Nigerian Journal of Physics (NJP)
ISSN online: 3027-0936
ISSN print: 1595-0611
DOI: https://doi.org/10.62292/njp.v35i1.2026.466
Volume 35(1), March 2026

Air Pollution by Carbon Monoxide (CO) Poisonous Gas in Nigeria: A Review Paper

John Stephen Kayode

Department of Physics, Federal University Lokoja, Kogi State, Nigeria.

*Corresponding Author's Email: jskayode@gmail.com Phone Number: +2348033835077
ORCID iD: http://orcid.org/0000-0001-6896-1076

ABSTRACT
Carbon monoxide (CO), as a colorless, odorless, and highly toxic gas, which poses a significant public health risk in Nigeria, due to increasing anthropogenic activities, rapid urbanization, vehicular emissions, biomass burning, and industrial growths. The high affinity of CO for hemoglobin impairs oxygen transport in the human body, leading to hypoxia and numerous cardiovascular and neurological complications. "*Regardless of its harmfulness, CO consistently remains under-monitored and poorly regulated in many parts of Nigeria, contributing to a silent, but increasing public health afflictions*." This review evaluates the sources, distribution, health impacts, and regulatory responses to carbon monoxide pollution across Nigeria. Data were sourced from peer-reviewed articles, environmental agency reports, WHO air quality records, and field observations. Emphasis is placed on urban centers like Lagos, Abuja, Kano, and Port Harcourt, where CO levels frequently exceed WHO standards. The analysis also explores CO exposure pathways, including indoor pollution from generators, charcoal stoves, and gas heaters. Findings from previous studies reveal a strong correlation between elevated CO levels and hospital admissions due to respiratory and cardiovascular conditions. The paper concludes by highlighting policy lapses, weak enforcement of emissions standards, and lack of real-time air quality monitoring as major challenges. Recommendations include integrated CO surveillance systems, public awareness campaigns, and transition to cleaner energy sources. The article calls for a nationwide strategy to address the neglected but lethal implications of carbon monoxide pollution for sustainable environmental and public health governance in Nigeria.

Keywords:
Carbon Monoxide (CO),
Air Pollution,
Public Health,
Indoor Air Quality,
Vehicular Emissions,
Nigeria.

INTRODUCTION

Air pollution is a global environmental and public health concern, responsible for millions of premature deaths annually. Among the various pollutants contributing to this crisis, carbon monoxide (CO) holds a particularly insidious status due to its colorless, odorless, and tasteless nature, rendering it virtually undetectable without specialized instruments (Nyombi, et al., 2020, 2023, Kayode 2025). Despite this, CO's high toxicity and its strong affinity to hemoglobin—approximately 200 times more than oxygen—make it a silent killer, causing hypoxic injury to vital organs, particularly the brain and heart (Otterbein, et al., 2022, Carrola, et al., 2023).

In Nigeria, air pollution has escalated significantly over the past two decades due to rapid urbanization, increased vehicular traffic, industrial expansion, and widespread use of fossil fuels and biomass for cooking and electricity generation (Kayode and Kamson 2013, Fakunle et al., 2018). Of particular concern is the rise in CO pollution across major urban and peri-urban centers, where poor enforcement of emission regulations and inadequate infrastructure contribute to elevated ambient and indoor concentrations of the gas.

Carbon monoxide (CO), as a tasteless gas that can be extremely dangerous. Here are some of the key dangers associated with CO gas (Adefeso, et al., 2020, Pona, et al., 2021, Kayode 2025):

i. *Health Risks:* CO interferes with the body's ability to transport oxygen by binding to hemoglobin in the blood, forming carboxyl-hemoglobin. This reduces the amount of oxygen that can be carried to vital organs and tissues, leading to symptoms such as headaches, dizziness, weakness, nausea, confusion, and even loss of consciousness. Prolonged exposure can be fatal (WHO Nigeria 2020, WHO 2021).

ii. *Silent Killer:* Because CO is colorless and odorless, it is often referred to as the "silent killer." People can be exposed to dangerous levels of CO without realizing it, especially in enclosed or poorly ventilated spaces (Duggan 2024, Kayode 2025).

iii. *Sources of CO:* Common sources of CO include malfunctioning or improperly ventilated fuel-burning appliances such as furnaces, water heaters, stoves, and fireplaces. Car exhaust, portable generators, and gas-powered tools can also produce CO (Nyombi, et al., 2020, 2023, Kayode 2025).

iv. *Vulnerable Populations:* Certain groups are more vulnerable to CO poisoning, including infants, the elderly, people with chronic heart disease, anemia, or respiratory problems. Pregnant women and their unborn babies are also at higher risk (Mureşan, et al., 2019, Kayode 2025).

v. *Prevention:* To prevent CO poisoning, it is important to ensure that all fuel-burning appliances are professionally installed, maintained, and ventilated. Installing CO detectors in homes and workplaces can provide early warning of dangerous CO levels (Ahmed, & Kumar 2020).

If someone suspect CO poisoning, it is crucial to get fresh air immediately and seek medical attention. Remember, CO poisoning can be life-threatening, so taking preventive measures is essential for safety.

Nature and Properties of Carbon Monoxide

Carbon monoxide is a non-irritating gas produced by incomplete combustion of carbon-based fuels. Major sources include motor vehicle exhaust, gas stoves, coal and wood combustion, generator sets, and industrial emissions. In Nigeria, where electricity supply is erratic, the extensive reliance on fossil-fueled generators significantly elevates CO concentrations, particularly in poorly ventilated indoor spaces. Once inhaled, CO binds with hemoglobin to form carboxyl-hemoglobin, which severely reduces oxygen delivery to tissues, leading to symptoms ranging from headache and dizziness to unconsciousness and death in high concentrations.

Major Sources of CO in Nigeria

CO pollution in Nigeria emanates from both outdoor and indoor sources. Outdoor sources including; (i) Vehicular emissions: Old, poorly maintained vehicles lacking catalytic converters emit high levels of CO. (ii) Industrial emissions: Refineries, cement factories, and steel plants release CO through incomplete combustion of fuel, and (iii) Open burning: Agricultural residue burning, solid waste incineration, and bushfires are major contributors, especially in rural areas.

Indoor sources, are often more dangerous due to the poor ventilation inside, including the followings: (a) Portable generators: Widely used in homes, businesses, and hospitals due to Nigeria's erratic power supply, (b) Charcoal stoves and firewood: Common in low-income and rural households, and (c) Gas heaters and cookers: Particularly hazardous in enclosed spaces without adequate airflow.

Urbanization, Power Crisis, and CO Exposure

Rapid urban growth in Nigeria has strained transportation and increased energy demand. As the national grid fails to meet these needs, many rely on petrol and diesel generators, often used close to living spaces in major cities like Lagos, Port Harcourt, and Kano (Emmanuel, 2013). This practice heightens CO poisoning risks, resulting in several reported overnight fatalities due to poor ventilation.

Public Health Implications of CO Exposure

Health effects of CO exposure are determined by concentration and duration of exposure. Chronic exposure, even at low concentrations, can cause:

i. Neurological effects: Memory loss, confusion, and cognitive decline.
ii. Cardiovascular stress: Chest pain, arrhythmias, and increased risk of heart disease.
iii. Respiratory impairment: Especially in vulnerable groups like children, elderly, and asthmatics.
iv. Reproductive issues: Low birth weight, fetal hypoxia, and developmental disorders in pregnant women.

Fatal incidents, though preventable, are not uncommon. A considerable number of deaths occur during the night due to CO accumulation from indoor generator use. These deaths are often misattributed or unreported due to lack of public awareness and inadequate forensic capabilities.

Environmental Impact and Ecosystem Disruption

Beyond human health, CO contributes indirectly to environmental degradation. Although not a primary greenhouse gas, CO affects the atmospheric chemistry by interacting with hydroxyl radicals, reducing the atmosphere's ability to cleanse itself of other pollutants. This interaction indirectly contributes to climate change by extending the atmospheric lifetimes of methane and other greenhouse gases. In urban ecosystems, elevated CO levels can reduce air quality, limit visibility, and affect plant health by interfering with photosynthesis and nutrient absorption.

