Cover page

INVESTIGATING URBAN HEAVY METAL POLLUTION: SITE-SPECIFIC SOIL CONTAMINATION AND EARTHWORM (*APORRECTODEA LONGA*) AS A BIOINDICATOR IN MARKET, LIVESTOCK AREA, MOAT, AND STADIUM/AIRPORT ENVIRONMENTS

BY

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DEPARTMENT OF ANIMAL AND ENVIRONMENTAL BIOLOGY

FACULTY OF LIFE SCIENCES

UNIVERSITY OF BENIN

FEBRUARY, 2025

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A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF ANIMAL AND ENVIRONMENTAL BIOLOGY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF BENIN, BENIN CITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF SCIENCE IN ANIMAL AND ENVIRONMENTAL BIOLOGY(BSCAEB)

FEBRUARY, 2025

CERTIFICATION

This is to certify that this project was carried out by **ANTHONY AIGBE ESEDE** of the Department of Animal and Environmental Biology, Faculty of Life Sciences, University of Benin, Benin City.

________________________ ________________________________

DR. O.C. ASEMOTA DATE

(Project Supervisor)

_________________________________ _____________________________

PROF. MYKE .O. OMOGBERALE DATE

(Head of Department)

DEDICATION

This work is dedicated to God Almighty.

AKNOWLEDGEMENT

I am deeply grateful to God Almighty for granting me the strength, wisdom, and resilience to complete this research.

I sincerely appreciate my project supervisor, Dr. O. C Asemota, whose invaluable guidance, encouragement, and expertise have been essential in shaping this study. His constructive feedback and continuous support have significantly contributed to the quality of my work.

I thank my colleagues for their collaboration, motivation, and shared knowledge. I also want to specially thank my project partner- Nessa, for her resilience, patience and assistance throughout the course of this project.

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ABSTRACT

Soil contamination by heavy metals is a growing environmental concern in urban areas due to industrial activities, traffic emissions, and waste disposal. This study examines the spatial distribution and bioaccumulation of heavy metals in soil from New Benin Market, a livestock area, Benin Airport, Ogbemudia Stadium, and Siluko Moat, using Aporrectodea longa as a bioindicator. Soil and earthworm samples were analyzed for Zn, Cu, Mn, Ni, Pb, Cd, and Fe using Atomic Absorption Spectroscopy (AAS), with statistical assessments conducted to determine site-specific variations. Results revealed site-dependent contamination patterns. The New Benin Market had lower concentrations, but bioaccumulation in earthworms indicated risks from vehicular emissions and metal-based products. The Livestock Area exhibited high Zn, Cu, and Fe levels probably due to animal waste and feed additives. At Benin Airport, Pb, Zn, and Cu levels were linked to aviation fuel combustion and vehicular emissions. Ogbemudia Stadium recorded the highest Zn and Ni concentrations possibly influenced by recreational activities and infrastructure maintenance. Siluko Moat showed notable Zn, Cu, and Fe contamination, with Pb and Cd probably due to urban runoff and sewage leaks. Earthworm bioaccumulation across sites underscores their role as ecological indicators and the influence of organic matter on metal retention. These findings emphasize the need for targeted remediation strategies, including phytoremediation, soil amendments, and stricter environmental regulations. Continuous monitoring and public awareness initiatives are essential for mitigating heavy metal pollution and ensuring sustainable urban land use.

CHAPTER ONE

1.0 Introduction

Soil is a fundamental component of terrestrial ecosystems, serving as a habitat for diverse organisms, a reservoir of nutrients, and a medium for various biochemical processes (Bardgett, 2005). However, increasing human activities such as industrialization, urbanization, and agricultural expansion have significantly altered soil composition, leading to widespread contamination (Lal, 2007). Among the various pollutants affecting soil, heavy metals are particularly concerning due to their persistence, toxicity, and bioaccumulative nature. These contaminants originate from both natural and anthropogenic sources, including vehicular emissions, industrial discharge, waste disposal, and agricultural runoff (Ali *et al.,* 2019). Once introduced into the soil, heavy metals pose a significant threat to environmental health, affecting soil fertility, biodiversity, and human well-being (Xu *et al.,* 2024).

In urban environments, heavy metal pollution is exacerbated by unregulated activities such as improper waste management, fuel combustion, and emissions from heavy traffic (Khanam *et al.,* 2023). Market areas, livestock zones, historical moats, and sports facilities such as stadiums and airports are particularly susceptible to contamination due to their high levels of human activity (Moises *et al.,* 2021). The release of heavy metals from these locations into surrounding soils can lead to bioaccumulation in soil organisms and, subsequently, bio-magnification along the food chain. Metals such as cadmium (Cd), lead (Pb), zinc (Zn), and copper (Cu) have been reported to accumulate in urban soils, posing health risks to humans through direct exposure, food consumption, and inhalation of contaminated dust (Li *et al.,* 2018). Additionally, these contaminants can leach into groundwater, further expanding their environmental impact.

Vehicular pollution is a major contributor to heavy metal accumulation in roadside soils, particularly in developing nations where emissions are not strictly regulated (Singh and Devi

2023). In Benin City, which serves as a major transport hub, heavy metal deposition from vehicles is a growing concern. The presence of major highways, commercial markets, abattoirs, and industrial zones leads to continuous exposure of urban soils to pollutants from traffic emissions and waste disposal (Mulikat 2022). The decomposition of waste from livestock areas and abattoirs also introduces additional contaminants, including heavy metals, antibiotics, and hormones, which can persist in the environment and disrupt ecological functions.

Earthworms (*Aporrectodea longa*) are widely recognized as bioindicators of soil health due to their ability to accumulate heavy metals in their tissues (Zhang *et al.,* 2022). These organisms play a crucial role in soil ecosystems by enhancing soil aeration, organic matter decomposition, and nutrient cycling. However, their exposure to contaminated soils results in metal bioaccumulation, which can serve as a reliable measure of soil pollution levels (Renu *et al.,* 2023). The accumulation of heavy metals in earthworms provides insights into the bioavailability of these contaminants and their potential impact on higher organisms within the food web. Studies have shown that earthworms can effectively reflect the extent of heavy metal contamination in different land-use areas, making them ideal organisms for ecotoxicological assessments (Suthar *et al.,* 2008)

This study seeks to conduct a site-specific risk assessment of heavy metals in soils across various anthropogenic activity sites within the southern senatorial district of Edo State. By leveraging the bioindicator potential of earthworms, the research will explore the spatial variability of soil contamination, the extent of heavy metal bioaccumulation, and the associated risks to both human and ecological health.

1.1 Aims and Objective.

To perform a site-specific risk assessment of heavy metals in soils using earthworms as bioindicators in the southern senatorial district of Edo State, Nigeria.

The objectives of this study were

1. To measure heavy metal concentrations in soils collected from diverse land-use sites, including urban parks, industrial zones, and landfill sites.
2. To identify spatial patterns in soil contamination and their correlation with specific anthropogenic activities.
3. To provide recommendations for soil management and remediation strategies based on site-specific risk profiles.

CHAPTER TWO

2.0 Literature Review

Soils can become contaminated with heavy metals and metalloids due to emissions from rapidly expanding industrial areas, mine tailings, disposal of high metal wastes, leaded gasoline and paints, land application of fertilizers, animal manures, sewage sludge, pesticides, wastewater irrigation, coal combustion residues, spillage of petrochemicals, and atmospheric deposition (Khan et al., 2008; Zang et al., 2010). Heavy metals are a poorly defined group of inorganic chemical hazards, but the most common ones found at contaminated sites include lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), copper (Cu), mercury (Hg), and nickel (Ni). (GWRTAC,1997)

Soils serve as the primary sink for heavy metals released into the environment by these anthropogenic activities (Kirpichtchikova *et al.,* 2006). Unlike organic contaminants, which can be oxidized to carbon dioxide by microbial action, most metals do not undergo microbial or chemical degradation. Therefore, their total concentration in soils can persist for a significant time after their introduction. However, changes in their chemical forms (speciation) and bioavailability are possible. The presence of toxic metals in the soil can significantly inhibit the biodegradation of organic contaminants.

Heavy metal contamination of soil can pose risks to human health and ecosystems through various pathways, including direct ingestion or contact with contaminated soil, the food chain (soil-plant-human or soil-plant-animal-human), consumption of contaminated groundwater, reduced food quality (due to phytotoxicity), decreased land usability for agricultural production leading to food insecurity, and land tenure issues. (McLaughlin *et al.,* 2000; Ling *et al.,* 2007)

To adequately protect and restore soil ecosystems contaminated by heavy metals, characterization and remediation are essential. Contemporary legislation regarding environmental protection and public health, at both national and international levels, is based on data that characterize the chemical properties of environmental phenomena, particularly those that affect our food chain (Kabata-Pendias and Pendias 2001). While soil characterization provides insight into heavy metal speciation and bioavailability, remediation efforts require knowledge of the contamination source, basic chemistry, and the environmental and health risks associated with these heavy metals.

