ASSESSMENT OF HEAVY METAL ACCUMULATION FROM ABATTOIR WASTES ON SOIL AND SELECTED EDIBLE VEGETABLES AT IKWIRIRI SLAUGHTERHOUSE, RUFIJI DISTRICT

AHMADA MOH'D IBRAHIM

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF
ENVIRONMENTAL STUDIES (SCIENCE)
DEPARTMENT OF PHYSICAL AND ENVIRONMENTAL SCIENCES
OF THE OPEN UNIVERSITY OF TANZANIA
2025

CERTIFICATION

The undersigned certifies that he has read and here by recommends for acceptance by the Open University of Tanzania a dissertation entitled, **“Assessment of Heavy Metal Accumulation from Abattoir Wastes on Soil and Selected Edible Vegetables at Ikwiriri Slaughterhouse, Rufiji District”** in partial fulfilment of the requirements for the award of Degree of Masters in Environmental Science (MES).

………………………………………

Dr. Josephat Saria

Supervisor

……………………..…………

Date

…………………………………..

Dr. Honest Anicetus
(Supervisor)

…………………..………

Date

COPYRIGHT

DECLARATION

I, **Ahmada Moh'd Ibrahim,** declare that, the work presented in this dissertation is original. It has never been presented to any other University or Institution. Where other people's works have been used, references have been provided. It is in this regard that I declare this work as originally mine. It is hereby presented in partial fulfilment of the requirement for the Degree of Master of Environmental studies (Science)

…………………………..………..

Signature

31/08/2025

………………………..………

Date

DEDICATION

I dedicate this work to my home family.

ACKNOWLEDGEMENT

First and foremost, I express my deepest gratitude to Almighty God for granting me good health, strength, and patience throughout the course of this work. While many individuals have contributed to the successful completion of this study, it would be difficult to mention each one by name. However, I would like to extend my heartfelt appreciation to a few whose support has been especially significant.

I would like to convey my heartfelt gratitude to my supervisors; Dr. Josephat Saria (OUT) and Dr. Honest Anicetus (MoH) for their tremendous support, assistance, motivation, and mentorship in the completion of my project. I would also like to thank my co-worker and friends for providing me with this wonderful assistance to work on the project. The completion of the project would not have been possible without their help and insights.

Special thanks to my family. Your prayer for me was the way to my success. Thus, many appreciations to my beloved family who spent sleepless night with me and always support in the moments when there was no one to response my inquiries.

ABSTRACT

This study assessed heavy metal contamination and associated health risks in green leafy vegetables cultivated using slaughterhouse wastewater in Ikwiriri Ward, Tanzania. A total of three vegetable species (*Vigna* sp., *Ipomoea* sp., and *Cucurbita sp.*), 12 soil samples, and 6 wastewater samples were collected and analyzed for Pb, Cr, Cu, Zn, and Fe using microwave plasma atomic emission spectroscopy (MP-AES) following microwave-assisted digestion. Heavy metal concentrations in vegetables ranged from 0.073 ± 0.011 to 0.158 ± 0.071 mg/kg (Pb), 0.182 ± 0.096 to 0.437 ± 0.181 mg/kg (Cr), 1.212 ± 0.208 to 2.307 ± 0.335 mg/kg (Cu), 2.933 ± 0.305 to 7.740 ± 0.928 mg/kg (Zn), and 15.543 ± 1.649 to 58.991 ± 17.196 mg/kg (Fe). In wastewater, Fe (2.098 ± 0.479 mg/L) showed the highest levels, followed by Zn (0.121 ± 0.030 mg/L), Pb (0.099 ± 0.076 mg/L), Cr (0.030 ± 0.001 mg/L), and Cu (0.027 ± 0.012 mg/L). While Cr, Zn, and Cu were within WHO and TBS permissible limits, Fe and Pb concentrations exceeded drinking-water thresholds, with Pb approaching the effluent limit (0.1 mg/L). Human health risk assessment revealed hazard indices (HI) in the order: *Vigna* sp. (1.65) > *Cucurbita sp.* (1.53) > *Ipomoea sp.* (0.75). Although individual metals posed limited risks (HQ < 1), cumulative non-carcinogenic risks (HI > 1) for *Vigna* sp. and *Cucurbita* sp. suggest potential health concerns, particularly for frequent consumers. These findings highlight the need for effective wastewater management, monitoring of leafy vegetables near abattoirs, and public health interventions to minimize exposure risks.

Keywords: *Abattoir Waste, Heavy Metal, Hazard Index, Health Risk Assessment.*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

ADI	Average Daily Intake
APHA	American Public Health Association
ATSDR	Agency for Toxic Substances and Disease Registry
CCV	Continuing Calibration Verification
CXS	Codex Standards
EPA	Environmental Protection Agency
FAO	Food and Agricultural Organisation
GAP	Good Agricultural Practices
GLV	Green Leafy Vegetables
IARC	International Agency for Research on Cancer
ICV	Initial Calibration Verification
mg/kg	Milligrams per kilogram
MPAES	Microwave Plasma Atomic Emission Spectroscopy
sp.	Species
TBS	Tanzania Bureau of Standards
USEPA	United States Environmental Protection Agency
WHO	World Health Organisation
µg/kg	Microgram per kilogram

CHAPTER ONE

INTRODUCTION

1.1 Introduction

This chapter explains the background of the research and provides a comprehensive foundation for the study by outlining all the critical components necessary to understand the scope, purpose, and relevance of the research.

1.2 Background Information

An abattoir is a specifically designated space where animals are processed for their meat. It is characterized as an establishment officially approved and registered by regulatory bodies to ensure the secure and hygienic procedures of slaughtering, inspection, processing, as well as the efficient preservation and storage of meat products intended for human consumption (Vershima, *et al.*, 2015). The wastewater generated by abattoirs emerges as a significant environmental hazard, largely due to the presence of mineral components. This wastewater comprises fluctuating levels of heavy metals, many of which pose a severe threat to both plants and the overall ecosystem (Osu, *et al.*, 2014).

