Chapter One

Introduction

1.1 Background to the Study

Cassava (*Manihot esculenta*) is one of the most important staple crops in tropical and subtropical regions around the world, particularly in Sub-Saharan Africa. Nigeria, being the largest producer of cassava globally, places significant emphasis on its cultivation and processing, with cassava playing a crucial role in ensuring food security, supporting livelihoods, and contributing to the nation's economic growth. Cassava processing in Nigeria is essential for producing various food products, including garri, starch, flour, and tapioca, which are consumed both domestically and exported internationally. However, despite its significance, the agro-industrial processing of cassava has considerable environmental implications[1].

The processing of cassava involves several steps, including peeling, washing, fermenting, drying, and milling. These processes generate large quantities of waste, which include both solid residues and effluents. The waste products from cassava processing, such as the peels, stalks, and wastewater, can have adverse environmental impacts when improperly managed. In particular, the effluents produced by cassava mills often contain harmful substances such as heavy metals and Polycyclic Aromatic Hydrocarbons (PAHs), which are toxic pollutants that can significantly affect soil and water quality in the surrounding areas[2]. These pollutants can enter the environment through the release of effluent water and solid residues, leading to contamination of nearby soils and crops[3].

Polycyclic Aromatic Hydrocarbons (PAHs) are a group of organic pollutants that are primarily formed through the incomplete combustion of organic materials. PAHs are widespread environmental contaminants known for their carcinogenic and mutagenic

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properties. They are released into the environment during various industrial activities, including cassava processing, which involves the heating and drying of cassava products[4]. When cassava waste is improperly disposed of or left to decompose in the open, PAHs can leach into the soil and contaminate the surrounding environment, affecting both soil fertility and plant growth[5]. The presence of PAHs in soils and crops has serious implications for human health, as these compounds can accumulate in the food chain, posing risks to both consumers and agricultural workers[6].

Heavy metals, such as lead (Pb), cadmium (Cd), and arsenic (As), are also commonly found in cassava processing waste due to contamination during processing, as well as from the use of contaminated water sources[7]. These metals are persistent in the environment and can accumulate in soils, making them a significant concern for agricultural productivity. Heavy metals can have toxic effects on plant growth, reducing crop yield and quality. Additionally, when these metals accumulate in crops, they can enter the human food chain through consumption, leading to long-term health issues such as kidney damage, cancer, and neurological disorders[8].

Cassava processing activities in Nigeria, particularly in rural areas, often lack proper waste management due to weak environmental regulations[9]. This leads to the discharge of untreated waste, causing significant environmental issues such as soil degradation, biodiversity loss, and water contamination[9]. Ido Local Government in Ibadan, Nigeria, known for its high cassava production, faces severe pollution challenges from numerous small-scale cassava mills that release effluent and solid waste into the environment, posing risks to soil health, agricultural productivity, and public health[10].

Despite cassava's economic importance, research on the environmental impact of its processing is limited, particularly concerning the contamination of soil and crops with

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heavy metals and Polycyclic Aromatic Hydrocarbons (PAHs)[11]. Existing studies focus more on cassava cultivation, neglecting the risks posed by waste from processing. This highlights the urgent need for comprehensive studies to evaluate pollutant concentrations in soils, crops, and cassava effluent near processing sites[12].

This study aims to assess the levels of heavy metals and PAHs in soils, plants, and effluent around cassava processing sites in Ido Local Government. By analyzing samples from varying distances, it will provide data on contamination levels, pollutant distribution, and associated risks[13]. The research seeks to raise awareness among local communities and inform policies for improved waste management practices[14].

1.2 Statement of the Problem

The presence of polycyclic aromatic hydrocarbons (PAHs) and heavy metals in the environment presents a serious threat to agricultural sustainability, food safety, and public health. In the agro-industrial cassava production zone of Ido Local Government, Ibadan, Nigeria, soils and crops may be increasingly exposed to these contaminants due to industrial activities, vehicle emissions, and the application of polluted irrigation water or agrochemicals.

Despite the region's prominence in cassava farming, there is insufficient data on the extent of PAHs and heavy metal accumulation in the soil and crops. This lack of information raises concerns about potential bioaccumulation in food sources, posing health risks to consumers and economic challenges for farmers. Additionally, existing soil management strategies may not effectively address the long-term consequences of contamination, underscoring the need for targeted research and interventions.

This study aims to investigate the presence and concentration levels of PAHs and heavy metals in the soil and cassava crops of Ido Local Government. The findings will provide

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crucial insights into environmental risks, support sustainable agricultural practices, and contribute to evidence-based policies that safeguard soil health, food security, and public health in agro-industrial regions.

1.3 Justification of the Study

This study focuses on cassava processing due to its vital role in Nigeria's agro-industrial sector. Cassava is a major staple crop, contributing significantly to food security, employment, and the economy. However, its processing generates harmful by-products, including effluents and solid waste, which are often discharged untreated into the environment[15]. Investigating cassava's environmental impact is crucial because its extensive cultivation and processing are key contributors to soil and water pollution in Nigeria[16].

The choice to analyze heavy metals rather than only physicochemical properties stems from their severe and long-term environmental and health impacts. Heavy metals like lead, cadmium, and arsenic persist in the soil, bioaccumulate in crops, and can cause chronic illnesses, including organ damage and cancer[17]. Physicochemical properties alone, such as pH and temperature, provide useful but limited information, while heavy metals directly indicate harmful contamination levels[18].

PAHs were selected among other pollutants due to their carcinogenic and mutagenic nature. Produced from incomplete combustion processes during cassava roasting and peel burning, PAHs persist in the environment and pose serious public health risks through soil, water, and crop contamination[19]. Their long-term environmental presence and health implications make them critical pollutants for assessment[20].

Ido Local Government was chosen for this study because it is a major hub for cassava processing in Oyo State, with numerous small-scale processors using traditional

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methods that often lead to environmental degradation[21]. The area's proximity to rivers and farmlands increases the risk of pollutant spread, making it an ideal site for investigating the impact of cassava processing waste on soil and crops[22]. Additionally, Ido is underrepresented in existing environmental studies, highlighting the need for localized research.

The aim of this study is to assess the concentration and impact of PAHs and heavy metals in soil and crops near cassava processing sites within Ido Local Government. The findings will provide essential data to inform environmental management policies, promote sustainable cassava processing practices, and safeguard public health.

1.4 Significance of the Study

This study is significant because it addresses critical environmental and public health concerns associated with cassava processing in Nigeria. Cassava is a staple food and a key agricultural product, but its processing often leads to pollution, which threatens the environment, soil quality, crop safety, and the well-being of local communities[23]. This research will shed light on the levels of polycyclic aromatic hydrocarbons (PAHs) and heavy metals in soil and crops within an agro-industrial cassava processing area in Ido Local Government, Ibadan.

One of the primary contributions of this study is to enhance awareness of the environmental risks linked to cassava processing. By quantifying the concentration of contaminants in soil and crops, the research will provide evidence-based insights that can guide interventions to reduce pollution and its adverse effects. For farmers and agro-industrial stakeholders, the study's findings will underscore the need for sustainable processing practices, helping them balance productivity with environmental conservation.

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The study also has broader implications for public health. PAHs and heavy metals are known carcinogens and can accumulate in food chains, posing long-term health risks to consumers. This research will help identify contamination hotspots and their potential impact on food safety, contributing to efforts aimed at reducing exposure to these hazardous substances[24].

Furthermore, the study's findings will be valuable to policymakers and environmental agencies by providing empirical data needed to formulate regulations and strategies to mitigate pollution in agro-industrial settings. It will also align with national and global sustainability goals, particularly those related to environmental protection, food security, and health. Ultimately, this study's significance lies in its potential to drive positive change, ensuring a safer and more sustainable future for Nigeria's cassava production and processing industry[25].

1.5 Aim and Objectives of the Study

This study aims to examine how the pollution caused by cassava processing affects soil and crop quality, particularly focusing on the presence of PAHs and heavy metals in both soils and cassava crops.

The objectives of the study are to:

1. Assess the concentration of PAHs and heavy metals in the soils of cassava processing sites.

2. Investigate the presence and concentration of PAHs and heavy metals in cassava crops grown near cassava processing sites in Ido Local Government Area

3. Examine the environmental impact of cassava processing waste and its effect on local ecosystems in Ido Local Government Area.

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1.6 Research Questions

The following are the key research questions that this study seeks to answer:

1. What are the concentration levels of PAHs and heavy metals in soils surrounding cassava processing sites in Ido Local Government Area (LGA), Ibadan, Nigeria?

2. How do PAHs and heavy metals accumulate in cassava crops grown near processing sites in Ido Local Government Area (LGA), Ibadan, Nigeria?

3. What are the potential health risks associated with consuming contaminated cassava products in Ido Local Government Area (LGA), Ibadan, Nigeria?

4. How does cassava processing waste affect local ecosystems and biodiversity in Ido Local Government Area (LGA), Ibadan, Nigeria?

1.7 Scope of Study

This study focuses on the environmental and health implications of Polycyclic Aromatic Hydrocarbons (PAHs) and heavy metals in cassava production areas in Nigeria, with particular emphasis on the Ido Local Government Area (LGA) in Ibadan.

The geographic scope of the study is focused on Ido Local Government Area (LGA), a key area in Ibadan, Oyo State, Nigeria.

While the study focuses on Ido LGA, it is expected that findings from this study will be relevant to other rural cassava-growing areas in Nigeria and beyond, especially in countries with similar agricultural profiles.

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1.8 Limitations of the Study

While the study provides a comprehensive examination of the environmental and health risks associated with cassava processing, there are limitations that must be acknowledged. The study will be conducted within the confines of Ido LGA, and its findings may not be entirely representative of cassava production practices in other regions of Nigeria.

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Chapter Two

Literature Review

2.1 Conceptual Review

2.1.1 The Role of Cassava in Nigeria's Agro-Industrial Sector

Cassava is one of the most important crops in Nigeria, both in terms of its contribution to the economy and its role in food security. It is grown in virtually all the 36 states of the country, with the highest concentrations found in the middle belt, southwestern, and southeastern regions[1]. In these areas, cassava farming has been integrated into the farming systems of smallholder farmers who rely heavily on traditional methods[2]. The crop's adaptability to a wide variety of soil types and climatic conditions makes it a favored choice for Nigerian farmers, particularly in regions with erratic rainfall patterns[3].

Cassava farming in Nigeria is dominated by small-scale farmers who often engage in subsistence farming with low input levels and limited access to technology. These smallholders, who often operate on plots less than five hectares, produce the bulk of the country's cassava output[4]. However, Nigeria is beginning to see a shift toward more industrialized farming practices as large-scale agribusinesses enter the sector. This transition is expected to improve yield per hectare, reduce labor costs, and help to modernize the sector[5]. Despite these positive trends, cassava farmers still face significant challenges such as inadequate infrastructure, poor access to financial services, and limited knowledge about modern farming techniques[6].

After harvest, cassava is taken to processing centers where it undergoes various operations that add value to the raw crop. The processing stage of cassava production is highly labor-intensive, and small-scale processors often use rudimentary methods such as manual peeling, fermentation, and sun-drying[7]. However, as the demand for cassava-based products has

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increased both locally and internationally, industrial-scale processing plants have begun to emerge in some regions. These plants utilize mechanized equipment that helps improve the efficiency and consistency of the processed products[8].

The main processed cassava products in Nigeria are garri, fufu, cassava flour, and starch. Garri is the most widely consumed cassava product and is produced by roasting grated cassava tubers. Fufu, another popular product, is made through fermentation and pounding of cassava[9]. Cassava flour, used as an alternative to wheat flour, is gaining popularity, especially in the production of gluten-free foods. Starch from cassava is widely used in the food, pharmaceutical, and paper industries, while tapioca, a type of starch, is used in beverages and other processed foods[10].

Cassava processing has created a vibrant industry, supporting millions of jobs in Nigeria. The sector has been a major source of employment, particularly in rural areas where the majority of cassava farming takes place. Food and Agriculture Organization (FAO), millions of Nigerians depend on cassava for their livelihood, with jobs ranging from farming and processing to transport and marketing[11]. The government has recognized the potential of cassava to contribute significantly to the country's economic development and has implemented various initiatives to support the sector, including the Presidential Cassava Initiative, which aims to increase cassava production and processing at the industrial level[12].

Despite the promise of growth in the cassava industry, the sector also faces numerous challenges, particularly in terms of environmental sustainability. The expansion of cassava cultivation has resulted in the degradation of soil health in some areas. Continuous farming of cassava without proper soil management practices has led to reduced soil fertility, erosion, and the depletion of important nutrients that are essential for crop growth[13]. Additionally, cassava processing generates significant amounts of waste, including effluents, which

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are often disposed of untreated, causing contamination of water bodies and soil[14]. Environmental regulations to address these challenges have not been effectively enforced, and many small-scale processors continue to use inefficient and polluting methods[15].

2.1.2 Environmental Pollution from Cassava Processing Activities

The environmental pollution resulting from cassava processing activities has become an area of increasing concern in Nigeria. Cassava processing produces significant quantities of waste, including effluents, solid waste, and air pollutants, all of which contribute to the degradation of the environment. While the cassava industry is a critical contributor to the Nigerian economy, its environmental footprint often goes unaddressed. Processing activities such as peeling, grating, fermenting, and drying are responsible for generating waste products that contain high concentrations of organic matter, suspended solids, and sometimes, toxic compounds like heavy metals and polycyclic aromatic hydrocarbons (PA/Hs)[16]. Most of these pollutants end up in nearby water sources and surrounding land, where they can cause long-term environmental harm if not properly managed.

The major pollutants generated during cassava processing include liquid effluents, solid waste, and gas emissions. Effluents are typically released during the washing, fermentation, and extraction processes, often contaminating nearby rivers, lakes, and other water bodies. These liquid discharges are often high in organic content and require treatment to prevent them from contaminating water sources[17]. In rural cassava processing centers, where proper waste management systems are frequently lacking, untreated effluents are dumped directly into the environment. This leads to a deterioration in water quality, affecting aquatic life and, in turn, the communities that rely on these water sources for drinking, irrigation, and domestic use[18].

Solid waste generated during cassava processing includes peels, starch residues,

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and other by-products. These materials are often left to decompose in open-air environments or dumped in nearby dumpsites. The decomposition of organic materials such as cassava peels can lead to the release of methane, a potent greenhouse gas, contributing to climate change. In addition, cassava peels can attract pests and become breeding grounds for disease vectors, further complicating the environmental impacts of the waste[19]. While cassava peel can be used for animal feed or composting, in practice, it often ends up as waste, contributing to land pollution and posing challenges for local waste management systems[20].

Air pollution is another critical issue in cassava processing areas, especially during roasting, a common method for preparing garri, one of Nigeria's most popular cassava products. Roasting is typically carried out over an open fire or in poorly ventilated stoves, which releases significant amounts of particulate matter, carbon monoxide, and other air pollutants. These emissions not only harm the respiratory health of those working in these processing centers but also contribute to outdoor air pollution, which can have broader environmental consequences[21]. In areas with high levels of cassava processing, the cumulative effect of such emissions on local air quality can be substantial, contributing to health problems like respiratory diseases and asthma, particularly in women and children who spend considerable time in processing environments[22].

Moreover, the widespread use of rudimentary and outdated processing techniques exacerbates the environmental pollution associated with cassava production. In many rural areas, small-scale processors continue to rely on traditional methods such as open-fire roasting, which are not only inefficient but also highly polluting. These methods generate significant environmental hazards, both in terms of air quality and waste management, and they contribute to the overall environmental burden of cassava processing activities[23]. There

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is a need for more sustainable and environmentally friendly cassava processing technologies that can help reduce the negative impact of the industry on the environment.

2.1.3 Impact on Soil and Water Quality

Cassava processing has a direct impact on soil and water quality in areas where waste is improperly managed. The release of organic effluents into water sources can increase the biological oxygen demand (BOD) of water bodies, reducing the oxygen available for aquatic organisms and leading to the death of fish and other aquatic life[24]. The organic load in these effluents can also cause eutrophication, a process in which excessive nutrients stimulate the growth of algae, leading to the depletion of oxygen in the water. Eutrophication has significant consequences for aquatic ecosystems and can reduce the availability of clean water for human consumption and agriculture[25].

Cassava processing waste can also contaminate soil, leading to the accumulation of toxic substances like heavy metals and PAHs. These pollutants can persist in the environment for extended periods, affecting soil fertility and crop production. In the long term, the build-up of contaminants in the soil can alter soil pH, reduce nutrient availability, and inhibit plant growth[26]. The presence of heavy metals in the soil, such as lead, cadmium, and arsenic, is particularly concerning, as these metals are toxic to plants and animals and can be transferred through the food chain. As cassava is an essential food crop in Nigeria, the contamination of soil and water sources can have widespread implications for food security and public health[27].

In areas where cassava processing activities are concentrated, the proximity to water bodies and agricultural land increases the risk of pollutant transfer from processing sites to surrounding ecosystems. For instance, the leaching of chemicals and organic compounds into groundwater can compromise the quality of drinking water for local communities[28]. The contamination of soil and water by cassava processing effluents is an urgent

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environmental issue that needs to be addressed through improved waste management practices and the adoption of cleaner processing technologies[29].

There have been several efforts to mitigate the environmental impact of cassava processing in Nigeria, but these initiatives face significant challenges. Government agencies, non-governmental organizations (NGOs), and private sector players have promoted the use of improved processing techniques, such as the adoption of mechanized cassava processing equipment that generates less waste and uses cleaner energy sources. However, these technologies are often costly and require significant investment, which many small-scale processors cannot afford[30]. Additionally, the lack of a coordinated waste management system in rural areas makes it difficult to implement sustainable solutions for managing cassava processing waste[31].

In some regions, local communities have explored alternative uses for cassava waste, such as turning cassava peels into biogas or using them as feed for livestock. These initiatives have the potential to reduce waste and create new economic opportunities, but they have not been widely adopted due to a lack of technical expertise, financial resources, and infrastructure[32]. Furthermore, the absence of strict environmental regulations and the lack of enforcement mechanisms contribute to the continued environmental degradation caused by cassava processing activities[33].

Despite these challenges, there is hope for addressing the environmental pollution associated with cassava processing in Nigeria. By incorporating waste minimization practices into cassava processing operations, such as water recycling, composting, and adopting low-emission technologies, the environmental burden of the industry can be significantly reduced[34]. However, this will require increased awareness, government support, and investment in sustainable technologies to ensure the long-term viability of the cassava

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industry without compromising the health of the environment and local communities.

2.2 Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are a group of chemically persistent organic compounds formed primarily during the incomplete combustion of organic material, such as during the burning of fossil fuels, biomass, or wood. They are ubiquitous environmental pollutants, widely distributed in the atmosphere, soil, and water, and have been identified as key contaminants in agricultural systems. In the context of cassava processing, PAHs are generated during roasting, peeling, and other thermal processing methods. These pollutants are of particular concern due to their carcinogenic, mutagenic, and teratogenic effects, which pose significant risks to both environmental and human health[35]. In the context of cassava processing, PAHs can originate from the burning of biomass fuels (like firewood or cassava peels) during roasting operations. Traditional cassava processing methods (such as garification, where cassava mash is roasted to produce garri) often involve open fires, leading to incomplete combustion that generates PAHs. These PAHs can persist in soil and crops near processing sites, given their hydrophobic and semi-volatile nature, thus posing risks of soil contamination and food-chain transfer. The toxicological significance of PAHs lies in their mutagenic and carcinogenic potential; chronic exposure (e.g. through contaminated food) is linked to increased cancer risk and other health issues in humans. Understanding PAHs as environmental pollutants is crucial for this study, as they represent the organic contaminant dimension of cassava-processing pollution and have direct implications for food safety and public health.

PAHs are a class of over 100 different chemicals, most of which are produced during the combustion of organic substances in low-oxygen conditions, such as when cassava is roasted over an open fire. These compounds are highly stable and can persist in the

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environment for long periods, particularly in soil and sediment, where they may accumulate and remain bioavailable for extended durations. As a result, PAHs pose a long-term risk to agricultural ecosystems, as they can be absorbed by crops and persist through the food chain[36]. Given that cassava is a major staple crop in Nigeria and several other parts of West Africa, the presence of PAHs in cassava processing areas represents a significant environmental and public health concern[37].

