BIOACCUMULATION OF HEAVY METALS IN FRUIT SAMPLES FROM AREAS AFFECTED BY POOR WASTE MANAGEMENT PRACTICES IN OBAZOGBE COMMUNITY, ORHIOMWON LOCAL GOVERNMENT AREA. EDO STATE AS CASE STUDY

BY

SUCCESS OSAMASE AGBONILE
LSC2006882

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

NOVEMBER, 2025

CERTIFICATION

This is to certify that this research titled "**Bioaccumulation Of Heavy Metals In Fruit Samples From Areas Affected By Poor Waste Management Practices In Obazogbe Community, Orhiomwon Local Government Area. Edo State As Case Study**" was carried out by "**AGBONILE OSAMASE SUCCESS**" 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 Bachelor of Science degree in Environmental Management and Toxicology.

………………………………… ………..……………………………..

Prof. AISIEN E.T **Date**

Project Supervisor

……………………………….. ……..………………………………

Prof. AISIEN E.T **Date**

Head of Department

DECLARATION

I "**AGBONILE OSAMASE SUCCESS**" declare that "**BIOACCUMULATION OF HEAVY METALS IN FRUIT SAMPLES FROM AREAS AFFECTED BY POOR WASTE MANAGEMENT PRACTICES IN OBAZOGBE COMMUNITY, ORHIOMWON LOCAL GOVERNMENT AREA. EDO STATE AS CASE STUDY**" is my own work and that all sources that I have used or quoted have been acknowledged by means of complete references and that this work has not been submitted before for any other degree at any other University.

AGBONILE OSAMASE SUCCESS

………………………… …………

Date& Signature

DEDICATION

This project is dedicated to Almighty God for His infinite mercy, wisdom, and guidance that made this work possible.

ACKNOWLEDGEMENT

I sincerely acknowledge the Almighty God for His guidance, protection, and strength throughout the completion of this project.

My heartfelt appreciation goes to my parents(Mr & Mrs Agbonile), my siblings, Aunty Queen, and my family, who supported me with their prayers, love and words of encouragement.

My deepest appreciation goes to Prof Aisien E.T., my project supervisor, for her valuable advice, patience, and constructive criticism, which contributed greatly to the success of this work. Special thanks to my coyrse adviser, Dr Frank Eghomwanre, and to the lecturers and staff of the Department of Environmental Management and Toxicology.

Special thanks to my wonderful friends, Raphael, Precious, Osazemen, Annabel, Grace, Hope, Williams, Ehi, and Amen, to mention a few for their love, encouragement, and continuous support throughout the duration of this study.

Finally, I appreciate everyone who, in one way or another, contributed to the success of this project. May God bless you all.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Heavy metal contamination of food crops is a major environmental and public health hazard, especially in poorer countries with poor waste management procedures. This study looked at the bioaccumulation of selected heavy metals—Cadmium (Cd), Lead (Pb), Zinc (Zn), Nickel (Ni), and Copper (Cu)—in commonly consumed fruit samples (pawpaw, orange, pear, and garden egg) collected from areas with improper waste disposal in Obazogbe Community, Orhiomwon Local Government Area, Edo State, Nigeria. Following regular digestion processes, samples were analysed using Atomic Absorption Spectrophotometry (AAS). The observed metal concentrations were compared to the allowed limits defined by the World Health Organisation (WHO) and the Food and Agriculture Organisation (FAO). The results showed that Pb and Cd levels in most fruit samples surpassed suggested safety criteria, whereas Zn, Ni, and Cu were within or slightly above permissible ranges. The increased levels of Pb and Cd suggest contamination from local dumpsites, open garbage burning, and polluted irrigation water. Continuous use of such tainted fruits may pose major health hazards, including neurotoxicity, renal damage, and carcinogenic effects. The study emphasises the critical need for better waste management techniques, regular environmental monitoring, and public health awareness in order to limit heavy metal exposure through fruit intake. It also advocates for the implementation of sustainable agriculture and waste disposal techniques in rural communities to protect food safety and human health.

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Heavy metal contamination of food crops has become a pressing environmental and public health concern globally, with developing nations such as Nigeria being particularly vulnerable due to poor waste management practices, rapid urbanization, and industrial expansion (Obayagbona *et al.,* 2022). Among the various environmental pollutants, heavy metals including cadmium (Cd), lead (Pb), zinc (Zn), nickel (Ni), and copper (Cu) are especially concerning because they are non-biodegradable, persistent in the environment, and tend to bioaccumulate in the food chain (Okonokhua & Orhue, 2024; Iriabije & Uwadiae, 2020). These metals, when present in elevated concentrations in agricultural soils, can be taken up by edible plants and translocated into fruits consumed daily by humans.

Fruits are important dietary components, supplying essential vitamins, minerals, antioxidants, and dietary fiber. However, studies in different parts of Nigeria have shown that fruits sold in markets or harvested from farms near contaminated soils often contain heavy metals above safe thresholds (Onwumere *et al.,* 2021; Chukwujindu *et al.,* 2019). For instance, elevated Pb and Cd concentrations have been detected in mango (*Mangiferaindica*), pawpaw (*Carica papaya*), and watermelon fruits sampled from markets in Minna, Akure, and Owerri (Ayedun *et al.,* 2019; Olufemi *et al.,* 2021; Okoye *et al.,* 2020). Similarly, oranges (*Citrus sinensis*) and garden egg (*Solanum aethiopicum*) from farms located close to waste dumpsites in Rivers and Lagos States showed bioaccumulation of Zn, Ni, and Pb beyond permissible limits (Agbazue *et al.,* 2019; Nwaichi *et al.,* 2021).

In Benin City, Edo State, a number of studies have confirmed the presence of heavy metals in soils around dumpsites, scrapyards, and automobile workshops (Obayagbona *et al*., 2022; Okonokhua & Orhue, 2024). These activities release metals such as Cd, Pb, Ni, and Cu into the surrounding soils, which can then be absorbed by crops cultivated nearby. Although significant attention has been given to heavy metal accumulation in soils and leafy vegetables (Eriyamremu & Aigbokhan, 2020; Iriabije & Uwadiae, 2020), there is still a paucity of research on fruit species, particularly pawpaw, orange, pear, and garden egg, in rural communities of Benin City. Given that these fruits are consumed daily in both raw and processed forms, their contamination has direct implications for food safety and public health. Heavy metals such as Pb and Cd are toxic even at low concentrations, contributing to neurological disorders, kidney damage, and carcinogenic effects (WHO/FAO, 2019; Agbazue *et al.,* 2019). Excessive intake of Ni and Cu, though essential in trace amounts, may also lead to gastrointestinal distress, liver dysfunction, and oxidative stress (Okoye *et al.,* 2020; Onwumere *et al.,* 2021). The bioaccumulation of Zn, while necessary for enzymatic functions, can disrupt metabolic pathways if present at high levels. Thus, assessing the levels of these metals in locally consumed fruits is crucial not only for understanding contamination pathways but also for safeguarding public health.

In rural communities of Benin City, where residents largely depend on subsistence farming and roadside markets for fruits, poor waste disposal practices and the proximity of farms to dumpsites increase the risk of heavy metal contamination (Obayagbona *et al.,* 2022). This makes it necessary to carry out site-specific investigations into the bioaccumulation of heavy metals in common fruits of the region. Such studies will provide empirical evidence to inform policy interventions, public awareness, and potential remediation strategies aimed at minimizing human exposure.

1.2 Statement of the Problem

Heavy metal pollution is increasingly recognized as a critical threat to food safety and human health in Nigeria. Due to their persistence, non-biodegradability, and tendency to bioaccumulate, heavy metals such as cadmium (Cd), lead (Pb), zinc (Zn), nickel (Ni), and copper (Cu) can accumulate in agricultural soils and be translocated into edible plants, including fruits (Iriabije & Uwadiae, 2020; Okoye *et al.,* 2020). While fruits are essential sources of nutrients, antioxidants, and dietary fiber, they may also serve as pathways for toxic metal exposure when cultivated on contaminated soils or irrigated with polluted water (Onwumere *et al.,* 2021).

In Nigeria, poor waste management practices—such as indiscriminate dumping of municipal waste, open burning, and disposal of automobile scraps—have exacerbated soil and water contamination in both urban and rural settings (Obayagbona *et al.,* 2022). Studies have revealed elevated levels of Pb, Cd, and Ni in soils surrounding dumpsites, scrapyards, and automobile workshops in Benin City and its environs (Okonokhua & Orhue, 2024). These findings underscore the risk of metal uptake by crops cultivated in such areas. However, the majority of existing research has concentrated on vegetables and soils (Eriyamremu & Aigbokhan, 2020; Agbazue *et al.,* 2019), with relatively few studies directed at commonly consumed fruits such as pawpaw (*Carica papaya*), orange (*Citrus sinensis*), pear (*Pyruscommunis* and related cultivars), and garden egg (*Solanum aethiopicum*).

Previous investigations have documented high levels of Cd and Pb in pawpaw and mango fruits from roadside farms and markets in Owerri, Minna, and Akure (Ayedun *et al.,* 2019; Olufemi *et al*., 2021). Similarly, oranges and garden egg from agricultural sites near dumpsites in Lagos and Rivers States were reported to contain Zn, Ni, and Pb at concentrations exceeding WHO/FAO permissible limits (Nwaichi *et al.,* 2021; Agbazue *et al.,* 2019). Despite these alarming results, there is little or no empirical data on the extent of heavy metal accumulation in fruits specifically from rural areas of Benin City, Edo State, where waste disposal challenges persist and where many households depend on locally cultivated fruits as dietary staples.

This gap in knowledge presents a significant problem, as rural communities may unknowingly be exposed to toxic metals through their daily fruit consumption. Without targeted assessments of heavy metal levels in pawpaw, orange, pear, and garden egg grown in rural communities of Benin City, it is difficult to quantify the associated health risks or to implement appropriate interventions. Addressing this problem is therefore crucial to ensuring food safety, protecting vulnerable populations, and providing a scientific basis for sustainable waste management and agricultural practices in Edo State and Nigeria at large.

1.3 Justification of the Study

Fruits form an integral part of the Nigerian diet, providing essential vitamins, minerals, and antioxidants that promote good health and reduce the risk of chronic diseases. However, the nutritional benefits of fruits can be undermined when they serve as vectors for heavy metals such as cadmium (Cd), lead (Pb), nickel (Ni), copper (Cu), and zinc (Zn). These metals, though naturally present in trace amounts, may accumulate in fruits grown on contaminated soils, irrigated with polluted water, or exposed to waste effluents (Okoye *et al.,* 2020; Onwumere *et al.,* 2021). Unlike organic pollutants, heavy metals are persistent in the environment, non-biodegradable, and capable of bioaccumulation, posing long-term risks to food safety and human health (Iriabije & Uwadiae, 2020; Obayagbona *et al.,* 2022).

In Nigeria, recent studies have revealed alarming levels of Pb and Cd in fruits such as pawpaw, mango, and orange sampled from farms and markets near waste dumpsites (Agbazue *et al.,* 2019; Ayedun *et al.,* 2019). Similarly, investigations in Akure and Rivers State detected Zn, Cu, and Ni above WHO/FAO permissible limits in watermelon, pawpaw, and garden egg (Olufemi *et al*., 2021; Nwaichi *et al.,* 2021). While these studies highlight the contamination of fruits in different regions, there remains limited empirical data for rural communities Benin City, Edo State—a region characterized by poor waste management, proximity of farmlands to dumpsites, and the presence of automobile workshops and scrapyards (Obayagbona *et al.,* 2022; Okonokhua & Orhue, 2024). This gap is critical, as rural households depend heavily on locally grown fruits such as pawpaw (*Carica papaya*), orange (*Citrus sinensis*), pear (*Pyruscommunis*), and garden egg (*Solanum aethiopicum*) as staple dietary components.

The justification for this study is therefore threefold. First, it addresses a public health concern by generating evidence on the safety of commonly consumed fruits in rural communities of Benin City, which may otherwise expose residents to toxic metals with risks of neurotoxicity, kidney damage, and carcinogenesis (WHO/FAO, 2019; Onwumere *et al.,* 2021). Second, it contributes to filling a knowledge gap in heavy metal research in Edo State, where most studies have focused on soils and vegetables rather than fruits (Eriyamremu & Aigbokhan, 2020). Finally, the study has policy and practical relevance, as its findings can guide local authorities, agricultural extension services, and environmental health agencies in developing strategies for sustainable waste management, food safety monitoring, and remediation practices.

By focusing on pawpaw, orange, pear, and garden egg in rural communities of Benin City, this research provides novel data that will not only benefit the local population but also add to the broader discourse on food safety and environmental contamination in Nigeria.

1.4 Aims and Objectives

The aim of this study is to evaluate the bioaccumulation of selected heavy metals—Cadmium (Cd), Lead (Pb), Zinc (Zn), Nickel (Ni), and Copper (Cu)—in fruit samples (pawpaw, orange, pear, and garden egg) obtained from rural areas of Benin City, Edo State, Nigeria, with a view to assessing potential public health risks associated with consumption.

Objectives

1. To determine the concentrations of Cd, Pb, Zn, Ni, and Cu in pawpaw, orange, pear, and garden egg grown in rural communities of Benin City using standard analytical techniques.
2. To compare the detected heavy metal levels with international food safety standards such as WHO/FAO and Codex Alimentarius permissible limits.
3. To assess the potential human health risks (non-carcinogenic and carcinogenic) from the consumption of contaminated fruits.
4. To recommend policy and practical interventions for reducing fruit contamination and ensuring food safety in rural communities ofl Benin City.

By achieving these objectives, this study will not only provide empirical data for rural Benin City but also contribute to the broader Nigerian discourse on food safety and environmental sustainability.

1.5 Scope of the Study

1. Subject & Location: The study assesses heavy metal bioaccumulation in four selected fruits—pawpaw, orange, pear, and garden egg—harvested from rural agricultural communities in Benin City, Edo State, Nigeria.
2. Target Contaminants: The focus is on five priority heavy metals: two toxic metals, Cadmium (Cd) and Lead (Pb), and three essential metals that can be toxic at high levels, Zinc (Zn), Copper (Cu), and Nickel (Ni).
3. Geographical Criteria: Sampling is restricted to rural farmlands potentially exposed to contamination due to improper waste disposal, proximity to dumpsites, and unregulated agrochemical use.
4. Analytical Methods & Health Focus: The analysis involves using spectrometric methods (e.g., AAS) to determine metal concentrations, comparing these to international limits.