Facilities of considerable scale involved in the slaughter and processing of livestock and poultry, commonly referred to as "slaughterhouses," discharge substantial pollution into rivers and the surrounding environment. Due to the scarcity of clean water, there is a widespread global practice of utilizing wastewater from slaughterhouses for irrigation purposes, despite its potential to introduce contaminants such as pathogens, nutrients, and heavy metals into agricultural soils (FAO, 2013; Keraita, *et al.*, 2008). Leafy vegetables like spinach, carrots, and cabbage absorb certain heavy metals when irrigated with abattoir effluent. Consequently, when these vegetables are consumed by humans, it adversely affects their health (Jia, *et al.*, 2018).

It is worth noting that the environmental impact of wastewater irrigation varies from city to city depending on industrialization, type of industry, nature of water distribution and/or the degree of water treatment and dilution. Among other pollutants heavy metals have drawn much attention due to their ubiquity, toxicity at trace level, and persistence in the environment (Ali, *et al.*, 2019). Vegetables are an important part of a healthy eating pattern and are excellent sources of many nutrients, including potassium, fibre, folate (folic acid), and vitamins A, E, and C. These nutrients are vital for overall health and the maintenance of body systems (U.S. Department of Agriculture, 2020). While consumption of fresh vegetables is essential, urban communities have a right to safe vegetables that are free from contamination, including chemical residues and pathogenic microorganisms (WHO 2015; Amoah, *et al.*, 2007).

Heavy metals exposure is becoming a critical issue especially in developing regions of the world. Accumulation in agricultural soil may not only result in contamination of soil but also in increased uptake by food crops which may affect its quality and safety. Plants can absorb heavy metals from soil and build up in higher concentrations in them (Tang, *et al.*, 2021). Heavy metal contamination of the food items is one of the most important aspects of food quality and safety assurance. Vegetables are consumed in both cooked and raw forms, thus vegetables containing toxic metals can cause detrimental effects on human health. Contamination of vegetables by heavy metals has recently received notable research attention because vegetables are consumed relatively in large amount and have the capacity to bioaccumulate heavy metals (Oluwatosin, *et al.*, 2010) consequently posing risk to human health and consumption of heavy metals through the food chain has been thoroughly documented worldwide.

Although previous studies have documented the presence of heavy metals in abattoir wastewater (e.g., Al-Wasify, *et al.*, 2019; Mohammed, *et al.*, 2020; Osibanjo *et al.*, 2007), and have outlined the toxicological significance of metals such as cadmium, chromium, and lead, there remains a significant lack of localized data assessing the impact of untreated abattoir effluents on agricultural soils and edible vegetables in Tanzania particularly in rural settings like Ikwiriri, Rufiji District.

Most existing research has focused on general water pollution or urban slaughterhouse waste, with limited focus on how such waste, when used directly for irrigation and fertilization, contributes to bioaccumulation of heavy metals in vegetables consumed by humans. Despite widespread informal irrigation practices using abattoir wastewater in Tanzania, little empirical evidence exists regarding whether the concentrations of heavy metals in vegetables and soils near slaughterhouses exceed FAO/WHO and TBS safety limits.

Moreover, while essential elements like copper, iron, and zinc have known benefits in trace amounts, the risk of toxicity due to unregulated exposure is poorly documented in local agricultural systems. Similarly, toxic metals like Cd, Cr, and Pb known to pose serious health threats even at low levels have not been sufficiently monitored in relation to their uptake by edible plants grown near abattoir sites.

Therefore, this study addresses a critical knowledge gap by providing localized, empirical data on heavy metal contamination in soil, wastewater, and commonly consumed vegetables grown near the Ikwiriri slaughterhouse. It further evaluates the potential human health risks associated with the consumption of these vegetables and comparing contamination levels to national and international safety standards. The findings aim to support evidence-based policymaking, enhance public health awareness, and inform sustainable environmental management practices.

1.3 Statement of the Problem

Operations within abattoirs typically generate substantial volumes of waste, which are often inadequately managed. These waste materials contain elevated levels of harmful substances. Unfortunately, abattoir waste is frequently disposed of without proper treatment, and some farmers use animal waste as organic fertilizer and untreated wastewater for the cultivation and irrigation of vegetables. As a result, there is a significant risk of harmful metals accumulating in the soil, potentially degrading soil quality and compromising the safety of vegetables grown in the area.

Local residents near the Ikwiriri slaughterhouse commonly use wastewater from the abattoir to irrigate their vegetable crops. This practice is concerning, as literature reports indicate that abattoir waste often contains elevated levels of heavy metals, among other harmful contaminants. Heavy metals, in particular, pose serious concerns due to their non-degradable nature and their potential to accumulate through trophic levels, ultimately leading to harmful effects on both the environment and human health. If the concentration levels of heavy metals surpass the permissible limits set by the FAO/WHO and Tanzania Bureau of Standards (TBS), consumers of vegetables may face severe health consequences. Therefore, determining the levels of the heavy metals is crucial for the safety evaluation of the selected vegetables in terms of human health.

Assessment of heavy metals concentrations in the vegetables and soil have been carried by several researchers from different countries like Tanzania including Kacholi and Sahu (2018), but limited published data are available on heavy metals concentrations in the soil and vegetables grown near slaughterhouses and irrigated using abattoir wastewater especially in Tanzania.

The present study determined the concentration of five heavy metals (Pb, Cr, Cu, Zn and Fe) in some most consumed vegetables (*Ipomoea* sp. - sweet potatoes, *Cucurbita* sp. - pumpkin leaves and *Vigna* sp. - cowpea leaves) grown locally near Ikwiriri slaughterhouse. The study also aimed to predict if there is any possible health to consumers from consumption of the named vegetables of the area. Furthermore, it evaluated whether the levels of heavy metals in the selected vegetables, wastewater and agricultural soil complied with national and/or international safety standards.