The primary pathways through which PAHs contaminate agricultural systems are atmospheric deposition, direct contamination through effluents, and leaching from contaminated soils. During the roasting and peeling processes of cassava, PAHs are emitted as airborne particles that settle on nearby soil and water bodies. These pollutants can also enter the soil through the discharge of waste effluents from processing activities, where they can remain in the environment for years due to their high persistence[38]. Studies have shown that PAHs can be readily absorbed by plants, where they accumulate in roots, stems, and leaves, potentially affecting the growth and development of crops. In cassava, the presence of PAHs in soil can lead to the bioaccumulation of these toxic compounds in edible parts of the plant, including the tubers, which are commonly consumed by humans and animals alike[39].

One of the major challenges in managing PAH contamination in agricultural systems is the fact that these compounds are hydrophobic, meaning they do not easily dissolve in water and instead tend to bind strongly to organic matter and particles in the soil[40]. This makes PAHs particularly difficult to remove from contaminated agricultural soils, and it also means that they can remain in the environment for years, leaching into nearby water sources and food crops. In addition to contaminating soil and water, PAHs have been shown to affect the microbial communities in the soil, altering the structure and function of soil ecosystems. Such disruptions can reduce soil fertility and hinder the natural biodegradation processes that are essential for maintaining soil health[41].

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The health risks posed by PAHs are significant. These compounds are well-documented carcinogens, mutagens, and teratogens that can cause a range of health problems in humans and animals. Long-term exposure to PAHs has been linked to cancers, particularly lung, skin, and bladder cancer, as well as respiratory diseases, liver damage, and developmental disorders in children[42]. In agricultural systems, where PAHs can accumulate in food crops, the potential for human exposure through the consumption of contaminated crops is a significant public health issue. Cassava, being a major food crop in Nigeria and other African nations, is particularly vulnerable to PAH contamination due to its widespread cultivation and consumption[43].

Several studies have identified the presence of PAHs in cassava processing areas, demonstrating that these pollutants are a common problem in regions where traditional roasting and open-flame processing methods are employed. In Nigeria, for example, research has found elevated levels of PAHs in the soil and water near cassava processing facilities, particularly in areas where small-scale processors use rudimentary roasting techniques[44]. These findings highlight the need for better monitoring and regulation of PAH contamination in agricultural systems, especially in cassava-growing regions.

Efforts to mitigate PAH contamination in cassava processing areas have focused primarily on improving processing methods. For instance, the adoption of cleaner technologies, such as mechanized processing and electric roasting ovens, could significantly reduce the amount of PAHs produced during cassava processing[45]. These technologies are designed to reduce the incomplete combustion of cassava during processing, thereby minimizing the formation of PAHs. Additionally, alternative processing techniques, such as solar drying or fermentation, have been explored as potential ways to reduce PAH contamination without compromising the quality of cassava products[46]. However, these technologies are often costly and not easily accessible to small-scale farmers and processors, particularly in rural areas where

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cassava is most commonly cultivated.

In addition to improving processing methods, strategies for reducing PAH contamination in agricultural systems also include soil remediation techniques. These methods, such as bioremediation and phytoremediation, aim to reduce the concentration of PAHs in contaminated soils by using microorganisms or plants to break down or absorb these compounds. Research into the use of specific plant species, such as certain types of grasses and legumes, has shown promise in remediating PAH-contaminated soils[47]. However, these techniques are still in the experimental stages and require further research and development to determine their effectiveness in real-world agricultural settings.

Overall, the presence of PAHs in agricultural systems, particularly in cassava processing areas, represents a significant environmental and public health challenge. While there are efforts to mitigate PAH contamination through cleaner processing technologies and soil remediation methods, much more needs to be done to address the long-term risks posed by these toxic compounds. Enhanced regulation, better monitoring of PAH levels in agricultural systems, and increased support for the adoption of cleaner technologies are essential for reducing the environmental and health impacts of PAH contamination in cassava processing areas[48].

2.2.1 Heavy Metals in Soils and Crops

"Heavy metals" is a term used for a group of metallic elements that have relatively high density and are toxic even at low concentrations. Common examples of heavy metals of concern include lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), and chromium (Cr). Heavy metals are persistent environmental pollutants due to their non-biodegradable nature and propensity to bioaccumulate in living organisms[49]. In soils, heavy metals can remain for decades, continually cycling through ecosystems. They often originate from anthropogenic sources such as industrial effluents, mining, waste disposal, and agricultural inputs (e.g.

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fertilizers, pesticides). In agro-industrial contexts like cassava processing, heavy metal contamination may arise from several pathways: use of contaminated water in processing, machinery and additives, or the concentration of naturally occurring metals through waste disposal (for instance, cassava mill effluent and solid wastes can mobilize metals in soils). Heavy metals are known to adversely affect soil quality and plant growth. Excessive metal concentrations in soil can inhibit microbial activity and enzyme function, leading to reduced soil fertility[50]. Plants growing on contaminated soils often exhibit stunted growth, chlorosis, and lower yields as heavy metals interfere with nutrient uptake and physiological processes. Importantly, certain food crops (including cassava) can uptake heavy metals from soil into edible tissues, thereby introducing these toxins into the food chain. Chronic dietary exposure to heavy metals is associated with serious health issues in humans: for example, lead and mercury can cause neurological damage, cadmium can induce kidney and bone disorders, and arsenic and chromium are carcinogenic. Because heavy metals accumulate in plant and animal tissues, they pose long-term food safety risks, prompting regulators to set maximum permissible levels in foods. In summary, heavy metals in the context of this study represent the inorganic pollutant burden from cassava processing activities, with implications for soil health, crop safety, and human health upon consumption of contaminated produce.

The accumulation of heavy metals in soil and crops occurs through a complex series of processes, including atmospheric deposition, irrigation with contaminated water, and the direct application of contaminated agricultural inputs, such as fertilizers and pesticides. Once heavy metals enter the soil, they can bind to soil particles or become part of the soil solution, making them available for plant uptake. Some metals, such as cadmium and lead, are taken up by plants through the roots, accumulating in various plant tissues, including roots, stems, leaves, and edible parts such as tubers. Other metals, such as mercury and arsenic, tend to accumulate more in the soil and may not readily transfer to plants, but they still

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represent a serious environmental hazard as they can contaminate nearby water sources[51].

In cassava, heavy metal contamination is of particular concern because the tubers, which are the edible part of the plant, have the potential to accumulate significant amounts of these toxic metals[52]. Studies have shown that cassava tubers can absorb lead, cadmium, and arsenic from contaminated soil, posing a direct threat to human health when consumed[53]. The concentration of heavy metals in cassava tubers can vary depending on several factors, including the type of metal, the concentration of the metal in the soil, and the plant's ability to uptake and translocate metals from the roots to the tubers[54]. For example, cadmium is known to be highly mobile in the soil and is readily absorbed by cassava roots, while lead tends to remain more concentrated in the soil, with limited translocation to the tubers[55].

The presence of heavy metals in soil and crops can have detrimental effects on soil fertility, agricultural productivity, and the health of the entire ecosystem[56]. Heavy metals can alter the physical, chemical, and biological properties of the soil, disrupt microbial activity and reduce soil fertility[57]. High concentrations of metals like lead and cadmium can inhibit plant growth, leading to stunted growth, chlorosis (yellowing of leaves), and reduced crop yields[58]. Additionally, the accumulation of heavy metals in plants can lead to toxicity, affecting various physiological processes such as photosynthesis, respiration, and nutrient uptake[59]. In cassava, heavy metal contamination can result in reduced tuber quality, affecting both yield and marketability[60].

Heavy metals also pose a serious threat to human health, as they can enter the food chain through the consumption of contaminated crops[61]. When humans consume cassava tubers contaminated with heavy metals, these metals can accumulate in the body over time, leading to chronic health conditions[62]. Long-term exposure to heavy metals like lead and cadmium has been linked to a range of health issues, including kidney damage, liver dysfunction,

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neurological disorders, and developmental problems in children[63]. Moreover, arsenic exposure has been associated with an increased risk of cancer, particularly in the lungs, bladder, and skin. The consumption of heavy metals through food is a major pathway for human exposure, and the contamination of staple crops like cassava poses a direct risk to public health[64].

The contamination of cassava with heavy metals is a widespread issue in developing countries, where agricultural practices often rely on low-cost inputs, such as untreated wastewater for irrigation and contaminated fertilizers[65]. In Nigeria, for example, studies have reported elevated levels of heavy metals in cassava-growing regions, particularly in areas close to industrial activities and urban centers[66]. Heavy metal contamination in these areas is largely attributed to the discharge of untreated industrial effluents and the use of polluted water for irrigation[67]. In some cases, contaminated fertilizers and pesticides have also contributed to the accumulation of heavy metals in the soil[68]. As a result, the risk of heavy metal contamination in cassava tubers is particularly high in regions with intensive industrial and agricultural activities.

In response to the growing concern about heavy metal contamination in agricultural systems, various strategies have been proposed to reduce metal uptake by crops and mitigate the associated risks[69]. One of the most commonly suggested approaches is soil remediation, which involves the removal or neutralization of heavy metals in contaminated soils. Methods such as phytoremediation, where plants are used to absorb and accumulate heavy metals, and bioremediation, where microorganisms break down or transform toxic metals, have been explored as potential solutions for cleaning up contaminated soils[70]. Additionally, the use of organic amendments, such as compost and biochar, has been shown to reduce heavy metal bioavailability in soil and reduce plant uptake[71].

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Another approach to reducing heavy metal contamination in cassava is to promote the use of cleaner and more sustainable farming practices[72]. For example, adopting organic farming techniques, which avoid the use of synthetic fertilizers and pesticides, could help reduce the levels of heavy metals in cassava production systems[73]. Additionally, encouraging the use of alternative water sources for irrigation, such as rainwater harvesting or the use of treated wastewater, could help reduce the reliance on contaminated water sources. Improved waste management practices in cassava processing areas could also minimize the release of heavy metals into the environment, thereby reducing the risk of contamination in the surrounding soil and crops[74].

Efforts to raise awareness about the risks of heavy metal contamination in agricultural systems are also crucial for addressing this issue[75]. Farmers and processors need to be educated about the potential sources of contamination and the importance of using safe inputs in cassava production. Government agencies and environmental organizations must also take an active role in regulating and monitoring heavy metal levels in agricultural products, particularly in high-risk areas[76]. Regular monitoring and testing of cassava crops for heavy metal contamination could help identify problem areas and allow for the implementation of corrective actions before contaminated crops reach the market[77].

Despite the challenges associated with heavy metal contamination in cassava production, there is growing recognition of the need for sustainable agricultural practices and environmental management strategies to protect both human health and the environment[78]. Addressing heavy metal contamination in cassava-growing regions is essential for ensuring the safety of the food supply, maintaining soil health, and promoting long-term agricultural productivity. By adopting cleaner processing methods, improving waste management practices, and implementing soil remediation techniques, the risks associated with heavy

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metal contamination in cassava production can be significantly reduced[79]. Continued research into the sources, pathways, and mitigation strategies for heavy metal contamination will be essential for developing effective solutions to this pressing environmental and public health challenge[80].

2.2.2 Agro-Industrial Pollution

Agro-industrial pollution refers to the contamination of the environment resulting from agricultural production and processing activities. This includes the release of pollutants during the processing of agricultural commodities in agro-allied industries[81]. Cassava processing is a pertinent example: converting cassava roots into products like garri, starch, or flour generates substantial liquid and solid wastes. These wastes rich in organic matter, cyanogenic compounds, and sometimes chemical additives if not properly managed, lead to environmental degradation. Liquid effluents (such as fermenting cassava wastewater) are often acidic and laden with organic pollutants; when discharged untreated, they can leach into soils and water bodies, altering pH and oxygen levels and facilitating the mobilization of heavy metals[82]. Solid wastes, including cassava peels and fibrous residues, are frequently heaped or burned near processing sites. The accumulation of these wastes or their open burning contributes to soil nutrient imbalance, introduces toxic substances (like PAHs from smoke or residual cyanide from cassava peels), and creates physical blight on the landscape[83]. Nigeria's Federal Institute of Industrial Research, processing of agro-industrial raw materials such as cassava, rice, and wood produces large amounts of wastes, and the build-up of these wastes without proper management leads directly to environmental pollution[84]. Impacts of agro-industrial pollution in cassava hubs include soil contamination, surface and groundwater pollution from leachates, offensive odours, proliferation of pests, and damage to local biodiversity. Given that many cassava processing operations in rural Nigeria are

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small-scale and lack pollution control infrastructure, agro-industrial pollution emerges as a key concept for this study – linking the industry (cassava processing) with its environmental externalities (pollutants in soil and crops)[85].

2.2.3 Soil Contamination

Soil contamination (or soil pollution) is defined as the presence of hazardous substances in soil at levels that pose a risk to the environment or human health. It occurs when anthropogenic chemicals or waste materials are introduced into the natural soil environment, altering its composition and function[86]. Common soil contaminants include hydrocarbons (from petroleum or combustion byproducts), heavy metals, pesticides, solvents, and other persistent organic pollutants. In agricultural settings, soil contamination can result from factors such as the overuse of agro-chemicals, irrigation with polluted water, atmospheric deposition of industrial emissions, or the inappropriate disposal of industrial and processing wastes. In the case of cassava processing areas, soil contamination may happen through direct discharge of starchy effluents and solid residues onto land, or via atmospheric fallout of particulates (ash, soot) from burning wastes. Contaminated soils often exhibit reduced fertility and biological activity: toxic substances can kill beneficial soil microorganisms and fauna, disrupt nutrient cycling, and reduce crop yields[87]. The soil can act as both a sink and a source for pollutants – for example, heavy metals can bind to soil particles and persist for long periods, gradually accumulating in food crops; similarly, hydrophobic organic pollutants like high-weight PAHs can adsorb to soil organic matter and remain available to biota over time. The significance of soil contamination in this study is paramount, as it represents the immediate medium through which cassava processing waste impacts crop production and environmental health[88]. Contaminated soil is a critical link between pollution sources and

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food safety: if soil in cassava farmlands is polluted, the cassava tubers and leaves may uptake contaminants, thereby introducing them into the human diet. Thus, assessing soil contamination by PAHs and heavy metals provides insight into the extent of environmental impact and potential exposure risks in the community.

2.2.4 Food Safety

Food safety is a concept that encompasses the handling, preparation, and storage of food in ways that prevent foodborne illness and protect consumer health. In the context of environmental contamination, food safety refers to the absence (or acceptable low levels) of harmful contaminants in food items destined for consumption. Chemical contaminants such as heavy metals and PAHs are of particular concern for food safety because they can be insidious and chronic hazards. Unlike acute microbial food poisoning, chemical contaminants may not cause immediate symptoms but can lead to long-term health issues. For instance, consumption of foodstuffs (like cassava products) contaminated with lead, cadmium, or PAHs over months and years can contribute to chronic diseases including cancers, organ damage, developmental disorders, and other serious conditions. Regulatory bodies and international agencies (e.g. WHO, FAO, Codex Alimentarius) set maximum residue levels and safety guidelines for various contaminants in food to protect public health. Ensuring food safety in the scope of this study means verifying whether cassava tubers and derived products from the study area contain pollutant levels within safe limits[89]. Cassava is a staple food in Nigeria, so any contamination in cassava-based foods (garri, fufu, lafun, etc.) could have widespread health implications. Food safety intersects with environmental science here through the concept of farm-to-table contamination: pollutants from agro-industrial activities (cassava processing) can make their way into crops and ultimately onto people's plates.

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Therefore, this literature review pays special attention to studies that have measured contaminant levels in foods and assessed dietary risk. Overall, maintaining food safety in agricultural communities near industrial cassava processing requires controlling pollution at the source and monitoring the quality of food crops to avoid dangerous exposures.

2.3 Theoretical Review

2.3.1 Ecological Systems Theory

Ecological Systems Theory, originally developed by Urie Bronfenbrenner in 1979, provides a useful lens for understanding how environmental factors at multiple levels interact to influence human outcomes. The theory conceptualizes the environment as a series of nested systems – from the microsystem (immediate settings like family or workplace) to the mesosystem (interconnections between microsystems), exosystem (external environments that indirectly affect individuals), and the broad macrosystem (societal and environmental context). In the realm of environmental health, this theory underscores that human health is shaped not only by immediate lifestyle or genetic factors but also by larger environmental contexts[90]. Applying Ecological Systems Theory to this study, one can view the industrial cassava processing site and its pollution as part of the community's ecosystem or macrosystem – an environmental context that can indirectly (and directly) affect individuals living and working in the area. For example, a cassava worker's microsystem (their farm or processing workplace) is embedded in a polluted environment (contaminated soil and crops), which in turn is influenced by broader socio-economic and regulatory contexts (macrosystem factors such as environmental policies, industrial practices, and community awareness). This theoretical perspective suggests that to fully understand the public health implications of cassava processing pollution, one must consider the multilevel interactions: how the

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pollutant-laden environment (soil, water, food) at the community level penetrates the daily experiences and health outcomes of individuals (e.g., through food consumption or livelihood activities). Ecological Systems Theory thus justifies a holistic approach – recognizing that interventions might be needed at multiple levels (individual behavior change, community education, policy enforcement) to mitigate health risks. In summary, this theory informs the study by highlighting that the environmental problem of PAHs and heavy metals contamination is embedded in a larger system of human-environment interactions[91]. The local ecosystem at Ido L.G.A (with its farms, processing mills, and residents) can be seen as an interconnected unit within which contamination spreads and impacts propagate, thus requiring a systems-thinking approach to analysis and solutions.

2.3.2 Risk Assessment Theory

Risk assessment is a systematic process used to evaluate the potential adverse health effects caused by environmental hazards. In environmental science and public health, Risk Assessment Theory provides the framework and principles for quantifying risk – typically through four steps: hazard identification, dose-response assessment, exposure assessment, and risk characterization[92]. The goal is to estimate the likelihood and severity of harm to human or ecological receptors given a certain level of exposure to a hazardous agent. Within the context of this study, the hazardous agents are PAHs and heavy metals emanating from cassava processing activities. Hazard identification involves recognizing that certain PAH compounds (like benzo[a]pyrene) and heavy metals (like lead, cadmium) are known carcinogens or toxins. Exposure assessment then considers how people might come into contact with these contaminants – for instance, through ingesting cassava tubers grown in contaminated soil, eating cassava products dried or roasted in environments with PAH-laden smoke, or via drinking water contaminated by processing effluent. A useful conceptual tool here is the Source–Pathway–Receptor model commonly employed in environmental risk

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assessments[2]. In this model, the *source* is the pollution origin (cassava mill waste, smoke, effluent), the *pathway* is how the pollutant travels (e.g., leaching into soil and uptake by crops, or deposition onto crops), and the *receptor* is the endpoint that experiences impact (human consumers, farm animals, or the ecosystem)[93]. Effective risk assessment requires establishing a linkage between source, pathway, and receptor – if any one of these is missing or broken, the risk may be negligible. In the scenario of cassava processing pollution, the linkages are quite evident: the waste (source) contaminates soil and crops (pathway), which then affects humans and wildlife that consume these resources (receptors). By applying risk assessment theory, the study can evaluate questions like: 'What levels of PAHs/heavy metals in cassava pose a significant health risk to consumers?' and 'What is the estimated cancer risk or hazard index for local populations eating contaminated cassava?' This theoretical approach ensures that the research not only documents contamination levels but also interprets their significance in terms of health risk metrics (e.g., comparing concentrations with safety guidelines or calculating risk quotients). In essence, risk assessment theory bridges the gap between raw environmental data and public health decision-making, guiding the study toward outcomes that can inform risk management strategies[94].

2.3.3 Environmental Degradation Models (DPSIR Framework)

Environmental degradation models provide a structured way to understand how human activities lead to environmental change and what consequences ensue. One widely used model in environmental studies is the DPSIR framework, which stands for Drivers–Pressures–State–Impact–Response (Figure 2.1).