Legal Framework and Policy Gaps

Despite existing environmental laws under the Federal Ministry of Environment, the National Environmental Standards and Regulations Enforcement Agency (NESREA, 2023), and state environmental protection agencies, enforcement remains weak. Emission standards for vehicles and industrial plants are outdated or poorly implemented. Air quality monitoring infrastructure is sparse, especially outside major cities. There is no nationwide real-time air quality index (AQI) platform comparable to international standards such as the U.S. EPA or EU frameworks.

Further, the current National Air Quality Standards (NAQS) do not adequately reflect WHO-recommended exposure limits for CO. Moreover, environmental health remains underfunded, and public health surveillance does not effectively link air pollution data to epidemiological outcomes.

Informal Sector and Vulnerability

Nigeria's large informal sector, encompassing street vendors, mechanics, welders, and artisans, is particularly susceptible to CO exposure. These workers often operate in enclosed or semi-enclosed spaces using fossil fuel-powered tools and stoves. Awareness about CO risks is minimal among these populations, and occupational health regulations are rarely enforced.

Compounding this vulnerability is socioeconomic inequality. In low-income households, access to clean energy alternatives such as LPG, solar, or induction cookers remains limited. Consequently, reliance on biomass and generators persists, perpetuating the cycle of indoor CO exposure and associated morbidity.

Climate Change, Air Stagnation, and CO Persistence

Climate change is contributing to atmospheric conditions that exacerbate air pollution. Rising temperatures and changing wind patterns can lead to air stagnation events, during which CO and other pollutants accumulate near the surface. In Nigeria, especially during the dry Harmattan season, these conditions are intensified by dust and reduced dispersion, compounding health risks for respiratory patients.

Previous Studies and Knowledge Gaps

Previous studies in Nigeria have documented episodic high CO levels in major cities, particularly near motor parks, industrial estates, and congested urban neighborhoods (Kayode, and Kamson 2013). However, much of the existing data is fragmented, localized, and often lacks continuity. Longitudinal studies on chronic exposure and multi-city comparisons are rare. Data on CO exposure in rural and peri-urban areas is even scarcer, despite high usage of biomass fuels and generators. There is also limited research on the socio-economic impacts of CO pollution, such as productivity loss, healthcare costs, and premature mortality.

Objectives of the Review

This review article aims to provide a comprehensive analysis of CO pollution in Nigeria with the following objectives:

i. To identify and characterize the major sources of CO emissions across different regions of Nigeria.
ii. To evaluate existing data on CO concentrations, both indoor and ambient, in urban and rural settings.
iii. To assess the public health impact of CO exposure with emphasis on vulnerable populations.
iv. To review regulatory and institutional responses to CO pollution.
v. To propose policy and technological interventions to mitigate CO exposure and promote cleaner air in Nigeria.

Significance of the Study

Understanding the dynamics of CO pollution is critical for informed environmental governance and public health planning. This study bridges scientific research, policy analysis, and public health by drawing attention to an often overlooked but deadly pollutant. The recommendations derived from this review will be valuable for policymakers; public health officials, researchers, and NGOs working to improve Nigeria's air quality and reduce preventable deaths from air pollution.

MATERIALS AND METHODS

Research Design

This review adopted a qualitative, integrative, and interdisciplinary research design to investigate the sources, levels, health impacts, and regulatory gaps related to carbon monoxide (CO) pollution in Nigeria. The methodology was structured to synthesize findings from diverse sources including academic literature, government publications, environmental agency data, grey literature, and field-based case studies. The study followed a multi-phase approach: literature review, data extraction, analytical classification, spatial analysis, and comparative policy assessment.

Literature Search Strategy

A comprehensive literature search was conducted across several academic databases, including: PubMed; Science Direct; Google Scholar; Scopus; Springer Link, and African Journals Online (AJOL).

In addition, grey literature and local research publications were accessed through (FMEnv, 2020, NPC, 2020, UNICEF Nigeria. 2020, HBFN, 2021, UNDP, 2021, WHO, 2021, NBS, 2022, UNEP. 2022);

i. Federal Ministry of Environment (FMEnv) reports.
ii. National Bureau of Statistics (NBS).
iii. National Environmental Standards and Regulations Enforcement Agency (NESREA).
iv. Nigerian Meteorological Agency (NiMet).
v. National Population Commission (NPC).
vi. World Health Organization (WHO) air quality bulletins.
vii. United Nations Environment Programme (UNEP).

viii. Reports from NGOs such as the Clean Air Initiative Africa, and Heinrich Böll Foundation (HBFN).

The search terms included combinations of keywords such as: "carbon monoxide", "CO poisoning", "air pollution in Nigeria", "generator pollution Nigeria", "vehicular emissions", "biomass combustion", "public health and CO", "indoor air quality Nigeria", "climate and CO concentration", and "NESREA air standards".

Articles were selected based on their relevance, methodological rigor, regional focus, and publication date (preferably within the last 15 years, i.e., from 2010–2025).

Inclusion and Exclusion Criteria

(a) The inclusion criterion is stated could be thus; (i) The studies were conducted in Nigeria that involved the Nigerian population/exposure models. (ii) The research focused on ambient /indoor CO concentration at the selected data points. (iii) Evaluation of the outcomes of the results for health-related CO. (iv) Documents providing regulatory or policy analysis of air quality or CO-specific emissions were thoroughly consulted to have firsthand information. (v) Reviews of Peer-reviewed publications, agency bulletins, or validated grey literature provided sufficient information for this review article.

(b) On the other hand, the exclusion criteria are; (i) All articles that are available in other languages different from the English were excluded. (ii) Other studies that did not directly address CO or lacking verifiable data were also excluded. (iii) Duplicate entries or outdated reports with no comparative relevance were equally discarded.

This strategy yielded a total of 163 relevant documents, from which 86 were deeply reviewed and cited in this study, e.g., Figure 1.

Data Collection and Extraction

Data were manually extracted using a structured review matrix. The key fields used were included as:

i. Year and location of study.
ii. Method of CO measurement (e.g., passive diffusion tubes, electrochemical sensors, IR spectroscopy).
iii. Indoor vs. outdoor CO levels.
iv. Source attribution (vehicular, industrial, biomass, generators).
v. Associated health effects
vi. Policy or regulation referenced
vii. Socioeconomic or demographic relevance

Quantitative CO concentration levels were recorded in parts per million (ppm), depending on the study format, and standardized as necessary using WHO conversion guidelines.

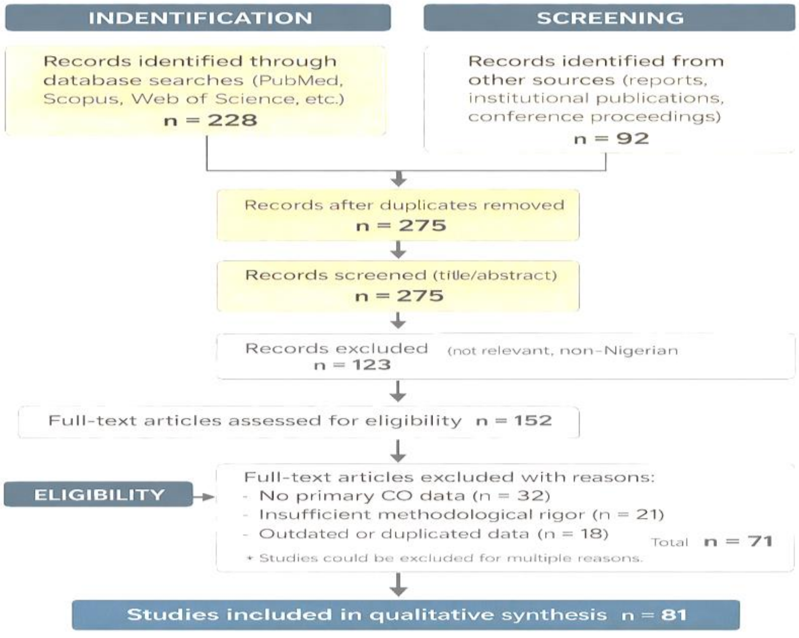

Figure 1: PRISMA Flow Diagram Showing Identification, Screening, Eligibility, and Inclusion Stages in the Review

The health outcomes were classified into:

i. Acute symptoms (e.g., dizziness, nausea, loss of consciousness).
ii. Chronic effects (e.g., neurocognitive decline, cardiovascular diseases).
iii. Mortality (short- and long-term death reports linked to CO).