1.4 Objectives

1.4.1 General Objective

The main objective of this study was to determine level of heavy metals (Pb, Cr, Cu, Zn and Fe) contamination in the soil and selected vegetables grown near Ikwiriri slaughterhouse.

1.4.2 Specific Objectives

1. To determine the accumulation of selected heavy metals (Pb, Cr, Cu, Zn and Fe) in vegetables *Ipomoea* sp. (sweet potato leaves), *Cucurbita* sp. (pumpkin leaves), and *Vigna* sp. (cowpea leaves) cultivated in proximity to the Ikwiriri slaughterhouse.
2. To analyze the concentrations of heavy metals (Pb, Cr, Cu, Zn and Fe) in abattoir wastewater and surrounding agricultural soils and to assess their influence on heavy metal accumulation in vegetables cultivated near the Ikwiriri slaughterhouse.
3. To determine human health risks due to consumption of vegetables contaminated by toxic heavy metals from abattoir waste.

1.5 Research Questions

1. What is the level of heavy metals (Pb, Cr, Cu, Zn and Fe) contamination in the selected vegetables grown near Ikwiriri slaughterhouse?
2. How do heavy metal concentrations in abattoir wastewater and surrounding agricultural soils influence the accumulation of these metals in vegetables grown near the Ikwiriri slaughterhouse?
3. Is there any possible risk to human health due to consumption of selected leafy vegetables (*Ipomea batatas*, *Cucurbita maxima* and *Vigna unguiculata*) grown near slaughterhouse?

1.6 Relevance of the Research

Heavy metals, such as lead, cadmium, chromium, are toxic to both aquatic and terrestrial ecosystems. They can accumulate in soil and water, posing a threat to the environment and wildlife. Excessive levels of heavy metals in wastewater can lead to contamination of surface water, groundwater, and soil, causing long-term ecological damage. Heavy metals can enter the food chain through contaminated water or soil. Consuming food or water with elevated levels of heavy metals can be detrimental to human health, potentially leading to various diseases and disorders.

Many countries have regulations and environmental standards in place to limit the discharge of heavy metals in wastewater. Compliance with these regulations is essential to avoid legal penalties and protect the environment. Monitoring heavy metal levels can help slaughterhouses identify potential sources of contamination within their processes. This information can be used to implement better waste management practices and reduce the environmental impact of their operations.

Assessing the levels of heavy metals in vegetables, soil and wastewater allows for a risk assessment of the potential harm to ecosystems, human populations, and agricultural land downstream of the discharge point. Understanding the heavy metal content in wastewater is crucial for selecting appropriate treatment methods. As concerns about environmental sustainability grow, it is essential for industries like slaughterhouses to reduce their environmental footprint. Monitoring and reducing heavy metal discharges can be a part of a broader sustainability strategy. In summary, determining the levels of heavy metals in wastewater from slaughterhouses is crucial to protect the environment, reduce human health risk, and regulatory compliance. It also aids in improving waste management practices and minimizing the ecological footprint of these facilities.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter provides a comprehensive review of previous studies, encompassing both experimental and theoretical research and systematic review studies conducted by various researchers in the related area. It examines methodologies employed, results, conclusions and highlighting findings that have significant relevance to the researched area.

2.2 Overview of Slaughterhouse Practices

Slaughterhouses are places where animals are slaughtered and processed for human consumption. Receiving and holding livestock; slaughtering and dressing of livestock carcasses; chilling of carcasses and their products; boning and packaging of carcasses; freezing of carcasses; rendering and drying of skins; waste treatment; and finally, transportation of processed meat and by-products are all common abattoir operations (Mozhiarasi, *et al.*, 2022). In developing countries slaughterhouses vary from large processing facilities in cities to small unregulated slaughter facilities in rural areas. According to FAO three kinds of slaughterhouses exist in developing countries which are modern abattoirs, old slaughterhouses and makeshift slaughterhouses (Clottey, 1995).

Modern abattoirs are the most progressive and ideal in conventional abattoir design, equipment, and services, and are typically constructed and managed by central governments with the aid of foreign technical experts. These abattoirs are managed on factory lines and offer a variety of services, including cold storage, processing, by-product usage, and waste recycling. Often ISO-certified and equipped with advanced hygiene infrastructure and compliance protocols, making them suitable for international trade and minimizing disease risk (WHO, 2020).

Old slaughterhouses establishments just provide the necessary infrastructure for licensed butchers and traders to slaughter cattle in line with public health, inspection, and marketing standards, for the predetermined costs. They are service businesses supervised by city or state governments, typically catering to residents in densely populated urban regions. Makeshift slaughterhouses include all kinds of locations such as converted buildings or rooms, the shade of trees, and open bare grounds that a butcher or community may find convenient for slaughtering operations.

These informal facilities often lack basic sanitation, infrastructure, and regulatory oversight, raising serious concerns for public health and environmental contamination (Grace*, et al.,* 2015; Abunna, *et al.,* 2017). They are more commonly found in villages and rural areas; however, they may occasionally be located in suburban zones or on the outskirts of large towns. Mostly privately owned and operating without formal authorization or licensing, these premises and their products are not inspected, regulated, or monitored under official trade and public health standards. The lack of oversight in such informal or unregistered slaughterhouses poses significant risks to food safety, public health, and disease surveillance efforts (FAO, 2001).

2.3 Environmental Pollution from Slaughterhouse

Abattoir operations result in the release of various wastes and pathogenic organisms that pollutes the environment and pose serious threat to human health and quality of life (Oruonye, 2015). Abattoir wastes can be divided into solid wastes, liquid waste and gas wastes. The solid waste consists mainly of bones, undigested ingesta, hairs and occasionally aborted feti, while the liquids comprise of blood, urine, water, dissolved solids and gut contents. On the other hand, doors and emissions produce gas wastes (Adeyemo, *et al.,* 2002).

