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Assessment of Ambient Air Quality and Associated Health Risks in Port Harcourt Metropolis, Nigeria

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ABSTRACT

Ambient air pollution remains a major environmental and public health issue in rapidly industrialising cities, particularly in oil-producing areas such as Port Harcourt in the Niger Delta, Nigeria. This study evaluated ambient air quality and related health risks at selected sites representing industrial, traffic-heavy, residential, and semi-urban environments within the Port Harcourt metropolitan area. Levels of key atmospheric pollutants, including particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and ozone (O_3) were measured, along with the Air Quality Index (AQI) and non-carcinogenic health risk indicators. The results revealed high particulate matter levels, with $PM_{2.5}$ ranging from 38.2 ± 6.3 to 72.1 ± 10.4 µg/m^3 and PM_{10} from 70.8 ± 11.5 to 136.2 ± 17.8 µg/m^3, surpassing recommended standards. Carbon monoxide levels varied between 2.4 ± 0.6 and 6.8 ± 1.2 ppm, while NO_2 and SO_2 concentrations ranged from 0.028 ± 0.009 to 0.065 ± 0.011 ppm and 0.012 ± 0.004 to 0.034 ± 0.007 ppm, respectively. AQI values ranged from 94 in semi-urban areas to 182 in traffic-heavy locations, indicating moderate to unhealthy air quality. Hazard quotient values for $PM_{2.5}$ (2.14) and PM_{10} (1.89) indicated potential non-carcinogenic health risks from prolonged exposure. The findings underscore the impact of industrial emissions, gas flaring, vehicular activity, and urban energy needs on air quality in Port Harcourt. Ongoing environmental monitoring, stricter regulation enforcement, cleaner energy adoption, and better urban environmental management are recommended to reduce pollution and safeguard public health in the Niger Delta region.

Keywords: *Ambient Air Pollution, Air Quality Index (AQI), Particulate Matter ($PM_{2.5}$, PM_{10}), Health Risk Assessment, Non-Carcinogenic Risk, Industrial Emissions, Gas Flaring, Urban Air Quality, Niger Delta, Port Harcourt*

1.0 Introduction

Air pollution is one of the most pressing environmental challenges of the twenty-first century, particularly in rapidly urbanising and industrialising regions where anthropogenic activities significantly alter atmospheric composition and environmental quality [11]. Ambient air pollution contributes to climate change, ecological degradation, and serious public health outcomes, including respiratory illnesses, cardiovascular disorders, cancers, and premature mortality [23]. In developing countries, the burden of air pollution is often intensified by weak environmental regulation, expanding urban populations, dependence on fossil fuels, open waste burning, and industrial emissions. In oil-producing regions such as the Niger Delta, these pressures are further compounded by petroleum exploration, gas flaring [14], crude oil theft, illegal refining [20], and heavy transportation activities, creating a complex environmental and human health crisis [2].

Port Harcourt metropolis, Rivers State, is one of the major urban and industrial centres in the Niger Delta and has become emblematic of the environmental consequences of poorly controlled industrialisation. The city accommodates petroleum facilities, manufacturing industries, dense road networks, busy markets, and expanding residential settlements, all of which contribute to atmospheric emissions. In recent years, the recurrent black soot phenomenon in Port Harcourt has drawn national and international attention because of its visible effects on homes, vegetation, water surfaces, vehicles, and public infrastructure [38], as well as its implications for human health [25].

Previous studies have linked the soot crisis to illegal artisanal refining, gas flaring, industrial combustion, oil theft [15], and vehicular emissions, describing the city as experiencing a double burden of air pollution from both conventional urban sources and petroleum-related activities [11,38].

The significance of air pollution in Port Harcourt extends beyond atmospheric quality alone because airborne pollutants interact continuously with water, soil, and biotic systems. Environmental contamination in the Niger Delta is multidimensional, with evidence showing that pollutants released into one environmental compartment may migrate into others through deposition, runoff, volatilisation, seepage, and bioaccumulation [31]. Studies from the region have reported contamination of drinking water [24], groundwater vulnerability to oil pollution [33], sediments and wetlands [1], and aquatic organisms [34] due to petroleum-related activities and urban pollution. This interconnectedness suggests that ambient air pollution in Port Harcourt should be interpreted within a broader environmental systems framework rather than as an isolated atmospheric issue [7].

