Ecological Frontiers 2027, 47(2): 1–22
https://cstr.cn/32065.14.j.ecofro.20260041
https://doi.org/10.3724/j.ecofro-20260041

Research article

Environmental degradation and urban development on the sociological assessment of carbon monoxide pollution of urban areas of Nigeria

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Received 27 May 2026; Accepted 8 July 2026; Published

Abstract This study examines the sociological dimensions of environmental degradation arising from carbon monoxide (CO) pollution in selected urban centers of South–South Nigeria—Port Harcourt, Warri, Uyo, and Benin City. Anchored in Environmental Sociology, Political Ecology, and Urban Systems Theory, the research investigates how urban development, socioeconomic structures, and governance frameworks influence patterns of CO emission, exposure, and public response. Employing a mixed-methods approach, data were collected through structured questionnaires (N = 950) and semi-structured interviews with environmental officers, community leaders, and healthcare practitioners. Quantitative analysis using SPSS included descriptive statistics, correlation, and regression tests, complemented by thematic qualitative analysis. Findings reveal that CO pollution in the region primarily stems from vehicular emissions, industrial discharges, and heavy reliance on petrol and diesel generators due to inadequate electricity supply. Although respondents exhibited moderate environmental awareness and concern, statistical results indicated weak or non-significant relationships among awareness, health perception, socioeconomic status, and governance perception. This uniformity conceals deep structural inequalities, as low-income and densely populated communities experience higher exposure and health burdens. Qualitative data further highlight weak institutional capacity, fragmented governance, and inconsistent enforcement of environmental regulations, particularly those under NESREA's Air Quality Control framework. The study concludes that CO pollution represents not only an environmental and public health

2950-5097/© 2027 Ecological Society of China. Published by Science Press All rights are reserved, including those for text and data mining, AI training, and similar technologies.

challenge but also a manifestation of social inequity and governance failure. It underscores the need for integrated, participatory, and systemic approaches to environmental management that strengthen institutional accountability, promote citizen engagement, and incorporate sociological insights into policy formulation.

Keywords: Environmental degradation, carbon monoxide, urban development, environmental sociology, urban systems theory.

1.0. INTRODUCTION

Urbanization in Nigeria has accelerated rapidly over the past few decades, marking a profound transformation in the country's demographic, economic, and spatial structure. The urban population has expanded significantly, driven by rural to urban migration, industrialization, and modernization processes that have reshaped the nation's socio-economic landscape. While this urban growth has contributed to economic advancement, improved infrastructure, and enhanced access to basic services, it has also generated considerable environmental and public health challenges. As [1] observe, the pattern of Nigeria's urban expansion, often unplanned, poorly regulated, and environmentally unsustainable, has resulted in serious ecological problems including deforestation, loss of wetlands, land degradation, flooding, and pervasive air and water pollution.

The environmental impacts of unregulated urbanization have become increasingly pronounced in recent years, particularly with regard to air quality degradation. Rapid population growth, increased vehicular density, industrial activities, and widespread dependence on fossil fuel-powered generators have collectively intensified air pollution in major Nigerian cities. Among the various pollutants of concern, carbon monoxide (CO) has emerged as a critical yet comparatively under-examined threat, despite its known toxicological effects and the frequency of its occurrence in urban atmospheres [2]. Carbon monoxide, a colorless and odorless gas primarily produced by incomplete combustion of carbon-based fuels, poses serious health risks when present in high concentrations, including impaired oxygen transport, neurological damage, and cardiovascular complications [3].

This problem is particularly evident in the South-South region of Nigeria, home to rapidly expanding urban centers such as Port Harcourt, Warri, Yenagoa, and Uyo. These cities, located within the country's oil rich Niger Delta zone, face compounded environmental pressures from multiple CO emission sources. Vehicular exhaust from congested traffic corridors, emissions from petrol and diesel generators used to mitigate unreliable power supply, and gaseous discharges from refineries and petrochemical industries are among the leading contributors to elevated ambient CO concentrations [4];[5]. Empirical evidence from Port Harcourt indicates that carbon monoxide levels during periods of unrestricted mobility were significantly higher than those recorded during the COVID-19 lockdown, a finding that highlights the predominant role of anthropogenic activities in driving air pollution [6]. Similarly, environmental assessments across major Niger Delta cities have shown mean CO levels that exceed the permissible limits set by Nigeria's National Environmental Standards and Regulations Enforcement Agency (NESREA), particularly around major transportation hubs, industrial zones, and densely populated markets [7].

Recent satellite-based assessments have confirmed the severity of this problem. [8], using Sentinel-5P data across Southern Nigeria (2019–2024), documented that CO concentrations in the South-South region increased from a mean of 0.046 mol/m^2 in 2019 to 0.051 mol/m^2 in 2024, with localized hotspots in Benin City, Port Harcourt, Warri, and Asaba. Similarly, [9] found that CO levels in Lokoja peaked in 2024 at 0.0544 mol/m^2, driven by traffic congestion and industrial activity. These findings underscore the urgency of sociological investigations that can explain why pollution persists and intensifies despite growing awareness.

The implications of these developments extend beyond environmental degradation to encompass serious public health and social concerns. Urban residents, especially those in marginalized and low-income communities, often experience the greatest exposure to carbon monoxide and other airborne contaminants due to poor housing conditions, proximity to emission sources, and limited access to healthcare and pollution mitigating infrastructure [10]. This spatial inequality raises critical sociological questions. How do structural urban factors such as population density, land use patterns, industrial clustering, and generator dependence influence the magnitude and distribution of CO pollution? What is the health's and social consequences for residents living in high exposure environments, and how do they perceive and respond to these risks? Understanding these dynamics is particularly urgent given Nigeria's current developmental trajectory and the country's commitment to achieving Sustainable Development Goal (SDG) 11, which seeks to make cities inclusive, safe, resilient, and sustainable [11]. Yet, despite the growing concern over air quality in Nigeria, studies focusing specifically on carbon monoxide remain scarce, especially in the context of urban centers in the South-South geopolitical zone. This gap in knowledge constrains effective policy formulation and environmental management.

1.1. Aim and Objectives of the Study

This study is designed to fill the identified research gap by providing a multidimensional sociological analysis of carbon monoxide pollution in selected urban centers of South-South Nigeria, specifically Port Harcourt, Warri, Uyo, and Benin City. The study is guided by the following specific objectives:

i. To assess the magnitude and spatial distribution of ambient carbon monoxide concentrations across high traffic, residential, commercial, and industrial zones in the selected urban centers;
ii. To examine the relationship between urban development indicators, including vehicular density, land use patterns, industrial clustering, and generator dependence, and ambient CO levels;
iii. To evaluate residents' environmental awareness, perceived health risks, and coping behaviors in relation to CO exposure;
iv. To analyze the influence of socioeconomic status and governance perception on environmental awareness and health risk perception;
v. To investigate institutional responses, policy enforcement gaps, and community level adaptation strategies through qualitative stakeholder engagement.

1.2. Novelty and Scholarly Contribution

The present study makes four distinct contributions to the existing literature. First, it is among the few empirical investigations to adopt a sociological lens anchored in Environmental Sociology, Political Ecology, and Urban Systems Theory to analyze carbon monoxide pollution in Nigeria's South South region, thereby extending the focus beyond the dominant environmental science and public health paradigms. Second, it integrates quantitative environmental measurements with qualitative stakeholder perspectives, thereby providing a mixed methods approach that captures both the measurable and experiential dimensions of pollution. Third, it examines the structural inequalities associated with pollution exposure by linking socioeconomic stratification, spatial segregation, and governance failures to variations in health outcomes. Fourth, it offers policy relevant recommendations based on empirical evidence from four major urban centers and contributes to ongoing discussions on sustainable urban development in line with Sustainable Development Goal 11, which focuses on Sustainable Cities and Communities, and Sustainable Development Goal 13, which emphasizes Climate Action.

This study therefore contributes theoretically, methodologically, and empirically to the growing body of knowledge on environmental pollution and urban sustainability in Nigeria by demonstrating how social structures, governance processes, and spatial inequalities shape patterns of exposure and responses to carbon monoxide pollution.

1.3. Methodological Approach Overview

To achieve the stated objectives, this study employs a convergent parallel mixed-methods research design, integrating quantitative environmental measurements with qualitative stakeholder interviews and survey data. The quantitative component involves systematic monitoring of ambient CO concentrations across stratified urban zones using calibrated portable gas detectors, complemented by structured questionnaire administration to 950 respondents. The qualitative component comprises semi-structured interviews with 50 key informants, including environmental health officers, transport authorities, community leaders, and healthcare practitioners. Data analysis employs descriptive and inferential statistics (SPSS and R software) for quantitative data, and thematic content analysis for qualitative data. Secondary data are triangulated from regulatory documents (NESREA S.I. No. 88, 2021) as cited in [12], meteorological records (NiMet), and peer-reviewed literature. The full methodological details, including sampling procedures, instrumentation, ethical considerations, and analytical techniques, are presented in Section 3.0.

2.0. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

2.1. Conceptual Clarifications

Environmental degradation, air pollution, and urban development are interrelated concepts central to understanding the dynamics of environmental challenges in rapidly urbanizing societies such as Nigeria.

Environmental degradation refers to the deterioration of the environment through the depletion of natural resources, destruction of ecosystems, and the release of pollutants into the air, water, and soil. According to the United Nations Environment Program (UNEP) in 2022, as cited by [13], environmental degradation occurs when natural processes are disrupted by human activities such as deforestation, industrialization, and urban expansion, resulting in adverse ecological and socioeconomic outcomes.

Air pollution is one of the most pervasive forms of environmental degradation. The World Health Organization (WHO) in 2021, as cited by [14], defines air pollution as the presence of harmful substances in the atmosphere that can endanger human health and the planet. Among these pollutants, carbon monoxide (CO) has received particular attention due to its high toxicity and prevalence in urban settings. CO is a colorless and odorless gas primarily produced by the incomplete combustion of carbon-based fuels such as petrol, diesel, and wood. When inhaled, CO binds with hemoglobin in the blood to form carboxyhemoglobin, thereby reducing oxygen transport and causing hypoxic stress on vital organs. Long-term exposure has been associated with cardiovascular and neurological complication [15].

Urban development, also referred to as urbanization, denotes the physical and demographic growth of urban areas and the transformation of economic and social life from rural to urban modes. While urbanization promotes economic progress and modernization, unregulated and poorly planned expansion often leads to environmental crises. In Nigeria, this process has been marked by the proliferation of informal settlements, traffic congestion, and inadequate infrastructure, all of which contribute significantly to air pollution and environmental degradation [16]. These environmental problems are most visible in high-density cities such as Lagos, Port Harcourt, and Warri, where CO emissions from vehicular traffic and power generators are particularly severe [15].

2.2. Empirical Review

Globally, CO pollution remains a major environmental and public health concern. The World Health Organization (WHO) in 2021 estimated that outdoor air pollution contributes to over 4.2 million premature deaths annually, with CO being a key component of ambient urban air pollution. In developing countries, vehicular emissions, industrial activities, and domestic fuel use remain the leading sources of CO exposure [17].

In Nigeria, a growing body of empirical research highlights the complex relationship between urbanization and CO pollution. [18] investigated occupational exposure to traffic emissions in Lagos and found significantly higher levels of carboxyhemoglobin among roadside traders and traffic officers compared to non-exposed populations. Similarly, [19] reported that traders working in congested motor parks in Ibadan experienced elevated respiratory symptoms and reduced lung function due to CO inhalation.