Wastewater generated from the operations of abattoirs is mainly from activities such as washing carcasses after hair and hide removal and after evisceration, rendering, washing of equipment, paunch handling, trimming, and scalding. High levels of salts, phosphates, nitrates, heavy metals, bacteria, viruses, and other microbes are frequently associated with abattoir liquid waste. The vast majority of abattoir liquid waste is discharged into rivers and the immediate surroundings of the abattoir (Mohammed, *et al.,* 2020).

Abattoir liquid waste is deemed toxic worldwide due to its relatively complex composition of lipids, proteins, fibers, high organic content, pathogens, and pharmaceuticals for veterinary purposes. The effluent also contains significant suspended materials such greases, hairs, meats, dung, grits, undigested feed, blood, and about 80% freshwater. Abattoir liquid waste also has high BOD, chlorides, dry residues, detergents, and disinfectants. Abattoir liquid waste also has high BOD, chlorides, dry residues, detergents, and disinfectants (Ng *et al.*, 2022).

Recent studies have consistently shown that abattoir effluents and related wastes are major contributors to the contamination of soil and water with heavy metals such as iron, copper, chromium, nickel, cadmium, cobalt, lead, and zinc. According to Ogun *et al.,* (2023), soils surrounding abattoirs in Lagos exhibit elevated concentrations of these metals, resulting in their accumulation in plants and disturbances to soil microbial communities. Supporting this, a 2023 meta-analysis involving 15 Nigerian abattoirs identified a consistent ecological risk linked to heavy metals in abattoir liquid waste, emphasizing the urgent need for more stringent environmental oversight. Various studies have identified specific heavy metals commonly found in abattoir wastewater, including copper, zinc, iron, manganese, chromium, nickel, cadmium, and mercury (Eze, *et al.*, 2020; Mohammed, *et al.*, 2020), as well as lead (Hassana, *et al.*, 2021).

2.3.1 Heavy Metals

Heavy metals are commonly defined as metals with a specific density greater than 5 g/cm^3 that pose significant environmental and biological risks due to their persistence and non-biodegradable nature (Tchounwou *et al.*, 2018). These metals can accumulate in soils and are absorbed by plants both from contaminated soils and atmospheric deposits on aerial plant parts, leading to their accumulation in edible tissues (Chen, *et al.*, 2020). Soil properties such as pH, organic matter content, and texture play critical roles in determining the bioavailability and uptake of heavy metals by plants (Khan, *et al.*, 2017). Additionally, agricultural activities including the use of fertilizers, sewage sludge, and irrigation with wastewater contribute to increased heavy metal concentrations in soils and consequently in plants (Singh, *et al.*, 2019).

Recent studies have demonstrated that organic waste from abattoirs can lead to elevated levels of iron, lead, and zinc in the environment (Adeyemi, *et al.*, 2019).

The excessive buildup of heavy metals in agricultural soils particularly through the use of contaminated wastewater for irrigation degrades soil health and facilitates the uptake of these metals by crops, thereby compromising food safety and quality. Heavy metals remain significant environmental contaminants with growing ecological, nutritional, and health implications (Xu, *et al.*, 2018; Wang & Chen, 2019). Their persistence in ecosystems, bioaccumulative nature, toxicity to aquatic life and humans, and tendency to magnify through food chains make heavy metal contamination a serious environmental and public health concern (Li, *et al.*, 2020).

Heavy metals continue to be major environmental contaminants, with their toxicity increasingly recognized as a critical issue for ecological, evolutionary, nutritional, and environmental health (Gupta, *et al.*, 2021; Sharma & Tripathi, 2017). These metals pose serious risks to aquatic ecosystems and human populations due to their persistence, bioaccumulative properties, and ability to magnify through food chains. Because they are non-degradable and toxic even at low concentrations, heavy metals contribute to numerous adverse health affects worldwide (Khan, *et al.*, 2018).

Certain heavy metals, such as iron, zinc and copper play vital roles in physiological processes when present in low to moderate amounts, supporting normal human tissue functions (Singh, *et al.*, 2019). However, excessive intake of these metals can be harmful. In contrast, metals like lead, mercury, cadmium, and arsenic are non-essential and highly toxic even at trace levels (Zhang & Wang, 2020). These non-essential metals are particularly dangerous for vulnerable populations, including pregnant women and young children, who are more susceptible to the toxic impacts of heavy metal exposure (Chen, *et al.*, 2022).

Several studies in Tanzania have examined heavy metal contamination in vegetables, although most did not focus explicitly on abattoir waste. However, they remain contextually relevant since the vegetables were grown near potential wastewater sources. For instance, Lema (2023) detected elevated levels of cadmium, lead, and chromium in vegetables cultivated along the Msimbazi River in Dar es Salaam, with concentrations exceeding FAO/WHO permissible limits. Similarly, Othman (2001) reported higher levels of lead, cadmium, chromium, zinc, nickel and copper were detected from vegetable sampled from vegetable gardens at Kiwalani, Tabata, Ukonga, Buguruni and Sinza, Dar es Salaam. Study conducted at Chang'ombe ward in Temeke district on the some commonly consumed vegetables revealed that levels of Pb in all vegetables were greater than the WHO/FAO recommended levels of contaminants in food products (Kacholi, *et al.,* 2017).

In accordance with the Agency for Toxic Substances and Disease Registry's toxicity classification system, heavy metals and metalloids such as arsenic, lead, and cadmium present in the environment are classed as 1, 2, and 7 on a scale from 1 to 7 (ATSDR, 2007). Acute and chronic toxic effects of heavy metals affect different body organs. Gastrointestinal and kidney dysfunction, nervous system disorders, skin lesions, vascular damage, immune system dysfunction, birth defects, and cancer are examples of the complications of heavy metals toxic effects. Simultaneous exposure to two or more metals may have cumulative effects (Costa, 2019).