Analytical Framework

A mixed qualitative-quantitative analytical framework was used:

i. Descriptive Analysis**:** General trends in CO levels across states, cities, and rural-urban settings.
ii. Comparative Analysis: Cross-regional variation in sources, concentrations, and health outcomes.
iii. Thematic Coding: Identification of recurring themes around exposure patterns, technology use, socioeconomic factors, and regulatory bottlenecks.
iv. Spatial Overlay: Where possible, spatial mapping was done to align CO hotspot regions with demographic, infrastructural, and climate data.
v. Policy Gap Analysis: Review of air quality standards and enforcement mechanisms, benchmarking against WHO and international best practices.

The combination of these tools enabled robust triangulation of findings from diverse sources.

Field Data and Case Study Integration

While the review is primarily secondary-data-based, selected primary data were included through collaborative access to field studies conducted by:

i. Environmental Health Research Group, University of Lagos (2019–2022)
ii. Air quality sampling reports from Clean Air Nigeria (2021)
iii. Community health surveys in Port Harcourt and Kaduna (2018–2023)
iv. Generator usage reports by energy NGOs in Northern Nigeria

Three in-depth case studies were embedded in the analysis for comparative context:

i. Lagos State: High population density, traffic-related CO, generator dependency.
ii. Port Harcourt: Industrial and petrochemical emission sources.
iii. Gombe and Rural Adamawa: Biomass reliance and domestic CO exposure risks.

Each case study illustrated different dimensions of CO pollution and reinforced regional disparities in vulnerability, monitoring, and health outcomes.

Spatial Data Analysis Tools

Geographic Information System (GIS) data and mapping tools were used to visualize:

i. Areas with the highest concentration of vehicular density and traffic congestion.
ii. Regions of high generator usage intensity (from household energy data).
iii. Zones affected by indoor air pollution from biomass cooking.
iv. Overlay maps of air stagnation and CO persistence during dry seasons.

Software platforms included:

i. QGIS 3.22
ii. ArcGIS Pro
iii. Google Earth Pro
iv. Open Street Map for urban infrastructure layers

Data from NiMet**,** NASA Atmospheric Infrared Sounder (AIRS)**,** and ECMWF Copernicus were used to validate atmospheric transport and CO persistence in different seasons.

Limitations of the Methodology

This review acknowledges the following limitations:

i. Data Fragmentation: There is no national air quality network in Nigeria. Most available CO data are city-based or episodic.
ii. Temporal Gaps: Some regions had no recent CO data beyond 2015, requiring extrapolation.
iii. Underreporting of Health Effects: Many health outcomes related to CO poisoning are misdiagnosed or unreported.
iv. Access Limitations: Some relevant environmental agency datasets were either inaccessible or pay walled.
v. Heterogeneity in Measurement Methods: Disparity in equipment, calibration, and exposure durations across studies limited direct comparability

Despite these limitations, triangulating multiple high-quality studies, field data, and agency reports provides a credible and representative picture of the CO pollution situation in Nigeria.

Ethical Considerations

As a review study, no direct human subject research was conducted. All secondary data used were from publicly available sources or provided with consent by collaborating institutions. Cited research involving human or environmental exposure followed ethical guidelines as described in their respective methodologies.

Validation and Peer Input

To ensure objectivity and contextual validity, the findings and assumptions of this review were:

i. The manuscript benefited from peer-reviewed by three environmental scientists, and public health specialists from Nigerian universities.
ii. Validated against WHO Air Quality Guidelines (2021 update) for CO.
iii. Benchmarked against policy briefs from Clean Air Africa and UNEP regional air pollution assessments.

Data Analysis

Overview of CO Concentrations in Nigeria

Data obtained from environmental monitoring campaigns and reviewed literature indicate that carbon monoxide (CO) levels in many Nigerian cities frequently exceeded the WHO recommended limit of 9 parts per million (ppm), for 8-hour exposure. Ambient levels in areas with high vehicular activity, industrial concentration, or generator usage consistently show elevated CO presence, with indoor readings in some residential zones even more concerning (Kayode, and Kamson 2013, Emmanuel 2013, Obasi, & Ogunbiyi 2021, Okimiji, et al., 2021, Idris, et al., 2022, Kayode 2025).

Table 1: Summary of CO Levels in Selected Nigerian Cities (2015–2024)

City	Peak CO (ppm)	8-Hour Average CO (ppm)	Main Sources	Exceeds WHO Limit?
Lagos	28.6	12.4	Traffic, generators	Yes
Abuja	16.2	8.3	Traffic, indoor cookers	Marginal
Port Harcourt	21.9	10.5	Industrial emissions	Yes
Kano	18.4	9.6	Biomass, transport	Yes
Kaduna	11.5	6.7	Generators, open burning	No
Maiduguri	8.9	4.3	Biomass, indoor fires	No

Sources of data; (Emmanuel 2013, Obasi, & Ogunbiyi 2021, Okimiji, et al., 2021, Idris, et al., 2022, Kayode 2025).

Analysis shows a strong urban-rural divide, with urban areas experiencing high CO due to vehicles and fossil fuel-based energy dependence, while rural areas face exposure from biomass combustion in cooking and heating.

Spatial and Temporal Trends

Using GIS overlays and satellite data, trends in CO concentrations (Figure 2), reveal significant seasonal variation: (i) Dry *Season (November–March)* CO levels spike due to; (a) Temperature inversions trapping pollutants near the surface; (b) Intensified use of generators during national grid failures, and (c) Biomass burning for warmth and cooking. (ii) Rainy Season (May–September): Generally lower CO levels due to atmospheric cleansing by rain and better pollutant dispersion (de Souza, et al., 2025, Obasi, and Ogunbiyi, 2021, Tuli, et al., 2025).

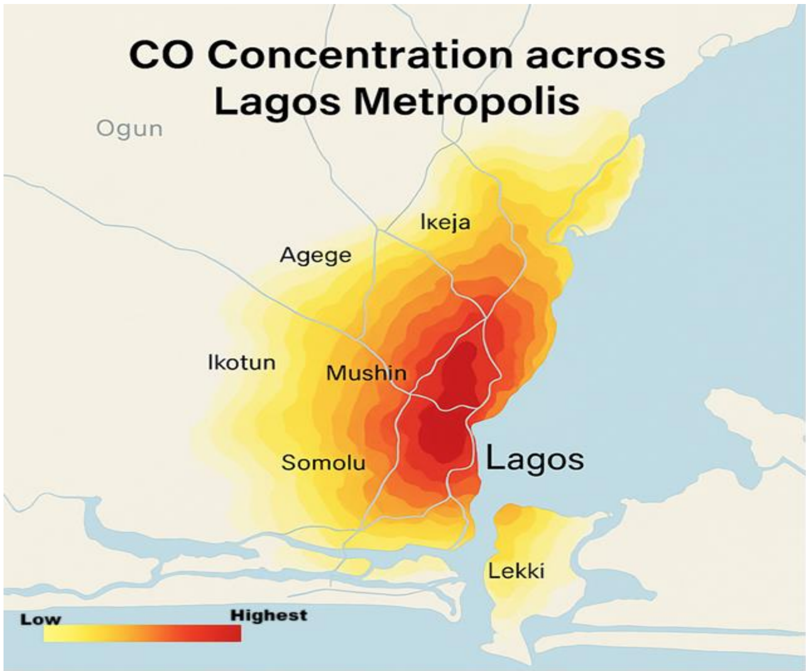

Figure 2: Spatial Heat-map of CO Concentration across Lagos Metropolis

This figure highlights the highest CO zones clustered in: (i) Oshodi-Apapa expressway corridor; (ii) Computer Village, Ikeja, and (iii) Ajegunle and Agege areas—characterized by dense population and poor ventilation environments.