Risk assessment is a valuable scientific tool that enables decision-makers to manage contaminated sites in a cost-effective manner while safeguarding public health and ecosystem integrity (Kabata-Pendias Pendias 2007). Techniques such as immobilization, soil washing, and phytoremediation are often considered among the best demonstrated available technologies (BDATs) for remediating heavy metal-contaminated sites (GWRTAC 1997). Despite their cost-effectiveness and environmental friendliness, these technologies have primarily been reported in developed countries. In many developing countries, they remain commercially unavailable, possibly due to a lack of awareness about their advantages and operational principles.

As awareness among governments and the public grows regarding the implications of contaminated soils on human and animal health, there is increasing interest within the scientific community in developing technologies to remediate contaminated sites (Bolan et al., 2008). In developing countries, where population density is high and funds for environmental restoration are scarce, low-cost and ecologically sustainable remedial options are needed to restore contaminated land. This restoration is vital for reducing associated health risks, making land available for agricultural production, enhancing food security, and alleviating land tenure problems.

2.1 Sources Of Heavy Metals

Heavy metals are ubiquitous in the environment due to both natural processes and human activities. People encounter these metals in various ways (Bakshi *et al.,* 2018). Heavy metals are persistent pollutants that do not decompose and can enter the human body through food, air, and water, accumulating over time. Human activities have significantly contributed to the introduction of heavy metals into ecosystems (Rasmussen *et al.,* 2007).

Even at low concentrations, the presence of heavy metals poses environmental concerns due to their toxicity. Minor increases in their concentration, whether stemming from natural or anthropogenic sources, can lead to serious environmental and health problems. Anthropogenic sources of heavy metal pollution include agricultural practices such as the use of pesticides and herbicides, the use of contaminated irrigation water, and the application of municipal waste as fertilizer (Bakshi *et al.,* 2018). . Other sources include waste disposal in farmland, mining operations, smoking, traffic emissions, sewage discharge, and building materials such as paints.

Previous studies conducted in Indonesia indicate that heavy metals released into the environment come mainly from industrialization, waste disposal, and agricultural activities. For instance, Budiyanto and Lestari (2017) reported that the coastal areas of Indonesia are contaminated with metals due to the direct discharge of approximately 1,100 tons of solid waste. This massive pollution threatens water safety and aquatic life, contributing to the large-scale death of aquatic animals, including coral reefs.

Humans and animals can also be exposed to toxic heavy metals through the inhalation of dusty soil. Heavy metal pollutants such as copper, lead, and zinc can accumulate in highway soils and vegetation from additives used in gasoline and lubricating oils (Eneje and Kelechi 2012)

Heavy metal contamination in the environment arises from both natural and anthropogenic sources. Cadmium (Cd) occurs naturally in black shale and is released through volcanic activity. It is also found in parent materials, marine sedimentary rocks, and phosphates (Bakshi *et al.,* 2018; Khan *et al.,* 2019). However, human activities significantly contribute to Cd contamination, particularly through the extraction and refining of non-ferrous metals, the manufacture and application of phosphate fertilizers, and the burning of fossil fuels. Other sources include incineration, domestic sewage, waste disposal, and emissions from industries such as tanneries and electroplating. Additionally, Cd is introduced into the soil through discarded batteries, paint, stained glass, and paper ink found in municipal solid waste (Bakshi *et al.,* 2018; Somani *et al.,* 2019; Ramelli *et al.,* 2012; Rezapour *et al.,* 2018).

Lead (Pb) is naturally present in acidic igneous rocks, argillaceous rocks, and sedimentary deposits. Limestone, dolomites, and black shale also contribute to Pb accumulation in the soil (Bakshi *et al.,* 2018). Anthropogenic sources of Pb pollution include mining and smelting activities, the use of lead-based paints, gasoline additives, automobile demolition, and pesticide applications. Pb is also released into the soil through industrial effluents, burning of waste, and the disposal of Pb-containing products such as batteries, soldering materials, pottery glazes, leaded crystal glassware, cosmetics, hair dyes, and gunshot ammunition. Additionally, relic fishing sinkers, tire weights, imported children’s toys, traditional remedies, and certain food packaging materials have been identified as contributors to Pb contamination (Bakshi *et al.,* 2018]; Ekere 2017; Khan *et al.,* 2019).

Zinc (Zn) occurs naturally in sedimentary and acidic granitic rocks, as well as in black shale and clayey sediments. Other geological sources include sandstone, limestone, and dolomite

(Bakshi *et al.,* 2018). In contrast, human activities introduce Zn into the environment through mining operations, zinc production facilities, and steel manufacturing. The combustion of coal and fuel, waste disposal, incineration, and the use of fertilizers and pesticides containing Zn further contribute to soil contamination (Bakshi *et al.,* 2018; Khan *et al.,* 2019; Lundberg *et al.,* 1997).

Copper (Cu) is another heavy metal that exists naturally in different parent rocks, particularly in basic igneous formations such as basalts. It is also found in shale-clay and black shale deposits (Bakshi *et al.,* 2018). Anthropogenic sources of Cu pollution include non-ferrous metal production, copper smelting, and steel manufacturing. Municipal incinerators, mining residues, sewage sludge, and mineral fertilizers also add Cu to the soil. Additionally, the recycling of biosolids and the use of Cu-based fungicides in agriculture contribute to contamination in farmland soils (Bakshi *et al.,* 2018; Khan *et al.,* 2019; Barceloux 1999).

Chromium (Cr) is a toxic element that poses cancer risks. In the environment, it exists in two stable oxidation states: chromium (III) and chromium (VI). Chromium (III) is considered a less hazardous form compared to chromium (VI). These two forms can convert into each other during industrial processes. However, converting chromium (VI) to chromium (III) is less harmful to the environment due to the lower toxicity of chromium (III). Chromium is widely used in various industries, which can threaten regional climates. Compared to natural chromium emissions from the environment, emissions from the ferrochrome industry are significantly higher (Coetzee *et al.,* 2020).

Cobalt (Co) is commonly found in vegetation, soils, rocks, and water, and it is used to produce alloys. Although the rate of cobalt discharge into the environment is low, it can be highly dangerous to humans. Cobalt affects the human body in both beneficial and harmful ways. While small amounts of cobalt typically do not have negative consequences, large discharges into the environment can lead to serious health issues or fatalities (Domingo, 1989).

Mercury (Hg), though less abundant, is naturally released into the environment through the degassing of the Earth's crust. It is also found in igneous and sedimentary rocks, as well as in argillaceous sediments (Bakshi *et al.,* 2018). However, human activities have significantly increased Hg pollution, primarily through the burning of fossil fuels and the production of steel, cement, and phosphate. The smelting of metals from sulfide ores is another major source of Hg contamination (Bakshi et al.*et al.,* 2018; Khan *et al.,* 2019).

The presence of these heavy metals in the environment, whether from natural or human-induced sources, poses significant ecological and health risks. Their persistence in soil, potential for bioaccumulation, and capacity to enter food chains necessitate continuous monitoring and regulatory measures to mitigate their impact.

2.2 Role of earthworm in improving soil structure and functioning

2.2.1 Soil structural development

The formation of soil structure from micro to macro scales is influenced by various interacting physical forces, including soil water content, the activities of larger organisms such as plant roots and earthworms, the presence of organic matter, and tillage practices (Millere et al., 2009). Earthworms, in particular, play a significant role in rearranging soil structure as they navigate through it, feed on it (Martin and Marinissen, 1993), and contribute materials due to their low efficiency in nutrient assimilation.

Depending on the species, earthworms can either compact or loosen the soil. Anecic and endogeic species primarily enhance soil structure through the production of casts in both vertical and horizontal burrows. This cast production alters soil bulk density by integrating organic matter. For instance, studies on the endogeic earthworm Reginaldia omodeoi showed an increase in soil bulk density from 1.24 to 1.31 g cm–3 and from 1.37 to 1.48 g cm–3 (Lavelle et al., 2014). Additionally, a significant change in bulk density was recorded, moving from 1.12 to 1.23 g cm–3, while porosity dropped from 58% to 53% in the presence of the tropical endogeic earthworm Pontoscolex corethrurus (Alegre *et al.,* 1996).

