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Impact of Heavy Metal Concentrations on Urban Soils in Port Harcourt Metropolis of Rivers State

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ABSTRACT
Heavy-metal contamination in urban soils become a critical public health concern in rapidly expanding cities, particularly within developing economies where industrial regulation and environmental governance remain weak. Urban residents—especially children—are exposed to contaminated soils through various pathways including ingestion, inhalation, thermal absorption, and food-chain transfer. This study assessed the concentrations of lead (Pb), zinc (Zn), iron (Fe), and copper (Cu) in top soils across diverse land-use types in Port Harcourt and evaluates their potential health risks within the framework of Sustainable Development Goal 3 (Good Health and Well-Being). Eighteen soil samples were collected from industrial, residential, commercial, agricultural, and institutional zones and analyzed following APHA (2005) and ASTM (2010) standards. Iron concentrations showed statistically significant variation ($p = .010$), with industrial zones recording the highest levels. Lead exhibited moderate but rising concentrations near automobile mechanic workshops and high-traffic roads. Although zinc and copper variations were not statistically significant, their spatial patterns indicate cumulative anthropogenic pollution. These findings suggest notable public health implications, particularly concerning neurotoxicity, respiratory challenges, metal-induced oxidative stress, and soil-to-food contamination risks. The study emphasizes the urgency for improved environmental monitoring, regulatory enforcement, public education, and remediation strategies to minimize health risks. Achieving SDG 3 in the metropolis requires integrated interventions that address both environmental contamination and human exposure pathways.
Keywords: Heavy metals, Soil contamination, Urban Soils, SDG 3, Port Harcourt.

INTRODUCTION
Urban soil contamination has emerged as one of the most persistent and underestimated threats to public health in modern cities. Rapid urbanization, industrial growth, and informal economic activities have increased the release of toxic metals into the environment. Heavy metals do not biodegrade; instead, they accumulate in soils over time, creating long-term exposure risks through food, air, and water pathways.

In Port Harcourt—a major commercial and industrial hub with extensive oil-related activities—the problem of environmental contamination is intensified by emissions from refineries, mechanical workshops, open-air waste burning, and heavy vehicular traffic. These anthropogenic activities release pollutants and heavy metals that settle into the soil and become accessible for human contact. Children playing outdoors, residents living near industrial sites, market sellers constantly interacting with dust, and farmers cultivating crops in peri-urban areas all face rising exposure risks. Kalagbor, Dibofori-Orji, and

Ekpete (2019) reported similar patterns of heavy-metal deposition resulting from soot and industrial emissions across Port Harcourt, highlighting the growing public-health concerns.

The public health implications are significant. Exposure to heavy metals such as lead, zinc, iron, and copper has been linked to neurological disorders, low cognitive performance, stunted development, respiratory illnesses, metabolic impairment, reduced immunity, kidney dysfunction, and chronic inflammation. Lead, in particular, accumulates in bones and tissues, causing long-term neurotoxicity even at low concentrations.

Despite these threats, soil contamination remains under-researched compared to air and water pollution. Limited regulatory oversight and inadequate environmental monitoring in Nigeria further complicate the issue. Addressing heavy-metal exposure is therefore central to achieving SDG 3, which aims to reduce illnesses caused by hazardous chemicals.

This study contributes to public health knowledge by assessing the spatial distribution of heavy metals in urban soils and analyzing their implications for vulnerable populations.

Theoretical Perspectives on Heavy Metal Accumulation in Urban Environments.

Heavy-metal contamination in urban areas has its earliest roots in the industrial revolution, when rapidly growing cities such as London began expanding manufacturing, coal burning, and metal processing on a large scale. These activities released persistent metals such as lead, copper, zinc, and mercury into surrounding soils, marking the beginning of long-term urban soil pollution. As industries multiplied in densely populated centres, waste disposal practices were unregulated, allowing metals to accumulate in residential neighbourhoods, factory districts, and transport corridors.

By the early 20th century, heavy-metal contamination had intensified globally with the rise of automobile transport. In cities like New York City, the use of leaded petrol became a dominant source of roadside soil pollution. Large volumes of lead particles settled along highways, markets, schools, and urban playgrounds, creating widespread and persistent contamination. Even after the gradual phase-out of leaded petrol from the 1970s onward, many urban soils continued to exhibit elevated lead levels because heavy metals do not degrade naturally.

