximum concentrations for CO and CO₂ across the day range between 0-10 ppm (with a city maximum-average of 5.88 ppm) and between 604-841 ppm (with a city maximum-average of 753 ppm) respectively. Findings also reveal that for CO, both average levels at the EMSs (except for 24-hour averaging time at Custom flyover and Muna Park) and across the day did not exceed the standard limits recommended by World Health Organization (WHO) and Federal Government of Nigeria (FGN). However, CO₂ is found to be higher than the global average of 422.8 ppm. By identifying CO and CO₂ levels, this paper provides useful air pollution data and information, highlighting targeted interventions by relevant stakeholders for critical times and areas with elevated pollution levels.

Keywords: Air Quality; Carbon Dioxide; Carbon Monoxide; Maiduguri; Urban Area.

Introduction

Air pollution remains one of the most pressing environmental issues of our time, with Carbon Dioxide (CO₂) and Carbon Monoxide (CO) being key contributors to its complex

dynamics. The pollutants, CO₂ and CO are respectively emitted through the complete and incomplete combustion of fuels, and have far-reaching implications for climate and public health (EEA, 2025; Manisalidis et al., 2020; NIEHS, 2025; WHO, 2021; WHO, 2024).

CO₂ is a significant greenhouse gas (GHG) that influences global climate patterns (United Nations, 2025; NOAA, 2025). The increase in atmospheric CO₂, driven largely by human activities such as the burning of fossil fuels, as well as Agriculture, Forestry and Land Use (AFOLU), has been a major factor in global temperatures rise (NASA, 2024a; NRDC, 2025; Nunes, 2023). GHGs trap heat in the Earth's atmosphere, leading to a phenomenon known as the greenhouse effect and global warming (NASA, 2024b).

The current global average concentration of CO₂ in the atmosphere has reached around 430 parts per million (ppm), a level that underscores the urgent need for effective climate action (NASA, 2025; NOAA, 2025; Statista, 2025). The consequences of elevated CO₂ levels are profound and multifaceted, including global warming, shifting rainfall patterns, which contributes to extreme weather events, and slow onset events (IPCC, 2021; Nunes, 2023).

In contrast, CO is a colorless, odorless gas that poses immediate risks to human health and air quality. CO is produced primarily through incomplete combustion of fuels in vehicles, industrial activities, and the burning of waste. Although its concentration in the atmosphere is relatively low compared to CO₂, CO has significant health implications and environmental impacts. It has serious health effects and can cause severe illness or death when inhaled at high concentrations (CARB, 2025; McMahon and Launico, 2025).

CO can interfere with the body's ability to transport oxygen, leading to symptoms such as headaches, dizziness, and in severe cases, it can be fatal. Long-term exposure to CO can exacerbate cardiovascular and respiratory conditions, particularly affecting vulnerable populations such as children and the elderly (Gaalema, 2023; Reboul et al., 2017; WHO, 2025).

Furthermore, CO contributes to the formation of ground-level ozone, a key component of smog that further degrades air quality and has additional adverse effects on respiratory health. By facilitating chemical reactions in the atmosphere that produce ozone, which is a climate change gas, CO contributes indirectly to climate change. For these reasons, CO is classified as a short-lived climate forcing agent, thus CO emission reductions is considered as a possible strategy to mitigate effects of global warming (CARB, 2025; Manisalidis et al., 2020).

This paper provides valuable information for understanding the spatial distribution and daily concentration trends of CO and CO₂ pollutants in Maiduguri city and underscores the need for strategic air quality management in urban environments to protect public health. Better air quality can lead to healthier residents, improves life expectancy and mitigate climate change. This information is key in developing effective policies and measures to reduce pollution and improve air quality.

Statement of the Problem

Air pollution is progressively becoming a major threat in urban areas. The general level of localized air pollution in urban environments is on the increase as a result of increased economic activities, including transportation, industries, and/or waste management (Okelola and Appollonia, 2013; Ucheje and Okolo, 2023). Due to incomplete combustion in stationary automobiles, traffic congestion contributes disproportionately to CO pollution, accounting for 50% in developing nations (Global Burden of Disease, 2020; Goyal, 2006). Other studies including Saville (1993) and Ucheje and Okolo (2023) also confirmed that traffic-related emissions account for 90–95% of global atmospheric CO levels and 80–90% of NO_x, hydrocarbons, and particulate matter.

Sufficient understanding of the characteristics of pollutants (in terms of how traffic related emissions significantly increase air pollution) in cities is necessary for the efficient air emissions control in urban areas. According to Ucheje and Ikebude (2015) and Ucheje and Agbazue (2014), the pattern, direction and rate of emissions' dispersion determine their overall impact on the environment and human health.