2.3.2 Sources of Heavy Metals in Abattoir Wastes

Animal tissues and blood often accumulate heavy metals such as lead, chromium, copper, zinc, and iron due to environmental exposure and bioaccumulation. During slaughtering, these metals can enter wastewater and solid waste streams (Usman *et al.*, 2022; Okareh & Oladipo, 2015). Slaughterhouse Equipment and Tools; Corrosion and wear of metal equipment used in the slaughtering facilities such as knives, hooks, and conveyors can leach metals like nickel, chromium, and iron into slaughterhouse wastewater. Cleaning Agents and Chemicals; Agents used in the slaughterhouses for cleaning and disinfection of surfaces and utensils may contain or mobilize heavy metals through chemical residues, adding to contamination levels in wastewater. Water Supply, according to Ng, *et al.*, 2022, contaminated water used in slaughterhouses for washing animals, equipment, and floors may contain heavy metals that become part of the wastewater and hence increase the overall metal load in abattoir effluent.

2.4 Studies of Heavy Metals in Abattoir Soil and Selected Metal Toxicity

The toxicological profiles of overexposure to heavy metals and their consequences, including mutagenicity, carcinogenicity, teratogenicity, genotoxicity, immunosuppressant, and physiological and biochemical disorders, cannot be under stated. Several studies conducted by the World Health Organization (WHO) have found that more than 10% of women are at risk of infertility because of their exposure to heavy metals such as lead, cadmium, mercury, and other pollutants, which are the most common environmental contaminants that can cause reproductive disorders (Apostoli and Catalani, 2011).

2.4.1 Lead

Lead is a naturally occurring element found in small amounts in the earth’s crust. It can also be found in soil from active industry or in the environment from disposal of lead-containing products, such as batteries (WHO, 2010). Pb contaminations occur in vegetables grown on contaminated soils, through air deposition or through sewage sludge/wastewater application (Oluwole, *et al.*, 2013). Ubwa, *et al.*, 2013 conducted study of lead contamination on the soil from abattoir waste and concentration of lead and reported range of 0.18 mg/kg to 0.83 mg/kg. Study conducted by (Osu and Okereke, 2015) in the vegetables irrigated using wastewater from abattoir reported lead concentration in the range of 0.03 – 0.34 mg/kg. Helen *at al.*, (2019) did the same study in the wastewater from abattoir and reported Pb concentration ranged from 0.02 mg/kg to 0.09 mg/kg.

Lead is a carcinogenic substance that causes damage to the DNA repair mechanism, cellular tumour regulating genes and chromosomal structure. Exposure to Pb can produce alteration in physiological functions of the body and is associated with many diseases (Jacobs *et al.*, 2009; Kianoush, *et al.*, 2012). Pb is highly toxic which has adverse effects on the neurological, biological, and cognitive functions in the bodies. The international level-of-concern for Pb poisoning is 10 µg/dl in the blood (Burki, *et al.*, 2012; Kianoush, *et al.*, 2013). Adulteration of opium with Pb has been considered as a threat to human health in recent years (Kianoush, *et al.*, 2015). Recent systematic reviews have identified associations between lead exposure and increased risk of gastrointestinal cancers including stomach and cancers of the bladder and urinary tract.

2.4.2 Chromium

Chromium in vegetables typically comes from irrigation with contaminated water, polluted soils, airborne particles, or the use of organic waste as fertilizer. Abattoirs contribute significantly to this contamination by discharging untreated wastewater rich in animal blood, tissues, and cleaning agents containing chromium. Study conducted by Olusola, *et al.*, (2020) in the agricultural abattoir soil reported 1.33 mg/kg of Cr, also Chukwu and Anuchi, (2016) reported 4.25 to 5.86 mg/kg of Cr from abattoir soil. Osu and Okereke, (2015) analysed Cr in the vegetables irrigated using abattoir wastewater and the result shown presence of mean concentration 0.05 mg/kg in the selected vegetables. Also, Cr accumulation in vegetables in the study by Mohammed, *et al.*, 2020, was found to be in the average concentration of 0.10333 mg/kg.

Several studies have reported the presence of Cr in abattoir liquid waste (Eze, *et al.*, 2020; Elemile, *et al.*, 2019). The Cr (VI) is related to a series of diseases and pathologies while Cr (III) is required in trace amounts for natural lipid and protein metabolism and also as a cofactor for insulin action (Achmad, *et al.*, 2017; Vincent, 2017; Vincent, 2019). Based on the International Agency for Research on Cancer (IARC) report (2018), hexavalent chromium has been classified as a group I occupational carcinogen (Loomis, *et al.*, 2018).

Chromium has been shown to exert multiple adverse effects on the human immune system and can cause significant liver damage, as evidenced by several studies (Deng, *et al.*, 2019; Pavesi & Moreira, 2020). It has been associated with histopathological changes such as hepatocellular steatosis, parenchymatous degeneration, and necrosis, as well as DNA damage, reduced antioxidant enzyme activity, and mitochondrial dysfunction including impaired mitochondrial bioenergetics, cell growth arrest, and apoptosis. These effects are collectively indicative of chromium-induced hepatotoxicity. Furthermore, chromium poisoning can have profound implications for various organ systems, including the respiratory, cardiovascular, gastrointestinal, hematological, hepatic, renal, and neurological systems (Ullah, *et al.*, 2017).

2.4.3 Copper

Copper has been detected in agricultural soil, vegetables, and wastewater, indicating widespread environmental contamination. In Ibadan, Adeniji, *et al.*, (2024) reported significantly elevated copper levels in soil and water near abattoirs compared to soil from designated reference sites, suggesting that abattoir activities are a major source of heavy metal pollution. Similarly, Ebong, *et al.*, (2020) found copper concentrations in studied soils ranging from 15.66 to 19.34 mg/kg. Osu and Okereke (2015) investigated copper levels in both abattoir soil and vegetables, reporting mean concentrations ranging from 0.05 to 1.70 mg/kg in soil and 4.4 to 9.1 mg/kg in vegetables. Additionally, a study by Osibanjo and Adie (2007) observed a copper concentration of 0.14 mg/L in wastewater effluent from the Bodija abattoir in Ibadan, Oyo State, Nigeria.