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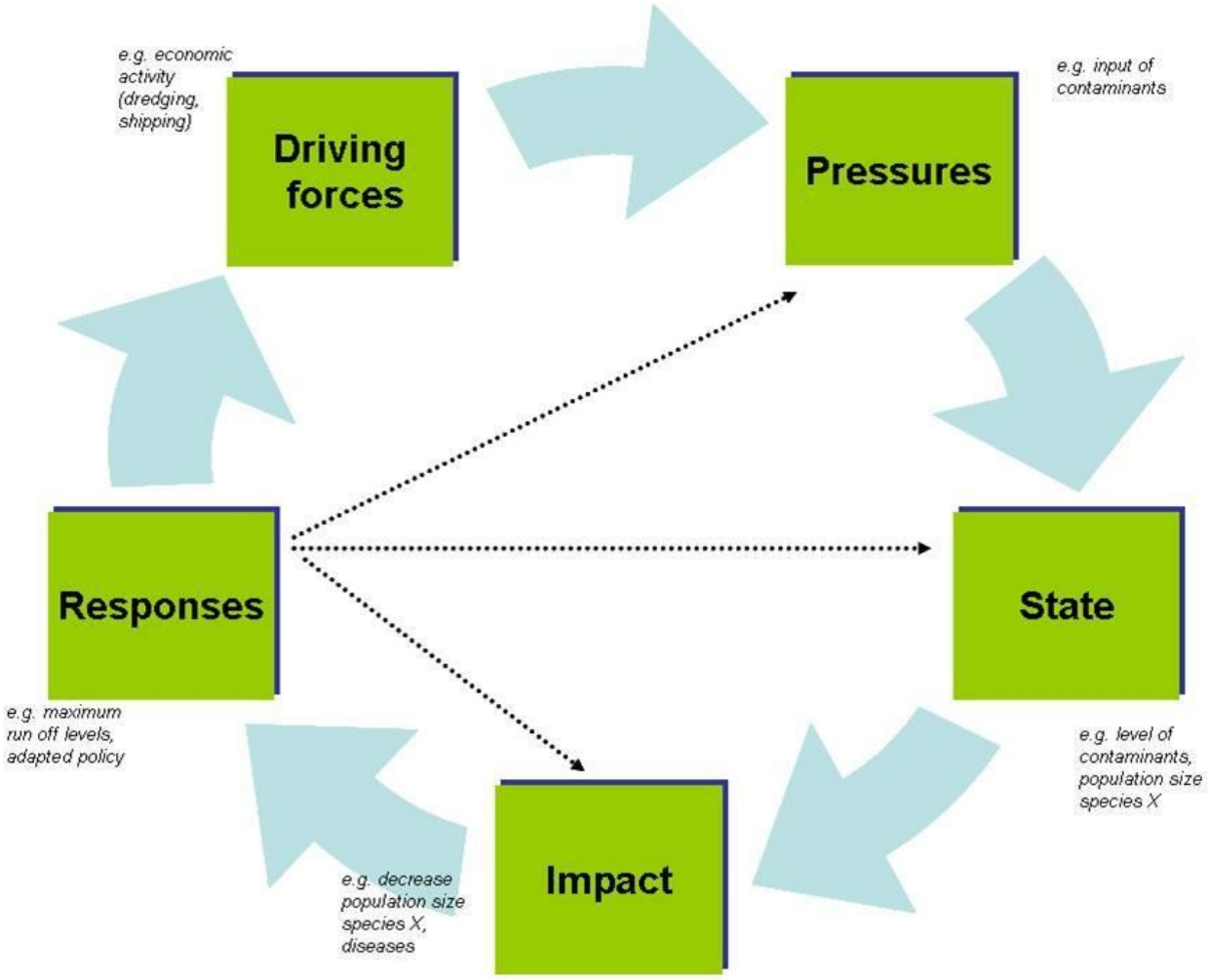


Figure 2.1: DPSIR Feedback Loop

Source: The Organisation for Economic Cooperation and Development

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According to this model employed by the European Environment Agency and others, a Driver such as the demand for cassava products leads to Pressures (direct stresses on the environment, such as waste discharge from processing plants). These pressures change the State of the environment – in this case altering soil and water quality (increased levels of PAHs and heavy metals, lower soil pH, etc.). The changed environmental state causes Impacts on ecosystems and human health: for example, polluted soils can reduce crop yields and contaminate food, and exposure to toxins can affect community health. Finally, society can undertake Responses – such as introducing wastewater treatment, enforcing environmental regulations, or educating farmers on sustainable practices – to mitigate the problem. Applying the DPSIR model to the cassava processing scenario helps conceptualize the cause-effect chain of events: the driver is the agricultural industrial activity (cassava processing driven by economic need and food demand); the pressure is the release of pollutants (effluents, emissions, solid waste dumping); the state is the observed contamination of soils and crops with PAHs and heavy metals; the impact includes degraded soil fertility, polluted food crops, and potential health risks to local populations; and the desired response would be improved waste management, policy intervention, or remediation efforts to restore environmental quality. Using such a model in this theoretical review allows the study to frame its findings within a broader context of environmental management. It emphasizes that the contamination issues at Ido L.G.A are not isolated incidents but are symptomatic of a larger system of interactions between human activities and the environment. Additionally, the DPSIR framework aligns with the study's objectives by underscoring that understanding the current state (contaminant levels in soil/crops) and impacts (risks to health and ecology) is essential for guiding effective responses (recommendations for pollution control and policy). In summary, environmental degradation models like DPSIR provide a

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conceptual roadmap for analyzing the problem: from identifying root causes to recognizing consequences and driving home the need for remedial action.

2.4 Review of Empirical Studies

2.4.1 Previous Studies on PAH and Heavy Metal Contamination in Cassava Processing Areas

In recent years, increasing attention has been given to the environmental and health impacts of cassava processing, particularly in relation to the contamination of soils and crops by Polycyclic Aromatic Hydrocarbons (PAHs) and heavy metals. The importance of cassava in the agricultural economies of many tropical countries, especially in Africa, has led to a substantial body of research exploring the effects of its cultivation and processing on the environment[95]. Cassava, as a primary food source and cash crop, contributes significantly to food security and local economies, particularly in rural areas where it is processed into various products like garri, fufu, and cassava flour. However, as with many agricultural practices, the environmental impact of cassava processing remains a critical area of concern due to the pollutants that are often generated during its preparation, including PAHs and heavy metals. These pollutants not only pose serious risks to the environment but also endanger human health, particularly in communities that are directly involved in the cassava processing industry.

A series of studies have emerged that evaluate the contamination of soil, water, and crops around cassava processing sites, with much of the research focused on Nigeria, a major cassava-producing nation. Nigeria accounts for a large portion of global cassava production, and its cassava processing sector is often characterized by small-scale, traditional practices. These methods, such as open-air roasting, burning of cassava peels, and inefficient use of processing materials, contribute significantly to the release of toxic by-products, including heavy metals and PAHs. These pollutants are harmful because they tend to accumulate in

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the soil, water, and food products, creating long-lasting environmental and health problems[96].

One of the key studies in this area examined the presence of heavy metals in soil samples collected from cassava processing sites in Nigeria. The study focused on the levels of cadmium (Cd), lead (Pb), and arsenic (As), which are known to be toxic and have long-term health effects on humans and animals. These heavy metals were found to be present in significantly high concentrations in soils around the cassava processing areas. The researchers concluded that the presence of these metals could be attributed to the traditional processing methods employed by local farmers, particularly the burning of cassava peels and the use of inefficient cooking materials such as wood. The burning of cassava peels during processing creates a source of pollution that releases these harmful metals into the surrounding environment. In particular, cadmium, lead, and arsenic have the potential to persist in the soil for many years, even decades, posing significant risks to human health, particularly through the consumption of contaminated cassava roots and crops[97].

The findings of the authors were particularly important because they highlighted the persistence of these pollutants in the environment, even after the processing activities have ceased. The study found that these heavy metals did not dissipate over time and instead accumulated in the soil and surrounding vegetation. This accumulation could have serious consequences for the local ecosystem, including reduced soil fertility, contamination of groundwater sources, and the bioaccumulation of metals in crops, which can then be passed on to humans and animals through the food chain. The potential for bioaccumulation in cassava crops was a significant concern, as it could lead to the contamination of both the cassava roots, which are consumed by humans, and the cassava leaves, which are used as animal feed. This would have profound implications for food safety, particularly in rural areas where cassava is a staple food[98].

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Furthermore, the need for more rigorous monitoring and regulation of cassava processing activities in Nigeria were emphasized. While cassava is a vital crop for food security, the environmental cost of its processing cannot be ignored. There is the need for the introduction of cleaner processing technologies that could reduce the emission of pollutants and lower the risks of contamination. This could include the use of improved cooking technologies, better waste management practices, and the development of policies that encourage sustainable agricultural practices among cassava farmers.

Another major contribution to this field came from Oa study on the levels of Polycyclic Aromatic Hydrocarbons (PAHs) in cassava products and their surrounding environments. PAHs are a group of organic compounds that are produced as a by-product of incomplete combustion processes. They are commonly found in the environment in areas where organic materials are burned, and cassava processing is no exception. In Nigeria, the traditional methods of roasting cassava and burning its peels release PAHs into the surrounding environment. These compounds are known carcinogens and mutagens, meaning they have the potential to cause cancer and genetic mutations. The study found that PAHs were present not only in the soil near the processing sites but also in the cassava products themselves, including garri, fufu, and cassava flour. These findings were alarming because they indicated that consumers of cassava-based products could be unknowingly exposed to PAHs, thus increasing the risk of health issues such as cancer, respiratory diseases, and other long-term illnesses[99].

PAHs are particularly concerning because they are persistent environmental pollutants that are difficult to break down. Once they are deposited in the soil or water, they remain for extended periods, continuing to affect the ecosystem and the health of those living in contaminated areas. PAH contamination was most severe near areas where open-air burning

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of cassava peels and other biomass took place. The study also highlighted that the levels of PAHs in the processed cassava products were not within the recommended safety limits set by global health organizations, further emphasizing the need for intervention and the adoption of cleaner processing methods[100].

In addition to the studies mentioned, other research has also pointed to the widespread occurrence of heavy metals and PAHs in cassava processing regions across West Africa. For instance, a study was conducted an extensive study of heavy metal contamination in soils and water around cassava processing sites in southwestern Nigeria in 2016[101]. The authors found that several heavy metals, including cadmium, lead, and nickel, were present at levels above the acceptable limits set by national and international environmental standards. These metals were primarily introduced through runoff from processing sites, as well as through the direct deposition of pollutants from the burning of cassava peels and other organic materials. The researchers emphasized the need for improved waste management and pollution control measures to prevent further contamination of soil and water resources in cassava-producing areas[101].

Similarly, another study examined the health implications of consuming cassava products that had been contaminated by heavy metals in 2017[102]. The study found a significant correlation between the levels of heavy metals in cassava products and the incidence of health issues, including kidney and liver diseases, among people living in cassava-processing communities. The researchers concluded that the bioaccumulation of heavy metals in cassava roots and leaves could result in chronic poisoning over time, especially among individuals who rely heavily on cassava as a staple food[102].

These studies collectively illustrate the severity of the environmental and health risks associated with cassava processing in Nigeria and other parts of Africa. The contamination

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of soil, water, and cassava crops by heavy metals and PAHs is a pressing issue that requires immediate attention from both researchers and policymakers. The studies underscore the need for the introduction of cleaner processing technologies, better waste management practices, and more effective environmental regulations to safeguard both the environment and public health[103].

Another major contribution came from authors who studied the levels of PAHs in cassava products and their surrounding environments[104]. PAHs are released during the incomplete combustion of organic materials like cassava peels and wood used in processing. This study found that PAHs, particularly benzo[a]pyrene, were present in both the soils near processing sites and in the processed cassava products, including garri and starch. The study concluded that the contamination from these compounds could potentially contribute to significant health risks such as cancer and respiratory diseases[104].

In a similar study, other authors focused on the distribution of heavy metals in cassava-processing environments in southwestern Nigeria. Soil, water, and cassava root samples were analyzed for heavy metals, with alarming results indicating that the metal concentrations in the soil were well above the recommended limits set by environmental agencies. This research highlighted that runoff from contaminated soils could carry metals into water bodies, exacerbating the pollution and posing additional risks to communities that rely on these water sources for drinking and irrigation[105].

One particularly striking finding came from a study which investigated the health implications of consuming cassava products contaminated with heavy metals. This study focused on the city of Ibadan, where cassava processing is a widespread activity. The study showed a correlation between high levels of heavy metals in processed cassava products and the incidence of chronic diseases, including kidney and liver damage, among the local

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population[106].

2.4.2 Studies on Cassava Processing Waste and Soil/Crop Contamination in Nigeria

Research on the environmental impact of cassava processing in Nigeria has grown in recent years, though it remains relatively limited compared to studies on other forms of agricultural pollution. One of the pioneering studies in this area assessed heavy metal contamination in soils around cassava processing mills in Delta State, Southern Nigeria[4]. Their study found that soils at cassava mill sites did contain elevated levels of metals like cadmium (Cd), zinc (Zn), copper (Cu), and nickel (Ni) compared to control sites, although most metal concentrations were below national intervention values. Notably, the researchers reported that anthropogenic inputs from cassava mill activities contributed significantly to the soil metal loads (except for some elements like Pb which remained low), indicating that the processing operations were indeed introducing contaminants into the local soils[107]. They observed that top soils closer to processing areas had higher metal concentrations than subsoils or distant soils, a pattern consistent with surface deposition of waste and wastewater around the mills. While the heavy metal levels were often below regulatory limits, the presence of any number of toxic metals was flagged as a concern for long-term soil health and the risk of groundwater contamination. This study is significant as it empirically confirmed that small-scale agro-processing can be a point-source of heavy metal pollution in rural environments.

Subsequent studies have reinforced and expanded upon these findings. For instance, investigations of soil contamination were carried out in the Niger Delta region of Nigeria focusing on cassava mill effluents. In one study, they measured heavy metal

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concentrations in soils receiving cassava mill waste and applied indices such as the Geo-accumulation Index and Enrichment Factor. Their results showed that certain heavy metals (notably chromium, zinc, and iron) were enriched in effluent-impacted soils relative to background levels, with contamination severity ranging from moderate to significant depending on the metal and site. The authors also performed an ecological risk assessment and found that the levels of some metals could pose ecological risks, and by extension potential health risks, especially if farmlands are irrigated with or located near these effluent discharges. They highlighted cassava mill effluent as an under-recognized source of rural pollution, noting its low pH and high organic content can facilitate the leaching of metals and other pollutants into the soil profile. These studies in the Niger Delta underscore that the issue is not isolated to one state; across Nigeria's cassava-producing regions, effluent management practices are often poor, leading to repeated observations of soil contamination around processing sites.

Another pertinent study which examines heavy metal pollution arising from cassava processing in a central Nigerian context. Heavy metal levels in and around cassava processing mills in Benue State (Central Nigeria) and reported detectable concentrations of metals such as lead, cadmium, and copper in both the processing waste and adjacent soils. Their paper, titled "Heavy Metals on Cassava Processing and the Environmental Effects in Central Nigeria," noted environmental effects including decreased soil pH and altered microbial counts in soils exposed to cassava waste, alongside the presence of toxic metals in those soils (though often within allowable limits)[108]. The significance of this central Nigerian study lies in its contribution to the geographic breadth of evidence: it suggests that cassava processing-related contamination is a widespread phenomenon, not confined to the well-studied southern Niger Delta alone. It also brought attention to the awareness levels of local processors, finding that many were unaware of the environmental effects of their waste

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disposal practices – a gap that points to the need for education as part of mitigation.



Figure 2.2: Cassava Processing in Nigeria (a.) Peeled Cassava (b.) Grating Cassava (c.) Cassava Peels

Source: Author's Field Work, 2025

2.4.3 PAHs and Cassava Processing- Nigerian Case Studies

While heavy metals have been the focus of numerous studies, research on PAH contamination related to cassava processing is comparatively sparse. However, there are studies in related domains that illustrate the risks of PAH deposition in agricultural products under certain conditions. A study investigated PAHs and trace metals in tubers and fruits from oil and gas flaring impacted communities in the Niger Delta, which, although not about cassava processing, provides relevant insights. In their results, cassava tubers harvested from areas near gas flares contained total PAH concentrations on the order of 3–4 mg/kg, significantly higher than those from control areas. This demonstrated that PAHs emitted into the air (in that case from petroleum activities) can deposit on or be absorbed by food crops, including cassava, leading to contamination of edible tissues. The authors warned that consumption of such contaminated cassava could pose health concerns, given the carcinogenic nature of certain PAHs[109]. By analogy, in cassava processing areas where biomass is burned (e.g., burning of cassava peels or use of firewood for roasting), one might expect PAH generation and deposition on nearby crops and soils. Indeed, anecdotal evidence and local observations in southwestern Nigeria suggest that traditional garri frying, which produces a lot of smoke, may elevate PAH levels in the immediate vicinity, potentially affecting the quality of the garri and other foodstuffs processed or stored nearby.

A direct empirical study on PAHs in cassava processing environments was conducted. It focused on the occurrence of polycyclic aromatic hydrocarbons in Nigerian cassava processing areas. Although the detailed findings of this study are not reproduced here, the reference indicates that its likely quantified PAH concentrations in environmental samples (soil or cassava products) from cassava processing sites. The inclusion of such a study in recent literature highlights growing scholarly recognition of PAHs as contaminants of concern alongside heavy metals in agro-industrial settings. The expectation from this

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study is that it provided data on PAH profiles and levels in and around cassava processing locations, possibly identifying key PAH compounds present and comparing them to safety benchmarks. This complements earlier studies of PAHs in foods (for example, studies have found PAHs in smoked dried fish and bush meats in Nigeria at concerning levels, showing that traditional food processing methods can introduce PAHs[5]). In the absence of many studies focusing specifically on cassava, we extrapolate from these related findings that cassava products processed with charring or smoking could contain PAH residues, and soils where processing byproducts are burned could likewise accumulate PAHs. More targeted research is clearly needed in this niche, but the existing empirical evidence justifies including PAHs in any comprehensive assessment of cassava processing pollution.

2.4.4 Nigerian Studies on Food Crop Contamination and Health Risk

The health and environmental risks associated with Polycyclic Aromatic Hydrocarbons (PAHs) and heavy metals in agro-industrial settings, particularly in cassava processing, are significant and multi-faceted. PAHs, which are formed through incomplete combustion of organic materials such as cassava peels, are among the most concerning pollutants due to their carcinogenic and mutagenic properties. When these compounds accumulate in the environment, they pose long-term threats to human health. Studies have shown that exposure to PAHs is linked to various types of cancer, including skin, lung, and bladder cancer, due to their ability to interfere with cellular DNA and induce mutations[110]. In addition to their carcinogenic nature, PAHs are also responsible for developmental issues, particularly in children, where exposure to these compounds can result in neurological disorders and cognitive impairments[111].

Heavy metals such as lead, cadmium, arsenic, and mercury, commonly found in cassava processing waste, represent another major health hazard. These metals, when introduced

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into the environment, do not degrade over time, and their toxic effects can persist for years. Lead, for example, is a neurotoxin that is particularly harmful to children, leading to developmental delays, reduced IQ, and attention deficits. Cadmium is known to accumulate in the kidneys and liver, causing damage to these organs and increasing the risk of kidney disease, while long-term exposure can also lead to bone demineralization. Arsenic, a potent carcinogen, is responsible for various cancers, including lung and skin cancer, as well as skin lesions and cardiovascular diseases[112]. Furthermore, mercury is associated with neurological disorders and damage to the gastrointestinal system, particularly when exposed in larger quantities over time.

The environmental risks associated with PAHs and heavy metals are equally alarming. These pollutants can contaminate soil, water, and air, leading to ecological damage. PAHs in particular are persistent in the environment, meaning they do not break down easily and can accumulate in the food chain. Soil contamination from PAHs can affect plant growth and the overall health of agricultural systems, leading to reduced crop yields and degraded soil fertility[113]. Heavy metals, on the other hand, can leach into groundwater sources, leading to the contamination of drinking water supplies and further exacerbating the potential health risks. In some cases, these metals can also enter aquatic ecosystems, affecting aquatic life and biodiversity. Additionally, atmospheric deposition of heavy metals can result in long-distance pollution, contaminating areas far removed from the original source[114].

