EVALUATING THE ROLE OF LOCATION-BASED POLLUTION IN HEAVY METAL CONTAMINATION OF VEGETABLES GROWN IN BENIN METROPOLIS.

BY

AGBONKONKON OSAZEMEN ESTHER (MISS)
LSC2003051

AN UNDERGRADUATE DISSERTATION SUBMITTED TO THE DEPARTMENT OF ENVIRONMENTAL MANAGEMENT AND TOXICOLOGY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF BENIN, BENIN CITY, EDO STATE, NIGERIA; IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR AWARD OF BACHELOR OF SCIENCE (B.Sc) DEGREE IN ENVIRONMENTAL MANAGEMENT AND TOXICOLOGY

DATE: NOVEMBER,2025

CERTIFICATION

This is to certify that this research titled "EVALUATING THE ROLE OF LOCATION-BASED POLLUTION IN HEAVY METAL CONTAMINATION OF VEGETABLES GROWN IN BENIN METROPOLIS." was carried out by "AGBONKONKON OSAZEMEN ESTHER (MISS) " and presented to the Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin, Benin City; in partial fulfillment of the requirements for the award of Bachelor of Science (B.Sc) in Environmental Management and Toxicology. It was conducted under suitable conditions, was carefully supervised and subsequently approved as having met the requirements for the award of a Bachelor of Science degree in Environmental Management and Toxicology.

______________________ ______________________

PROF.(MRS.) E.T. AISIEN **DATE**

(PROJECT SUPERVISOR)

______________________ ______________________

PROF.(MRS.) E.T. AISIEN **DATE**

(HEAD OF DEPARTMENT)

DECLARATION

I "AGBONKONKON OSAZEMEN ESTHER (MISS)" declare that "EVALUATING THE ROLE OF LOCATION-BASED POLLUTION IN HEAVY METAL CONTAMINATION OF VEGETABLES GROWN IN BENIN METROPOLIS." is my work and that all sources that I have used or quoted have been acknowledged using complete references and that this work has not been submitted before for any other degree at any other University.

______________________ ______________________

AGBONKONKON OSAZEMEN ESTHER **DATE**

DEDICATION

This report is dedicated to God Almighty for His divine guidance, protection and grace throughout the course of this project. I also dedicate it to my beloved parents Mr. and Mrs. AGBONKONKON, my wonderful family and to Mrs Idehen of blessed memory whose steadfast love, prayers, encouragement and financial support have been the cornerstone of my academic journey.

ACKNOWLEDGEMENT

First and foremost, I would like to express my profound gratitude to the Almighty for giving me strength, good health, and determination throughout the project process.

My deepest gratitude goes to my parents, Mr. and Mrs. Agbonkonkon, for their endless love, prayers, and steadfast support which have been my greatest source of strength and motivation. I am also sincerely thankful to my siblings Mr. Eghosa Agbonkonkon, Mrs. Osadebamwen Eguasa, Mrs. Osarugue Afolabi, Miss Osaguimaro Agbonkonkon and my dear Osayemwenre for their guidance, encouragement and generous financial support throughout my studies. Your care, faith and constant motivation have played a vital role in the success of my academic journey.

My sincere gratitude goes to my project supervisor and the Head of Department Prof.(Mrs.) E.T. Aisien for her patient guidance, valuable feedback and insightful contributions that greatly enhanced this research as well as her commendable mentorship and commitment to excellence.

Special thanks to my Course Adviser Dr. Eghomwanre Frank for his consistent support and encouragement throughout my academic journey. Also I appreciate my lecturers, Dr Ekene, Dr Ameachi and the entire lecturers in the department for their investment in my academic development.

Finally, I extend my sincere appreciation to my amazing friends Jessica, Precious, Osato, Success and all my wonderful friends for their love, support, laughter and companionship which made this academic journey memorable and fulfilling.

TABLE OF CONTENTS

CONTENT **PAGE**

CHAPTER ONE

INTRODUCTION

CHAPTER TWO

2.0 LITERATURE REVIEW

CHAPTER THREE

3.0 MATERIALS AND METHODOLOGY

CHAPTER FOUR

4.0 RESULTS AND INTERPRETATION

CHAPTER FIVE

5.0 DISCUSSION

LIST OF TABLES

ABSTRACT

Urban vegetable cultivation in Benin Metropolis contributes significantly to household nutrition but faces contamination risks from heavy metals. This study assessed heavy metal concentrations in vegetables grown in polluted areas (Ibiwe axis) and less contaminated zones (Oko community). A comparative cross-sectional design was adopted, and samples of *Talinum triangulare* (water leaf), *Ocimum gratissimum* (scent leaf), *Vernonia amygdalina* (bitter leaf) and *Telfairia occidentalis* (pumpkin leaf) were collected from dumpsites, mechanic workshops and residential gardens. Following acid digestion, cadmium (Cd), lead (Pb), nickel (Ni), copper (Cu) and zinc (Zn) levels were determined using Atomic Absorption Spectrophotometry. Independent sample t-tests ($p < 0.05$) showed significantly higher concentrations of Cd, Zn and Ni in vegetables from polluted sites. For instance, Cd in water leaf was 0.017 ± 0.001 mg/kg in polluted sites compared with 0.004 ± 0.001 mg/kg in cleaner areas, while Zn in scent leaf reached 0.080 ± 0.001 mg/kg against 0.002 ± 0.001 mg/kg. Bitter leaf showed the highest accumulation across all metals, particularly Ni ($p = 0.001$). Although overall concentrations were below WHO/FAO limits, polluted-site vegetables contained 4–40 times more metals than those from unpolluted zones. These findings highlight that cultivation location strongly influences metal accumulation and emphasize the need for stricter environmental controls and regular monitoring to safeguard public health.

CHAPTER ONE

INTRODUCTION

1.1 Background of study

Urban agriculture is increasingly practiced in Nigerian cities, including Benin Metropolis, where residents cultivate vegetables in both polluted and relatively unpolluted urban zones. However, environmental contamination, especially from heavy metals, poses a significant threat to food safety and public health. Heavy metals such as cadmium (Cd), lead (Pb), nickel (Ni), copper (Cu), and zinc (Zn) are of particular concern due to their toxicity, persistence, and potential to bioaccumulate in edible crops (Angon *et al*., 2024; Rahim *et al*., 2024; Manwani *et al*., 2022).

Vegetables, particularly leafy varieties, are highly susceptible to heavy metal uptake due to their large surface area and direct exposure to contaminated air, soil, and irrigation water (Chen *et al*., 2024; Shetty *et al*., 2025). This poses a serious threat to food safety and public health, as these metals can accumulate in human tissues over time, leading to chronic illnesses such as kidney damage, neurological disorders, and even cancer (Manwani *et al*., 2022; Gupta *et al*., 2012; Gupta *et al*., 2022). The risk is especially pronounced in urban and peri-urban areas where vegetables are often cultivated close to roadsides or industrial zones, increasing their exposure to pollutants (Hosen *et al*., 2024).

In Nigeria, vegetables like spinach (Amaranthus spp.), fluted pumpkin (Telfairia occidentalis), and waterleaf (Talinum triangulare) are dietary staples, consumed daily by millions of people (Fasuyi, 2007; Adeniyi *et al*., 2012). Despite their nutritional benefits, the potential for heavy metal contamination in these crops remains under explored, particularly in densely populated cities like Benin city.

Benin Metropolis presents a compelling case for evaluating location-based pollution due to its contrasting urban zones. Oko community, characterized by lower traffic density and minimal industrial activity, serves as a relatively unpolluted reference site (Nwankwo *et al*., 2019). In contrast, Ibiwe axis(Jegede lane and 2nd Ibiwe str.) is a high-traffic urban hub with elevated vehicular emissions and poor waste management, contributing to increased levels of environmental pollutants (Iwuala and Oriaku, 2019). Studies have shown that vehicular emissions and urban runoff in areas like Ibiwe axis significantly elevate concentrations of heavy metals in surrounding soils and vegetation.

The accumulation of heavy metals in vegetables grown in polluted urban areas has been linked to serious health risks, including kidney damage, neurological disorders, and carcinogenic effects (Manwani *et al*., 2022; Rahim *et al*., 2024). While Cu and Zn are essential micronutrients, their excessive accumulation can be harmful, and metals like Cd and Pb are toxic even at low concentrations (Masindi and Muedi, 2018).

Given the public health implications, it is imperative to assess the levels of heavy metals in commonly consumed vegetables and evaluate the associated health risks.