Furthermore, it appears that the daily trend of the concentration levels of CO and CO₂ pollutants (pattern and rate) at different times in urban areas has received little attention, despite the volume of research on what constitutes air pollution in major cities including Nigeria. Second, not much research has been done on taking into account differing locations and times including those with low/zero traffic density. Such gaps have the tendency of misrepresenting actual emissions records.

Therefore, this paper attempts to close the existing gaps that have received little or no attention, to enhance the accuracy in assessing and understanding the environmental and health consequences of CO and CO₂ levels. The study is thus, aimed at determining the concentration levels of CO and CO₂ pollutants in spatially distributed EMSs at different times, in Maiduguri city in Nigeria for year 2025, so as to obtain the overall daily average and trend for the city and for the selected station.

Aim and Objectives

The primary aim of this paper is to assess the atmospheric concentrations of CO and CO₂ for multiple 24-hour periods at different locations and specific time intervals within Maiduguri Metropolis for the year 2025, identify the key sources, evaluate their specific environmental and health impacts and suggest mitigation measures. This assessment will serve as a basis for developing targeted policies and measures to mitigate the adverse effects of these pollutants in Maiduguri and other urban areas.

The specific objectives of the study are to;

1. Characterize the pattern of CO and CO₂ emissions in spatially selected areas (both low and high-traffic) in Maiduguri, Nigeria;
2. Assess the impact of anthropogenic factors on the concentrations of CO and CO₂ pollutants in the chosen areas;

3. Examine the difference in the concentration of the pollutants in the selected areas/times in the city and consider the average values;
4. Determine the nexus between the average CO and CO₂ concentrations in Maiduguri and the daily pattern of economic activities, particularly transportation.

Literature Review

The study of air quality and atmospheric emissions concentration levels in Nigerian urban environment such as Maiduguri city is limited. The following sections give a detailed review of relevant studies at the local, National, Regional and International levels.

Local, City/National Level Review

Hussaini et al. (2018a; 2018b; 2018c; 2023) studied the rates of emissions from solid biomass, road transport, industry, and buildings in Maiduguri city. These studies focused on the rates of emissions from the different source sectors only, and not the atmospheric concentrations or air quality in the city.

Idriss et al. (2021) assessed concentration of CO pollutant in high traffics area of Post office in Maiduguri city, between 8:00 am to 8:00 pm of the day. The minimum and maximum results obtained over three weeks ranged between 12-36 ppm. This study only focused on a single pollutant (CO), one emission station and a limited time period of the day.

Okafor et al. (2023) deployed a quantitative technique to determine the emission profile of transport nodes in Ikeja, Lagos through the use of AEROQUAL 500s to sample CO, CO₂, CH₄ and N₂O at the three selected locations. The measurement for each gas was taken at 20 minutes intervals for 1 hour during each peak periods. They found that CO (56-73 ppm), CO₂ (769-834 ppm) and CH₄ (1.33-23 ppm) concentrations were highest during the AM peak and PM peak periods and lower during the inter-peak period, while NO_x (0.016-0.017 ppm) concentration were relatively stable throughout the periods.

This study covered both CO and CO₂, but shows accuracy concerns. Limiting the assessment periods to 20 minutes intervals for only 1 hour, and considering only peak periods imply ignoring low emissions periods, which may not give an accurate computation of the average concentrations at the chosen locations. The limitation of the study to only three emissions stations further the reduce its potential to represent air quality status in urban environments.

Shote et al. (2023) presents air quality index for formaldehyde and environmental emissions emanating from four service stations in Lagos metropolis. The results show that CO stands at 2.2 ppm and CO₂ at 453 ppm. These authors have limited emissions monitoring stations and time periods to reflect more accurate emissions assessment.

Aroh et al. (2024) studied numerous gaseous emissions but focused on a limited spatial environment, the Port Harcourt International Airport and its environs, and found CO and CO₂ concentrations to be between 0.00-1.48 ppm and 0.04-0.18 ppm respectively. On the

other hand, Olanrewaju, et al. (2024) conducted a study on various ambient air pollutants using air quality monitor, including CO (0.004-0.043 ppm) and CO₂ (469-972 ppm), but was limited to 15 locations across a particular institution, Lead City University, Ibadan city, Nigeria.

Ucheje and Ofoezie (2025) examined air pollutant levels in high- and low-traffic areas of Port Harcourt, considering the effects of traffic and weather conditions, to assess the pattern of air pollution concentrations in the city's high and low traffic density zones. Five locations were chosen based on traffic density, and the concentrations of CO (5.2-23.5 ppm), VOC, SO₂, NO₂ and PM were tracked. They counted the number of cars traveling through a site during three hours in the morning, afternoon, and night-time, to create traffic records at the chosen places. The limitation in this research lies in the limited number of stations, without taking CO₂ into account.