Given the widespread contamination risks and potential health effects, it is crucial to implement strategies to mitigate the environmental impact of cassava processing. These strategies may include the use of cleaner production technologies, the treatment of effluents before they are discharged into the environment, and the introduction of environmentally sustainable cassava processing methods. The introduction of stricter environmental

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regulations and monitoring systems could also help to limit the levels of PAHs and heavy metals in agricultural areas. Through these efforts, the negative health and environmental impacts of cassava processing can be reduced, promoting safer and more sustainable agricultural practices.

Beyond cassava-centric research, it is instructive to look at the broader body of Nigerian studies on crop contamination by industrial activities. The impact of cassava processing on soil and water quality in a Nigerian community. This reports that improper disposal of cassava wastewater led to elevated chemical oxygen demand (COD) and lowered pH in surrounding water bodies and also noted trace amounts of heavy metals in soils near processing sites (attributed to the use of contaminated water and utensils in processing). Similarly, the study of environmental pollution from cassava processing shows that high cyanide concentrations from cassava effluents were affecting soil microbiota and that heavy metal traces were present in effluent-discharge sites, though not at acutely toxic levels. Both studies called for better waste management practices, such as neutralization of effluents and designated soak-away pits, to mitigate pollution.

In southwestern Nigeria, some research has been done on roadside and urban garden contamination that, while not about cassava processing, sheds light on the issue of crops accumulating pollutants. For instance, heavy metal accumulation in cassava leaves grown along busy roads in Ogbomoso, Nigeria, has higher levels of Pb and Cd in their leaves compared to rural farm controls (due to vehicular emissions)[115]. This underscores that cassava plants can uptake pollutants from their growing environment, whether the source is traffic or industrial waste.

As for health risk assessments in Nigeria related to contaminated foods, a few studies have attempted to quantify the risk to consumers. The cassava effluent-contaminated soil

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conducted an ecological and health risk assessment of heavy metals. They computed indices such as the Hazard Quotient (HQ) for heavy metals if cassava grown on such soil were consumed. Their findings, as referenced, suggested that certain metals (e.g. cadmium) could pose non-carcinogenic health risks to local consumers if exposure was continuous. Moreover, general reviews on PAHs in Nigeria have indicated that food consumption is a major exposure pathway for PAHs for Nigerians, with several studies documenting PAH presence in popular smoked or roasted foods[6]. Cassava products, being a dietary staple, would be a critical part of such exposure if they contain these contaminants.

In summary, empirical studies in Nigeria relevant to this dissertation show a consistent pattern: cassava processing activities can introduce both heavy metals and PAHs into the local environment, contaminating soils and sometimes crops. Documented cases range from the Niger Delta to the Middle Belt, demonstrating the geographic spread of the issue. The contamination levels reported are variable – often below strict regulatory limits, but still above natural background and enough to raise concerns due to the cumulative exposure of local populations. These studies also highlight a gap in knowledge on PAHs in these contexts, as well as a need for interdisciplinary approaches (combining soil science, food chemistry, and toxicology) to fully evaluate the implications. The literature provides evidence for the problem this study addresses and guides the methodology (e.g., which contaminants to measure, what sample media to focus on, and what risk models to apply). Crucially, they reinforce the rationale for this research: given Nigeria's status as the world's largest cassava producer and the prevalence of rudimentary processing techniques, understanding and managing the environmental contaminants arising from cassava agro-industries is key to safeguarding both environmental quality and public health[116].

2.5 Theoretical and Conceptual Framework

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Drawing on the concepts and theories reviewed, this study is guided by an integrated theoretical framework that links environmental contamination to health outcomes in an agro-ecological system. The framework can be visualized as a flow from pollution source to human impact, underpinned by ecological and risk assessment principles:

(a) **Pollution Source (Driver/Pressure)**: The cassava processing activities in Ido L.G.A serve as the starting point. Here, Bronfenbrenner's ecological model would situate these activities in the community's environment (exosystem), acknowledging that socio-economic drivers (like demand for cassava products and livelihood needs) are the motivations behind the processing (a **Driver** in DPSIR terms). The processing itself exerts **Pressures** on the environment by releasing wastes (solid, liquid, gaseous). This study specifically looks at two pressure agents: PAHs (from combustion processes) and heavy metals (from wastes/effluents) emitted by the processing operations.

(b) **Environmental Pathway and State Change**: Once released, these pollutants enter environmental media – soil (and to some extent water and air). The Source–Pathway–Receptor model is useful here: the contaminants move through pathways such as percolation into soils, adsorption onto soil particles, uptake by plant roots, or deposition onto crop surfaces[3]. The presence of contaminants alters the state of the local environment, which we measure as the concentrations of PAHs and heavy metals in soil and cassava crop samples. This altered state is characterized by contaminated soil chemistry (possibly lower pH, presence of toxins) and contaminated plant tissues. In the conceptual framework, this corresponds to the "Environmental Contamination" box – essentially, the new steady state of the environment under pressure from cassava processing pollution.

(c) **Exposure and Receptor**: The next part of the framework deals with how this

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contamination translates into exposure for receptors. The primary receptors of concern are human consumers (residents who eat cassava from these farms or drink from local water sources) and the ecosystem itself (soil biota, plants, perhaps livestock). The framework incorporates Risk Assessment Theory by delineating exposure routes: ingestion of contaminated cassava tubers is the key exposure pathway for humans, while soil organisms are directly exposed to contaminants in their habitat. We consider the intensity and frequency of these exposures (e.g., how much cassava a typical person consumes from local farms per day) to evaluate risk. This portion of the framework aligns with the impact in DPSIR – the consequences of the state change. Impacts include potential health effects on humans (e.g. elevated cancer risk from PAHs, heavy metal poisoning symptoms over long-term) and ecological effects (e.g. reduced crop productivity, biodiversity loss in soil fauna).

(d) **Moderating Factors and Context**: The framework also acknowledges that certain factors can influence the severity of outcomes. Borrowing from Ecological Systems Theory, one can see how factors at various levels play a role – for instance, individual behaviour (microsystem), such as whether farmers peel cassava and discard peels in fields or whether they wash roots thoroughly, can affect contamination levels on the food. Community practices (mesosystem), like communal dumping sites or burning practices, can modulate how concentrated the pollution is. Broader forces (macrosystem), including the enforcement of environmental regulations or availability of cleaner processing technology, also come into play. These contextual factors are integrated into the conceptual framework as influencing variables that can exacerbate or mitigate risk.

(e) **Response and Feedback**: Finally, the framework envisions a feedback loop consistent with DPSIR's response element. Based on the findings (the measured

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contamination and assessed risks), responses could include interventions such as introducing sedimentation pits for effluent, training for processors on proper waste disposal, phytoremediation of contaminated soils, or policy measures by local authorities. The conceptual model is thus not static; it is oriented towards informing action. Any such responses would ideally reduce future pressures (for instance, treating effluent to remove cyanide and metals before discharge) and thereby improve the state of the environment, creating beneficial feedback.

This integrated theoretical framework ensures that the study does not view the issue narrowly. Instead, it recognizes the complex system of interactions at play – exactly as theories like Bronfenbrenner's and DPSIR encourage us to do. It also sets the stage for the methodology and analysis: we will measure the state (contaminant levels), evaluate impacts (by comparing to safety standards or performing risk calculations), and discuss responses (recommendations), thereby covering all components of the framework. The strength of this approach is that it connects the empirical data to real-world outcomes and management, guided by established theoretical insights into how environmental problems develop and can be addressed[117].

2.6 Summary of Gaps in the Literature

The above review reveals that while some research has been conducted on PAHs and heavy metals in relation to cassava processing, there are notable gaps and limitations in the existing literature. First, few studies have simultaneously addressed both PAHs and heavy metals in cassava processing contexts. Most of the Nigerian studies tend to focus on heavy metal contamination of soils (as these are easier to analyse and have well-established protocols), whereas PAH contamination in cassava processing environments remains underexplored. This gap is critical because communities are exposed to a mixture of pollutants in reality –

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thus a holistic assessment is needed[118].

Second, there is a geographical and contextual gap. Much of the research attention has centered on the Niger Delta region (likely because of its history of oil pollution which spurs interest in environmental studies). Regions like Ido Local Government Area in Oyo State (and many other high cassava-producing areas in southwestern and middle-belt Nigeria) have been underrepresented in empirical studies. The environmental dynamics in these areas might differ from those in the Niger Delta (for instance, different soil types, processing practices, or regulatory oversight), so it is not guaranteed that findings from one region generalize to another. This study aims to fill that gap by providing data from Ido L.G.A., thereby broadening the national dataset on cassava-related pollution.

Another gap lies in the depth of risk analysis in existing studies. While several works have measured contaminant levels, fewer have translated these into assessments of risk to human health or ecological integrity. For example, heavy metal concentrations might be reported without reference to food safety standards or without calculating how hazardous those levels are to consumers. As a result, policymakers and local stakeholders may not grasp the full implications. The literature would benefit from more studies that connect the dots between contamination data and health risk outcomes (e.g., computing the hazard index for consuming cassava with a given concentration of lead). By incorporating a risk assessment component, this dissertation addresses this shortcoming.

Additionally, the effect of processing methods on contamination is not well documented in the literature. Cassava processing can vary from traditional methods (open fires, manual grating and pressing) to more mechanized or improved methods. There is a paucity of studies comparing pollution levels arising from different processing techniques. Such insights could be valuable for recommending technology upgrades or best practices. The current

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literature does not provide clear guidance on whether, for instance, the introduction of improved processing ovens or better waste containment significantly reduces PAH or heavy metal contamination. This study, through field observations and literature synthesis, will attempt to highlight these aspects and suggest where further research is needed.

Methodologically, many existing studies have relatively small sample sizes or narrow scopes – for instance, sampling only soil and not the crops, or examining one heavy metal in isolation. This creates a gap in understanding the full spectrum of contamination. The present study is designed to be more comprehensive by analyzing multiple media (soil and cassava tubers) and multiple contaminants (a suite of heavy metals and a range of PAH compounds). It thereby contributes a more complete picture, addressing the multi-faceted nature of the pollution problem.

Finally, a significant gap is in the translation of research to practice. Literature indicates the problems (contaminated soil, toxic cassava effluent, etc.), but there is often a missing link regarding feasible mitigation strategies in rural Nigerian contexts. Few studies go beyond stating that pollution exists to discussing how it could be remedied or what barriers exist to implementing solutions (such as poverty, lack of awareness, or policy enforcement challenges). This dissertation intends not only to identify pollution levels but also – through its discussion and conclusions – to bridge this gap by suggesting practical interventions and highlighting the need for capacity-building among local processors.

In summary, the existing body of work confirms that cassava processing can impact environmental quality, but it leaves several questions unanswered. There is a need for more comprehensive, region-specific, and risk-oriented research – a niche that this study aims to fill. By focusing on an area (Ido L.G.A.) not extensively studied before, by including both organic and inorganic pollutants, and by framing the results in terms of health and

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ecological risk, this work will address the outlined gaps. It will also provide a foundation for future research to build upon, such as longitudinal studies on pollutant accumulation or intervention-based studies to test mitigation effectiveness. In doing so, it hopes to move the discourse forward from merely recognizing problems to formulating science-based solutions for the cassava processing industry's environmental challenges.

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Chapter Three

Methodology

3.1 Description of the Study Area

This study was carried out in Ido Local Government Area of Ibadan, Oyo state, Nigeria. Cassava processing sites in his semi-rural region, characterized by extensive cassava farming and small-scale garri production were used as sampling locations. Ido local government comprises multiple villages (such as Apata, Omi-Adio, Akufo, Orile-Ilugun, Ilaju, and Apete), and is basically an agrarian region with small scale industries focusing majorly on cassava processing (Fig. 3.1).

The communities in the study area are primarily rural and agriculturally driven. In all three sites visited, cassava is the central crop, and it is cultivated extensively on surrounding farmland. Farmers bring in fresh cassava roots daily from their farms, often in large quantities. Processing centers, most of which are manually operated, convert the cassava into popular local products such as garri and fufu. These products are not only consumed locally but are also distributed to other parts of the state and beyond.

At each local cassava mill, farmers grated and pressed fermented cassava mash to produce starch or garri, discharging the residual cassava mill effluent (a cyanide-rich, acidic wastewater) directly onto nearby land or into shallow pits. The pervasive sour odour and pale coloration of the effluent-soaked soils are evident at the sampling area.

While the economic value of cassava in these areas is undeniable, the environmental costs are equally visible. In some locations, I observed stagnant pools of water near processing areas, darkened by residues and releasing foul odour. These are likely sources of Polycyclic Aromatic Hydrocarbons (PAHs) and other pollutants. Furthermore, the residues left

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after processing are often dumped indiscriminately, or burnt in open air-practices that could release harmful substances into the soil, air, and nearby water bodies.

The dispersed nature of cassava processing centers, combined with the lack of coordinated environmental safeguards, makes Ido LGA an important yet vulnerable site for studying the environmental impact of agro-industrial activities. My journey through the area provided more than just data; it painted a clear picture of the tension between economic sustainability and environmental health in rural agricultural communities.

In addition to these firsthand observations, it became clear that both traditional and mechanized cassava processing methods coexist in Ido LGA, each contributing uniquely to the region's environmental footprint. Traditional processing units are typically small-scale, often family-run, and situated near residential compounds or farmlands. These setups usually rely on manual labor, with minimal technical input and virtually no structured waste disposal systems. In contrast, the more industrialized facilities-though fewer in number-utilize equipment like hydraulic presses and mechanical graters to increase output. However, these mechanized centers often lack proper effluent treatment facilities, thereby releasing large volumes of untreated wastewater directly into the environment.

Cassava effluents observed during the field visits were visibly thick and milky, a by-product of the fermentation and pressing processes. These effluents are known to contain high levels of organic matter, including linamarin-a precursor to cyanide-and other compounds that pose serious risks to both soil health and aquatic ecosystems. In several sites, runoff from these effluents was seen flowing into nearby streams and irrigation channels, raising concerns about long-term contamination of water sources vital for both domestic use and crop cultivation.

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Furthermore, waste generated from peeling and grating, along with burnt cassava residues, is often dumped in open fields or drainage paths. During interviews with local workers and farmers, it was evident that awareness of the long-term environmental implications of these disposal practices was limited. While some acknowledged the foul smell and occasional crop discoloration, most considered these issues as unavoidable consequences of a necessary livelihood.

The proximity of processing sites to farmland and water bodies amplifies the risk of cross-contamination. In many of the locations, processing units were less than 50 meters away from cultivated plots or water channels, which facilitates the easy transfer of contaminants. This close interface between processing activity and natural resources highlights the urgent need for environmental monitoring and regulation, particularly regarding the presence and accumulation of hazardous substances such as Polycyclic Aromatic Hydrocarbons (PAHs).

Given cassava's economic and nutritional importance in the region, sustainable processing practices are essential. Without proper intervention, the continuous discharge of untreated waste and effluents threatens not only the ecological balance but also the agricultural productivity and public health of these rural communities. This calls for a strategic framework that balances cassava's economic benefits with proactive environmental management—ensuring that development in Ido LGA remains both productive and sustainable in the long term.

These environmental realities informed the design of the sampling strategy adopted for this research. In order to comprehensively assess the extent of contamination resulting from cassava processing activities across the region, three major cassava processing communities were selected**:** Omi Adio**,** Orile-Ilugun**,** and Ilaju**.** These locations are representative of the broader cassava agro-industrial ecosystem in Ido LGA. They not only reflect the spatial

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dispersion mentioned earlier but also embody a variety of processing intensities, proximity to water bodies, and environmental management practices-or lack thereof.

3.1.1 Population and Sample

The population of interest included all cassava processing sites and the surrounding agricultural lands in Ido LGA. For practicality, a purposive sampling approach was used to select representative cassava processing centres known for high production volumes and continuous effluent discharge. A total of three (Omi-Adio, Orile-Ilugun, and Ilaju) cassava processing sites were selected, encompassing different communities within the LGA to capture geographic variability. At each site, the target sample types were soil (at depths of 0-30 cm), cassava plant leaves, and cassava wastewater (effluent)[1].

3.1.2 Sampling Technique and Layout

Within each selected processing site, samples were collected along a transect radiating outwards from the effluent source to represent a gradient of exposure. Four distances were established for sampling: 0 m, 50 m, 200 m, and 1 km from the effluent discharge point. The 0 m location (often at the point where effluent is released onto soil) captures maximum impact, while 50 m and 200 m sites represent intermediate exposure as one move away from the cassava mill. The 1 km site served as a control, located in the same general area but sufficiently far (≥1000 m) from any cassava effluent influence. This control site was typically upwind/upstream and outside the drainage path of the processing waste, chosen to reflect baseline environmental conditions[2]. At each distance, sampling was done in triplicates. In practice, multiple subsamples were taken and later composited to form a representative sample per distance. The sampling layout is thus a nested design: at each of 3 sites, samples were taken at 4 distances, with each sample type collected in triplicate.

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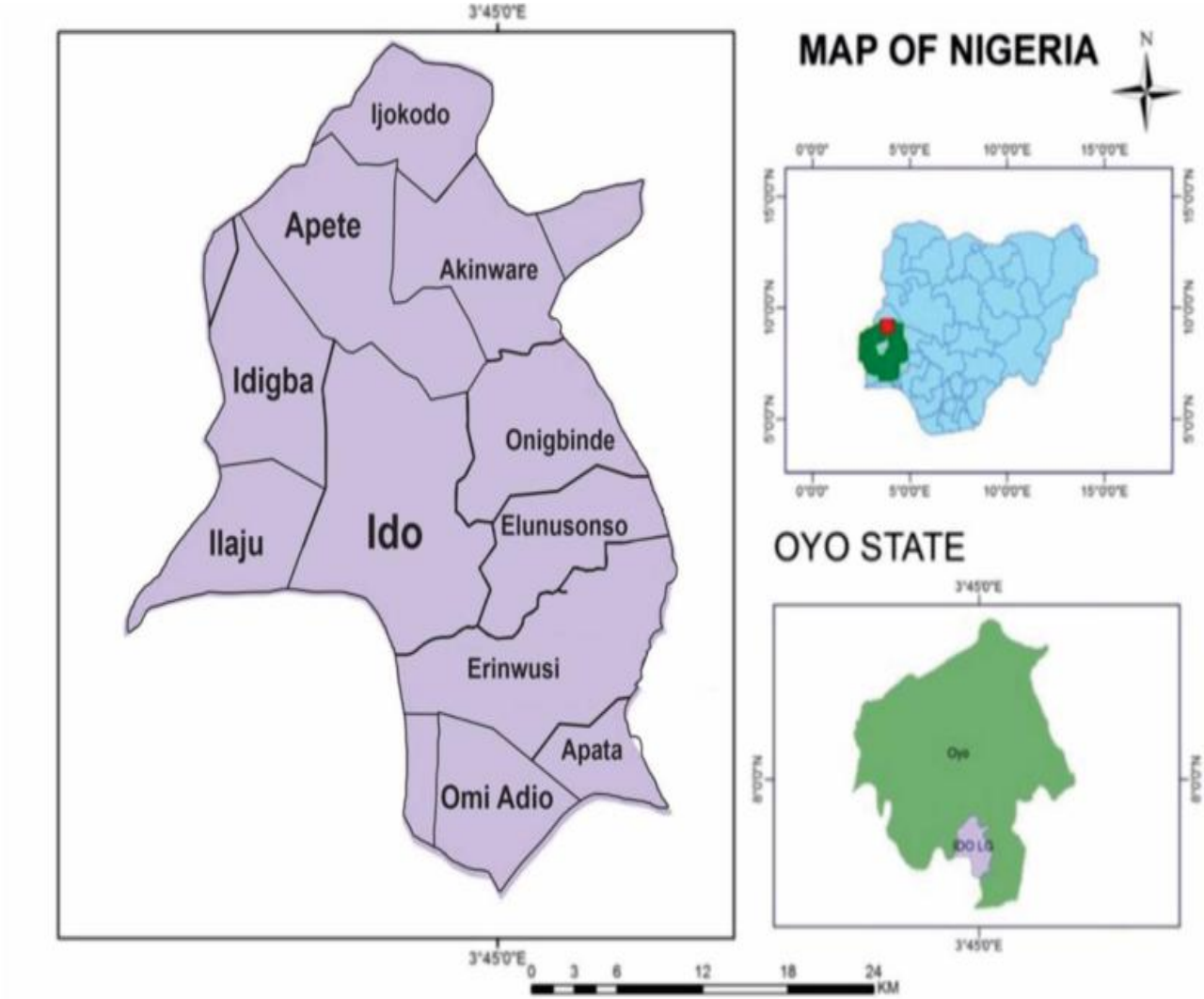


Figure 3.1: Map showing the location of Ido community

Source: Author's Field Work, 2025

3.2 Sample Collection

3.2.1 Soil Samples

At each of the four designated distances (0 m, 50 m, 200 m, 1 km) from a cassava processing point, soil samples were collected from two depth intervals – topsoil samples were taken from 0–15 cm depth, while subsoil samples were taken from 15–30 cm depth, using a clean stainless steel hand auger or soil corer[3]. Three subsamples from the vicinity (within a 5 m radius of the distance marker) were combined to form a composite sample for that depth and distance. The composite was placed in a pre-cleaned plastic sample bag. Large stones, roots, and debris were manually removed from the sample[4]. The soil samples were air-dried for 72 hours to reduce moisture, then gently crushed with a sterile mortar and pestle. Sieved through a 2 mm mesh (for homogenization) and then through a 0.5 mm sieve for the portion intended for chemical analysis[5]. Each processed soil sample was stored in an acid-washed polypropylene container, labelled with the site, distance, and depth, and kept in a cool, dry place prior to analysis.