1.2 Statement of the problem

Urban agriculture plays a crucial role in enhancing food security and livelihoods in Nigerian cities, including Benin Metropolis. However, the proximity of cultivation sites to pollution sources, such as major roads, industrial zones, and waste dumps, raises concerns about the safety of vegetables grown in these environments (Oluyemi *et al*., 2008). Leafy vegetables like Ocimum gratissimum, Vernonia amygdalina, Telfairia occidentalis, and Talinum triangulare are known to bioaccumulate heavy metals from contaminated soil, water, and air, posing health risks to consumers.

Benin Metropolis presents a contrast between relatively unpolluted areas like Oko community and heavily polluted zones such as Ibiwe axis, which is characterized by high vehicular traffic and poor waste management. Yet, limited empirical data exists comparing heavy metal concentrations in vegetables grown across these locations. This gap in knowledge hinders effective public health interventions, as consumers may unknowingly ingest vegetables containing hazardous levels of cadmium (Cd), lead (Pb), nickel (Ni), copper (Cu), and zinc (Zn), some of which are toxic even at trace levels (WHO, 2011).

Furthermore, environmental policies and agricultural guidelines in Nigeria often lack localized data to inform risk assessments and regulatory standards. Without targeted research evaluating how location-based pollution influences heavy metal accumulation in edible crops, urban farmers and consumers remain vulnerable to long-term health effects. This study therefore aims to investigate the influence of location-based pollution on heavy metal contamination in vegetables cultivated in Benin Metropolis.

1.3 Justification of the study

The increasing reliance on urban agriculture in Benin Metropolis has made the cultivation of vegetables within city boundaries a vital source of nutrition and income for many households. However, the potential for environmental pollution to compromise the safety of these vegetables necessitates a thorough investigation into the quality of produce grown in different urban zones. This study is particularly relevant because it focuses on commonly consumed leafy vegetables, scent leaf, bitter leaf, pumpkin leaf, and water leaf, which are integral to local diets and widely cultivated across the metropolis.

By comparing vegetable samples from Oko community (a relatively unpolluted area) and Ibiwe axis (a known polluted zone), the research provides insight into how location-based pollution influences the accumulation of heavy metals such as cadmium, lead, nickel, copper, and zinc. These metals pose serious health risks when present in elevated concentrations, and their presence in food crops can have long-term implications for public health.

The study is also justified by the need to generate localized data that can inform environmental monitoring, agricultural practices, and food safety regulations. While national and international standards exist for permissible levels of heavy metals in food, there is a lack of site-specific research that addresses the unique environmental conditions of Benin Metropolis. This research fills that gap by offering evidence-based findings that can guide policy decisions, raise public awareness, and promote safer urban farming practices.

1.4 Aim and objectives of the Study

The aim of this study is to evaluate the role of location-based pollution in heavy metal contamination of vegetables grown in Benin Metropolis.

The specific objectives of this study are to:

- Determine the concentrations of cadmium, lead, nickel, copper, and zinc in selected vegetables (scent leaf, bitter leaf, pumpkin leaf, and water leaf) cultivated at Ibiwe axis and Oko community in Benin Metropolis.
- Compare the levels of heavy metal accumulation in vegetables grown in the areas suspected to be polluted with high concentration of heavy metals (Ibiwe axis) with those areas suspected to be of less concentration of heavy metals (Oko community).

- Assess the potential influence of location-based pollution on the safety of vegetables consumed by residents of Benin Metropolis.

1.5 Scope of the Study

- Focuses on determining the concentration and distribution of Cadmium (Cd), Lead (Pb), Nickel (Ni), Copper (Cu), and Zinc (Zn) in vegetable samples.
- Limited to two urban areas in Edo State: Ibiwe axis (Jegede Lane, 2nd Ibiwe Street) and Oko Community.
- Involves collection and laboratory analysis of vegetable samples.
- Compares metal levels in vegetables from high metallic polluted and less metallic polluted sites.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Concept of Heavy Metal Pollution

Heavy metal pollution refers to the presence of metallic elements in the environment at concentrations that pose risks to ecological and human health. These metals, including cadmium (Cd), lead (Pb), nickel (Ni), copper (Cu), and zinc (Zn), are introduced into ecosystems through both natural and anthropogenic activities. Unlike organic pollutants, heavy metals are non-biodegradable and persist in the environment, accumulating in soil, water, and living organisms over time (Masindi and Muedi, 2018).

Heavy metals are typically defined as elements with high atomic weight and density greater than 5 g/cm^3. They exhibit properties such as toxicity, persistence, and the ability to bioaccumulate in living organisms. While some heavy metals like copper and zinc are essential micronutrients, others such as cadmium and lead are toxic even at low concentrations. Their chemical behavior, including oxidation states and solubility, influences their mobility and toxicity in the environment (McClements, 2024; Helmenstine, 2024).

Heavy metals enter the environment through several pathways. Traffic emissions release metals such as lead and cadmium into roadside soils through vehicular exhaust and tire wear. Industrial activities, including mining, smelting, and manufacturing, emit nickel, chromium, and other metals into air and water. Waste disposal practices, particularly the improper handling of electronic waste, batteries, and industrial sludge, further contribute to contamination. Rapid urbanization and construction activities also lead to increased pollution from fossil fuel combustion and runoff (Masindi and Muedi, 2018; Samanta, 2024). These sources are especially concentrated in urban centers, making cities like Benin Metropolis particularly vulnerable to environmental contamination.

Heavy metals are persistent in the environment due to their non-degradable nature. Once introduced, they remain in soils and sediments for decades, resisting natural breakdown. Their bioaccumulation potential allows them to concentrate in plant tissues and magnify through food chains, posing risks to herbivores and humans alike. For instance, cadmium and lead have been shown to accumulate in leafy vegetables, which are subsequently consumed by humans, leading to chronic exposure (Surabhi and Zainith, 2024; Nnaji *et al*., 2023).

Several documented cases highlight the dangers of heavy metal pollution in Nigeria. A notable example is the lead poisoning crisis in Zamfara State, where artisanal gold mining resulted in widespread contamination and fatalities, particularly among children. Another case involves the Great Kwa River in Cross River State, where industrial discharge and urban runoff have elevated heavy metal concentrations in aquatic life (Laoye *et al*., 2025). These cases underscore the urgent need for localized studies, such as the present research in Benin Metropolis, to assess and mitigate heavy metal risks in urban agriculture.

2.2 Health Implications of Heavy Metal Contamination

Heavy metals are widely recognized for their toxicity, persistence, and ability to disrupt biological systems, posing significant risks to human health. The toxicological impacts vary across metals but are generally associated with oxidative stress, enzyme inhibition, and interference with essential metabolic processes.

Cadmium (Cd) is classified as a human carcinogen and has been linked to kidney dysfunction, bone demineralization, and cardiovascular diseases. Chronic exposure may lead to the development of itai-itai disease, characterized by severe musculoskeletal pain and osteomalacia (Yadav and Pervez, 2024). Lead (Pb) is neurotoxic, with children being particularly vulnerable to its effects, including intellectual disabilities, behavioral disorders, and developmental delays. In adults, Pb exposure has been associated with hypertension, renal impairment, and cardiovascular disease (Jomova *et al*., 2025). Nickel (Ni), although an essential micronutrient in trace quantities, becomes toxic at higher concentrations, leading to allergic reactions, respiratory complications, and increased risks of nasal and lung cancers upon long-term exposure (Engwa *et al*., 2019).

Similarly, copper (Cu) is vital for enzymatic activities and physiological processes, but excessive intake may result in gastrointestinal disorders, hepatotoxicity, and neurological impairment. Zinc (Zn), another essential trace element that supports immune function and wound healing, can exert toxic effects when present in high concentrations, including suppression of copper absorption, gastrointestinal distress, and compromised immunity (Jomova *et al*., 2025). Collectively, these metals exert their toxic effects by disrupting antioxidant defense mechanisms, generating reactive oxygen species, and promoting cellular damage.

2.2.1 Bioaccumulation Through the Food Chain

Heavy metals enter the food chain through contaminated soil, air, and water sources. Plants, particularly leafy vegetables, absorb these metals either through their root systems or by direct deposition on leaves. Herbivores feeding on contaminated plants subsequently accumulate these toxins, and as predators consume herbivores, the concentration of metals further increases through biomagnification (Bienfang *et al*., 2024). The bioaccumulation of heavy metals in human tissues, particularly the liver, kidneys, and bones, leads to long-term health effects. For instance, cadmium and lead stored in bones can be mobilized during pregnancy and aging, heightening risks of maternal and developmental toxicity (Carter, 2018).