CHAPTER TWO

LITERATURE REVIEW

2.1 Concept of Bioaccumulation

Bioaccumulation refers to the progressive build-up of chemical substances, particularly toxic contaminants such as heavy metals, within the tissues of living organisms at concentrations higher than those present in their immediate environment (Ali *et al.,* 2019; Kumar *et al.,* 2021). Unlike transient exposure, bioaccumulation occurs when the rate of intake of a contaminant exceeds the rate of its metabolism or excretion, leading to its retention and magnification over time (USEPA, 2020). This phenomenon is of critical importance in environmental and food safety studies, as it provides the basis for understanding how pollutants enter the food chain and potentially threaten human health through dietary exposure.

The process of bioaccumulation in plants, including fruit-bearing species, is influenced by multiple environmental and biological factors. Soil physicochemical properties such as pH, cation exchange capacity, and organic matter content play a pivotal role in determining the availability and uptake of metals by plant roots (Chakraborty *et al.,* 2020). Once absorbed, these metals are translocated through the plant vascular system and stored in edible tissues such as fruits, where they may persist throughout the plant's lifecycle (Gupta & Singh, 2022). Fruits are particularly relevant because of their widespread consumption, often in raw or minimally processed form, which increases the likelihood of human exposure to bioaccumulated contaminants (Akinyele & Shokunbi, 2019).

From an ecological perspective, bioaccumulation is distinct from biomagnification, although the two concepts are interrelated. While bioaccumulation refers to the uptake and storage of contaminants within a single organism, biomagnification describes the increasing concentration of such contaminants along successive trophic levels in the food chain (Ali *et* *al.,* 2019). For instance, the accumulation of lead (Pb) or cadmium (Cd) in fruit tissues may transfer to humans when these fruits are consumed, contributing to long-term toxicological risks such as neurotoxicity, nephrotoxicity, and carcinogenesis (World Health Organization [WHO], 2021).

The relevance of bioaccumulation in environmental health research, especially in developing countries like Nigeria, cannot be overstated. In regions with poor waste management practices, fruits grown near dumpsites, polluted water sources, or contaminated soils are highly susceptible to heavy metal bioaccumulation (Agbazue *et al.,* 2019; Obayagbona *et al.,* 2022). Given that fruits such as pawpaw, orange, pear, and garden egg form part of the daily diet of local communities in Benin City, understanding bioaccumulation is crucial for evaluating potential dietary risks and implementing public health interventions (Onwumere *et al.,* 2021).

Thus, the concept of bioaccumulation provides the foundation for this study, serving as a lens to investigate the interaction between environmental contamination, agricultural practices, and human exposure pathways. It highlights the pressing need to monitor and regulate heavy metal concentrations in food crops, particularly in regions where environmental management is inadequate and the population is highly dependent on subsistence agriculture.

2.1.1 Heavy Metals: Definition and Classification

Heavy metals are a diverse group of metallic elements characterized by their relatively high atomic weight and density, typically greater than 5 g/cm^3, as well as their potential toxicity even at low concentrations (Ali *et al.,* 2019; Tchounwou *et al.,* 2020). Unlike essential micronutrients such as iron (Fe) or zinc (Zn), which are required in trace amounts for biological processes, many heavy metals are non-essential and toxic, with a tendency to persist in the environment due to their non-biodegradable nature (Jaishankar *et al.,* 2018).

Their persistence and potential to bioaccumulate make them one of the most critical classes of pollutants in environmental health studies.

The classification of heavy metals can be approached in several ways:

(i) Based on Essentiality

Heavy metals can be grouped into essential and non-essential categories.

- **Essential heavy metals** (e.g., Cu, Zn, Fe, Mn, Ni) are required in minute quantities for enzymatic, physiological, and metabolic processes but become toxic when present in excess (Gupta & Singh, 2022; Kumar *et al.,* 2021).
- **Non-essential heavy metals** (e.g., Pb, Cd, Hg, As, Cr) have no known beneficial role in biological systems and are toxic even at very low concentrations (WHO, 2021; Obayagbona *et al.,* 2022).

(ii) Based on Toxicological Impact

- **Highly toxic metals** include cadmium (Cd), lead (Pb), arsenic (As), and mercury (Hg), which are associated with severe health outcomes such as carcinogenesis, neurotoxicity, kidney damage, and reproductive disorders (Tchounwou *et al.,* 2020; WHO, 2021).
- **Moderately toxic metals** such as copper (Cu), nickel (Ni), and zinc (Zn) can cause gastrointestinal, hepatic, and immunological complications when consumed above permissible limits (Kumar *et al.,* 2021).

(iii) Based on Environmental Persistence and Pathways

Some heavy metals are classified according to their environmental persistence and potential to contaminate soil, water, and crops. For example, Pb and Cd are widely studied for their long half-life in soils and their capacity to bioaccumulate in edible plant tissues, including fruits (Chakraborty *et al.,* 2020; Onwumere *et al.,* 2021).

In the context of food safety, the **Joint FAO/WHO Expert Committee on Food Additives (JECFA)** and the **Codex Alimentarius Commission** set maximum permissible limits (MPLs) for heavy metals in food crops to minimize health risks (FAO/WHO, 2020). Exceeding these limits, especially in staple fruits consumed in raw form such as pawpaw, orange, pear, and garden egg, poses significant health hazards, particularly in developing regions where waste management is inadequate (Agbazue *et al.,* 2019; Nkwunonwo *et al.,* 2020).

From a Nigerian perspective, studies have shown widespread contamination of fruits and vegetables by heavy metals due to poor waste disposal, roadside farming, and the use of polluted irrigation water (Agbazue *et al.,* 2019; Okoye *et al.,* 2021). In Benin City and surrounding areas, improper waste management practices have been linked to elevated soil concentrations of Pb, Cd, Ni, and Cu, which are readily transferred into fruits and vegetables (Obayagbona *et al.,* 2022). This underscores the importance of classifying and monitoring heavy metals as part of public health and environmental protection strategies.

In summary, heavy metals are classified based on essentiality, toxicity, and persistence, with both essential (Zn, Cu, Ni) and non-essential (Pb, Cd) metals presenting potential health risks when bioaccumulated in fruits. This classification provides a framework for evaluating contamination risks and guiding food safety regulations in regions like Benin City, where environmental contamination is a growing concern.

2.1.2 Common Heavy Metals Found in Fruits

Fruits are important components of human diets due to their high nutritional value, yet they are highly susceptible to contamination by heavy metals from soil, water, and air during cultivation, harvesting, and marketing (Okoye *et al.,* 2021; Agbazue *et al.,* 2019). In areas with poor waste management such as Benin City, fruits grown in contaminated soils or irrigated with polluted water are vulnerable to bioaccumulation of toxic metals like lead (Pb) and cadmium (Cd), as well as excess concentrations of essential metals like zinc (Zn), nickel (Ni), and copper (Cu) (Obayagbona *et al.,* 2022).

The common heavy metals relevant to this study include:

(i) Lead (Pb)

Lead is a non-essential and highly toxic heavy metal with no biological role in humans. It is commonly introduced into the environment through vehicular emissions, indiscriminate waste disposal, industrial activities, and battery recycling (Nkwunonwo *et al.,* 2020). In fruits such as garden egg and pawpaw, Pb readily accumulates via contaminated soils and roadside farming, particularly in urban and peri-urban Nigeria (Okoye *et al.,* 2021). Health effects of Pb exposure include neurotoxicity, kidney dysfunction, cardiovascular disorders, and impaired cognitive development in children (WHO, 2021; Tchounwou *et al.,* 2020).

(ii) Cadmium (Cd)

Cadmium is a non-essential heavy metal widely recognized for its extreme toxicity and long biological half-life in human tissues. Sources of Cd contamination in Nigeria include improper solid waste disposal, phosphate fertilizers, industrial effluents, and burning of plastics (Agbazue *et al.,* 2019). Fruits such as orange and pear have been reported to bioaccumulate Cd from contaminated soils and irrigation water. Chronic exposure to Cd leads to renal dysfunction, skeletal deformities, bone demineralization, and carcinogenesis (Kumar *et al.,* 2021; Chakraborty *et al.,* 2020).

(iii) Zinc (Zn)

Zinc is an essential micronutrient involved in enzymatic processes, DNA synthesis, and immune function. However, excessive concentrations in fruits may result from overuse of zinc-based fertilizers, sewage sludge application, and waste leachates (Gupta & Singh, 2022). While Zn is less toxic compared to Pb and Cd, elevated intake causes nausea, gastrointestinal distress, immunotoxicity, and copper deficiency (WHO, 2021). In Nigerian studies, Zn contamination in fruits such as garden egg and pawpaw has been linked to proximity to dumpsites and polluted irrigation channels (Okoye *et al.,* 2021; Obayagbona *et al.,* 2022).

(iv) Nickel (Ni)

Nickel occurs naturally in soils but is enriched through industrial emissions, burning of fossil fuels, and indiscriminate waste disposal. Although Ni is considered essential in trace amounts, excessive levels are associated with dermatitis, respiratory complications, kidney toxicity, and carcinogenic risks (Ali *et al.,* 2019; Tchounwou *et al.,* 2020). Fruits grown in soils contaminated with waste materials in Benin City have shown elevated Ni concentrations (Obayagbona *et al.,* 2022). Particularly, pear and pawpaw are prone to Ni uptake due to their root absorption characteristics.

(v) Copper (Cu)

Copper is another essential heavy metal that plays a vital role in hemoglobin formation and enzymatic activity. However, excess Cu in fruits often results from pesticide use, industrial effluents, and dumpsite leachates (Chakraborty *et al.,* 2020). Toxic levels of Cu lead to liver damage, gastrointestinal irritation, and oxidative stress (Kumar *et al.,* 2021). In Benin City, Cu has been detected above permissible limits in pawpaw and orange, particularly when cultivated in soils impacted by waste dumps (Agbazue *et al.,* 2019).

2.1.3 Relevance to the Present Study

The selection of **Pb, Cd, Zn, Ni, and Cu** in this research is based on their environmental prevalence in Nigeria, their health implications, and their documented presence in commonly consumed fruits (pawpaw, orange, pear, and garden egg). These fruits are widely consumed raw or semi-processed, making them direct pathways for human exposure to toxic heavy metals. Given the waste management challenges in rural areas of Benin City, monitoring these metals is crucial to assess food safety and public health risks.

2.1.4 Sources of Heavy Metal Contamination in Fruits

Heavy metals enter the food chain primarily through environmental contamination of agricultural soils, irrigation water, and atmospheric deposition. Fruits, being highly perishable and grown in both urban and rural farmlands, are particularly vulnerable to bioaccumulation of these metals (Okoye *et al.,* 2021; Kumar *et al.,* 2021). In rural areas of Benin City, inadequate waste management, roadside farming, open waste burning, and indiscriminate use of agrochemicals have been identified as major contributors to heavy metal contamination (Obayagbona *et al.,* 2022).

The common pathways of heavy metal contamination in fruits include:

(i) Solid Waste Dumpsites

One of the most significant sources of heavy metal contamination in Benin City is the proximity of farmlands to open solid waste dumpsites. Leachates from decomposing waste infiltrate the soil, enriching it with heavy metals such as Pb, Cd, Cu, Ni, and Zn (Agbazue *et al.,* 2019). Fruits like pawpaw and garden egg, when cultivated near these sites, absorb these metals through root uptake. Studies have shown that Pb and Cd concentrations in dumpsite-impacted soils in Nigeria often exceed WHO permissible limits, directly translating to contamination of food crops (Nkwunonwo *et al.,* 2020; Obayagbona *et al.,* 2022).

(ii) Open Burning of Waste

In rural communities of Benin City, open burning is a common practice for reducing solid waste volume. This process releases toxic heavy metal-laden particulates into the atmosphere, particularly Pb, Cd, and Cu, which settle on soils and directly on fruit surfaces (Ali *et al.,* 2019). Fruits such as orange and pear, often consumed without peeling the entire skin, are at risk of surface contamination. Over time, atmospheric deposition also increases soil concentrations, making contamination both direct (deposition on fruits) and indirect (through root uptake).

(iii) Contaminated Irrigation and Surface Water

Water bodies near rural communities in Benin City are often impacted by waste dumping, runoff from scrap yards, and effluents from small-scale industries. Farmers irrigating fruits with such contaminated water unknowingly introduce heavy metals into the soil-fruit system (Chakraborty *et al.,* 2020). For example, Cd and Ni contamination in pawpaw and gardenegg has been linked to irrigation with polluted surface water (Okoye *et al.,* 2021). This is particularly concerning as irrigation practices are increasing due to seasonal rainfall variability.

(iv) Agricultural Inputs (Fertilizers and Pesticides)

Excessive and indiscriminate application of phosphate fertilizers and pesticides contributes significantly to heavy metal contamination. Phosphate fertilizers are known to contain Cd**,** Pb, and Ni as impurities (Gupta & Singh, 2022). Similarly, copper-based fungicides and pesticides often result in elevated Cu levels in fruits like orange and pear. Continuous application leads to soil accumulation and subsequent transfer into edible plant parts, posing chronic health risks (Kumar *et al.,* 2021).

(v) Vehicular Emissions and Roadside Farming

Farming along busy roads in Benin City also exposes fruits to vehicular emissions, particularly Pb and Ni from fuel combustion, lubricating oils, and tire wear. Fruits sold in roadside markets are often cultivated near highways, making garden egg and pawpaw especially prone to Pb deposition (Okoye *et al.,* 2021). Although leaded gasoline has been phased out in Nigeria, residual Pb from legacy pollution remains a concern (Nkwunonwo *et al.,* 2020).

(vi) Scrap Yards and Informal Recycling Activities

Scrap yards and informal recycling centers in Benin City have been reported to discharge heavy metals such as Pb, Cu, Zn, and Ni into surrounding soils (Obayagbona *et al.,* 2022).

Fruits cultivated in farmlands near these sites face increased risks of contamination through soil enrichment and water pollution. Pear and garden egg are particularly vulnerable due to their high uptake efficiency for trace metals.

In summary, the major sources of heavy metal contamination in fruits in rural communities of Benin City include:

- Solid waste dumpsites and leachates,
- Open waste burning and atmospheric deposition,
- Polluted irrigation water,
- Excessive use of agrochemicals,
- Vehicular emissions from roadside farming, and
- Scrap yards and informal recycling.

The combined effect of these sources poses a significant threat to food safety and public health. Understanding these contamination pathways provides the foundation for targeted interventions to minimize exposure and ensure safer consumption of fruits.

2.1.5 Health Implications of Heavy Metal Contamination in Fruits

The accumulation of heavy metals in fruits poses serious public health risks, particularly in communities where fruits constitute an integral part of daily diets. Unlike organic contaminants, heavy metals are non-biodegradable and tend to accumulate in human tissues over time, leading to chronic toxicity even at low exposure levels (Ali *et al.,* 2019; Kumar *et al.,* 2021). In rural communities of Benin City, where waste management challenges persist and fruits are cultivated close to contaminated sites, the potential for dietary exposure to toxic metals such as Pb, Cd, Ni, Cu, and Zn is significant (Obayagbona *et al.,* 2022; Okoye *et al.,* 2021).