3.2.2 Cassava Plant (Leaf) Samples

Cassava leaves were sampled from cassava plants present at or near the same 0 m, 50 m, 200 m, and 1 km points. At each location, several cassava plants (3–5 plants) were selected randomly (or at 0 m, the plants visibly growing on effluent-exposed soil were chosen). From each plant, a few mature green leaves (third or fourth fully-expanded leaves from the top of the cassava stem) were cut using a stainless-steel knife and pruning shears. The leaves (petioles removed) from the multiple plants were combined into one composite leaf sample per location to account for plant-to-plant variability. The composite fresh leaves were placed in clean paper bags. In the field, the leaves were gently rinsed with distilled water to remove surface dust or soil particles, then air-dried. In the lab, the leaves were further processed: they

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were oven-dried at 60 °C to constant weight (to prevent mould and to stop enzymatic activity). The dried leaves were then ground into fine powder using a clean ceramic mortar sieved (<0.5 mm) and stored in a sealed polyethylene bag for subsequent analysis of contaminants.

3.2.3 Cassava Effluent (Wastewater) Samples

Fresh cassava mill effluent was collected directly from each processing site (typically at the point of discharge from the press or collection pit). Using sterile polypropylene bottles (1 litre capacity), samples of the liquid effluent were carefully taken. If the effluent was flowing, the bottle was held mid-stream (to avoid sediment) and allowed to fill; if it was pooled, the sample was scooped from just below the surface. About 2–3 litre of effluent was collected per site to ensure sufficient volume for all laboratory analyses. Immediately upon collection, the effluent samples were sealed and placed in a cooler with ice packs at ~4 °C to preserve their integrity[6]. The opaque sample kegs protected the samples from sunlight, which is important because parameters like biochemical oxygen demand (BOD) or certain metal species could change with biological activity or photolysis. All effluent samples were collected during active processing periods to ensure they were fresh and representative (cassava effluent characteristics can vary daily, so timing was coordinated with processing schedules)[7].

All collected samples were transported under sterile, controlled conditions to the laboratory for analyses. The soil and plant samples, being dry, were kept in clean dry boxes, while the effluent samples remained in the iced cooler. At the laboratory, samples were stored appropriately (effluents refrigerated at 4 °C, soils and plant powders at room temperature in a desiccated environment) until analysis commenced.

3.3 Sample Analyses

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The analysis phase was subdivided based on sample type, with standardized procedures applied to each category of sample. All methods were selected to quantify either polycyclic aromatic hydrocarbons (PAHs) or heavy metals (the target contaminants), as well as general physicochemical parameters of environmental significance. Analyses followed internationally recognized standard methods (such as APHA Standard Methods or ASTM protocols) to ensure accuracy and comparability[8].

3.3.1 Crop Analysis (Cassava Leaves)

3.3.1.1 Heavy Metal Analysis in Leaves

The concentrations of heavy metals in cassava leaves (specifically, metals of concern such as lead (Pb), cadmium (Cd), chromium (Cr), zinc (Zn), nickel (Ni), and possibly iron (Fe) and copper (Cu)) were determined by atomic absorption spectrophotometry (AAS). Prior to AAS measurement, the leaf samples underwent acid digestion to extract the metals into solution. Approximately 1.0 g of the dried leaf powder was weighed into a borosilicate glass digestion flask. A mixture of concentrated acids – typically nitric acid (HNO_3) and perchloric acid ($HClO_4$) in a ratio of 4:1 – was added to the sample. (This nitric-perchloric acid digestion is a standard method for plant tissues, effectively destroying organic matter and releasing metals into the liquid phase). The flask was heated gently on a hotplate under a fume hood until dense white fumes cleared, indicating the completion of digestion. After cooling, the digest was filtered (Whatman No. 42 filter paper) into a 50 mL volumetric flask and diluted to volume with deionized water. This clear solution – containing the dissolved metals from the plant – was then analysed by AAS. The AAS instrument was calibrated with certified standard solutions for each target metal (for example, Pb at 283.3 nm, Cd at 228.8 nm, etc.)[9]. Calibration curves with multiple points were run to ensure linearity, and a blank digest (with no plant material) was also prepared to check for contamination. Each metal's concentration

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in the leaf digest was read at the appropriate wavelength and optimized lamp conditions on the AAS, following the instrument's standard conditions. Quality control measures included analysing a standard reference plant material and spiking a sample with a known metal amount to check percent recovery. Heavy metal concentrations were reported in milligrams of metal per kilogram of dry leaf (mg/kg dry weight).

3.3.1.2 PAH Analysis in Leaves

To assess polycyclic aromatic hydrocarbon contamination in cassava leaves, a solvent extraction followed by chromatographic analysis was performed. About 10 g of dried cassava leaf powder was placed in a Soxhlet extractor thimble. PAHs were extracted using an organic solvent mixture (commonly n-hexane: acetone or dichloromethane) over a period of several hours (e.g., 6–8 h)[10]. The warm solvent continuously cycled through the sample, dissolving PAH compounds out of the plant matrix. The resulting extract was concentrated (evaporated) to a small volume (1–2 mL) using a rotary evaporator at low temperature. This concentrate was then subjected to gas chromatography–mass spectrometry (GC–MS) analysis, following the U.S. EPA Method 8270 protocol for semi-volatile organics[6]. Before GC–MS injection, an internal standard mix of deuterated PAHs was added to each sample extract to aid quantification and recovery tracking. The GC–MS was operated in selected ion monitoring mode targeting the PAH compounds of interest (such as naphthalene, phenanthrene, fluoranthene, chrysene, benzo[a]pyrene, etc.). The separation occurred on a fused-silica capillary column, and the mass spectrometer scanned diagnostic fragment ions for each PAH. Identification of each PAH in the cassava leaf extract was based on matching retention times and mass spectra with those of authentic standards. Quantification used the internal standard method, comparing the peak areas of target PAHs to those of calibration standards run under identical conditions[6]. Standard quality checks (including calibration verification, method blanks, and replicate analyses) were implemented according to EPA 8270

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guidelines. The results were expressed in micrograms of PAH per kilogram of leaf (µg/kg dry weight). This method aligns with widely accepted procedures for PAH determination in environmental plant samples – solvent extraction followed by GC–MS provides both sensitivity and specificity for detecting the suite of priority PAHs[10]. Detecting PAHs in cassava leaves can indicate atmospheric deposition of these pollutants (e.g. from burning biomass or vehicular emissions) or uptake from contaminated soils; however, cassava leaves are not typically a significant sink for PAHs, so detection (if any) was expected to be low.

3.3.2 Soil Analysis

The soil samples (topsoil and subsoil composites from each distance) were subjected to a comprehensive set of analyses to characterize both their general physicochemical properties and the levels of contaminants (heavy metals and PAHs).

3.3.2.1 Physicochemical Parameters of Soil

Several key soil properties were measured using standard soil science methods to understand the baseline soil conditions and possible impact of cassava effluent:

(a) **pH:** Soil pH was determined in a 1:2.5 soil-to-water suspension using a calibrated digital pH meter[11]. For each sample, 10 g of air-dried soil was mixed with 25 mL of distilled water and shaken for 30 minutes. After allowing the suspension to settle, the pH electrode (glass electrode) was inserted into the supernatant and the reading recorded once stabilized[12]. The pH meter was standardized with pH 4.0, 7.0 (and 10.0 if needed) buffer solutions before measurements. This method corresponds to **AOAC** and **APHA** standard procedures for soil pH[12]. Soil pH is important as cassava effluent can be acidic; changes in soil pH at effluent-exposed sites could indicate buffering or acidification due to the waste.

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(b) **Total Organic Carbon (TOC):** The organic carbon content of the soil was measured by the Walkley-Black wet oxidation method[13]. In this classic procedure, ~0.5 g of finely ground soil was treated with a known excess of 1 N potassium dichromate ($K_2Cr_2O_7$) solution and concentrated sulfuric acid, which oxidizes organic carbon to CO_2. After digestion (and cooling), the remaining dichromate was titrated with ferrous ammonium sulphate using ferroin indicator to determine how much dichromate was consumed by oxidizing the soil organic matter[13]. The TOC (%) was calculated from the titration results, applying a correction factor for incomplete oxidation (Walkley-Black typically assumes ~77% efficiency unless a heat catalyst is used). This method is a standard in soil chemistry. It provides insight into soil organic matter, which can influence contaminant binding; for instance, soils high in organic carbon might retain more PAHs (since PAHs are hydrophobic and bind to organic matter).

(c) **Available Phosphate (PO_4^{3-}):** Available phosphorus in soil was determined by the Bray P-1 method (suitable for acidic soils common in Southern Nigeria)[14]. A known weight of soil (5 g) was extracted with Bray P-1 extractant (0.03 N NH_4F + 0.025 N HCl) by shaking for 5 minutes. The extract was filtered, and the phosphate in the extract was then measured calorimetrically by the ascorbic acid molybdenum blue method[14]. In this colorimetric test (APHA 4500-P E), ammonium molybdate and antimony potassium tartrate react with orthophosphate in the sample to form a phosphomolybdate complex, which is reduced by ascorbic acid to yield a blue-coloured solution[14]. The intensity of the blue colour, measured at 882 nm on a spectrophotometer, is proportional to the phosphate concentration[8]. A series of phosphate standard solutions was run to prepare a calibration curve. Results were reported as mg of available P per kg of soil. This method (Bray-1 with ascorbic acid

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finish) is widely used and referenced in agronomic studies for available soil phosphorus. It helps to determine if cassava effluent (which may contain some phosphorus from cell material) has altered soil fertility or not.

(d) **Exchangeable Cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}):** The major exchangeable bases in soil – calcium, magnesium, potassium, and sodium – were extracted using neutral 1 M ammonium acetate solution (at pH 7) according to standard soil testing protocols[15]. In this procedure, 10 g of soil was leached with ammonium acetate, which displaces Ca, Mg, K, and Na from the soil's cation exchange sites. The filtrate extract was collected, and the concentrations of Ca^{2+} and Mg^{2+} were determined using the Atomic Absorption Spectrophotometer (AAS), while K^{+} and Na^{+} were determined by flame photometry or AAS[10]. The AAS for Ca and Mg was calibrated with known standards and operated at the appropriate wavelengths (e.g., Ca at 422.7 nm, Mg at 285.2 nm), and emission readings for K and Na were taken (or AAS in emission mode)[15]. This method follows standard procedures in soil analysis (Jackson, 1962; or current ASTM D** methods) and has been validated for accuracy in numerous studies[16]. Exchangeable cation results (in cmol(+)/kg or in mg/kg) indicate soil fertility and reflect if effluent inputs (which might add sodium or other salts) have affected soil chemical balance. For instance, a high Na level could indicate sodicity from the effluent, whereas Ca and Mg could be diluted if effluent leaching occurs.

(e) **Other Soil Parameters:** Additional soil tests were performed such as moisture content (by gravimetric oven-drying at 105 °C), particle size distribution (via hydrometer or sieve analysis to classify soil texture), and possibly total nitrogen (by Kjeldahl method) if relevant to understanding fertility. These are ancillary to the main aims but help describe the soil matrix. Moisture content ensures comparison on a dry-weight basis, and texture can influence contaminant retention (clay vs sand). For

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brevity, detailed methods for these are not expanded here, but standard protocols (ASTM D2216 for moisture, hydrometer method for particle size, etc.) were followed.

3.3.2.2 Heavy Metal Analysis in Soil

The determination of heavy metals in soil samples was executed using acid digestion followed by Atomic Absorption Spectrophotometry, analogous in concept to the plant analysis but with a stronger digestion to account for the soil's mineral matrix. Approximately 1.0 g of the dried, sieved soil was placed in a Teflon digestion vessel. A two-step acid digestion was performed: first, the sample was treated with 10 mL of concentrated nitric acid (HNO_3) and heated gently to oxidize organic matter and leach readily soluble metals; after cooling, 5 mL of concentrated hydrochloric acid (HCl) was added (a procedure similar to EPA Method 3050B or the aqua regia digestion approach). The mixture was heated to near boiling for about 2 hours. Optionally, a few drops of perchloric acid or hydrogen peroxide could be added to ensure complete breakdown of organics. (In some cases, for total metals including those in silicate lattices, a hydrofluoric acid step is used, but given safety concerns, the aqua regia digest suffices for most heavy metals of interest, though it may not capture all silicate-bound fractions.) After digestion, the sample was filtered and diluted to a known volume with deionized water. The resulting solution was then analysed by AAS for the target metals Pb, Cd, Cr, Zn, Ni, Cu, and Fe. Each metal was quantified at its specific analytical wavelength with calibration standards run in the same acid matrix. Blanks and duplicate digestions were also carried through to monitor any contamination or analytical precision. The AAS method is consistent with APHA (3120 B for ICP or 3111 B for AAS) and ASTM standards for metals in environmental samples. For quality assurance, standard reference soil materials (with known metal contents) were also digested and analyzed, and the recovery was

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checked to fall within acceptable ranges (generally 85–115%). Heavy metal concentrations in soil were reported in mg/kg (dry weight). These data reveal the degree of soil contamination at varying distances; for instance, significantly elevated heavy metals at 0 m relative to 1 km would indicate contamination from the cassava effluent, especially if the metals follow a decreasing trend with distance.

3.3.2.3 PAH Analysis in Soil

The analysis of PAHs in soil involved extraction of soil samples followed by GC–MS, similar to the procedure for plant samples but with a more rigorous extraction method due to the complex soil matrix. About 20 g of dried soil from each sample was thoroughly mixed with anhydrous sodium sulfate (to ensure dryness) and loaded into a Soxhlet extractor or an automated extractor system. PAHs were extracted using an organic solvent such as dichloromethane or hexane/acetone (EPA Method 3540C – Soxhlet Extraction – or an accelerated solvent extractor can be used for efficiency[11]). The extraction typically ran for 16–24 h in Soxhlet (or a shorter cycle in pressurized extraction) until the solvent in the thimble was clear, indicating exhaustive extraction. The extract was then concentrated and subjected to a clean-up step: it was passed through a silica gel or alumina column to remove polar interferents, yielding a cleaner hydrocarbon fraction. The purified extract was concentrated to 1 mL and spiked with surrogate/internal standards. PAH analysis was carried out on a GC–MS system as described for leaves. The instrument was calibrated for 16 EPA priority PAHs (from naphthalene to benzo[g,h,i] perylene) across a suitable range (e.g., 0.1 to 10 mg/L standards). The GC–MS method (comparable to EPA 8270D for solids) was tuned to detect PAHs with appropriate ions; for example, the molecular ion and key fragments for each PAH were monitored. Identification was confirmed by matching the retention time and ion ratios to those of calibration standards. To ensure method fidelity, a method blank (with clean Ottawa sand) and a spiked matrix sample were run with each batch of soil

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samples. The surrogate recovery (often deuterated PAHs added at the start of extraction) was checked to be within control limits (typically 70–130%). PAH concentrations in soil were reported in µg/kg. This analysis allows us to see if cassava processing sites (which might involve wood fires for roasting garri, or fuel use, etc.) have PAH residues in soil. However, it's more expected that heavy metals might be present from machinery (wear of grater teeth, etc.)[1] or from contaminated water, whereas PAHs might not be a primary contaminant from cassava processing itself unless there is significant smoke deposition. The results would nonetheless show the environmental baseline for PAHs in these agricultural soils.

3.3.3 Effluent (Wastewater) Analysis

The cassava processing effluent samples were analysed for a range of physicochemical parameters to characterize the wastewater and identify potential pollutants. The methods largely followed Standard Methods for the Examination of Water and Wastewater (APHA) protocols and are itemized below:

(a) **pH:** The pH of the effluent was measured in the lab using a calibrated pH meter with a glass electrode, as per APHA 4500-H^+ method. Before measurement, each effluent sample was well mixed. The electrode was standardized with pH 4.0, 7.0, and 10.0 buffers. Then it was immersed in a beaker containing the effluent sample and the pH was recorded once stable. Cassava effluent is typically acidic (due to organic acids from fermentation), so pH is a critical parameter indicating its corrosivity and potential impact on soils.

(b) **Electrical Conductivity (EC):** EC was measured using a conductivity meter (APHA 2510 B). The meter (calibrated with KCl standard solution for 1413 µS/cm) had its probe dipped into the effluent sample at room temperature, and the reading in microSiemens per centimeter (µS/cm) was taken when stabilized. Conductivity

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reflects the total ionic content (salts) of the wastewater, which could include cyanide, chloride, sulfate, etc. A high EC in effluent can lead to soil salinization.

(c) **Total Dissolved Solids (TDS):** TDS was determined gravimetrically following APHA 2540 C. A known volume of filtered effluent (e.g., 100 mL) was passed through a pre-weighed glass-fiber filter paper. The filtrate (containing dissolved solids) was collected in a clean evaporating dish. Separately, the increase in weight of the filter paper represents total suspended solids, and the residue from filtrate upon evaporation represents TDS. In practice, APHA suggests evaporating the filtered sample in a drying oven at 180 °C until dry, then cooling and weighing. However, the procedure in this study followed a simplified approach where the filter paper was dried at 105 °C for a short time and re-weighed to get TSS, and by difference from a total solids measurement the TDS was inferred. For clarity: we measured Total Solids (TS) by evaporating 100 mL of well-mixed effluent in a pre-weighed flask at 105 °C to constant weight. We also measured Total Suspended Solids (TSS) by capturing solids on a filter and drying it. Then TDS was calculated as TS – TSS. Results were expressed in mg/L. These parameters indicate the load of dissolved and particulate matter in the effluent, which affect water quality and soil pore clogging.

(d) **Total Alkalinity and Bicarbonate:** The alkalinity of the effluent (mainly due to bicarbonate since cassava effluent contains fermentative CO_2 which can form HCO_3^-) was measured by titration (APHA 2320 B). 50 mL of effluent was titrated with 0.1 N sulfuric acid using phenolphthalein and methyl orange indicators in a two-step titration. Phenolphthalein alkalinity was first determined (dropwise addition of acid until pH ~8.3, phenolphthalein endpoint faint pink to clear), then methyl orange was added and titration continued to pH ~4.5 (methyl orange endpoint from yellow to orange). The volumes of acid used allowed calculation of bicarbonate (HCO_3^-) and

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total alkalinity (expressed as mg/L $CaCO_3$). Bicarbonate concentration was derived from phenolphthalein alkalinity if any (for carbonate) and total for bicarbonate. Given cassava effluent is often acidic, alkalinity might be low; nonetheless this test indicates buffering capacity.