Mayowa and Mobolaji (2024) study utilized Geographic Information System (GIS) and remote sensing technologies to assess and identify regional and temporal patterns of CO emissions from 2018 to 2023, and recommend mitigation strategies addressing climate impacts in Nigeria. Land cover data was incorporated to examine the relationship between industrialization, urbanization, and emissions. Also, transportation network data were overlaid on emission maps in ArcGIS Pro to evaluate the transportation sector's contribution. The study found CO emissions to be 0.0462 – 0.053 mol but did not take account of CO₂ emissions.

Regional Level Review

Mignamissi and Djeufack (2021) examined the relationship between urbanization and the intensity of CO₂ emissions on a panel of 48 African countries over the period 1980–2016, using an augmented STIRPAT model. They found that if urbanization is a highly significant factor for pollution in Africa, the effect is heterogeneous for different levels of pollution, and that the overall effect of urbanization on global warming is positive and significant. The study focused on CO₂ emissions in relation to urbanization without considering its concentration levels.

Gonsan et al. (2023) analyzed the temporal trends and variability of annual anthropogenic CO₂ emissions in 16 West African countries over the 1970-2015 period using Emissions Database for Global Atmospheric Research (EDGAR) data. They found that the trends correlate with the demographic and economic growth of these countries. This study focused on rates of CO₂ emissions at the country level and did not consider emissions concentrations for an urban area.

Henneman (2016) used the Greenhouse Gas and Air Pollution Inter Action Synergies (GAINS) model to identify policies that satisfy multiple goals of emissions reductions (of both local air pollution and greenhouse gases) and affordable energy supply for various mitigation strategies in South Africa. The study focused on quantifying country-wide air

pollution and greenhouse emissions and costs of controls, with no consideration for atmospheric concentrations of the pollutants.

Yang and Solsona (2025) employed Carbon Dioxide emission intensity (CEI) and per capita Carbon Dioxide emissions (PCE) as dual indicators to evaluate the spatial spillover effects of 54 “Belt and Road Initiative” (BRI) African countries on their neighboring countries’ carbon emissions from 2007 to 2023. The study was inclined towards revealing the complex relationship between BRI African economic development and environmental outcomes, with no focus on pollutant concentrations.

Liu et al. (2024) aimed at assessing the current state of the development of African cities’ emission inventories, considering a city-level greenhouse gas emission inventory as a guide to mitigation action.

International Level Review

Lan et al. (2020) considered cities and their surrounding areas as the main sources of anthropogenic CO₂ emissions and thus, continuous measuring of CO₂ in urban areas is of great significance to the study of human CO₂ emissions. They developed a compact, precise, and self-calibrated in-situ CO₂/H₂O sensor to measure CO₂ concentrations (which stands at 401-434 ppm) continuously in the city center of Munich, Germany, from February 2018 to January 2019. The study focused on establishing a correlation between urban CO₂ concentrations and influencing factors including vegetation photosynthesis and respiration (VPR), planetary boundary layer (PBL) height, and anthropogenic activities. However, the study emphasized the emissions variations on a larger scale of days and months in the city center of Munich, and ignored to consider the hourly variations across the days. The confinement of the study area to the city center and the exclusion of CO in the gases left room for further studies in this area.

Somoye and Akinwande (2023) study explores how the urban population (UBNP) influences Carbon Dioxide emissions (CO₂e) levels in BRICS-T from 1990–2021 (192 observations) using Pooled OLS and Fixed Effects techniques, utilizing energy intensity (ENIT) and economic growth (GDP) as control variables. The study focused on the correlation between CO₂ emissions rates and urban population, energy intensity and economic growth, and does not consider CO₂ emissions concentrations.

Gap in Literature

From the literature, overall assessment of the atmospheric concentrations of CO and CO₂ emissions for multiple 24-hour periods, at short (3-hour) intervals, and for adequate number of monitoring stations in an urban environment is lacking. Thus, this paper contributes novel findings in the area of emissions assessment and air quality information for urban areas.

Methodology and Data

The paper measured CO and CO₂ pollutants in sample locations across Maiduguri city using air quality monitoring device (*S360 Multi-gas Analyzer*). The paper identified the local sources of the pollutants and examined how different levels of these gases are distributed across the city. To this end, fourteen (14) emissions monitoring stations (EMSs) were chosen at strategic locations to give a general overview of the spatial distribution of air quality in terms of CO and CO₂ within the city. At each EMS, measurements are taken across 24 hours at 3-hour intervals from 6am to 3am.