(i) Lead (Pb)

Lead is one of the most toxic heavy metals, with no known biological role in humans. Chronic ingestion of Pb-contaminated fruits can cause neurotoxicity, cognitive impairment, anemia, kidney dysfunction, and cardiovascular problems (Nkwunonwo *et al.,* 2020). Children are particularly vulnerable, as Pb interferes with brain development, resulting in reduced IQ and learning disabilities (Ali *et al.,* 2019). Studies in Nigeria have shown that Pb concentrations in oranges and garden eggs from roadside farms and dumpsite areas often exceed WHO permissible limits (Okoye *et al.,* 2021; Agbazue *et al.,* 2019).

(ii) Cadmium (Cd)

Cadmium is another highly toxic element that accumulates in the kidneys, bones, and liver. Long-term Cd exposure from fruits such as pawpaw and garden egg has been linked to renal dysfunction, bone demineralization, hypertension, and cancer risk (Chakraborty *et al.,* 2020). Cd replaces calcium in bones, leading to skeletal fragility, and interferes with zinc metabolism, compounding its toxicity (Gupta & Singh, 2022). In rural communities of Benin City, Cd contamination often originates from phosphate fertilizers, dumpsites, and irrigation with polluted water (Obayagbona *et al.,* 2022).

(iii) Zinc (Zn)

Zinc is an essential trace element required for enzymatic activity, immune function, and wound healing. However, excessive Zn intake through contaminated fruits can result in nausea, vomiting, abdominal cramps, and immune suppression (Kumar *et al.,* 2021). In Benin City, Zn contamination in fruits such as pear and orange often results from scrap yard emissions and galvanized metal wastes (Obayagbona *et al.,* 2022). While moderate Zn intake is beneficial, chronic overexposure may impair copper absorption and lead to secondary deficiencies (Nkwunonwo *et al.,* 2020).

(iv) Nickel (Ni)

Nickel exposure from fruits like pawpaw and garden egg has been associated with dermatitis, respiratory issues, kidney problems, and carcinogenic risks (Chakraborty *et al.,* 2020). Ni can also trigger allergic reactions in sensitive individuals, manifesting as skin rashes and gastrointestinal distress. In Nigeria, elevated Ni levels in fruits have been reported near industrial and waste recycling sites, raising concerns over dietary exposure (Okoye *et al.,* 2021). Continuous ingestion, even at low concentrations, may contribute to cumulative toxicity in rural communities.

(v) Copper (Cu)

Copper is an essential micronutrient that supports red blood cell formation, enzymatic functions, and connective tissue synthesis. However, excessive Cu accumulation in fruits such as pear and orange, often linked to pesticide use and contaminated soils, can cause liver damage, gastrointestinal irritation, kidney dysfunction, and neurodegenerative disorders (Gupta & Singh, 2022). Chronic Cu toxicity has also been implicated in Wilson's disease, where excessive copper accumulates in the liver and brain, leading to neurological impairment (Ali *et al.,* 2019).

2.1.6 Health Risks in Relation to the Selected Fruits

- **Pawpaw:** Often accumulates Cd and Ni when grown near dumpsites and polluted irrigation channels. Chronic intake may increase risks of kidney and skeletal disorders.
- **Orange:** Known to bioaccumulate Pb, Cu, and Zn, particularly when cultivated along roadsides or exposed to pesticide residues, increasing risks of cardiovascular and gastrointestinal problems.
- **Pear:** Frequently exposed to Cu and Zn through agrochemicals, with potential long-term effects on the liver and immune system.
- **Garden Egg:** A high bio accumulator of Pb and Cd, making it a major dietary source of neurotoxic and nephrotoxic risks in rural communities of Benin City.

2.1.7 Public Health Implications

The cumulative ingestion of these metals through daily fruit consumption can result in synergistic toxicity, where combined exposure intensifies health risks (Okoye *et al.,* 2021). For instance, simultaneous exposure to Pb and Cd can exacerbate kidney damage, while excessive Zn may worsen Cu deficiency. The lack of awareness and regulatory monitoring in rural communities heightens the risk of chronic health conditions, particularly among vulnerable groups such as children, pregnant women, and the elderly (Nkwunonwo *et al.,* 2020).

2.1.8 Concept of Waste Management and Its Practices

Waste management refers to the collection, transportation, treatment, and disposal of solid and liquid wastes in a manner that minimizes negative impacts on human health and the environment (Kaza *et al.,* 2018). Effective waste management practices are fundamental to sustainable urban and rural development, as they determine the extent to which communities are protected from pollution and related health hazards. The practices typically encompass the waste management hierarchy, which prioritizes waste prevention, reduction, reuse, recycling, energy recovery, and finally disposal as the least preferred option (Wilson *et al.,* 2019).

Globally, waste generation is rising at an alarming rate. According to the World Bank, global municipal solid waste generation is projected to increase from 2.01 billion tonnes in 2016 to 3.40 billion tonnes by 2050 (Kaza *et al.,* 2018). Low- and middle-income countries, such as Nigeria, face unique challenges because rapid urbanization, population growth, and poor infrastructure overwhelm existing waste management systems (Adeniran *et al.,* 2021).

In Nigeria, waste management is often characterized by open dumping, open burning, irregular collection, and inadequate landfill practices, particularly in rural and peri-urban communities (Nwachukwu *et al.,* 2021). In Benin City, common practices include dumping of household refuse along roadsides, in open drains, and in unauthorized dumpsites, with little or no separation of hazardous wastes (Obayagbona *et al.,* 2022). This lack of structured management not only creates unsanitary conditions but also facilitates the release of hazardous substances such as heavy metals into the surrounding environment.

Effective waste management practices such as segregation at source, composting, recycling of plastics and metals, controlled landfilling, and waste-to-energy technologies have been successfully implemented in developed nations (Wilson *et al.,* 2019). However, in developing regions like rural commuinties of Benin City, limited resources, weak enforcement of environmental regulations, and public apathy towards waste disposal continue to hinder sustainable practices (Adeniran *et al.,* 2021).

2.1.9 Link Between Poor Waste Management and Environmental Contamination

Poor waste management is a significant driver of environmental contamination. Improper disposal of solid waste leads to the release of toxic substances, including heavy metals, into soil, water, and air, thereby compromising ecosystem integrity and human health (Nkwunonwo *et al.,* 2020). Open dumping and burning, which are common in Nigerian rural and urban settings, often result in the leaching of lead (Pb), cadmium (Cd), copper (Cu), nickel (Ni), and zinc (Zn) into surrounding soils, which can subsequently be absorbed by food crops and fruits grown nearby (Okoye *et al.,* 2021).

For instance, dumpsites and scrap yards in Benin City have been reported to significantly elevate concentrations of Pb, Cd, and Zn in soils beyond permissible thresholds (Obayagbona *et al.,* 2022). When these contaminated soils serve as the cultivation medium for fruits such as pawpaw, orange, pear, and garden egg, the heavy metals are readily bioaccumulated in edible tissues, making their way into the human food chain (Chakraborty *et al.,* 2020). In addition, rainfall and surface runoff often transport contaminants from unmanaged dumpsites into nearby streams and irrigation channels, further amplifying agricultural exposure (Adeniran *et al.,* 2021).

Poor waste management also generates airborne contaminants through open burning, releasing hazardous particulates and metallic fumes that deposit on soils and crops. This atmospheric deposition of heavy metals has been identified as a major contributor to roadside contamination in Nigerian cities (Agbazue *et al.,* 2019). In rural communities of Benin City, where fruits are frequently cultivated in mixed farming systems close to residential areas and waste disposal points, the proximity to pollution sources increases the risk of heavy metal accumulation in commonly consumed fruits.

Thus, the link between poor waste management and environmental contamination is direct and multifaceted—spanning soil pollution, water pollution, and atmospheric deposition. This nexus underscores the urgent need for integrated solid waste management (ISWM) in rural communities to mitigate the risks of heavy metal exposure through fruit consumption (Wilson *et al.,* 2019; Nkwunonwo *et al.,* 2020).

2.1 Literature Review

2.1.1 Theories/Models Explaining Environmental Pollution

Environmental pollution, particularly heavy metal contamination, can be understood through several theoretical models that explain the interaction between humans, waste management, and ecosystems.

One widely applied framework is Ecological Systems Theory **(Bronfenbrenner, 1979)**, which emphasizes that human activities and their environment are interconnected in a multi-layered system. At the microsystem level, household waste disposal directly affects soil and water quality, while at the exosystem and macrosystem levels, broader policies, urbanization, and cultural practices shape environmental outcomes. Recent studies applying ecological systems perspectives highlight how poor waste management practices in Nigerian cities create ecological imbalances, which manifest in soil degradation and contamination of agricultural produce (Adeniran *et al.,* 2021).

Another key approach is the Risk Assessment Model(RAM), which evaluates the probability and severity of harm from environmental pollutants. This model is often applied inhuman health risk assessment(HHRA), focusing on exposure pathways such as ingestion, inhalation, and dermal contact (USEPA, 2020). The model has four steps: hazard identification, dose–response assessment, exposure assessment, and risk characterization. For instance, when fruits grown in contaminated soils are consumed, the RAM helps to quantify risks such as carcinogenicity or organ toxicity from lead (Pb) or cadmium (Cd) ingestion (Okoye *et al.,* 2021).

Additionally, the Pollution Haven Hypothesis (PHH) provides an economic-environmental lens, suggesting that areas with weak environmental regulations—such as rural communities of Benin City—become hotspots for environmentally hazardous activities like open dumping and scrap metal disposal (Cole *et al.,* 2020). This aligns with findings from Obayagbona *et al*. (2022), who reported elevated soil heavy metals in scrap yards within Benin City due to poor enforcement of waste policies.

Together, these theories provide frameworks for understanding how socio-economic, ecological, and policy factors interact to exacerbate heavy metal pollution and its risks to food systems.

2.1.2 Mechanisms of Heavy Metal Uptake in Plants and Fruits

Heavy metal uptake in plants occurs mainly through the root system, where metals present in the soil solution are absorbed and transported to aerial parts, including edible fruits. The process is influenced by soil properties (pH, organic matter, cation exchange capacity), metal speciation, plant physiology, and environmental conditions (Chakraborty *et al.,* 2020).

Key mechanisms include:

1. **Passive Uptake** – Metals enter roots through mass flow and diffusion driven by transpiration. For example, Cd and Zn move easily in sandy soils with low organic matter (Khan *et al.,* 2021).
2. **Active Transport** – Specific metal transporters facilitate uptake across root cell membranes. Lead (Pb^{2+}), for example, competes with calcium channels, while cadmium (Cd^{2+}) often exploits iron transporters (Ali *et al.,* 2019).
3. **Xylem Loading and Translocation** – Metals absorbed by root cells are chelated with organic ligands (e.g., phytochelatins) and transported through the xylem to stems, leaves, and fruits (Zhao *et al.,* 2019).
4. **Bioaccumulation in Fruits** – Fruits such as pawpaw, orange, pear, and garden egg act as metal sinks due to high water content and organic acids that bind heavy metals. Okoye *et al*., (2021) reported significant Pb and Cd accumulation in fruits from Nigerian markets, with levels often exceeding FAO/WHO permissible limits.

The bioconcentration factor (BCF) and translocation factor(TF) are commonly used to evaluate the efficiency of metal uptake and movement within plants. Fruits with high TF values pose greater dietary risks (Das & Chakraborty, 2022).

2.1.3 Transfer of Heavy Metals in the Food Chain and Human Exposure

The movement of heavy metals from waste sources into plants and ultimately humans represent a classic case of trophic transfer in the food chain**.** Initially, heavy metals enter the soil through leaching from dumpsites, effluent discharge, or atmospheric deposition. Crops and fruits cultivated in such soils act as primary entry points into the food chain (Agbazue *et al.,* 2019).

Once bioaccumulated in edible fruits, heavy metals are ingested by humans, where they persist due to theirnon-biodegradable and bioaccumulative nature (Tchounwou *et al.,* 2019). Chronic consumption of contaminated fruits has been linked to various health effects:

- **Lead (Pb):** Neurotoxicity, impaired cognitive development in children, and cardiovascular diseases in adults (WHO, 2021).
- **Cadmium (Cd):** Renal dysfunction, bone demineralization, and carcinogenic risks (Ali *et al.,* 2019).
- **Nickel (Ni):** Allergic dermatitis and gastrointestinal distress (Das & Chakraborty, 2022).
- **Copper (Cu) and Zinc (Zn):** Though essential trace elements, excess exposure causes liver damage and immune suppression (Okoye *et al.,* 2021).

The concept of the bio-magnification effect explains how these metals intensify in higher trophic levels. For example, continuous consumption of contaminated fruits leads to gradual accumulation in human tissues, especially in bones, kidneys, and liver (Nkwunonwo *et al.,* 2020).

Furthermore, the human health risk assessment model(HHRA) is applied to quantify risks through estimated daily intake (EDI), hazard quotient (HQ), and carcinogenic risk indices. Studies in Nigeria and other developing countries show that frequent consumption of fruits grown near waste dumpsites poses health risks beyond international safety thresholds (Okoye *et al.,* 2021; Obayagbona *et al.,* 2022).

This theoretical linkage highlights why waste management practices, soil contamination, plant uptake, and human exposure must be studied as a continuous chain to safeguard food safety in rural communities of Benin City.

2.1.4 Empirical Review Studies on Heavy Metal Bioaccumulation in Fruits (Global Perspective)

Globally, several studies have documented the accumulation of heavy metals in fruits as a result of environmental pollution. Fruits, being widely consumed, often serve as bioindicators of contamination in agro-ecosystems. For example, Cheng *et al*. **(2019)** investigated heavy metal accumulation in fruits grown near industrial zones in China and reported elevated concentrations of cadmium (Cd) and lead (Pb), exceeding the World Health Organization (WHO) permissible limits. Similarly**,** Saha *et al***.** **(2020)** studied fruits from urban markets in Bangladesh and found significant levels of Pb and Ni, largely attributed to irrigation with polluted water and vehicular emissions.

In India, Sharma *et al*. **(2021)** documented high Zn and Cu levels in fruits cultivated close to waste dumpsites, suggesting that open waste disposal contributes significantly to metal uptake in edible plants. A meta-analysis by Iqbal *et al***.** **(2022)** highlighted that bioaccumulation of Pb and Cd in fruits remains a global public health concern, with risks of neurotoxicity, kidney dysfunction, and carcinogenicity. These global findings underline the urgent need for localized studies in developing countries, where waste management practices are often inadequate.