Across Africa, heavy-metal pollution expanded during the post-independence industrial era, when cities such as Lagos experienced rapid industrialization without adequate environmental controls. Informal activities—mechanic workshops, battery recycling, welding, metal fabrication, open burning of waste, and poor refuse management—became major contributors of lead, zinc, copper, and iron in urban soils. Many of these activities occurred directly within residential zones, increasing human exposure. Weak regulation and rapid population growth further accelerated contamination, especially in peri-urban and low-income settlements.

Modern studies show that heavy-metal contamination remains a persistent challenge in many developing urban centres. Inadequate zoning, urban sprawl, industrial clustering, and the growth of informal economic activities continue to elevate metal concentrations in soils. Markets, traffic corridors, dumpsites, and industrial parks often record the highest levels due to continuous deposition from multiple sources. Climate factors such as wind, flooding, and erosion also redistribute contaminated soil particles across different land-use zones, extending exposure risks.

In Port Harcourt, the history of heavy-metal accumulation reflects a combination of industrial growth, petroleum-related activities, rapid population increase, and uncontrolled land-use change. As the city expanded into a major economic and oil-industry hub in Nigeria, emissions from refineries, mechanical workshops, heavy traffic, open waste burning, and commercial activities contributed significantly to the deposition of lead, iron, zinc, and copper in urban soils. Today, the city exhibits contamination patterns similar to those seen historically in other industrialized and rapidly urbanizing regions, making soil quality a critical environmental and public-health concern. Understanding this historical context is essential for interpreting the current state of soil pollution in Port Harcourt and developing sustainable interventions.

Heavy metals are naturally occurring elements found in rocks, soils, and minerals. However, human activities have significantly increased their concentration in the environment beyond natural levels. These metals are non-biodegradable, meaning they do not break down easily. Instead, they persist for decades, accumulate in biological tissues, and disrupt physiological and biochemical processes in plants, animals, and humans.

Common heavy metals of environmental concern include lead (Pb), cadmium (Cd), mercury (Hg), chromium (Cr), zinc (Zn), copper (Cu), and arsenic (As). These metals become harmful when their concentrations exceed normal background levels.

Key Sources of Heavy Metal Pollution

The major sources of heavy metal pollution in most developing countries include:

Industrial activities – metal smelting, battery production, cement factories, steel processing, paint manufacturing, and chemical plants release heavy metals into the environment.

Improper waste disposal – electronic waste (e-waste), used batteries, metal scraps, and industrial effluents introduce toxic metals into soils and water bodies.

Petroleum refining and crude oil spills – common in many African cities such as Port Harcourt, Warri, and Lagos. Refinery emissions, gas flaring, and oil spills deposit metals such as nickel, vanadium, and lead into the environment.

Agricultural activities – inappropriate use of fertilizers, pesticides, and herbicides increases the level of heavy metals like arsenic, copper, and chromium in farmland soils.

Vehicular emissions – exhaust fumes, brake linings, tyre wear, and fuel combustion release lead, cadmium, and zinc into the atmosphere.

Burning of solid waste – open burning of plastics, electronics, and domestic waste releases several toxic metals into the air.

As a result of these activities, many urban areas such as Accra, Nairobi, Lagos, and Port Harcourt have documented cases of elevated heavy metal pollution in air, soil, and water. Exposure to these metals has been associated with increased respiratory problems, kidney damage, immune suppression, and neurological illnesses.

Mechanisms of Human Exposure to Heavy Metals

Humans are exposed to toxic metals through several pathways. These exposure routes depend on environmental conditions, occupation, and lifestyle.

1. Ingestion

This occurs when contaminated materials are swallowed intentionally or unintentionally. Examples include: Eating contaminated food crops grown in polluted soils, drinking water polluted with industrial discharges, consuming fish or livestock that have accumulated heavy metals and

Contamination from food, which is one of the most common exposure pathways in agricultural communities.

2. Inhalation

Heavy metals can be inhaled when they are present in the air as dust or fumes. The air becomes contaminated when: dust is blown from polluted soils, particulates rise during dry seasons.