The Study Area

Maiduguri is the oldest town and the largest city in north east Nigeria and the capital of Borno State, located on latitude 11.8310981, and longitude 13.1509672. Maiduguri is located along the seasonal Ngadda (Alo) River, the waters of which disappear in the Firki ("black cotton") swamps of Lake Chad, northeast of the city (Britannica, 2025).

The city is key to the state's long-term development, with a population of 1.2 million (hosting 0.6% of total Nigeria's population and 20% of Borno's State population), a population density of 11,375 people per square kilometer, and a GDP of \$4.6B billion (Bell and Card, 2021; Bello, 2019; MAPTONS, 2025; World Bank, 2023). Emissions sources are largely from transportation, waste management and off-grid electricity generation.

Established in 1907, Maiduguri has grown into a significant urban center within the region, playing a crucial role in trade, business and education (Britannica, 2025). The city has long served as a commercial centre with links to Niger, Cameroon and Chad and to nomadic communities in the Sahara. The city has borne the largest burden of support to those displaced by the internal conflict (upto 800,000 persons), rapidly increasing its population (Bell and Card, 2021).



Figure 1: Map of the study area (Maiduguri) showing the emissions monitoring stations (EMSs)

Device Description

The S360 is a portable, pump-suction multi-gas analyzer designed for industrial safety, capable of detecting up to 16 different gases simultaneously, including combustible, toxic, and greenhouse gases (CO_2 , O_2 , H_2S , CH_4 , etc.).

It features a high-resolution color touchscreen, advanced alarm systems (sound/light), and is used for leak detection, underground pipelines, and environmental monitoring.

The device is designed to be durable, featuring shock resistance, making it suitable for harsh industrial environments. Key features and specifications are as follow:

Detection Range: Customizable sensor configurations (single or multi-gas). For instance, CO_2 can be detected up to 5000 ppm.

Sampling Method: Built-in pump-suction.

Display: Clear LCD touch screen.

Alerts: Advanced audio and visual alarm system for hazardous conditions.

Performance: High sensitivity with quick response times.

Data Management: Capable of storing up to 500 alarm records.

Power: Rechargeable 3.6V and 7.2V lithium-ion batteries.

Environmental: Operates in high humidity (5-90% RH, no condensation).

Data Collection Procedure

Outdoor data were collected at fourteen (14) sample stations across Maiduguri city for different 24-hour periods, taking a length of 2-3 months to end. The criteria for the choice of the EMSs included spacing and the extent of coverage of Maiduguri city. The EMSs were spaced at roughly equal distances, ranging from the city center to the city ends in all directions, covering the whole urban environment.

At the EMSs, the S360 device was set on and left for few minutes to boot and stabilize. The screen readings displayed for the stations were then recorded, and the procedure repeated for all the EMSs, starting from 6am to 3am for 24 hours, at 3-hour interval (Table 1).

The step-wise approach is as follows:

- Selecting suitable EMSs for the study
- Identify suitable time intervals (3-hours) for CO_2 and CO concentration measurement
- Measuring the atmospheric levels of CO_2 and CO along important roads within Maiduguri Metropolis at all the EMSs, at 3-hour time intervals of the day.
- Displaying the spatial distribution of CO_2 and CO gas across the city and computations for average values are done.

- Recommending effective, locally led strategies for mitigating CO₂ and CO emissions, including policy recommendations, technological interventions, and public awareness initiatives.

Ethical Considerations and Research Safety Procedures

Ethical considerations and research safety procedures in this study focused on ensuring data integrity, protecting personal privacy, upholding environmental justice, and maintaining the physical safety of researchers and the public. Key ethical considerations included informed consent, data accuracy, and transparency, while safety protocols involved strict handling of equipment and adherence to regulations.

Ethical Considerations:

- Informed Consent and Transparency
- Environmental Justice and Equity
- Data Privacy and Confidentiality
- Data Integrity and Accuracy
- Data Sovereignty
- Avoiding "Green-washing"

Research Safety Procedures:

- Hazard Mitigation in Fieldwork
- Equipment Safety Protocols
- Secure Data Handling and Storage
- Compliance with Standards
- Two-Person Rule

Core Principles:

- Beneficence
- Non-maleficence
- Anonymity
- Accountability

Study Limitations

The scope of this paper is limited to the assessment of outdoor atmospheric CO₂ and CO concentration levels in Maiduguri Metropolis. However, the accuracy of the study is dependent upon the number of EMSs, thus the selection of limited (14 EMSs) sampling stations may reduce the accuracy of the data. Also, data records may not have been taken

at the exact target hour, because moving through a few close stations to take records for the target hour may result in an increase/decrease of about ± 15 minutes.