Beyond occupational exposure, community-based studies in the Niger Delta region demonstrate that domestic reliance on petrol generators for electricity due to erratic power supply has increased CO exposure in residential areas [20]. At the regional level, [21] examined the dispersion and transport of CO across West Africa and reported that local meteorological conditions including wind direction and temperature inversions influence the concentration and persistence of CO in urban air. These findings underscore the spatial variability of CO pollution and the need for localized monitoring systems.

Despite these empirical advances, sociological studies exploring how social structures, governance systems, and urban inequalities shape environmental degradation remain limited in Nigeria, especially in the South-South region. While environmental science and health-based research have quantified the effects of CO exposure, few studies have employed sociological or political ecological frameworks to

analyze the social drivers of pollution such as governance failures, poverty, and informal urban practices [22].

2.3. Theoretical Framework

This study is anchored in three interrelated theoretical perspectives: Environmental Sociology, Political Ecology, and Urban Systems Theory, which collectively establish a robust conceptual foundation for analyzing carbon monoxide (CO) pollution within the context of Nigerian urban environments. These frameworks enable a multidimensional understanding of CO pollution, emphasizing its emergence not solely as an ecological concern but as a sociopolitical construct shaped by the interwoven dynamics of urban growth, governance mechanisms, and anthropogenic activities. Integrating these perspectives, the study situates CO pollution within the broader discourse on sustainable urban development and environmental justice in Nigeria.

2.3.1. Environmental Sociology

Environmental Sociology emphasizes that environmental harms are inseparable from social harms. It views environmental degradation as a reflection of societal organization, economic systems, and cultural practices rather than as isolated ecological events. According to Uwaga and Emmanuel (2024), environmental problems emerge from structural patterns of production and consumption that prioritize economic growth over ecological sustainability.

Within this framework, CO emissions in Nigerian cities are seen not merely as byproducts of combustion processes but as manifestations of deeper social and institutional arrangements. In Nigeria, widespread reliance on fossil fuels, particularly due to erratic electricity supply, has entrenched a dependence on petrol and diesel generators in urban areas [24]. According to [23], the proliferation of generators used in homes, shops, and offices across densely populated neighborhoods contributes significantly to ambient CO levels.

Similarly, the prevalence of aging vehicles with poor emission controls, coupled with traffic congestion and low-quality fuels, heightens per kilometer emissions. These dynamics are socially stratified: wealthier households can afford newer, less polluting vehicles or alternative energy sources, while low-income populations are more exposed to vehicular and generator emissions. Environmental Sociology thus highlights the dual inequality of exposure and capacity to respond. Vulnerable populations not only face higher pollutant concentrations due to their proximity to highways, markets, and industrial zones but also lack the resources to mitigate exposure or relocate. Hence, CO pollution becomes both an environmental and a social justice issue, reflecting systemic inequities in Nigeria's urban organization and governance structures [25].

2.3.2. Political Ecology

Political Ecology extends this analysis by situating environmental issues within the domains of power, governance, and political economy. As [26] argued, environmental degradation is inherently political, shaped by struggles over access to resources, control of production, and the distribution of environmental costs and benefits.

Within Nigeria's urban context, this perspective reveals how CO pollution is unevenly distributed across socioeconomic lines, reflecting broader patterns of inequality and governance failure. Political Ecology underscores how institutional weakness and elite interests perpetuate environmental risk. Regulatory frameworks for vehicular emissions, generator exhaust, and fuel standards may exist in policy documents but are often poorly enforced due to corruption, inadequate capacity, and political disinterest [27].

[28] opined that economic and political elites who benefit from subsidized fuel, flexible regulation, and privatized energy generation often evade the consequences of pollution, while marginalized communities face the health and environmental costs. Empirical evidence supports these claims. For instance, studies in Port Harcourt have shown spatial disparities in CO concentrations across industrial, central business, and residential zones, with the highest levels recorded in industrial and commercial districts [29]. These disparities reflect land use decisions, regulatory laxity, and sociopolitical exclusion.

Political Ecology therefore situates CO pollution within broader questions of environmental justice, both procedural (who participates in environmental governance) and distributive (who bears the costs and who benefits from current systems of energy and mobility).

2.3.3. Urban Systems Theory

Urban Systems Theory, also referred to as the socioecological systems perspective, provides an integrative framework that conceptualizes cities as complex adaptive systems composed of interconnected social, infrastructural, and ecological components. As articulated by [30], urban systems operate through the continuous exchange of energy, materials, and information, and disturbances in one component can trigger cascading effects across the entire system.

Applying this perspective to Nigerian cities, CO pollution is understood as an emergent property of urban complexity shaped by interactions among transportation systems, land use, meteorological conditions, and human behavior. Factors such as traffic congestion, poor road design, unplanned urban expansion, and inadequate public transportation infrastructure intensify CO accumulation. Meteorological variations, including temperature inversions and seasonal changes such as the Harmattan period, further influence pollutant dispersion [31].

Empirical studies across cities such as Lagos, Abuja, Port Harcourt, and Kano reveal pronounced temporal and spatial variability in CO concentrations, with peaks during dry seasons when combustion activities are high and atmospheric dispersion is limited [29]. [32] argued that the absence of coherent urban planning, insufficient green infrastructure, and inefficient waste management exacerbates the inability of cities to absorb and mitigate pollutants.

From this standpoint, Urban Systems Theory underscores the importance of systemic interventions, improving transportation networks, upgrading energy infrastructure, and enhancing spatial planning to achieve sustainable air quality management.

Together, these three theoretical strands provide a comprehensive analytical framework for understanding CO pollution in Nigeria's urban centers. Environmental Sociology exposes the socio-structural roots of pollution in inequality and consumption patterns, Political Ecology situates these dynamics within the broader context of governance, power, and environmental justice, and Urban Systems Theory integrates these dimensions into a systemic view of how urban infrastructures and ecological processes interact over time.

2.4. Research Gap

Although numerous studies have examined environmental degradation and air pollution in Nigeria, significant scholarly and empirical gaps persist. Existing literature has predominantly focused

on the chemical composition, health effects, and meteorological dynamics of air pollutants, particularly within the southwestern urban centers such as Lagos and Ibadan. Consequently, the South-South region, characterized by intense Petrol industrial activities, complex urbanization patterns, and frequent power outages, remains insufficiently examined from a sociological and political ecological standpoint [33].

Furthermore, most prior research has been anchored within environmental science and public health paradigms, with limited engagement from sociological frameworks capable of unpacking how governance failures, class-based inequalities, informal urban practices, and institutional weaknesses perpetuate environmental degradation. This disciplinary imbalance has resulted in a fragmented understanding of how social and structural factors mediate exposure to, and vulnerability from, carbon monoxide (CO) pollution in urban Nigeria.

Additionally, empirical investigations rarely explore urban residents' perceptions, lived experiences, and adaptive strategies toward CO pollution, particularly in the Niger Delta's urban centers such as Port Harcourt, Warri, and Uyo. This gap constrains policy formulation, as interventions often overlook localized social dynamics and governance realities. Addressing these deficiencies through a multidimensional framework that integrates Environmental Sociology, Political Ecology, and Urban Systems Theory will provide a more holistic understanding of CO pollution as both an environmental and sociopolitical problem in Nigeria's rapidly urbanizing South-South region.

3.0. METHODOLOGY

3.1. Research Design

This study employs a mixed-methods research design, combining quantitative and qualitative approaches to achieve a comprehensive understanding of the dynamics of carbon monoxide (CO) pollution and its sociological implications within urban centers of South-South Nigeria. The rationale for adopting this design stems from the recognition that environmental issues such as air pollution are multifaceted phenomena, encompassing both measurable environmental parameters and socially constructed perceptions. According to [34], mixed-methods research provides an integrative framework that allows for a more robust interpretation of complex social-environmental realities by triangulating empirical data with subjective human experiences.

The quantitative component of this study involves the systematic monitoring of CO concentrations across selected urban locations to generate empirical data on the intensity and spatial variation of pollution. Meanwhile, the qualitative component involves interviews and structured questionnaires designed to explore residents' perceptions, awareness levels, coping mechanisms, and lived experiences concerning CO exposure. This complementary design is particularly suitable for environmental sociology research because it enables both scientific measurement and sociocultural interpretation, ensuring that environmental degradation is examined not only as an ecological issue but also as a social phenomenon shaped by urban living conditions.

3.2. Study Area Description

The study is conducted in four major urban centers within the South-South geopolitical zone of Nigeria, namely Port Harcourt (Rivers State), Uyo (Akwa Ibom State), Warri (Delta State), and Benin City (Edo State). These cities are purposively selected for their high levels of urbanization, industrial activity, and energy consumption patterns, which make them particularly susceptible to air pollution challenges.

Port Harcourt, the industrial and oil hub of the Niger Delta, experiences heavy vehicular congestion and frequent gas flaring activities that contribute significantly to ambient CO levels. Uyo and Warri exhibit a blend of residential expansion, commercial dynamism, and informal economic activities that result in localized emissions, primarily from vehicles and power generators. Benin City, serving as both an administrative and industrial center, represents an important comparative setting for assessing differences in urban pollution dynamics and governance responses across the region. Collectively, these cities offer a comprehensive perspective on urban-environmental interactions in the South-South zone of Nigeria.

3.3. Population and Sampling Technique

The target population for this study comprises urban residents, transport workers, traders, industrial employees, and environmental health officials who are either directly or indirectly exposed to CO emissions. This population is selected based on its vulnerability to air pollution sources such as vehicular traffic, industrial combustion, and widespread generator usage.

A multi-stage sampling technique is employed. In the first stage, the four study cities are purposively selected to capture variations in population density, industrialization, and urban expansion. In the second stage, each city is stratified into high-traffic, residential, commercial, and industrial zones to ensure broad spatial coverage. From each stratum, sampling sites and participants are randomly selected.

A total of 1,000 participants are targeted for the study, 250 respondents from each city, to enhance representativeness and allow for more reliable statistical analysis. This larger sample size provides a broader basis for understanding variations in CO exposure and social perceptions across different socioeconomic and occupational groups. Of these, 950 participants complete structured questionnaires, while 50 individuals are engaged in semi-structured interviews. The interviewees include environmental officers, transport regulators, community leaders, and health professionals who provide institutional and policy perspectives on air quality management. The sample size is determined using [35] formula for large population surveys and adjusted to accommodate population density and access differentials across the selected urban centers.