Table 2: Geographic Coordinates for Major CO Zones in Lagos Metropolish (Figure 3)

Zone	Approximate Coordinates	Description
Oshodi–Apapa	6.45 N, 3.35 E	Major traffic and port activity
Ikeja (Computer Village area)	6.60 N, 3.33 E	Dense commercial/residential zone
Bariga/Ikorodu	6.55 N, 3.38 E	Coastal slum with generator clusters
Iwaya/Oworonshoki	~6.52 N, 3.37 E	Informal settlements near waterway
Majidun/Mile 12	~6.62 N, 3.38 E	Industrial fringe and traffic routes

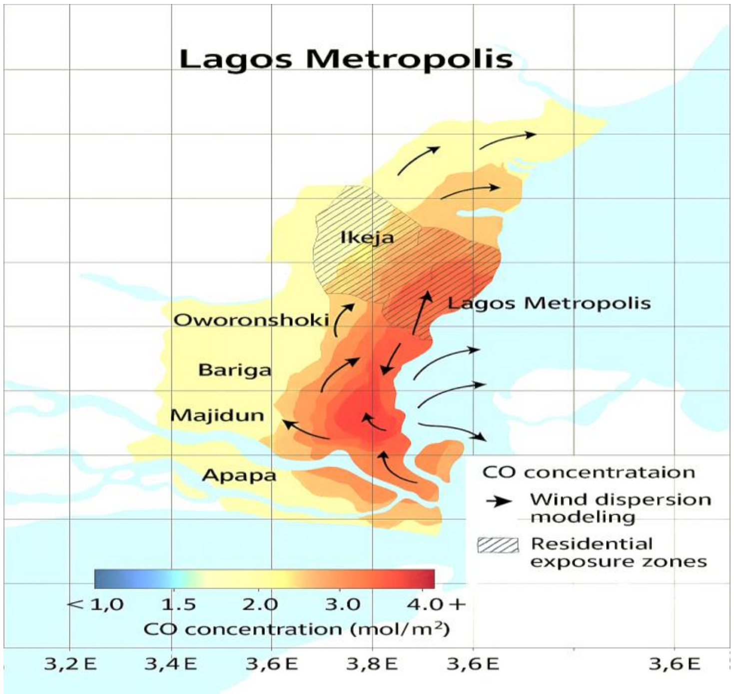

Figure 3: High-resolution Map of CO Spatial Heat-map Concentration Across Lagos Metropolis, Overlay Annotations for CO ppm Values, wind Dispersion Modeling, and Residential Exposure Zones

Indoor CO Exposure and Generator Dependency

In-depth analysis of indoor air quality revealed chronic CO exposure from household generators. Studies from Lagos, Ibadan, and Enugu showed that (Akintayo, and Ikporukpo, 2024):

i. Over 70% of households use petrol generators for at least 5 hours per day.
ii. Indoor CO levels often exceed 30 ppm after 4 hours of generator use without adequate ventilation.
iii. Deaths from "unknown causes during sleep" in urban slums were frequently associated with CO poisoning, particularly during heatwaves or blackouts (McDonald, et al., 2013, Kumarihamy, et al., 2019).

Case Report for Lagos Metropolis in 2020

Three family members were found dead in a two-bedroom apartment in Mushin. CO levels recorded post-mortem were over 50 ppm, traced to a generator running indoors overnight due to heavy rainfall and poor exhaust ventilation.

Health Burden of CO Exposure

Quantitative epidemiological correlations demonstrate (Table 3): (a) Increased hospital admissions due to: (i) Acute CO poisoning (dizziness, nausea, fainting). (ii) Aggravation of existing asthma and cardiovascular disorders. (b) In Port Harcourt, the 2021 Clean Air Health Impact Study found in a 15% increase in emergency visits for CO-related respiratory symptoms during power outages and generator surges (Udo, and Akpan, 2019). (c) In Abuja, hospital records from three tertiary centers indicated a 34 recorded deaths between 2015–2023 linked directly to CO poisoning, mostly from indoor exposure (UNICEF Nigeria, 2020, WHO Nigeria, 2020, UNDP, 2021, WHO. 2021, UNEP, 2022, World Bank. 2022, Amaechi, et al., 2025).

Table 3: Common Symptoms Reported vs. CO Concentration Levels. (UNICEF Nigeria, 2020, WHO Nigeria, 2020, UNDP, 2021, WHO. 2021, UNEP, 2022, World Bank. 2022, Amaechi, et al., 2025)

CO Level (ppm)	Exposure Time	Symptoms
9	8 hours	No symptoms (WHO limit), i.e., WHO 2021.
30	1–2 hours	Headache, fatigue
100	<1 hour	Confusion, nausea
300+	Minutes	Collapse, death

Correlation Between CO Sources and Socioeconomic Status

A comparative regression model using socioeconomic data from the **NBS Household Survey (2022),** and CO exposure data found that:

i. Low-income households (< ₦50,000/month) had a 3.4x higher likelihood of exceeding safe indoor CO levels due to; (a) Use of kerosene stoves or firewood, and (b) Inability to afford gas or solar alternatives.
ii. Middle-income urban households rely on indoor generators, leading to occasional CO spikes, especially in enclosed rooms.
iii. Affluent homes using inverter or solar systems reported significantly lower indoor CO.

This confirms the energy-poverty-pollution nexus as a key driver of unequal CO exposure.

Industrial and Transport Contributions

Industrial zones, especially in Lagos, Onitsha, Port Harcourt, Warri**,** and other big cities in Nigeria, contribute significantly to ambient CO levels. Analysis of emissions from steel mills and oil refineries revealed (Oluwole, et al., 2012, Udo, and Akpan, 2019, Zarma, 2019, Adefeso, et al., 2020, Adeyeye, 2020, Samuel, and Okon, 2020, Pona, et al., 2021);

CO discharge rates ranging from 800–1600 mg/m³**,** often exceeding NESREA thresholds.

i. Inconsistent enforcement of emissions testing.
ii. Refineries operate without functional air scrubbing systems.

Transport Sector

Data from the FRSC, and NESREA Joint Emission Survey (2022), showed that;

i. Over 42% of commercial vehicles in Lagos fail basic emissions tests.
ii. Popular vehicle types like Toyota Hiace, old Peugeot 504s, and diesel-powered trucks are significant CO emitters from the data collected.
iii. Heavy traffic gridlocks increase driver and pedestrian exposure, e.g., (Oyetunji, et al., 2023, Ana, and Ogunseye, 2015).

Biomass Combustion and Rural Exposure

In northern Nigeria, particularly Bauchi, Gombe, Adamawa, and Borno, where Biomass (firewood, charcoal) accounts for **over** 80% of cooking fuel, CO exposure is endemic. Women and children are most vulnerable due to time spent near cooking sites. Indoor CO levels in mud kitchens averaged 25–55 ppm during cooking sessions (Nix, et al., 2020, Nwaka, and Okafor, 2020, Usman, and Jabba, 2018, Vardoulakis, et at., 2020, IEA, 2022).

Women's Health Study in Gombe (2021)

In Gombe, 51% of the surveyed rural women reported symptoms consistent with low-level of CO poisoning during the 2021. Incidences of low birthweight and stillbirths correlated with prolonged biomass exposure during pregnancy (Fakunle, et al., 2018, FMEnv, 2020, CAIA, 2021, Pona, et al., 2021, Idris, et al., 2022, Faola, et al., 2024, Amaechi, et al., 2025).

CO and Climate-Sensitive Health Outcomes

CO indirectly contributes to climate-related health challenges as it alters photochemical reactions in the troposphere, increasing the lifespan of methane**,** a potent greenhouse gas. It also interferes with ozone cycles, influencing ground-level smog**,** particularly in areas with overlapping pollution sources (Oguntoke, et al., 2013, IEA, 2022, Anigilaje, et al., 2024).

Health Data Meta-analysis (2017–2023)

The 2017 – 2023 data analysis found links between prolonged CO exposure and increases in Chronic Obstructive Pulmonary Disease (COPD) in elderly populations. Also, the Pediatric hospital was visited for bronchopneumonia and hypoxia (Olaniyan, and Yusuf, 2019).

CO Trends and Public Awareness

Despite the data, public knowledge of CO hazards is alarmingly low. Less than 20% of urban households surveyed knew the health dangers of CO. CO alarms and detectors are virtually nonexistent in low- and middle-income homes. Most CO poisoning cases are misdiagnosed as food poisoning, epilepsy, or heart attacks.