For data at 12am and 3am, the EMSs may not be accessible due to security concerns. For those times, accessible stations were arbitrarily considered as proxy stations. This is based on the justification that anthropogenic activities responsible for air pollution usually diminish by 10pm in Maiduguri, and may come to a standstill by 12am. Hence, considering the time period of inactivity at midnight (12am-3am), air pollutants were assumed to have been somewhat uniformly distributed across the city due to wind movements, and thus pollutants concentrations are not expected to differ widely. Finally, the study did not take account of meteorological data (temperature, humidity, wind speed, wind direction) which may also affect the accuracy of the results.

Table 1: Atmospheric concentrations of CO and CO₂ at sample stations in Maiduguri City

Station name	Pollutants (ppm)	6:00 am	9:00 am	12:00 pm	3:00 pm	6:00 pm	9:00 pm	12:00 am	3:00 am	Average
Post Office Roundabout	CO	2	3	3	3	5	5	0	0	2.63
	CO ₂	733	596	596	584	631	645	656	597	630
Baga Park	CO	0	0	4	3	6	6	0	0	2.38
	CO ₂	417	581	553	421	611	703	613	603	563
Chabbal Junction	CO	0	0	0	0	1	0	0	0	0.13
	CO ₂	312	411	331	281	312	122	606	602	372
Al-ansar Junction	CO	0	0	0	0	0	1	0	0	0.13
	CO ₂	481	841	714	518	670	729	623	599	647
Federal Highcourt	CO	0	0	0	0	0	0	0	0	0.00
	CO ₂	470	570	610	591	585	810	625	601	608
NNPC Depot	CO	0	0	0	8	0	0	0	0	1.00
	CO ₂	480	418	638	555	625	611	627	603	570
FRSC Junction	CO	0	1	0	0	0	2	0	0	0.38
	CO ₂	841	772	722	601	500	412	622	600	634
Molai Park	CO	2	1	0	2	4	5	0	0	1.75
	CO ₂	122	427	285	215	217	178	626	602	334
Borno Express	CO	3	1	7	4	0	0	0	0	1.88
	CO ₂	481	841	714	518	670	510	622	598	619
Airport Roundabout	CO	2	2	6	8	1	6	0	0	3.13
	CO ₂	718	729	740	623	640	671	628	604	669
1000 Housing	CO	3	2	1	2	1	1	0	0	1.25
	CO ₂	570	530	510	602	711	707	613	602	606
Custom Flyover	CO	2	10	7	0	7	4	0	0	3.75
	CO ₂	741	747	722	810	670	472	606	597	671
Muna Park	CO	5	8	4	4	4	5	0	0	3.75
	CO ₂	521	545	262	666	721	741	656	603	589

Station name	Pollutants (ppm)	6:00 am	9:00 am	12:00 pm	3:00 pm	6:00 pm	9:00 pm	12:00 am	3:00 am	Average
Unimaid Gate 2	CO	1	3	1	4	8	9	0	0	3.25
	CO ₂	440	419	480	590	510	719	605	601	546
Average values	CO	1.43	2.21	2.36	2.71	2.64	3.14	0.00	0.00	1.81
	CO ₂	523	602	563	541	577	574	623	601	575
Maximum values	CO	5	10	7	8	8	9	0	0	5.88
	CO ₂	841	841	740	810	721	810	656	604	753

Discussion

The results of the study provide data and information on the levels of atmospheric concentrations of CO and CO₂ across various locations in Maiduguri city at different times of the day. Locations with heavy traffic, such as major roundabouts and bus stations, at morning and evening hours, show elevated CO and CO₂ levels, reflecting the influence of vehicular emissions. Conversely, places/times of low traffic activities indicated lower concentrations of both CO and CO₂ (Figure 2). The discussion involves reviewing the air quality data for evaluation against national and international air quality standard limits.