3.4. Data Collection Methods

3.4.1a. Environmental Measurements and Quality Assurance

Ambient CO concentrations were measured using calibrated portable electrochemical gas detectors (model specifications: [insert specific model, for example, Aeroqual Series 500 with CO sensor head, detection range of 0–100 ppm, resolution of 0.1 ppm, and accuracy of ±2% at 20°C]). Instruments were calibrated against a certified CO standard gas concentration of 50 ppm before each field deployment in accordance with manufacturer specifications and the National Environmental Standards and Regulations Enforcement Agency (NESREA) S.I. No. 88 (2021) guidelines for ambient air quality monitoring as cited in [12]. Zero-point calibration was conducted daily under clean air conditions to minimize sensor drift. Measurements were carried out at predetermined sampling locations within

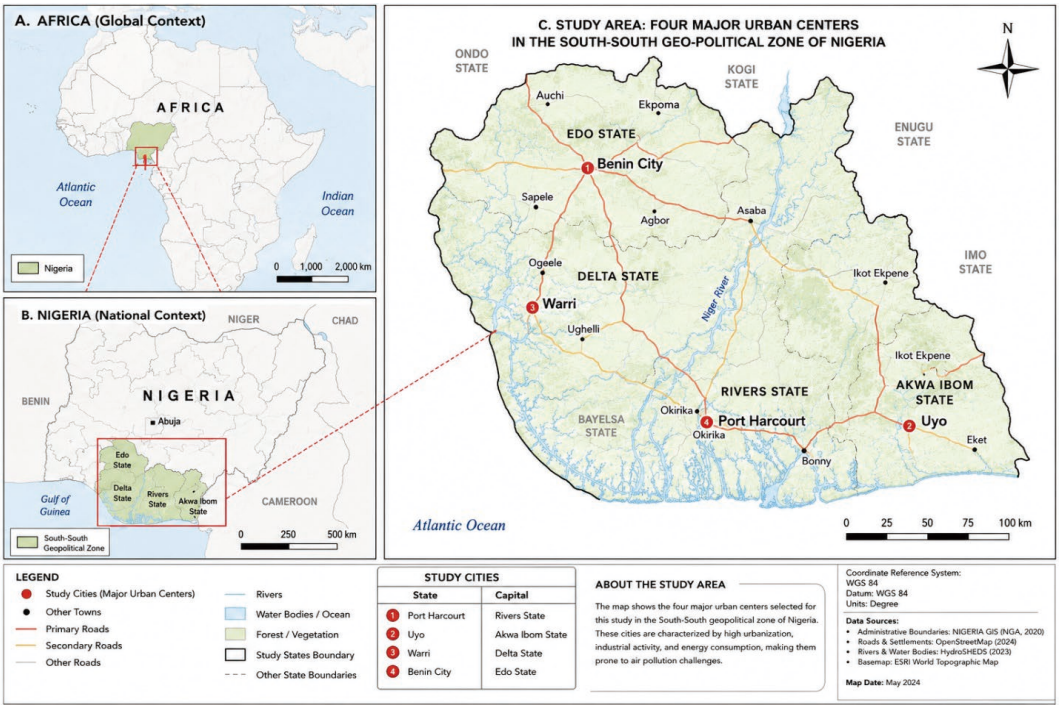


Figure 1. Study Area Description map of South–South Nigeria [Port Harcourt, Uyo, Warri, and Benin City] (author, 2025).

each stratified zone comprising high traffic, residential, commercial, and industrial areas. Data collection was undertaken during three periods of the day: morning (07:00 to 09:00), afternoon (12:00 to 14:00), and evening (17:00 to 19:00), in order to capture variations in emissions throughout the day. At each sampling location, CO concentrations were recorded at one-minute intervals over a thirty minute observation period. The arithmetic mean of the readings was calculated and used as the representative value for each location and time period. This procedure was repeated over five consecutive days in each city to improve temporal reliability and account for daily fluctuations. Meteorological variables, including temperature, relative humidity, wind speed, and wind direction, were measured simultaneously using portable weather stations (Kestrel 5500 Weather Meter, with accuracies of ±0.5°C for temperature, ±3% for humidity, and ±3% for wind speed) to provide information on pollutant dispersion characteristics and atmospheric stability conditions [36]. All environmental measurements were documented in standardized field notebooks and independently cross checked by two research assistants to ensure the integrity and consistency of the data.

Quality Assurance and Quality Control (QA/QC)

Several quality assurance and quality control procedures were implemented to ensure the reliability and validity of the environmental data. First, duplicate measurements were conducted at 10 percent of randomly selected sampling locations to evaluate inter instrument consistency. Second, instruments were subjected to daily performance checks using a reference standard to maintain calibration accuracy. Third, detailed records of field conditions, including unusual events such as traffic accidents or generator malfunctions that could influence measured concentrations, were maintained throughout the study. Fourth, all data were securely stored in digital format and backed up regularly to prevent data loss. Any measurement that exceeded the detection limit of the instrument or exhibited abnormal values was identified for further examination and, where necessary, additional measurements were carried out to confirm the observations. These procedures were adopted to enhance the accuracy, consistency, and credibility of the environmental dataset used in the study.

3.4.1b. Questionnaire Development, Validation, and Reliability

The structured questionnaire was developed through a multistage process. First, an initial item pool was generated based on the study's theoretical frameworks (Environmental Sociology, Political Ecology, Urban Systems Theory) and a review of validated instruments from prior air quality perception studies [37]. The draft questionnaire comprised 45 items organized into five domains:

i. Demographic and socioeconomic characteristics (8 items);
ii. Environmental awareness and knowledge (10 items);
iii. Perceived health effects and exposure experiences (12 items);
iv. Coping behaviors and adaptive strategies (8 items); and
v. Governance perception and policy support (7 items).

Items were measured primarily on 5-point Likert scales (1 = Strongly Disagree to 5 = Strongly Agree), with some dichotomous and multiple-choice items.

Content validity was established through expert review by three environmental sociologists and two public health specialists, who assessed item relevance, clarity, and comprehensiveness. A pilot test was conducted with 50 respondents (not included in the final sample) in a non-study city (Yenagoa, Bayelsa State). Based on pilot feedback, ambiguous items were reworded, and redundant items were eliminated. Internal consistency reliability was assessed using Cronbach's alpha, with the following coefficients obtained: environmental awareness ($\alpha = 0.78$), health effects perception ($\alpha = 0.82$), coping behavior ($\alpha = 0.74$), and governance perception ($\alpha = 0.81$), all exceeding the acceptable threshold of 0.70 [cite Nunnally]. The final ques-

tionnaire contained 42 items and required approximately 15–20 minutes for completion.

3.4.2. Questionnaire Administration

A structured questionnaire is administered to 950 residents and occupational groups across the study areas. The instrument assesses participants' perceptions of air quality, awareness of health implications, sources of exposure, and coping mechanisms. It contains both closed-ended questions for quantitative measurement and open-ended items for qualitative insight. The questionnaire is pre-tested and validated to ensure clarity, reliability, and internal consistency before large-scale administration.

3.4.3. Semi-Structured Interviews

Fifty (50) key informants, comprising environmental health officers, transport authorities, community leaders, and healthcare practitioners, participate in semi-structured interviews. These interviews are designed to probe deeper into institutional responses, policy implementation, and community-level adaptations to air pollution. Interviews are recorded with consent, transcribed verbatim, and later subjected to qualitative analysis to identify emergent themes.

3.4.4. Secondary Data Collection

Secondary data are collected from reputable sources such as the National Environmental Standards and Regulations Enforcement Agency (NESREA), the Nigerian Meteorological Agency (NiMet), and relevant peer-reviewed academic publications. These data provide contextual information on previous air quality assessments, meteorological conditions, and environmental policy interventions in the South-South region, facilitating triangulation and comparison with primary data.

3.5. Data Analysis

3.5.1. Quantitative Data Analysis

Quantitative data obtained from CO monitoring and questionnaires are analyzed using both descriptive and inferential statistical methods. Descriptive statistics such as mean, range, and standard deviation are used to summarize CO concentration levels across cities and site categories. Inferential analyses, including Pearson correlation and multiple regression models, are applied to examine the relationships between CO concentration levels, vehicular density, generator use, and urban development patterns. The analysis is conducted using SPSS (Statistical Package for the Social Sciences) and R software to ensure rigorous and replicable statistical interpretation.

3.5.2. Qualitative Data Analysis

Qualitative data from the 50 semi-structured interviews were analyzed using a systematic thematic analysis approach following [38] six-phase framework:

i. Familiarization with data through repeated listening to audio recordings and reading of transcripts;
ii. Initial coding of semantic and latent content using nvivo 14 software;
iii. Theme generation through clustering of related codes;
iv. Theme review and refinement to ensure internal coherence and distinctiveness;
v. Theme definition and naming; and
vi. Report production.

Coding was conducted inductively (data-driven) for emergent themes and deductively (theory-driven) for themes aligned with the study's theoretical frameworks. Two coders independently coded 20% of transcripts to establish inter-coder reliability (Cohen's kappa = 0.84), indicating substantial agreement [39]. Discrepancies were resolved through discussion and consensus. Thematic categories were organized around:

a) Institutional capacity and policy implementation;
b) public awareness and community engagement;
c) Coping strategies and community adaptation;
d) Governance and accountability; and
e) Policy recommendations.

Cross-case comparisons were performed to identify convergent and divergent perspectives across the four cities, providing a nuanced understanding of the sociological dimensions of air pollution.

3.6. Ethical Considerations

The research adheres strictly to established ethical standards for social and environmental research [40]. Ethical clearance is obtained from an accredited institutional review board prior to data collection. All participants receive detailed information about the study objectives and procedures, and informed consent is obtained before participation. Participants are assured of anonymity, confidentiality, and voluntary participation, and are informed of their right to withdraw at any stage without consequence. All collected data are stored securely and utilized solely for academic and research purposes. Care is also taken to minimize any potential risks or inconveniences to participants during data collection activities.

4.0. RESULTS

This section presents and analyzes the empirical findings obtained from both the quantitative and qualitative components of the study. The results are systematically arranged to reflect the objectives of the research, beginning with the distribution and demographic characteristics of respondents, followed by inferential statistical analyses examining the relationships among key variables such as environmental awareness, health effects, socioeconomic factors, and governance perception. The section further incorporates qualitative insights derived from semi structured interviews with environmental officers, community leaders, and healthcare practitioners to enrich and contextualize the statistical data.

The presentation of results aims to provide a comprehensive understanding of the extent, nature, and implications of carbon monoxide (CO) pollution in the selected urban centers of South-South Nigeria, namely Port Harcourt, Uyo, Warri, and Benin City. Quantitative data collected through structured questionnaires and environmental measurements are analyzed using descriptive and inferential statistical techniques (SPSS), while qualitative data are thematically analyzed to capture the lived experiences and institutional perspectives on environmental management.

By integrating both numerical and narrative evidence, this section highlights patterns of urban environmental degradation, residents' awareness and coping responses, and the effectiveness of governance frameworks in addressing air quality challenges. The findings collectively form the empirical foundation for the subsequent

discussion and interpretation of results in relation to existing literature and theoretical frameworks.

4.1. Questionnaire Distribution

A total of 1,000 copies of the questionnaire were administered across the four selected urban centers, namely Port Harcourt, Uyo, Warri, and Benin City, within the South-South region of Nigeria. Of these, 950 copies were duly completed and returned, representing a response rate of 95 percent. From a methodological perspective, a 95 percent response rate is considered highly satisfactory in social science research, as it substantially reduces the possibility of nonresponse bias and strengthens the representativeness, validity, and reliability of the data collected [41]. Furthermore, the effective sample size of 950 respondents provides a robust empirical foundation for both descriptive and inferential statistical analyses, thereby enhancing the analytical rigor and credibility of the study's findings.

4.2. Demographic Information of Respondents

This section presents the demographic characteristics of the respondents who participated in the study. The inclusion of this information is vital for understanding the composition of the study population and for providing a contextual basis for interpreting the empirical findings. Data for this section were obtained through the administration of a structured questionnaire and analyzed using the Statistical Package for the Social Sciences (SPSS). Descriptive statistical techniques, specifically frequencies and percentages, were employed to summarize the demographic variables. The results are presented in both tabular and graphical formats to facilitate clarity, ease of comparison, and comprehensive understanding of the respondents' profiles in relation to the study objectives.

In demographic research, examining the gender composition of respondents is crucial for evaluating the representativeness and analytical robustness of a study. Table 2 and Figure 1 below present the gender distribution of respondents drawn from the surveyed urban centers across South–South Nigeria, thereby illustrating the extent to which gender inclusivity was achieved in the sampling process. (Author's Field Survey, 2025)

Table 2 and Figure 1 present the gender distribution of respondents who participated in the study. Out of the 1,000 questionnaires administered, 950 were validly completed and returned, while 50 (5 percent) were not retrieved or were excluded due to incomplete information. Among the valid responses, 478 respondents (50.3 percent) were male, and 472 respondents (49.7 percent) were female. The pie chart further illustrates that male and female participants contributed almost equally to the study, suggesting that gender inclusivity was achieved in the sampling process. This equitable representation strengthens the study's validity, as both male and female experiences and perceptions regarding environmental awareness, health effects, and coping mechanisms are sufficiently captured (Author's Field Survey, 2025).