A long-term field study conducted in tropical conditions revealed that the interplay between compacting earthworms (R. omodeoi) and de-compacting species from the small Eudrilidae family helped preserve soil structure over time. Earthworms also influence the size distribution of soil aggregates. De-compacting species, such as Millsonia anomala, can disrupt macro-aggregates created by compacting species, while the opposite is true for casts produced by the de-compacting earthworms (Blanchart *et al.,* 1997). This highlights the variability in how earthworms regulate the dynamics of soil structure. It was reported that when compacting earthworms like R. omodeoi were introduced into yam and maize crops, the proportion of aggregates larger than 2 mm increased from 30% to 54% and from 25% to 42%, respectively (Gilot, 1997). Earthworms are estimated to produce casts at rates between 40 to 100 tonnes per hectare per year, significantly contributing to the formation of stable soil aggregates, and can convert 18 to 42% of soil material into macro-aggregates within just two months.

2.2.2 Sensitivity of earthworms to heavy metals

Earthworms maintain close association with soil particles through their digestive tract and their permeable skin (Roubalova *et al.,* 2015). They exhibit a high sensitivity to soil pollutants because of the distribution of sensory tubercles and the presence of chemoreceptors at both the anterior and posterior ends of their bodies (Langdon *et al.,* 2003; Cui *et al.,* 2022). The ecological distribution of earthworms influences their sensitivity to soil pollution, as different species have varied living and feeding habits (Huang *et al.,* 2021). Bouche (1977) categorized earthworms into three primary ecological groups—epigeic, anecic, and endogeic—based on their ecosystem services and processes.

Fourie *et al.* (2007) identified species-specific differences in sensitivity concerning DNA damage across five earthworm species: epigeic (E. fetida, Amynthas diffringens, and Dendrodrilus rubidus), anecic (Microchaetus benhami), and endogeic (A. caliginosa) when exposed to cadmium (Cd). They determined that E. fetida and D. rubidus, both epigeic species, exhibited the greatest sensitivity to Cd pollution. However, Huang et al. (2021) found in their research that endogeic and anecic earthworms exhibited a higher sensitivity to heavy metal bioaccumulation compared to epigeic species. They also noted that as soil contamination intensified, endogeic and anecic species significantly declined, while epigeic species gradually became more prevalent. Suthar *et al.,* 2008 noticed species-specific patterns of metal accumulation in earthworms in relation to their ecological types. They proposed that feeding behavior, ecological classification, niche structure, and the distribution of toxicants in soil layers are key factors influencing metal accumulation patterns in earthworms. Additionally, they indicated that variations in the burrowing behavior of anecic and endogeic species might affect their metal bioaccumulation trends (Suthar *et al.,* 2008). Lukkari and Haimi (2005) discovered that epigeic earthworms (E. *fetida*) exhibited a more stringent regulation of heavy metal concentrations in their tissues compared to endogeic earthworms (A. *tuberculata*), suggesting they are better tolerated to heavy metal exposure. Sinkakarimi *et al.,* 2020 found that endogeic species (A. rosea and A. trapezoids) were more vulnerable to lead (Pb) and Cd contamination than epigeic species (E. *fetida*), as indicated by weight loss, mortality rates, lipid peroxidation levels, total antioxidant capacity, and DNA damage in coelomocytes. Thus, the behavioral differences among species lead to varying sensitivities to soil contaminants (Langdon *et al.,* 2003).

2.3 Bioaccumulation of heavy metals

Heavy metals are persistent pollutants in the environment, which allows them to enter and accumulate in organisms (Ali *et al.,* 2019). Earthworms primarily take up heavy metals from the soil through direct skin contact and ingestion (Wijaywardena et al., 2017). The extent of heavy metal accumulation in earthworms is influenced by various factors such as the specific genera of earthworm, the physicochemical characteristics of the soil, the level of contamination, as well as environmental conditions like soil moisture and temperature (Xiao et al., 2022).

Research indicates that the intestinal area, specifically the chloragogenous tissue that covers the coelomic surface of the intestine, tends to accumulate high levels of heavy metals (Sturzenbaum *et al.,* 2004). The longitudinal and circular muscles within the earthworm's digestive tract play a significant role in this accumulation process (Kilic, 2011). A study by Leveque *et al.* (2013) examined the distribution of lead (Pb) in earthworm tissues, revealing that lead was chiefly found in the longitudinal muscles and the gut wall of the contaminated worms (Pandey et al., 2016).

2.4 Toxicity of Heavy Metals

2. 4.1. Neurotoxicity

Manganese is a vital element that plays a role in various physiological functions within the body. Although short-term exposure to manganese may have neuroprotective properties by decreasing apoptotic cell death, prolonged exposure can result in damaging neurological conditions such as Alzheimer's and Parkinson's diseases. These disorders are linked with heightened apoptotic cell death and disturbances in homeostasis (Goldhaber, 2003). The regulation of manganese levels in cells depends on sufficient intake, storage, and excretion facilitated by different cell receptors and ion channels. When manganese exposure exceeds safe levels, the receptors that facilitate manganese absorption are downregulated, while those that aid in its removal are upregulated. Nonetheless, continued accumulation of manganese may lead to an increase in reactive oxygen species (ROS), which can cause mitochondrial dysfunction. This dysfunction could trigger the release of cytochrome c, activating the apoptotic precursor caspase-9 and leading to the activation of caspase-3. The active form of caspase-3 subsequently interacts with a pro-apoptotic protein, protein kinase C delta (PKCd). The cleavage of PKCd by caspase-3 contributes to DNA fragmentation and the process of apoptosis (Harischandra *et al.,* 2019).

Arsenic exposure has harmful effects on the central nervous system, resulting in cognitive deficits and has been linked to several neurological disorders, including developmental issues and a heightened likelihood of neurodegenerative diseases. Arsenic toxicity can impair synaptic transmission and disrupt the balance of neurotransmitters (Garza-Lombó *et al.,* 2019). The neurotoxic effects of arsenic are associated with various apoptotic mechanisms. Firstly, arsenic and its methylated derivatives can induce caspase-mediated apoptosis in neural cells through the MAPK signaling pathways, such as ERK2, JNK, and p38, which engage intrinsic mitochondrial-apoptotic pathways. Moreover, arsenic can cause an increase in intracellular calcium levels, which can play a role in apoptosis. In contrast, apoptosis may also be modulated by the promotion of autophagy via the activation of AMP-activated protein kinase (AMPK) and the repression of the mammalian target of rapamycin (mTOR). Autophagy is regarded as a homeostatic mechanism where double-membraned autophagosomes gather cellular components for subsequent degradation after fusing with lysosomes (Garza-Lombó *et al.,* 2019).

Neurodegenerative diseases, including amyotrophic lateral sclerosis, Parkinson's disease, Alzheimer's disease, and multiple sclerosis, can arise from neurotoxicity caused by cadmium (Branca et al., 2018). A multitude of preclinical studies indicates that cadmium severely disrupts the functioning of both the peripheral nervous system (PNS) (Miura *et al.,* 2013) and the central nervous system (CNS) (Marchetti, 2014), leading to clinical symptoms such as peripheral neuropathy, olfactory dysfunction, neurological issues, learning challenges, cognitive impairments, motor function deficiencies, and behavioral changes in both adults and children. Additionally, cadmium neurotoxicity impacts various cellular functions, including differentiation, proliferation, and cellular death. The neurotoxic effects of cadmium are predominantly due to apoptosis in neural cells, which is influenced by numerous factors that promote apoptosis, such as impaired neurogenesis, suppression of neuronal gene expression, epigenetic modifications, and endocrine disruptions (Wang and Du, 2013).

Pathological studies of humans and animals exposed to thallium show that this toxin can inflict considerable harm on both the brain and peripheral nerves. The consequences include cerebral edema, vascular congestion in the cerebral hemispheres, modifications in capillary structure within the brain, cerebellar edema featuring pyknotic Purkinje cells, and localized areas of necrosis (Davis *et al.,* 1981).

Besides manganese, arsenic, and cadmium, many other heavy metals are known for their neurotoxic effects. For example, excessive levels of copper and zinc can similarly impair neurodevelopment, much like iron (Prohaska, 2000). Accumulation of excess copper can result in Wilson's disease, a genetic disorder leading to neurobehavioral changes comparable to schizophrenia. While a lack of zinc adversely affects neurodevelopment, the implications of excess zinc remain uncertain (Cai *et al.,* 2005). An experimental investigation by Ken-ichiro Tanaka and Masahiro Kawahara found that copper may exacerbate zinc-induced neurotoxicity (Tanaka and Kawahara, 2017).

2.4.2 Carcinogenicity

Arsenic causes modifications at the epigenetic level, leads to DNA damage, affects the expression of p53 protein, alters histones, impacts DNA methylation, and reduces p21 expression (Martinez *et al.,* 2011; Park *et al.,* 2015). Exposure to arsenic heightens the risk of cancer by interacting with proteins involved in DNA binding and disrupting the mechanisms responsible for DNA repair (Garcia-Esquinas *et al.,* 2013).