2.2.2 Case Studies of Health Risks Associated with Contaminated Vegetables

Several studies have highlighted the health risks of vegetable consumption in polluted environments. In Faisalabad, Pakistan, vegetables irrigated with untreated wastewater contained elevated levels of Cd, Pb, Ni, and Cr, with Hazard Quotients (HQs) above recommended safety thresholds, suggesting risks of cancer, kidney damage, and neurological disorders (Jabeen *et al*., 2023). Similarly, in Sasar, Romania, vegetables cultivated in industrially contaminated soils contained elevated concentrations of Cu, Cd, and Zn. Although the Health Risk Index (HRI) remained within permissible limits, the study emphasized the danger of long-term exposure and called for continuous monitoring (Smical *et al*., 2025).

In Nigeria, cases of lead poisoning in Zamfara State, linked to artisanal mining activities, and heavy metal contamination of the Great Kwa River in Cross River State, illustrate the disproportionate health risks faced by communities exposed to contaminated food and water sources (Laoye *et al*., 2025). These findings emphasize the importance of localized assessments in urban agricultural areas such as Benin Metropolis, where vegetables cultivated in polluted environments may pose significant risks to food safety and public health.

2.3 Vegetables as Indicators of Environmental Pollution

Leafy vegetables play a vital role in the Nigerian diet, not only because of their culinary versatility but also because of their significant nutritional and medicinal values. Scent leaf (Ocimum gratissimum) is an important vegetable rich in vitamins A, B6, and C, and contains bioactive compounds such as eugenol and tannins, which have been traditionally employed in the treatment of infections, digestive problems, and respiratory ailments (FitNigerian, 2022). Bitter leaf (Vernonia amygdalina) has long been recognized for its pharmacological importance, with properties that are anti-inflammatory, anti-diabetic, and anti-malarial. It supports liver health and is often used to manage gastrointestinal disorders and hypertension (Pangbenta, 2025). Similarly, pumpkin leaf (Telfairia occidentalis) is a valuable vegetable consumed across Nigeria for its high iron, calcium, and antioxidant content, particularly recommended for improving blood levels and reproductive health. Water leaf (Talinum triangulare), on the other hand, is a rich source of vitamins C and E and omega-3 fatty acids, and is traditionally consumed for its ability to address anemia and aid digestion. These vegetables are widely cultivated in both urban and peri-urban areas due to their accessibility and affordability, but their high surface area and rapid growth rate also predispose them to contamination by environmental pollutants.

The uptake of heavy metals in leafy vegetables occurs primarily through their root system from contaminated soils and water, while secondary accumulation results from foliar deposition of airborne pollutants. Metals such as cadmium (Cd), lead (Pb), and nickel (Ni) gain entry into the plant system via ion channels and transport proteins that are naturally meant for the regulation of essential elements like calcium and magnesium (Khan *et al*., 2015). Once absorbed, these metals may be sequestered in vacuoles or bound to organic acids and proteins to mitigate toxicity. Studies have shown that leafy tissues are particularly prone to storing heavy metals, with the general pattern of accumulation being leaf > root ≈ stem > tuber (Meng *et al*., 2025). Environmental conditions, including soil pH, organic matter content, and the presence of competing ions, greatly influence the extent of uptake, with acidic soils enhancing metal solubility and availability to plants.

Leafy vegetables are therefore considered effective bioindicators of pollution due to their physiological and morphological traits. Their broad leaf surface area enhances direct interaction with atmospheric pollutants such as lead and mercury, while their relatively short life cycle makes them useful for monitoring contamination trends within a limited timeframe. Their widespread cultivation and consumption also make them practical sentinels for food safety monitoring and public health risk assessment (Choudhary, 2019; Narayanti *et al*., 2024). Research evidence demonstrates that vegetables cultivated near highways, industrial zones, and sewage-irrigated fields often accumulate higher levels of toxic metals compared to those grown in less polluted areas. For instance, a study in Tianjin, China, revealed that spinach recorded the highest mercury accumulation among leafy vegetables grown in sewage-irrigated zones, confirming its reliability as a sensitive indicator of pollution (Zheng *et al*., 2018).

A similar trend has been reported in West Africa. Along the Nigeria–Benin Seme border, significant concentrations of heavy metals were detected in vegetables cultivated near highways. In particular, Telfairia occidentalis and Corchorus olitorius accumulated elevated levels of lead, copper, and iron, largely due to atmospheric deposition from vehicular emissions and irrigation with contaminated water. The detected levels of lead and iron exceeded the permissible limits set by WHO and FEPA, underscoring the risks of chronic human exposure through dietary intake (Osundiya *et al*., 2014). This case highlights the relevance of leafy vegetables as environmental sentinels and the need for routine monitoring in urban agricultural zones to mitigate pollution risks.

2.4 Influence of Location-Based Pollution on Crop Contamination

Roadside and traffic-related pollution remain critical contributors to soil and crop contamination, particularly in urban and peri-urban agricultural zones. Emissions from vehicles release heavy metals such as lead (Pb), cadmium (Cd), zinc (Zn), and copper (Cu) into the environment through exhaust fumes, tire wear, brake linings, and road dust. These pollutants can settle on the surfaces of soils and plants or be washed into the soil during rainfall events, thereby altering soil pH and affecting microbial activity (Yu, 2024). A study conducted in Sango-Ota, Ogun State, Nigeria, reported elevated concentrations of Cu, Zn, Pb, and Mn in roadside soils, with levels decreasing progressively with increasing distance from the road, highlighting the localized impact of traffic emissions on soil chemistry and crop safety (Giwa, 2021). Beyond heavy metals, polycyclic aromatic hydrocarbons (PAHs), another group of pollutants associated with vehicular traffic, have also been shown to bind to fine dust particles. These pose additional risks to crops and human health due to their genotoxic properties (WHO, 2021). Such contaminants not only reduce crop yield and quality but also present long-term public health risks through bioaccumulation along the food chain.

Differences in the spatial distribution of heavy metals between urban and peri-urban environments have also been documented. Urban soils typically accumulate higher levels of heavy metals due to the influence of industrial activities, dense traffic, and improper waste disposal. A comparative study in Wuhan and Enshi, China, revealed that urban soils had greater spatial heterogeneity and higher anthropogenic metal loads compared to peri-urban soils, which were influenced more by natural factors such as geology and weathering processes (Sun *et al*., 2025). Despite lower industrial activity, peri-urban agricultural areas are not exempt from contamination, as they remain vulnerable to informal waste disposal practices, agricultural runoff, and their proximity to expanding urban centers (Golia *et al*., 2024). Metals such as arsenic (As), cadmium (Cd), and lead (Pb) persist in soils for long periods, meaning that even peri-urban farmlands remain at risk of long-term contamination. This gradient between urban and peri-urban zones has important implications for crop safety and underscores the need for tailored monitoring strategies in different ecological settings.

Comparisons between polluted and unpolluted sites further highlight the influence of location-based pollution on soil and crop quality. In the Niger Delta region of Nigeria, microbial activity and biodegradation capacity were significantly reduced in hydrocarbon-contaminated soils compared to unpolluted controls, with negative consequences for soil fertility and crop productivity (Olanipekun *et al*., 2015). Similarly, a study in Abuja reported that carbon monoxide (CO) and fine particulate matter (PM2.5) levels in high-traffic areas exceeded WHO permissible limits, raising concerns about the indirect impact on nearby agricultural systems and food safety (Otse *et al*., 2018). Globally, research conducted in Faisalabad, Pakistan, demonstrated that urban soils recorded higher contamination factors and pollution load indices for cadmium and lead compared to peri-urban zones, with elevated risks particularly among children due to dietary exposure (Mehmood *et al*., 2019). These comparative assessments emphasize the importance of evaluating localized sources of pollution to guide agricultural zoning policies and safeguard food security.

A clear example of the localized impacts of traffic corridors is evident along the Lagos-Ibadan Expressway in Nigeria, one of Africa's busiest highways. A study along this route revealed that soils sampled within 5 meters of the road contained significantly higher levels of Pb, Zn, and Cu compared to soils farther away. Crops grown within this zone not only exhibited stunted growth but also accumulated higher concentrations of these metals, thereby posing risks to both consumers and farmers who rely on them for sustenance and income (Oyesiku, 2020). This case study underscores how proximity to polluted locations directly influences the level of contamination in soils and crops, reaffirming the role of location-based pollution in shaping agricultural and public health outcomes.