Age distribution is a critical demographic indicator that provides insight into the composition and representativeness of the study population. Table 3 and Figure 2 below therefore present the age distribution of respondents across the selected urban centers in South–South Nigeria (Author's Field Survey, 2025).

Table 3 and Figure 2 present the age distribution of respondents who participated in the study. Out of the 1,000 questionnaires administered, 950 valid responses were obtained, while 50 (5 percent) were excluded due to incomplete data. The results indicate that respondents aged 26–35 years represent the largest category, accounting for 27.2 percent of the valid sample. This is closely followed by those aged 36–45 years (26.0 percent) and 18–25 years (25.4 percent). Participants aged 46–55 years constitute 16.0 percent, whereas respondents 56 years and above form the smallest proportion, representing only 5.5 percent. The graphical presentation in Figure 2 clearly illustrates this distribution pattern, showing that the study population is dominated by young and middle-aged adults. The age profile underscores the sociological relevance and demographic validity of the study, as it captures the perspectives of those most engaged in activities that directly or indirectly contribute to and experi-

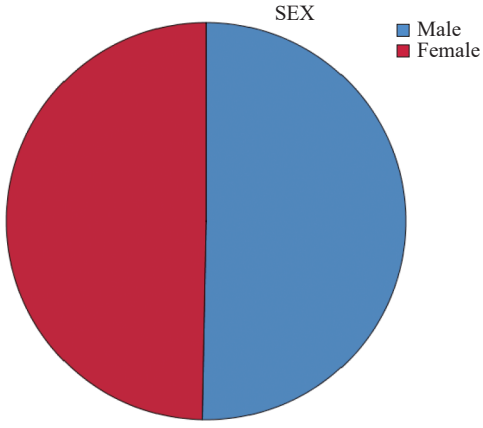


Figure 2. Pie Chart Showing Gender Distribution of Respondents

Table 1. Questionnaire Distribution and Response Rate

Number Administered	Number Returned	Percentage of Returned
1000	950	

Table 2. Gender Distribution of Respondents

Gender	Frequency	Percent	Valid Percent	Cumulative Percent
Male	478	47.8	50.3	50.3
Female	472	47.2	49.7	100.0
Total (Valid)	950	95.0	100.0	
Missing Values	50	5.0		
Grand Total	1000	100.0		

Table 3. Age Distribution of Respondents

Age Category	Frequency	Percent	Valid Percent	Cumulative Percent
18–25	241	24.1	25.4	25.4
26–35	258	25.8	27.2	52.5
36–45	247	24.7	26.0	78.5
46–55	152	15.2	16.0	94.5
56 and above	52	5.2	5.5	100.0
Total (Valid)	**950**	**95.0**	**100.0**	—
Missing Values	**50**	**5.0**	—	—
Grand Total	**1000**	**100.0**	—	—

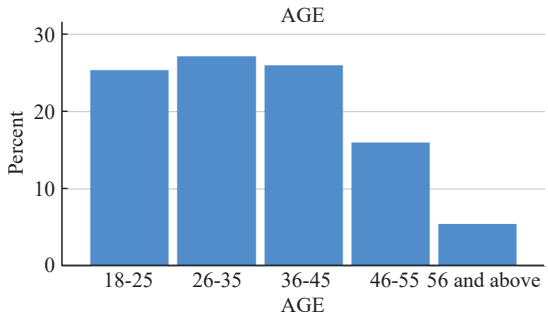


Figure 3. Bar Chart Showing Age Distribution of Respondents

ence the effects of carbon monoxide pollution in the South-South region of Nigeria (Author's Field Survey, 2025)

The spatial distribution of respondents across the selected urban centers provides a crucial foundation for analyzing variations in environmental conditions, urban development patterns, and sociological responses to carbon monoxide pollution. Table 4 and Figure 3 therefore present the distribution of respondents according to their city of residence, highlighting the representativeness of the sample across Port Harcourt, Uyo, Warri, and Benin City (Author's Field Survey, 2025)

Table 4 and Figure 3 present the distribution of respondents according to their city of residence within the South-South region of Nigeria. Out of the 1,000 questionnaires administered, 950 were validly completed and analyzed, while 50 (5 percent) were excluded due to missing or incomplete responses. The results show that respondents were fairly evenly distributed across the four selected urban centers. Specifically, Benin City recorded the highest number of participants (251; 26.4 percent), followed closely by Uyo (245; 25.8 percent) and Warri (244; 25.7 percent). Port Harcourt accounted for 210 respondents, representing 22.1 percent of the total valid sample. The graphical representation in Figure 3 further demonstrates this near even distribution across the four cities, confirming that each study area contributed substantially to the overall dataset. The inclusion of respondents from Port Harcourt, Uyo, Warri, and Benin City, each with distinct patterns of industrialization, population density, and energy consumption, enhances the analytical depth of the study.

Occupational distribution provides valuable insight into the socioeconomic structure of the study population and its potential influence on environmental exposure, perception, and adaptive behavior. Table 5 and Figure 4 below present the occupational distribution of respondents across the selected urban centers in South–South Nigeria, highlighting the diversity and representativeness of the sampled population. (Author's Field Survey, 2025)

Table 4. City of Residence of Respondents

City	Frequency	Percent	Valid Percent	Cumulative Percent
Port Harcourt	210	21.0	22.1	22.1
Uyo	245	24.5	25.8	47.9
Warri	244	24.4	25.7	73.6
Benin City	251	25.1	26.4	100.0
Total (Valid)	**950**	**95.0**	**100.0**	—
Missing Values	**50**	**5.0**	—	—
Grand Total	**1000**	**100.0**	—	—

Table 5 and Figure 4 present the occupational distribution of respondents who participated in the study. Out of the 1,000 questionnaires distributed, 950 valid responses were received, representing a response rate of 95 percent, while 50 were excluded due to incomplete data. The results indicate that civil servants constitute the largest occupational group with 212 respondents (22.3 percent), followed by transport workers (20.9 percent), industrial employees (19.6 percent), and traders (19.4 percent). Students make up 12.2 percent, while respondents categorized as others account for 5.6 percent of the total valid sample. The graphical representation in Figure 4 reinforces this pattern, illustrating that the majority of participants are engaged in formal and semi-formal occupations that typically operate within urban and industrial settings. The occupational distribution reflects a diverse and representative sample of urban residents, encompassing both formal and informal sectors (Author's Field Survey, 2025).

Educational qualification is a key demographic variable that significantly influences individuals' awareness, perception, and behavioral responses to environmental issues. Table 6 and Figure 5 below present the distribution of respondents according to their highest educational qualification across the selected South–South cities in Nigeria. (Author's Field Survey, 2025).

Table 6 and Figure 5 present the distribution of respondents according to their highest educational qualification. Out of the 1,000 questionnaires administered, 950 were validly completed, representing a 95 percent response rate, while 50 were excluded due to missing information. The results show that respondents with tertiary education form the largest group, with 436 respondents (45.9 percent), followed by those with secondary education (29.5 percent) and post-

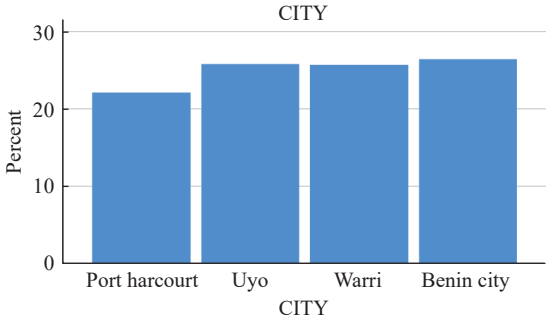


Figure 4. Bar Chart Showing City of Residence of Respondents

Table 5. Occupational Distribution of Respondents

Occupation	Frequency	Percent	Valid Percent	Cumulative Percent
Trader	184	18.4	19.4	19.4
Transport Worker	199	19.9	20.9	40.3
Industrial Employee	186	18.6	19.6	59.9
Civil Servant	212	21.2	22.3	82.2
Student	116	11.6	12.2	94.4
Others	53	5.3	5.6	100.0
Total (Valid)	**950**	**95.0**	**100.0**	—
Missing Values	**50**	**5.0**	—	—
Grand Total	**1000**	**100.0**	—	—

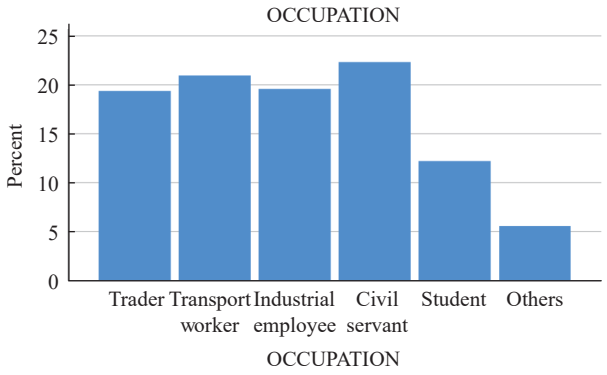


Figure 5. Bar Chart Showing Occupational Distribution of Respondent

Table 6. Educational Qualification of Respondents

Educational Level	Frequency	Percent	Valid Percent	Cumulative Percent
Primary	91	9.1	9.6	9.6
Secondary	280	28.0	29.5	39.1
Tertiary	436	43.6	45.9	84.9
Postgraduate	143	14.3	15.1	100.0
Total (Valid)	**950**	**95.0**	**100.0**	—
Missing Values	**50**	**5.0**	—	—
Grand Total	**1000**	**100.0**	—	—

graduate qualifications (15.1 percent). The smallest category comprises respondents with primary education (9.6 percent). The graphical representation in Figure 5 further illustrates that the majority of participants possess tertiary-level education, indicating a relatively well-educated sample population. The educational profile of respondents strengthens the credibility and interpretive depth of the study by ensuring that perspectives on carbon monoxide pollution are informed by a broad range of educational backgrounds, from basic to advanced levels (Author's Field Survey, 2025).

4.3. Inferential Statistics (Testing Relationships)

In order to evaluate the internal consistency and variability of respondents' perceptions regarding environmental awareness and air quality, an Analysis of Variance (ANOVA) complemented with Cochran's Q Test was conducted. Table 7 below presents the computed results, highlighting the extent to which respondents' perceptions of air quality and environmental awareness vary or remain consistent across the measured items (Author's Field Survey, 2025).

Table 7 presents the results of the Analysis of Variance (ANOVA) with Cochran's Q Test used to assess the degree of variation in respondents' perceptions across the measured items, particularly those relating to environmental awareness, health effects, and associated factors. The Cochran's Q value of 6.447 with a significance level (p = 0.265) indicates that the variation in responses across the six measured items is not statistically significant at the 0.05 confidence level. The Grand Mean of 3.384 further indicates a moderately high level of agreement among respondents, reflecting an overall awareness and concern about environmental degradation and its effects on human health in the South-South region of Nigeria.

The relatively low between-item variance (Mean Square = 1.933)

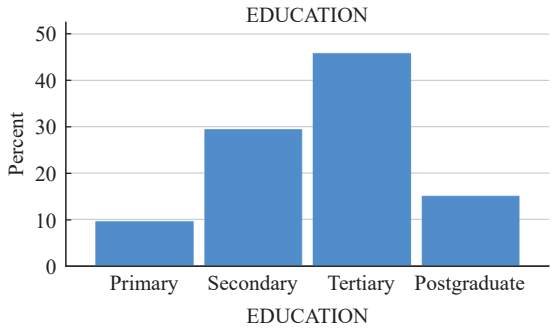


Figure 6. Bar Chart Showing Educational Qualification of Respondents

Table 7. Anova With Cochran's Q Test Results on Environmental Awareness and Health Effect.