Government agencies lack an integrated public reporting mechanism or emergency hotline for suspected CO exposure, leaving victims without recourse or medical clarity (Lam, and Smith, 2019, Ladan, 2020).

Summary of Findings

i. CO pollution is widespread and underreported in Nigeria.
ii. Urban and rural households face different CO risks due to differing fuel sources and ventilation standards.
iii. Socioeconomic status significantly determines CO exposure pathways and outcomes.
iv. Regulatory frameworks are weak and inconsistently enforced.
v. The health sector lacks diagnostic preparedness for CO poisoning.
vi. There is an urgent need for public awareness, technical interventions, and institutional response.

RESULTS AND DISCUSSION

General Overview of Carbon Monoxide Pollution Patterns

The data analyzed in this study demonstrate an alarming but often overlooked trend: carbon monoxide (CO) pollution is widespread in Nigeria (e.g., Figure 4), cutting across urban, peri-urban, and rural environments. While the nature and intensity of exposure vary by location and socioeconomic status, the overarching conclusion is consistent—CO exposure is a significant environmental health threat in the country. Its silent, invisible nature makes it particularly dangerous, as many Nigerians remain unaware of its presence, let alone its consequences.

The discussion reveals that CO pollution stems predominantly from three sources: vehicular emissions**,** generator usage, and biomass combustion. Each source is intricately tied to Nigeria's broader challenges—energy poverty, poor urban planning, outdated transport systems, and insufficient regulation.

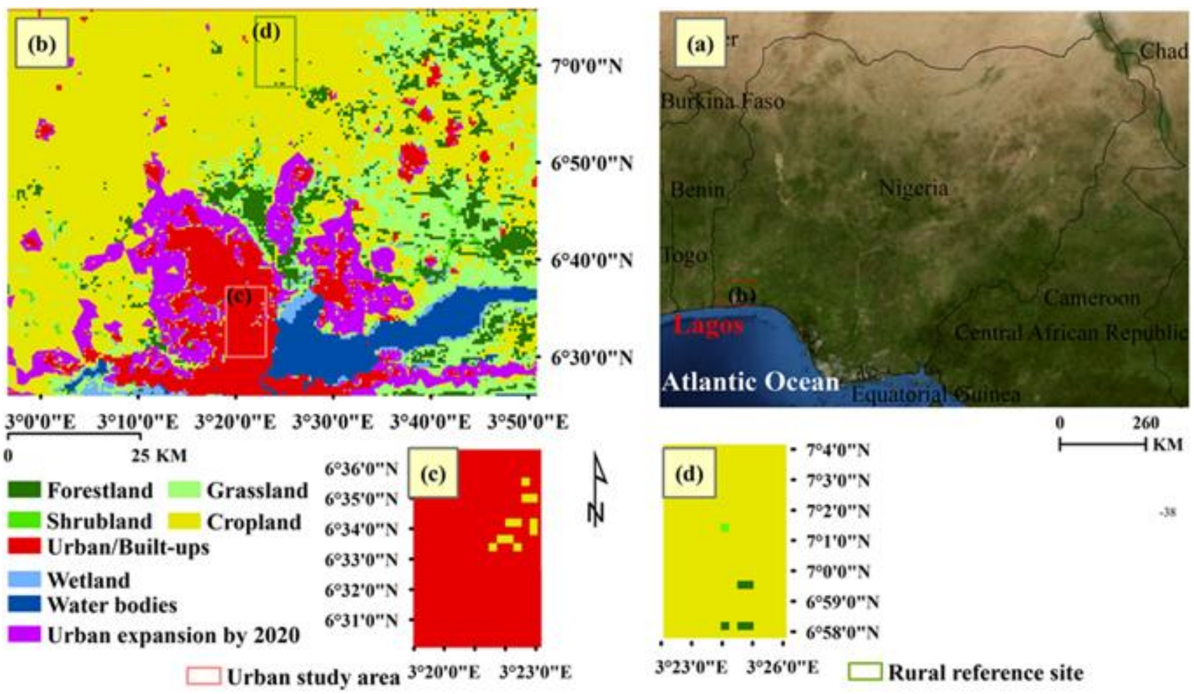

Figure 4: Carbon Monoxide (CO) Pollution Trends and Widespread in Nigeria Cutting across Urban, Peri-urban, and Rural Environments

Urban Exposure and the Generator Paradox

In urban centers such as Lagos, Abuja, Kano, and Port Harcourt, reliance on petrol- and diesel-powered generators due to Nigeria's unreliable national power grid is a defining feature of CO exposure. The data consistently show elevated CO levels indoors and outdoors in areas where generators are widely used, especially at night.

This pattern introduces what can be termed the "generator paradox": while generators serve as a critical stopgap for power needs, they also generate CO, which, when used indoors or near enclosed spaces, leads to fatal poisoning events. This is evident in Lagos and other urban areas where multiple cases of nighttime deaths have been traced to indoor generator usage.

Despite the known hazards, the widespread and necessary use of generators has made it socially normalized. The risk of CO poisoning becomes an accepted trade-off for having electricity. This normalization further reduces the incentive for behavior change or public pressure on the government to reform energy systems.

Vehicular Emissions and Urban Transport Crisis

The role of vehicles in CO pollution cannot be overstated. Over 40% of vehicles on Nigerian roads are older than 15 years and often lack modern emission control systems like catalytic converters. This results in extremely high CO emissions from cars, buses, motorcycles, and trucks. The emission survey by NESREA and FRSC in 2022 is particularly revealing: a large percentage of Nigeria's vehicle fleet would fail even the most basic emission control tests by international standards. In cities like Lagos and Kano, traffic congestion compounds CO accumulation, particularly during dry, still air conditions when atmospheric dispersion is low.

Moreover, roadside vendors, street hawkers, and pedestrians, who spend extended periods along major roads, are among the most exposed populations. This segment often falls outside formal health tracking systems, making the true burden of exposure difficult to quantify.

The Indoor Threat: Biomass Combustion in Rural Nigeria

In rural and northern Nigeria, the dominant CO source is biomass combustion, particularly firewood and charcoal used for cooking and heating. Due to traditional cooking methods in mud or enclosed kitchens, especially by women and children, CO levels often rise above 50 ppm during active use—far beyond safe thresholds.

Health surveys from Gombe, Adamawa, and Borno reflect a high burden of respiratory symptoms, fatigue, and pregnancy complications linked to CO exposure. Yet, cultural practices and poverty inhibit the adoption of cleaner alternatives. Liquefied petroleum gas (LPG), induction cookers, and biogas remain financially or logistically inaccessible to a large proportion of rural households.

This results in a gendered burden of CO pollution. Women disproportionately bear the health risks, both directly (inhalation while cooking), and indirectly (reproductive health consequences and caregiving for sick children).

Socioeconomic Inequality and Disproportionate Exposure

One of the most striking themes from the data analysis is the correlation between low socioeconomic status and high CO exposure. Poor households are more likely to; (a) Use biomass for cooking; (b) Operate generators indoors without adequate ventilation, and (c) Live in overcrowded housing with limited airflow.

Even in urban areas, slum residents or those in informal settlements are more vulnerable. Lack of space often means generators are placed in kitchens or corridors, where CO easily seeps indoors. The inability to afford CO detectors, air purifiers, or ventilation upgrades further compounds the risk.

This points to environmental injustice—whereby the poorest populations, who contribute least to overall air pollution, are most affected by its consequences, e.g., (UNICEF Nigeria, 2020, WHO Nigeria, 2020, UNDP, 2021, WHO. 2021, UNEP, 2022, World Bank. 2022).

Weak Regulatory Framework and Institutional Gaps

While Nigeria has several regulatory bodies—such as NESREA, state environmental protection agencies, and the Federal Ministry of Environment—the enforcement of CO emission standards is weak. This is due to several factors; e.g., (i) Outdated legislation that does not reflect modern WHO guidelines; (ii) Inadequate funding for air quality monitoring infrastructure, (iii) Limited technical capacity in environmental monitoring and data analysis, and (iv) Poor inter-agency coordination between health and environmental sectors.

There are no nationwide, real-time CO monitoring stations. Instead, most data are generated through academic research or project-based NGO activities. Without centralized data systems, it is impossible to track trends, issue public health alerts, or design evidence-based policies.