Copper is well known to accumulate in the liver due to Wilson's disease. Epidemiological studies have shown that exposure to high copper concentration is associated with an increased risk of cardiovascular disease (CVD) (Chowdhury, *et al.*, 2018). Accumulating evidence indicated that Cu exposure can cause the production of oxidative stress products (including reactive oxygen species), pro-inflammatory factors, abnormal blood lipid metabolism, and endothelial cell damage.

2.4.4 Zinc

Zinc is prevalent metal in the air, water, and soil. However, its abnormally high environmental concentrations are primarily attributed to anthropogenic activities. Zinc is an essential element required by in the body and involved in many aspects of cellular metabolism. It is required for the catalytic activity of hundreds of enzymes, and it plays a role in enhancing immune function, protein and DNA synthesis, wound healing, and cell signalling and division (King and Cousin, 2014). Zinc also supports healthy growth and development during pregnancy, infancy, childhood, and adolescence and is involved in the sense of taste (Nagraj, *et al.*, 2017).

Study conducted by Olusola, *et al.*, 2020 on abattoir soils revealed concentration of zinc to be Zn 40.28 mg/L. Osu and Okereke, 2015 studied zinc in vegetables and they reported concentration of zinc with range from 0.02 to 1.3 0.39mg/kg. Abdullahi, *et al.*, 2023 in the study of heavy metals from abattoir effluent the observed level of zinc was 0.18 mg/L. Despite of having biological importance in human body, acute as well as chronic exposure may occur in human body by consumption of vegetables highly contaminated with such heavy metals.

The manifestation of acute zinc poisoning could include nausea, vomiting, diarrhoea, fever and lethargy. While long term chronic exposure to excessive zinc levels could resulting in metabolic interference with other trace elements (Wong, *at al*., 2019). Acute ingestion of toxic amounts of zinc commonly causes symptoms such as abdominal pain, nausea, and vomiting. Additional effects may include lethargy, anemia, and dizziness (Sharma, *et al.*, 2017; Elin, 2018). Chronic exposure to elevated zinc levels has been linked to adverse effects on the gastrointestinal, hematological, respiratory, cardiovascular, and neurological systems (Chen, *et al.*, 2020).

2.4.5 Iron

Iron (Fe) is the most abundant metal in the earth’s crust (Kumar, *et al.,* 2017). Fe is found in meat, whole grain products, potatoes, and vegetables. According to the Environmental Protection Agency’s (EPA) rules for common water sources, iron is designated a secondary pollutant (Odetola, *et al.*, 2021). A study by Osu and Okereke (2015) on soils and selected edible vegetables in an abattoir area reported iron (Fe) concentrations ranging from 86.3 ± 1.1 to 254.5 ± 1.02 mg/kg in agricultural soils, while the Fe content in the analyzed vegetables ranged from 5.45 mg/kg to 10.1 mg/kg. Similarly, Adeyebo, *et al.*, (2019) found iron concentrations of 0.54 mg/L in abattoir wastewater, further indicating contamination from slaughterhouse activities.

Iron remains critically necessary for diverse biological processes across organisms. Following regulatory failure, excessive iron can accumulate and induce siderosis, especially in organs like the liver, pancreas, heart, and endocrine tissues including the thyroid, adrenal glands, and pituitary often resulting in hepatic cirrhosis, diabetes, cardiomyopathy, and hormonal dysfunction (Porter and Rawla, 2023; Olynyk and Ramm, 2022).

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter provides a comprehensive explanation of the procedures and strategies employed in conducting the current study. It outlines in detail the methodologies adopted, including the protocols, techniques, and tools utilized throughout the various stages of the research process. These stages encompass sample collection, sample preparation and analysis, data collection, data analysis, as well as the quality control techniques implemented to ensure the reliability and validity of the data obtained.

3.2 Description of the Study Area

The present study was conducted at Ikwiriri ward Rufiji District, Pwani Region (Figure3.1). Rufiji is one of the six districts of the Pwani Region of Tanzania. It is bordered to the north by the Kisarawe and Mkuranga Districts, to the east by the Indian Ocean, to the south by the Kilwa District, Lindi Region and to the west by the Morogoro Region. Rufiji District is one of the six Districts of the Coast Region, the others being Bagamoyo, Kibaha, Kisarawe, Mafia and Mkuranga. Rufiji District, located in the south of the Region, has six Divisions with 19 Wards divided into 94 registered villages with 385 hamlets. The district covers an area of approximately 14,500 square kilometres. Ikwiriri is one of administrative ward out of 22 wards of Rufiji located at 7º57’S and 38°58’E.