2.5 Heavy Metal Contamination of Vegetables in Nigeria

Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), and arsenic (As) are non-biodegradable and toxic to humans and ecosystems even at low concentrations. Their accumulation in vegetables is of major concern due to their potential for bioaccumulation and biomagnification along the food chain, which may result in serious public health risks (Taiwo *et al.*, 2024).

Studies from different Nigerian cities have consistently demonstrated significant contamination of vegetables with heavy metals. In Lagos, elevated concentrations of Pb, Cd, and Cr were reported in commonly consumed vegetables such as *Talinum triangulare*, *Telfairia occidentalis*, and *Amaranthus hybridus*. These values often exceeded WHO limits of Pb (>0.3 mg/kg), Cd (>0.2 mg/kg), and Cr (>1.3 mg/kg). Industrial zones such as Kosofe and Amuwo-Odofin recorded the highest contamination levels, indicating the role of industrial activity in pollution (Ogundele *et al.*, 2019; Sogbanmu *et al.*, 2012; Odumosu *et al.*, 2021; Ani *et al.*, 2024).

In Ibadan, vegetables like Celosia argentea, Corchorus olitorius, and Talinum triangulare were found to contain Pb levels as high as 1.70 mg/kg, while Cd levels also exceeded recommended safety limits. The major contributors to this contamination were identified as traffic emissions and wastewater irrigation practices, both of which are common in peri-urban farming systems (Dada *et al.*, 2024; Taiwo *et al.*, 2024).

Enugu presented a slightly different picture, as residential gardens showed heavy metal contamination in *Telfairia occidentalis*, *Amaranthus viridis*, and *Vernonia amygdalina*. Although Pb and Cd concentrations were within WHO/FAO permissible limits, hazard index (HI) values greater than one indicated that the consumption of these vegetables could still pose significant long-term health risks (Akpanyung, 2019; Ibegbu *et al*., 2021).

In Port Harcourt, the contamination levels were particularly alarming. Vegetables cultivated along the Eleme, Port Harcourt Road recorded extremely high concentrations of Cr (26.2 mg/kg), Pb (10.4 mg/kg), Cd (9.4 mg/kg), and Ni (36.8 mg/kg). These values far exceeded global safety standards and were attributed to emissions from industrial facilities, heavy traffic, and dumpsites (Anthony *et al*., 2025; Ogbo and Patrick-Iwuanyanwu, 2019; Okorosaye-Orubite and Igwe, 2017).

Benin City also revealed concerning findings. Vegetables such as lettuce and cucumber contained iron concentrations surpassing the WHO's permissible limit of 425 mg/kg, largely due to the use of refuse ash and greywater irrigation in urban farming systems. This suggests that agricultural practices in the city significantly contribute to contamination (Egharevba *et al*., 2017).

Across Nigerian cities, leafy vegetables have been shown to accumulate higher concentrations of metals compared to other vegetables. This is because their broad surface areas facilitate the deposition of airborne particles, while their shallow root systems enhance absorption of contaminants from polluted soils and irrigation water (Sogbanmu *et al*., 2012; Ani *et al*., 2024). While Fe and Zn are the most abundant elements detected, Cd and Pb pose the greatest health risks due to their high toxicity and carcinogenic potential (Taiwo *et al*., 2024; Ogbo and Patrick-Iwuanyanwu, 2019).

Comparisons with WHO/FAO standards highlight the severity of the problem. Maximum concentrations of Pb, Cd, and Cr in Nigerian vegetables often exceed permissible limits by several folds, especially in urban and industrial centers. Moreover, hazard quotient (HQ) and cancer risk (CR) values for Cd and Pb are consistently higher than safe thresholds, suggesting long-term exposure risks for consumers (Ibegbu *et al*., 2021; Odumosu *et al*., 2021).

In conclusion, heavy metal contamination of vegetables in Nigeria is widespread and particularly severe in industrial and traffic-dense areas. While some vegetables remain within safe limits, others—especially leafy greens, regularly exceed WHO/FAO guidelines, making them unsafe for long-term consumption. The evidence points to the urgent need for regular monitoring by regulatory authorities, improved public awareness on the dangers of contaminated vegetables, and the adoption of safer irrigation and waste management practices to mitigate exposure risks (Dada *et al*., 2024; Okorosaye-Orubite and Igwe, 2017).

CHAPTER THREE

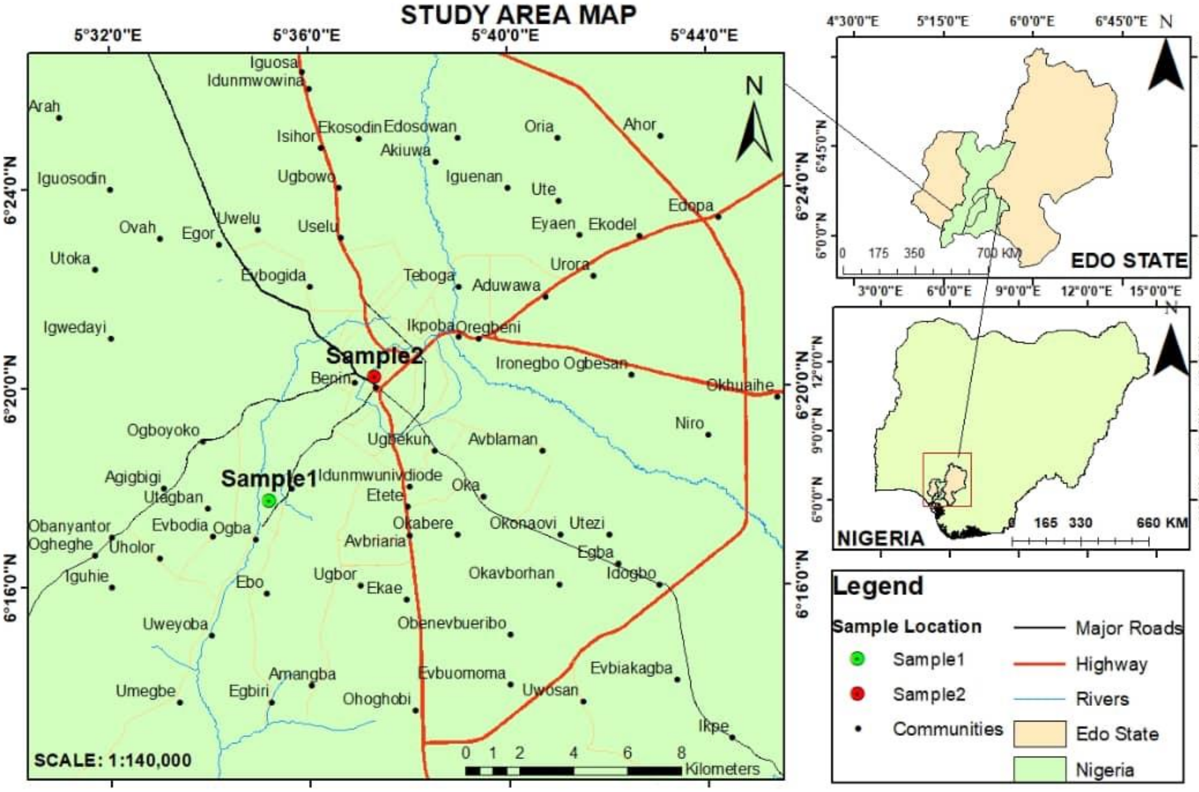
3.0 MATERIALS AND METHODOLOGY

3.1 Study Area

This study was conducted in Benin Metropolis, Edo State, Nigeria. Benin Metropolis is the capital of Edo State and one of the fastest-growing urban centres in southern Nigeria. It lies approximately between latitude 6°20′N to 6°30′N and longitude 5°30′E to 5°45′E, covering an area of about 1,204 km^2. The city is characterized by rapid population growth, urban expansion, and unregulated development. These trends have led to increased waste generation, vehicular traffic, and proliferation of small-scale industrial activities such as mechanic workshops, block moulding industries, metal fabrication, and open-air markets.

The geology of Benin Metropolis is dominated by the Benin Formation, which consists mainly of unconsolidated coastal plain sands. The soils are ferrallitic, porous, and well-drained, making them suitable for vegetable farming. However, these soils are also vulnerable to contamination from anthropogenic sources, especially in areas adjacent to roadsides, dumpsites, and industrial establishments.

The climatic condition in the area favours year-round cultivation of leafy vegetables. The choice of Benin Metropolis as a study area is informed by its rapid urbanization, widespread practice of urban agriculture, and proximity of vegetable gardens to pollution sources such as refuse dumps, major roads, and mechanic workshops. These factors make it an appropriate location to evaluate the role of site-specific pollution in heavy metal accumulation in vegetables.



