RESILIENCE AND LIVABLE CITIES IN A WARMING WORLD

A FESTSCHRIFT IN HONOUR OF

TPL. DR. JOSHUA ADEWUMI ADEBISI FNITP, RTP



EDITED BY

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Editors:
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CHAPTER 02

ENVIRONMENTAL SAFETY RISKS OF TRAFFIC-RELATED CARBON MONOXIDE EMISSIONS IN UYO METROPOLIS, AKWA IBOM STATE, NIGERIA

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Abstract
This study assesses the environmental safety risks of traffic-related carbon monoxide emissions In Uyo Metropolis, Akwa Ibom State, Nigeria by focusing on spatial and temporal variations. Using a combination of primary and secondary data sources, vehicular traffic counts, CO measurements and meteorological data (relative humidity, atmospheric pressure, wind speed, wind direction, and temperature) were collected at 19 selected road locations. CO concentrations were measured at 2 meters and 5 meters above ground level using a Gasman auto-sampler, with geographic coordinates recorded via GPS for spatial accuracy. Data analysis involved descriptive statistics, multiple regression analysis, and Analysis of Variance (ANOVA). The results showed that traffic volume and road width positively correlate with CO concentration, with R-squared values of 0.84 at 2m and 0.63 at 5m. ANOVA indicated significant differences in CO levels across different time periods ($p < 0.001$), with morning peak levels being the highest. Spatial analysis using Empirical Bayesian Kriging (EBK) revealed that CO concentrations were highest along major roads, particularly near intersections with heavy congestion. Findings confirm that traffic-related variables significantly influence CO pollution levels, posing potential health risks due to prolonged exposure. The study recommends adaptive traffic management strategies, improved public transit options, and GIS-based monitoring tools to mitigate pollution and enhance urban air quality. Implementing these measures will be crucial in ensuring sustainable urban development and protecting public health.

Keywords: Carbon monoxide pollution, traffic volume, spatial analysis, air quality, Geographic Information Systems (GIS).

1.0 Introduction

Over the past two decades, the world has witnessed unprecedented urban growth, with metropolitan outskirts expanding at a pace often surpassing the population growth of core urban centres. According to the Organization for Economic Co-operation and Development (OECD, 2018), metropolitan peripheries have grown faster than central districts in the past 15 years, a shift driven by rapid urbanisation, motorisation, and socio-economic restructuring. While this has fuelled economic dynamism and spatial development, it has also intensified traffic congestion, urban sprawl, and commuting distances. These trends raise pressing concerns about environmental sustainability and public health, particularly with respect to vehicular emissions.

Globally, vehicular emissions are a major contributor to air pollution and greenhouse gas accumulation. The World Health Organization (WHO, 2021) notes that

exceedance of air quality guideline levels is associated with important risks to public health, and numerous reviews have shown that vehicle exhausts significantly degrade ambient air quality and increase the burden of respiratory and cardiovascular illnesses. Policies in many developed countries such as the United States of America Clean Air Act and the Euro emissions standards have reduced traffic-related pollutants in cities like Los Angeles, London, and Berlin. Nevertheless, traffic surges and unfavourable meteorological conditions continue to challenge effective air-quality management even in these regions (Brugge, Durant, and Rioux, 2007).

The public health dimension and implications of vehicular pollution is well established (Akanmu & Salisu, 2024; Odesanya, 2021). The World Health Organization (2014) identifies air pollution as the leading global environmental health risk, contributing to around seven million premature deaths annually. Carbon monoxide (CO) a colourless, odourless gas produced primarily by incomplete combustion of fossil fuels is among the most pervasive traffic-related pollutants. Its ability to bind with haemoglobin reduces oxygen transport in the bloodstream, leading to health problems ranging from dizziness and fatigue to cardiovascular disease and premature death. Research indicates that even small increases in ambient CO concentrations can have serious consequences: a 1 mg/m^3 rise has been linked to a 0.91% increase in daily mortality (Chen, Zhao, Chen, and Kan, 2021), while similar increases in China resulted in a 2.08% rise in Years of Life Lost (YLL) (Wang, Zhang, Niu, Li, and Liu, 2021).

In high-income countries, decades of emission regulations and continuous air quality monitoring have reduced CO levels considerably. By contrast, many lo - and middle-income countries continue to face persistently high concentrations due to rapid motorisation, poor vehicle maintenance and widespread use of second-hand vehicles, weak enforcement, and inadequate public transport systems. In African cities, studies suggest that between 90% and 95% of ambient CO originates from gasoline and diesel-powered vehicles (Savile, 1993; Abam & Unachukwu, 2009; Victor & Akpan, 2015). Under certain meteorological conditions such as temperature inversions, these emissions accumulate, triggering smog episodes and exacerbating risks of respiratory diseases, cardiovascular problems, birth defects, and neurological disorders.