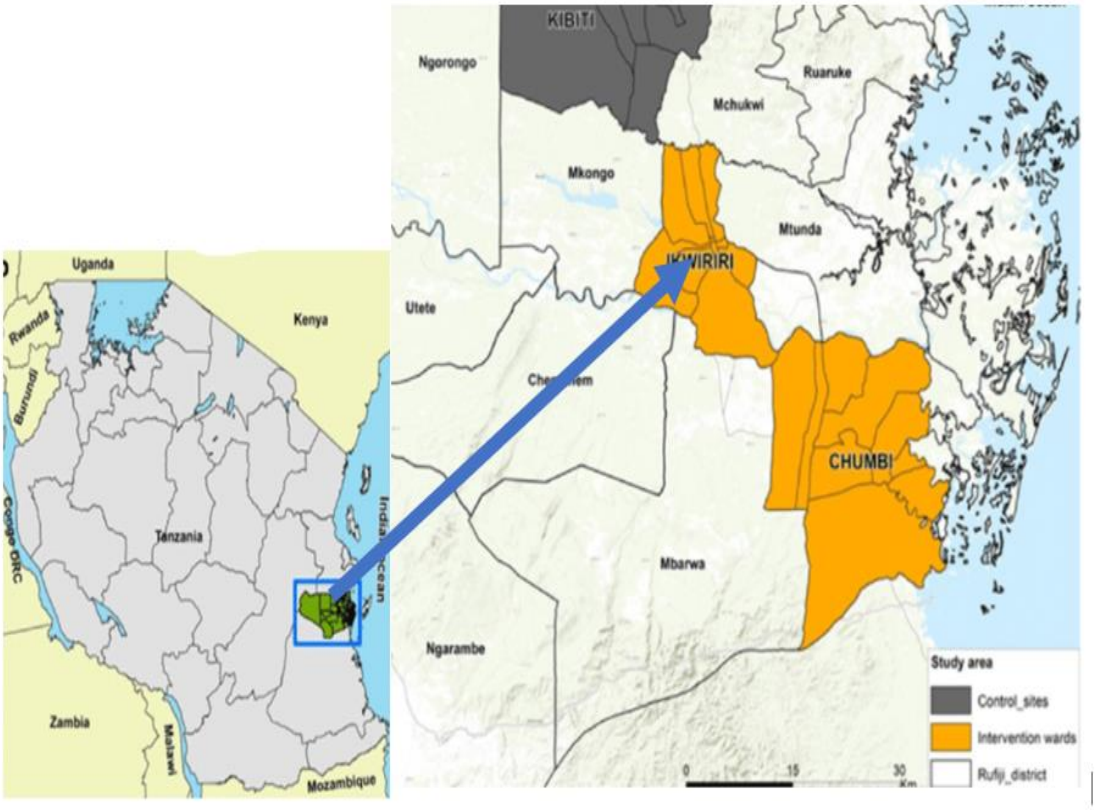


Figure 3.1: Map of the Study Site Indicating Sample Collection Area
Source: Adopted from Mlacha, et al, (2020).

The selection of the study area was based on the practice of vegetable farming activities near the Rufiji abattoir, where untreated wastewater from the slaughterhouse is commonly used for irrigation. This situation raises significant concerns about potential contamination of vegetable and agricultural soil with heavy metals. The area provides a relevant context to the study.

3.3 Sample Collection

3.3.1 Vegetable Samples Collection

The selected vegetables for this study were pumpkin leaves (*Vigna* sp.), sweet potato leaves (*Ipomoea* sp.) and cowpea leaves (*Cucurbita* sp.). These vegetables were selected based on their widespread availability on farms near the studied abattoir area and their common consumption within the Ikwiriri ward. The edible parts of the vegetables were collected in an interval of seven days during dry season making a total of three samples each. About 500 g of each vegetable samples were obtained from local farms near slaughterhouse at Ikwiriri Ward, Rufiji district, over a period of three weeks from 8 June to 24 June 2024 and kept in pre-cleaned polyethylene bags. Each day the samples were transferred to Tanzania Bureau of Standard (TBS) Laboratory for analysis.

3.3.2 Soil Samples Collection

Soil samples were collected from the same locations where vegetable samples were obtained to ensure spatial correlation between soil and plant data. Sampling was carried out at a depth of approximately 15 cm, which corresponds to the active root zone of most vegetable crops (Kihampa & Mwegoha, 2010), using a clean hand auger in accordance with standard agronomic practices (OMAFRA, 2023). At each site, multiple soil cores were taken in a zigzag pattern to capture field variability, then mixed thoroughly to form a composite sample representative of each field. A total of three composite soil samples were collected at weekly intervals over a period of three weeks. Samples were placed in pre-cleaned polyethylene bags, properly labelled, and transported to the TBS Laboratory.

In the laboratory, the soil samples were oven-dried at 75 °C for two days, gently crushed, passed through a 2 mm sieve, homogenized, and stored in airtight containers for further chemical analysis. This procedure aligns with best practices for soil sampling in vegetable cropping systems, ensuring reliable trace metal and nutrient assessments.

3.3.3 Wastewater Samples

At the discharge point of the Slaughterhouse, the sample bottles (polyethylene bottles) were properly labelled and rinsed twice with the wastewater before collection. A total of nine (9) samples of wastewater (effluent) from abattoir were collected to three pre-cleaned bottles, three samples every after seven days and acidified with 1 ml HNO_3. The purpose of the acid is to maintain metals in a dissolved state and to prevent their adsorption onto the container surfaces during storage and analysis (EPA, 2022). Information such as the date of collection, location and serial identification for each sample was recorded on labels affixed to each sample container.

Figure 3.2: Slaughtering Site at Ikwiriri Showing the Operational Slaughter Slab
Source: Developed by the Researcher from field area 2024.

3.4 Sample Preparation and Digestion

The collected vegetable samples were rinsed with distilled water to remove the dust particles followed by cut edible parts into small pieces using pre-cleaned stainless-steel knife, and then both vegetables and soil samples were dried in the laboratory oven at 75°C for 3 days. The dried vegetable and soil samples were then uniformly grounded into fine texture using commercial blender and stored in polyethylene bags at room temperature, until time of acid digestion.

Accurately 1.0 g of the oven-dried, ground samples was weighed into a 250 mL beaker that had been previously washed with nitric acid and distilled water. A mixture of 5 mL HNO3, 15 mL concentrated H2SO4, and 0.3 mL HClO4 was added to the sample using a pipette (Saria, 2020). The mixture was digested in a fume cupboard, with heating continued until a dense white fume appeared. This was then digested for 15 minutes, allowed to cool, and diluted with distilled water. The mixture was filtered through acid-washed Whatman No. 44 filter paper into a 50 mL volumetric flask and diluted to the mark volume.