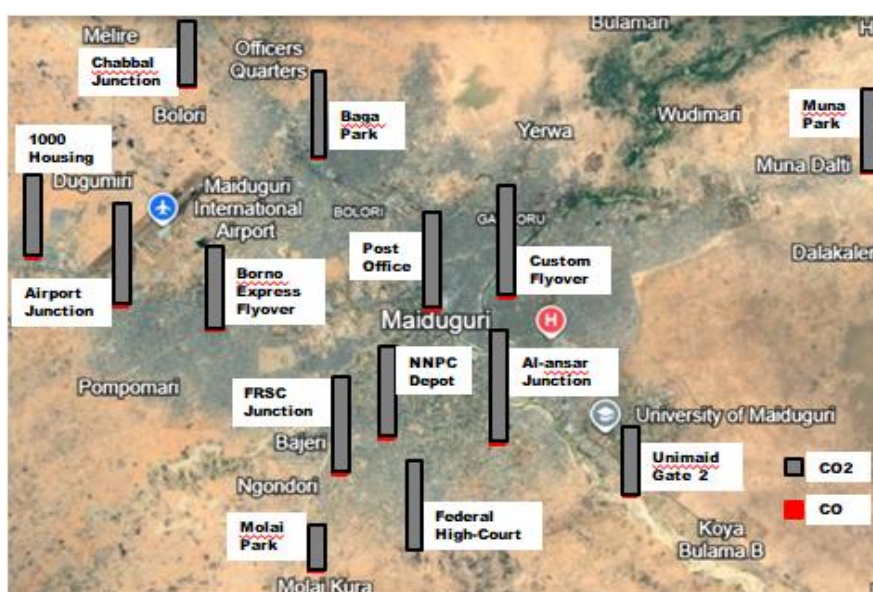


Figure 2: Spatial representation of average CO and CO₂ levels at EMSs in Maiduguri

Comparison to other Results

The averages of CO and CO₂ at the 14 EMSs for 24-hour periods (in space) in the city show a range of 0-3.75 ppm and 334-671 ppm respectively. On the other hand, the averages at the 3-hour intervals for the stations (in time) across the day range between 0-3.14 ppm for CO and 523-623 ppm for CO₂. The overall average concentrations at the city level in space and time for CO and CO₂ stand at 1.81 ppm and 575 ppm respectively. Similarly, the average concentrations for the maximum values in space and time stand at 5.88 ppm for CO and 753

ppm for CO₂. Table 2 compares current findings to other research results from urban environments at the local, national, regional and international levels.

The results of CO and CO₂ concentrations show meaningful interactions with results from other relevant studies at all levels. A total of seven (7) studies for CO and five (5) studies for CO₂ are compared to the current results. For CO in current study, 4/7 of the results are below other results and 3/7 above. This means a high degree of accuracy in the current study. For CO₂ in current study, 2/5 of the results are below other results and 2/5 above, while 1/5 is within the range. This also shows a higher degree of accuracy for CO₂ in the current study. Figure 3 presents an interactive diagram between the study results and other relevant findings.

Table 2: Comparison of current findings for average CO and CO₂ to other relevant results

Author	Area of study	Result(s) from other studies	Remark (Current results) (CO: 1.81 ppm; CO ₂ : 575 ppm)
Idriss et al. (2021)	Maiduguri, Nigeria	CO: 12-36 ppm	CO: below range
Okafor et al. (2023)	Ikeja, Lagos, Nigeria	CO: 56-73 ppm CO ₂ : 769-834 ppm	CO: below range CO ₂ : below range
Shote et al. (2023)	Lagos, Nigeria	CO: 2.2 ppm CO ₂ : 453 ppm	CO: below CO ₂ : above
Aroh et al. (2024)	Port Harcourt, Nigeria	CO: 0.00-1.48 ppm CO ₂ : 0.04-0.18 ppm	CO: above range CO ₂ : above range
Ucheje and Ofoezie (2025)	Port Harcourt, Nigeria	CO: 5.2-23.5 ppm	CO: below range
Olanrewaju, et al. (2024)	Ibadan, Nigeria	CO: 0.004-0.043 ppm CO ₂ : 469-972 ppm	CO: above range CO ₂ : within range
Mayowa and Mobolaji (2024)	Nigeria (National)	CO: 1.035-1.187 ppm	CO: above range
Lan et al. (2020)	Munich, Germany	CO ₂ : 401-434 ppm	CO ₂ : below range