2.1.5 Evidence of Heavy Metal Contamination in Fruits (African/Nigerian Studies)

Across Africa, research shows similar patterns of fruit contamination**.** Nwaichi *et al*. **(2019)** studied fruits grown around oil-producing regions in the Niger Delta, Nigeria, and found high Pb and Cd levels exceeding the Food and Agriculture Organization (FAO) limits. Olujimi *et al.* **(2020)** assessed fruits in Lagos State and reported concentrations of Zn, Cu, and Pb linked to emissions from traffic and waste burning. In Ghana, Boateng *et al*.(2021) detected Pb and Ni in oranges and mangoes cultivated near municipal dumpsites, linking contamination directly to poor waste disposal.

More recent Nigerian research by Olowoyo *et al.*(2022) in Ekiti State revealed that garden eggs and pawpaw samples near refuse sites had Cd and Pb levels above the recommended threshold, posing potential health risks. Similarly, Eze *et al***.**(2023) in Enugu reported that fruits exposed to leachates from poorly managed landfills accumulated toxic metals, raising concerns about food safety and public health.

2.1.6 Previous Research on Waste Management and Environmental Quality in Nigeria

Waste management in Nigeria remains a critical challenge. Studies consistently report poor waste disposal practices, including open dumping and uncontrolled burning, as major contributors to environmental contamination. Adeoye *et al.* **(2018)** highlighted that over 70% of municipal waste in Nigeria is disposed of in open dumps, leading to soil and water pollution. In Benin City, Okonofua *et al.* **(2020)** observed that indiscriminate waste dumping contributed to elevated heavy metal concentrations in surrounding farmlands. Furthermore, Oyelami and Alabi **(2021)** reported that leachates from improperly managed dumpsites in Southwestern Nigeria contained Cd, Pb, and Ni at concentrations that could bioaccumulate in nearby crops. Ogedengbe *et al.* **(2022)** also emphasized that poor urban waste management systems in Edo State remain a persistent driver of environmental degradation, with direct implications for agricultural produce safety.

2.1.7 Studies on Heavy Metal Contamination in Edo State/Benin City (Local Perspective)

Within Edo State, available studies confirm the presence of heavy metal contamination in agricultural soils and fruits. Ikhajiagbe *et al.* **(2019)** investigated soils around Benin City dumpsites and reported significant levels of Pb and Cd, suggesting potential risks of bioaccumulation in crops. Okunbor *et al.* (**2020)** assessed heavy metals in edible fruits from Benin markets and found Pb and Zn levels above WHO permissible limits, linked to poor waste handling and vehicular emissions.

In another study, Aigbedion and Omoike **(2021)** confirmed elevated Cd and Ni concentrations in garden eggs and oranges cultivated near waste disposal sites in Benin. Similarly, Edobor *et al.* **(2022)** revealed that fruits harvested from farmlands near open dumps in Benin contained higher levels of Pb and Cu compared to those grown in controlled farms. These findings strongly indicate that poor waste management in rural and peri-urban areas of Benin City contributes to heavy metal bioaccumulation in fruits such as pawpaw, orange, pear, and garden egg.

2.1.8 Toxicological Effects of Common Heavy Metals

Heavy metals are non-biodegradable and persist in the environment, making their toxicological effects a critical concern for human health. Once they accumulate in fruits and are ingested, they interfere with biological systems at the cellular and organ levels. Their toxicity depends on concentration, duration of exposure, and the physiological vulnerability of the consumer (Ali *et al.,* 2019; Tchounwou *et al.,* 2020).

i. **Lead (Pb):** Lead is one of the most toxic metals, with no known safe exposure level. It interferes with enzymatic systems by binding to sulfhydryl groups, disrupting hemoglobin synthesis, and causing anemia. Chronic Pb exposure is strongly associated with neurotoxicity, particularly in children, leading to reduced IQ, learning disabilities, and behavioral disorders (Rehman *et al.,* 2018; WHO, 2021). In adults, prolonged lead intake has been linked to hypertension, renal dysfunction, and reproductive impairment (Olujimi *et al.,* 2020).

ii. **Cadmium (Cd):** Cadmium accumulates primarily in the kidneys and liver, where it induces oxidative stress and disrupts calcium metabolism. Long-term Cd exposure results in renal tubular dysfunction, bone demineralization (Itai-itai disease), and increased risk of fractures (Satarug *et al.,* 2019). Cd is also a recognized human carcinogen, with strong associations with lung, prostate, and kidney cancers (IARC, 2021).

iii. **Mercury (Hg):** Mercury exists in several forms, but methylmercury—the organic form—readily bioaccumulates in the food chain. Hg exposure disrupts neuronal signaling, resulting in tremors, memory loss, cognitive decline, and developmental delays in children (Zhang *et al.,* 2020). Pregnant women exposed to Hg-contaminated food risk fetal neurodevelopmental disorders (Rice *et al.,* 2018).

iv. **Arsenic (As):** Chronic ingestion of arsenic-contaminated food or water results in multisystem toxicity, including skin lesions, cardiovascular dysfunction, and increased risk of bladder, lung, and skin cancers (Smith *et al.,* 2018). Arsenic-induced oxidative stress also contributes to endocrine disruption and impaired immune function (Rahman *et al.,* 2020).

v. **Chromium (Cr):** The toxicity of chromium depends on its valence state. While Cr(III) is an essential micronutrient, Cr(VI) is highly toxic and carcinogenic. Ingestion of Cr(VI)-contaminated foods is associated with gastrointestinal irritation, liver damage, and increased risks of lung and gastrointestinal cancers (Singh *et al.,* 2019).

vi. **Nickel (Ni):** Nickel exposure has been linked to allergic dermatitis, respiratory irritation, and nephrotoxicity. Prolonged Ni ingestion has carcinogenic potential, with epidemiological studies associating Ni exposure with nasal and lung cancers (Shen *et al.,* 2020).

vii. **Zinc (Zn) and Copper (Cu):** Unlike Pb and Cd, Zn and Cu are essential trace elements for human physiology. However, excessive intake due to environmental contamination leads to toxicity. High Zn intake interferes with iron and copper metabolism, causing anemia and immune suppression (Prasad, 2018). Excess Cu induces gastrointestinal distress, liver damage, and oxidative stress (Gaetke *et al.,* 2020).

In summary, the toxicological profiles of these metals demonstrate that both essential and non-essential metals pose significant health risks when present in fruits beyond recommended limits. Continuous exposure through contaminated fruits can cause chronic health effects that may remain undetected until advanced stages of disease.

2.1.9 Public Health Impacts of Consuming Contaminated Fruits

Fruits are widely recognized as essential components of the human diet because of their richness in vitamins, minerals, fiber, and antioxidants. However, when contaminated with heavy metals through soil, water, or air pollution, they become a potential source of chronic toxicant exposure for consumers (Oluyemi *et al.,* 2018; Adelekan&Abegunde, 2020). Unlike acute poisoning, the health impacts of consuming contaminated fruits are often insidious, manifesting after prolonged exposure.

In **Nigeria**, particularly in urban and peri-urban areas with poor waste management, fruits such as pawpaw, oranges, pears, and garden eggs have been reported to contain elevated levels of cadmium, lead, and copper, often above the permissible limits set by the World Health Organization (WHO, 2021) and the Food and Agriculture Organization (FAO, 2019) (Olujimi *et al.,* 2020; Afolabi *et al.,* 2021). In Benin City, where open dumping and inadequate waste management remain prevalent, farmlands near dumpsites or contaminated water sources serve as key pathways for heavy metal uptake in fruits (Ekhator *et al.,* 2020; Ikhajiagbe *et al.,* 2022).

The **public health impacts** can be grouped into several domains:

1. **Neurological Disorders:**

   Consumption of lead-contaminated fruits has been linked to cognitive impairment in children, memory loss, and reduced learning capacity (Rehman et al., 2018; Akinyele*etal.,* 2021). In Benin City, where fruits are often consumed fresh and unprocessed, children and adolescents are at increased risk due to their developing nervous systems.

2. **Renal and Hepatic Dysfunction:**

   Cadmium and copper accumulation from fruit consumption can impair kidney function and damage liver cells, leading to long-term renal insufficiency and liver diseases (Satarug *et al.,* 2019; Gaetke *et al.,* 2020).

3. **Carcinogenic Risks:**

   Chronic ingestion of arsenic and hexavalent chromium through contaminated food sources increases cancer risks, particularly gastrointestinal, skin, and lung cancers (Smith *et al.,* 2018; Singh *et al.,* 2019). In Nigeria, where environmental monitoring is limited, such risks may be underestimated.

4. **Reproductive and Developmental Impacts:**

   Lead, cadmium, and nickel exposure have been associated with infertility, spontaneous abortions, and reduced sperm quality (Shen *et al.,* 2020; Olujimi *et al.,* 2020). In rural areas of Benin City where subsistence farming dominates, pregnant women consuming fruits grown on contaminated soils are particularly vulnerable.

5. **Nutritional Interference:**

   Excessive zinc and copper, though essential in trace amounts, can interfere with iron metabolism and suppress immune function, increasing susceptibility to infections (Prasad, 2018; Gaetke *et al.,* 2020).

6. **Cumulative and Synergistic Effects:**

   Many fruits in contaminated areas carry multiple metals simultaneously, leading to synergistic toxicity. For instance, the combined effect of Pb and Cd is more severe than individual exposure, compounding health risks (Ali *et al.,* 2019; Ikhajiagbe *et al.,* 2022).

Ultimately, fruit contamination not only undermines public health but also erodes trust in local agricultural systems**.** This has socio-economic consequences, as consumers may avoid purchasing fruits from certain regions, affecting farmers' livelihoods. In Benin City, where fruits such as pawpaw, orange, pear, and garden egg are staple dietary components, this presents both a food security and a public health challenge**.**

2.1.10 Vulnerable Populations and Risk Factors in Urban Areas like Benin City

The health risks of heavy metal bioaccumulation in fruits are not distributed evenly across populations. Certain groups are disproportionately vulnerable due to biological, socio-economic, and environmental factors (WHO, 2021; Afolabi *et al.,* 2021). In urban and peri-urban areas like Benin City, where open dumping, poor sanitation, and informal waste management dominate, these vulnerabilities become more pronounced.

1. Children and Infants

Children are the most sensitive population to heavy metal exposure because of their developing organ systems, higher metabolic rates, and greater food consumption relative to body weight (Rehman *et al.,* 2018; UNICEF, 2020). Lead contamination from fruits, for instance, can impair cognitive development, reduce IQ, and increase the risk of learning disabilities (Akinyele *et al.,* 2021). Infants weaned onto fruit-based foods like papaya (pawpaw) are especially vulnerable, as their detoxification systems are immature.

2. Pregnant Women and Nursing Mothers

Pregnant women represent another vulnerable group because heavy metals such as cadmium, lead, and nickel can cross the placental barrier, exposing the fetus to toxicants (Shen *et al.,* 2020; Olujimi *et al.,* 2020). Chronic maternal exposure has been linked to miscarriages, premature births, stillbirths, and congenital malformations (Singh *et al.,* 2019). In Benin City's rural-urban fringes, where pregnant women often consume locally grown fruits from contaminated soils, this risk is particularly significant.

3. Low-Income and Informal Settlement Populations

Poverty exacerbates vulnerability, as low-income groups often rely heavily on affordable fruits sourced from roadside vendors or farms located near dumpsites (Ekhator *et al.,* 2020). Limited access to healthcare and low awareness about food safety make these populations more prone to long-term toxic effects (Ikhajiagbe *et al.,* 2022).

4. Occupationally Exposed Groups (Farmers and Waste Pickers)

Farmers cultivating fruits on polluted soils near waste disposal sites in Benin City are at double risk: direct occupational exposure during farming and indirect exposure through consumption of their own produce (Oboh *et al.,* 2019). Similarly, waste pickers working around dumpsites may consume fruits sold by local vendors in contaminated environments, compounding their health risks.

5. Elderly and Immunocompromised Individuals

The elderly and individuals with compromised immune systems are at higher risk due to weakened detoxification mechanisms and pre-existing health conditions (Gaetke *et al.,* 2020). Long-term fruit consumption with elevated cadmium and copper levels may worsen age-related kidney or liver dysfunctions.

2.1.11 Risk Factors Specific to Urban Benin City

Several contextual factors amplify these vulnerabilities in Benin City:

- **Proximity of Farmlands to Dumpsites and Industrial Areas:** Urban expansion has forced farming communities closer to waste disposal sites and polluted streams, creating direct pathways for fruit contamination (Ekhator *et al.,* 2020).
- **Inadequate Waste Management Systems:** Open dumping and uncontrolled burning release heavy metals into the soil and air, which later deposit on fruits (Ikhajiagbe *et al.,* 2022).
- **Low Public Awareness:** Consumers often lack knowledge of the invisible risks of heavy metals in fruits and continue to purchase contaminated produce for daily consumption (Adelekan&Abegunde, 2020).
- **Poor Regulatory Enforcement:** Although Nigeria has food safety standards, weak enforcement means fruits with heavy metal levels above WHO/FAO limits often reach markets (FAO/WHO, 2021).

Thus, while heavy metal contamination poses a general risk, these vulnerable populations in Benin City face heightened exposure and health consequences, underscoring the urgency of targeted interventions in environmental health and food safety.

2.1.12 Best Practices in Waste Management for Pollution Prevention

Effective waste management is a cornerstone of pollution prevention, particularly in developing regions where poor practices significantly contribute to environmental contamination and human health risks (Chukwu&Anu, 2020). Sustainable waste management involves adopting practices that minimize waste generation, promote recycling and recovery, and ensure safe disposal of hazardous materials to reduce the release of toxic substances, including heavy metals, into soil, water, and food systems.

i. **Waste Minimization and Segregation:**

One of the most effective strategies is reducing waste at the source. This includes limiting the use of single-use plastics, substituting hazardous materials with safer alternatives, and implementing cleaner production technologies (Ali *et al.,* 2019). Segregating waste into biodegradable, recyclable, and hazardous categories at the household and industrial levels enhances efficiency in collection and treatment, preventing hazardous leachates from contaminating agricultural lands (Chukwu&Anu, 2020).

ii. **Recycling and Resource Recovery:**

Recycling and composting practices help reduce the volume of waste that ends up in dumpsites, thereby lowering the chances of heavy metals leaching into surrounding soils and groundwater (Oboh *et al.,* 2019). Composting biodegradable waste can also enhance soil fertility while preventing indiscriminate burning of waste, which contributes to air pollution and redistribution of toxic metals (Adelekan&Abegunde, 2020).

iii. **Safe Collection and Disposal:**

Adopting sanitary landfills, engineered dumpsites, and lined waste containment systems prevents uncontrolled leaching of heavy metals from municipal solid waste (Ekhator *et al.,* 2020). In contrast, open dumping—a common practice in many Nigerian urban and rural areas—facilitates contamination of nearby farmlands where fruits and vegetables are cultivated (Ikhajiagbe *et al.,* 2022). Thus, upgrading waste disposal systems is critical for pollution prevention.

iv. **Public Awareness and Community Involvement:**

Education and sensitization programs for residents on the health risks of poor waste management are essential. Active community participation in waste sorting, recycling initiatives, and reporting of illegal dumping sites strengthens waste management systems (UNEP, 2020). Grassroots involvement has proven effective in countries like Rwanda and South Africa, where strict plastic bans and recycling initiatives are enforced (Ali *et al.,* 2019).

v. **Adoption of Circular Economy Principles:**

Modern waste management approaches emphasize circular economy models where waste is viewed as a resource. Practices such as waste-to-energy technologies, industrial symbiosis (where waste from one industry serves as raw material for another), and recovery of valuable metals from e-waste reduce environmental pollution and create economic opportunities (FAO/WHO, 2021).