(e) **Chloride (Cl^-):** Chloride content in the effluent was determined by the Argentometric method (Mohr's titration), consistent with APHA 4500-Cl^- B. 100 mL of effluent sample was placed in a flask, and 1 mL of potassium chromate (K_2CrO_4) indicator was added. This solution was titrated with standard 0.014 N silver nitrate ($AgNO_3$) solution. Silver nitrate reacts with chloride to form silver chloride precipitate; once all chloride is consumed, the first excess drop of $AgNO_3$ reacts with the chromate indicator to form a reddish-brown silver chromate precipitate, marking the endpoint (color change from yellow to light reddish brown). The volume of $AgNO_3$ used was plugged into the formula to compute chloride concentration in mg/L. This method is a classic argentometric titration and was performed carefully to avoid overshooting the endpoint. Chloride in cassava effluent could originate from the cassava itself or from process water; it's important for assessing potential groundwater contamination and corrosion potential.

(f) **Sulphate (SO_4^{2-}):** Sulphate was measured using a turbidimetric method (APHA 4500-SO_4^{2-} E). A measured volume of effluent (typically 50 mL) was treated with conditioning reagents including glycerol and NaCl (to control solubility and ionic strength) and then barium chloride crystals were added. Sulphate reacts with Ba^{2+} to form a barium sulphate suspension. After a set time of gentle stirring, the turbidity of the suspension was measured at 420 nm with a spectrophotometer, comparing against a calibration curve prepared with known sulphate standards. The result gives sulphate concentration in mg/L. (Alternatively, if available, an ion chromatography

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technique could be used; however, the turbidimetric method is straightforward and commonly used in water analysis.) Sulphate in cassava effluent might be low unless sulphate-rich water or additives were used; measuring it helps in understanding if any significant anionic load besides organic acids is present.

(g) **Nitrate (NO_3^-):** Nitrate was determined by a colorimetric method (such as the brucine sulphate method or cadmium reduction method) per APHA 4500-NO_3^-. In this study, a simple UV-spectrophotometric screening was done: the effluent sample was filtered, and its absorbance at 220 nm (where nitrate has a strong absorbance) and 275 nm (for interference correction) were measured. Using APHA guidelines, the difference in absorbance (corrected for organic interference at 275 nm) was used to estimate nitrate concentration, with calibration from KNO_3 standards. Because cassava effluent is rich in organic nitrogen (from proteins in cassava tubers) and not initially in nitrate, this step was more to see if any nitrification had occurred in standing effluent or if background water contributed nitrates. Results were expressed in mg/L NO_3^--N.

(h) **Dissolved Oxygen (DO):** DO in freshly collected effluent was measured on-site where possible using a portable DO meter (or by Winkler titration in the lab if the field measurement was not feasible). The Winkler method (APHA 4500-O) involves fixing the oxygen with manganese sulphate and alkaline iodide reagents in a BOD bottle at the time of collection, then titrating the liberated iodine with sodium thiosulfate in the lab. However, cassava effluent typically has very low DO (high BOD load depletes oxygen). Field DO meter readings (after calibration in air) were taken by immersing the probe in the effluent pool; values were recorded in mg/L. Low or zero DO was observed, as expected, indicating a strong oxygen demand.

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(i) **Chemical Oxygen Demand (COD):** COD was determined by the dichromate reflux titration method (APHA 5220 B). In this method, 2.5 mL of effluent was refluxed with 1.5 mL of standard potassium dichromate solution in the presence of 3.5 mL concentrated sulfuric acid and silver sulphate catalyst (mercury sulphate can be added to mask chloride if chloride is high). The mixture was heated for 2 hours at 150 °C. After digestion, the remaining dichromate was titrated with standardized ferrous ammonium sulphate (FAS) using ferroin indicator. The colour changes from bluish-green to reddish-brown signifies the endpoint. A blank (distilled water) and a standard glucose or potassium hydrogen phthalate solution were run in parallel for quality control. COD results were calculated in mg/L O_2. COD represents the amount of organic (and oxidizable inorganic) matter in the effluent and is a key pollution parameter. Cassava effluent is known to have extremely high COD due to starches, sugars, and cyanogenic compounds; this test quantifies that load.

(j) **Phosphate (PO_4-P):** Soluble orthophosphate in the effluent was measured by the same **ascorbic acid colorimetric method** described for soil extracts, but here applied directly to the water sample (after appropriate dilution if needed). 5 mL of filtered effluent was treated with ammonium molybdate-antimony reagent and ascorbic acid, and the blue colour measured at 882 nm. The APHA 4500-P E method was followed, and results were reported as mg/L PO_4^{3-} (or as P). Cassava effluent might contain some phosphate from cell contents, though not typically very high. This parameter, along with nitrate, indicates nutrient pollution potential (eutrophication risk).

(k) **Other Parameters:** In addition to the above, the study measured Biochemical Oxygen Demand (BOD_5) on the effluent. A 5-day BOD test was set up by diluting the effluent with oxygen-saturated water, seeding with microbial inoculum, and incubating in BOD bottles at 20 °C in the dark for 5 days. DO was measured initially

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and after 5 days; the drop in DO gave the BOD_5 (with corrections for dilution and any seed). This standard test (APHA 5210 B) indicates the biodegradable organic load. Given the high COD, BOD was expected to be high as well; values were expressed in mg/L O_2 consumed. Furthermore, **cyanide** content was an important parameter (cassava effluent contains linamarin which can hydrolyse to cyanide). Although not explicitly listed in the prompt, literature suggests cyanide is a critical effluent pollutant. If measured, it would be by a titrimetric or colorimetric method (e.g., APHA 4500-CN with pyridine-pyrazalone or an ion-selective electrode). For completeness, we note that total cyanide was analysed by first distilling the sample in an acid setup to release HCN, which was captured in NaOH and then quantified calorimetrically. Results (if measured) would be in mg/L CN^-.

All analytical methods above adhered to relevant standard methods (APHA, ASTM, or ISO standards) to ensure data quality and acceptance. For example, pH, alkalinity, chloride, sulphate, etc., followed APHA 23rd edition guidelines; heavy metals followed APHA or ASTM D methods for AAS; and organics (PAHs) followed U.S. EPA methods integrated into standard lab practices. Each test included proper blanks, calibration standards, duplicates, and spikes where applicable. The laboratory (EISL) that conducted the analyses is ISO-certified, and all instruments were calibrated and maintained as per manufacturers' recommendations.

In summary, the effluent analysis provided a profile of the cassava wastewater: low pH, high organic load (COD/BOD), significant cyanide, and possibly elevated suspended solids and nutrients, all of which help explain the potential for soil and crop impact. These data complement the soil and crop analyses by linking the source characteristics to the observed environmental concentrations[17].

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3.4 Data Analysis

After laboratory analyses, the raw data were compiled and subjected to statistical analysis to address the research questions. The approach combined descriptive statistics (to summarize concentrations and properties) with inferential statistics (to test hypotheses about differences between groups, such as between distances or between sample types).

Initially, all concentration values for heavy metals, PAHs, and other parameters were tabulated for each site, distance, and sample type. Using Microsoft Excel and SPSS (Statistical Package for the Social Sciences, Version 25), summary statistics were computed: mean, standard deviation (SD), minimum, maximum, and coefficient of variation for each variable. These descriptive stats provided an overview of central tendencies and variability[18]. For example, the mean concentration of Pb in topsoil at 0 m versus at 1 km could be compared, and the SD indicated how much variation existed among the replicate samples

To infer patterns and significance:

(a) **Analysis of Variance (ANOVA):** A one-way ANOVA was performed for key response variables (e.g., heavy metal levels in soil) with **distance** as the factor. For each metal in soil, we tested whether the mean concentrations at 0 m, 50 m, 200 m, and 1 km were significantly different (at $\alpha = 0.05$). The assumption of ANOVA (approximate normality and equal variances) was checked; data were log-transformed if needed to stabilize variances. If the ANOVA F-test indicated a significant effect of distance ($p < 0.05$), it implied that contamination levels differed depending on proximity to the effluent source. In such cases, a post-hoc test (Tukey's HSD) was applied to determine which pairwise distances differed. Similarly, ANOVAs were conducted for heavy metal concentrations in cassava leaves across distances, and for comparing topsoil vs subsoil (two-way ANOVA if treating depth and distance

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as two factors). For effluent parameters, which were measured per site (not by distance), ANOVA was not applicable; instead, simple comparisons with regulatory standards or literature values were made.

(b) **Descriptive Comparisons:** The means of parameters at effluent-exposed soils (0 m) were compared with means at control soils (1 km). A **t-test** (independent two-sample t-test) was used for each metal to see if the 0 m vs 1 km difference was statistically significant. This serves as an alternative test directly addressing contamination (since control sites ideally reflect background levels). Likewise, cassava leaves from polluted sites were compared to control-site leaves. These tests complement ANOVA and can be easier to interpret (effectively testing the hypothesis that effluent has no effect, by comparing impacted vs control).

(c) **Correlation Analysis:** Pearson correlation coefficients were computed to explore relationships between variables, for instance between metal levels in soil and in cassava leaves. A strong positive correlation (r close to 1) between, say, soil lead and leaf lead across sites would suggest uptake of lead by cassava plants. Also, correlations among different heavy metals in soil were examined to see if they originate from a common source (effluent) or have different behaviors.

(d) **Regression Modeling:** In a few cases, simple linear regression was used to model the decay of contaminant concentration with distance. Distance (in log scale) was the independent variable and concentration the dependent. The fit of these models (R^2 values) provided insight into how predictably contamination decreases away from the source. For example, a high R^2 in a regression of soil Zn vs log(distance) would imply a clear gradient attributable to the effluent source.

The statistical analyses were carried out using SPSS, ensuring that each dataset was coded correctly (factor levels for distances, etc.). Results were considered significant at the

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95% confidence level ($p < 0.05$). Findings were typically reported with the mean ± SD for each group. Where ANOVA indicated differences, the text specifies which groups were higher or lower (e.g., "significantly higher Pb in 0 m soils than in 200 m and control soils, $p < 0.01$"). Data were presented in tables and graphs for clarity – for instance, bar charts with error bars (±SD) showing concentration vs distance for various parameters[19].

3.5 Ethical Approval

No formal ethical approval was required for this study. The research did not involve human subjects or personal data, focusing instead on environmental samples (soil, plants, and water) and standard laboratory analyses. However, the study was conducted with a strong sense of ethical and professional responsibility. Permission was obtained from local landowners and cassava processors before collecting samples on their premises, and the purpose of the study was explained to all stakeholders in understandable terms. All sampling and disposal of chemical wastes in the lab were done in an environmentally responsible manner, following the guidelines of the University's research ethics and safety committees (where applicable). Since only environmental materials were involved, institutional ethical review was not mandatory; nevertheless, the researcher adhered to all relevant regulations and best practices to ensure safety and integrity in the research process.

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Endnotes

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Chapter Four

Results and Discussions of Findings

4.1 Results of Findings

The physicochemical quality of water samples from three locations: Omi-Adio, Orile-Ilugun, and Ilaju all in Ido LGA, Oyo State were examined. The results provide insights into potential anthropogenic influences, pollution sources, and environmental risks. The parameters analyzed included pH, conductivity, total dissolved solids (TDS), major ions (bicarbonate, chloride, sulphate, nitrate), and organic pollution indicators (COD and phosphate).

4.1.1 Result of Physicochemical Properties of Cassava Effluents from the Sample Locations

The results of the physicochemical properties of cassava effluents from the sample locations are shown in Table 4.1

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Table 4.1: Result of Physicochemical Properties of Cassava Effluents from Sample Locations

Locations	pH	Conductivity (µS/cm)	TDS (mg/L)	Alkalinity (mg/L)	Bicarbonate (mg/L)	Chloride (mg/L)	Sulphate (mg/L)	Nitrate (mg/L)	DO (mg/L)	COD (mg/L)	Phosphate (mg/L)
Omi – Adio	2.79± 0.21	3860 ± 21.20	1915 ± 15.10	1.90 ± 0.20	347 ± 2.51	926 ± 3.76	463 ± 5.11	9.451 ± 0.45	1.00 ± 0.02	67 ± 2.45	4.456 ± 0.23
Orile – Ilugun	3.03 ± 0.10	8720 ± 25.76	4334 ± 21.35	4.6 ± 0.42	785 ± 12.20	2093 ± 41.11	1046 ± 12.10	11.545 ± 0.35	0.8 ± 0.25	86 ± 1.15	5.776 ± 0.15
Ilaju	2.90 ± 0.05	3561 ± 35.51	1890 ± 25.25	2.1 ± 0.06	332 ± 10.10	1023 ± 20.25	385 ± 10.23	8.934 ± 0.55	0.9 ± 0.05	73 ± 2.33	4741 ± 25.23

Source: Author's Field Work, 2025

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Table 4.2: Physicochemical Properties of Soil Samples from all locations

Parameter	OMI-ADIO	ORI LE-ILUGUN	ILAJU
pH	2.79	3.03	2.90
Conductivity (µS/cm)	3860	8720	3561
TDS (mg/L)	1915	4334	1890
Alkalinity (mg/L)	1.9	4.6	2.1
Bicarbonate (mg/L)	347	785	332
Chloride (mg/L)	926	2093	1023
COD (mg/L)	463	1046	385
Phosphate (mg/L)	9.451	11.545	8.934
Sulphate (mg/L)	1	5.776	0.9
Nitrate (mg/L)	67	86	73

Source: Author's Field Work, 2025

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Table 4.3 Physicochemical Properties of Plant Samples from all Locations

Location	pH	Nitrogen %	Phosphate (mg/kg)	Ca^{2+}(mg/kg)	Na^{+}(mg/kg)	Mg^{2+}(mg/kg)
OMI-ADIO	6.1	29.09	31.1	2345	428.67	1453.67
ORILE ILAJU	6.23	27.14	31.48	2326.25	343.5	1563.75
ILAJU	6.18	28.26	30.06	2359	335.25	1459.5

Source: Author's Field Work, 2025

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Table 4.4: Concentrations of PAHs in Plant Samples across Sample Locations

Sample Location	Fluorene (mg·kg⁻¹ dry weight)	Phenanthrene (mg·kg⁻¹ dry weight)	Anthracene (mg·kg⁻¹ dry weight)
OMI-ADIO	0.42	ND	ND
ORILE-ILUGUN	ND	0.34	0.38
ILAJU	ND	0.30	0.36

Source: Author's Field Work, 2025

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Table 4.5: Concentrations of PAHs in Soil Samples across Sample Locations

Sample Location	Fluoranthene ($mg \cdot kg^{-1}$ dry weight)	Pyrene ($mg \cdot kg^{-1}$ dry weight)	Benzo[a]pyrene ($mg \cdot kg^{-1}$ dry weight)
OMI-ADIO	0.02	0.02	0.08
ORILE-ILUGUN	ND	ND	ND
ILAJU	0.03	0.02	0.05

Source: Author's Field Work, 2025

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Table 4.6: Descriptive Statistics of Heavy Metals Concentrations in Plant Samples Across all Sample Locations

Metal	*Mean*	*Std Dev*	*Min*	*Max*
Cr	0.07	0.06	0.00	0.12
Ni	6.26	0.40	5.95	6.73
Pb	43.58	3.77	39.34	46.65
Cd	109.17	3.30	105.7	112.3
Fe	67.72	2.37	65.70	70.42
Co	65.16	2.27	62.53	67.00
Cu	10.84	0.40	10.45	11.25
Mn	19.45	1.07	18.34	20.47

Source: Author's Field Work, 2025

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Table 4.7: Descriptive Statistics of Heavy Metals Concentrations in soil Samples Across all Sample Locations

Element	Mean	Std Dev	Min	Max
Cr	27.13	17.34	0.00	63.10
Ni	143.35	174.85	5.30	437.40
Pb	118.04	37.95	13.90	161.50
Cd	81.26	21.34	44.00	132.00
Fe	259.78	97.48	87.75	418.10
Co	13.42	5.36	3.90	20.55
Cu	45.49	23.64	8.65	75.75
Mn	70.79	46.73	7.60	127.85

Source: Author's Field Work, 2025

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Table 4.8: Descriptive Statistics of Heavy Metals Concentrations in Effluent Samples across all Sample Locations

Metal	Min	Max	Mean	Std. Dev
Cr	31.05	41.15	36.95	5.19
Ni	7.10	32.90	16.12	14.18
Pb	131.00	172.50	151.00	20.92
Cd	78.40	102.50	91.13	12.13
Fe	100.60	111.30	105.25	5.37
Co	12.15	72.90	33.40	33.35
Cu	53.20	75.05	67.05	11.54
Mn	200.60	290.90	255.23	46.22

Source: Author's Field Work, 2025

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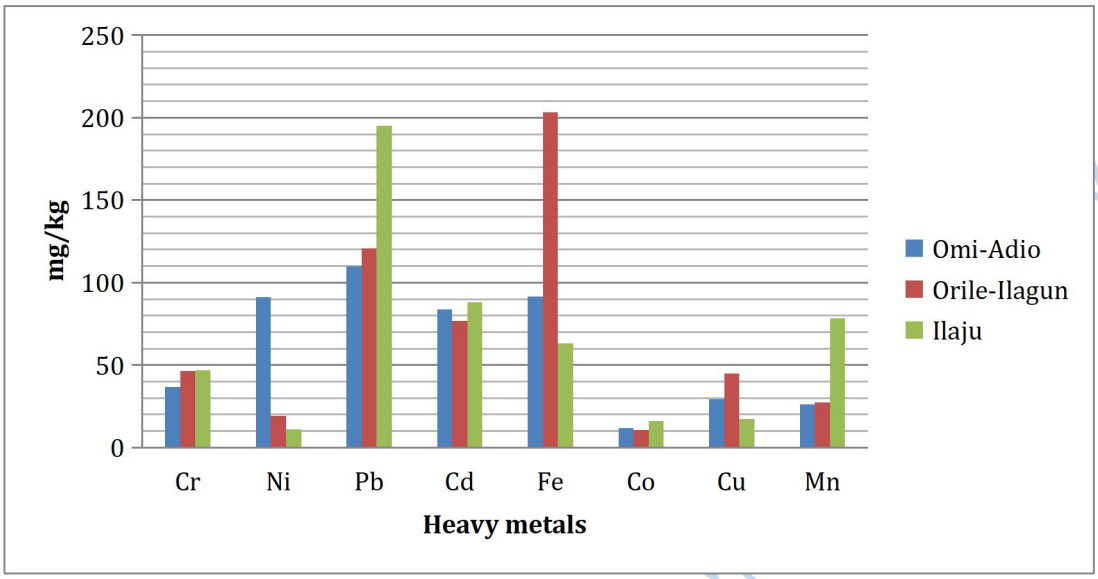


Figure 4.1: Heavy Metal concentrations in Plant Samples across Locations

Source: Author's Field Work, 2025

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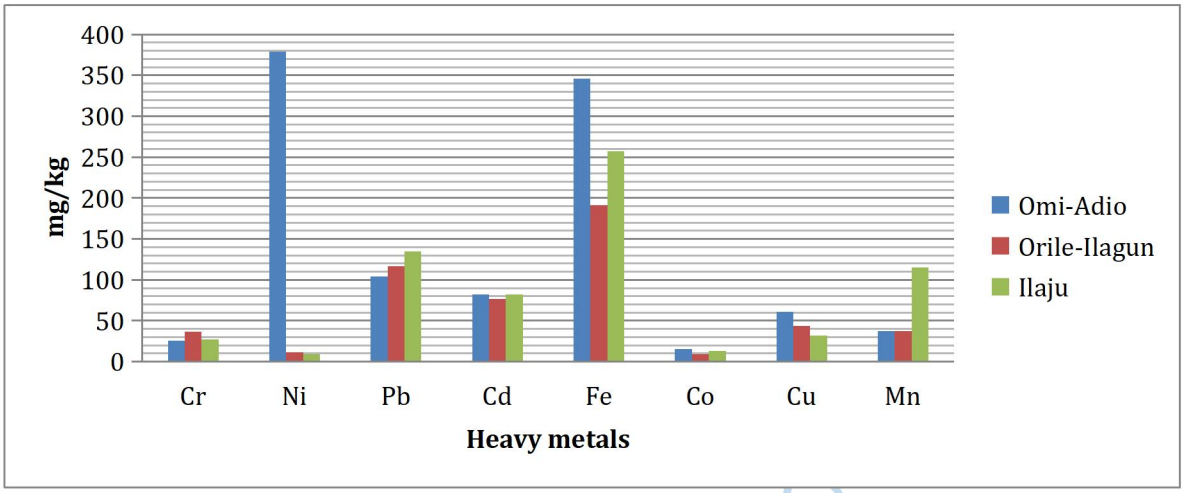