Nigeria, Africa's most populous country, exemplifies these challenges and is ranked 23rd globally for poor air quality (IQAir, 2023). Also, Nigeria's reliance on fossil fuels and weak enforcement of emission standards have led to growing pollution burdens. Studies conducted in Lagos, Abuja, and Port Harcourt consistently link vehicular pollution with elevated health risks (Salisu, Fasina, Shodunke, Akanmu, Sanni, & Olorunfemi, 2023; Okobia, Onwuemele, & Adepoju, 2021; Shehu, Suleiman, & Oloyede, 2019). However, mid-sized but fast-growing cities such as Uyo, the capital of Akwa Ibom State, remain under-researched despite experiencing similar growth pressures. Uyo has undergone rapid transformation in the last two decades, marked by spatial expansion, rising vehicle ownership, and a road-dominated transport system. The city's traffic mix includes minibuses, tricycles, taxis, motorcycles, and private cars, many of which operate without emission testing. Roadside trading activities place vendors, commuters, and transport workers in close proximity to exhaust plumes. Compounding the problem is the absence of continuous CO monitoring infrastructure in Uyo, creating a critical data gap on actual concentration levels and their spatiotemporal variations. Vulnerable groups such as traffic wardens, school children,

and street traders are likely to experience the highest exposures, often for prolonged daily durations.

This study therefore, addresses a critical gap in environmental safety research in mid-sized Nigerian cities. By combining field measurements of CO concentrations with traffic volume and meteorological data, it offers a deep understanding of pollution dynamics in Uyo.

2.0 Literature Review

Urban transportation systems are central to economic activity and everyday movement within cities, yet they also represent one of the most significant sources of urban air pollution worldwide. Global environmental assessments continue to show that the transport sector contributes a substantial share of energy-related emissions, with road transport accounting for the largest portion due to its dependence on fossil fuels (United Nations Environment Programme [UNEP], 2022). Among the various pollutants associated with road traffic, carbon monoxide (CO) is particularly important. It is produced through incomplete fuel combustion and is widely used as an indicator of urban air quality conditions (World Health Organization [WHO], 2021). In densely populated cities, where congestion is common, CO emissions are closely tied to vehicular activity and traffic intensity (Seinfeld and Pandis, 2016).

A growing body of empirical research shows that traffic conditions play a major role in shaping carbon monoxide concentrations. Factors such as traffic volume, vehicle speed, and idling time directly influence the amount of emissions released into the atmosphere. Zhang and Batterman (2013), for example, demonstrated that these traffic flow characteristics are strong predictors of roadside pollution levels. More recent evidence from Sub-Saharan Africa supports this relationship. In Hawassa City, Ethiopia, Eneyew et al. (2024) found clear spatial and temporal variations in CO concentrations, with the highest levels recorded along major roads during periods of heavy congestion. Similarly, broader modelling studies indicate that inefficient traffic conditions particularly, stop-and-go movement lead to increased fuel consumption and higher emission levels (Jiang et al., 2025).

In addition to traffic conditions, meteorological factors also play an important role in determining how carbon monoxide behaves in the urban atmosphere. Conditions such as low wind speeds, temperature inversions, and high humidity can limit the dispersion of pollutants, allowing them to accumulate near ground level (Seinfeld & Pandis, 2016; Kumar et al., 2021). This interaction between emissions and weather conditions highlights the complexity of urban air pollution and the need to consider multiple influencing factors. The health effects of carbon monoxide exposure are well documented. As a colourless and odourless gas, CO poses a significant risk because it binds with haemoglobin in the blood, reducing the body's ability to transport oxygen (WHO, 2018). Even short-term exposure can lead to symptoms such as headaches, dizziness, and reduced mental clarity, while prolonged exposure has been linked to more serious cardiovascular and neurological conditions (Raub et al., 2000). These risks are especially pronounced in developing countries, where many people live and work close to busy roads and where environmental regulations are often not strictly enforced (Amegah and Agyei-Mensah, 2017).

The link between transport systems and air pollution is further influenced by the structure of the built environment. Urban form, land-use patterns, and road network design all affect how pollutants are generated and dispersed Salisu, Babatunde, Akanmu, Sanni & Olorunfemi (2025). Also, Marshall et al. (2005) showed that compact urban development, when not supported by adequate transport infrastructure, can increase exposure to traffic-related pollution. In a similar vein, Chen et al. (2017) found that high-density urban areas often experience higher emission concentrations due to increased traffic demand and limited dispersion capacity. At the street level, physical features such as building height and road width also matter. The "street canyon" effect, where tall buildings line narrow roads, can restrict airflow and trap pollutants, leading to higher concentrations at pedestrian level (Xie et al., 2009).

In many cities across the Global South, informal economic activities are concentrated along busy roads, meaning that low-income populations often face greater exposure risks (Amegah and Agyei-Mensah, 2017). This highlights the importance of considering social factors when assessing environmental risk. Also, across the Global South and Sub-Saharan Africa, traffic-related air pollution has become a major environmental and public health concern. Rapid urban growth and increasing motorization have led to rising emission levels in many cities. At the same time, challenges such as weak institutional frameworks, poor vehicle maintenance, and the widespread use of older vehicles contribute to higher emission rates (Schwela, 2012). Recent studies using both satellite and ground-based data confirm that carbon monoxide concentrations in many African cities frequently exceed recommended safety limits, particularly along busy traffic corridors (Eneyew et al., 2024).