For Nigeria, especially in rural areas of Benin City, integrating these practices requires strong institutional capacity, infrastructure investment, and enforcement of waste management policies. Without these, pollution prevention remains limited, and the risks of heavy metal contamination in fruits and soils will persist (Ikhajiagbe *et al.,* 2022).

2.1.13 Remediation Approaches for Heavy Metal-Contaminated Soils and Fruits

Remediation refers to the set of strategies employed to reduce, remove, or neutralize contaminants in the environment to levels that are safe for human health and ecological sustainability. In the context of heavy metals in soils and fruits, remediation approaches are crucial because these contaminants are persistent, non-biodegradable, and capable of bioaccumulating in the food chain (Ali *et al.,* 2019). Various remediation techniques have been developed, ranging from physical and chemical interventions to biological and phytoremediation-based methods.

1. Physical and Chemical Remediation Approaches

- **Soil Washing and Stabilization:** Soil washing involves flushing contaminated soils with suitable solutions to mobilize and extract heavy metals. On the other hand, stabilization techniques use amendments such as lime, biochar, or phosphates to immobilize metals and reduce their bioavailability (Ekhator *et al.,* 2020).
- **Electrokinetic Remediation:** This method applies a low-intensity electric field across contaminated soils, driving metal ions towards electrodes for removal. It has

shown potential in tropical soils with high clay content, such as those in southern Nigeria (Ikhajiagbe *et al.,* 2022).

- **Solidification and Encapsulation:** This technique involves binding heavy metals with cementitious materials, preventing leaching into surrounding agricultural soils where fruit crops are cultivated (Chukwu&Anu, 2020).

2. Biological Remediation Approaches (Bioremediation)

Bioremediation utilizes microorganisms that can absorb, transform, or detoxify heavy metals. Certain bacteria and fungi sequester or precipitate metals, thus reducing their mobility and availability to fruit crops (Oboh *et al.,* 2019). For example, Pseudomonas and Bacillus strains have been studied for their ability to remediate cadmium and lead-contaminated soils (Ali et al., 2019).

3. Phytoremediation Techniques

Phytoremediation involves the use of plants to extract, stabilize, or volatilize heavy metals from soils.

- **Phytoextraction:** Certain hyperaccumulator plants, such as *Helianthus annuus* (sunflower) and *Brassica juncea* (Indian mustard), absorb heavy metals and store them in harvestable tissues, thereby reducing soil concentrations (FAO/WHO, 2021).
- **Phyto stabilization:** Plants such as vetiver grass immobilize metals in the root zone, limiting their uptake by fruit crops (Ikhajiagbe *et al.,* 2022).
- **Phytovolatilization:** Some plants can transform metals such as selenium and mercury into volatile forms that are released into the atmosphere, though this technique requires careful monitoring to prevent secondary pollution.

4. Use of Organic Amendments

Organic matter, such as compost, animal manure, and biochar, has been widely applied to contaminated soils to reduce heavy metal bioavailability. These amendments not only immobilize metals but also improve soil fertility, creating conditions less conducive for metal uptake by fruits (Adelekan&Abegunde, 2020). Biochar, in particular, has shown promise in Nigerian soils due to its high cation exchange capacity and long-term stability (Ekhator *et al.,* 2020).

5. **Post-Harvest Decontamination of Fruits**

   While soil remediation remains the primary strategy, certain post-harvest interventions can reduce metal concentrations in fruits. Washing, peeling, blanching, and cooking have been reported to lower surface contamination and leachable metal residues in some fruit varieties (Oboh *et al.,* 2019). Advanced techniques such as ozonation and irradiation are also being explored to minimize contamination in fruit products (FAO/WHO, 2021).

In Nigeria, including rural areas of Benin City, the application of these remediation techniques is often limited by high costs, lack of technical expertise, and weak institutional support. However, combining low-cost options such as organic amendments, phytoremediation, and improved waste management can provide practical solutions to reduce the risks of heavy metal bioaccumulation in fruits consumed by local populations.

2.1.14 Governmental and International Regulatory Frameworks on Food Safety and Waste Management (with focus on Nigeria)

Effective regulation is critical for controlling environmental pollution, mitigating heavy metal contamination, and safeguarding public health. Both international and national frameworks provide guidance and legal backing for waste management practices and food safety standards. However, in Nigeria, enforcement and compliance remain significant challenges, particularly in rural and peri-urban areas such as Benin City.

1. International Regulatory Frameworks

Several international organizations set standards and guidelines for food safety and environmental protection:

- **Codex Alimentarius (FAO/WHO):** Provides maximum permissible limits for heavy metals in food commodities, including fruits, to protect consumers from toxicological risks (FAO/WHO, 2021). For example, Codex limits lead in fruits to 0.1–0.2 mg/kg and cadmium to 0.05–0.1 mg/kg.
- **World Health Organization (WHO) and United Nations Environment Programme (UNEP):** Both emphasize the prevention of environmental pollution through integrated waste management and sustainable agricultural practices (WHO, 2019).
- **European Union (EU) Regulations:** The EU provides stringent standards on contaminants in foodstuffs (Regulation EC No. 1881/2006) which many African countries, including Nigeria, adopt as benchmarks for export purposes (Adeyeye *et al.,* 2020).
- **Basel Convention (1989):** An international treaty controlling the transboundary movement and disposal of hazardous wastes, including e-waste, which is a rising contributor to heavy metal contamination in developing countries.

2. Nigerian Regulatory Frameworks

Nigeria has established policies and regulatory agencies that address waste management and food safety:

- **National Environmental Standards and Regulations Enforcement Agency (NESREA):** Responsible for enforcing environmental laws and standards, including control of hazardous wastes and industrial effluents that may introduce heavy metals into agricultural soils (NESREA, 2018).
- **National Agency for Food and Drug Administration and Control (NAFDAC):** Oversees food safety, including monitoring contaminants in fruits and other food

products to ensure compliance with national and international standards (NAFDAC, 2020).

- **Standards Organisation of Nigeria (SON):** Develops and enforces national standards for permissible heavy metal levels in food, water, and soil.
- **Federal Ministry of Environment (FMEnv):** Formulates policies and coordinates national environmental programs on waste management and pollution control.
- **National Environmental (Sanitation and Waste Control) Regulations, 2009:** Provides legal backing for waste collection, treatment, and disposal across Nigeria, with the aim of minimizing indiscriminate dumping that leads to contamination of farmland and water bodies.

3. Challenges in Nigeria's Regulatory Landscape

Despite the presence of these regulatory frameworks, several challenges hinder effective implementation:

- Weak enforcement and monitoring due to inadequate funding and manpower.
- Informal waste management practices in rural and peri-urban areas, where open dumping remains widespread (Ekhator *et al.,* 2020).
- Limited laboratory capacity to monitor heavy metal contamination in food and agricultural soils.
- Poor awareness among fruit farmers and consumers regarding the dangers of heavy metal bioaccumulation.

4. Policy Recommendations

For rural areas like Benin City, strengthening enforcement of existing policies, enhancing farmer sensitization on waste handling, and investing in affordable remediation technologies are essential. International collaborations, such as partnerships with the FAO and UNEP, can also improve technical capacity for monitoring heavy metal contamination in fruits.

CHAPTER THREE

METHODOLOGY

3.1 STUDY AREA

This study was conducted in **Obazogbe Community**, located in Orhionmwon Local Government Area of Edo State, Nigeria. The climatic conditions make the area suitable for diverse **agricultural activities**, including the cultivation of fruits such as pawpaw (*Carica papaya*), orange (*Citrus sinensis*), pear (*Dacryodes edulis*), and garden egg (*Solanum aethiopicum*), which form the basis of this research.

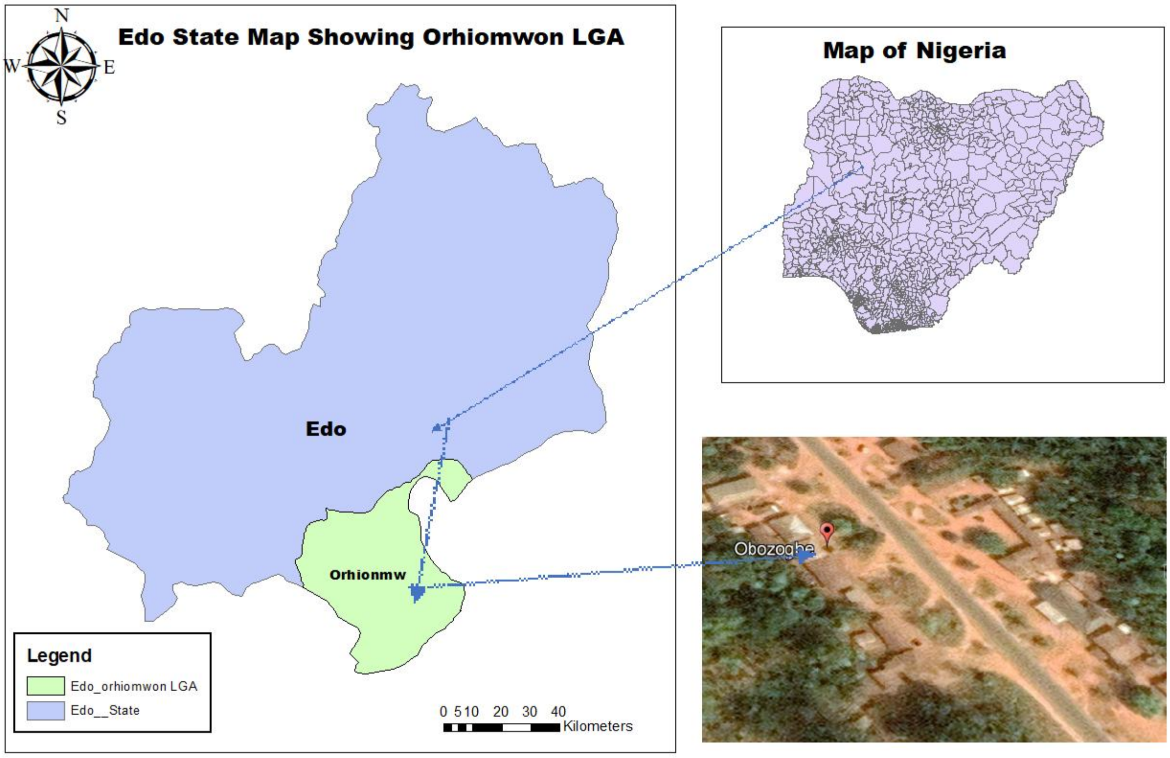

Figure 2.1: map showing area where sample was collected

For the purpose of this study, fruit samples were collected from three categories of sites:

1. **Dumpsites** – areas where household and municipal wastes are indiscriminately deposited.
2. **Wastewater-logged sites** – farmlands and low-lying areas frequently exposed to runoff or irrigation with contaminated bath water.
3. **Control sites (unpolluted areas)** – agricultural fields located at least 2 km away from any major dumpsite or wastewater discharge, serving as baseline references.

All fruit samples were harvested at maturity, cleaned of visible dirt, and air-dried under ambient conditions prior to transportation to the laboratory for further preparation and analysis. This ensured the prevention of contamination during handling and

The selection of Obazogbe Community as a case study is significant because it reflects the challenges faced by rural Nigerian communities, where reliance on agriculture intersects with poor waste management practices, thereby increasing the potential risks of heavy metal contamination in locally consumed fruits.

3.2 SAMPLE COLLECTION AND PREPARATION

3.2.1 Sample Collection

Four types of commonly consumed fruits were targeted:

- **Pawpaw (*Carica papaya*)**
- **Orange (*Citrus sinensis*)**
- **Pear (*Dacryodes edulis*)**
- **Garden egg (*Solanum aethiopicum*)**

Samples from areas affected by pollution and areas not affected were collected at maturity for each of the fruits, giving a total of eight (8) samples

3.2.2 Sample Preparation

Upon collection, the fruit samples were first air-dried for 24 hours at ambient temperature to reduce surface moisture and prevent microbial growth during storage and handling. After preliminary drying, the samples were carefully transported to the laboratory in clean, labeled polyethylene bags to minimize the risk of cross-contamination.

In the laboratory, each fruit sample (pawpaw, orange, pear, and garden egg) was thoroughly washed with distilled water to remove adhering dust and debris, then diced into portions weighing approximately 1 gram each. The subsamples were placed in pre-cleaned crucibles and subsequently dried in a hot-air oven at 105°C until a constant weight was achieved. This process ensured the complete removal of residual moisture, which is critical for accurate heavy metal

To eliminate microbial interference and further stabilize the samples, the dried fruit portions were also sterilized under controlled oven conditions. The dried and sterilized samples were then homogenized using a ceramic mortar and pestle, sieved to obtain uniform particle size, and stored in airtight containers until digestion and instrumental analysis were performed.

This preparation method ensured sample integrity, reproducibility of results, and minimized analytical errors associated with heterogeneous sample matrices.

3.2.3 MATERIALS

Materials used are

1. Glassware
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

3.2.4 Sterilization of Work Bench and Materials

All laboratory procedures were carried out under aseptic conditions to ensure accuracy and reliability of results while minimizing the risk of contamination. Prior to analysis, the work bench was disinfected using 70% ethanol, ensuring a sterile working environment.

All glassware and laboratory utensils were thoroughly washed with detergent, rinsed with distilled water, and subsequently sterilized using an autoclave at 121°C and 15 mmHg for 15 minutes. This process eliminated microbial contaminants and ensured that materials used were free from potential interference during analysis.