In addition, metal-rich fumes are released from factories, welding workshops, and vehicle exhausts and inhalation of these metals is especially dangerous because metal particles can travel long distances and enter indoor spaces.

3. Dermal Absorption

Although less common, metals can enter the body through the skin. This often happens in: mechanics and welders working with metal equipment, farmers handling contaminated soil, construction workers handling treated wood and metal-rich cement.

In addition, People bathing in contaminated water and skin contact allows small amounts of metals to pass into the bloodstream over time.

4. Occupational Exposure

Certain occupations involve higher risks of heavy metal exposure.
Such workers include:

- Battery makers
- Metal fabricators
- Miners
- Welders
- Painters
- Refinery workers
- E-waste recyclers

These jobs expose individuals to heavy metal fumes, dust, or direct contact daily. Heavy metals pose serious environmental and health risks due to their persistence, bioaccumulation, and toxicity. Human exposure occurs through ingestion, inhalation, dermal absorption, and occupational contact. Awareness, monitoring, and proper waste management are crucial to reducing the dangers associated with heavy metal pollution.

Health Impacts of Major Heavy Metals

Lead (Pb)

- Causes irreversible damage to children's nervous systems
- Reduces IQ and learning capacity
- Linked to behavioral disorders
- Damages kidneys and blood-forming organs

Zinc (Zn)

- Necessary in small amounts
- Excess causes nausea, immune dysfunction, and metabolic imbalance

Iron (Fe)

- High concentrations induce oxidative stress
- Weakens organs and causes fatigue
- Excess inhalation can damage respiratory tissues

Copper (Cu)

- Essential micronutrient
- Toxic in excess
- Causes liver stress, gastrointestinal complications, and neurological irritation

Heavy-Metal Pollution in Nigerian Cities

Studies in Lagos and Aba show lead and iron concentrations exceeding WHO limits in roadside soils. In Onitsha, extreme Pb levels in market zones were linked to increased cases of childhood anemia. These parallels suggest that Port Harourt faces similar risks due to its industrial density and informal economic practices.

The Study Area

Port Harcourt metropolis is comprised of Obio/Akpor and Port Harcourt local government areas. Port Harcourt actually started in 1912 as a small fishing settlement located around the then ancient town of Obumutu, located some kilometers from the mouth of the Bonny River. Port-Harcourt metropolis is situated between latitudes o4^{o} 43^{1} and 0457^{1} North of the Equator and longitudes 0653^{1} and 0808^{1} East of the Greenwich Meridian. The area is approximately 1803km^{2} (Rivers State Statistical Year Book, 2022). The area is bounded in the North by Ikwerre and Etche Local Government Areas; in the south by Degema and Okirika Local Government Areas and in the West by Emohua Local Government Area. This implies that the area has exceeded its initial limit for about 1000 times. Presently it has expanded to engulf greater parts of Ikwerre, Etche, Oyigbo, Eleme and Okirika Local Government Areas seen to be part of the Greater Port-Harcourt Region. It is gradually expanding to the West covering Emohua Local Government Area.

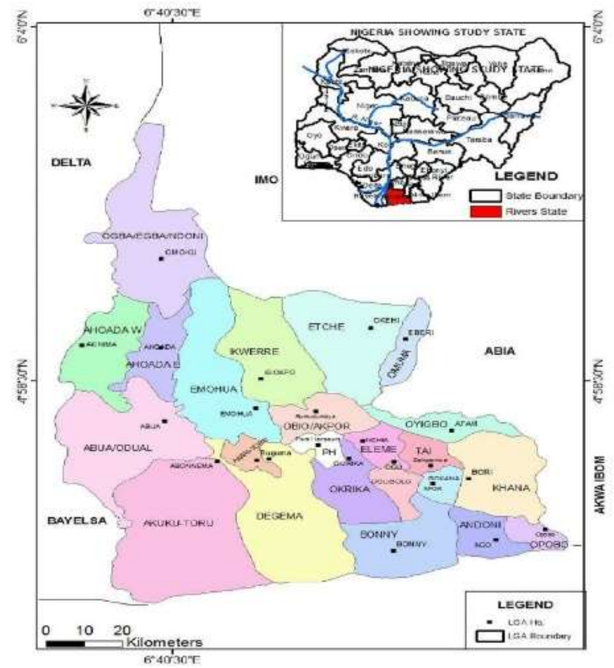

Figure 1: Rivers State showing the Study Area and other LGAs
Source: Adapted from Prof. N. G. Naluba (2016)

MATERIALS AND METHODS

This study employed an experimental research design to investigate the impact of urban-induced land activities on soil quality. The experimental approach involves conducting a controlled test on soil samples to determine the extent of pollution and compare the results with the standards set by the World Health Organization (WHO) and the Nigerian Federal Ministry of Environment.