In Nigeria, the situation reflects many of these broader trends. Road transport dominates urban mobility, and vehicular emissions are widely recognized as the primary source of carbon monoxide in most cities. This is driven by rapid urbanization, increasing vehicle ownership, and the heavy reliance on imported second-hand vehicles (Akanmu, Gbadamosi & Omole, 2022; Odesanya, 2021; Abam and Unachukwu, 2009). Studies conducted in cities such as Lagos show that traffic congestion, vehicle age, and fuel quality are key factors influencing emission levels (Akanmu & Salisu, 2024; Okedere et al., 2021; Akinfolarin et al., 2017). However, despite these insights, many medium-sized cities remain under-studied, leaving important gaps in understanding how emissions vary across different urban contexts.

Uyo is a clear example of a rapidly growing city where these challenges are becoming more visible. Increasing traffic volumes along major roads, combined with the widespread use of informal transport modes such as minibuses and tricycles, contribute to rising carbon monoxide emissions. At the same time, commercial activities and pedestrian movement are heavily concentrated along these corridors, increasing the level of human exposure to pollution. Despite this, the city lacks a continuous air quality monitoring system, making it difficult to obtain reliable data on emission levels and exposure patterns. This lack of data limits the ability of policymakers to respond effectively to environmental and public health concerns.

Most existing air quality assessment models are designed for cities with well-established monitoring systems and detailed transport data (United States Environmental Protection Agency [USEPA], 2020). Such conditions are often absent in cities like Uyo, where informal transport systems, mixed land-use patterns, and weak

regulatory enforcement shape the urban environment. As a result, these models may not fully capture local realities. However, recent advances in environmental monitoring provide new possibilities. Studies have shown that portable sensors, combined with geospatial technologies and traffic data, can be used to generate detailed and reliable air quality assessments even in data-limited settings (Okedere et al., 2021; Wang et al., 2021). Taking all these factors into account, there is a strong need for a context-specific carbon monoxide emission and environmental safety risk model for Uyo. Such a model should bring together information on traffic patterns, built environment characteristics, and socio-demographic exposure. By using locally relevant data and appropriate analytical tools, it would be possible to develop a clearer and more accurate understanding of emission patterns and associated risks. Ultimately, this would support better decision-making in urban planning, environmental management, and public health, helping to improve environmental safety in the city.

2.1 Gaps in Existing Air Quality and Emission Assessment Frameworks

Existing air quality and emission assessment frameworks exhibit significant limitations when applied to developing urban contexts, particularly in African and Nigerian cities. Most global emission models are designed on the assumption that there are robust, continuous air quality monitoring systems and comprehensive transport datasets. However, such infrastructure is largely absent or underdeveloped in many cities within the Global South, thereby limiting the applicability and accuracy of these models in such environments (USEPA, 2020).

In addition, many of these frameworks inadequately account for the prevalence and influence of informal mobility systems, which constitute a substantial component of urban transportation in African cities. Modes such as minibuses, motorcycles, and informal shared transport systems are often excluded or poorly represented in conventional emission models, despite their significant contribution to urban air pollution patterns (Amegah, 2017). Further shortcomings are evident in the insufficient representation of street-level characteristics that influence pollutant generation and dispersion. Elements such as street geometry, roadside trading activities, informal parking practices, and traffic congestion dynamics are rarely integrated into standard modelling approaches. Moreover, existing frameworks tend to overlook variations in human exposure patterns, even though exposure levels differ considerably across socio-demographic groups based on occupation, mobility behavior, and proximity to emission sources.

Another critical limitation lies in the use of generalized emission factors that do not accurately reflect the characteristics of vehicle fleets in African cities. Many models rely on emission factors derived from newer, well-maintained vehicles typical of developed countries, whereas urban centres in Nigeria predominantly rely on older, imported vehicles with differing emission profiles. These limitations collectively underscore the need for more context-sensitive modelling approaches that are tailored to the socio-economic, infrastructural, and environmental realities of cities such as Uyo.

2.2 Conceptual and Theoretical Underpinnings

The conceptual basis of this study is grounded in two complementary frameworks namely the Environmental Risk Assessment (ERA) model and the Urban Environmental Stress Theory **(**UEST**).** Together, they provide a multidimensional understanding of how traffic-induced CO emissions generate environmental safety risks and how urban populations experience and respond to them.

2.2.1 Environmental Risk Assessment (ERA) Framework

Environmental Risk Assessment (ERA) offers a systematic process for identifying, evaluating, and managing environmental hazards that threaten human health and ecological systems. According to the United States Environmental Protection Agency (USEPA, 2022), the ERA framework consists of four key components namely hazard identification, dose–response assessment, exposure assessment and risk characterization. Applied to traffic-related CO emissions, ERA enables the tracing of causal links from vehicle exhaust **sources** to human exposure and health outcomes. Osei and Antwi (2023) demonstrated this approach in **Accra,** Ghana**,** mapping pollution hotspots against vulnerable populations, while Adebayo et al. (2022) applied it in Lagos**,** Nigeria, emphasizing its usefulness in identifying health risk thresholds among roadside vendors and commuters.

In the present study, ERA is employed to model the relationship between traffic volumes, CO concentration levels, and exposure durations in Uyo. This framework supports quantitative estimation of safety risks and provides a foundation for evidence-based mitigation strategies.