3.2 Research Design

The study adopted a comparative cross-sectional design aimed at investigating the influence of site-specific pollution on heavy metal concentrations in vegetables. This design is suitable for comparing contaminant levels across sites with varying exposure to pollution sources within the same time frame.

Comparing vegetables grown in areas with high metallic pollutants and those from areas with low metallic pollutants, the study provides a clear assessment of how environmental location contributes to potential health risks associated with vegetable consumption.

The metals of interest. Lead (Pb), Cadmium (Cd), Zinc (Zn), Copper (Cu), and Iron (Fe), were selected based on their environmental and health significance. Pb and Cd are toxic even at low concentrations, Zn and Cu are essential micronutrients but toxic at high levels while Fe is abundant in the soil but excessive accumulation can be problematic.

3.3 Sampling Design and Site Selection

A targeted site selection approach was used to identify vegetable farms and gardens that represented varying levels of potential contamination.

Areas with high metallic pollutants:

- A major dumpsite at 2nd Ibiwe Street.
- A residential garden adjacent to a mechanic workshop at Jegede Lane.

Areas with low metallic pollutants:

- A residential backyard garden located far from major roads and waste dumps at Dimaro Street in Oko Community.

3.4 Sample Size and Replication

Each digested sample was analyzed in duplicate. A total of eight composite vegetable samples were collected. At each site, three sub-samples (about 150–200 g each) of the available vegetable species were harvested randomly and pooled together to form a composite representative sample.

3.5 Sample Collection and Handling

Vegetable samples were collected using acid-washed polyethylene bags, clearly labelled, and immediately delivered to the laboratory to prevent degradation.

3.6 Sample Preparation

Vegetable samples collected from the study site were taken to the laboratory, where they were thoroughly washed and rinsed with distilled water to eliminate surface impurities. The samples were then cut into smaller sections (roots, stems, and leaves) using a clean stainless-steel knife. These portions were air-dried and later ground into fine powder using a clean mortar and pestle. The powdered samples were sieved through a 2 mm plastic sieve and stored in clearly labeled containers. Subsequently, 1 g of each sample was accurately weighed with an analytical balance and transferred into a clean, sterilized beaker. Acid digestion was carried out in a fume cupboard using a heating mantle until complete digestion was achieved. The resulting solutions were filtered through Whatman filter paper into 100 mL volumetric flasks, made up to the mark with distilled water, and stored in clean, sterilized sample bottles for further analysis.

3.7 Materials

The materials used are :

1. Glassware (beakers, conical flasks, volumetric flasks)
2. Foil Paper
3. Sample Bottles
4. Weigh Balance
5. Labels
6. Pipette
7. Distilled Water
8. Nitric Acid
9. HCL
10. filter paper
11. Fume cupboard
12. Mortar and Pestle
13. Sieve
14. Protective equipment (gloves, lab coat, nose mask)

3.8 Digestion of Samples

Ten millilitres (10 mL) of concentrated nitric acid (HNO_3) was added to each 1 g sample, followed by 10 mL of hydrochloric acid (HCl) in a 1:1 ratio of HNO_3 to HCl. The mixture was heated in a fume cupboard until a clear solution was obtained.

After digestion, the solution was allowed to cool and was made up to the mark with distilled water.

3.9 Preparation of Standards and Calibration of AAS

Certified stock solutions (1000 mg/L) for Pb, Cd, Zn, Cu, and Fe were used to prepare working standards. Calibration curves were established by aspirating standard solutions into the Atomic Absorption Spectrophotometer. Only calibration curves with a correlation coefficient (R2) ≥ 0.995 were accepted.

Instrumental blanks and quality control standards were run after every eight (8) samples to maintain precision.

3.10 Heavy Metal Analysis

The AAS was operated under recommended conditions for each element. Duplicate readings were taken for each sample, and mean values were recorded. Results were expressed in mg/kg on a dry weight basis.

3.11 Quality Assurance and Quality Control (QA/QC)

- To ensure accuracy and reliability, the following steps were observed:
- All glassware was soaked in 10% nitric acid and rinsed with distilled water.
- Procedural blanks were included in each digestion batch.

- To ensure the accuracy and reliability of the results, all samples were analyzed twice.
- Recovery tests were performed, and results between 90–110% were considered acceptable.

3.12 Data Analysis

Heavy metal concentrations were tabulated and statistically analyzed using SPSS version 25. Descriptive statistics (mean, standard deviation, and range) were computed. Independent sample t-tests were used to compare mean concentrations between areas with high metallic pollutants and areas with low metallic pollutants, with significance tested at $p < 0.05$. The results were compared with WHO/FAO permissible limits for heavy metals in food crops.

CHAPTER FOUR

4.0 RESULTS AND INTERPRETATION

4.1 Introduction

This chapter presents the results of the laboratory analysis of heavy metal concentrations in selected vegetables from areas suspected to be polluted with heavy metals (Ibiwe axis) and areas with lesser concentration of heavy metals Oko community within the Benin Metropolis. The data is presented in tables and interpreted in line with the specific objectives of the study, which were to determine the concentrations of heavy metals, compare their accumulation between locations, and assess the potential health implications.

4.2 Heavy Metal Concentrations in Selected Vegetables

The concentrations of Cadmium (Cd), Zinc (Zn), Nickel (Ni), Lead (Pb), and Copper (Cu) in scent leaf, bitter leaf, pumpkin leaf, and water leaf from both study locations are summarized in Table 4.1. The results are presented as mean ± standard deviation of duplicate analyses.

Table 4.1: Mean Concentration (± Standard Deviation) of Heavy Metals (mg/L) in Vegetables from Polluted and Unpolluted Sites.

Vegetable Type	Location	Cd (mg/L)	Zn (mg/L)	Ni (mg/L)	Pb (mg/L)	Cu (mg/L)
Water Leaf	Polluted	0.017±0.001	0.075±0.001	0.010±0.001	0.006±0.001	0.012±0.003
Water Leaf	Unpolluted	0.004±0.001	0.002±0.000	0.002±0.001	0.001±0.000	0.002±0.001
Scent Leaf	Polluted	0.015±0.001	0.080±0.001	0.036±0.001	0.008±0.001	0.006±0.001
Scent Leaf	Unpolluted	0.002±0.000	0.002±0.001	0.002±0.000	0.001±0.000	0.001±0.000
Bitter Leaf	Polluted	0.009±0.001	0.053±0.002	0.021±0.001	0.009±0.001	0.008±0.001
Bitter Leaf	Unpolluted	0.001±0.000	0.002±0.001	0.002±0.001	0.002±0.001	0.002±0.001
Pumpkin Leaf	Polluted	0.011±0.001	0.030±0.001	0.037±0.001	0.007±0.001	0.010±0.001
Pumpkin Leaf	Unpolluted	0.002±0.001	0.001±0.000	0.002±0.001	0.001±0.000	0.002±0.001

KEY:
Polluted: Areas suspected to be polluted with high concentrations of heavy metals.
Unpolluted: Areas suspected to have less concentration of heavy metals.

The results show that all five heavy metals were detected in vegetables from both locations, with consistently higher concentrations observed in samples from areas suspected to be polluted with heavy metals (Ibiwe axis) and areas with lesser concentration of heavy metals (Oko community)

4.2.1 Cadmium (Cd) Concentrations

Cd concentrations ranged from 0.009 mg/L (Bitter Leaf) to 0.017 mg/L (Water Leaf) in polluted areas, and 0.001 mg/L (Bitter Leaf) to 0.004 mg/L (Water Leaf) in unpolluted areas.

4.2.2 Zinc (Zn) Concentrations

Zn concentrations ranged from 0.030 mg/L (Pumpkin Leaf) to 0.080 mg/L (Scent Leaf) in polluted areas, and 0.001 – 0.002 mg/L in unpolluted areas.

4.2.3 Nickel (Ni) Concentrations

Ni concentrations ranged from 0.010 mg/L (Water Leaf) to 0.037 mg/L (Pumpkin Leaf) in polluted areas, and 0.002 mg/L in unpolluted areas.

4.2.4 Lead (Pb) Concentrations

Pb concentrations ranged from 0.006 mg/L (Water Leaf) to 0.009 mg/L (Bitter Leaf) in polluted areas, and 0.001–0.002 mg/L in unpolluted areas.

4.2.5 Copper (Cu) Concentrations

Cu concentrations ranged from 0.006 mg/L (Scent Leaf) to 0.012 mg/L (Water Leaf) in polluted areas, and 0.001–0.002 mg/L in unpolluted areas.