Figure 4.2: Heavy Metal Concentrations in Soil Samples across Locations

Source: Author's Field Work, 2025

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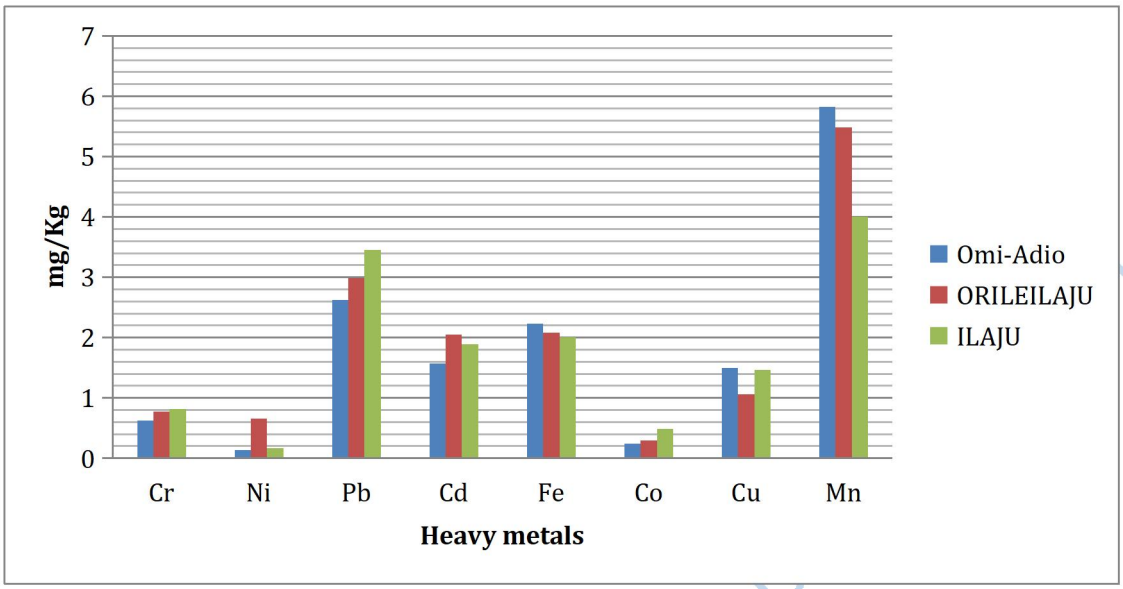


Figure 4.3: Heavy Metal Concentrations in Effluent Samples across Locations

Source: Author's Field Work, 2025

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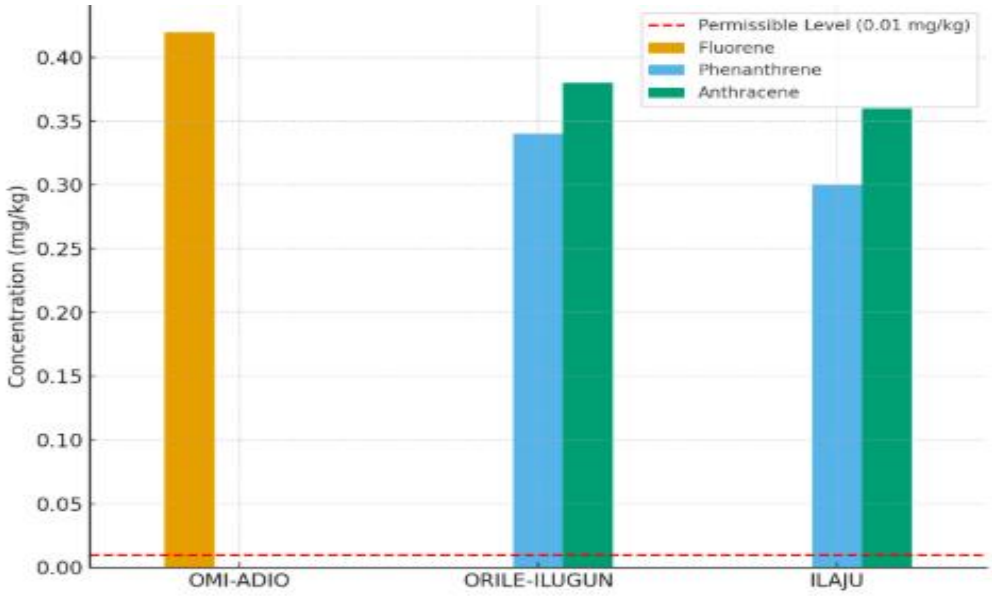


Figure 4.4: PAHs Concentration in Plant Samples across Locations

Source: Author's Field Work, 2025

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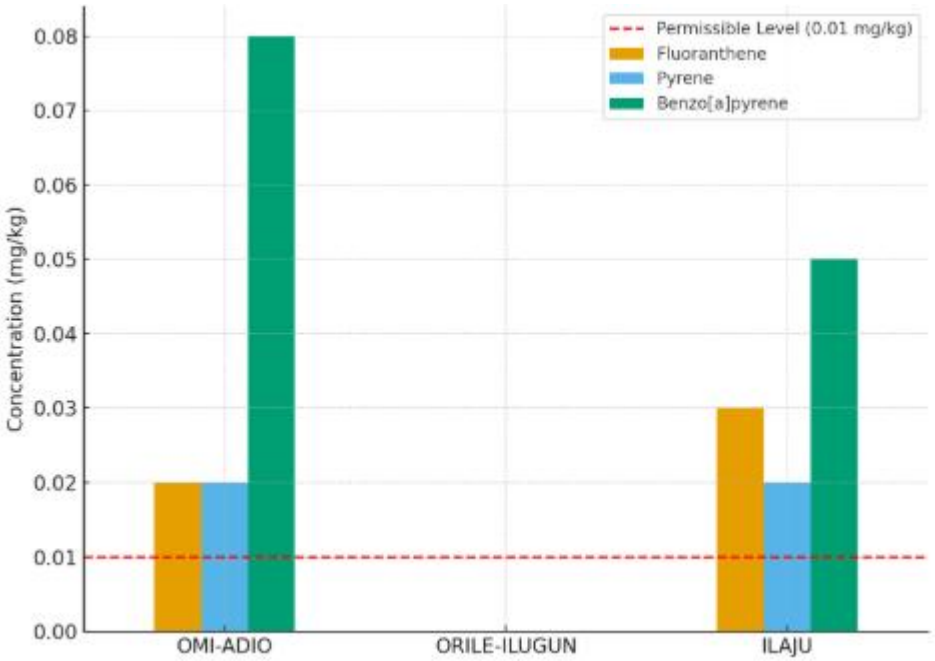


Figure 4.5: PAHs Concentration in Soil Samples across Sample Locations

Source: Author's Field Work, 2025

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4.2 Discussion of Findings

4.2.1 Discussion of Physicochemical Properties of Cassava Effluent from the Sample Locations

All cassava effluents were acidic, with pH ranging from 2.79 (Omi-Adio) to 3.03 (Orile-Ilugun) as shown in Table 4.1. These values are far below the permissible range for potable water (6.5-8.5) according to WHO and NSDWQ standards. The acidic pH found in the cassava effluents may be due to industrial or agricultural runoff, fermentation of organic wastes from cassava processing, or leaching of acid-forming compounds from soils[1]. Acidic water can enhance the leaching of toxic metals like iron, aluminum, and lead into the water column, posing health risks upon consumption.

Conductivity values ranged from 3561 µS/cm (Ilaju) to 8720 µS/cm (Orile-Ilugun). Corresponding TDS values ranged from 1890 mg/L to 4334 mg/L. Both parameters indicate high mineralization and contamination, exceeding the WHO limit for TDS in drinking water (1000 mg/L). Elevated conductivity and TDS suggest anthropogenic influences such as industrial effluents, leachates from waste dumps, or saline intrusion[2]. Orile-Ilugun, which had the highest values, may be experiencing intense contamination from cassava waste leachates or septic system leakages.

Alkalinity was lowest at Omi-Adio (1.9 mg/L) and highest at Orile-Ilugun (4.6 mg/L), with corresponding bicarbonate levels of 347-785 mg/L. While alkalinity levels are generally low, bicarbonate concentrations are relatively high, particularly at Orile-Ilugun likely as a buffering response to acidic conditions. High bicarbonate could also arise from microbial degradation of organic matter[3].

Chloride concentrations ranged from 926 mg/L to 2093 mg/L, all exceeding the WHO limit of 250 mg/L. Sulphate levels were also high (385-1046 mg/L), surpassing the WHO

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maximum of 400 mg/L while nitrate levels (8.934-11.545 mg/L) were within acceptable limits (<50 mg/L), but suggest mild eutrophication. The high chloride and sulphate levels are indicative of wastewater intrusion, cassava processing effluents, and potential groundwater salinization[4]. Elevated sulphate also points to the decomposition of protein-rich wastes.

COD ranged from 67 mg/L to 86 mg/L, significantly high for natural waters (typical threshold < 20 mg/L). This confirms heavy organic pollution, particularly at Orile–Ilugun. High COD levels correlate with cassava processing discharge and microbial breakdown of organic acids, which deplete dissolved oxygen and deteriorate water quality[5].

Phosphate concentrations ranged from 4.46 mg/L (Omi-Adio) to 5.78 mg/L (Orile-Ilugun) is well above the eutrophication threshold of 0.1 mg/L for surface water bodies. This signifies strong nutrient enrichment likely from fermentation effluents, soap or detergent usage, and food processing residues. Elevated phosphate poses ecological risks including algal blooms and aquatic habitat degradation[6].

Of all the sample locations under study, Orile–Ilugun appears most polluted across nearly all parameters, suggesting more intensive cassava processing, higher population density, or direct discharge of effluents. Omi-adio samples also show signs of anthropogenic pressure but with slightly lower severity.

Researchers previously reported similar acidic and high-TDS waters near cassava processing zones in southwest Nigeria[4]. Other studies found phosphate levels above 3 mg/L in water from food-processing environments, attributing it to organic waste dumping[7]. These comparisons confirm that the Ido LGA effluents exhibit physicochemical signatures consistent with pollution from cassava milling and agro-waste discharge. The cassava effluents analyzed from Ido LGA display marked deterioration in quality, with high acidity,

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salinity, and organic/nutrient pollution. The findings raise concern over the potability, agricultural suitability, and ecological safety of local water sources.

Hierarchical cluster analysis (HCA) was applied using *Ward's* method and *Euclidean* distance metric to group the three sampling locations: Omi-Adio, Orile-Ilugun and Ilaju. Based on the eleven cassava effluent parameters analyzed: pH, electrical conductivity, total dissolved solids (TDS), alkalinity, bicarbonate, chloride, chemical oxygen demand (COD), phosphate, sulphate, and nitrate.

Orile-Ilugun showed distinctive pollution characteristics, likely influenced by industrial effluents or domestic waste leaching, given the abnormally high conductivity, chloride, and COD. In contrast, Omi-Adio and Ilaju while still acidic (pH < 3), exhibit relatively lower nutrient and salt load possibly indicating agricultural runoff or cassava processing wastewater as primary contributors. This finding aligns with in similar observation from previous studies[8].

Omi-Adio and Ilaju shared pollution from agricultural or small-scale cassava processing sources. Low alkalinity and bicarbonate suggest poor buffering capacity, raising risks of metal mobilization (ref). Orile-Ilugun indicates pollution from industrial effluent with high organic and ionic loads. The high COD and phosphate concentrations may trigger eutrophication in adjacent surface waters. The extremely low pH values (< 3) across all sites are alarming and unfit for human consumption or agricultural reuse**,** violating WHO and Nigerian Drinking Water Standards[27]. Such acidity may enhance the leaching of heavy metals from sub-surface strata into water supplies.

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4.2.2 Physicochemical Parameters of Soil Samples

Table 4.2 above presents the physicochemical soil parameters including pH, nitrogen (%), phosphate (mg/kg), total organic carbon (TOC %), and concentrations of calcium (Ca^{2+}), sodium (Na^{+}), and magnesium (Mg^{2+}) across twelve sampling points within the Omi-Adio, Orile-Ilugun, and Ilaju zones.

The chart reveals spatial variability in soil quality influenced by cassava effluent discharge. Nitrogen and phosphate **levels** were elevated in all locations, particularly at Omi-Adio and Ilaju, where nitrogen concentrations exceeded 65%. These high levels reflect potential accumulation from decomposing cassava residues and wastewater leaching. This finding aligns with authors who reported significantly increased nitrogen and phosphorus in effluent-affected tropical soils due to high organic load from cassava mill discharges[9].

Phosphate concentrations peaked at Orile-Ilugun Point 3 (48.2 mg/kg), suggesting persistent input of phosphorous-rich organic waste. This is consistent with the role of agro-industrial waste in enhancing soil phosphorus but warned of eutrophication risks in nearby water bodies due to leaching. The soil pH values**,** ranging from 6.14 to 6.81, indicate a slightly acidic to near-neutral environment. Omi-Adio consistently recorded the highest pH which could be attributed to buffering from native soil minerals or less effluent penetration. Similar observations noted that effluent-affected soils in cassava mills often exhibit mild acidification depending on organic acid content and soil buffering capacity[10].

Total Organic Carbon (TOC %) ranged from 3.41% to 3.87% with the highest values observed in Orile-Ilugun and Ilaju zones, suggesting higher accumulation of decaying organic materials.

Regarding exchangeable cations**,** Ca^{2+} concentrations were highest in Omi-Adio

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soils, likely due to calcium carbonate leaching from processing waste or soil parent material. Mg^{2+} levels were notably higher in Orile-Ilugun and Ilaju peaking at 2.35 mg/kg, a trend that may reflect effluent-driven mobilization of divalent cations[11]. Na^{+} concentrations were generally low but slightly elevated in Orile-Ilugun possibly due to the inflow of saline effluents, detergent-laced runoff, or industrial residues.

Overall, the column chart serves as a visual confirmation of localized soil nutrient enrichment and ionic imbalance resulting from cassava-processing activities. These alterations, while potentially beneficial to short-term soil fertility, may also lead to long-term degradation through salinization, nutrient leaching, and pH shifts. Sustainable waste management strategies and soil remediation practices are therefore essential to mitigate adverse impacts.

4.2.3 Physicochemical Characteristics of Plant Samples

Plant leaf nutrient composition is a critical indicator of soil fertility, plant health, and environmental quality. Variations in parameters such as pH, nitrogen, phosphate, and essential cations (Ca^{2+}, Na^{+}, Mg^{2+}) can reflect differences in soil conditions and anthropogenic influences (Table 4.3). Cluster analysis of plant nutrient data of leaf samples from three sampling locations was performed to identify similarities and differences in nutrient profiles[12].

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The relatively narrow range of pH and nutrient values indicates moderate variation across locations, with Omi-Adio samples generally having higher nitrogen content and Ca^{2+} concentrations. To better understand the variation and interrelationships among the physicochemical characteristic of the plant samples collected from the sampling locations, a Principal Component Analysis (PCA) was performed. The PCA biplot (Figure 4.16) simplifies the complexity in high-dimensional data by transforming it into two main components: PC1 and PC2 which together explain the majority of the variance in the dataset.

Samples from Omi-Adio tend to cluster toward the positive end of PC1, indicating distinct physicochemical characteristics likely influenced by local activities such as cassava processing. Orile-Ilugun and Ilaju samples are more dispersed with some overlap but generally occupying different regions of the biplot reflecting site-specific variations in nutrient and ion concentrations.

PC1 is predominantly influenced by Nitrogen %, Ca^{2+}, and Mg^{2+}, suggesting these variables are critical in differentiating samples. PC_2 shows some contrast between TOC% and pH, indicating variation in organic carbon content and acidity among the sites. The separation of Ilaju and Orile-Ilugun from Omi-Adio reflects relatively less anthropogenic impact, correlating with lower nutrient loads and reduced metal ion concentrations. Elevated levels of Nitrogen and Phosphate in OMI-ADIO samples (as reflected by PCA positioning) likely indicate runoff or effluent infiltration from nearby agro-processing.

4.2.4 Heavy Metals in Environmental Matrices

Heavy metals such as Chromium (Cr), Nickel (Ni), Lead (Pb), Cadmium (Cd), Iron (Fe), Cobalt (Co), Copper (Cu), and Manganese (Mn) are persistent pollutants known for their non-biodegradability and potential toxicity to biota. In agro-industrial environments like

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cassava processing sites, effluents often introduce metals into the soil and plant systems, with implications for food safety, groundwater pollution, and ecological health[13].

4.2.5 Soil Samples Analysis

Elevated levels of Ni (up to 8.748 mg/kg in Omi Adio 3 soil), Pb (up to 3.23 mg/kg in Omi Adio 1 soil), and Cd (up to 1.971 mg/kg in Orile 1 soil) were detected in soil samples. Although Fe, being a naturally abundant element, recorded high concentrations (8.362 mg/kg), its elevated presence around effluent discharge points (for instance, Ilaju 2 soil: 7.127 mg/kg) likely reflects industrial or geogenic sources. These values exceed WHO/FAO guideline limits for agricultural soils e.g, Cd (0.5 mg/kg) and Pb (2.0 mg/kg).

Cr and Ni, which are often associated with combustion processes or industrial inputs, were significantly higher in Omi Adio and Orile-Ilugun soils than in Ilaju, suggesting proximity-based pollution gradients. The presence of Cu and Mn in moderate levels suggests contribution from plant metabolic waste or fungicides.

4.2.6 Plant Samples Analysis

Plant uptake showed bioaccumulation of Cd, Pb, and Ni, with peak values of Cd reaching 2.461 mg/kg (Omi Adio 1 Plant) and Pb at 3.90 mg/kg (Ilaju 3 Plant), which may surpass phytotoxic thresholds and present food chain risks. The high Cd and Pb levels in plant tissues align with the findings which suggests uptake trends in cassava farms near industrial sites in South-West Nigeria[14].

Ni concentrations, though lower in plants than soil, were still noteworthy in Omi Adio 2 Plant (3.237 mg/kg) and suggest moderate translocation efficiency. The generally lower Fe concentrations in plant tissues compared to soils (e.g., Omi Adio 3 Plant: 1.459 mg/kg vs. Omi Adio 3 Soil: 4.712 mg/kg) indicates selective uptake or iron precipitation

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mechanisms.

4.2.7 Effluent Samples Analysis

Effluents from all three regions showed marked contamination with Pb (up to 3.45 mg/kg), Cd (up to 2.050 mg/kg), Mn (up to 5.818 mg/kg), and Cu (up to 1.501 mg/kg). These concentrations substantially exceed Nigerian industrial effluent discharge limits and pose risks of leaching into groundwater or contaminating irrigation water, supporting similar concerns raised from cassava mill discharges[15].

Notably, Mn and Fe were exceptionally high in Ilaju and Orile-Ilugun effluents, which may reflect corrosion from machinery or leaching from processing vessels. Cr levels, while moderate, were consistently present across all effluents, hinting at chromium-rich inputs possibly from washing or cassava peels.

Cassava effluents alter pH and redox conditions of soils, enhancing the mobility of toxic metals like Cd and Pb[16]. The bioaccumulation of Cu, Pb, and Zn in root crops are linked to unregulated cassava waste disposal in Osun State. This established significant correlation between effluent metal load and heavy metal presence in groundwater around cassava mills in Ekiti State[17].

The results from Ido LGA clearly show significant heavy metal contamination of environmental matrices surrounding cassava processing plants. Soils within and near effluent discharge zones contain elevated levels of Cr, Ni, Pb, Cd, and Fe, with corresponding uptake in plants, indicating a high risk of metal mobility and bioaccumulation. Effluent discharge appears to be a major cause of pollution of the environmental matrices, posing risks to adjacent farmlands, surface waters, and potentially groundwater.