2.2.2 Urban Environmental Stress Theory (UEST)

The Urban Environmental Stress Theory (UEST) extends the ERA framework by introducing a socio-psychological dimension to environmental exposure. Originating from ecological psychology, UEST posits that environmental stressors such as noise, congestion, and air pollution interact with human coping mechanisms. When these stressors exceed adaptive capacity, they result in physiological strain, mental fatigue, and reduced productivity (Evans and Cohen, 1987; Braubach and Fairburn, 2010).

Recent studies have applied UEST to urban air pollution contexts. Kanyiwa et al. (2022), for example, linked chronic exposure to traffic emissions in Harare**,** Zimbabwe**,** with increased cardiovascular stress among commuters. In Port Harcourt**,** Nigeria, Nwachukwu and Ekanem (2021) found that prolonged exposure to vehicular pollutants heightened respiratory illnesses and reinforced residents' perceptions of environmental insecurity. For Uyo, where urbanization has outpaced infrastructure development, UEST provides a lens for understanding how chronic CO exposure translates into cumulative stress among vulnerable groups such as schoolchildren, traffic wardens, and traders.

Meanwhile, the integration of ERA and UEST establishes a holistic framework for this research. While ERA offers the quantitative risk assessment of CO exposure,

UEST provides the qualitative interpretation of its social and psychological implications. Conceptually, the relationship can be expressed as:

Traffic Volume → CO Emissions → Human Exposure → Physiological and Psychological Stress → Environmental Safety Risks.

This causal chain underscores that traffic-induced CO emissions are not solely an air quality issue but a multidimensional urban safety concern. For Uyo, where regulatory and monitoring systems remain underdeveloped, applying this integrated framework allows for both empirical quantification and socio-environmental interpretation of risks essential steps toward designing resilient, health-conscious urban transport policies.

3.0 Materials and Methods

3.1 The Study Area

Uyo metropolis is located between longitudes 7°54′ and 8°00′ East of the Greenwich Meridian and latitudes 4°59′ and 5°14′ North of the Equator (Figure 1). The study area extends over a radius of approximately 15 kilometers and shares boundaries with several Local Government Areas (LGAs): Nsit Ibom, Etinan, and Ibesikpo Asutan to the south; Uruan and Nsit Atai to the east; Itu and Ibiono Ibom to the north; and Abak and Ibiono Ibom to the west. As the administrative capital of Akwa Ibom State, Uyo occupies a strategically central position, interfacing with six adjoining LGAs—Etinan, Uruan, Itu, Ibiono Ibom, Nsit Ibom, Nsit Atai, Nsit Ubium, and Ibesikpo Asutan. This centrality enhances its role as a major administrative, commercial, and transportation hub within the state. The city is well connected by an extensive network of roads linking it to nearby towns such as Abak, Itu, Ikot Ekpene, Oron, Eket, and Etinan. Improved road infrastructure across these corridors has significantly reduced travel time, allowing access to most parts of the state within an hour's drive. Additionally, the Aba–Calabar Highway, which traverses the northwestern flank of the metropolis, further strengthens Uyo's regional accessibility and mobility connections.

The designation of Uyo as the capital of Akwa Ibom State on September 23, 1987, marked a major milestone in its urban evolution. Its favourable central location made it the natural choice for the state capital, catalysing rapid economic growth, administrative expansion, and infrastructural development. Over the years, these developments have led to increased vehicular traffic and intensified land-use activities within the metropolis. The growth of governmental institutions, commercial establishments, and residential neighbourhoods has generated higher mobility demands and, consequently, traffic congestion. This steady rise in vehicular movement underscores the importance of effective transportation management and air-quality monitoring as essential components of sustainable urban planning in Uyo.

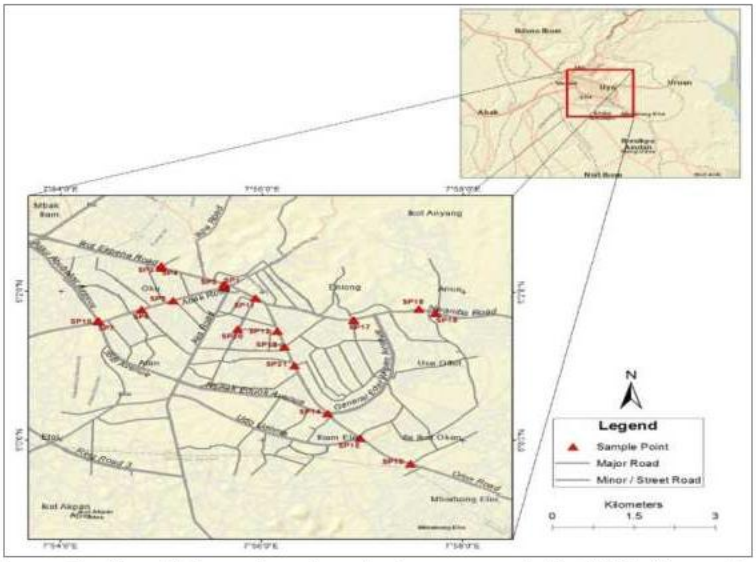


Figure 1: Uyo Urban showing study area and Air Pollution points

3.2 Methodology

The study employed a mixed-method approach combining primary and secondary data to assess the influence of vehicular traffic and meteorological factors on ambient carbon monoxide (CO) concentrations in Uyo Metropolis. Field data collection was conducted in February (dry season) and December 2024 (wet season) to capture seasonal variations in pollution patterns and meteorological dynamics. Also, Traffic volume data were obtained through manual counts at 19 strategically selected road locations (see Table 1.3), representing different land-use functions and traffic densities across the city. Counting was done at three distinct time intervals:

i. Morning peak: 7:30 a.m. – 10:30 a.m.
ii. Afternoon off-peak: 12:30 p.m. – 2:30 p.m.
iii. Evening peak: 4:30 p.m. – 7:30 p.m.