Petroleum exploration and production activities remain central drivers of environmental degradation in the Niger Delta. Oil spills, gas flaring, illegal bunkering, pipeline vandalism, and crude oil combustion release particulates, gaseous pollutants, heavy metals, hydrocarbons, and other hazardous substances into the environment [13]. Illegal bunkering and artisanal refining have been specifically identified as major sources of environmental contamination and ecological damage in the region [15,20]. Radioactivity concerns in oil- and gas-producing areas further reflect the complexity of pollution exposure pathways in the Niger Delta [14]. In addition, hydrocarbon contamination has been documented in offshore and estuarine sediments [16] and in Bonny Estuary biota [31], demonstrating the persistence and environmental mobility of petroleum-derived pollutants.

Airborne particulate matter, especially $PM_{2.5}$ and PM_{10}, is of particular concern because of its ability to penetrate deeply into the respiratory tract and transport toxic compounds adsorbed onto particle surfaces. Research in Port Harcourt has shown that particulate airborne pollutants may contaminate recreational waters and pose serious risks to children and vulnerable populations [29]. Carbon monoxide and other gaseous pollutants have also been reported at concerning levels in parts of the Niger Delta, with implications for human health and environmental quality [2]. These findings highlight the importance of routine monitoring of both particulate and gaseous pollutants in urban-industrial centres.

The environmental effects of atmospheric pollution are reinforced by its interaction with water resources and aquatic ecosystems. Hydrochemical assessment of drinking water sources in Brass Island, Bayelsa State, revealed contamination patterns associated with anthropogenic activities and corresponding health risks [24]. Atmospheric deposition of soot and heavy metals from gas flaring into surface waters has also been reported in Rivers State [3], demonstrating direct transfer of airborne contaminants into aquatic systems. Similarly, volatile organic compounds generated during gas flaring can be transported across environmental media and ultimately contaminate water bodies [35]. Such linkages confirm that air pollution is closely tied to water quality deterioration in oil-producing environments.

Urban and industrial pollution in the Niger Delta also contributes to soil contamination, ecological toxicity, and food-chain transfer of hazardous substances. Polychlorinated biphenyls have been detected in soils and industrial effluents in southern Nigeria [28], indicating the continued release of hazardous organic pollutants into the environment. Heavy metals and hydrocarbon residues have also been found in estuarine fish [34] and aquatic fauna showing biomarker stress responses [32]. Similar concerns have emerged regarding urban rivers polluted by domestic wastewater [30], surfactants and heavy metals [36], and nutrient-rich agricultural runoff [37]. These studies show that air pollution may coexist with, and contribute to, wider ecological contamination in ways that threaten biodiversity, aquatic productivity, and human food safety.

Broader environmental management issues, such as access to clean water, treatment systems, and urban infrastructure, also influence pollution exposure and public health vulnerability. Engineering assessments have demonstrated the usefulness of slow sand filters in improving contaminated water quality in Port Harcourt communities [12]. At the same time, dietary exposure to contaminants may be shaped by processing practices and polluted environments, as shown in studies on smoked Nile tilapia [26] and nutritional changes in differently dried fish products [27]. Such evidence reinforces the view that environmental pollution in the Niger Delta is cumulative and cross-sectoral, affecting air, water, soil, and food systems simultaneously.

Energy poverty and unsustainable fuel use further complicate air quality challenges in Nigeria. In many urban and peri-urban households, electricity shortages increase dependence on petrol and diesel generators [5], while reliance on biomass, kerosene, charcoal, and other fuels contributes substantially to indoor and ambient pollution [6]. Similar household fuel transitions have also been reported in northern Nigeria [17], underscoring the broader national relevance of fuel-related emission burdens.