4.3 Comparison of Heavy Metal Accumulation between Locations

An Independent Samples T-test was conducted to determine if the differences in heavy metal concentrations between Areas with high metallic pollutant (Ibiwe axis) and areas with low metallic pollutant (Oko community) sites were statistically significant. A p-value of less than 0.05 ($p < 0.05$) was considered significant. The results are presented in Table 4.2.

Table 4.2a: T-test Results for Heavy Metal Accumulation in Water Leaf

Metal	Mean Difference (mg/L)	p-value	Significance
Cd	0.013	0.003	Yes
Zn	0.073	0.009	Yes
Ni	0.0085	0.037	Yes
Pb	0.005	0.126	No
Cu	0.010	0.079	No

From Table 4.2a,

For Water Leaf, three metals, Cadmium (Cd), Zinc (Zn), and Nickel (Ni), showed statistically significant differences between polluted and unpolluted sites ($p < 0.05$). Zinc had the highest mean difference (0.073 mg/L), suggesting it is the most influenced by environmental contamination. Lead (Pb) and Copper (Cu) were not significant ($p > 0.05$), which indicates their accumulation levels were similar in both locations or that variation within samples masked potential differences.

Table 4.2b: T-test Results for Heavy Metal Accumulation in Bitter Leaf

Metal	Mean Difference (mg/L)	p-value	Significance
Cd	0.0075	0.042	Yes
Zn	0.0505	0.003	Yes
Ni	0.019	0.001	Yes
Pb	0.007	0.010	Yes
Cu	0.006	0.014	Yes

From Table 4.2a,

All five metals in Bitter Leaf showed statistically significant differences ($p < 0.05$), indicating strong evidence of heavy metal accumulation due to pollution. Nickel (Ni) had the lowest p-value (0.001), confirming a very strong effect of pollution on its concentration. Zinc (Zn) also showed a high mean difference (0.0505 mg/L), suggesting considerable uptake.

Table 4.2c: T-test Results for Heavy Metal Accumulation in Scent Leaf

Metal	Mean Difference (mg/L)	p-value	Significance
Cd	0.013	0.049	Yes
Zn	0.0785	0.001	Yes
Ni	0.034	0.019	Yes
Pb	0.007	0.090	No
Cu	0.0045	0.070	No

From table 4.2c,

For Scent Leaf, Cadmium (Cd), Zinc (Zn), and Nickel (Ni) displayed statistically significant differences ($p < 0.05$) between polluted and unpolluted sites. Among them, Zinc (Zn) had the highest mean difference (0.0785 mg/L). However, Lead (Pb) and Copper (Cu) were not significant ($p > 0.05$).

Table 4.2d: T-test Results for Heavy Metal Accumulation in Pumpkin Leaf

Metal	Mean Difference (mg/L)	p-value	Significance
Cd	0.009	0.006	Yes
Zn	0.029	0.022	Yes
Ni	0.035	<0.001	Yes
Pb	0.006	0.105	No
Cu	0.0085	0.037	Yes

From table 4.2d,

In Pumpkin Leaf, four metals, Cadmium (Cd), Zinc (Zn), Nickel (Ni), and Copper (Cu), showed statistically significant accumulation ($p < 0.05$). Nickel (Ni) recorded the lowest p-value (<0.001). Lead (Pb), however, was not significant ($p = 0.105$), implying its accumulation was less affected by pollution or varied greatly across samples.

CHAPTER FIVE

5.0 DISCUSSION

This study evaluated the role of location-based pollution on heavy metal contamination of vegetables cultivated in Benin Metropolis. The results showed that all five metals analyzed, cadmium (Cd), zinc (Zn), nickel (Ni), lead (Pb), and copper (Cu), were present in both study locations but were consistently higher in vegetables obtained from the suggested metallic polluted (Ibiwe axis) compared with those from the lesser metallic polluted (Oko community). This pattern clearly indicates that environmental pollution associated with traffic, atmospheric deposition, and urban runoff plays a significant role in metal accumulation in edible crops.

The results clearly showed that vegetables grown in the polluted Ibiwe area contained significantly higher concentrations of cadmium (Cd), lead (Pb), nickel (Ni), copper (Cu), and zinc (Zn) compared to those from the relatively lesser polluted Oko community. These findings provide strong evidence that urban environmental pollution directly affects the safety and quality of food crops. They also align with growing global research linking urban agriculture to heavy metal exposure and public health risks.

The elevated heavy metal levels observed in vegetables from Ibiwe axis are consistent with findings reported across different regions of Nigeria and other developing urban centers. Awe *et al*. (2023) found similarly high concentrations of Pb, Cu, and Zn in vegetables grown near major roads and industrial zones in Ilorin and Osogbo, attributing the contamination mainly to vehicular emissions and industrial effluents. Likewise, Oloruntoba *et al*. (2024) conducted a meta-analysis of 120 studies and concluded that urban farming in Nigeria is frequently affected by heavy metal pollution due to inadequate waste management, dense traffic, and poor environmental regulation.

Rahim *et al*. (2024) further reported that leafy vegetables sold in urban markets often exceed WHO/FAO permissible limits for Cd, Pb, and Ni, underscoring the health hazards associated with consuming produce from contaminated areas. Similar results were documented in India by Gupta *et al*. (2022), who observed that vegetables grown close to roads and industrial estates accumulated significantly higher concentrations of heavy metals, particularly Pb and Zn. Hoskins (2024) also found that vegetables marketed within urban centers contained more heavy metals than those from peri-urban or rural farms, suggesting that both pre-harvest soil contamination and post-harvest environmental exposure contribute to the problem.

Collectively, these studies strengthen the conclusion that geographic location and pollution intensity are key determinants of heavy metal accumulation in vegetables. The pattern seen in Ibiwe axis reflects a broader urban contamination trend observed in cities worldwide.

The notably higher concentrations of Zn and Ni across all vegetable species from Ibiwe, up to 40-fold and 18-fold increases, respectively, highlight the strong influence of local environmental conditions on metal uptake. Several factors likely contributed to these elevated levels. Vehicular emissions are one of the most important contributors. Ibiwe axis(Jegede lane and 2nd Ibiwe str.) experiences heavy traffic congestion, resulting in continuous release of Pb and Ni from fuel combustion, brake pad wear, and tire abrasion. Similar associations were reported by Ogunlesi *et al*. (2021), who identified traffic density as a major source of roadside vegetable contamination in Lagos.

Industrial and commercial activities also play a role. Numerous workshops and small-scale manufacturing outlets near Ibiwe axis may release pollutants such as Cu and Zn into the environment through improper waste disposal, oil leaks, and corrosion of metallic materials. These sources increase metal availability in the surrounding soil and irrigation water. In addition, atmospheric deposition further enriches soil and plant surfaces with Cd, Pb, and other metals. Ani *et al*. (2025) observed that natural cleansing mechanisms such as rainfall are insufficient to offset persistent deposition in heavily polluted urban zones, Ani *et al*. (2025).

The consistent statistical significance ($p < 0.05$) of Zn and Ni accumulation across all four vegetable types supports the conclusion that the contamination pattern is systematic and location-driven rather than random. This implies that vegetables cultivated in high-traffic or industrialized locations are likely to exhibit predictable and elevated metal burdens.

5.1 Health and Safety Implications

The health implications of these findings are considerable. Continuous consumption of contaminated vegetables can lead to bioaccumulation, where trace metals gradually build up in the human body to toxic levels. Each of the metals identified in this study has well-documented health effects. Cadmium (Cd) causes kidney dysfunction, skeletal damage, and bone demineralization when exposure is prolonged (WHO, 2021). Lead (Pb) is highly toxic and affects nearly every organ system. In children, chronic exposure leads to cognitive deficits, learning difficulties, and behavioral disorders, while in adults it contributes to hypertension and renal disease (CDC, 2022). Nickel (Ni) is associated with respiratory problems, allergic dermatitis, and has been classified as a human carcinogen by the International Agency for Research on Cancer (IARC). Copper (Cu) and Zinc (Zn), though both essential micronutrients, can cause gastrointestinal distress, liver toxicity, and mineral imbalance when taken in excess.

These risks are intensified when contaminated vegetables are consumed regularly, as repeated ingestion leads to cumulative exposure. The dramatic increases recorded in this study, particularly the 40-fold rise in Zn in scent leaf, highlight an urgent need for environmental monitoring, regulatory enforcement, and public education on safe urban farming practices. The findings confirm that pollution from location-specific factors such as traffic density, industrial emissions, and atmospheric deposition directly compromises the safety of edible crops. Proactive measures including soil testing, regulation of roadside farming, and improved urban waste management are critical to mitigate these risks and protect public health.