Lead is acknowledged as a carcinogen that hinders DNA repair processes, affects cellular tumor-suppressing genes, and alters chromosomal structures and sequences by producing reactive oxygen species (ROS) (Silbergeld *et al.,* 2000).

Mercury generates a significant amount of ROS from its peroxidative effects, which can activate signaling pathways that encourage tumor growth. These ROS can harm critical cellular elements, such as proteins, lipids, and DNA, resulting in cellular damage (Reczek and Chandel, 2017; Zefferino *et al.,* 2017).

Nickel acts as a carcinogen by affecting various mechanisms associated with cancer progression, including gene regulation, transcription factor management, and free radical generation. It modifies the expression of specific long non-coding RNAs, mRNAs, and microRNAs. Nickel also contributes to the methylation of the promoter and the downregulation of gene 3 (MEG3), thereby enhancing the regulation of hypoxia-inducible factor-1, both of which are crucial in the cancer development process (Zambelli *et al.,* 2016; Zhou *et al.,* 2017).

2.4.3 Nephrotoxicity

Exposure to cadmium produces pronounced nephrotoxic effects, including glucosuria, Fanconi-like syndrome, phosphaturia, and aminoaciduria (Hazen-Martin *et al.,* 1993; Reyes et *al.,* 2013). It has a direct impact on the proximal tubular epithelium, resulting in higher cadmium levels in urine and disorders such as aminoaciduria, 32-microglobulinuria, glucosuria, and reduced phosphate reabsorption in the renal tubules (Goyer, 1989). Extended exposure may lead to renal tubular acidosis, kidney failure, and hypercalciuria (Friberg *et al.,* 2019; Jacquillet *et al.,* 2007).

Lead adversely affects all body organs, but its most significant impact is on the kidneys. Acute lead nephropathy results in dysfunction of the proximal tubules, leading to symptoms akin to Fanconi syndrome. Chronic exposure can result in hyperplasia, interstitial fibrosis, tubular atrophy, kidney failure, and glomerulonephritis.

Acute mercury exposure can result in tubular necrosis, commonly presenting with symptoms such as acute respiratory distress, changes in mental status, abdominal pain, excessive salivation, tremors, vomiting, chills, and low blood pressure. Long-term exposure to mercury damages the renal epithelium and leads to necrosis in the proximal tubule's pars recta, resulting in tubular failure, increased albumin and retinol-binding protein in the urine, and a nephritic state characterized by membranous nephropathy (Lentini *et al.,* 2017).

The elimination of thallium sulfate through the kidneys is slow, potentially taking up to two months after ingestion. Renal damage is indicated by signs like albuminuria and hematuria; nevertheless, thallium poisoning generally does not result in a notable decline in renal function (Yumoto *et al.,* 2017).

2.4.4 Hepatotoxicity

The negative impact of lead on liver cells is well documented. Exposure to lead elevates oxidative stress, which can lead to liver damage. Additionally, when organic solvents are present alongside lead, they can further harm the liver due to their similar toxic properties (Farmand *et al.,* 2000; Malaguarnera *et al.,* 2012). Long-term exposure to lead poses significant risks to liver cells, causing a reduction in glycogen levels and an influx of cells, potentially leading to chronic cirrhosis (Hegazy and Fouad, 2014).

Cadmium primarily affects two key human tissues: the renal cortex and the liver (Bernard, 2004). During acute exposure, cadmium tends to accumulate in the liver and is linked to various liver dysfunctions. It alters the cellular redox balance, resulting in oxidative stress and damage to liver cells (Zalups, 2000). Both acute and chronic exposure to cadmium can lead to liver failure and heighten the risk of cancer (Hyder *et al.,* 2013).

Copper is particularly known for its accumulation in the liver, especially in cases of Wilson's disease. Increased copper levels can provoke oxidative stress, meaning that the presence of copper in the liver serves not only as a diagnostic indicator of the disease but also presents a pathophysiological issue. Elevated levels of copper are also found in cholestatic liver diseases, which result from decreased copper excretion by the bile rather than being a direct cause of liver issues (Deering *et al.,* 1977; Gross *et al.,* 1985; Yu *et al.,* 2019).

Various studies have indicated that chromium(VI) (Cr(VI)) has toxic effects on the liver, leading to histopathological changes such as fatty liver, degeneration of liver tissue, and cell necrosis. Exposure to Cr(VI) is linked to increased levels of reactive oxygen species (ROS), lipid damage, inhibition of DNA, RNA, and protein synthesis, genetic damage, reduced activity of antioxidant enzymes, and mitochondrial dysfunction—including compromised energy production in mitochondria, halted cell growth, and cell death through apoptosis (Hasanein and Emamjomeh, 2019).

CHAPTER THREE

3.0 Materials And Methods

3.1 Study Area

The study took place in Benin City, the capital of Edo State, Nigeria, located within the Southern Senatorial District. Benin City is the largest city in the district and includes several local government areas, such as Oredo, Ovia South West, Egor, Ovia North East, Orhionmwon, Ikpoba Okha, and Uhunmwode. These areas are diverse, with a mix of urban, industrial, agricultural, and residential environments, making it an ideal place for studying environmental impacts. We chose different locations around Benin City to represent various activities that could affect the environment. These included New Benin Market, Benin Airport, Samuel Ogbemudia Stadium, Siluko Moat and the Uwasota Livestock Market. These places, ranging from schools and markets to sports venues and transport hubs, provided a broad picture of the various ways human activities affect the environment in Benin City.

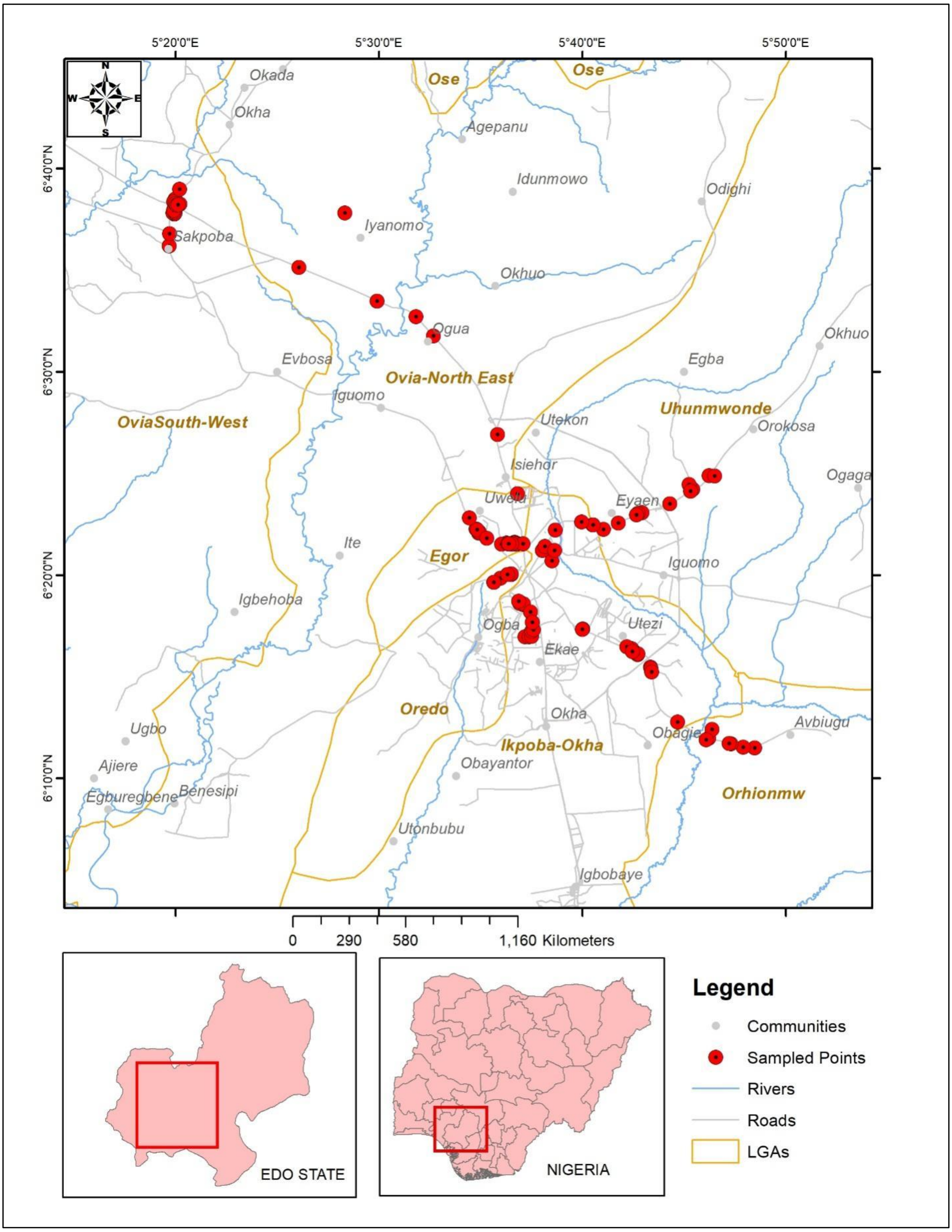

figure 3.1 (map showing study area)

3.2 Sampling Methods

Soil and Earthworm Collection

3.2.1 Soil Sample Collection

Soil samples were collected from various locations within Benin City, Edo State, Nigeria, representing diverse environmental settings, such as industrial zones, residential areas, and agricultural fields. The collection was carried out following standard soil sampling protocols to ensure representativeness and accuracy of the results.