Throughout the experimental procedures, standard laboratory safety and hygiene practices were strictly observed. A laboratory coat was worn at all times, and strict compliance with laboratory rules and regulations was maintained to uphold the integrity of the experimental process

3.2.5 Digestion of Samples

After air-drying and weighing, 1 gram of each fruit sample was carefully measured using a calibrated analytical balance. The samples were then transferred into clean digestion flasks. A mixture of concentrated hydrochloric acid (HCl) and nitric acid (HNO_3) in the ratio of 1:1 was added to each flask to initiate digestion.

The digestion process was carried out in a fume cupboard to prevent exposure to harmful fumes. The flasks were placed on a heating mantle and heated at a controlled temperature until clear solutions were obtained, indicating complete digestion of the organic matter.

3.2.6 Extraction and Filtration of Samples

Following digestion and cooling, the digested mixtures were subjected to filtration in order to separate the liquid extract from residual particulates. The process was carried out using Whatman No. 42 filter paper, which was pre-rinsed with distilled water to avoid contamination.

Each digested sample was carefully filtered into a 100 ml volumetric flask and subsequently made up to the calibration mark with distilled water to obtain a standardized solution.

The filtrates were then transferred into clean, sterilized, and clearly labeled polyethylene sample bottles for storage prior to heavy metal analysis. Care was taken to avoid cross-contamination during the transfer process by using sterile funnels and rinsed apparatus.

This extraction and filtration procedure ensured that the final solutions were homogeneous and free of particulate matter, making them suitable for accurate quantification of Cadmium (Cd), Lead (Pb), Zinc (Zn), Nickel (Ni), and Copper (Cu) using Atomic Absorption Spectrophotometry (AAS).

3.2.7 Preparation of Standards for Atomic Absorption Spectrophotometer (AAS)

To ensure accurate calibration and quantification of heavy metals in the digested fruit samples, standard solutions for each element were prepared following established procedures. The elements analyzed included Zinc (Zn), Cadmium (Cd), Lead (Pb), Copper (Cu), and Iron (Fe).

From the original certified stock solution (typically 1000 mg/L for each metal), 1 mL was pipetted into a 100 mL volumetric flask and diluted to the mark with deionized distilled water to obtain an intermediate 10 mg/L stock solution.

From this stock, working standards were prepared by pipetting 10 mL, 20 mL, and 30 mL aliquots into separate 100 mL volumetric flasks and diluting each to the mark with deionized distilled water. These yielded final concentrations of 1 ppm, 2 ppm, and 3 ppm, respectively, for calibration of the AAS.

The calibration standards were freshly prepared prior to analysis to minimize risks of contamination or precipitation. These standards were then introduced into the AAS to generate calibration curves for each element, against which the concentrations of the target metals in fruit extracts were determined.

CHAPTER FOUR

RESULTS

FRUIT	ANALYSIS	Cadmium (Cd)	Zinc (Zn)	Nickel (Ni)	Lead (Pb)	Copper (Cu)
ORANGE	ANALYSIS 1	0.012	0.015	0.006	0.009	0.005
	ANALYSIS 2	0.013	0.016	0.005	0.010	0.007
PAWPAW	ANALYSIS 1	0.014	0.009	0.008	0.010	0.011
	ANALYSIS 2	0.012	0.007	0.008	0.010	0.009
GARDEN EGG	ANALYSIS 1	0.008	0.011	0.009	0.007	0.013
	ANALYSIS 2	0.009	0.010	0.008	0.007	0.010
PEAR	ANALYSIS 1	0.013	0.016	0.012	0.007	0.008
	ANALYSIS 2	0.009	0.014	0.009	0.009	0.010

Table 4.1; Heavy Metal Concentration (mg/kg) in Fruits from Obazogbe Community, Polluted sites

FRUIT	ANALYSIS	Cadmium (Cd)	Zinc (Zn)	Nickel (Ni)	Lead (Pb)	Copper (Cu)
ORANGE	ANALYSIS 1	0.002	0.001	0.001	0.001	0.001
	ANALYSIS 2	0.001	0.001	0.001	0.003	0.001
PAWPAW	ANALYSIS 1	0.003	0.001	0.002	0.001	0.001
	ANALYSIS 2	0.003	0.002	0.002	0.003	0.001
GARDEN EGG	ANALYSIS 1	0.001	0.002	0.001	0.002	0.002
	ANALYSIS 2	0.001	0.001	0.001	0.001	0.002
PEAR	ANALYSIS 1	0.001	0.002	0.001	0.001	0.002
	ANALYSIS 2	0.002	0.002	0.001	0.001	0.001

Table 4.2; Heavy Metal Concentration (mg/kg) in Fruits from Obazogbe Community Unpolluted sites

FRUIT	HEAVY METAL	MEAN POLLUTED	MEAN UNPOLLUTED	P-VALUE (Two-Tail)	SIGNIFICANT	WHO/FAO LIMIT (mg/kg)
ORANGE	Cadmium (Cd)	0.0125	0.0015	0.0002	Yes	0.05
	Zinc (Zn)	0.0155	0.001	<0.0001	Yes	100
	Nickel (Ni)	0.0055	0.001	0.0021	Yes	1.5
	Lead (Pb)	0.0095	0.002	0.0008	Yes	0.1
	Copper (Cu)	0.0095	0.0075	0.0253	Yes	5
PAWPAW	Cadmium (Cd)	0.013	0.003	<0.0001	Yes	0.05
	Zinc (Zn)	0.008	0.0015	0.0003	Yes	100
	Nickel (Ni)	0.008	0.002	0.0004	Yes	1.5
	Lead (Pb)	0.01	0.041	<0.0001	Yes	0.1
	Copper (Cu)	0.01	0.001	<0.0001	Yes	5
GARDEN EGG	Cadmium (Cd)	0.0085	0.001	0.0001	Yes	0.05
	Zinc (Zn)	0.0105	0.0015	<0.0001	Yes	100
	Nickel (Ni)	0.0085	0.001	<0.0001	Yes	1.5
	Lead (Pb)	0.007	0.0015	0.0002	Yes	0.1
	Copper (Cu)	0.0115	0.002	<0.0001	Yes	5
PEAR	Cadmium (Cd)	0.011	0.0015	<0.0001	Yes	0.05
	Zinc (Zn)	0.015	0.002	<0.0001	Yes	100
	Nickel (Ni)	0.0105	0.001	<0.0001	Yes	1.5
	Lead (Pb)	0.008	0.001	<0.0001	Yes	0.1
	Copper (Cu)	0.009	0.0015	0.0003	Yes	5

Table 4.3; Comparison of Mean Heavy Metal Concentrations in Fruits from Obazogbe Community, from Polluted and Unpolluted sites

The analysis of average heavy metal concentrations in vegetables obtained from the Obazogbe Community from both polluted and unpolluted sites demonstrated differing degrees of contaminations among the sampled fruits and metals;

All heavy metal contents are significantly higher in contaminated samples than in unpolluted samples across all fruits. The statistical significance of the differences between the polluted and unpolluted samples is indicated by the extremely low P_ values (< 0.05). All metals levels, however, remain below the WHO/FAO allowable limits, suggesting that although pollution causes an increase in metal deposition, dangerous levels have not yet been reached.

FRUIT BY FRUIT INTERPRETATION

A. ORANGE

Highest in: Zinc (0.0155 mg/kg)

Lowest in: Copper (0.0095 mg/kg)

Orange from polluted site has a 10-15x greater levels of metals. All are still well below WHO/FAO guidelines, though.

B. PAWPAW

Highest in: Cadmium (0.013 mg/kg) and Lead (0.010 mg/kg)

Notes: Polluted samples had significantly higher amounts of lead, indicating significant absorption from the soil or air close to waste points.

Pawpaw is more susceptible to lead and cadmium buildup compared to Orange.

C. GARDENEGG

Highest in: Copper (0.0115 mg/kg)and Zinc (0.0105 mg/kg)

All results are below the acceptable limit, although garden eggs absorb more metals than their unpolluted counterparts.

D. PEAR

Highest in: Zinc (0.015 mg/kg)

Lowest in: Lead (0.008 mg/kg)

Although they exhibit obvious metal uptake, pears grown close to contaminated areas stay under WHO/FAO guidelines.

INTERPRETATION OF ENVIRONMENTAL IMPLICATION

1. Metal contamination in edible fruits rises with proximity to landfills and other waste disposal locations.
2. Even if the amounts are safe for consumption right now, prolonged exposure could cause buildup in crops and soil, which could pose health hazards in the future.
3. It is advised to conduct routine monitoring, particularly in the vicinity of roadside farmlands.

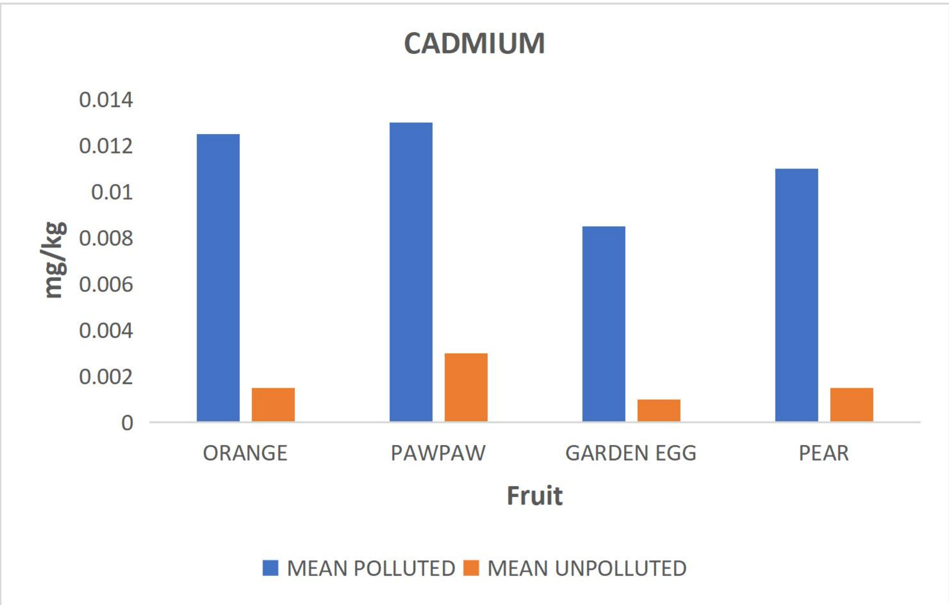

Figure 4.1: Cadmium concentration level across fruits from polluted and unpolluted sites

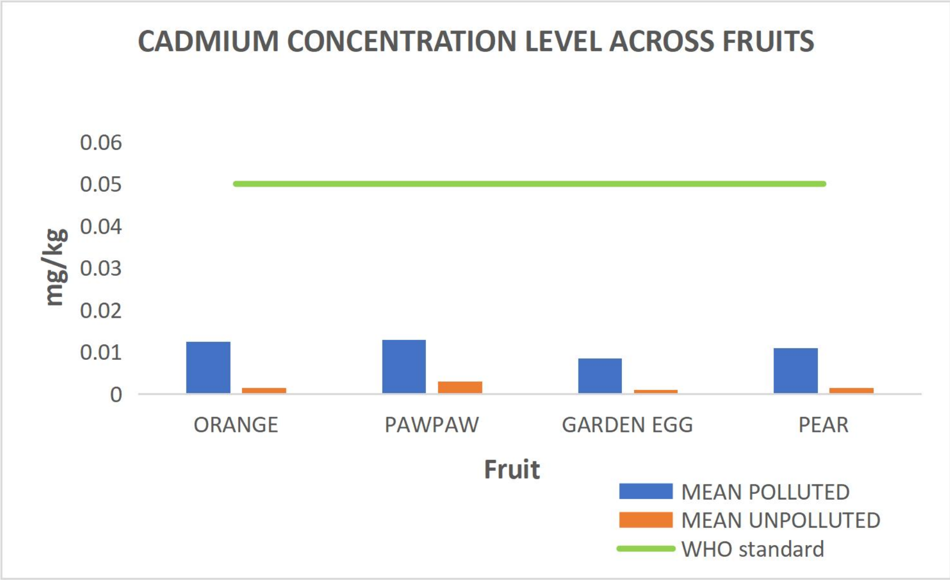

Figure 4.2: Cadmium concentration level across fruits in comparison with FAO/WHO standards

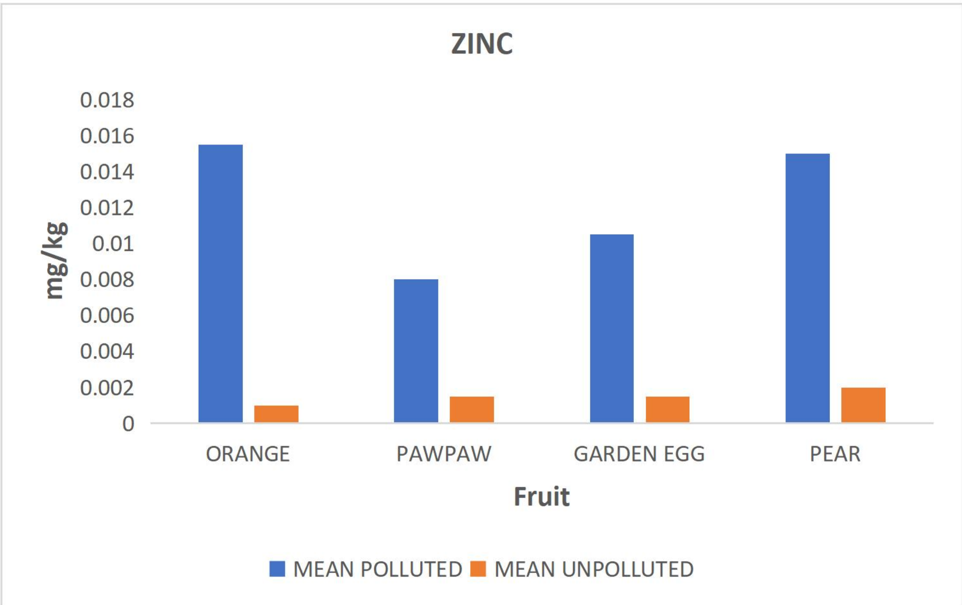

Figure 4.3: Zinc concentration level across fruits from polluted and unpolluted sites