By adopting this method, this study aims to provide experimental evidence on the cause -and- effects of urbanization on soil quality, thereby contributing to the existing body of knowledge on environmental pollution.

The study made use of qualitative and quantitative data. Qualitative data describes features of the phenomenon that was measured while quantitative data are numerical data that was counted or measured. This data was obtained through the primary and secondary data sources.

The primary data, which is the focus of the research, was obtained through laboratory analysis of soil sample of the study area. While the secondary source are pieces of information already compiled by organisations, institutes, establishments internet, journal, magazines or previous studies.

The study is made up of two kinds of population parameters-the fringe settlements around Port Harcourt where the outward growth is observed, and the number of regular households. There are over 30 of such settlements witnessing rapid growth within and around Port Harcourt (Ministry of Lands, Housing & Urban Development Diary, 2019). The human population of the study included members of the various households from the different segments of the city that make up the study area. According to the 2006 national population and housing census, the population of Obio/Akpor was 462,350 in 2006 and 529,705 in 2010 while Port Harcourt was 538,558 in 2006 and 617,016 in 2010. Hence, in 2006, the population of the Metropolis was 1,000,908 (both local government areas put together). The area's population as projected to 2010 was 1,146,721 (i.e. 529705+617016) while the total number of regular households for both local government areas was 234,787 (i.e. 108,777 + 126,010) (NPC, 2006); and when projected to 2010, it is about 298,180 regular households.

This study focuses on selected areas within the Port Harcourt Metropolis. To achieve this, the researcher developed a sampling frame that targets impacted areas across five key land-use categories: residential, industrial, commercial, agricultural and institutional.

This sampling approach ensures a comprehensive representation of the various land-use types within the metropolis.

Table 1: Sample Collection Points

S/N	Land Use Categories	Soil Sample collection	Coordinates	Control	Coordinates
1.	Residential Areas:	Eagle island	4.47.5.2152° N 6.58.47.8524° E	IAU	Lat 4.48.16.8948° N Lon 6.59.10.2516° E
		Elelewon	4.48.56.1600 °N 7,02.59.2800 °E		
		Ogbunabali	4.50.10.8888° E 6.59.45.5676 °N		
2.	Industrial Areas:	Elekahia (Mechanic workshop)	4.49.19.3512° N 7.1.17.0328° E	RSU	Lat 4.48.1.6848° N Lon 6.58.55.4304° E
		Ikoku (mile 2) (Mechanic workshop	4.48.12.294° N, 6.59.49.1244° E		
		Rumuokoro (mechanic village)	4.51.11.7108° N, 7.3.46.0332 ° E		
3.	Agricultural	Igwuruta (farming settlement)	4.52.59.8800° N, 7.01.59.8800° E	CEAP	Lat.4.50.10.8888° N Lon 6.59.45.5676° E
		Ozuoba (farming settlement)	4.46,59.8800°N, 7.01.59.8800° E		
		Rukpokwu (farming settlement)	4.55.59.8800°N, 7.04.00.1200° E		
4.	Institutional	RSU (Nkpolu)	4.48.1.8072°N, 6.58.59.4768° E		
		IAUE (Rumuolumeni)	4.49.00.1200° N, 7..01.59.8800° E		
		CEAP (Rumuola)	4.48.28.1164 °N 6.56.19.878° E		
5.	Commercial	Mile 1 market	4.46.23.8800° N 7.01.00.12007° E		
		Oil mill market	4.51.11.7108 N 7.3.46.0332 E		
		Rumuodomaya (slaugher market)	4.52.23.8908° N 6.59:56.94° E		

Source: Researcher's fieldwork, 2025

This study employed simple random sampling to select locations randomly within each land-use category, including residential, industrial, and commercial areas. To ensure spatial accuracy, all sampling points was geo-referenced using GPS coordinates, and a sampling map created to visualize the distribution of sampling locations. This selection captures pollution gradients effectively.