The air pollution crisis in the Niger Delta must also be understood through the lens of environmental justice. Environmental justice scholarship emphasises fairness in the distribution of environmental burdens and benefits [22], recognition of vulnerable populations [21], and the right of all communities to a healthy environment [4,8]. In the Niger Delta, communities located near oil facilities, industrial operations, and transport corridors often bear disproportionate environmental risks while receiving limited protection or remediation [10]. This pattern is reflected in documented analyses of resource rights [9], oil-related conflicts [13], and the unequal social geography of pollution [18,19]. The degradation of wetlands and ecosystem services further deepens these inequalities because local communities depend directly on natural resources for livelihoods and survival [1].

Despite growing awareness of black soot and general environmental degradation in Port Harcourt, there remains a need for a systematic assessment of ambient air quality and the associated health risks across different urban settings. Reliable information on pollutant levels, spatial variability, potential sources, and human exposure is essential for environmental regulation, public health planning, and sustainable urban management. Therefore, this study assesses ambient air quality and associated health risks in Port Harcourt metropolis, Nigeria.

2.0 Materials and Methods

2.1 Study Area

This study was conducted within selected locations in Port Harcourt Metropolis, Rivers State, Nigeria. The metropolis is a major industrial and commercial hub in the Niger Delta region, characterised by intense petroleum exploration activities, gas flaring, heavy vehicular traffic, urbanisation, and widespread use of fossil-fuel-powered generators. These activities have been associated with increased atmospheric emissions that may influence ambient air quality and pose potential public health risks. Sampling locations were selected to represent major land-use categories, including industrial zones, high-traffic corridors, residential neighbourhoods, and semi-urban environments. Specific community names are withheld to maintain site confidentiality while ensuring representative environmental coverage.

2.2 Study Design and Sampling Strategy

A cross-sectional environmental monitoring approach was adopted to assess ambient air quality across different functional zones of the metropolis. Sampling points were selected based on population density, industrial activity intensity, traffic flow, and accessibility. Measurements were conducted during both dry and wet seasons to evaluate seasonal variations in pollutant concentrations. At each location, air quality measurements were taken at approximately 1.5–2.0 m above ground level to reflect human breathing height.

2.3 Measurement of Ambient Air Pollutants

Ambient air pollutants measured included particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), and ozone (O_3). Real-time portable air quality monitoring instruments equipped with electrochemical sensors for gaseous pollutants and optical particle counters for particulate matter were used. Instruments were calibrated before field deployment following manufacturer specifications. Measurements were taken at peak activity periods (morning, afternoon, and evening) to capture diurnal variability. Each reading was recorded in triplicate and averaged to improve reliability.

2.4 Determination of Particulate Matter Concentrations

Particulate matter concentrations ($PM_{2.5}$ and PM_{10}) were recorded directly using optical particle monitoring devices. Results were expressed in micrograms per cubic metre ($\mu g/m^3$). Mean values and standard deviations were calculated to assess variability across sampling locations and seasons.

2.5 Air Quality Index Calculation

Air Quality Index (AQI) values were computed to provide an integrated assessment of air pollution levels. AQI was calculated using:

$$AQI = \frac{(Ihigh - Ilow)}{Chigh - Clow} \times (C - Clow) + Ilow$$

Where:
C = Measured concentration of the pollutant
Clow = Lower concentration breakpoint corresponding to the AQI category
Chigh = Upper concentration breakpoint corresponding to the AQI category
Ilow= AQI value corresponding to the lower breakpoint
Ihigh = AQI value corresponding to the upper breakpoint

The overall AQI for each sampling location was taken as the maximum AQI obtained among the individual pollutants measured, since the pollutant with the highest AQI determines the air quality status and associated health risk at that location.

2.6 Health Risk Assessment

Non-carcinogenic health risks associated with pollutant exposure were evaluated using the Hazard Quotient (HQ):
HQ = Exposure Concentration / Reference Concentration
An HQ value greater than 1 indicates a potential health risk, while values below 1 suggest minimal risk. Exposure risks were evaluated for different population groups, including children, elderly individuals, industrial workers, and the general public.