1. **Preparation**: A total of 10 to 15 soil samples were collected from each study site. The sampling was conducted during the dry season to minimize the influence of rainfall on the metal content in the soil. For each location, soil was sampled at a depth of 0-15 cm using a stainless steel auger, which was cleaned thoroughly between samples to avoid cross-contamination (Müller, 2004).
2. **Sample Handling**: The collected soil samples were air-dried in a shaded area to prevent decomposition and loss of volatile compounds. The samples were sieved using a 2 mm mesh to remove larger particles, such as stones and plant roots, ensuring that only fine soil particles were analyzed (Sparks, 2003).
3. **Digestion Process**: The soil samples (5g each) were subjected to digestion using the Aqua Regia method. The procedure involved adding 7.5 ml concentrated hydrochloric acid (HCl) and 2.5 ml concentrated nitric acid (HNO3) in a 3:1 ratio, to the soil samples placed in digestion tubes. The mixture was then heated in a water bath at 100°C for 2 hours, with intermittent shaking every 20 minutes. After cooling, the digests were filtered through Whatman filter paper into 25 ml volumetric flasks. The resulting filtrate was made up to the mark with distilled water for subsequent analysis using Atomic Absorption Spectroscopy (AAS) (Liu et al., 2008; USEPA, 1996).

3.2.2 Earthworm Sample Collection

Earthworm samples were collected from the same locations where soil samples were taken, particularly focusing on areas with potential contamination from anthropogenic activities such as agricultural fields, roadsides, and landfill sites. Earthworms, specifically *Aporrectodea longa*, were selected due to their prevalence in the region and their ability to bioaccumulate heavy metals from the soil (Gomez et al., 2015).

1. **Collection Method**: Earthworms were collected by hand-sorting the soil. The soil was gently excavated to a depth of approximately 20 cm, ensuring minimal disturbance to the worms. Care was taken to collect earthworms from different parts of the sampling locations to ensure that the samples were representative of the entire area (Bouche, 1977).
2. **Handling**: The earthworms were carefully placed in clean containers with moist soil to prevent desiccation during transportation to the laboratory. The samples were kept in a cool place to minimize stress and avoid any loss of metal contaminants from the worms.
3. **Digestion Process**: Upon arrival at the laboratory, the collected earthworms were weighed (5g each) and digested using 3 ml of concentrated nitric acid (HNO3). The worms were heated to dryness on a hot plate and re-dissolved in 2 ml of concentrated HNO3. The solution was made up to a 25 ml volume using distilled water. The resulting digests were stored in clean, labeled plastic containers for analysis of metal content using AAS

3.3 Analysis

Both the soil and earthworm digests were analyzed for heavy metals, including Chromium (Cr), Cadmium (Cd), Lead (Pb), Nickel (Ni), Zinc (Zn), and Copper (Cu), using a Buck

Scientific AAS Model 205A. The concentration of metals in each sample was determined by the absorption of light at specific wavelengths corresponding to the metals being analyzed

3.4 Quality Assurance / Quality Control

To ensure the dependability of the findings in this current research, we conducted suitable quality checks. We employed analytical-grade reagents for calibrating the instruments. Additionally, we evaluated the precision and data credibility by calculating the coefficients of variation for duplicate analyses, which revealed variations of less than 10%.

3.5 Statistical Analysis

Data analysis was performed using the computer software EXCEL and Statistical package for social sciences (SPSS) version 20. One-way analysis of variance (ANOVA) was used to determine significant difference ($p < 0.05$) between groups. The results are presented as mean ± standard deviation. Duncan Multiple Range (DMR) Post Hoc test was used to find out homogenous subset within groups

3.7 Sampling Labeling And Storage

Each sample container was labeled with a unique identifier including coordinates, samples type and sample date.

3.7.1 Soil Sample Storage

Soil samples were stored in clean, airtight containers to prevent contamination and water loss.

3.8 Sample Analysis

3.8.1 Heavy Metal Determination

Soil samples were prepared by homogenizing. Heavy metal concentrations in the soil samples were analyzed using appropriate techniques such as ICP – MS (Inductively Coupled Plasma Mass Spectrometry) and AAS (Atomic Absorption Spectroscopy).

Water samples were filtered to remove particulate matter. Samples were now acidified with a suitable acid (e.g., nitric acid) to stabilize the metals. Prepared samples were introduced into ICP – MS and the concentration of the target heavy metals were measured.

3.8.2 Bacterial Determination

A serial dilution of the soil sample is prepared using sterile diluent, a series of dilution are plated unto appropriate growth media (e.g., agar plate) using spread or pour method. Plates are then incubated at appropriate temperatures for bacterial growth (e.g., 30 – 37 ℃). After incubation, bacterial colonies were counted on plates. And the colony – forming units (CFU) per gram of soil where calculated.

Water samples were analyzed for bacterial contamination using standard microbiological techniques such as membrane filtration method, multiple-tube fermentation method.

3.9 Methodology

3.9.1 Soil Sample Digestion

Soil samples were air-dried and sieved before digestion. A 5 g portion of each sample was weighed into a digestion tube, followed by the addition of 7.5 mL of concentrated hydrochloric acid (HCl) and 2.5 mL of concentrated nitric acid (HNO_3) in a 3:1 ratio, forming 10 mL of aqua regia. The digestion tube was covered and heated in a water bath at 100°C for 2 hours, with intermittent shaking every 20 minutes to ensure proper digestion. After cooling to room temperature, the digest was filtered through Whatman filter paper into a 25 mL standard volumetric flask. The filtrate was then diluted to the mark with distilled water and transferred into a plastic container for further analysis. Heavy metal concentrations, including chromium (Cr), cadmium (Cd), lead (Pb), nickel (Ni), zinc (Zn), and copper (Cu), were determined using a Buck Scientific Atomic Absorption Spectrophotometer (AAS) Model 205A.

3.9.2 Earthworm Digestion

The sampled earthworm species, *Aporectodea longa*, was analyzed for heavy metal accumulation. A 5 g portion of thawed earthworm tissue was digested using 3 mL of concentrated citric acid (HNO_3) and heated to dryness on a hot plate. The dried digest was then re-dissolved in 2 mL of concentrated HNO_3, after which the solution was diluted to 25 mL with distilled water. The prepared sample was stored in a clean plastic container for AAS analysis to determine heavy metal concentrations in the earthworm tissue.

CHAPTER FOUR

4.0 Results

4.1.1 Soil Sample Collected From New Benin Market

In soil samples collected from New Benin Market, the concentrations of various metals were measured. Zinc (Zn) levels ranged from 0.1260 mg/kg to 1.387 mg/kg, with an average concentration of 0.7565 mg/kg ± 0.8917 mg/kg. Copper (Cu) levels varied between 0.01800 mg/kg and 0.6360 mg/kg, averaging 0.3270 mg/kg ± 0.4370 mg/kg. Manganese (Mn) concentrations spanned from 0.07400 mg/kg to 0.1890 mg/kg, resulting in a mean of 0.1315 mg/kg ± 0.08132 mg/kg. Nickel (Ni) levels ranged from 0.06900 mg/kg to 0.1740 mg/kg, with an average of 0.1215 mg/kg ± 0.07425 mg/kg. Lead (Pb) concentrations extended from 0.009000 mg/kg to 0.02900 mg/kg, leading to a mean of 0.01900 mg/kg ± 0.01414 mg/kg. Cadmium (Cd) levels ranged from 0.005000 mg/kg to 0.01400 mg/kg, achieving an average of 0.009500 mg/kg ± 0.006364 mg/kg. Lastly, iron (Fe) levels ranged from 0.3950 mg/kg to 1.353 mg/kg, with a mean concentration of 0.8740 mg/kg ± 0.6774 mg/kg.