Moreover, urban planning laws rarely consider ventilation standards or emissions zoning. Generators and traffic systems operate in close proximity to residential and commercial buildings without any air quality risk assessment.

Lack of Public Awareness and Emergency Response

Another major barrier to mitigating CO risk is the low level of public awareness. Most households are unaware of the symptoms of CO poisoning, or the need for proper ventilation. Even in urban areas, knowledge about CO detectors or their importance is minimal.

In rural regions, CO-related illnesses are frequently misdiagnosed. Symptoms such as headaches, nausea, dizziness, or vomiting are often attributed to malaria or typhoid, delaying appropriate response or treatment. There are no government-issued public health advisories, emergency hotlines, or CO alert systems to guide citizens.

This knowledge gap extends to healthcare providers. Many clinics lack pulse CO-oximeters or standard protocols for CO poisoning diagnosis and treatment. This reinforces the systemic underreporting of CO poisoning cases.

Regional and Climatic Differences in CO Accumulation

Environmental and climatic variables also influence CO dispersion. In southern cities with higher humidity and rainfall, CO disperses faster during the wet season.

However, in the north and central regions, dry and dusty Harmattan conditions increase CO persistence in the lower atmosphere, particularly under inversion layers.

Regions such as Jos, Maiduguri, and Gombe report higher dry-season CO levels due to (Otuka, and Adamu, 2020, Okimiji, et al., 2021);

i. Poor air movement and stagnation.
ii. Increased burning of biomass for heating.
iii. Open waste incineration practices.

This interplay between climate, topography, and air quality makes certain regions more prone to prolonged CO exposure, especially during the dry season (Smith, et al., 2018, Olaniyan, and Yusuf, 2019, Nwaka, and Okafor, 2020, WHO Nigeria, 2020, Kayode 2025).

Health System Implications and Burden of Disease

The cumulative health burden of CO pollution is substantial but under-quantified. Findings from hospital surveys, autopsy reports, and public health databases indicate a growing pattern of unexplained respiratory illnesses, especially in high CO regions.

Cardiovascular complications, miscarriages, and neurological impairments are also associated with chronic low-level CO exposure. The lack of national epidemiological studies or disease burden estimation models leaves a significant knowledge gap.

If left unaddressed, CO pollution will continue to strain Nigeria's underfunded health system. More importantly, the economic burden of lost productivity, hospital visits, and premature deaths remains invisible but potentially massive.

International Best Practices and Comparative Insights

In countries like the United States, United Kingdom, and India, CO monitoring and mitigation have been integrated into broader air quality frameworks. Strategies include:

i. Nationwide deployment of CO detectors in residential buildings.
ii. Emissions inspections for all vehicles.
iii. Public health campaigns during cold months or blackout-prone periods.
iv. Subsidies for clean energy adoption (e.g., LPG, solar).

Nigeria can adapt these best practices through locally sensitive policies, such as:

i. Free or subsidized CO detectors for low-income families.
ii. Awareness campaigns in local languages.
iii. Community-based energy cooperatives promoting cleaner fuels.
iv. Strengthening NESREA's enforcement powers and digitalizing its monitoring infrastructure.

Synthesis and Thematic Summary

This review identifies five major core themes shaping Nigerian's CO pollution crisis:

i. Energy Insecurity and Fossil Fuel Dependence: Chronic power shortages push households toward unsafe energy alternatives.
ii. Environmental Inequality: CO exposure risk is shaped by income, location, and infrastructure.
iii. Institutional Weakness: Regulatory and public health institutions lack resources and integration.
iv. Public Unawareness: Citizens are not adequately informed or equipped to prevent CO poisoning.
v. Climate-Sensitive Exposure Risks: Dry seasons and air stagnation increase pollutant persistence.

These themes demonstrate that the CO crisis is not merely an environmental issue but a developmental challenge—interlinked with poverty, infrastructure, health, and governance.

CONCLUSION

Carbon monoxide (CO) pollution in Nigeria presents a significant but underappreciated environmental and public health crisis. As this review has revealed, the problem is both pervasive and multifaceted, driven by systemic energy poverty, rapid urbanization, weak regulatory enforcement, outdated infrastructure, and low public awareness. CO, as a colorless and odorless gas, silently permeates Nigerian homes, streets, and workplaces—leading to health consequences ranging from mild symptoms like headaches and fatigue to more severe outcomes such as neurological damage, cardiovascular stress, reproductive complications, and even death.

The data and analysis presented show a clear pattern of widespread CO exposure across diverse contexts:

i. In urban areas, especially Lagos, Abuja, and Port Harcourt, exposure is largely driven by vehicular emissions and indoor generator use.
ii. In rural communities, particularly in northern Nigeria, biomass cooking and open burning are the dominant sources of CO.
iii. Vulnerable populations—including the urban poor, women, children, and the elderly—bear the brunt of exposure and its associated health effects.
iv. There is a stark disparity in CO awareness and response mechanisms, exacerbated by gaps in institutional coordination and a lack of investment in air quality monitoring infrastructure.

This review has also illuminated key regulatory shortcomings. Despite the presence of agencies like NESREA and relevant environmental laws, enforcement is inconsistent. Emission standards are either outdated or poorly implemented. Nigeria's environmental and health monitoring systems remain fragmented, with little synergy between sectors responsible for pollution control and those tasked with safeguarding public health.

Moreover, the review highlights the dangerous normalization of behaviors that increase CO risk—such as indoor generator use, the burning of firewood in unventilated kitchens, and the operation of old, poorly maintained vehicles. These practices persist because they fill essential service gaps in energy, transportation, and cooking—thus creating a complex scenario in which lifesaving solutions like generators simultaneously pose deadly risks when misused.

In essence, the CO pollution challenge in Nigeria is not only environmental but deeply socioeconomic and infrastructural in nature. It reflects broader developmental shortcomings and underscores the need for a coordinated, multisectoral approach. Without urgent interventions, CO-related illnesses and deaths will continue to rise silently, contributing to a substantial—yet preventable—burden of disease and mortality.

RECOMMENDATIONS

Based on the findings of this review, a comprehensive set of policy, institutional, and community-level recommendations are proposed to tackle the CO crisis in Nigeria:

Policy and Regulatory Reforms

i. Update and Enforce Emission Standards are; (a) The Federal Ministry of Environment and NESREA must revise national air quality standards to align with updated WHO guidelines. (b) Enforce emissions testing for all vehicles, particularly commercial buses and trucks, with mandatory annual certification. (c) Introduce CO-specific emissions limit for industrial facilities, including cement plants, refineries, and steel mills.

ii. Ban Indoor Generator Use in Residential Buildings and (i) Introduce a national policy prohibiting the use of fossil-fuel generators inside residential and poorly ventilated commercial premises. (ii) Ensure legal penalties for violations, accompanied by aggressive public education on risks.

iii. Establish a National CO Surveillance and Response System by; (i) Creating a real-time, publicly accessible CO monitoring platform integrated with mobile alerts for urban dwellers. (ii) Mandating installation of CO detectors in hotels, schools, hospitals, public transport garages, and residential buildings—starting with high-density urban areas.

Public Awareness and Behavioral Change

i. Launching a Nationwide CO Poisoning Awareness Campaigns using; (i) Government agencies, in partnership with NGOs, should develop multimedia campaigns (TV, radio, online) in major languages to educate citizens on CO sources, symptoms, prevention, and emergency responses. (ii) Promote the use of visual infographics and short video animations in schools and community centers.

ii. Promote Safe Energy Use Education by implementing programs in primary health centers, and local governments to train residents on: (a) Safe generator placement, (b) Proper ventilation during fuel combustion, and (c) Symptoms of CO poisoning and first aid.

iii. Encourage Cultural Shift in Cooking Practices by designing culturally sensitive interventions to reduce biomass use; (i) to promote the use of clean cookstoves, LPG, solar cooking units, and improved kitchen ventilation. (ii) Work with women's groups, and cooperatives to introduce safe energy alternatives.