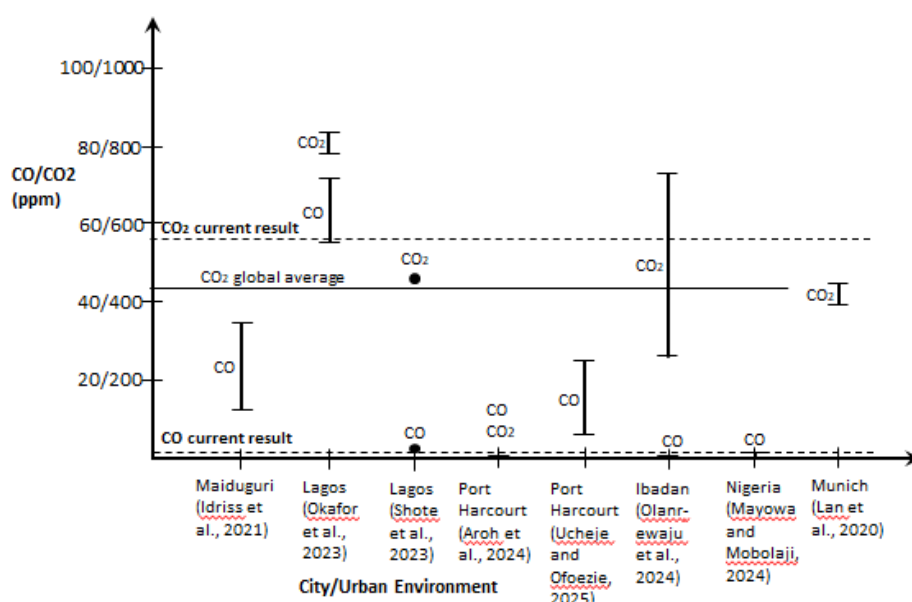


Figure 3: Interactive comparison of the average CO and CO₂ levels to other relevant studies

Air Quality and Environmental Assessment

In the standard Air Quality Guideline (AQG), recommendations on air quality standards are given for CO by the World Health Organization (WHO, 2021) as well as local national standards (FGN, 2020) as shown on Table 3. For CO₂, the National Oceanic and Atmospheric Administration (NOAA, 2025) indicates current global CO₂ average at 422.8 ppm for year 2024. Facts on Climate Change (2024) further indicates that this CO₂ level results to a global temperature increase of 1.2°C above pre-industrial levels.

From Table 1, CO average levels at all EMSs (except for 24-hour averaging time at Custom flyover and Muna Park) in Maiduguri are within the recommended standard limits for all the averaging times, whereas for the city level, average CO level (1.81 ppm) is within all standard limits and maximum-average level (5.88 ppm) breaches the 8-hour (FGN, 2020) and 24-hour averaging time (WHO, 2021) limits. For CO₂, both average and maximum-average levels in the city are beyond the global average of 422.8 ppm.

Table 3: Air Quality Guidelines (AQG) for different averaging time

Pollutant	Average city concentrations (ppm)	Averaging time	Acceptable concentration limits		Global average
			mg/m ³	ppm	
CO	Average – 1.81 Maximum – 5.88	15-min	100 ^a	87.3	
		1-hour	35 ^a /10 ^b	30.6/8.7	
		8-hour	10 ^a /5 ^b	8.7/4.4	
		24-hour	4 ^a	3.5	
CO ₂	Average – 575 Maximum – 753	-			422.8 ^c

Sources: ^aWHO (2021); ^bFGN (2020); ^cNOAA (2025).

Trend Analysis

A graph of the average CO and CO₂ emissions concentrations for Maiduguri city is plotted against time of the day, indicating the overall emissions dynamics across the day, to reveal their characteristics in terms of their averaging times. The maximum values of the concentrations are chosen as the worst-case scenarios, while the average values are considered as the best air quality at any given time in the city. As shown on Figure 4, the graph lines for CO are exhibiting similar trends across the day, low in the early morning (6am), showing minor spikes around 9am and 9pm, then indicating sharp downward trends, reaching 0 ppm at midnight (12pm). CO₂ shows low sensitivity to daily anthropogenic activities, maintaining an approximate value of 600 ppm through midnight (12am-3am) CO₂.