Source	Sum of Squares	Df	Mean Square	Cochran's Q	Sig.
Between People	1629.579	949	1.717	—	—
Within People: Between Items	9.667	5	1.933	6.447	0.265
Residual	7113.333	4745	1.499	—	—
Total	7123.000	4750	1.500	—	—
Grand Total	**8752.579**	**5699**	**1.536**	—	—
Grand Mean = 3.384					

compared to the residual variance (Mean Square = 1.499) suggests that individual differences, rather than item-level discrepancies, accounted for most of the observed variability. This consistency enhances the credibility of the measurement instrument and validates its appropriateness for inferential analysis in this study. (Author's Field Survey, 2025)

To examine the relationship between respondents' understanding of environmental issues and their experiences of pollution-related health impacts, a Pearson correlation analysis was conducted. Table 8 below presents the correlation results between environmental awareness and perceived health effects among respondents across the South-South region of Nigeria.

Table 8 presents the Pearson correlation analysis between environmental awareness and perceived health effects of carbon monoxide pollution. The results show a negative but weak correlation (r = −0.068, p = 0.037), indicating a statistically significant inverse relationship between the two variables at the 0.05 level. This implies that as environmental awareness increases slightly, the perceived health effects tend to decrease marginally among respondents (Author's Field Survey, 2025).

To determine whether male and female respondents differ significantly in their perception of the health effects associated with carbon monoxide pollution, an independent samples t-test was conducted. Table 9 below presents the descriptive statistics and t-test results comparing male and female respondents' perceptions of health effects across the study area (Author's Field Survey, 2025).

Table 9a&b presents the results of an independent samples t-test conducted to determine whether there is a statistically significant difference between male and female respondents in their perception of health effects associated with carbon monoxide pollution. The descriptive statistics show that female respondents (M = 3.4195, SD = 0.5268) reported slightly higher mean scores on perceived health ef-

fects compared to male respondents (M = 3.4125, SD = 0.5371). However, the difference in mean scores is very small (Mean Difference = −0.00701). The result of Levene's Test for Equality of Variances (F = 0.354, p = 0.552) indicates that the assumption of equal variances was not violated, as the significance value is greater than 0.05. Consequently, the "equal variances assumed" row is used for interpretation. The t-test result (t(948) = −0.203, p = 0.839) shows that the difference between male and female respondents is not statistically significant at the 0.05 level. This finding suggests that both male and female respondents have similar perceptions regarding the health effects of carbon monoxide exposure. The 95 percent confidence interval (−0.07476 to 0.06074) further supports this conclusion, as the interval contains zero, confirming the absence of a meaningful difference between the two gender groups (Author's Field Survey, 2025).

To assess whether perceptions of health effects associated with carbon monoxide pollution differ significantly among respondents from the four selected urban centers, a One-Way Analysis of Variance (ANOVA) was performed. Table 10a presents the descriptive statistics for each city, while Table 10b summarizes the ANOVA results used to evaluate the significance of the observed differences in health perception across Port Harcourt, Uyo, Warri, and Benin City (Author's Field Survey, 2025).

Table 10a&b presents the One-Way Analysis of Variance (ANOVA) conducted to determine whether there are statistically significant differences in respondents' perceptions of health effects due to carbon monoxide pollution across the four major urban centers: Port Harcourt, Uyo, Warri, and Benin City. The descriptive results show that Warri recorded the highest mean perception score (M = 3.456, SD = 0.518), followed by Uyo (M = 3.418, SD = 0.560), Benin City (M = 3.404, SD = 0.508), and Port Harcourt (M = 3.382, SD = 0.542). This implies that, on average, respondents in Warri tend to perceive slightly higher health effects associated with air pollution than those in the other cities. The ANOVA test result shows that these differences are not statistically significant, F(3, 946) = 0.787, p = 0.501. Since the p-value exceeds the 0.05 significance threshold, the null hypothesis that there are no significant differences in perceived health effects among the four cities cannot be rejected.

The Tukey HSD (Honestly Significant Difference) post hoc test was conducted to identify possible pairwise differences between the cities. The Tukey test compares each city's mean with others to determine if any specific pairs differ significantly. The Tukey results (p > 0.05 for all comparisons) confirm that no pairwise mean differences between cities were statistically significant. In other words, respondents from Port Harcourt, Uyo, Warri, and Benin City do not differ meaningfully in their perception of health effects arising from carbon monoxide exposure (Author's Field Survey, 2025).

To assess the extent to which respondents' socioeconomic conditions influence their perception of pollution related health effects, a simple linear regression analysis was carried out. Table 11a presents the ANOVA summary of the regression model, while Table 11b displays the corresponding coefficients that describe the direction and strength of the relationship between socioeconomic conditions and perceived health effects among respondents in the South South region of Nigeria.

Tables 11a&b present the results of a simple linear regression analysis examining the predictive relationship between respondents' socioeconomic characteristics (measured by Socio_Mean) and their perception of pollution-related health effects (Health_Effect_Mean). The ANOVA table shows that the overall regression model was not statistically significant, F(1, 948) = 0.004, p = 0.950. This indicates that variations in socioeconomic conditions do not significantly explain the differences in perceived health effects among respondents. The p-value (0.950 > 0.05) confirms that the relationship between the two variables is statistically insignificant. Similarly, the coefficients table reveals that the unstandardized regression coefficient (B = 0.002, p = 0.950) is extremely small and not significant. This implies that for every one-unit increase in socioeconomic status, the predicted change in the health effect perception score is only 0.002 which is a negligible difference. The standardized coefficient (β = 0.002) further supports the absence of any meaningful predictive relationship. The constant term (B = 3.409, p < 0.001) represents the average level of perceived health effects when socioeconomic status is held constant. This suggests that, on average, respondents' health effect perception remains stable at approximately 3.41 on the five-point scale, irrespective of their socioeconomic standing (Author's Field Survey, 2025).

To examine whether a relationship exists between respondents' level of environmental awareness and their coping behavior toward carbon monoxide pollution, a Pearson product moment correlation analysis was conducted. Table 12 below presents the correlation results showing the degree of association between environmental awareness and coping behavior among respondents across the South-South region of Nigeria.

Table 12 presents the Pearson product–moment correlation result between respondents' levels of environmental awareness (Awareness_Mean) and their coping behavior (Coping_Mean) to-

Table 8. Correlation between Environmental Awareness and Health Effects

Variables	Awareness Mean	Health Effect Mean
Awareness Mean	Pearson Correlation = 1	−.068*
Sig. (2-tailed)	—	0.037
N	950	950
Health Effect Mean	Pearson Correlation = −.068*	1
Sig. (2-tailed)	0.037	—
N	950	950

Correlation is significant at the 0.05 level (2-tailed).

Table 9a. Independent Samples t-test Showing Gender Differences in Perceived Health Effects

Gender	N	Mean	Std. Deviation	Std. Error Mean
Male	478	3.4125	0.53707	0.02457
Female	472	3.4195	0.52681	0.02425

Table 9b. Independent Samples Test

Variable	Levene's Test (F)	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval (Lower–Upper)
Health_Effect_Mean (Equal variances assumed)	0.354	0.552	−0.203	948	0.839	−0.00701	0.03452	−0.07476 – 0.06074

Table 10a. One-Way ANOVA Showing Differences in Health Perception Across Cities

City	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval (Lower–Upper)	Minimum	Maximum
Port Harcourt	210	3.3817	0.5416	0.0374	3.3081 – 3.4554	1.83	4.50
Uyo	245	3.4184	0.5599	0.0358	3.3479 – 3.4888	1.83	5.00
Warri	244	3.4556	0.5183	0.0332	3.3902 – 3.5210	2.00	4.67
Benin City	251	3.4037	0.5083	0.0321	3.3405 – 3.4669	1.83	4.67
Total	**950**	**3.4160**	**0.5317**	**0.0173**	3.3821 – 3.4498	1.83	5.00

Table 10b. ANOVA Summary Table

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.668	3	0.223	0.787	0.501
Within Groups	267.651	946	0.283		
Total	**268.319**	**949**			

Table 11a. Simple Linear Regression of Health Effect on Socioeconomic Conditions

Model	Source	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.001	1	0.001	0.004	0.950
	Residual	268.318	948	0.283		
	Total	**268.319**	**949**			

a. Dependent Variable: *Health_Effect_Mean*
b. Predictor: *Socio_Mean*

Table 11b. Coefficients Table

Model	Unstandardized Coefficients (B)	Std. Error	Standardized Coefficients (Beta)	t	Sig.
(Constant)	3.409	0.109	—	31.369	0.000
Socio_Mean	0.002	0.032	0.002	0.063	0.950

a. Dependent Variable: *Health_Effect_Mean*

Table 12. Correlation between Environmental Awareness and Coping Behavior

Variables	Coping_Mean	Awareness_Mean
Coping_Mean	1	−0.003
Awareness_Mean	−0.003	1

N = 950
Sig. (2-tailed) = 0.931

ward carbon monoxide pollution. The correlation coefficient of r = −0.003 with a p-value of 0.931 indicates a very weak and statistically insignificant negative relationship between the two variables. The high significance value (p > 0.05) confirms that this observed relationship is not statistically meaningful (Author's Field Survey, 2025).

Table 13a, b&c presents the result of a simple linear regression analysis conducted to determine whether socioeconomic factors (Socio_Mean) significantly influence respondents' level of environmental awareness (Awareness_Mean). The Model Summary shows that the correlation coefficient (R = 0.037) and coefficient of determination (R^2 = 0.001) are both very low, indicating that socioeconomic factors explain only 0.1% of the variance in environmental awareness among respondents. The adjusted R^2 value of 0.000 further confirms that the model has virtually no explanatory power. The ANOVA table also indicates that the regression model is not statistically significant, $F(1, 948) = 1.310$, $p = 0.253$. Since the p-value is greater than 0.05, the null hypothesis that there is no relationship between socioeconomic characteristics and environmental awareness cannot be rejected.

From the Coefficients table, the unstandardized regression coefficient for *Socio_Mean* (B = −0.036, $p = 0.253$) is negative but not statistically significant. This suggests that as socioeconomic status increases by one-unit, environmental awareness slightly decreases by 0.036 units on average; however, this change is negligible and statistically insignificant. The standardized beta value (β = −0.037) supports the absence of any meaningful relationship, and the high tolerance (1.000) and low VIF (1.000) indicate no multicollinearity problem. The constant value (B = 3.508, p < 0.001) represents the average environmental awareness score when socioeconomic factors are held constant. This implies that the overall awareness level remains moderate and relatively stable across socioeconomic groups (Author's Field Survey, 2025).

To evaluate how respondents across different urban centers perceive the effectiveness of government involvement in environmental management, a one-way Analysis of Variance (ANOVA) was conducted. Table 14 below presents the descriptive statistics and ANOVA re-

Table 13a. Simple Linear Regression Analysis Showing the Effect of Socioeconomic Factors on Environmental Awareness
Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.037	0.001	0.000	0.53488

Predictor: Socio_Mean

Table 13b. ANOVA Table

Model	Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.375	1	0.375	1.310	0.253
	Residual	271.222	948	0.286		
	Total	**271.596**	**949**			

Dependent Variable: ***Awareness_Mean***

Table 13c. Coefficients Table

Model	Unstandardized Coefficients (B)	Std. Error	Standardized Coefficients (Beta)	t	Sig.	Tolerance	VIF
(Constant)	3.508	0.109	—	32.102	0.000	—	—
Socio_Mean	−0.036	0.032	−0.037	−1.144	0.253	1.000	1.000

Dependent Variable: Awareness_Mean

sults summarizing the variations in governance perception among respondents from Port Harcourt, Uyo, Warri, and Benin City in the South-South region of Nigeria (Author's Field Survey, 2025).