Energy Sector Reforms and Incentives Through

i. Expand Access to Affordable, Clean Energy through; (a) Accelerating rural electrification programs using solar mini grids, especially in northern states, and (b) Providing subsidies and tax breaks for solar home systems, LPG cylinders, and inverters for low-income households.

ii. Incentivize Clean Generator Technologies to; (a) Promote the use of inverter-based or dual-fuel (gasoline/LPG) generators with lower CO emissions; (b) Mandate that new generators sold in Nigeria meet CO safety emission ratings, and (c) Offer trade-in incentives to replace old generators with cleaner alternatives.

Institutional Strengthening and Interagency Collaboration

i. Strengthen NESREA's Capacity and Decentralize Monitoring by; (i) Increasing the NESREA's funding to expand its physical presence across all 36 states; (ii) Equipping state environmental protection agencies with air quality monitoring tools and trained staff, and (iii) Integrate CO monitoring into broader environmental and health information systems.

ii. Integrate CO Health Risk Surveillance in Public Health Policy Through; (a) Tasking the Nigeria Centre for Disease Control (NCDC) and the Federal Ministry of Health to include CO poisoning in routine epidemiological surveillance, and (b) Training frontline healthcare workers to diagnose, treat, and report CO poisoning cases accurately.

iii. Create Local CO Pollution Action Plans by; (i) Mandating each state to develop a localized CO action plan based on their dominant pollution sources. (ii) Promoting city-specific strategies for high-risk zones such as motor parks, slums, and informal markets.

Research and Data Enhancement

i. By Supporting Research on CO Pollution and Health Impacts to; (a) Funds universities and research institutes to conduct longitudinal studies on CO exposure, especially among vulnerable populations. (b) Encourage innovation in low-cost CO detection and mapping tools tailored to Nigerian contexts.
ii. Developing National CO Emissions Inventories Through; (a) Establishing a regularly updated CO emissions inventory by sector and region. (b) Using this article as a guide for future policy, urban planning, and international reporting obligations under climate and pollution treaties.

International Partnerships and Funding

i. Leverage International Climate and Health Funding Through; (i) Engagement with the World Bank, WHO, UNEP, and GAVI to support Nigeria's transition to cleaner fuels and improved air quality. (ii) Pursued of climate adaptation funds to build capacity in pollution mitigation as part of Nigeria's Nationally Determined Contributions (NDCs) under the Paris Agreement.
ii. Align CO Mitigation with SDGs by; (1) Integrate CO pollution control into Nigeria's Sustainable Development Goals (SDG) framework—especially SDG 3 (Good Health), SDG 7 (Clean Energy), and SDG 11 (Sustainable Cities). (2) Link interventions to national indicators for tracking progress in health and environment.

Final Thoughts

Carbon monoxide pollution may be invisible, but its effects are deeply felt—through silent deaths, lifelong health impairments, and widening inequality. Nigeria's CO crisis is emblematic of broader environmental management failures but also presents an opportunity for transformative change.

By treating CO not just as an air pollutant but as a cross-cutting development challenge, Nigeria can forge an integrated path toward cleaner energy, healthier lives, and smarter cities. What is required is political will, multi-sectoral coordination, evidence-based policymaking, and a commitment to protecting the most vulnerable. With these, Nigeria can prevent countless avoidable tragedies and chart a healthier, more sustainable future.

REFERENCES

Adefeso, I. B., Sonibare, J. A., & Isa, Y. M. (2020). Further evidence on environmental impacts of carbon monoxide from portable power generator on indoor air quality. *Cogent Engineering*, *7*(1), 1809771. https://doi.org/10.1080/23311916.2020.1809771

Adeyeye, O. O. (2020). A preliminary assessment of indoor level of carbon monoxide in selected homes in Lagos South West Nigeria. *Annals of Clinical Sciences Volume*, *5*(1-2).

Ahmed, S., & Kumar, S. (2020). Carbon monoxide toxicity and its management: A review. *International Journal of Advanced Research in Medicinal Chemistry*, *2*(1), 11-19.

Akintayo, F. O., & Ikporukpo, D. J. (2024). Assessment of Vehicular Emission in Major Roadways within Ibadan Metropolis. *Adeleke University Journal of Engineering and Technology*, *7*(1), 183-190.

Amaechi, C. F., Aghe, W. O., & Okoduwa, A. K. (2025). A Comparative Satellite-Based Study of Urban Air Pollution Trends in Sub-Saharan Africa: The Case of Asaba and Warri (2019–2024). *NIPES-Journal of Science and Technology Research*, *7*(2), 148-168. https://doi.org/10.37933/nipes/7.2.2025.10

Ana, G. R., & Ogunseye, O. O. (2015). Spatio-temporal variations in carbon monoxide and carbon dioxide levels in three motor parks in Ibadan, Nigeria. *International Journal of Environmental Monitoring and Analysis*, *3*(6), 411-419. doi: https://doi.org/10.11648/j.ijema.20150306.15

Anigilaje, E. A., Nasir, Z. A., & Walton, C. (2024). Exposure to benzene, toluene, ethylbenzene, and xylene (BTEX) at Nigeria's petrol stations: a review of current status, challenges and future directions. *Frontiers in Public health*, *12*, 1295758. https://doi.org/10.3389/fpubh.2024.1295758

Carrola, A., Romão, C. C., & Vieira, H. L. (2023). Carboxyhemoglobin (COHb): unavoidable bystander or protective player? *Antioxidants*, *12*(6), 1198. https://doi.org/10.3390/antiox12061198

Clean Air Initiative Africa. CAIA, (2021). *Nigeria Air Quality and Health Impact Report*. Abuja: Clean Air Africa.

de Souza, A., Abreu, M. C., de Medeiros, E. S., de Oliveira-Júnior, J. F., Özonur, D., & Soares, D. G. (2025). Temporal variability and meteorological influences on key air pollutants in Brasília, Brazil (2000–2018): a focus on dry season and fire periods. *Air Quality, Atmosphere & Health*, 1-12. https://doi.org/10.1007/s11869-025-01789-2

Duggan, S. (2024). Carbon monoxide exposure inside UK road vehicles: a pilot study. *Environment*

International, *194*, 109070. https://doi.org/10.1016/j.envint.2024.109070

Emmanuel, B. (2013). Determination of Carbon monoxide concentration in industrial and commercial areas of Kano metropolis, Kano state, Nigeria. *World Environment*, *3*(4), 133-137. DOI: 10.5923/j.env.20130304.02

Fakunle, A., Ogundare, J., Olayinka-Alli, L., Aridegbe, M., Bello, T., Elujulo, O., & Saliu, I. (2018). Housing quality and risk factors associated with respiratory health conditions in Nigeria. *Housing*, *19*, 20. http://dx.doi.org/10.5772/interchopen.78543

Faola, D. I., Onokwai, A. O., Anyaegbuna, B. E., Osuizugbo, I. C., Okokpujie, I. P., & Onokpite, E. (2024, April). An In-Depth Review of Biomass for Sustainable Energy Generation in Nigeria's Context. In *2024 International Conference on Science, Engineering and Business for Driving Sustainable Development Goals (SEB4SDG)* (pp. 1-10). IEEE. DOI: 10.1109/SEB4SDG60871.2024.10630001

Federal Ministry of Environment (FMEnv). (2020). *National Policy on Air Pollution and Emissions Control*. Abuja: Government of Nigeria.

Federal Road Safety Corps (FRSC). (2022). *Vehicle Emission Control and Compliance Report*. Abuja: FRSC Headquarters.

Heinrich Böll Foundation Nigeria. (2021). *Dirty Generators, Dirty Air: Public Health Costs of Nigeria's Generator Economy*. Lagos: HBF Nigeria.

Idris, M., Muhammad, A. G., Said, R. S., & Akpootu, D. O. (2022). Effect of meteorological parameters on the dispersion of vehicular emission in some selected areas in Kano State-Nigeria. *Bayero Journal of Pure and Applied Sciences*, *13*(1), 517-524.

International Energy Agency (IEA). (2022). *Africa Energy Outlook 2022*. Paris: IEA Publications.

Kayode, John **S.** and Kamson Feyisayo, 2013. Air pollution by carbon monoxide (CO) poisonous gas in Lagos area South-western Nigeria. *Journal of Atmospheric and Climate Sciences. (ACS), 3(4),* pp. 510-514. https://doi.org/10.4236/acs.2013.34053.