5.2 Conclusion

This study successfully achieved its objectives by determining heavy metal concentrations, demonstrating statistically significant differences between locations, and assessing the associated health implications. In conclusion, the findings provided compelling evidence that location-based pollution is a major driver of heavy metal contamination in vegetables in Benin Metropolis. The significantly higher concentrations of Zn, Ni, Cd, Pb, and Cu in vegetables from Ibiwe axis confirm the profound impact of urban anthropogenic activities, primarily vehicular traffic. This underscores a significant food safety issue that requires urgent attention.

REFERENCE

Adelekan, B. A. and Abegunde, K. D. (2011). Heavy metals contamination of soil and groundwater at automobile mechanic villages in Ibadan, Nigeria. *International Journal of the Physical Sciences*, **6**(5): 1045-1058.

Adeniyi, S. A., Ehiagbonare, J. E. and Nwangwu, S. C. O. (2012). Nutritional evaluation of some staple leafy vegetables in Southern Nigeria. *International Journal of Agricultural and Food Science*, **2**(2): 37-43.

Adeyemi, O. and Afolabi, A. (2022). Assessment of the concentration of heavy metals in two vegetables in Ilorin and Osogbo, Nigeria. *African Journal of Agricultural Research*, **17**(2): 1-13.

Akinola, T. and Ojo, M. (2023). Heavy metal content in dumpsite soils and vegetables: A case study of Ondo Town, Nigeria. *GSC Advanced Research and Reviews*, **14**(3): 141–147.

Akpanyung, E. O. (2019). Heavy Metal Contamination of Vegetables in Enugu. *International Journal of Research in Informative Science Application and Techniques*, 1-13

Angon, P. B., Islam, M. S., Das, A., Anjum, N., Poudel, A. and Suchi, S. A. (2024). Sources, effects and present perspectives of heavy metals contamination: Soil, plants and human food chain. *Heliyon,* **10**(7): 1-12.

Ani, E., Ndubuisi, K. L., Ofodile, L. N. and Otika, O. (2024). Metal Pollution and Antioxidant Composition of Vegetables in Urban Lagos. *AKSU Journal of Agriculture and Food Sciences*, **9**(2): 106–123.

Anthony, P. A. and Umoh, E. O. (2025). Impacts of Heavy Metals Pollution on Waterleaf Grown along Eleme-Port Harcourt Road. *Indian Institute For Advance Research and Development*, 1-15.

Awe, A. E., Adesina, G. O., Adelasoye, K. A., Abiola, S. O. and Adeniji, A. A. (2024). Assessment of the concentration of heavy metals in two vegetables in selected urban metropolises (Ilorin and Osogbo), Nigeria. *African Journal of Agricultural Research*, **20**(3): 272-277

Bienfang, P. K., Trapido-Rosenthal, H. and Laws, E. A. (2024). Bioaccumulation/Biomagnifications in Food Chains. *Encyclopedia of Sustainability Science and Technology*, 1-13.

Carter, K. N. (2018). The Effects Of Bioaccumulation On The Ecosystem. Sciencing. Avalable at: https://www.sciencing.com/effects-bioaccumulation-ecosystem-13721/. Accessed 28th October 2025.

Chen, X., Ren, Y., Li, C., Shang, Y., Ji, R., Yao, D. and He, Y. (2024). Study on Factors Influencing the Migration of Heavy Metals from Soil to Vegetables in a Heavy Industry City. *Sustainability*, **16**(24): 1-14.

Choudhary, S. (2019). Plants as Indicators of Environmental Pollution. International Journal of All Research Education & Scientific Methods, 1-15.

Dada, A. O., Makanjuola, B. C. and Adewumi, M. O. (2024). Heavy Metals in Leafy Vegetables in Ibadan. *Journal of Environment Pollution and Human Health*, **12**(2): 24–30.

Doherty, V. F., Sogbanmu, T. O., Kanife, U. C. and Wright, O. (2012). Heavy metals in vegetables from selected urban farms in Lagos, Nigeria. African Journal of Food Science, 6(6): 155–160.

Egharevba, I., Aluyor, E., Ossai, J. and Oiwoh, O. (2017). Assessment of heavy metals contamination in vegetables and fruits sold in Benin City, Edo State, Nigeria. *The Nigerian Research Journal of Engineering and Environmental Sciences*, **2**(1): 161-168.

Emmanuel, B. (2025). Assessment of Heavy Metal Contamination and Health Risks from Urban-Grown Vegetables in Kano State, Nigeria. *ChemClass Journal*, **9**(2): 1-18.

Engwa, G. A., Ferdinand, P. U., Nwalo, F. N. and Unachukwu, M. N. (2019). Heavy metal toxicity in humans. *Poisoning in the modern world: new tricks for an old dog*,1-7.

Enuneku, A., Osubor, C. and Ikhajiagbe, B. (2017). Assessment of heavy metal contamination in roadside soils and vegetables in Benin City, Nigeria. *Journal of Applied Sciences and Environmental Management*, **21**(2): 345–350.

FAO/WHO. (2021). Joint FAO/WHO food standards programme: Codex Alimentarius Commission. Available at: https://www.fao.org/fao-who-codexalimentarius/en/. Accessed 28th October 2025

Fasuyi, A. O. (2007). Bio-nutritional evaluations of three tropical leaf vegetables (Telfairia occidentalis, Amaranthus cruentus and Talinum triangulare) as sole dietary protein sources in rat assay. *Food chemistry*, **103**(3): 757-765.

FitNigerian. (2022). Scent Leaf: Health Benefits, Uses, Side Effects. Available at: Ahttps://www.fitnigerian.com/scent-leaf/. Accessed 28th October 2025.

Giwa, S. O., Odufuwa, B. O., Adama, K. O. and Sosanya, A. O. (2018). Road traffic induced pollution of roadside soil: A case study of Sango-ota, Ogun State, Nigeria. *Nigerian Journal of Technological Research*, **13**(2): 89-97.

Golia, E., Kallithrakas-Kontos, N. and Tsatsaroni, E. (2024). Potentially toxic elements in urban and peri-urban soils: A comparative study. *Journal of Ecological Engineering*, **25**(2): 1–10.

Gupta, N., Khan, D. K. and Santra, S. C. (2012). Heavy metal accumulation in vegetables grown in a long-term wastewater-irrigated agricultural land of tropical India. *Environmental Monitoring and Assessment*, **184**(11): 6673-6682.

Gupta, N., Yadav, K. K., Kumar, V., Prasad, S., Cabral-Pinto, M. M., Jeon, B. H. and Alsukaibia, A. K. D. (2022). Investigation of heavy metal accumulation in vegetables and health risk to humans from their consumption. *Frontiers in Environmental Science*, 10, 1-12.

Helmenstine, A. M. (2024). Heavy Metal Definition and List. ThoughtCo. Available at: https://www.thoughtco.com/definition-of-heavy-metal-605190. Accessed 28th October 2025.

Hosen, A., Jahan, R. A., Simol, H. A., & Huda, M. N. (2024). Assessing heavy metal contamination in leafy vegetables and associated health risks. *CABI Agriculture and Bioscience*, **5**(116): 1-15.

Hoskins, J. (2024). Heavy Metal Contamination in Leafy Vegetables: Health Risks and Safety Measures. Available at: https://naturalsciencenews.com/article/4765. Accessed on the 24th October 2025.

Ibegbu, D., Anthonius, A. E., Vivian, A., Nonso, C. E. and Ikechukwu, E. E. (2021). Health Risks of Heavy Metals in Vegetables in Enugu. European Journal of Nutrition and Food Safety, **13**(1): 1–14.

Ihedioha, J. N., Ukoha, P. O. and Ekere, N. R. (2020). Health risk assessment of heavy metals in urban-grown vegetables in Enugu, Nigeria. *Environmental Monitoring and Assessment*, **192**(3): 1–12.

Iwuala, I. S. and Oriaku, T. O. (2019). Assessment of vehicular carbon dioxide emission at major road intersections in Benin City, Edo State Nigeria. SPE Nigeria Annual International Conference and Exhibition. *Society of Petroleum Engineers*, 1-16

Jabeen, F., Manzoor, M., Ibrahim, M. (2023). Assessment of health risks associated with the consumption of wastewater-irrigated vegetables in urban areas. *International Journal of Environmental Science and Technology*, 20, 7367–7376.