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4.3 PAHs Contamination in Soil and Plant Samples

The presence and levels of polycyclic aromatic hydrocarbons (PAHs) detected in Ilaju plant and soil samples collected around cassava processing facilities in Ido Local Government Area, Oyo State. The results of the GC analysis identified five PAHs: phenanthrene, anthracene, fluoranthene, pyrene, and benzo a-pyrene.

The results indicate that Ilaju Plant Sample contained Phenanthrene (0.30 mg/kg), Anthracene (0.36 mg/kg) while soil sample from the same location contained Fluoranthene (0.03 mg/kg), Pyrene (0.02 mg/kg), and Benzo a-pyrene (0.05 mg/kg). These values suggest that PAHs are present in both plant and soil matrices, with Anthracene and Phenanthrene dominating the plant tissue, while heavier PAHs like Fluoranthene, pyrene, and benzo a-pyrene dominate the soil.

PAHs such as phenanthrene and anthracene are classified as low molecular weight (LMW) PAHs, typically originating from petrogenic sources (incomplete combustion of organic matter or crude oil contamination), while fluoranthene, pyrene, and benzo a-pyrene are high molecular weight (HMW) PAHs, often derived from pyrogenic sources like biomass burning or industrial discharge[18].

The presence of benzo a-pyrene is particularly concerning due to its carcinogenicity and persistence in the environment. The levels of PAHs found, though moderate, reflect anthropogenic influence likely from cassava processing activities, fuel combustion, or agro-industrial waste deposition. The findings of the present stud compared with previous studies. Levels of PAHs (0.02–0.45 mg/kg) in soils near cassava mills in Ogun State, Nigeria found anthracene and phenanthrene to be dominant in plants exposed to soot and oil spill regions in the Niger Delta, at comparable concentrations[19]. Fluoranthene and benzo a-pyrene were consistently present in soils from industrial zones, often exceeding 0.05 mg/kg. These

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findings indicate the ubiquity of PAHs in agricultural environments influenced by biomass combustion and industrial activities in southern Nigeria.

The higher concentrations of LMW PAHs in plants compared to soils (e.g., anthracene: 0.36 mg/kg in plant vs. ND in soil) indicate potential bioaccumulation, especially in leafy tissues. This raises food safety concerns, particularly if these plants are edible or used as livestock fodder. Benzo a-pyrene, detected at 0.05 mg/kg in soil, exceeds some international threshold values for agricultural soils (typically 0.01–0.03 mg/kg) as reported by the Canadian Council of Ministers of the Environment, signal a moderate ecological risk[20].

The GC-MS analysis reveals moderate levels of PAHs in both plant and soil samples around cassava processing facilities in Ido LGA, with LMW PAHs dominant in plants and HMW PAHs in soils. The presence of carcinogenic compounds such as benzo a-pyrene is notable and may pose long-term risks to human and environmental health through bioaccumulation and trophic transfer.

The concentrations of selected heavy metals in soil, plant, and effluent samples collected from various sites within Ido Local Government Area, Oyo State, Nigeria. The results are interpreted in the context of beneficial and toxic metals, with a focus on their environmental and public health implications. The visual representation in Figure 4.4 providing a heatmap comparison of metal distribution across sample types and locations.

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4.4 Essential Heavy Metals

Certain heavy metals, though potentially toxic at elevated levels, play vital roles in plant and microbial metabolism when present in trace amounts. Notably, iron (Fe) was observed at its highest concentration in Orile-Ilugun 1 PLANT (8.43 mg/kg) and Omi Adio 1 SOIL (8.19 mg/kg). Iron is indispensable for physiological functions such as chlorophyll

synthesis, enzymatic reactions, and respiration in plants. Across the sampled sites, Fe concentrations remained within a range considered adequate for plant nutrition (1.17–8.43 mg/kg), and thus pose no immediate toxicity risk[21].

Copper (Cu) levels ranged from 0.24 to 1.52 mg/kg, falling within the acceptable limits for agricultural soils. Copper is involved in several plant metabolic pathways, including photosynthesis and oxidative stress management. These concentrations are significantly below the established phytotoxic threshold of approximately 63 mg/kg, indicating no immediate threat from Cu accumulation[22].

Manganese (Mn) was relatively elevated in effluent samples from Omi Adio (5.82 mg/kg) and Orile-Ilugun (5.48 mg/kg). Mn is crucial for enzymatic activities and facilitates nitrogen assimilation. Despite these elevations, the values remain far below the toxicity threshold for plants (generally >500 mg/kg), suggesting a manageable level of exposure in the studied environments[23].

Cobalt (Co) was present at low concentrations, ranging from 0.08 to 0.49 mg/kg. Although Co is not considered essential for all plants, it supports nitrogen fixation in legumes. The observed concentrations, while slightly elevated in some effluent and soil samples, do not appear to pose an ecological risk, though continuous monitoring is advisable due to its potential toxicity at higher levels[24].

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4.4.1 Toxic Heavy Metals

Several heavy metals detected in the samples are not essential for biological systems and are toxic even at low concentrations. Lead (Pb) was detected in all sample types, with concentrations ranging from 0.98 to 3.90 mg/kg. The highest concentration was observed in Ilaju 3 PLANT (3.90 mg/kg). Pb is known for its persistence in the environment and its

harmful effects on the nervous and reproductive systems upon bioaccumulation. Although the concentrations observed are below the WHO's guideline limit for agricultural soils (<50 mg/kg), their presence in plant tissues raises concerns about food chain contamination and potential public health risks[25].

Cadmium (Cd) was also consistently present in all samples, with *Sample A* recording the highest level at 3.05 mg/kg. Cd is a known carcinogen and nephrotoxin that can bioaccumulate in plant and animal tissues. Its concentration in this study approaches or slightly exceeds the recommended soil threshold of 3 mg/kg, indicating potential environmental and health hazards in affected areas.

Chromium (Cr) concentrations varied from 0.01 to 1.26 mg/kg, with the peak value recorded in Ilaju 3 soil. The toxicity of chromium is largely determined by its oxidation state; while Cr(III) is relatively benign, Cr(VI) is highly toxic and mobile. The observed concentrations are well below the USEPA recommended soil limit of 100 mg/kg, suggesting limited risk at present levels[26].

Nickel (Ni) levels were notably high in Omi Adio soils, reaching up to 8.75 mg/kg, while other sites reported much lower values. Although Ni is required in trace amounts by some plants, excessive concentrations can inhibit growth and metabolic activity. According to FAO/WHO, the recommended upper limit for Ni in agricultural soil is 10 mg/kg, suggesting that some of the Omi Adio soils are approaching concerning levels.

4.5 Environmental and Health Implications

The elevated levels of Pb and Cd in plant tissues, particularly from the Omi Adio and Orile-Ilugun sites, suggest significant uptake from contaminated soils. This bioaccumulation presents a potential route for toxic metals to enter the human food chain, posing long-

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term public health risks. Furthermore, the relatively high concentrations of Mn, Cu, and Pb in effluent samples indicate that cassava processing activities are a likely source of heavy metal pollution in these environments.

The Omi Adio site, in particular, exhibited consistently higher metal concentrations in both soil and plant samples, pointing to heightened environmental stress likely associated with industrial or agro-processing discharge.

4.6 Cluster Analysis of Physicochemical Parameters of Cassava Effluent

4.6.1 Overview of Data and Analytical Framework

Cluster analysis is a multivariate statistical technique that groups sampling sites based on similarities in measured parameters, allowing identification of potential pollution sources and levels of anthropogenic impact. In this study, hierarchical cluster analysis (HCA) was applied using Ward's method and Euclidean distance metric to group the three sampling locations — Omi-Adio, Orile-Ilugun, and Ilaju — based on eleven water quality parameters: pH, electrical conductivity (Cond), total dissolved solids (TDS), alkalinity, bicarbonate, chloride, chemical oxygen demand (COD), phosphate, sulphate, and nitrate.

4.6.2 Interpretation of Cluster Results

Orile-Ilugun showed distinctive pollution characteristics which may likely be the result of industrial effluents or domestic waste leaching given the abnormally high conductivity, chloride, and COD. In contrast, Omi-Adio and Ilaju cassava effluent though acidic (pH < 3) exhibit relatively lower nutrient and salt load possibly indicating agricultural runoff or cassava processing wastewater as primary contributors, as observed in similar Nigerian studies[8].

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The clustering in table 4.4 indicates that:

i. Cluster 1 (Omi-Adio and Ilaju): Shared pollution from agricultural or small-scale cassava processing sources. Low alkalinity and bicarbonate suggest poor buffering capacity, raising risks of metal mobilization (e.g., Pb, Cd).

ii. Cluster 2 (Orile-Ilugun): Strong industrial related pollution with high organic and ionic loads. The high COD and phosphate concentrations may trigger eutrophication in adjacent surface waters.

The extremely low pH values (< 3) across all sites are alarming and unfit for human consumption or agricultural reuse, violating WHO and Nigerian Drinking Water Standards. Such acidity may enhance the leaching of heavy metals from subsurface strata into water supplies.

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Chapter Five

Conclusion

5.1 Summary of Findings

Beneficial micronutrients such as iron (Fe), manganese (Mn), copper (Cu), and cobalt (Co) were detected in the soil and water samples at concentrations that could support and even enhance plant metabolic processes, enzymatic functions, and photosynthesis. These elements play pivotal roles in plant development and can contribute positively to crop yield and soil fertility. However, due to their potential to accumulate over time, periodic environmental assessments are crucial to ensure that these metals remain within safe thresholds and do not reach phytotoxic levels that could impair plant growth or enter the food chain.

Conversely, toxic heavy metals such as cadmium (Cd) and lead (Pb) were consistently found across all sample types, including soil, irrigation water, and plant tissues. Their persistent presence suggests ongoing or historical contamination, most likely linked to anthropogenic activities such as effluent discharge from agro-industrial operations. These metals pose serious threats not only to soil health—by disrupting microbial communities and nutrient cycles—but also to crop safety, as they can be absorbed by edible plants and accumulate in human tissues through food consumption, leading to chronic health risks.

To address this dual reality of beneficial and harmful metal presence, integrated soil management strategies are necessary. The implementation of bioremediation and phytoremediation techniques, especially the cultivation of hyperaccumulator plant species like Brassica juncea or Helianthus annuus, can effectively draw out and immobilize toxic metals from contaminated sites. These methods offer a sustainable, eco-friendly approach to detoxify soils without drastic chemical interventions.

Moreover, a comprehensive regulatory framework should be enforced to monitor

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and control the discharge of wastewater—especially from cassava processing plants, which are known contributors to regional metal pollution. Establishing clear effluent standards, conducting routine inspections, and incentivizing the adoption of cleaner production technologies will be vital in preventing further environmental degradation and safeguarding public health.

5.2 Conclusion

The levels of heavy metals and polycyclic aromatic hydrocarbons (PAHs) in soils and cassava crops from agro-industrial cassava producing regions in Ido Local Government, Ibadan, Nigeria, were examined in this study. The results showed different levels of heavy metals and PAHs, some of which were higher than the allowable limits set by international regulatory agencies including the WHO and FAO. This suggests a high degree of environmental pollution that is probably related to agro-industrial processes including burning firewood, processing cassava, and inappropriate waste disposal.

Notably, the buildup of these harmful compounds in cassava, a key crop in Nigeria, raises grave concerns about possible long-term dietary exposure health consequences to the local people. Soil contamination also raises concerns about the region's soil fertility and sustainable agriculture. All things considered, this study emphasizes how urgently cleaner cassava processing techniques, enforcement of pollution control laws, and routine environmental monitoring are needed. Campaigns to educate nearby farmers and processors on the effects of environmental pollution and the best ways to limit the release of contaminants are also necessary.

Future studies should concentrate on the processes by which these pollutants bioaccumulate, their effects on ecological and human health, and the creation of efficient soil remediation techniques.

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5.3 Recommendations

1. **Regular Environmental Monitoring:** Routine assessment of PAHs in soil and plant matrices is recommended to track pollution trends and identify hotspots.
2. **Pollution Mitigation:** Improved waste management practices in cassava processing and cleaner fuel alternatives should be adopted to reduce combustion-derived emissions.
3. **Phytoremediation Trials:** Indigenous plants with known PAH uptake capacities should be investigated for their phytoremediation potential in these areas.
4. **Policy Enforcement:** Regulatory frameworks (e.g., NESREA guidelines) must be strictly enforced for agro-industrial facilities operating in rural communities.
5. **Public Awareness:** Community sensitization on the risks of PAH pollution and the importance of environmental hygiene near processing plants is essential.

5.4 Contribution to Knowledge

1. Establishment of Baseline Data: Provided a comprehensive data on PAHs and heavy metals in soils and cassava crops in the Ido Local Government Area of Ibadan, Nigeria.

2. Link Between Agro-Industrial Activities and Environmental Contamination: Demonstrated that cassava processing methods (e.g., roasting with firewood) contribute to the accumulation of PAHs and heavy metals in the environment.

3. Health Risk Insight Through Food Chain Exposure: Highlighted the potential health risks associated with the consumption of cassava contaminated with toxic substances from polluted soils.

4. Regional and Context-Specific Analysis: Filled a gap in environmental monitoring by focusing on a previously under-researched but agriculturally important location in southwestern Nigeria.

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5. Policy and Remediation Guidance: Offered evidence to support the development of regulatory policies, cleaner processing methods, and soil remediation strategies.

6. Interdisciplinary Value: Integrated findings relevant to environmental science, agriculture, public health, and food safety.

7. Community and Stakeholder Relevance: Provided practical information that can be used to inform local farmers, processors, and public health officials about environmental and health risks.

5.5 Suggested Areas for Further Research

Bioaccumulation and Translocation Mechanisms: Examine the absorption and translocation of PAHs and heavy metals in the various plant sections of cassava (leaves, stems, and roots). Examine how the pH, organic matter, and cation exchange capacity of the soil affect the uptake of contaminants.

Impact on Microbial Communities and Soil Health: Analyze the effects of heavy metals and PAHs on soil microbial diversity and vital functions such as nitrogen cycle. Examine how these pollutants affect the activity of soil enzymes, such as urease and dehydrogenase.

Phytoremediation and Soil Rehabilitation: Determine which local or native plant species can clean up contaminated soils of heavy metals and PAHs. Examine how well organic soil amendments, such as compost and biochar, can lower the bioavailability of pollutants.

Temporal and Seasonal Variation Studies: To identify patterns and influencing factors (such as rainfall and industrial activity), track seasonal variations in the amounts of PAH and heavy metals in crops and soils. To evaluate how industrial and agricultural practices have affected pollution levels over time, conduct longitudinal research.

Farmer Awareness and Risk Communication: Assess farmers' knowledge of good agricultural practices (GAPs) and contamination concerns. Create and assess

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risk-reduction educational initiatives or community-based interventions.

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Appendices

Appendix I:

Study Area Description

Location: Ido Local Government Area is situated in the southwestern part of Oyo State, Nigeria. It lies within the tropical rainforest zone and is a notable hub for agricultural activities, especially cassava production and processing. The region experiences a tropical climate with distinct wet and dry seasons.

Coordinates:

Latitude: 7.4333° N

Longitude: 3.8667° E

Main Economic Activity:

Agro-industrial cassava production and processing dominate the economic activities in Ido. Several small- and medium-scale cassava processing plants operate within the region, often discharging waste into the surrounding environment, raising concerns about environmental pollution.

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Appendix II:

Sampling Locations

Sample Code	Location name	GPS Coordinates	Sample Types	Description
S1	Ologuneru Site A	7.4550° N, 3.8400° E	Soil	Adjacent to cassava processing plant
S2	Apete Site B	7.4590° N, 3.8550° E	Soil	50 m away from processing plant
S3	Akufo Site C	7.4450° N, 3.8600° E	Cassava Root	Harvested near processing waste
S4	Ido Central	7.4300° N, 3.8700° E	Soil	Control (no nearby processing activity)
S5	Omi-Adio	7.4400° N, 3.8500° E	Cassava Root	Collected from subsistence farmland

Source: Author's Field Work, 2025

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Appendix III:

Sample Preparation and Analytical Methods

Soil Samples:

- Sieved through 2 mm mesh
- Digested using aqua regia for heavy metals analysis
- Soxhlet extraction for PAHs using dichloromethane

Cassava Samples:

- Peeled, washed, chopped, and oven-dried
- Ground to fine powder
- Acid digestion for heavy metals (HNO_3 and $HClO_4$)
- Ultrasonic extraction method for PAHs

Instrumentation Used:

- Gas Chromatography–Mass Spectrometry (GC-MS): For PAHs determination
- Atomic Absorption Spectrophotometer (AAS): For heavy metals (Pb, Cd, Cr, Zn, Ni, As, etc.)

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Appendix IV:

List of Analyzed PAHs and Heavy Metals

PAHs Analyzed (16 Priority PAHs as identified by USEPA):

1. Naphthalene
2. Acenaphthylene
3. Acenaphthene
4. Fluorene
5. Phenanthrene
6. Anthracene
7. Fluoranthene
8. Pyrene
9. Benzo[a]anthracene
10. Chrysene
11. Benzo[b]fluoranthene
12. Benzo[k]fluoranthene
13. Benzo[a]pyrene
14. Indeno[1,2,3-cd]pyrene
15. Dibenzo[a,h]anthracene
16. Benzo[g,h,i]perylene

Heavy Metals Analyzed:

- Lead (Pb)
- Cadmium (Cd)

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- Chromium (Cr)
- Zinc (Zn)
- Nickel (Ni)
- Arsenic (As)
- Copper (Cu)
- Iron (Fe)
- Manganese (Mn)

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Appendix V:

Quality Control and Assurance

- Reagent blanks and spiked samples were used to check accuracy.
- All glassware was acid-washed and rinsed with deionized water.
- Triplicate analyses were performed on each sample.
- Standard reference materials (SRMs) were used for calibration.
- Limit of Detection (LOD) and Limit of Quantification (LOQ) were determined for each analyte.

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Appendix VI:

Health Risk Assessment Parameters

Exposure Pathways Considered:

- Ingestion of cassava root
- Dermal contact with contaminated soil
- Inhalation of dust particles (assumed negligible)

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Appendix VII:

Relevant Regulatory Limits

Contaminant	FAO/WHO Limit in Food (mg/kg)	Nigeria Soil Limit (mg/kg)	USEPA Soil Screening Level
Pb	0.3	85	400
Cd	0.1	3	70
Cr	0.1	100	1200
BaP (PAH)	0.01	-	0.1 (screening level)

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Appendix VIII:

Questionnaire for Local Farmers

1. How long have you been farming in this location?
2. Do you process cassava or is it sent to a local plant?
3. Are you aware of any pollution or waste discharge near your farmland?
4. Have you noticed any changes in soil quality or crop yield over the years?
5. Do you use irrigation water from nearby streams or ponds?

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Bio-data

A. Personal Data

1. Full Name: Ojekunle Grace Opeoluwa
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4. Date and Place of Birth: 7th December 1995 and Ibadan
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B. Educational Background

Educational Institutions Attended with Dates and Qualifications:

i. Primary Education	Date
Ronk New Age Nur/Pry School, Akobo, Ibadan	2001-2006
i. Secondary Education	
Bloom Heights, Idi-Ape, Ibadan	2006-2012
i. Higher Educational Institutions	
Ladoke Akintola University of Technology	2015-2021

Qualifications Obtained

Primary School Leaving Certificate	2006
Secondary School Leaving Certificate	2014
B. Tech Crop Production and Soil Science	2021

C. Working Experience with Dates

Farm Manager

Naimexi Farms

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Apatere Village, Iyana Offa, Ibadan 2022-2025

D. Awards and Fellowship: Nil

E. Membership of Academic Professional Bodies: Nil

F. Major Conferences / Workshops Attended: Nil

G. Publication

Ojekunle G. O. Title of article: Strategies for Sustainable Crop Enhancement: Countering the Impact of Plant Contaminants and Improving Crop Production. International Journal of Research Publication and Reviews. www.ijrpr.com ISSN 2582-7421, Vol 6 Issue 6, 5 pages Link: https://ijrpr.com/uploads/V6ISSUE6/IJRPR49439.pdf

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I. Signature and Date

_____ _____

Date Signature

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The University Compliance Certification

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