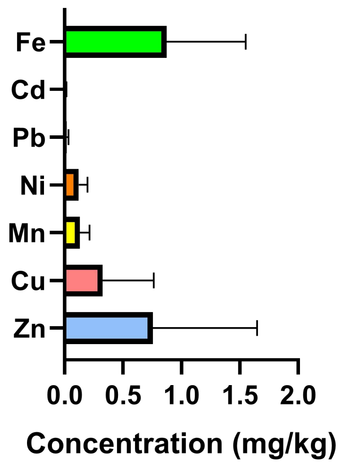

Fig 4.1.1 Heavy metals in soil from New Benin Market

4.1.2 Earthworm Sample Collected From New Benin Market

In earth worm samples collected from New Benin Market, Zn concentrations ranged from 1.389 mg/kg to 1.390 mg/kg, yielding a mean of 1.390 ± 0.0007 mg/kg. Meanwhile, Cu fluctuated between 0.6380 mg/kg and 0.6390 mg/kg, with an average of 0.6385 ± 0.0007 mg/kg. Mn values varied from 0.1910 mg/kg to 0.1920 mg/kg, attaining a mean of 0.1915 ± 0.0007 mg/kg, whereas Ni ranged between 0.1760 mg/kg and 0.1770 mg/kg, with a mean of 0.1765 ± 0.0007 mg/kg. Pb levels spanned from 0.03100 mg/kg to 0.03200 mg/kg, achieving an average of 0.03150 ± 0.0007 mg/kg. Furthermore, Cd values fluctuated between 0.01600 mg/kg and 0.01700 mg/kg, with a mean of 0.01650 ± 0.0007 mg/kg, while Fe ranged from 0.01600 mg/kg to 0.01700 mg/kg, leading to an average of 0.01650 ± 0.0007 mg/kg.

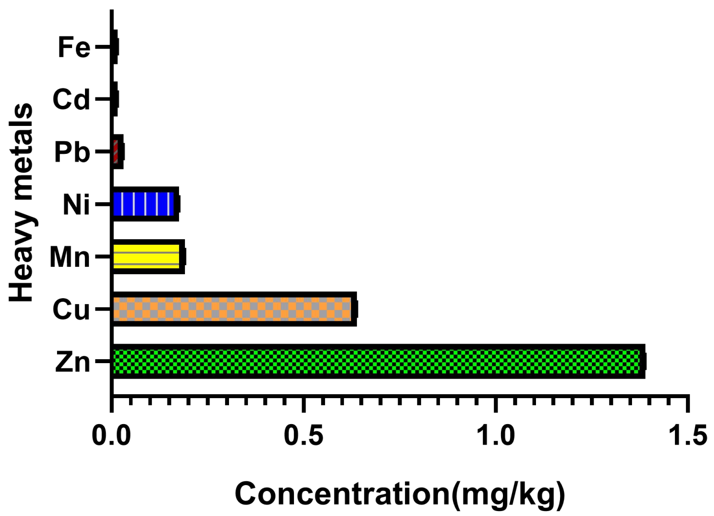

Fig 4.1.2 Heavy metals in earthworm from New Benin Market

4.2.1 Soil Sample Collected From a Livestock Area

In soil samples collected from Livestock Area, Zn concentrations ranged from 1.732 mg/kg to 1.961 mg/kg, with a mean of 1.847 mg/kg ± 0.1619 mg/kg, while Cu levels varied between 0.6980 mg/kg and 0.7420 mg/kg, averaging 0.7200 mg/kg ± 0.03111 mg/kg. Mn concentrations spanned from 0.1670 mg/kg to 0.1930 mg/kg, achieving a mean of 0.1800 mg/kg ± 0.01838 mg/kg and Ni was recorded between 0.1540 mg/kg and 0.1870 mg/kg, with a mean of 0.1705 mg/kg ± 0.02333 mg/kg. Pb concentrations extended from 0.03700 mg/kg to 0.04500 mg/kg, leading to a mean of 0.04100 mg/kg ± 0.005657 mg/kg, while Cd ranged from 0.02100 mg/kg to 0.02500 mg/kg, attaining an average of 0.02300 mg/kg ± 0.002828 mg/kg. Lastly, Fe levels ranged from 1.674 mg/kg to 2.020 mg/kg, with a mean of 1.847 mg/kg ± 0.2447 mg/kg.

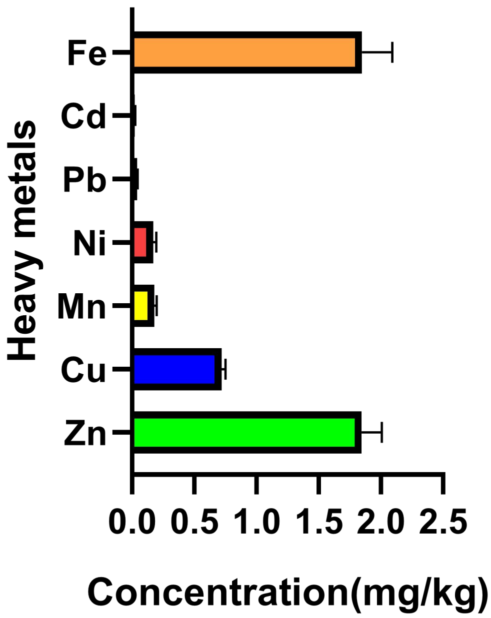

Fig 4.2.1 Heavy metals in soil from livestock area

4.2.2 Earthworm Sample Collected From a Livestock Area

In earthworm samples collected from livestock area, Zn concentrations ranged from 1.745 mg/kg to 1.759 mg/kg, with a mean of 1.752 ± 0.0099 mg/kg. Cu levels varied between 0.7580 mg/kg and 0.7650 mg/kg, averaging 0.7615 ± 0.0049 mg/kg. Mn concentrations spanned from 0.1720 mg/kg to 0.1780 mg/kg, achieving a mean of 0.1750 ± 0.0042 mg/kg. Ni ranged from 0.1490 mg/kg to 0.1520 mg/kg, with a mean of 0.1505 ± 0.0021 mg/kg. Co values fluctuated between 0.04600 mg/kg and 0.04800 mg/kg, yielding an average of 0.04700 ± 0.0014 mg/kg. Pb concentrations varied from 0.02200 mg/kg to 0.02400 mg/kg, with a mean of 0.02300 ± 0.0014 mg/kg, while Cd levels ranged from 0.01900 mg/kg to 0.02000 mg/kg, attaining an average of 0.01950 ± 0.0007071 mg/kg. Fe concentrations spanned from 1.689 mg/kg to 1.702 mg/kg, with a mean of 1.696 ± 0.0092 g/kg.

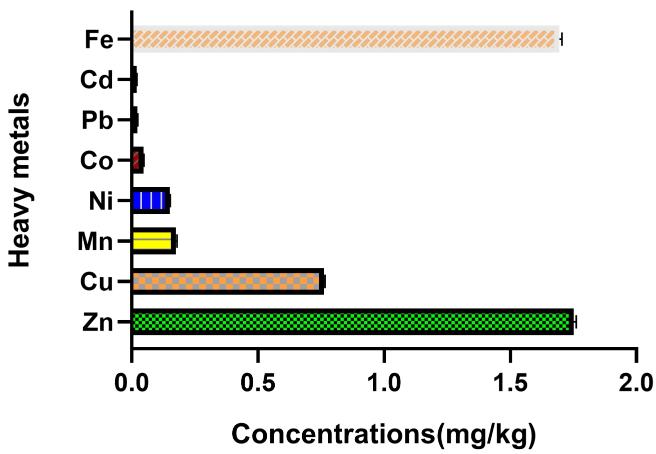

Fig 4.2.1 Heavy metals in earthworm from livestock area

4.3.1 Soil Sample Collected From Benin Airport

Soil samples collected from Benin Airport showed varying concentrations of heavy metals. Zn concentrations ranged from 1.200 mg/kg to 2.330 mg/kg, with a mean of 1.765 mg/kg ± 0.7990 mg/kg, while Cu levels varied between 0.1770 mg/kg and 0.5930 mg/kg, averaging 0.3850 mg/kg ± 0.2942 mg/kg. Mn concentrations spanned from 0.06300 mg/kg to 0.1820 mg/kg, achieving a mean of 0.1225 mg/kg ± 0.08415 mg/kg, and Ni was recorded between 0.05900 mg/kg and 0.1740 mg/kg, with a mean of 0.1165 mg/kg ± 0.08132 mg/kg. Pb concentrations extended from **0**.04100 mg/kg to 0.05300 mg/kg, leading to a mean of 0.04700 mg/kg ± 0.008485 mg/kg**,** while Cd ranged from 0.02200 mg/kg to 0.02300 mg/kg, attaining an average of 0.02250 mg/kg ± 0.000707 mg/kg. Lastly, Fe levels ranged from 0.5650 mg/kg to 1.458 mg/kg, with a mean of 1.012 mg/kg ± 0.6314 mg/kg.