Vehicles were categorized into motorcycles, tricycles, minibuses, private cars, and heavy-duty trucks to facilitate source attribution of emissions. This approach follows standard transport emission assessment protocols (Sharma and Dixit, 2018; Abam and Unachukwu, 2009). Also, the ambient CO concentrations were measured at each of the 19 sites using a Gasman Auto-Sampler (electrochemical sensor, range: 0–100 ppm, accuracy: ±5%). Measurements were recorded at two vertical heights — 2 m (breathing height) and 5 m above ground — to evaluate human exposure at different levels as in table 1.1. The instrument was positioned 2 m away from the nearest traffic lane to avoid direct exhaust plumes while maintaining representative roadside conditions. Measurements were conducted concurrently with traffic counts during all three time periods, ensuring temporal consistency. The geographical coordinates of each site were obtained

using a Global Positioning System (GPS) device for spatial mapping and interpolation.

In addition, the meteorological variables including temperature (°C), relative humidity (%), atmospheric pressure (hPa), wind speed (m/s), and wind direction were obtained from the Nigerian Meteorological Agency (NiMet) station in Uyo. These were supplemented by on-site measurements recorded during sampling periods using portable weather sensors. Also, secondary spatial data were obtained from the Akwa Ibom State Ministry of Lands and Town Planning, including an updated Uyo urban base map and road network data. These were digitized and processed in ArcGIS 10.8, enabling the overlay of traffic, CO concentration, and meteorological variables for spatial analysis.

4.0 Results and Discussion

4.1 Data Analysis

4.1.1 Descriptive Statistics

Descriptive analyses (mean, minimum, maximum, standard deviation, and variance) were computed for traffic volume, CO concentration, and meteorological parameters. These descriptive summaries provided baseline information on urban pollution levels and diurnal variations across locations and heights.

4.1.2 Correlation and Regression Analysis

Pearson's correlation analysis revealed that CO concentration was positively correlated with traffic volume and road width but negatively correlated with atmospheric pressure ($r = -0.51$ at 2 m). Multiple linear regression models indicated strong explanatory power, with adjusted $R^2 = 0.84$ at 2 m and $R^2 = 0.63$ at 5 m, suggesting that near-ground CO levels are more strongly influenced by vehicular activity and micro-meteorological variations. An ANOVA test showed statistically significant differences in CO levels across time periods ($p < 0.05$). Tukey post-hoc tests confirmed that morning peak levels ($M = 5.2$ ppm, $SD = 1.0$) were significantly higher than afternoon off-peak levels ($M = 1.5$ ppm, $SD = 1.3$), while morning and evening peaks did not differ significantly.

4.1.3 Safety Risk Assessment

Measured CO concentrations were benchmarked against the World Health Organization (WHO, 2021) and National Environmental Standards and Regulations Enforcement Agency (NESREA, 2011) air quality limits. Exceedances were observed in some high-traffic corridors during peak periods, particularly at breathing height (2 m), where concentrations occasionally surpassed the WHO 8-hour limit of 9 ppm as in Table 1.2. This indicates potential exposure risks for traffic wardens, roadside traders, commuters, and schoolchildren frequently near busy intersections.

Table 1.1: Weighted data from the field

Site	Latitude	Longitude	Road Width	Temp.	Relative Humidity	Pressure	Wind Speed	Traffic Morning	Traffic Afternoon	Traffic Evening	Daily_Mean_CO_2m_ppm	Daily_Mean_CO_5m_ppm
S01	5.032472	7.917474	10.86	24.39	41.33	1040.83	0.35	3770	4531	4853	11.39	10.43
S02	5.067043	7.936711	9.59	24	67	1045.43	0.4	3758	3089	3259	8.45	6.86
S03	5.05392	7.90837	7.93	25.82	62.84	1042.56	0.36	3796	3706	4933	9.28	9.05
S04	5.04592	7.917529	9.87	24.77	38.82	1041.92	0.39	3502	1866	4318	8.76	7.17
S05	5.019361	7.921982	7.48	24.12	56.14	1044.70	0.23	4357	4939	5300	11.16	10.87
S06	5.01936	7.927364	12.03	24.5	67	1046.67	0.3	2898	4631	3266	9.48	8.41
S07	5.013485	7.947111	8.65	24.3	67	1043.97	0.47	2265	3454	4380	8.29	7.21
S08	5.061971	7.91198	10.75	25.31	67	1044.14	0.37	2185	3563	2892	8.08	6.85
S09	5.046067	7.930854	8.92	25.67	63.59	1047.32	0.25	2463	2208	3465	7.65	5.7
S10	5.052484	7.935545	10	25.91	67	1043.73	0.29	2829	4696	2364	8.68	7.78
S11	5.011235	7.902787	10.14	25.92	40.93	1042.27	0.3	2356	3679	4401	9.62	8.27
S12	5.068195	7.936453	8.26	25.8	50.32	1045.22	0.38	2260	4105	2906	7.68	6.85
S13	5.059947	7.910231	12.34	25.03	56.4	1042.43	0.34	3993	4639	5201	11.98	11.07
S14	5.02274	7.903903	11.33	24.7	31.96	1042.10	0.32	4254	3522	2858	9.89	8.59
S15	5.020909	7.956933	12.19	24	67	1047.02	0.37	2671	5781	2655	9.3	7.87
S16	5.021004	7.957938	11.95	26.08	67	1042.32	0.4	3210	5089	5133	11.53	10.42
S17	5.028255	7.948504	10.41	25.06	57.84	1036.00	0.35	2249	1982	1463	7.79	6.12
S18	5.041485	7.918277	12.09	24.87	47.88	1044.24	0.33	3857	2343	4393	9.47	7.92
S19	5.035917	7.90586	7.76	26.14	30.59	1042.01	0.34	2722	2736	3767	8.27	6.41