All laboratory analyses were carried out on soil samples at a depth of 0–15 cm, representing the topsoil layer most influenced by anthropogenic activities. The soil samples were air-dried at room temperature, gently crushed using a porcelain mortar and pestle, and passed through a 2 mm sieve to remove stones, roots, and debris. The processed samples were stored in labeled polyethylene bags prior to laboratory analysis. Heavy metals were extracted via aqua regia digestion and quantified using AAS. Calibration curves, reagent blanks, and reference standards ensured accuracy. ANOVA tested spatial variation and the results compared with WHO, and NESREA permissible limits.

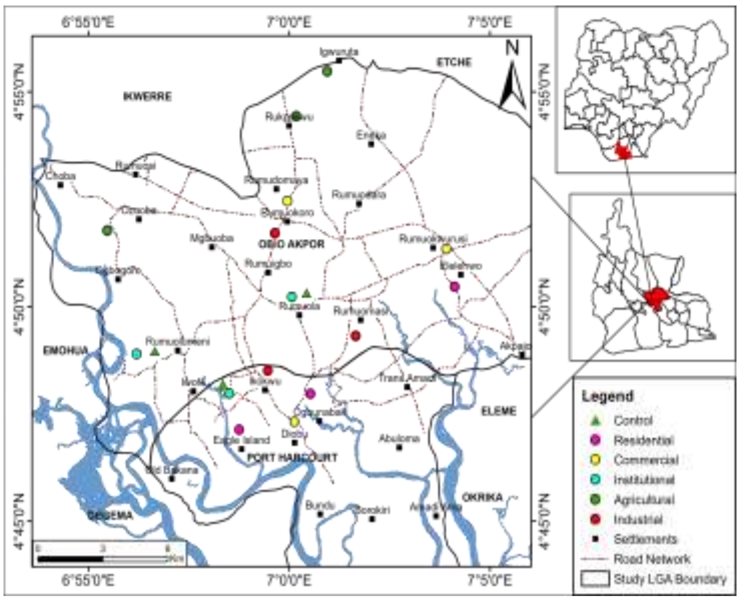

Figure 2: Sample Locations
Source: Researcher's fieldwork, 2025

RESULT AND DISCUSSION

The data used for this study were lab oratorically generated. The laboratory results for soil samples collected from Eagle Island show notable differences when compared with the control values, highlighting the influence of local environmental conditions on soil quality. The soil analysis from Eagle Island (0-15 cm depth) reveals significant environmental concerns when compared to the control sample and NESREA standards. While the pH (6.33) is acceptable and heavy metals like lead (9.70 mg/kg), zinc (2.70 mg/kg), and cobalt (<0.001 mg/kg) are well within safe limits, the site shows alarming nutrient enrichment with total nitrogen at 13.06% (approximately 130 times the 0.1-0.2% standard) and phosphate at 6.36 mg/kg (exceeding the 2-4% range). These elevated nutrient levels strongly suggest contamination from sewage discharge, agricultural runoff, or industrial waste, which is further complicated by the soil's low cation exchange capacity (8.92 Cmol/kg) that limits its ability to retain and buffer nutrients. The stark contrast with control values particularly nitrogen (0.52% in control) and phosphate (0.15 mg/kg in control) indicates that Eagle Island has experienced significant anthropogenic pollution that requires immediate investigation and remediation to prevent further environmental degradation and potential health risks.

Table 2: Result for Laboratory Analysis for Soil Samples

COORDINATE	S/N	Samples analysed	Result	Control	NESREA
		Soil Samples in Eagle Island	**PARAMETERS**		
	1.	pH	6.33	4.993333	6.0-8.5
4.47.5.2152° N 6.58.47.8524° E	2.	CEC (Cmol/kg)	8.92	28.91	5-25(cmol/kg)
	3.	TOM (mg/kg)	10.07	12.69333	-
SAMPLE ID	4.	PO4 (mg/kg)	6.36	0.153333	2-4%
	5.	Total Nitrogen	13.06	0.516667	0.1-0.2%
Eagle Island	6.	Fe (mg/kg)	27.14	74.982	-
DEPTH (CM)	7	Pb (mg/kg)	9.695	15.013	164mg/kg
0-15	8.	Zn (mg/kg)	2.695	27.801	~421mg/kg
	9	Co (mg/kg)	<0.001	<0.001	~100mg/kg

Source: Researcher's fieldwork and analysis, 2025
Method Source "American Society for Testing and Materials" (ASTM) 2010
"American Public Health Association" (APHA) 23th Edition 2005.