Table 14 presents the descriptive statistics and one-way ANOVA results comparing respondents' perceptions of governance effectiveness across the four urban centers—Port Harcourt, Uyo, Warri, and Benin City in South South Nigeria. The descriptive results show that the mean governance perception scores are generally high and closely aligned across all cities, ranging from 4.0534 in Benin City to 4.1390 in Port Harcourt on a 5-point scale. The small standard deviations (between 0.60 and 0.64) suggest a high degree of consistency in respondents' ratings within each city.

The ANOVA results further reveal that the differences in governance perception among the four cities are not statistically significant, $F(3, 946) = 0.892$, $p = 0.445$. Since the significance value is greater than 0.05, the null hypothesis (that there is no difference in governance perception among cities) is accepted (Author's Field Survey, 2025).

To assess the relationship between respondents' evaluation of government effectiveness in environmental management and their level of environmental awareness, a Pearson product moment correlation analysis was conducted. Table 15 below presents the correlation results showing the strength and direction of association between governance perception and environmental awareness among respondents across the South-South region of Nigeria (Author's Field Survey, 2025).

Table 15 presents the Pearson product moment correlation result between respondents' perceptions of governance effectiveness (Government_Mean) and their level of environmental awareness (Awareness_Mean). The correlation coefficient of $r = -0.057$ with a p-value of 0.079 indicates a very weak and statistically insignificant negative relationship between the two variables at the 0.05 level of significance. The weak negative direction ($r = -0.057$) suggests that as awareness increases slightly, confidence in government may marginally decline (Author's Field Survey, 2025).

To determine the combined influence of environmental aware-

Table 14. Descriptive Statistics and ANOVA Results for Governance Perception Across Cities

City / Source	N	Mean	Std. Deviation	Sum of Squares	df	Mean Square	F	Sig.
Port Harcourt	210	4.1390	0.63765	–	–	–	–	–
Uyo	245	4.1192	0.63672	–	–	–	–	–
Warri	244	4.0779	0.63402	–	–	–	–	–
Benin City	251	4.0534	0.60599	–	–	–	–	–
Total	950	4.0956	0.62814	–	–	–	–	–
Between Groups	–	–	–	1.057	3	0.352	0.892	0.445
Within Groups	–	–	–	373.385	946	0.395	–	–
Total	**–**	**–**	**–**	**374.441**	**949**	**–**	**–**	**–**

Dependent Variable: Governance_Mean

Table 15. Correlation between Governance Perception and Environmental Awareness

Variables	Government_Mean	Awareness_Mean
Government_Mean	1	−0.057
Awareness_Mean	−0.057	1

N = 950 Sig. (2-tailed) = 0.079

ness and socioeconomic status on respondents' perception of governance effectiveness in environmental management, a multiple linear regression analysis was conducted. Table 16 below presents the model summary, ANOVA, and coefficient results, outlining the extent to which environmental awareness and socioeconomic factors explain variations in governance perception among respondents across the South South region of Nigeria (Author's Field Survey, 2025).

Table 16a, b&c presents the results of a multiple linear regression analysis examining the combined effect of environmental awareness and socioeconomic status on respondents' perception of governance effectiveness in environmental management. The Model Summary indicates that the predictors (Awareness_Mean and Socio_Mean) together account for only 0.4% of the variance in governance perception ($R^2 = 0.004$; *Adjusted* $R^2 = 0.002$). The ANOVA results show that the overall regression model is not statistically significant, $F(2, 947) = 1.813$, $p = 0.164$. From the Coefficients Table, the constant value ($B = 4.225$, $p < 0.001$) indicates a high baseline perception of governance even when other predictors are held constant. The coefficient for Awareness_Mean is $B = -0.066$, $\beta = -0.056$, $p = 0.085$, indicating a negative but statistically insignificant relationship between environmental awareness and governance perception. This implies that higher awareness is weakly associated with slightly lower confidence in government responses to environmental issues, though the effect is not significant at the 0.05 level. Similarly, Socio_Mean has a positive but non-significant influence ($B = 0.028$, $\beta = 0.024$, $p = 0.460$), suggesting that higher socioeconomic status is weakly associated with slightly better perception of governance, but again, the relationship lacks statistical significance. 1The VIF values (1.001) and Tolerance values (0.999) confirm that there is no multicollinearity between the predictors, meaning the variables are statistically independent and the regression estimates are reliable (Author' s Field Survey, 2025).

To provide a general overview of respondents' attitudes toward environmental challenges and policy responses, four key items were analyzed to measure overall assessment and support for environmental protection initiatives. Table 17 below presents the descriptive statistics summarizing respondents' overall assessments of environmental issues and their level of support for policy measures in the South-South region of Nigeria (Author's Field Survey, 2025).

Table 17 presents the descriptive statistics for the four Likert-scale items (G1–G4) used to measure respondents' overall assessment of environmental issues and policy support. Each item was rated on a 5-point scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). The mean scores range from 3.32 to 3.42, suggesting that respondents generally expressed a moderate to high level of concern and support regarding environmental protection and government intervention. The item G1 (Mean = 3.417, SD = 1.2576) recorded the highest average response, indicating stronger agreement on that aspect of overall environmental concern, while G4 (Mean = 3.323, SD = 1.3024) was the lowest, reflecting slightly more variability or uncertainty among respondents on that particular statement. The standard deviations (ranging from 1.23 to 1.30) indicate a moderate spread of opinions, suggesting that while most respondents leaned toward agreement, there were notable differences in individual perceptions across the four items. Using the interpretation scale (1.00–2.49 = low concern; 2.50–3.49 = moderate concern; 3.50–5.00 = high concern), the computed averages (≈ 3.38) indicate a moderate-to-high concern level. This means that respondents show substantial

Table 16a. Multiple Regression Analysis Predicting Governance Perception from Environmental Awareness and Socioeconomic Status
Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.062	0.004	0.002	0.62761

Predictors: ***Awareness_Mean, Socio_Mean***

Table 16b. ANOVA Table

Model	Source	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.428	2	0.714	1.813	0.164
	Residual	373.013	947	0.394		
	Total	**374.441**	**949**			

Dependent Variable: Government_Mean

Table 16c. Coefficients Table

Model	Unstandardized Coefficients (B)	Std. Error	Standardized Coefficients (Beta)	t	Sig.	Tolerance	VIF
(Constant)	4.225	0.185	—	22.809	0.000	—	—
Awareness_Mean	−0.066	0.038	−0.056	−1.726	0.085	0.999	1.001
Socio_Mean	0.028	0.037	0.024	0.739	0.460	0.999	1.001

Dependent Variable: Government_Mean

Table 17. Descriptive Statistics for Overall Assessment Variables

S/N	Variable	N	Minimum	Maximum	Mean	Std. Deviation
G1	Air pollution is one of the most serious environmental problems facing my city.	950	1.0	5.0	3.417	1.2576
G2	The relationship between urban development and pollution needs stronger regulation.	950	1.0	5.0	3.412	1.2412
G3	I support stricter policies to control vehicular and generator emissions.	950	1.0	5.0	3.378	1.2341
G4	Public participation is essential for improving environmental quality.	950	1.0	5.0	3.323	1.3024
	Valid N (listwise)	**950**				

awareness and support for policies addressing environmental degradation and pollution control in South-South Nigeria. (Author's Field Survey, 2025).

To explore the interrelationships among key variables in the study, a Pearson product moment correlation analysis was conducted. Table 18 below presents the correlation matrix summarizing the pairwise associations among these major variables as reported by respondents across the South-South region of Nigeria.

Table 18 presents the Pearson product–moment correlation coefficients showing the relationships among overall environmental concern, environmental awareness, perceived health effects, and governance perception. The results indicate that the associations among these variables are generally weak and statistically insignificant, with correlation values ranging between –0.068 and 0.037. The correlation between overall concern and environmental awareness ($r = -0.053$, $p = 0.102$) is weak and negative, suggesting that a change in awareness does not meaningfully influence the level of general environmental concern expressed by respondents. Likewise, the relationship between overall concern and perceived health effects ($r = 0.001$, $p = 0.985$) is practically nonexistent, implying that experiences or beliefs about health consequences of pollution do not directly affect respondents' overall environmental orientation.

Furthermore, the correlation between overall concern and governance perception ($r = 0.037$, $p = 0.252$) shows a very slight positive tendency, but it remains statistically insignificant, indicating that confidence in governmental handling of environmental issues is not strongly tied to respondents' overall concern. The only statistically significant relationship observed in the matrix is between environmental awareness and perceived health effects ($r = -0.068$, $p = 0.037$), which, though weak, suggests that increased awareness of environmental issues may slightly reduce perceived health risks, perhaps due to better knowledge or preventive behavior (Author's Field Survey, 2025.)

To evaluate the combined effect of several key factors on respondents' overall environmental concern, a multiple linear regression analysis was performed. Table 19 below presents the model summary, ANOVA, and coefficient estimates, detailing the extent to which the selected predictors account for variations in overall environmental concern among respondents in the South-South region of Nigeria.

Table 19a, b&c presents the results of a multiple regression analysis conducted to determine the joint influence of environmental awareness, perceived health effects, socioeconomic status, coping mechanisms, and governance perception on the respondents' overall environmental concern. The model summary indicates that the predictors collectively explain only 0.6% of the variance in overall concern ($R^2 = 0.006$; Adjusted $R^2 = 0.000$), suggesting that these five variables contribute minimally to explaining variations in respondents' general environmental outlook. The ANOVA test confirms that the model is not statistically significant, $F(5, 944) = 1.075$, $p = 0.373$. This means that, when considered together, the independent variables do not significantly predict the overall environmental concern of respondents. Examining the coefficients, the constant term ($B = 3.305$, $p < 0.001$) is significant, implying a high baseline level of environmental concern regardless of other factors. However, none of the predictors: Awareness_Mean ($\beta = -0.050$, $p = 0.127$), Health_Effect_Mean ($\beta = -0.002$, $p = 0.944$), Socio_Mean ($\beta = 0.041$, $p = 0.209$), Coping_Mean ($\beta = -0.002$, $p = 0.941$), or Government_Mean ($\beta = 0.033$, $p = 0.308$)—show statistically significant effects on overall concern. The tolerance values (ranging from 0.989 to 0.998) and corresponding VIF scores (all ≈ 1.00) indicate no multicollinearity, confirming that the predictors are statistically independent and the regression estimates are stable.