Source: Author's field work (2025)

Table 1.2: Comparison of WHO and NESREA CO Ambient Air Quality Standards

Averaging Time	WHO Limit (ppm)	WHO Limit (mg/m^3)	NESREA Limit (ppm)	NESREA Limit (mg/m^3)
1-hour average	25	28.6	35	40.0
8-hour average	9	10.3	10	11.4
24-hour average	—	—	10	11.4

Source: WHO (2021); NESREA (2011)

4.1.4 Spatial Analysis

Given that CO data were collected at discrete GPS points, Empirical Bayesian Kriging (EBK) Regression Prediction was applied in ArcGIS to generate continuous concentration surfaces for both 2 m and 5 m levels. Predictor variables identified as significant in the regression analysis were incorporated into the EBK model to enhance spatial prediction accuracy. The interpolated maps revealed spatial clustering of high CO levels along major road corridors and commercial intersections (e.g., Ikot Ekpene Road, Aka Road, and Oron Road). Concentrations were notably higher near the city core and declined outward toward peri-urban and rural fringes. The near-ground CO surface (2 m) showed higher pollutant accumulation compared to elevated levels (5 m), indicating limited dispersion at pedestrian height.

4.2 Spatio-Temporal Implications

4.2.1 Implications for Residents and Public Health

The spatio-temporal pattern of CO distribution in Uyo suggests disproportionate exposure risks among residents living or working near major traffic corridors. The implications are:

i. Morning and evening peaks correspond to commuting hours, when exposure intensity is highest.
ii. Roadside traders, transport workers, schoolchildren, and traffic wardens are particularly vulnerable, as they spend prolonged periods within 2–3 m of active emission sources.
iii. The higher CO concentrations at breathing height (2 m) imply that pedestrians inhale the most polluted air layers, heightening the risk of hypoxia, cardiovascular stress, and long-term respiratory issues.

Hence, communities adjoining major arterials such as Ikot Ekpene Road, Oron Road, Aka Road, and Abak Road, experience cumulative exposure effects, especially during calm wind and temperature inversion conditions typical of the dry season.

4.2.2 Implications for the Urban Environment

Spatially, the concentration patterns demonstrate that Uyo's road corridors act as linear pollution sources, influencing the microclimate and environmental quality of adjacent neighborhoods. These include;

i. Persistent vehicular emissions contribute to localized heat build-up, reduced air quality, and potential urban heat island intensification.

ii. Pollutant deposition on roadside vegetation and infrastructure accelerates biological stress and material corrosion, respectively.
iii. The limited dispersion of CO during low wind speeds implies that pollutants may linger in built-up zones, affecting urban livability and ecological balance.

Temporally, seasonal analysis indicates that the dry season exhibits higher pollutant accumulation due to reduced humidity, lower atmospheric mixing, and greater traffic intensity. In contrast, the wet season promotes partial pollutant washout, resulting in temporarily cleaner air but not eliminating chronic exposure risks.

4.2.3 Broader Planning Implications

These findings underscore the necessity for:

i. Integrating air quality monitoring into Uyo's urban transport planning framework.
ii. Designating low-emission zones (LEZs) around high-traffic areas and sensitive land uses (schools, markets, hospitals).
iii. Promoting non-motorized transport corridors and periodic vehicle emission inspections.
iv. Implementing urban green buffers and tree belts along major corridors to aid pollutant absorption.

Table 1.3: Descriptive Statistics of Measured Variables

Period	N	Range	Min	Max	Mean	Std. Dev.	Variance
Traffic (Morning)	19	2172	2185	4357	3126.05	751.82	565226.5
Traffic (Evening)	19	3837	1463	5300	3779.32	1098.7	1207141
Traffic (Afternoon)	19	3915	1866	5781	3713.63	1134.88	1287956
Daily Mean Traffic	19	2967.33	1898	4865.33	3539.67	720.6	519268.3
Road Width (m)	19	4.86	7.48	12.34	10.13	1.62	2.63
Temperature (Â°C)	19	2.14	24	26.14	25.07	0.74	0.55
Relative Humidity (%)	19	36.41	30.59	67	55.14	12.91	166.67
Atmospheric Pressure (hPa)	19	11.32	1036	1047.32	1043.41	2.6	6.74
Wind Speed (m/s)	19	0.24	0.23	0.47	0.34	0.06	0
CO @ 2m (Morning)	19	6.53	6.47	13	9.48	1.66	2.76
CO @ 2m (Afternoon)	19	7.33	4.42	11.75	7.73	2.16	4.67
CO @ 2m (Evening)	19	5.98	7.57	13.55	10.69	1.98	3.93
Daily Mean CO @ 2m	19	4.33	7.65	11.98	9.3	1.36	1.84
Daily Mean CO @ 5m	19	5.37	5.7	11.07	8.1	1.63	2.65