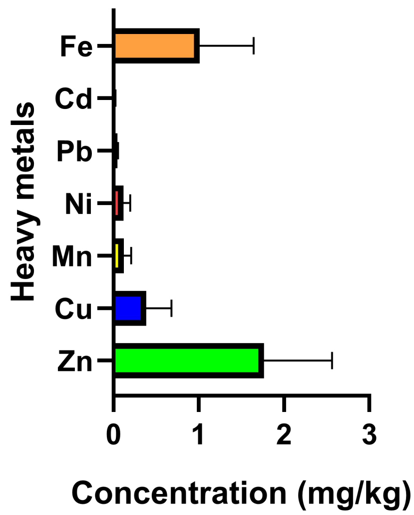

Fig 4.3.1 Heavy metals in soil from Benin Airport roa

4.3.2 Earthworm Sample Collected From Benin Airport

For earthworm samples collected from the Benin Airport site, Zn concentrations varied between 2.330 mg/kg and 2.350 mg/kg, yielding an average of 2.340 ± 0.0141 mg/kg. Cu ranged from 0.1770 mg/kg to 0.1790 mg/kg, with a mean of 0.1780 ± 0.0014 mg/kg. Similarly, Mn fluctuated from 0.06300 mg/kg to 0.06500 mg/kg, attaining an average of 0.06400 ± 0.0014 mg/kg. Ni spanned from 0.05900 mg/kg to 0.06200 mg/kg, leading to a mean of 0.06050 ± 0.0021 mg/kg. Pb values ranged from 0.02400 mg/kg to 0.04100 mg/kg, yielding a mean of 0.03250 ± 0.0120 mg/kg. Also, Cd concentrations varied slightly between 0.02300 mg/kg and 0.02500 mg/kg, with an average of 0.02400 ± 0.0014 mg/kg, while Fe levels fluctuated between 0.5650 mg/kg and 0.5750 mg/kg, achieving a mean of 0.5700 ± 0.0071 mg/kg.

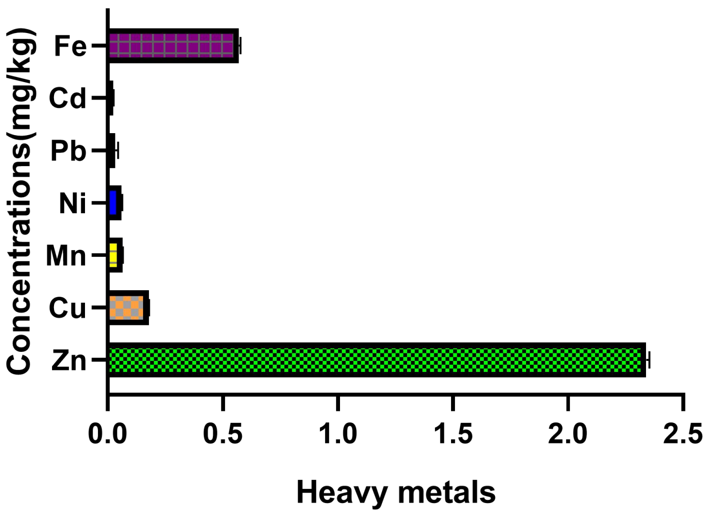

Fig 4.3.2 Heavy metals in earthworm from Benin Airport road

4.4.1 Soil Sample Collected from Ogbemudia Stadium

For the soil samples collected from Ogbemudia Stadium, . Zu concentrations ranged from 1.503 mg/kg to 3.316 mg/kg, with a mean of 1.931 mg/kg ± 1.959 mg/kg, while Mn and Cu levels varied between 0.3690 mg/kg and 0.5460 mg/kg, averaging **0**.4575 mg/kg ± 0.1252 mg/kg. Ni concentrations spanned from 0.1380 mg/kg to 0.3690 mg/kg, achieving a mean of 0.2535 mg/kg ± 0.1633 mg/kg, and Pb was recorded between 0.04800 and 0.1440, with a mean of 0.09600 mg/kg ± 0.06788 mg/kg. Cd concentrations extended from 0.01300 mg/kg to 0.04200 mg/kg, leading to a mean of 0.02750 mg/kg ± 0.02051 mg/kg**.** Fe levels ranged from 0.98 mg/kg to 1.018 mg/kg, attaining an average of 1.039 ± 0.18 mg/kg

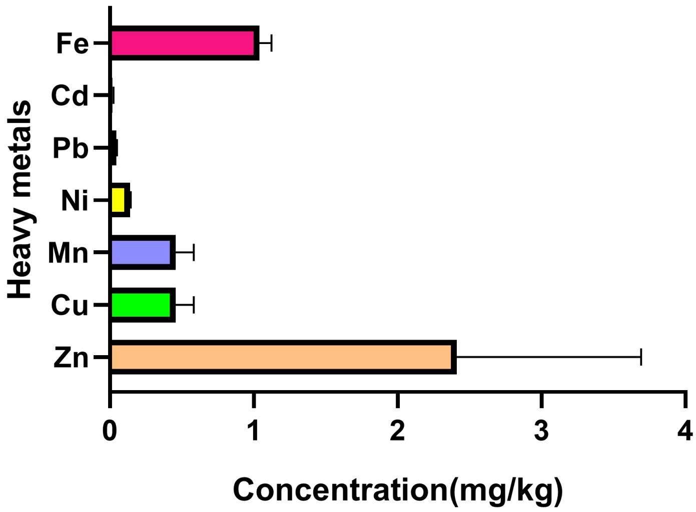

Fig 4.4.1 Heavy metals in soil from Ogbemudia stadium

4.4.2 Earthworm Sample Collected from Ogbemudia Stadium

For the earthworm samples collected from Ogbemudia Stadium, Zn concentrations ranged from 1.399 mg/kg to 1.412 mg/kg, with a mean of 1.406 ± 0.0092 mg/kg. Cu levels varied between 0.3680 mg/kg and 0.3750 mg/kg, averaging 0.3715 ± 0.0049 mg/kg. Mn concentrations spanned from 0.1530 mg/kg to 0.1590 mg/kg, achieving a mean of 0.1560 ± 0.0042 mg/kg. Ni ranged from 0.1470 mg/kg to 0.1510 mg/kg, with a mean of 0.1490 ± 0.0028 mg/kg. Pb values fluctuated between 0.01400 mg/kg and 0.03600 mg/kg, yielding an average of 0.02500 ± 0.0156 mg/kg. Cd concentrations varied from 0.01400 mg/kg to 0.03600 mg/kg, with a mean of 0.02500 ± 0.0156 mg/kg, while Fe levels ranged from 0.01200 mg/kg to 0.01300 mg/kg, attaining an average of 0.01250 ± 0.0007071 mg/kg

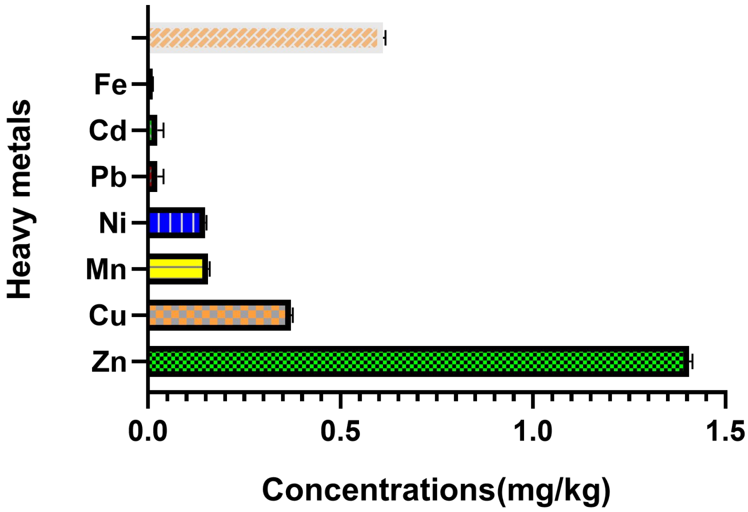

Fig 4.4.2 Heavy metals in earthworm from Ogbemudia stadium

4.5.1 Soil Sample Collected from Siluko Moat

For soil samples collected from Siluko Moat, Zn concentrations ranged from 0.2610 to 0.7240, with a mean of 0.4925 ± 0.3274, while Cu levels varied between 0.1520 and 0.2630, averaging 0.2075 ± 0.07849. Mn concentrations spanned from 0.07400 to 0.09400, achieving a mean of 0.08400 ± 0.01414, and Ni was recorded between 0.06300 and 0.6680, with a mean of 0.3655 ± 0.4278. Pb concentrations extended from 0.03200 to 0.03600, leading to a mean of 0.03400 ± 0.002828, while Cd ranged from 0.01600 to 0.01700, attaining an average of 0.01650 ± 0.0007071. Lastly, Fe levels ranged from 0.3900 to 0.6250, with a mean of 0.5075 ± 0.1662.