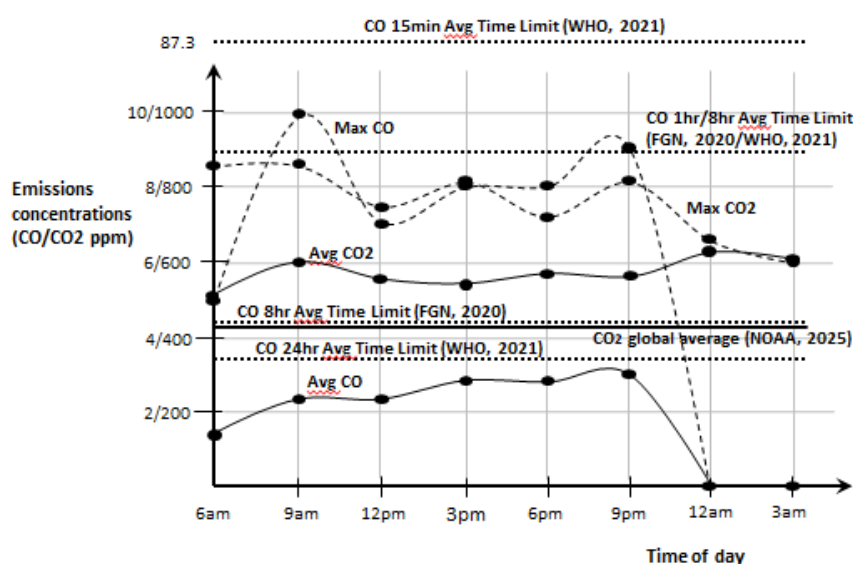


Figure 4: Daily trends of CO and CO₂ levels in Maiduguri Metropolis

In the early morning hours (6:00 am), the concentrations of the gases are relatively low, likely due to near-absent anthropogenic activities. As the day progresses, through 9:00am towards 12:00pm, the average concentration levels for both CO and CO₂ increase, rising to higher levels. This rise can be largely attributed to increased transportation activities typical of morning rush hour.

Emissions level for Avg CO₂ drop to lower values between 9pm-9pm, rising back to higher value towards midnight. Avg CO shows gradual increase between 9pm-9pm, dropping to 0 ppm towards midnight. Considering both Max and Avg trends, CO₂ trends converge to a common value of 600 ppm towards midnight (12am-3am), and for CO, the trends converge to 0 ppm at 12am. These new values continue at roughly constant values until 6am the next morning. The difference in the concentration behaviors of CO (0 ppm) and CO₂ (600 ppm)

at midnight show that CO₂ emissions is more global than local, while CO emissions is more local.

For standard air quality requirements for CO level (Table 3), both average and maximum trends fall far below the 15min averaging time limit by WHO (2021), while average CO trend fall below both 8hr and 24hr averaging times limits by FGN (2020) and WHO (2021) respectively. For maximum CO trend, CO concentrations indicate overshoots at two points (8am-10.30am and 7.30pm-9pm) for the 1hr and 8hr averaging time limits by FGN (2020) and WHO (2021) respectively. However, the averaging times for the two points are still within the WHO (2021) requirements for good air quality.

Conclusion

This paper examined the outdoor atmospheric concentrations of Carbon Monoxide (CO) and Carbon Dioxide (CO₂) across the urban environment of Maiduguri Metropolis for 24-hour period. The analysis reveals that the average daily CO levels in the city are notably lower than recommended limits by both Federal Government of Nigeria (FGN) and World Health Organization (WHO). However, maximum CO trend shows brief overshoots at 8am and 9pm, for 1hr and 8hr averaging times by FGN and WHO respectively. For CO₂ concentrations, both average and maximum trends in the city are above the current global average atmospheric GHG concentration of 422.8 ppm, indicating increasing GHG emissions from urban environments.

The daily trends of CO and CO₂ emissions reveal the impact of socio-economic activities (transportation, industry and waste) on air quality in urban areas. Effective management of these pollutants is essential (especially at overshoot points) for enhancing air quality and safeguarding public health in Maiduguri in the long-term.

Recommendations

Mitigating CO and CO₂ pollution involves a combination of technology, policy measures, and public awareness, in terms of improving vehicle emissions standards, reducing heavy reliance on diesel for energy generation by improving on-grid power infrastructure or providing incentives for off-grid clean energy adoption, improving waste management practices and behavioral change to minimize open burning.

For CO₂, strategies include transitioning to renewable energy sources, improving energy efficiency across various sectors, and adopting Carbon Dioxide removal (CDR) solutions. Addressing CO emissions requires improved combustion technologies, stricter emission standards for vehicles and industrial processes, and public education and awareness on the dangers of CO exposure. Comprehensive efforts to reduce the emissions of both gases are crucial for improving air quality and combating climate change, ultimately protecting both human health and the environment.

Other specific recommendations to mitigate urban emissions include the following:

1. Implementing effective traffic management strategies, including optimizing traffic flow to reduce congestion and vehicle emissions, especially during peak hours. Encouraging the use of public transportation and promoting car-pooling could also help lower CO and CO₂ levels.
2. Increasing green spaces, reducing deforestation and promoting urban vegetation can help absorb CO₂ and improve air quality. Planting trees and maintaining parks can act as carbon sinks and natural filters, reducing the concentration of pollutants in the air.
3. Public awareness campaigns are important. Educating members of the public about the health and environmental effects of CO and CO₂, and ways to reduce personal exposure to CO, can help individuals make informed decisions and contribute to overall air quality improvement.
4. A multi-stakeholder approach involving relevant Ministries, Departments and Agencies (including Borno State Ministry of Environment, Borno State Environmental Protection Agency, Borno State Urban Planning and Development Board, Federal Ministry of Environment Nigeria, etc.) to deliver on the above objectives.

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