Source: Author's statistical analysis (2025)

4.3 Spatial Distribution of Carbon Monoxide Concentrations

Figure 1.2 presents the spatial distribution of carbon monoxide (CO) concentrations (mg/L) across Uyo's urban core, interpolated from the 19 field sampling points using Empirical Bayesian Kriging (EBK) regression prediction. Sample points (SP1–SP21) are shown as red dots, overlaid on the road network. Concentrations range from 2.95 mg/L in the peripheral, low-traffic zones to 5.50 mg/L along central arterial roads. The spatial pattern shows a clear association between elevated CO levels and the major transportation corridors. Hotspots are concentrated around SP20, SP14, and

SP1locations characterized by high vehicular density and frequent congestion whereas peripheral areas such as SP7, SP16, and SP18 display comparatively lower levels. These hotspots often coincide with traffic junctions, bus terminals, and road segments with persistent stop-and-go movement, which promotes localized emission build-up.

This spatial trend is consistent with the statistical analysis results. Pearson correlation coefficients revealed a strong positive relationship between daily mean traffic volume and CO concentration at both 2 m ($r = 0.78$) and 5 m ($r = 0.72$) heights, as well as a moderate positive correlation with road width ($r = 0.63$ for both heights). Conversely, atmospheric pressure showed a negative association with CO at 2 m ($r = -0.51$), suggesting that lower pressure conditions may facilitate pollutant accumulation. The multiple regression models explained 84% of the variance in CO concentration at 2 m and 63% at 5 m, confirming that traffic intensity and roadway characteristics are significant predictors of spatial CO variability.

From a public health perspective, the map underscores the risk zones where short-term CO concentrations approach or exceed WHO/NESREA guideline thresholds. Populations living or working within these high-exposure corridors are particularly vulnerable, especially during morning and evening peak periods when measured CO levels were statistically higher (ANOVA, $p < 0.001$). This spatial-statistical alignment highlights the urgent need for targeted interventions such as traffic decongestion strategies, promotion of mass transit, and installation of vegetative buffers—to mitigate localized CO exposure.

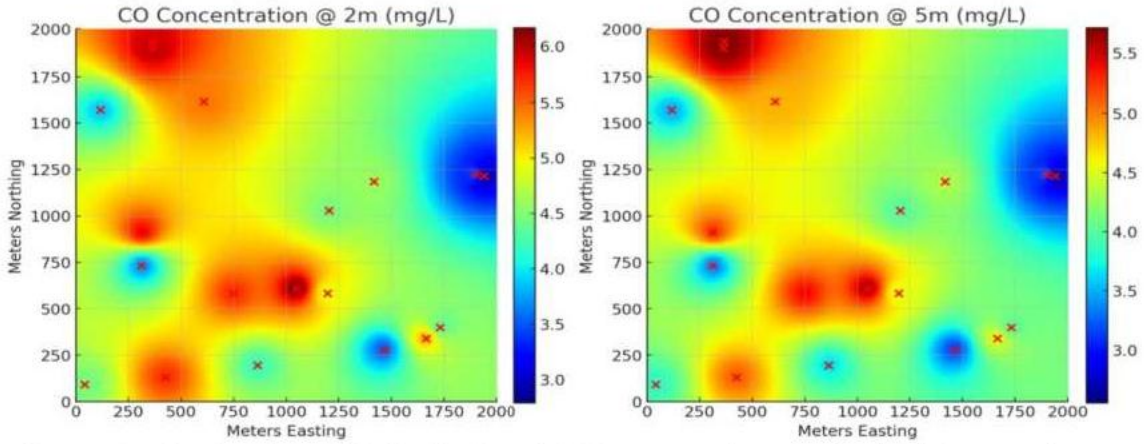


Figure. 1.2 Showing the spatial distribution of (CO) concentrations 2 and 5 (mg/L) across the Uyo urban area

4.4 Spatial Distribution of CO Concentrations

The simulated maps of carbon monoxide (CO) distribution (Figure 1.2 (a)–(b) provide a spatially explicit depiction of pollutant variability across the study area. Visual interpretation reveals distinct concentration gradients that correspond with traffic intensity patterns and localized meteorological influences. The highest CO

concentrations are spatially clustered along major arterial roads, roundabouts, and commercial hubs, particularly in proximity to the central business district (CBD). This aligns with existing evidence that vehicular emissions constitute the primary source of CO in urban Nigerian environments (Akinyemi et al., 2021; Eze et al., 2023). Notably, the maps show concentration hotspots coinciding with areas of persistent traffic congestion, such as major intersections and bus terminals. In these locations, reduced vehicle speeds, frequent idling, and high traffic density likely result in incomplete combustion, thereby elevating CO levels (Odesanya, 2021; Ajayi & Balogun, 2020). By contrast, peripheral zones with lower traffic volume and more open terrain exhibit markedly lower CO values, reinforcing the role of vehicular activity as a spatial driver of pollutant distribution.