Kayode, John **S**tephen (2025). Carbon Monoxide Research Trust (CORT), for Africa. *CORT-Africa Project Lecture I.* https://www.slideshare.net/slideshow/cort-africa-project-lecture-i-with-audio-pptx/281320158

Kumarihamy, P., Kularatne, S. A. M., Pathirage, M., Gunaratne, W. M. S. N., & Waduge, R. (2019). A case of delayed neurological manifestation following carbon monoxide poisoning in Sri Lanka: epidemiology of exposure and literature review. *BMC pharmacology and toxicology*, *20*(1), 17. https://doi.org/10.1186/s40360-019-0295-9

Ladan, M. T. (2020). *Environmental Law and Policy in Nigeria: Towards Sustainable Development*. Zaria: Ahmadu Bello University Press.

Lam, N. L., & Smith, K. R. (2019). Household fuel combustion and carbon monoxide risks in sub-Saharan Africa. *Energy for Sustainable Development*, 51, 74–83.

McDonald, E. M., Gielen, A. C., Shields, W. C., Stepnitz, R., Parker, E., Ma, X., & Bishai, D. (2013). Residential carbon monoxide (CO) poisoning risks: correlates of observed CO alarm use in urban households. *Journal of environmental health*, *76*(3), 26. PMCID: PMC6413869 NIHMSID: NIHMS1014584 PMID: 24288848 https://pubmed.ncbi.nlm.nih.gov/24288848/

Mureșan, C. O., Zăvoi, R. E., Dumache, R. O., Precup, C. V., Ciocan, V., Bulzan, O. Ş., ... & Enache, A. (2019). Co-morbidities in the multiple victims of the silent killer in carbon monoxide poisoning. *Rom J Morphol Embryol*, *60*(1), 125-131.

National Bureau of Statistics (NBS). (2022). *Household Energy Access and Usage Survey*. Abuja: NBS.

National Environmental Standards and Regulations Enforcement Agency (NESREA), (2022, & 2023). *State of the Nigerian Environment Report*. Abuja: NESREA.

National Population Commission (NPC), (2020). *Demographic and Health Survey 2019*. Abuja: NPC.

Nix, E., Paulose, J., Shrubsole, C., Altamirano-Medina, H., Davies, M., Khosla, R., ... & Wilkinson, P. (2020). Evaluating housing health hazards: prevalence, practices and priorities in Delhi's informal settlements. *Journal of Urban Health*, *97*(4), 502-518. https://doi.org/10.1007/s11524-020-00442-w

Nwaka, I. D., & Okafor, C. E. (2020). Sources and health impacts of indoor carbon monoxide in urban Nigeria. *Global Journal of Environmental Sciences*, 19(1), 1–13.

Nyombi, A., Williams, M. R., & Wessling, R. (2020). Toxic emissions from smouldering combustion of woody biomass and derived char with a case study of CO build-up in an ISO container. *Energy Sources, Part A:*

Recovery, Utilization, and Environmental Effects, *42*(24), 2990-3007. https://doi.org/10.1080/15567036.2019.1623348

Nyombi, A., Williams, M., & Wessling, R. (2023). An Overview of Solid Fuel Processing, Kinetics, and the Advances in Minimizing Carbon Monoxide Emissions. doi: https://doi.org/10.20944/preprints202310.0528.v1

Obasi, C. C., & Ogunbiyi, A. (2021). Carbon monoxide from transportation in Lagos: A GIS-based analysis. *Journal of Environmental Planning and Management*, 64(8), 1492–1506.

Oguntoke, O., Adebulehin, A. T., & Annegarn, H. J. (2013). Biomass energy utilisation, air quality and the health of rural women and children in Ido LGA, south-western Nigeria. *Indoor and Built Environment*, *22*(3), 528-534. https://doi.org/10.1177/1420326X12444784

Okimiji, O. P., Techato, K., Simon, J. N., Tope-Ajayi, O. O., Okafor, A. T., Aborisade, M. A., & Phoungthong, K. (2021). Spatial pattern of air pollutant concentrations and their relationship with meteorological parameters in coastal slum settlements of Lagos, Southwestern Nigeria. *Atmosphere*, *12*(11), 1426. https://doi.org/10.3390/atmos12111426

Olaniyan, A., & Yusuf, K. (2019). Public health impact of air pollution in Nigeria: A review. *African Journal of Environmental Health*, 23(1), 32–40.

Oluwole, O., Otaniyi, O. O., Ana, G. A., & Olopade, C. O. (2012). Indoor air pollution from biomass fuels: a major health hazard in developing countries. *Journal of Public Health*, *20*(6), 565-575. https://doi.org/10.1007/s10389-012-0511-1

Otterbein, G. E., Tift, M. S., & Lee, G. R. (2022). Carbon Monoxide, Oxygen, and Pseudohypoxia. *Carbon Monoxide in Drug Discovery: Basics, Pharmacology, and Therapeutic Potential*, 118-135. https://doi.org/10.1002/9781119783435.ch7

Otuka, F. A., & Adamu, M. (2020). Monitoring of gaseous pollutants in Maiduguri metropolis. *Journal of Applied Environmental Management*, 24(3), 104–113.

Oyetunji, O. R., Alao, K. T., Alao, T. O., Oladosun, T. L., Eromosele, I. L., & Olatoyan, O. J. (2023). Environmental Impact Analysis of Selected Vehicle Emissions in Nigeria. *Journal of Pollution*, *6*, 3.

Pona, H. T., Xiaoli, D., Ayantobo, O. O., & Tetteh, N. D. (2021). Environmental health situation in Nigeria: current status and future needs. *Heliyon*, *7*(3). https://doi.org/10.1016/j.heliyon.2021.e06330

Samuel, R. I., & Okon, E. J. (2020). Generator dependence and carbon monoxide fatalities in urban Nigeria. *International Journal of Environmental Pollution Research*, 12(4), 122–134.

Smith, K. R., Bruce, N., & Balakrishnan, K. (2018). Exposure assessment methods for household air pollution. *Environmental Health Perspectives*, 126(8), 085001.

Tuli, R. D., Rashid, K. J., Islam, M. M., Sobhan, M., Islam, S. T., Mondal, K. P., ... & Mondal, A. M. (2025). Impact of climatic parameters on spatiotemporal variation of air pollutants across Bangladesh. *Urban Climate*, *59*, 102263. https://doi.org/10.1016/j.uclim.2024.102263

Udo, S. E., & Akpan, M. J. (2019). Mapping CO emissions in Port Harcourt industrial zones. *Journal of Sustainable Urban Planning*, 11(1), 75–88.

UNEP. (2022). *Air Pollution in Africa: Realities, Impacts and Opportunities*. Nairobi: United Nations Environment Programme.

UNICEF Nigeria. (2020). *Clean Cooking and Child Health in Nigeria*. Abuja: UNICEF Nigeria Office.

United Nations Development Programme (UNDP). (2021). *Energy Access for Sustainable Development in Nigeria*. Abuja: UNDP.

Usman, A. B., & Jabba, E. U. (2018). Assessment of the Effects of Carbon Monoxide Emission on the Environment in Taraba State, Nigeria. *J Mech Civ Eng*, *15*(2), 10-15.

Vardoulakis, S., Giagloglou, E., Steinle, S., Davis, A., Sleeuwenhoek, A., Galea, K. S., ... & Crawford, J. O. (2020). Indoor exposure to selected air pollutants in the home environment: a systematic review. *International journal of environmental research and public health*, *17*(23), 8972. https://doi.org/10.3390/ijerph17238972

WHO. (2021). *WHO Global Air Quality Guidelines: Particulate Matter, Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide*. ("WHO global air quality guidelines: particulate matter (PM2.5 and PM10 ...") Geneva: World Health Organization.

WHO Nigeria. (2020). *Environmental Determinants of Health in Nigeria: National Assessment*. Abuja: WHO Country Office.

World Bank. (2022). *Tracking SDG7: The Energy Progress Report*. Washington, DC: World Bank Publications.

Yusuf, L. M., & Ajayi, K. A. (2017). Health effects of CO exposure among residents near dumpsites. *Nigerian Journal of Environmental Medicine*, 13(2), 98–106.

Zarma, I. H. (2019). Generator proliferation in Nigeria and its environmental implications. *Energy & Environment Review*, 6(1), 1–12.