Table 3: Analysis of Soil Samples

	ANALYSIS OF SOIL SAMPLES		
Parameter	**IAU Control**	**RSU Control**	**CEAP Control**
pH	5.26	5.24	4.48
CEC (Cmol/kg)	28.91	<0.01	<0.01
TOM (mg/kg)	11.25	12.97	13.86
PO4 (mg/kg)	0.08	0.24	0.14
Total Nitrogen	0.39	0.71	0.45
Fe (mg/kg)	112.913	32.603	79.43
Pb (mg/kg)	12.637	14.176	18.226
Zn (mg/kg)	32.613	35.943	14.847
Co (mg/kg)	<0.001	<0.001	<0.001

Source: Researcher's Field Work & Analysis (2025)

The analysis of the soil samples from the three control sites; IAU, RSU, and CEAP (Table 3) shows notable variations in their physicochemical properties and trace metal concentrations. Soil pH values indicate acidic conditions across all sites, with CEAP (pH 4.48) being the most acidic. The cation exchange capacity (CEC) is highest at IAU (28.91 Cmol/kg), while RSU and CEAP recorded extremely low values (<0.01 Cmol/kg), suggesting poorer nutrient retention in those soils. Total organic matter (TOM) is relatively higher at CEAP (13.86 mg/kg), followed by RSU (12.97 mg/kg) and IAU (11.25 mg/kg), indicating moderate organic content across the controls. Phosphate (PO_4) levels remain low at all sites, though RSU records the highest value (0.24 mg/kg). Total nitrogen is highest at RSU (0.71 mg/kg), suggesting better soil fertility compared to IAU and CEAP. Among the heavy metals, iron (Fe) is most abundant at IAU (112.913 mg/kg), while lead (Pb) is highest at CEAP (18.226 mg/kg) and zinc (Zn) at RSU (35.943 mg/kg). Cobalt (Co) remains negligible across all control samples, indicating minimal contamination.

The results show that heavy-metal pollution in urban soils of the metropolis represents a substantial public health hazard. Iron concentrations in industrial regions suggest strong influence from metal works, combustion emissions, refinery activities, and frequent waste burning. Pb presence in roadside and mechanic areas reflects sustained contamination from traffic emissions and mechanical waste.

Children face the highest risks because they frequently play in contaminated soil, inhale dust, and engage in hand-to-mouth behavior. Cognitive impairment from Pb exposure, respiratory irritation from Fe-rich dust, and metabolic disturbances from Zn and Cu pose long-term health threats.

Environmental injustice is evident: low-income communities located near industrial and waste zones suffer disproportionately. This aligns with research showing that poor urban planning and weak regulatory enforcement increase the burden of disease.

CONCLUSION

Heavy-metal contamination in urban soils of Port Harourt poses escalating risks to public health, particularly in industrial, roadside, and high-density residential zones. The persistence and accumulation of Pb, Zn, Fe, and Cu demonstrate long-standing environmental degradation. Without intervention, chronic exposure will intensify disease burdens and reduce quality of life, especially among children and marginalized communities.

RECOMMENDATIONS

- Regulatory Enforcement

Stricter control over industrial emissions, mechanical waste disposal, and roadside activities is needed.

- Soil Monitoring

Regular soil testing in industrial and high-risk zones to track pollution levels.

- Public Health Education

Community sensitization on risks of contaminated soil and safe hygiene habits.

- Remediation Measures

Introduce phytoremediation, compost amendments, and soil washing in polluted areas.

- Urban Planning Controls

Establish buffer zones around mechanic workshops and prohibit residential development around industrial sites.

- Safe Urban Agriculture

Certify soils before crop cultivation and discourage farming on contaminated plots.

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