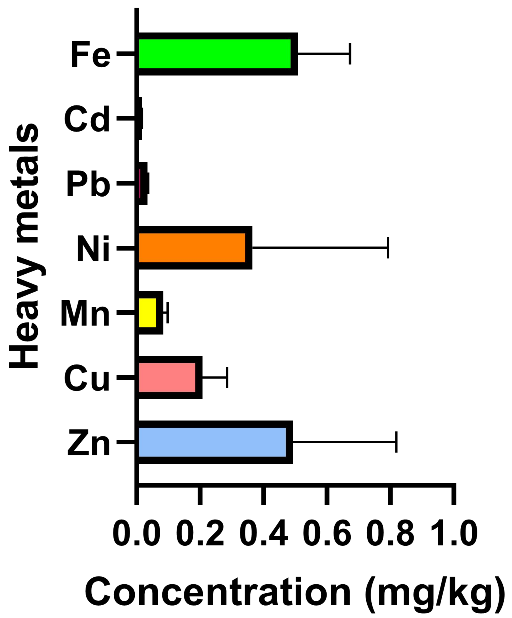

Fig 4.5.1 Heavy metals in soil from Siluko Moat

4.5.2 Earthworm Samples Collected From Siluko Moat

For earthworm samples collected from Siluko Moat , Zn concentrations varied between 2.500 mg/kg and 2.510 mg/kg, with an average of 2.505 ± 0.0071 mg/kg. Similarly, Cu ranged from 0.5270 mg/kg to 0.5280 mg/kg, attaining a mean of 0.5275 ± 0.0007 mg/kg. Mn fluctuated between 0.1630 mg/kg and 0.1640 mg/kg, with an average of 0.1635 ± 0.0007 mg/kg, while Ni concentrations spanned from 0.1260 mg/kg to 0.1270 mg/kg, leading to a mean of 0.1265 ± 0.0007 mg/kg. Pb values varied between 0.02400 mg/kg and 0.05600 mg/kg, yielding an average of 0.04000 ± 0.0226 mg/kg. Also, Cd fluctuated between 0.02300 mg/kg and 0.02400 mg/kg, with an average of 0.02350 ± 0.0007 mg/kg, while Fe ranged from 1.458 mg/kg to 1.459 mg/kg, achieving a mean of 1.459 ± 0.0007 mg/kg.

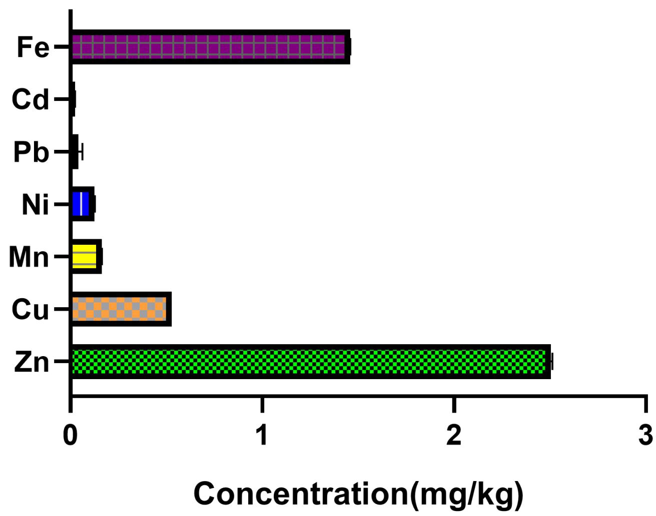

Fig 4.5.2 Heavy metals in earthworm from Siluko Moat

CHAPTER FIVE

5.0 Discussion

Heavy metals constitute one of the most dangerous groups of environmental contaminants because of their persistent nature, toxicity, tendency to accumulate in organisms and ability to undergo food chain amplification (Enuneku and Ezemonye, 2013)

5.1 Site-Specific Heavy Metal Contamination and Its Implications

5.1.1 New Benin Market

The analysis of soil samples from the New Benin Market revealed relatively lower heavy metal concentrations compared to other study sites, with Zn, Cu, Mn, Ni, Pb, Cd, and Fe recorded at varying levels. However, the bioaccumulation of these metals in *Aporrectodea longa* suggests that even at low soil concentrations, earthworms can accumulate heavy metals, highlighting potential risks to soil biota and trophic transfer (Uwizeyimana, *et al.,* 2017). Compared to studies in other urban markets, the concentrations of Pb and Cd, though low, align with findings by Odoh *et al.,* 2013 in Nigeria, where anthropogenic sources such as vehicular emissions and metal-based consumer products contribute to localized contamination.

5.1.2 Livestock Area

Soil samples from the Livestock Area exhibited higher concentrations of Zn, Cu, and Fe compared to the market site. The presence of elevated Pb and Cd suggests contamination from animal waste, feed additives, and veterinary pharmaceuticals, consistent with findings by Yu *et al.,* 2024. Bioaccumulation in earthworms was also higher than soil in the market samples, confirming the role of organic matter in metal retention and uptake (Hodson *et al.,* 2013). The spatial distribution of heavy metals in livestock-dominated regions underscores the impact of agricultural activities on soil quality.

5.1.3 Benin Airport

The Benin Airport site exhibited moderate to high levels of Zn, Cu, and Pb in soil, with significant bioaccumulation in earthworms. The elevated Pb levels may be attributed to aviation fuel combustion and vehicular emissions, aligning with studies by Sun *et al.,* 2006 on airport-associated contamination. The lower Mn and Ni concentrations, relative to other sites, suggest site-specific input patterns influenced by transport-related emissions rather than industrial or agricultural sources.

5.1.4 Ogbemudia Stadium

Soil samples from Ogbemudia Stadium revealed the highest recorded levels of Zn and Ni, with notable Pb and Cd presence. The high metal concentrations could be linked to recreational activities, traffic, and infrastructure maintenance, consistent with findings by Huber *et al.,* 2016. The bioaccumulation in earthworms further supports the role of soil particle adsorption and organic matter in heavy metal retention (Mekersi, *et al.,* 2024).

5.1.5 Siluko Moat

Soil samples from Siluko Moat exhibited notable heavy metal concentrations, with Zn, Cu, and Fe being more prominent, reflecting potential urban runoff, waste disposal, and natural geochemical contributions. The presence of Pb and Cd, although in lower concentrations, suggests contamination from anthropogenic sources such as sewage leaks, atmospheric deposition, and potential agricultural runoff. This aligns with findings by Nahmani *et al.* (2007), who reported similar bioaccumulation trends in earthworms from urban and roadside soils. The higher accumulation of Zn and Cu in *Aporrectodea longa* compared to soil confirms their bioavailability and the influence of organic matter on metal retention, as previously documented by Hodson *et al.* (2013).

5.2 Spatial Patterns in Soil Contamination and Anthropogenic Activities

The observed spatial distribution of heavy metal contamination is strongly correlated with specific anthropogenic activities at each site. The highest levels of Zn and Cu were found in the livestock area and Ogbemudia Stadium, likely due to agricultural inputs and surface run-off. In contrast, Pb levels were consistently elevated at the airport and stadium, reflecting traffic and fuel combustion sources. Similar trends have been documented in urban environments worldwide, indicating that land-use patterns significantly influence contamination hotspots (Solgi, and Oshvandi, 2018).

5.3 Recommendations for Soil Management and Remediation Strategies

Based on the site-specific contamination profiles, the following soil management and remediation strategies are recommended:

1. **Phytoremediation:** The use of hyperaccumulator plants such as *Brassica juncea* (Indian mustard) and *Vetiveria zizanioides* (vetiver grass) could be effective in Pb and Cd-contaminated sites, particularly in market and airport areas .
2. **Soil Amendments:** The application of biochar and organic compost can reduce metal bioavailability and improve soil microbial health in the livestock area

3. **Regulatory Measures:** Periodic monitoring and implementation of guidelines to limit waste disposal and emissions from high-risk areas such as airports and recreational centers.
4. **Public Awareness and Policy Development:** Awareness campaigns for local vendors, livestock farmers, and transport authorities can aid in reducing contamination sources at the community level.

5.4 Conclusion

This study highlights the influence of anthropogenic activities on heavy metal contamination in different land-use areas. The bioaccumulation of metals in *Aporrectodea longa* underscores the ecological risk posed by contaminated soils. Site-specific remediation strategies should be prioritized to mitigate the environmental and public health risks associated with heavy metal pollution.

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