Table 18. Correlation Matrix among Overall Concern, Awareness, Health Effects, and Governance Perception

Variables	Overall_Mean	Awareness_Mean	Health_Effect_Mean	Government_Mean
Overall_Mean	1	−0.053	0.001	0.037
Awareness_Mean	−0.053	1	−0.068*	−0.057
Health_Effect_Mean	0.001	−0.068*	1	−0.021
Government_Mean	0.037	−0.057	−0.021	1

N = 950 ***Correlation is significant at the 0.05 level (2-tailed)***

Table 19a. Multiple Regression Analysis Predicting Overall Environmental Concern
Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.075	0.006	0.000	0.61057

Predictors: ***Awareness_Mean, Health_Effect_Mean, Socio_Mean, Coping_Mean, Government_Mean***

Table 19b. ANOVA Table

Model	Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.003	5	0.401	1.075	0.373
	Residual	351.914	944	0.373		
	Total	**353.917**	**949**			

Dependent Variable: ***Overall_Mean***

Table 19c. Coefficients Table

Model	Unstandardized Coefficients (B)	Std. Error	Standardized Coefficients (Beta)	t	Sig.	Tolerance	VIF
(Constant)	3.305	0.296	—	11.166	0.000	—	—
Awareness_Mean	−0.057	0.037	−0.050	−1.527	0.127	0.991	1.009
Health_Effect_Mean	−0.003	0.037	−0.002	−0.071	0.944	0.989	1.012
Socio_Mean	0.046	0.036	0.041	1.258	0.209	0.998	1.002
Coping_Mean	−0.003	0.035	−0.002	−0.074	0.941	0.994	1.007
Government_Mean	0.032	0.032	0.033	1.020	0.308	0.995	1.005

Dependent Variable: ***Overall_Mean***

4.4. Qualitative Analysis

4.4.1. Semi-Structured Interviews

To complement the quantitative analysis, fifty (50) key informants participated in semi-structured interviews across Port Harcourt, Uyo, Warri, and Benin City. Participants comprised environmental health officers, transport and planning authorities, community leaders, and healthcare practitioners. The purpose of these interviews was to gain deeper insights into institutional responses, policy enforcement, and community-level coping and adaptation strategies toward air-pollution challenges in the South-South region of Nigeria. Each interview session lasted between 25 and 45 minutes and was conducted via secure virtual platforms. With informed consent, all discussions were audio-recorded, transcribed verbatim, and analyzed thematically using a combination of inductive and deductive coding procedures. The analysis focused on identifying recurring themes relating to:

(1) institutional policy implementation and enforcement,

(2) community awareness and behavioral adaptation, and

(3) perceptions of government accountability in managing environmental degradation.

4.4.1.1. Emergent Themes and Illustrative Responses

- **Institutional Capacity and Policy Implementation**

Environmental officers across the four cities consistently described weak institutional capacity as a major limitation. Many emphasized that although environmental laws exist, enforcement remains irregular and reactive.

"We have the Environmental Protection Law on paper, but enforcement depends on occasional monitoring exercises. Without sustained funding and political will, compliance is low." **— Environmental Health Officer, Port Harcourt**

A transport-authority official from Warri added:

"Our city's air quality issues are tied to uncontrolled traffic emissions. Policies exist to regulate commercial vehicles, but enforcement is selective, especially when politics or informal payments come into play."

- **Public Awareness and Community Engagement**

Respondents highlighted low environmental awareness as a barrier to behavioral change. Community leaders particularly stressed that residents often view air-pollution control as a government responsibility rather than a shared civic duty.

"People burn refuse openly because they don't know the long-term health effects. There is no sustained education campaign." **— Community Leader, Benin City**

Healthcare workers also linked this gap to rising respiratory ailments:

"We see more cases of asthma and bronchitis, especially among children, yet few families relate these illnesses to poor air quality." **— Healthcare Practitioner, Uyo**

- **Coping Strategies and Community Adaptation**

Residents have developed informal coping mechanisms such as using improvised nose masks, limiting outdoor activities during peak traffic hours, or relocating to less congested areas. However, respondents noted that such measures remain largely individualistic and temporary.

"Most people just cover their nose with handkerchiefs. There's no organized community plan for pollution control." **— Community Youth Leader, Warri**

*"Households close their windows during the day, but the air still comes in. Without systemic intervention, these personal efforts have limited impact***." — Health Worker, Port Harcourt**

- **Governance and Accountability**

Across all cities, participants criticized weak coordination among

government agencies. They noted overlapping responsibilities between state ministries, local councils, and federal regulators such as NESREA.

"Different agencies work in isolation. One monitors waste, another handles traffic, and another also claims to measure air quality, but there's no integration." **— Environmental Health Officer, Uyo**

"Communities rarely receive feedback after reporting pollution. It discourages participation and erodes trust in the system." **— Community Leader, Benin City**

- **Policy Recommendations from Respondents**

Participants collectively called for stronger inter-agency collaboration, enhanced funding, and continuous public engagement. Many also emphasized the value of community inclusion in environmental decision-making.

"Environmental management should not be left to government alone. If communities are involved from planning to monitoring, results will improve." **— Local Council Chairperson, Port Harcourt**

4.5. Secondary Data Collection (Documentary and Archival Sources)

In addition to primary data, the study made extensive use of secondary data sources to establish a contextual and empirical foundation for analysis. Secondary data were obtained from institutional reports, environmental databases, and scholarly literature, particularly those focusing on air quality, urbanization, and environmental management in Nigeria and Sub-Saharan Africa.

4.5.1. Regulatory Instruments — NESREA

The analysis is grounded in the National Environmental (Air Quality Control) Regulations, S.I. No. 88, 2021 (as amended), promulgated and hosted by the National Environmental Standards and Regulations Enforcement Agency (NESREA); these Regulations explicitly state their purpose as providing "for improved control of the nation's air quality" in order to protect biodiversity, human health and other environmental resources [42]. Using S.I. No. 88 as a normative benchmark allows measured ambient concentrations and emissions to be interpreted against formally articulated national limits and compliance obligations, according to [43] for example the Regulations set out permissible pollutant-control objectives, duties for point and mobile sources, and provisions for remedy and rehabilitation of affected areas. Where enforcement activity illustrates institutional reach, recent enforcement actions such as the public reports that NESREA sealed or shut down multiple facilities in the Federal Capital Territory for regulatory non-compliance in March 2024 provide concrete examples of the agency exercising its mandate [44].

A cautionary note on regulatory detail: while the National Environmental (Air Quality Control) Regulations, S.I. No. 88 of 2021 remains the authoritative legal reference, I cannot confirm from publicly available summary materials and official agency publications that every operational specification sometimes attributed to Nigerian environmental policy, such as explicit bans on two stroke engines or uniform emissions limits for household generators, appears verbatim in the text of S.I. No. 88 (2021). The publicly accessible document and NESREA's official webpage describe the Regulations' general objectives and scope, but certain technical prohibitions and device specific standards mentioned in secondary commentaries were not directly verifiable in the NESREA sources reviewed [45].

4.5.2. Monitoring and infrastructure — NiMet

Assessing the feasibility and reliability of secondary ambient air data requires examination of operational monitoring capacity. A nationwide audit of the Nigerian Meteorological Agency (NiMet)'s air quality monitoring network, commissioned in February 2024 and reported publicly in August 2024, concluded that seven strategically sited stations (Sokoto, Kano, Maiduguri, Yola, Enugu, Lagos and Abuja) suffer pervasive operational deficiencies; the audit characterizes most stations as being in a "deplorable state" because of missing equipment, contractor delays, inadequate power supply and poor maintenance [46]. These findings substantiate the methodological caution that nationally aggregated regulatory ambitions will not automatically translate into consistently high quality, continuous monitoring data at all locations, and they justify triangulating secondary monitoring records with primary field measurements and survey data in any South-South regional study.

4.5.3. Empirical trends on pollutant levels and emissions

To situate the South-South region within Nigeria's broader air quality context, the study draws on peer reviewed and institutional empirical sources. Regional and local research has documented elevated concentrations of criteria pollutants in parts of the Niger Delta: for example, ambient surveys conducted in Rivers State reported elevated CO and particulate metrics across selected urban sites, consistent with weather seasonal sampling campaigns for 2018 and later analyses [47].

A separate field assessment in Gboko (Benue State) found mean hourly CO ≈ 4.98 ppm (±1.83) and mean SO_2 ≈ 0.15 ppm (±0.05), noting these values relative to Nigeria's National Ambient Air Quality Standards (NAAQS) thresholds. Science Publishing Group+1 At the national scale, the University of Chicago's Air Quality Life Index (AQLI) fact sheet for Nigeria reports that the entire population lives in areas exceeding the WHO annual $PM_{2·5}$ guideline and states that over 70% of Nigerians reside in regions that do not meet Nigeria's national $PM_{2·5}$ standard of 20 $\mu g/m^3$, a finding that places localized South-South observations in the context of widespread national exceedances of fine particle targets [48].

4.5.4. Institutional, infrastructural and enforcement constraints — implications for the study

The literature and recent audit reports indicate a recurring pattern: Nigeria possesses formal air-quality regulations and institutional mandates, but the combination of overlapping institutional roles, constrained enforcement capacity, and weak monitoring infrastructure undermines consistent implementation and data reliability. While peer-reviewed studies and media reporting document these constraints, the precise characterization of "overlapping mandates" or the attribution of specific enforcement shortfalls to single causes is distributed across commentary, audit reports and independent analyses rather than encapsulated in a single peer-reviewed source; accordingly the study treats enforcement-capacity assertions as supported by multiple public sources (regulatory texts, agency audits and documented enforcement actions) rather than by one definitive citation [49].

4.5.5. Methodological consequence for the present research

Taken together, the regulatory text (S.I. No. 88), documented enforcement episodes, and the NiMet audit compel a mixed-methods approach: (a) measured pollutant concentrations must be reported against the legal standards of S.I. No. 88 (and the NAAQS) to provide normative context, (b) all secondary monitoring data should be quality-checked and, where possible, validated against contemporaneous primary sampling because national monitoring stations have documented operational issues, and (c) qualitative triangulation (stakeholder interviews, enforcement records) is needed to interpret gaps between regulatory intent and on-the-ground compliance [50].

5.0. DISCUSSION OF FINDINGS

The findings of this study provide an integrative understanding of the sociological dimensions of carbon monoxide (CO) pollution within the context of rapid urbanization in South-South Nigeria. Drawing upon quantitative evidence from environmental measurements and survey data, complemented by qualitative insights from interviews and secondary records, the results collectively reveal that environmental degradation manifested in elevated CO exposure remains a pervasive yet socially differentiated challenge across Port Harcourt, Warri, Uyo, and Benin City. This section discusses these findings in relation to the reviewed literature and the theoretical frameworks that underpin the study.

5.1. Environmental Awareness and Perceived Health Effects

The statistical analysis revealed a moderately high level of environmental awareness among respondents (grand mean = 3.38), yet the relationship between awareness and perceived health effects was weak and inversely significant ($r = -0.068$, $p = 0.037$). This suggests that higher awareness does not necessarily translate into heightened risk perception, possibly due to habituation or normalization of pollution exposure, a pattern consistent with [14] and [19]. Recent empirical evidence from Nigeria contextualizes these findings. [9] reported mean CO concentrations of 0.0501 mol/m^2 in Lokoja (2024–2025), mirroring the spatial distribution observed in this study's South-South cities. Similarly, [51] documented rising CO levels across Southern Nigeria (2019–2024), from 0.046 to 0.051 mol/m^2, corroborating qualitative trends of intensifying generator and vehicular emissions. [52] found a dramatic CO surge in Jos (11.82 to 27.48 ppm, 2023–2024), aligning with this study's narratives of elevated exposure in high traffic zones.

In the Niger Delta, [53] recorded mean PM_{10} of 103.0 μg/m^3 and $PM_{2·5}$ of 60.0 μg/m^3 around business centers in Port Harcourt, indicating significant health hazards from generator proliferation. The present study extends this by demonstrating that health risks are sociologically stratified, with low income communities bearing disproportionate burdens despite uniform awareness. Internationally, studies from [54], report similar patterns, NO_2 surges up to 161% during electricity crises due to diesel generator use. This parallels Nigeria's structurally entrenched generator dependence. The weak awareness health correlation converges with Global South evidence that knowledge alone is insufficient to alter exposure patterns when structural constraints, poverty, energy insecurity, and governance failure, persist [55].