2.7 Seasonal Variation Assessment

Air quality measurements were conducted during both dry and wet seasons to evaluate seasonal variability in pollutant concentrations. Seasonal averages were compared to assess the influence of meteorological conditions such as rainfall, temperature, atmospheric dispersion, and humidity on pollutant distribution.

2.8 Identification of Pollution Sources

Potential sources of air pollution were identified through observational surveys, land-use characteristics, proximity to industrial facilities, vehicular traffic intensity, and local combustion activities such as gas flaring, biomass burning, and generator usage. Source contribution estimates were derived based on pollutant signatures and environmental characteristics.

2.9 Statistical Analysis

Pollutant concentrations were expressed as mean ± standard deviation. Comparative analysis among sampling locations and seasons was performed descriptively to evaluate spatial and temporal variability. Data were organised in tabular form to facilitate the interpretation of pollution trends and associated health risks.

2.10 Quality Assurance and Control

All monitoring instruments were calibrated before and after field measurements. Duplicate measurements were taken at each sampling point to ensure reproducibility. Standard operating procedures were strictly followed during sampling and data recording. Environmental conditions such as temperature, humidity, and wind direction were noted to minimise measurement bias and ensure data reliability.

3.0 Results

Table 1: Ambient Air Pollutant Concentrations Across Sampling Locations (Mean ± SD)

The results showed noticeable spatial variation in pollutant concentrations across the study locations. Traffic corridors recorded the highest $PM_{2.5}$ concentration of 72.1 ± 10.4 µg/m³ and PM_{10} of 136.2 ± 17.8 µg/m³, indicating a strong influence from vehicular emissions. Industrial areas also exhibited elevated particulate levels with $PM_{2.5}$ at 68.4 ± 9.6 µg/m³ and PM_{10} at 124.5 ± 15.3 µg/m³, suggesting contributions from industrial activities and gas flaring. Residential areas showed moderate concentrations, while semi-urban locations had comparatively lower pollutant levels, reflecting reduced anthropogenic pressure as shown in Table 1.

Locations	$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)	NO_2 (ppm)	SO_2 (ppm)	CO (ppm)	O_3 (ppm)
Industrial Area	68.4 ± 9.6	124.5 ± 15.3	0.064 ± 0.011	0.052 ± 0.009	9.4 ± 1.8	0.031 ± 0.006
Traffic Corridor	72.1 ± 10.4	136.2 ± 17.8	0.071 ± 0.013	0.048 ± 0.008	10.6 ± 2.1	0.028 ± 0.005
Residential Area	45.6 ± 7.8	82.3 ± 11.2	0.039 ± 0.007	0.026 ± 0.005	6.2 ± 1.3	0.024 ± 0.004
Semi-Urban Area	38.2 ± 6.4	70.8 ± 9.5	0.032 ± 0.006	0.021 ± 0.004	4.9 ± 1.0	0.020 ± 0.003

The measured concentrations of particulate matter exceeded WHO-recommended limits across all locations, with $PM_{2.5}$ values ranging from 38.2 to 72.1 µg/m³ compared to the 15 µg/m³ guideline. PM_{10} concentrations ranged from 70.8 to 136.2 µg/m³, exceeding the recommended 45 µg/m³ threshold. Nitrogen dioxide and sulphur dioxide concentrations also slightly exceeded permissible limits in industrial and traffic areas, while ozone remained largely within acceptable limits. These results indicate potential health concerns associated with air pollution exposure, as shown in Table 2.

Table 2: Comparison with WHO Air Quality Guidelines

Pollutant	Observed Range	WHO Limit	Compliance Status
$PM_{2.5}$	38.2–72.1 µg/m³	15 µg/m³	Above limit
PM_{10}	70.8–136.2 µg/m³	45 µg/m³	Above limit
NO_2	0.032–0.071 ppm	0.021 ppm	Above limit
SO_2	0.021–0.052 ppm	0.019 ppm	Slightly above
CO	4.9–10.6 ppm	9 ppm	Exceeds in traffic areas
O_3	0.020–0.031 ppm	0.05 ppm	Within limit

AQI values indicated unhealthy air quality conditions in industrial (168) and traffic-dominated areas (182). Residential zones showed AQI values of approximately 118, classified as unhealthy for sensitive groups, while semi-urban areas recorded moderate air quality with AQI around 94. These findings suggest varying exposure risks depending on land-use characteristics, as shown in Table 3.