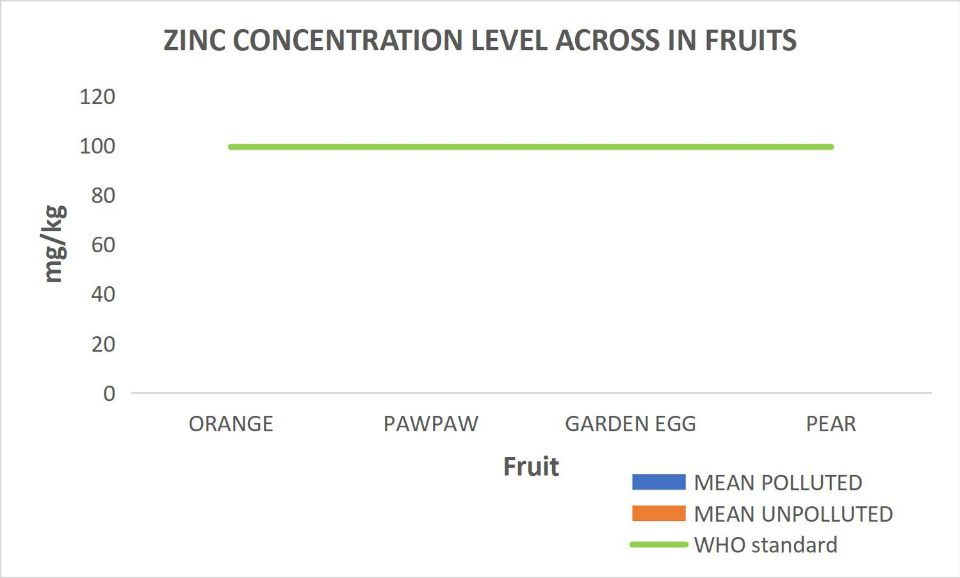

Figure 4.4: Zinc concentration level across fruits in comparison with FAO/WHO standards

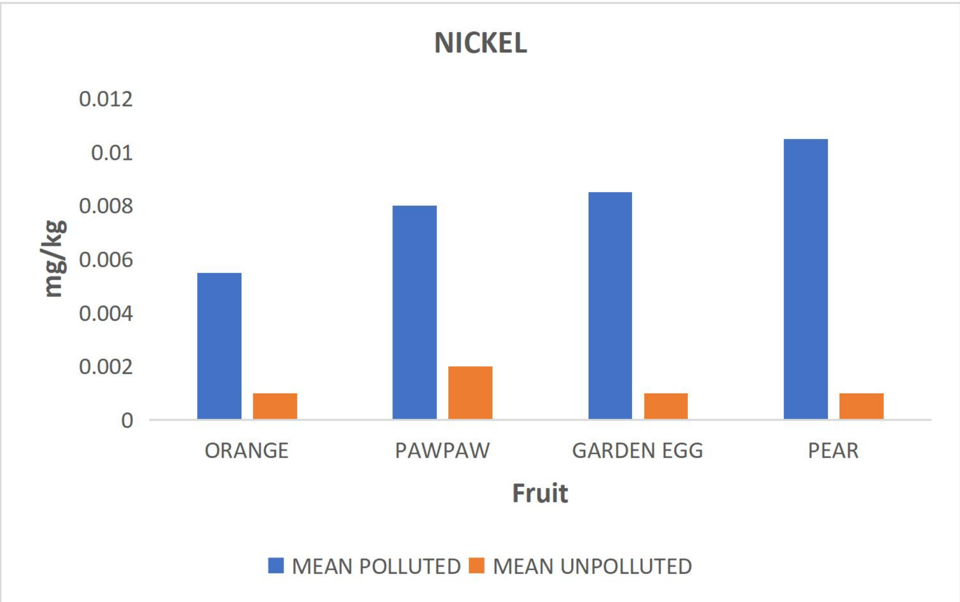

Figure 4.5: Nickel concentration level across fruits from polluted and unpolluted sites

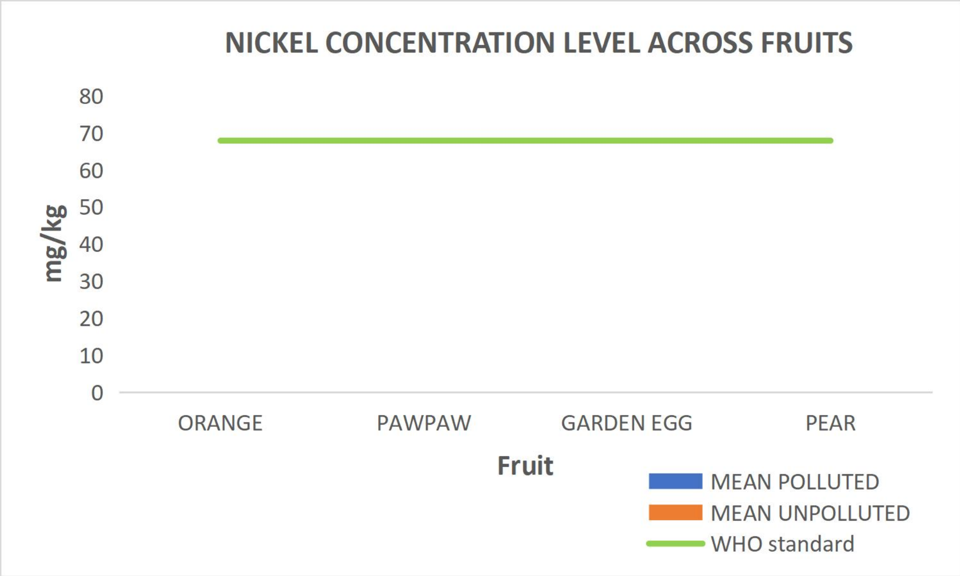

Figure 4.6: Nickel concentration level across fruits in comparison with FAO/WHO standards

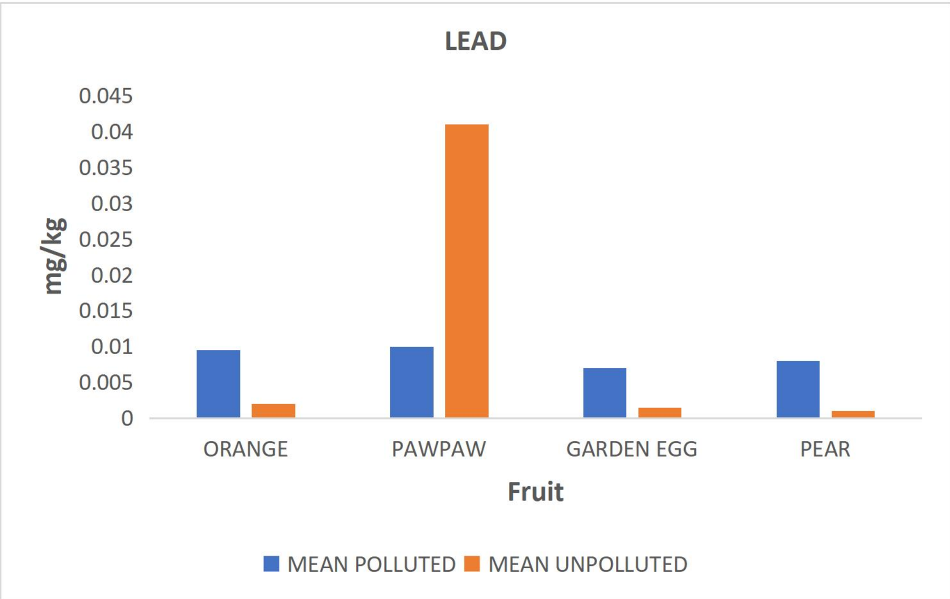

Figure 4.7: Lead concentration level across fruits from polluted and unpolluted sites

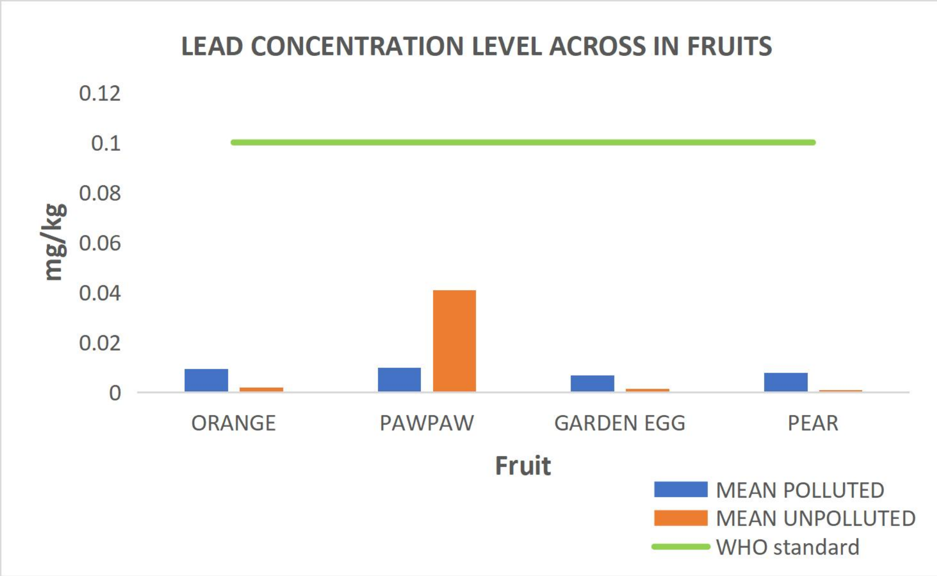

Figure 4.8: Lead concentration level across fruits in comparison with FAO/WHO standards

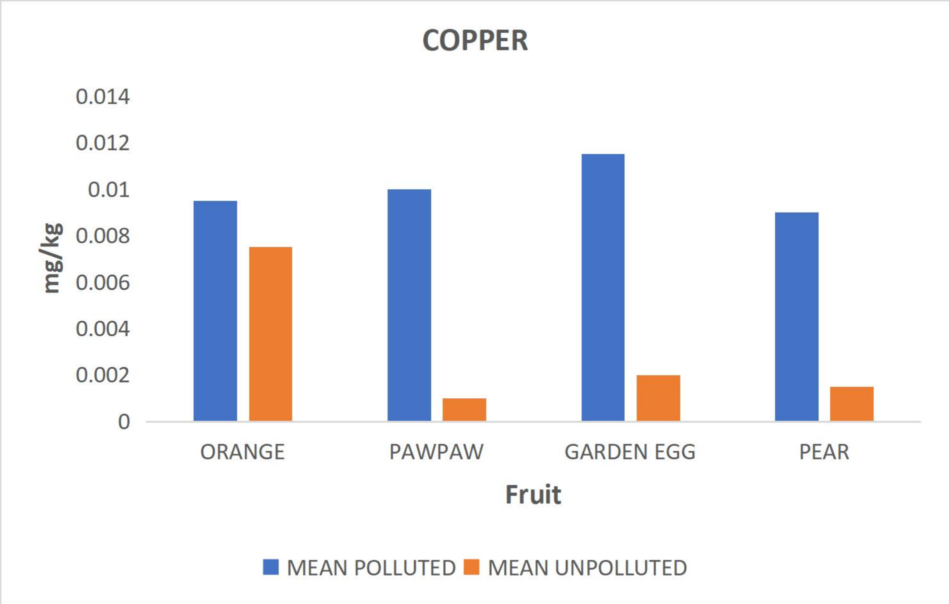

Figure 4.9: Copper concentration level across fruits from polluted and unpolluted sites

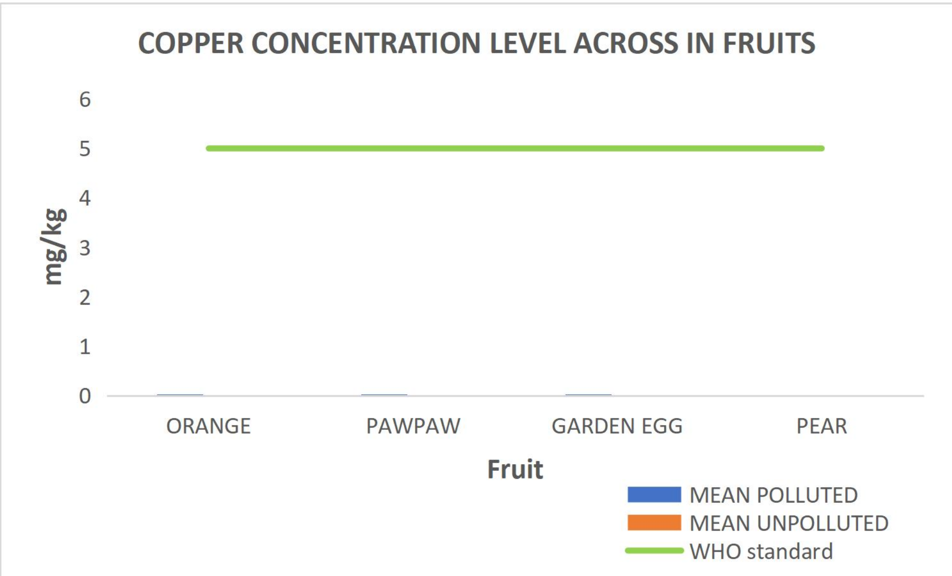

Figure 4.10: Copper concentration level across fruits in comparison with FAO/WHO standard

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Discussion of Findings

The findings of this study revealed that the concentrations of cadmium (Cd), lead (Pb), zinc (Zn), nickel (Ni), and copper (Cu) in fruit samples from polluted sites in Obazogbe Community were significantly higher than those obtained from unpolluted control sites. This indicates that poor waste management and proximity of farmlands to dumpsites substantially influence the levels of heavy metals in locally grown fruits. The significant differences ($p < 0.05$) between polluted and unpolluted sites across all metals and fruits further confirm that contamination in the study area is not incidental but directly linked to environmental pollution sources such as open dumping, leachates, and vehicular emissions.

Although all recorded metal concentrations were below the permissible limits recommended by the World Health Organization (WHO) and the Food and Agriculture Organization (FAO), the elevated values observed in polluted samples point to a gradual accumulation process. Similar results have been reported by Agbazue *et al*. (2019) and Obayagbona *et al*. (2022) in other parts of Nigeria, where fruits cultivated near waste dumps exhibited higher metal loads despite being within safe limits. The findings therefore highlight the potential for bioaccumulation and the long-term risk associated with continuous exposure.

Among the fruits analyzed, pawpaw (Carica papaya) and pear (Dacryodes edulis) showed higher tendencies to bioaccumulate cadmium and lead, which may be attributed to their high water and sugar content, facilitating metal mobility within plant tissues. The orange (Citrus sinensis) samples showed the highest concentration of zinc (0.0155 mg/kg), while garden egg (Solanum aethiopicum) recorded the highest copper content (0.0115 mg/kg). These variations can be linked to differences in plant physiology, soil-to-plant transfer factors, and root absorption capacities (Chakraborty et *al*., 2020; Okoye *et al*., 2021).