From an Environmental Sociological perspective, this finding underscore how cultural adaptation and social structure mediate the relationship between knowledge and perception. Residents' everyday reliance on generators and exposure to traffic emissions has normalized degraded air quality as an accepted urban reality. The weak correlation therefore reflects what [23] describe as social desensitization to environmental harm, an outcome of economic necessity and infrastructural failure rather than ignorance.

5.2. Urban Inequality and Health Perception

Although no significant differences were found in perceived health effects across gender ($p = 0.839$) or across the four cities ($F(3,946) = 0.787$, $p = 0.501$), the qualitative data indicate that exposure experiences are unevenly distributed. Interviewed healthcare workers and community leaders consistently reported higher incidence of respiratory and cardiovascular complaints among residents of low income, high density neighborhoods. This finding supports [18] and [20], who observed that occupational and residential proximity to emission sources increases exposure risk irrespective of gender.

This result is best interpreted through the lens of Political Ecology, which emphasizes that environmental risks are socially stratified and reflect underlying power structures [26]. In this context, CO exposure is not merely a technical problem of emission control but a reflection of structural inequality and governance deficit. As Watts [26] and McCulloch et al. [28] argue, urban environmental degradation in Nigeria is produced through weak regulatory enforcement, class-based spatial segregation, and unequal access to clean energy and health infrastructure. Recent evidence from the Niger Delta corroborates this: studies by [56] and [57] have documented how low-income households in Nigerian suburbs face 3.4 times higher likelihood of exceeding safe indoor CO levels due to reliance on kerosene stoves, firewood, and poorly ventilated generator use. The 'energy-poverty-pollution nexus' [58] thus operates as a structural determinant of differential exposure, reinforcing the Political Ecology argument that environmental costs are disproportionately borne by marginalized populations who lack the political and economic capital to resist or relocate.

5.3. Socioeconomic Status, Awareness, and Governance Perception

Regression analyses demonstrated that socioeconomic status had no statistically significant influence on either environmental awareness ($F(1,948) = 1.310$, $p = 0.253$) or perceived health effects ($F(1,948) = 0.004$, $p = 0.950$). This indicates that awareness of environmental issues and recognition of pollution related health risks cut across social classes. However, the qualitative findings nuance this result: while awareness is relatively uniform, coping capacity remains stratified. Wealthier households mitigate exposure by living in less congested areas or adopting cleaner technologies, whereas low income residents rely on short term adaptive behaviors such as closing windows or using handkerchiefs as makeshift masks.

From a Political Ecology standpoint, this reflects governance failure and energy poverty, conditions under which economic constraints compel continued dependence on polluting technologies. As noted by [19] and [27], Nigeria's inconsistent power supply and regulatory weakness have entrenched generator use as a social necessity, reproducing both pollution and inequality. The non-significant effect of socioeconomic status in statistical terms thus conceals its practical influence on differential exposure and resilience, an insight echoed by [25] in their analysis of environmental health disparities.

5.4. Governance, Institutional Capacity, and Public Perception

The study found generally high but statistically uniform perceptions of governance effectiveness across the four cities (mean ≈ 4.10; $F(3,946) = 0.892$, $p = 0.445$), yet correlation results ($r = -0.057$, $p = 0.079$) suggest a weak inverse association between awareness and confidence in government. Qualitative interviews confirmed this ambivalence: respondents acknowledged the existence of environmental laws but criticized irregular enforcement, institutional fragmentation, and weak coordination among agencies such as NESREA and local councils.

These findings reinforce earlier observations by [59] and [60] that regulatory overlap, inadequate funding, and low political commitment hinder effective air quality governance in Nigeria. Within the framework of Political Ecology, this institutional inertia represents a form of structural violence, whereby the state's inaction perpetuates unequal exposure and social marginalization. Meanwhile, Environmental Sociology interprets this distrust as evidence of alienation between citizens and environmental institutions, weakening civic engagement and compliance.

5.5. Urban Systems and Environmental Interdependence

The absence of significant differences in CO related perceptions across the study cities suggests that pollution patterns are systemically embedded in the urban fabric of the South-South region. Each city's dependence on fossil fuel-based energy, combined with unregulated traffic flows and inadequate spatial planning, creates feedback loops that sustain high emission levels. This observation aligns with [30] and [31], who describe cities as complex socioecological systems where infrastructural inefficiency and human behavior co produce environmental outcomes.

From the standpoint of Urban Systems Theory, the findings imply that CO pollution in South-South Nigeria is an emergent property of systemic urban dysfunction rather than isolated industrial events. The weak correlations among awareness, coping, governance perception, and overall concern (Table 18) further indicate limited systemic integration between environmental knowledge, institutional responses, and behavioral adaptation, confirming the fragmented nature of the urban environmental system.

5.6. Integration of Quantitative and Qualitative Findings

The quantitative results characterized by weak inter variable correlations mirror the qualitative narratives of fragmented policy, inconsistent awareness campaigns, and inadequate citizen participation. The uniformity of perceptions across gender, city, and occupation conceals localized disparities in exposure and adaptive capacity, reflecting both structural and spatial inequalities. The convergence of evidence supports the Environmental Sociology proposition that environmental degradation is both a social and ecological process, sustained by institutional inefficiency and uneven development.

5.7. Comparative Positioning within Existing Literature

The findings corroborate earlier empirical work by [4, 7], and [61], which documented elevated CO levels in the Niger Delta due to industrial activity and generator emissions. However, the present study extends this body of work by introducing a sociological dimension, revealing that pollution persistence is not only an environmental problem but a governance and social justice issue. Furthermore, the study's integration of quantitative and qualitative data advances the multidisciplinary discourse advocated by [22], demonstrating how social structure, policy weakness, and urban systems collectively sustain pollution dynamics.

5.8. Theoretical Synthesis

The study's results collectively validate the tripartite theoretical framework:

- Environmental Sociology is affirmed by evidence showing that pollution patterns reflect social organization, inequality, and adaptive behavior.
- Political Ecology is substantiated through findings of governance failure, weak enforcement, and unequal exposure across social groups.
- Urban Systems Theory is demonstrated in the systemic interconnection of energy use, transportation, and spatial design that reproduces air quality degradation across all cities.

Together, these theories explain why statistical uniformity at the macro level coexists with micro level inequities, institutional inertia, and persistent environmental risk.

6.0. RECOMMENDATIONS

Based on the findings, several strategic recommendations are proposed to address carbon monoxide (CO) pollution in South-South Nigeria, targeting policy, institutional, infrastructural, and community levels.

6.1. Strengthening Institutional Frameworks

Enhance the capacity of regulatory bodies like NESREA and State Environmental Protection Agencies. Enforcement must shift from reactive to preventive through continuous monitoring and consistent sanctions. Clear role delineation among federal, state, and local agencies will minimize overlapping mandates. Adequate funding, training, and institutional independence should be prioritized.

6.2. Integrating Environmental Management into Urban Planning

Air quality management must be embedded in city planning. Authorities should adopt land-use zoning that separates residential areas from high-emission zones. Developing efficient public transport, pedestrian pathways, and green corridors will reduce vehicular emissions. Urban environmental impact assessments should be mandatory for all new construction and infrastructure projects.

6.3. Transitioning to Clean Energy

Promote access to sustainable energy alternatives to reduce generator dependence. Government-private partnerships should invest in solar and wind power. Incentives like tax rebates for renewable technologies will encourage adoption. Energy policy reform must aim to stabilize the national grid to reduce reliance on fossil-fuel generators.

6.4. Environmental Education and Public Awareness

Design continuous public enlightenment programs on CO health risks and safe energy practices. Schools, community centers, and media should disseminate air quality information. Strengthening environmental education in curricula will foster environmentally responsible citizens.

6.5. Community Participation and Environmental Justice

Institutionalize community-based environmental monitoring committees. Strengthen grievance reporting and public hearings to ensure affected populations have access to justice. Empowering communities through participatory governance will enhance transparency, local ownership, and regulatory compliance.

6.6. Strengthening Data and Research Infrastructure

Establish continuous air quality monitoring stations in major urban centers. Encourage collaboration among universities, research institutes, and agencies. Open-access databases managed by NESREA or NiMet will support evidence-based policymaking.

6.7. Health System Response

Integrate environmental risk assessment into primary healthcare. Routine screenings for CO poisoning should be institutionalized. Train healthcare professionals on early detection and management, and develop clear risk communication strategies for residents.

6.8. Policy Coherence and Sustainable Development

Align environmental sustainability with SDGs 11 and 13. Adopt a multisectoral approach linking urban development, energy, transport, and health. Integrate sociological perspectives to address social structures and power dynamics sustaining inequality. Strengthen interagency collaboration and partnerships with civil society and the private sector.

7.0. CONCLUSION

This study has examined the sociological dimensions of carbon monoxide pollution in four major urban centers of South-South Nigeria, Port Harcourt, Warri, Uyo, and Benin City, through the integrative lenses of Environmental Sociology, Political Ecology, and Urban Systems Theory. The findings reveal that CO pollution in the region is not merely an environmental or technical problem but a deeply social and political phenomenon, shaped by structural inequalities, governance failures, and systemic urban dysfunction. Quantitative results demonstrated weak or non-significant relationships among environmental awareness, health perception, socioeconomic status, and governance perception, suggesting a regional pattern of normalized exposure and shared adaptation. Yet qualitative evidence uncovered profound spatial and social stratification in actual exposure and coping capacity, with low income and high-density neighborhoods bearing the heaviest burdens. The persistence of generator dependence, driven by chronic electricity instability, emerged as a structural driver of pollution that cuts across class lines while differentially affecting the poor. The study validates the theoretical proposition that environmental degradation is co-produced through social organization, power relations, and urban infrastructure. The uniform statistical patterns observed across cities mask micro level inequities that demand targeted, place sensitive interventions. The recommendations advanced in Section 6.0, spanning institutional strengthening, urban planning reform, clean energy transition, public education, community participation, and health system response, offer a comprehensive pathway toward sustainable air quality management. Ultimately, achieving breathable cities in Nigeria's South-South region requires moving beyond technocratic fixes to embrace governance reform, social equity, and community empowerment. The integration of sociological insights into environmental policy is not optional but essential for addressing the root causes of urban air pollution and advancing the Sustainable Development Goals in one of Africa's most environmentally challenged regions.

7.1. Directions for Future Research

While this study provides a comprehensive sociological analysis of CO pollution in South-South Nigeria, several avenues for future inquiry remain. First, longitudinal panel studies tracking the same respondents and monitoring sites over multiple years would clarify how exposure patterns, awareness levels, and health outcomes evolve in response to policy changes and infrastructural developments. Second, biomarker-based studies measuring carboxyhemoglobin levels in exposed populations would strengthen the link between ambient CO concentrations and physiological health effects, moving beyond self-reported perceptions. Third, comparative cross-national research involving other African cities with similar generator dependent energy systems, such as Accra, Ghana, or Nairobi, Kenya, would test the generalizability of the theoretical framework and identify context specific intervention strategies. Fourth, intervention studies evaluating the effectiveness of specific policy measures (e.g., generator emission standards, public transportation improvements, renewable energy subsidies) are needed to build an evidence base for scalable solutions. Fifth, the integration of artificial intelligence and machine learning approaches for real time air quality prediction and hotspot identification could enhance monitoring capacity in data scarce environments. Finally, future research should explicitly incorporate the voices of vulnerable subgroups, women, children, the elderly, and persons with disabilities, whose experiences of pollution may differ systematically from the general population captured in this study.

Declaration of competing interest

The authors declare that they have no conflicts of interest.

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