Jomova, K., Alomar, S. Y., Nepovimova, E., Kuca, K. and Valko, M. (2025). Heavy metals: toxicity and human health effects. *Archives of Toxicology*, 99, 153–209.

Khan, A., Khan, S., Amjad Khan, M., Qamar, Z. and Waqas, M. (2015). The uptake and bioaccumulation of heavy metals by food plants. *Environmental Science and Pollution Research*, 22, 13772–13799.

Kumar, A., Meena, R. and Singh, R. (2024). Heavy metal contamination in vegetables grown near urban roadsides: A case study from India. *Environmental Monitoring and Assessment*, **196**(4): 1–14.

Laoye, B., Olagbemide, P., Ogunnusi, T. and Akpor, O. (2025). Heavy Metal Contamination: Sources, Health Impacts, and Sustainable Mitigation Strategies with Insights from Nigerian Case Studies. *F1000Research*, 14, 1-13.

Manwani, S., Vanisree, C. R. and Jaiman, V. (2022). Heavy metal contamination in vegetables and their toxic effects. Sustainable crop production. *Recent Advances*, 6, 1-18.

Masindi, V. and Muedi, K. L. (2018). Environmental contamination by heavy metals. In M. Larramendy and S. Soloneski (Eds.), *Heavy Metals*, 115–132.

McClements, D. (2024). Heavy Metals: Definition, Properties, Uses, and Types. *Xometry*. 1-9.

Mehmood, K., Batool, Z. and Khan, M. A. (2019). Heavy metals in urban and peri-urban soils: A comparative study of contamination levels and health risks. Human and Ecological Risk Assessment: *An International Journal*, **25**(6): 1600–1615.

Meng, Y., Zhang, L., Li, L. (2025). Accumulation Characteristics of Trace Elements in Leafy Vegetables Under Cd and As Stress. *Agronomy*, 15(8): 1-10.

Narayanti, P. S., Astija and Kundera, I. N. (2024). Plant Bioindicators in Assessing Air Quality: A Short Review. *International Journal of Environment and Pollution Research*, **12**(2): 1–11.

Nnaji, N. D., Onyeaka, H., Miri, T. and Ugwa, C. (2023). Bioaccumulation for Heavy Metal Removal: A Review. *SN Applied Sciences*, **5**(125): 1-11.

Nwankwo, W., Olayinka, A. S. and Ukhurebor, K. E. (2019). The urban traffic congestion problem in Benin City and the search for an ICT-improved solution. *International Journal of Science and Technology*, **8**(12): 65-72.

Odumosu, B. T., Njoku, E. J., Fatunsin, O. T., Adeogun, O. O. and Alabi, O. S. (2021). Microbial and Heavy Metals Contaminations in Vegetables in Lagos. *Nigerian Journal of Microbiology*.1-12.

Ogbo, A. B. and Patrick-Iwuanyanwu, K. C. (2019). Heavy Metals Contamination and Health Risk in Rivers State. *European Journal of Nutrition and Food Safety*, **9**(2): 134–151.

Ogundele, F. O., Iwara, A. I. and Jeremiah, C. J. (2019). Heavy Metal Contents in the Soil and Leaves of Different Vegetables in Lagos State. *Asian Journal of Applied Sciences*, **12**(3): 108–113.

Okorosaye-Orubite, K. and Igwe, F. U. (2017). Heavy Metals in Edible Vegetables at Abandoned Solid Waste Dump Sites in Port Harcourt. IOSR-JAC, **10**(11): 37–46.

Olanipekun, O. O., Akinyemi, O. D. and Ojo, A. O. (2015). Comparative study of microbial activities in hydrocarbon contaminated and uncontaminated soils in the Niger Delta region of Nigeria. *Journal of Environmental Protection*, **6**(3): 273–280.

Oloruntoba, A., Omoniyi, A. O., Shittu, Z. A., Ajala, R. O. and Kolawole, S. A. (2024). Heavy metal contamination in soils, water, and food in nigeria from 2000–2019: A systematic review on methods, pollution level and policy implications. *Water, Air and Soil Pollution*, **235**(9): 1-15.

Olowoyo, J. O., Mugivhisa, L. L and Tshivhase, S. (2012). Uptake and translocation of heavy metals by vegetables grown near a high traffic road in South Africa. *Environmental Science and Pollution Research*, **19**(6): 2295–2303.

Oluyemi, E. A., Feuyit, G., Oyekunle, J. A. O. and Ogunfowokan, A. O. (2008). Seasonal variations in heavy metal concentrations in soil and some selected crops at a landfill in Nigeria. *African Journal of Environmental Science and Technology*, **2**(5): 89–96.

Orimisan, A. E., Olarewaju, A. J., Babaniyi, B. R. and Olumuyiwa, A. O. (2024). Heavy metal content in dumpsite soils and vegetables: a case study of Ondo Town, Nigeria. GSC Advanced Research and Reviews, **19**(01): 097-104.

Osundiya, M. O., Ayejuyo, O. O., Olowu, R. A. (2014). Bioaccumulation of heavy metals in leafy vegetables grown along Nigeria-Benin Seme Border. *Advances in Applied Science Research*, **5**(1): 1–7.

Otse, M. O., Eze, C. N., & Ogbuagu, D. H. (2018). Assessment of level of air pollutants and particulate matter within Abuja Metropolis, Nigeria. University of Nigeria Repository, 1-18.

Pangbenta. (2025). 10 Potential Health Benefits of Scent Leaf and Bitter Leaf. https://pangbenta.com/herbs/health-benefits-scent-leaf-and-bitter-leaf/

Rahim, N., Noor, A., Kanwal, A., Tahir, M. M. and Yaqub, A. (2024). Assessment of heavy metal contamination in leafy vegetables: Implications for public health. *Environmental Monitoring and Assessment*, **196**(684): 1-17

Samanta, S. K. (2024). Heavy Metal Contamination and Speciation in the Environment. *Journal of Emerging Technologies and Innovative Research*, 1-14.

Shetty, B. R., Jagadeesha, P. B. and Salmataj, S. A. (2025). Heavy metal contamination and its impact on the food chain: exposure, bioaccumulation, and risk assessment. *CyTA-Journal of Food*, **23**(1): 1-16.

Smical, I., Muntean, A., Micle, V. (2025). Study on Human Health Risks Associated with Consuming Vegetables Grown in Industrially Polluted Soil in Sasar Area, NW Romania. *Sustainability*, 17(9), 1-12.

Sogbanmu, T. O., Doherty, V. F., Kanife, U. C. and Wright, O. (2012). Heavy Metals in Vegetables from Lagos. *Global Advanced Research Journal of Environmental Science and Toxicology*, **1**(6): 137–142.

Sun, J., Zhang, Y., Liu, H., & Wang, L. (2025). Exploring the spatial distribution characteristics of urban soil heavy metals in Wuhan and Enshi, China. Agronomy, **15**(2):1-18.

Zainith, S. (2024). Sources and Pathways of Heavy Metals and Their Persistence in Ecosystems. *Heavy Metal Contamination in the* Environment, 19-33.

Taiwo, A. M., Akintunde, O. O., Gbadebo, A. M., Akinremi, C. A. and Oyedepo, J. A. (2024). Assessment of Levels and Possible Health Implications of Heavy Metals in Vegetables. *Vegetos*. 1-13.

Uwadiae, S. E., Iriabije, T. O. and Aluyor, E. O. (2018). Analysis of some heavy metal contents in selected vegetables from states in Nigeria. *Ethiopian Journal of Environmental Studies and Management*, *11*(2): 1-12.

Washington State Department of Ecology. (2017). Sources of copper in urban stormwater. Available at: https://apps.ecology.wa.gov/publications/documents/1703005.pdf. Accessed 28th October 2025.

World Health Organization (WHO). (2011). Guidelines for drinking-water quality (4th ed.). Geneva: WHO Press. Available at: https://www.who.int/publications/i/item/9789241549950. Accessed 28th October 2025.

Yadav, M. and Pervez, A. (2024). Impact of Heavy Metals Contamination on Human Health. In *Heavy Metal Toxicity: Human Health Impact and Mitigation Strategies*, 99-128.

Yu, E. (2024). Soil pollution from roads: How traffic contaminates farmland. TheWaterChannel. Available at: https://thewaterchannel.tv/thewaterblog/soil-pollution-from-roads/. Accessed 28th October 2025.

Zheng, S., Wu, Z., Chen, C. (2018). Evaluation of leafy vegetables as bioindicators of gaseous mercury pollution. *Environmental Science and Pollution Research*, 25, 413–421.