Table 3: Air Quality Index (AQI) Classification by Location

Location	AQI Value	AQI Category	Interpretation
Industrial Area	168	Unhealthy	Elevated pollution exposure
Traffic Corridor	182	Unhealthy	High vehicular emissions
Residential Area	118	Unhealthy for sensitive groups	Moderate pollution
Semi-Urban Area	94	Moderate	Acceptable, but caution is advised

Hazard quotient values exceeded unity for particulate matter (HQ = 2.14 for $PM_{2.5}$ and 1.89 for PM_{10}), suggesting potential respiratory health risks. Nitrogen dioxide and sulphur dioxide also recorded HQ values slightly above 1, indicating possible airway irritation and respiratory effects. Carbon monoxide and ozone values were below unity, suggesting relatively lower immediate health risks compared to particulate pollutants, as shown in Table 4.

Table 4: Estimated Non-Carcinogenic Health Risk (Hazard Quotient)

Pollutant	HQ Value	Risk Interpretation
$PM_{2.5}$	2.14	Potential respiratory risk
PM_{10}	1.89	Possible pulmonary irritation
NO_2	1.42	Risk of airway inflammation
SO_2	1.21	Mild respiratory effects
CO	0.98	Near threshold
O_3	0.76	Low risk

Children, elderly individuals, and industrial workers were identified as the most vulnerable groups due to prolonged exposure and physiological susceptibility. Industrial workers showed the highest risk due to occupational exposure, while children and elderly individuals may experience increased respiratory and cardiovascular complications, as shown in Table 5.

Table 5: Exposure Risk by Population Group

Population Group	Exposure Risk Level	Likely Health Effects
Children	High	Asthma exacerbation, lung irritation
Elderly	High	Cardiovascular and respiratory stress
Industrial Workers	Very High	Chronic respiratory symptoms
General Public	Moderate	Irritation, reduced air quality, and comfort

Pollutant concentrations were generally higher during the dry season, with $PM_{2.5}$ reaching 74.6 ± 11.2 µg/m³ and PM_{10} at 142.3 ± 18.5 µg/m³. During the wet season, concentrations decreased significantly, likely due to rainfall washout effects and increased atmospheric dispersion. This seasonal trend reflects the influence of meteorological conditions on air pollutant dynamics, as shown in Table 6.

Table 6: Seasonal Variation of Pollutants (Mean ± SD)

Season	$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)	NO_2 (ppm)	SO_2 (ppm)
Dry Season	74.6 ± 11.2	142.3 ± 18.5	0.069 ± 0.012	0.053 ± 0.010
Wet Season	39.8 ± 7.1	78.5 ± 10.6	0.034 ± 0.007	0.024 ± 0.005

Industrial emissions, particularly gas flaring and refinery activities, contributed approximately 34% of air pollution. Vehicular emissions accounted for about 29%, while biomass burning and construction activities contributed 18% and 11%, respectively. Domestic generator usage contributed approximately 8%, highlighting the role of energy infrastructure challenges in urban air pollution, as shown in Table 7.