Meteorological factors also appear to influence the observed patterns. Areas experiencing low wind speeds during the sampling period show less dispersion and consequently higher localized concentrations, as evidenced by the denser plume shapes in the simulations. Conversely, zones with higher wind speeds and open-air corridors demonstrate more diffuse CO spread, suggesting enhanced pollutant dilution (Olowosegun et al., 2022). The simulated spatial gradients in Figure 1.1 (a) –(a) are consistent with measured point data, indicating that the modelling approach effectively captured the interplay between traffic volume, urban morphology, and atmospheric conditions. These results corroborate similar findings in other African urban contexts, such as Accra (Dartey et al., 2020) where high-traffic corridors exhibit pollutant levels exceeding WHO air quality guidelines. The visual outputs are particularly valuable for identifying high-risk exposure zones, supporting targeted mitigation interventions such as improved traffic management, vehicle emission inspections, and roadside vegetation buffers.

5.0 Conclusion and Recommendations

This study provides a comprehensive analysis of carbon monoxide (CO) emissions in Uyo Urban, Akwa Ibom State, revealing that traffic volume and road characteristics are significant determinants of CO concentration. The highest levels were consistently recorded along major transport corridors such as Oron Road, Ikot Ekpene Road, and Abak Road, particularly during morning and evening rush hours when traffic density peaks. A strong correlation was observed between traffic congestion, road width, and CO concentration, with measured levels ranging from within to above the World Health Organization (WHO) ambient air quality standards.

Overall, the air quality status of Uyo is poor, exposing residents especially commuters, traders, traffic wardens, and school children to heightened health risks, including respiratory and cardiovascular complications, due to prolonged exposure. The findings also indicate a rising trend in CO concentrations during the period, consistent with global and national trajectories, and strongly linked to rapid motorisation, poorly regulated vehicle emissions, and weak traffic management practices.

As Uyo continues to expand in spatial extent, population density, and economic activity, the challenge of traffic-induced CO pollution is likely to intensify, further straining public health and environmental sustainability. The findings highlight the urgent need for integrated interventions such as stricter vehicle emission regulations,

improved traffic management, investment in sustainable transport alternatives, expansion of urban greenery, and the incorporation of air quality monitoring into city planning. These measures, if effectively enforced, will play a vital role in mitigating CO pollution, improving urban air quality, and safeguarding the health and well-being of Uyo's residents.

Based on the findings of this study, the following recommendations are proposed to mitigate the impacts of carbon monoxide (CO) pollution in Uyo and promote a cleaner, healthier urban environment:

i. Strengthen Traffic Management and Emission Control: Since vehicular traffic is the dominant source of CO emissions in Uyo, there is an urgent need to strengthen emission regulations and vehicle inspection programs. Enforcement of stricter emission standards, coupled with routine maintenance checks, will ensure that vehicles on the road meet acceptable environmental standards. Furthermore, the adoption of intelligent traffic management systems such as adaptive traffic lights, synchronized signal controls, and improved road network design will help reduce congestion and idling emissions. Encouraging high-occupancy vehicle (HOV) lanes and promoting the use of cleaner and more efficient public transport systems, cycling, and pedestrian-friendly infrastructure can further reduce dependence on private cars.

ii. Expand Urban Green Infrastructure and Pollution Buffer Zones: Urban greenery plays a crucial role in absorbing and dispersing CO and other traffic-related pollutants. The Uyo metropolis should prioritize the development of tree-lined streets, roadside vegetation, and designated green buffer zones along major traffic corridors such as Oron Road and Ikot Ekpene Road. Expanding parks, urban forests, and vegetative barriers near schools, hospitals, and markets will improve air quality and enhance the city's ecological resilience while providing thermal comfort and aesthetic benefits.

iii. Establish Integrated Air Quality Monitoring and Forecasting Systems: An integrated and real-time air quality monitoring network should be established across strategic locations in Uyo. These systems should be linked to meteorological parameters such as wind speed, temperature, and humidity to enable comprehensive analysis and prediction of pollution patterns. The integration of predictive models will allow authorities to identify pollution hotspots, issue public advisories, and implement short-term interventions during periods of high CO concentration.

iv. Enhance Public Awareness and Community Participation: Public education and awareness are essential for achieving sustainable reductions in CO emissions. Environmental health campaigns should be conducted in schools, markets, and motor parks to inform residents about the dangers of carbon monoxide exposure and preventive measures. Community-level initiatives promoting carpooling, the use of fuel-efficient or hybrid vehicles, and the reduction of generator use can collectively contribute to lowering urban CO levels.

v. Promote Clean Energy Transition and Long-Term Policy Frameworks: Long-term mitigation requires a gradual transition from fossil fuel dependence to clean and renewable energy sources. Policies encouraging the adoption of solar energy,

improved energy efficiency standards, and the introduction of electric mobility should be prioritized. Collaboration between local, state, and federal governments as well as partnerships with international environmental and energy agencies will be essential in mobilizing technical expertise and financial resources to support sustainable energy transitions in Uyo.

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