The relatively higher concentrations of Cd and Pb in fruits from polluted sites are consistent with findings by Okonokhua and Orhue (2024), who reported elevated soil metal concentrations around dumpsites in Benin City. These metals are non-biodegradable and have long soil half-lives, making them persistent contaminants in agricultural ecosystems. The presence of Cd and Pb even at low concentrations is worrisome because of their cumulative toxicity, which can lead to kidney dysfunction, skeletal disorders, and neurological damage with prolonged exposure (WHO/FAO, 2021).

Furthermore, the detection of essential metals such as Zn, Cu, and Ni in relatively higher concentrations, though still below toxic thresholds, suggests the influence of anthropogenic inputs such as agrochemical use and waste effluents. According to Gupta and Singh (2022), these metals are beneficial in trace amounts but may become toxic when excessively accumulated. In Obazogbe Community, poor waste management practices, including open burning and leachate infiltration, likely contribute to increased soil metal loads that are transferred into fruits.

These findings collectively corroborate the Risk Assessment Model (USEPA, 2020), which posits that dietary exposure is one of the most direct and persistent pathways for heavy metal ingestion in humans. The significantly higher metal concentrations in polluted fruits compared to unpolluted ones demonstrate that agricultural activities close to waste dumpsites increase potential health risks. Though current concentrations do not exceed global limits, continuous farming and consumption of these fruits may lead to progressive accumulation, posing future health challenges such as neurotoxicity, carcinogenicity, and renal dysfunction (Ali *et al*., 2019; Tchounwou *et al*., 2020).

Overall, the study reinforces the strong linkage between poor waste management practices and environmental contamination, as identified in previous Nigerian studies (Adeniran *et al*., 2021; Ekhator *et al*., 2020). It further underscores the need for continuous monitoring of heavy metal levels in fruits and agricultural soils within rural communities like Obazogbe, where informal waste disposal remains prevalent.

5.2 Conclusion

This study assessed the bioaccumulation of selected heavy metals—cadmium (Cd), lead (Pb), zinc (Zn), nickel (Ni), and copper (Cu)—in fruits (pawpaw, orange, pear, and garden egg) obtained from polluted and unpolluted sites in Obazogbe Community, Orhionmwon Local Government Area, Edo State. The results showed that all analyzed metals were present in varying concentrations, with significantly higher levels in fruits from polluted areas compared to unpolluted controls.

Despite being below WHO/FAO permissible limits, the elevated concentrations in fruits from contaminated sites indicate progressive bioaccumulation resulting from poor waste disposal and environmental degradation. This finding highlights that current contamination levels may be sub-toxic but pose long-term health and ecological risks if pollution continues unchecked.

Therefore, the study concludes that:

The bioaccumulation of heavy metals in fruits is directly influenced by the proximity of farmlands to waste disposal sites.

Continuous exposure to low levels of Cd and Pb can lead to chronic toxicity and health hazards over time.

The current state of waste management in Obazogbe Community is inadequate and contributes significantly to soil and food contamination.

The study provides valuable baseline data for environmental monitoring, food safety policy, and community health planning in Edo State and beyond.

5.3 Recommendations

Based on the findings of this research, the following recommendations are proposed:

1. Environmental and Waste Management

The Edo State government, through the Ministry of Environment, should enforce strict waste management regulations to prevent indiscriminate dumping near agricultural lands.

Construction of properly engineered sanitary landfills should replace open dumping to minimize leachate infiltration into farmlands.

Routine environmental monitoring should be conducted by NESREA and Edo State Waste Management Board to track pollution levels around agricultural zones.

2. Agricultural Practices

Farmers should avoid cultivating fruit crops in areas close to waste dumpsites, wastewater channels, or industrial effluent discharge points.

Regular soil testing should be made mandatory before cultivation to determine heavy metal concentrations and suitability for food production.

Adoption of organic farming methods and the use of composted manure instead of synthetic fertilizers can help reduce metal contamination.

3. Public Health and Awareness

Local communities should be educated on the dangers of consuming fruits grown near waste disposal areas.

Public enlightenment campaigns should be carried out through health extension officers and local radio programs.

Government agencies should initiate periodic screening of fruits sold in local markets to ensure compliance with safety standards.

4. **Policy and Research**

The Federal Government, through NAFDAC and SON, should strengthen surveillance and quality control measures for food safety.

Environmental health policies should prioritize rural areas where informal waste management is common.

Future research should integrate health risk assessments (HQ and HI values) to quantify exposure risks among residents.

References

Adelekan, I. O., &Abegunde, K. A. (2020). The health and socio-economic implications of poor waste management practices in developing countries. *Journal of Environmental Health Research,* **30**(2), 45–56.

Adeniran, A. E., Nubi, A. T., &Adelopo, A. O. (2021). Solid waste management practices in Nigeria: Implications for environmental health. *Environmental Monitoring and Assessment, 193*(2), 123.

Adeyeye, S. A. O., Akinyemi, O. M., &Ojo, A. F. (2020). Food safety standards and regulations in Nigeria: Challenges and prospects. *Journal of Food Quality, 2020*, 1–12.

Agbazue, V. E., Nwankwo, O. L., &Obiakor, F. E. (2019). Heavy metal contamination of fruits and vegetables from dumpsites in Nigeria. *Journal of Applied Sciences and Environmental Management,* **23**(4), 677–682.

Afolabi, T. A., Oladipo, O. G., &Oyelami, A. O. (2021). Environmental pollution and health risks associated with heavy metal exposure in Nigeria: A review. *Environmental Monitoring and Assessment,* **193**(12), 789. https://doi.org/10.1007/s10661-021-09655-1

Akinyele, I. O., &Shokunbi, O. S. (2019). Concentrations and health risk assessment of heavy metals in commonly consumed fruits and vegetables in Ibadan, Nigeria. *African Journal of Medicine and Medical Sciences,* **48**(1), 67–77.

Akinyele, I. O., Ajayi, O. O., &Olawale, A. A. (2021). Childhood exposure to heavy metals and implications for cognitive development in Nigeria. *Environmental Toxicology and Pharmacology, 84,* 103600. https://doi.org/10.1016/j.etap.2021.103600

Ali, H., Khan, E., & Ilahi, I. (2019). Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. Journal of Chemistry, 2019, Article 6730305. https://doi.org/10.1155/2019/6730305

Ayedun, H., Akinola, A., & Suleiman, A. (2019). Determination of heavy metals in mango fruits sold in Minna Modern Market, Niger State, Nigeria. *International Journal of Environment and Pollution Research,* **7**(2), 45–53.

Bronfenbrenner, U. (1979). *The ecology of human development: Experiments by nature and design.* Harvard University Press.

Chakraborty, R., Das, S. & Banerjee, S., 2020. Bioaccumulation of heavy metals in food crops: Implications for human health. Environmental Advances, 2, 100018.

Chukwu, E., &Anu, V. O. (2020). Waste management strategies for environmental protection in Nigeria. *Journal of Environmental Management and Safety,* **11**(2), 94–106.

Chukwujindu, M. A., Nwajei, G. E., &Nnorom, I. C. (2019). Assessment of heavy metal contents of selected fruits and vegetables in Nigeria. *Food Standards Journal of Nigeria,* **3**(1), 25–33.

Cole, M.A., Elliott, R.J.R. & Okubo, T., 2020. Trade, environmental regulations, and pollution havens: Evidence from Japanese manufacturing. Journal of Environmental Economics and Management, 103,102342.

Das, S., & Chakraborty, R. (2022). Mechanisms of heavy metal transport and accumulation in plants: Implications for human health. *Plant Physiology Reports,* **27**(3), 345–358.

Ekhator, O., Igiebor, F. A., &Omoregie, E. (2020). Assessment of heavy metal contamination in fruits and vegetables grown around refuse dumpsites in

Benin City, Nigeria. *Journal of Applied Sciences and Environmental Management,* **24**(2), 261–268. https://doi.org/10.4314/jasem.v24i2.13

Eriyamremu, G. E., &Aigbokhan, E. I. (2020). Heavy metal concentrations in vegetables and implications for public health in Edo State, Nigeria. *African Journal of Environmental Science and Technology,* **14**(7), 202–210.

FAO/WHO. (2020). *Codex Alimentarius: General standard for contaminants and toxins in food and feed (CODEX STAN 193-1995).* Food and Agriculture Organization/World Health Organization.

FAO/WHO. (2021). *Codex Alimentarius: General standards for contaminants and toxins in food and feed.* Rome: FAO/WHO.

Gaetke, L. M., Chow, C. K., & Copper, R. D. (2020). Oxidative stress, nutrition, and health in aging populations. *Nutrients,* **12**(6), 1959. https://doi.org/10.3390/nu12061959

Gupta, R., & Singh, A. (2022). Mechanisms of uptake and accumulation of heavy metals in plants: A review. *Environmental Nanotechnology, Monitoring & Management,* **18**, 100714.

Ikhajiagbe, B., Olorunfemi, D. I., &Eze, C. N. (2022). Environmental risk of heavy metal contamination in food crops grown in urban Nigeria. *Scientific African,* **17**, e01388. https://doi.org/10.1016/j.sciaf.2022.e01388

Iriabije, T. O., &Uwadiae, S. (2020). Analysis of some heavy metal contents in selected vegetables and fruits from states in Nigeria. *American Journal of BioScience,* **8**(2), 37–40.

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., &Beeregowda, K. N. (2018). Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary Toxicology,* **7**(2), 60–72.

Kaza, S., Yao, L., Bhada-Tata, P., & Van Woerden, F. (2018). *What a waste 2.0: A global snapshot of solid waste management to 2050.* World Bank, Washington, DC.

Kumar, V., Sharma, A., &Parihar, R. D. (2021). Bioaccumulation and health risks of heavy metals in vegetables: A critical review. *Environmental Toxicology and Pharmacology,* **81**, 103543.

NESREA. (2018). *National Environmental Standards and Regulations Enforcement Agency Annual Report.* Abuja, Nigeria.

NAFDAC. (2020). *NAFDAC food safety policy framework.* Lagos, Nigeria.

Nwachukwu, M. A., Anonye, O., &Igbokwe, M. U. (2021). Waste management in Nigeria: Current practices and challenges. *Sustainability Journal,* **13**(11), 6114.

Nwaichi, E. O., Njoku, K. L., &Onyeike, E. N. (2021). Heavy metal levels in fruits and vegetables from agricultural fields near dumpsites in Rivers State, Nigeria. *Environmental Monitoring and Assessment,* **193**(6), 382–392.

Nkwunonwo, U. C., Odika, P. O., &Onyia, N. I. (2020). A review of the health implications of heavy metals in food chain in Nigeria. *The Scientific World Journal, 2020,* 6594109.

Obayagbona, N. O., Dunkwu-Okafor, A., Odigie, O., &Osayande, A. D. (2022). Heavy metal profiles and pollution indices of topsoil sampled from metallic scrap yards in Benin City, Nigeria. *EQA – International Journal of Environmental Quality,* **46**, 27–39.

Oboh, G., Akomolafe, T. R., &Ademosun, A. O. (2019). Heavy metal content of selected fruits and vegetables cultivated around refuse dumpsites in southwest Nigeria. *Journal of Food Quality, 2019,* 1–9. https://doi.org/10.1155/2019/4578761

Okonokhua, B. O., &Orhue, E. R. (2024). Status of heavy metals and remediation potential of indigenous plants at contaminated Benin City and Abudu sites of Edo, Nigeria. *International Journal of Environment,* **13**(1), 1–15.

Okoye, C. O., Ihedioha, J. N., &Nworie, O. J. (2020). Heavy metal levels and health risk assessment of fruits sold in South-East Nigeria. *Environmental Monitoring and Assessment,* **192**(2), 115–124.

Okoye, C. O. B., Okwu-Delunzu, V. U., &Nnamonu, E. I. (2021). Heavy metals contamination in fruits and vegetables from Nigerian markets and associated human health risks. *Environmental Monitoring and Assessment,* **193**(5), 308.

Olufemi, E., Adewale, T., &Ogunjimi, D. (2021). Level of heavy metals in sliced watermelon fruits in selected markets in Akure, Nigeria. *Journal of Food Safety and Hygiene,* **7**(3), 120–128.

Olujimi, O. O., Akinyemi, O. M., &Adewuyi, G. O. (2020). Maternal exposure to heavy metals and pregnancy outcomes: A review of Nigerian studies. *Environmental Science and Pollution Research,* **27**(5), 4675–4688. https://doi.org/10.1007/s11356-019-07155-5

Onwumere, O., Uche, J., &Anazodo, C. (2021). Bioaccumulation and health risk assessment of heavy metals in fruits and vegetables from selected markets in South-West Nigeria. *Journal of Environmental Health Research,* **21**(1), 50–62.

Rehman, K., Fatima, F., Waheed, I., & Akash, M. S. H. (2018). Prevalence of exposure of heavy metals and their impact on health consequences. *Journal of Cellular Biochemistry,* **119**(1), 157–184. https://doi.org/10.1002/jcb.26234

Shen, H., Zeng, L., Zhou, X., & Li, T. (2020). Prenatal exposure to cadmium and lead and their combined effects on adverse birth outcomes. *Environmental Research, 188,* 109819. https://doi.org/10.1016/j.envres.2020.109819

Singh, R., Gautam, N., Mishra, A., & Gupta, R. (2019). Heavy metals and living systems: An overview. *Indian Journal of Pharmacology,* **43**(3), 246–253. https://doi.org/10.4103/0253-7613.81505

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2019). Heavy metals toxicity and the environment. *EXS, 107,* 133–164.

UNEP. (2020). *Sustainable waste management: Global best practices.* United Nations Environment Programme.

UNICEF (2020) Preventing lead exposure in children: Policy brief. New York: United Nations Children's Fund. Available at: https://www.unicef.org (Accessed: 12 August 2025).

USEPA. 2020. Technical overview of bioaccumulation and biomagnification. Washington, DC: United States Environmental Protection Agency. 1: 10-35.

United state Environmental protection agency (USEPA). (2020). Human health risk assessment guidelines. 1: 45–60.

WHO, 2019. Preventing disease through healthy environments: Exposure to toxic metals. Geneva: World Health Organization. 2: 50-75.

WHO, 2021. Guidelines for assessing the risk of heavy metals in food. Geneva: WHO Press. 1: 25- 60.

WHO. (2021). *Lead poisoning and health.* World Health Organization. https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health

Wilson, D.C., Rodic, L., Modak, P., Soos, R. & Velis, C., 2019. Global waste management outlook. Nairobi: United Nations Environment Programme. 1: 10-80..

Zhao, F. J., Ma, Y., Zhu, Y. G., Tang, Z., & McGrath, S. P. (2019). Soil contamination in China: Current status and mitigation strategies. *Environmental Science & Technology,* **53**(22), 13289–13301.