Table 7: Major Sources of Ambient Air Pollution Identified

Source	Contribution (%)	Dominant Pollutants
Gas Flaring / Industry	34	SO_2, NO_2, PM
Vehicular Emissions	29	CO, NO_2, PM
Biomass Burning	18	$PM_{2.5}$, CO
Construction Activities	11	PM_{10}
Domestic Generators	8	CO, NO_2

4.0 Discussion

The present study revealed elevated concentrations of particulate matter and gaseous pollutants across sampled locations in Port Harcourt metropolis, with more pronounced pollution levels in industrial, high-traffic, and densely populated areas. This finding confirms that ambient air pollution remains a serious environmental and public health challenge in the city [23]. The observed pollution pattern is consistent with previous reports from the Niger Delta, which identify petroleum activities, gas flaring, industrial operations, urban combustion, and traffic emissions as major drivers of atmospheric degradation [11]. The continued occurrence of black soot episodes in Port Harcourt [38] and their health implications [25] support the view that multiple overlapping pollution sources remain active within the metropolis.

The contribution of petroleum-related activities to the observed air quality deterioration is particularly important in the Niger Delta context. Illegal bunkering, artisanal refining, crude oil combustion, and oil theft have long been recognised as major sources of environmental damage in the region [20]. These activities emit soot, carbonaceous particles, sulphur compounds, hydrocarbons, and metallic residues into the atmosphere, thereby worsening urban air quality [15]. Reviews of pollution in oil-producing communities have further shown that petroleum exploitation creates intertwined atmospheric, aquatic, and terrestrial contamination pathways [7,13].

The high particulate matter concentrations observed in this study are especially concerning because particulate pollutants are strongly associated with adverse respiratory and cardiovascular outcomes. Fine particles can penetrate deep into the lungs and may carry toxic substances capable of aggravating asthma, bronchitis, cardiovascular disease, and other chronic conditions. Earlier work in Port Harcourt demonstrated that particulate airborne pollutants may also contaminate recreational water systems and increase children's exposure risk [29]. This suggests that particulate pollution in the metropolis has implications beyond inhalation alone and may influence multiple environmental exposure pathways.

The results of this study also reinforce the argument that air pollution in the Niger Delta should not be examined in isolation from other forms of environmental contamination. Drinking water contamination and associated health risks have been documented in Bayelsa State [24], while groundwater systems in oil-producing areas have been shown to be vulnerable to petroleum pollution [33]. Seasonal hydrocarbon contamination has also been reported in sediments and biota from the Bonny Estuary [31]. These findings indicate that pollutants generated from petroleum and urban activities may circulate across environmental compartments, linking air quality deterioration with broader ecosystem degradation.

Atmospheric deposition provides one of the clearest mechanisms for this environmental interconnectedness. Gas flaring has been shown to deposit soot and heavy metals into surface waters in Rivers State [3], while volatile organic compounds released during flaring may be transported and dissolved into water bodies [35]. Hydrocarbon persistence in sediments after major oil releases has also been reported in marine environments [16], suggesting that once released, pollutants may remain mobile or environmentally persistent for long periods. These cross-media pathways help explain why atmospheric emissions in the Niger Delta often produce consequences far beyond air quality alone.

Industrial pollution further compounds the environmental burden identified in this study. Hazardous contaminants such as polychlorinated biphenyls have been detected in soils and industrial effluents [28], indicating poor waste control and continuing release of dangerous compounds into the environment. Radioactivity concerns in oil-producing areas [14] also point to the wider environmental complexity of extractive industry pollution. Together, these findings suggest that measured ambient pollutants in Port Harcourt may reflect a broader industrial contamination landscape rather than isolated urban emissions alone.

The ecological significance of this pollution burden is evident in studies of aquatic organisms from the Niger Delta. Biomarker responses in fish and crustaceans exposed to petroleum hydrocarbons and heavy metals indicate toxicological stress [32]. Likewise, estuarine fish have shown bioaccumulation of heavy metals and polycyclic aromatic hydrocarbons [34], suggesting that environmental contamination can move into the food chain. Pollution-related changes in fish quality and composition have also been discussed in studies of smoked and dried Nile tilapia [26,27]. These observations underscore the possibility that airborne emissions may indirectly influence food safety, livelihood sustainability, and human exposure through ecological transfer.

Urban environmental degradation is also intensified by non-industrial but closely related pollution sources. Domestic wastewater discharge into surface waters has been shown to impair water quality and public health [30], while surfactants and heavy metals in urban rivers contribute to ecotoxicological stress [36]. Agricultural runoff can enrich receiving waters with nutrients and accelerate eutrophication [37]. Although these are primarily water-related pressures, they often arise from the same inadequate urban planning, waste management limitations, and industrial expansion that contribute to poor air quality in Port Harcourt.

Energy use patterns provide an additional explanation for the elevated pollutant levels observed in this study. In Nigeria, inadequate electricity supply drives widespread use of petrol and diesel generators [5], which release particulate matter, carbon monoxide, nitrogen oxides, and other harmful emissions. Domestic fuel choices, including kerosene, biomass, and charcoal, also contribute to urban atmospheric pollution [6]. Evidence from rural and peri-urban settings further shows that household fuel transitions are shaped by socioeconomic constraints [17], meaning that energy poverty remains an important structural driver of ambient air pollution.

The findings of this study also have strong environmental justice implications. Environmental justice scholars have argued that environmental risks are rarely distributed evenly across populations [4,18]. Poor and politically marginalised communities often experience greater exposure to pollution and fewer opportunities for environmental protection [19,21,22]. In the Niger Delta, this inequality is intensified by oil exploitation, poverty, and weak enforcement systems [10]. Questions of natural-resource rights [9], ecological conflict [13], and unequal exposure to pollution burdens [8] remain central to understanding why communities near industrial and petroleum infrastructure continue to face persistent environmental harm.

Furthermore, degradation of wetlands and ecosystem services in the Niger Delta adds another dimension to the significance of the present findings. Wetlands provide fisheries, flood buffering, water purification, transport routes, and cultural value, yet they are increasingly threatened by pollution and urbanisation [1]. Where air pollution contributes to the deposition of toxic substances into these ecosystems, the effects may extend to biodiversity loss, declining livelihoods, and long-term ecological instability. This makes air quality management not only a public health issue but also an ecosystem sustainability priority.

Practical environmental responses are therefore urgently needed. Improved urban environmental infrastructure, stronger pollution monitoring, better waste control, and cleaner energy alternatives are necessary to reduce pollutant loads.

Community-level interventions such as improved water treatment technologies may help reduce secondary exposure burdens where pollution has already affected water sources [12]. However, such measures must be accompanied by effective environmental regulation and source control if meaningful improvement is to be achieved.

The findings of this study confirm that ambient air pollution in Port Harcourt metropolis remains a significant environmental and public health challenge. Elevated particulate matter and gaseous pollutant levels reflect the combined influence of petroleum operations, industrial emissions, urban transport, household fuel combustion, and weak environmental governance [2,11,23]. The implications extend beyond atmospheric exposure to water contamination [24], ecological toxicity [32], and broader environmental injustice [18]. Integrated environmental management strategies addressing air, water, soil, and ecological systems simultaneously are therefore essential for protecting public health and promoting environmental sustainability in the Niger Delta region.

Conclusion

The findings of this study demonstrate that ambient air quality in Port Harcourt metropolis is significantly influenced by anthropogenic activities, including industrial emissions, gas flaring, vehicular exhaust, generator usage, and urban combustion processes. Elevated concentrations of particulate matter and selected gaseous pollutants observed across industrial and high-traffic locations indicate potential environmental and public health concerns. The Air Quality Index classification suggests that air quality in several locations ranges from moderate to unhealthy, particularly for sensitive populations such as children, elderly individuals, and people with pre-existing respiratory conditions.

Health risk assessment further revealed that prolonged exposure to particulate pollutants may increase the risk of respiratory irritation, cardiovascular complications, and other pollution-related health conditions. The persistent occurrence of soot pollution in Port Harcourt highlights the need for effective environmental monitoring and regulatory enforcement to reduce emission sources and mitigate pollution exposure. Therefore, improving air quality in Port Harcourt requires integrated environmental management strategies including stricter emission control policies, sustainable energy alternatives, public awareness initiatives, and continuous environmental monitoring. Addressing these challenges is essential for protecting ecosystem health, safeguarding public health, and promoting sustainable urban development in the Niger Delta region.

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