The wastewater samples from each sampling bottle were thoroughly mixed by shaking. A 50 mL filtered aliquot of each wastewater sample was pipetted into a digestion flask. The metal content in the water was determined by digesting the sample in 3 ml of concentrated HNO_3 and 3 mL of H_2O_2 at temperatures below 80°C for 1 hour until a clear solution was obtained. This clear solution was then diluted to 100 ml with distilled water in a volumetric flask, and a blank digestion was performed in the same manner EPA Method 3015A (U.S. EPA, 1996). The blank solution contained all reagents except the wastewater. All samples were digested in triplicate. The resulted solution was mixed well using vortex mixer ready for instrumental analysis.

3.5 Sample Analysis

The heavy metals were analysed by Microwave Plasma Atomic Emission Spectroscopy (Agilent model 4210 MPAES) at Tanzania Bureau of Standards laboratory. Multielement standard solution Supelco from Merck (Germany) containing all target metal was used to prepare calibration standards.

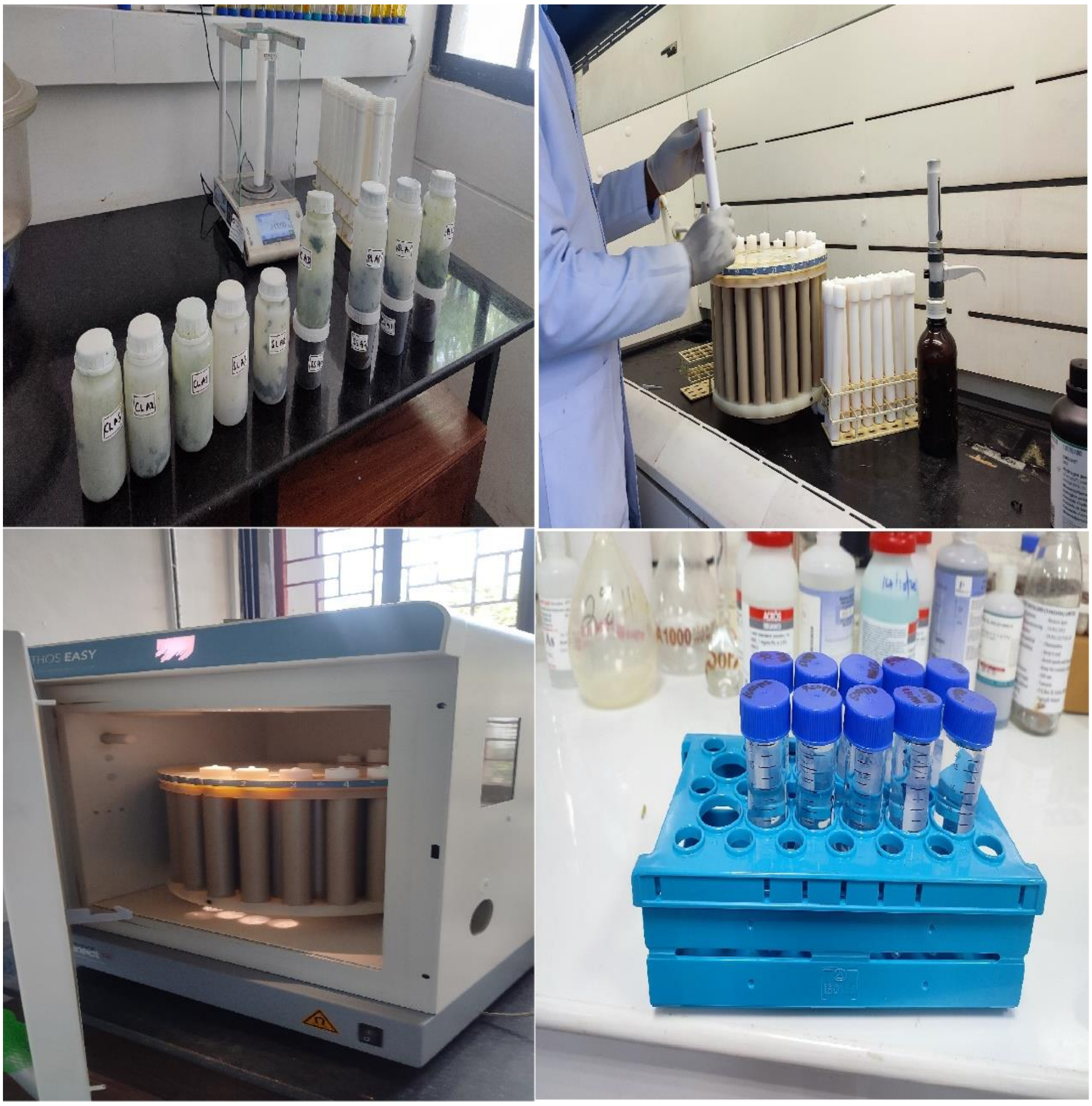


Figure 3.3: Steps Involved in the Preparation of Samples for Analysis

3.6 Quality Assurance

Appropriate quality assurance procedures and precautions were taken to ensure the reliability of the results. Samples were carefully handled to avoid contamination. Glassware and apparatus were properly cleaned, and reagents of analytical grade with high purity were used. Reagent blank determinations were employed to correct the instrument readings. Blank samples, Initial Calibration Verification (ICV), and Continuing Calibration Verification (CCV) were also included. The ICV was run prior to sample analysis to verify the acceptability of the calibration curve, whereas the CCV was performed after each calibration and after every 20 readings to provide a continuing periodic check on accuracy and instrument drift. Each sample was analyzed in duplicate. The instrument was calibrated with six to nine multi-element calibration standards, depending on the detection limits for each element. The correlation coefficient (R^2) of the calibration curve was accepted only when it was 0.995 or higher.

The percentage recoveries of were done by comparing mean values of the analysed heavy metals to the values from certified reference materials. The percentage recoveries provide a measure of the accuracy and reliability of the analytical methods and instruments used to measure heavy metal concentrations in the samples. This is particularly important when making decisions based on the data, such as compliance with regulatory limits or human health risk.

3.7 Soil to Vegetable Transfer Factor

Soil-to-plant transfer is a major pathway for human exposure to metals through the food chain. The Transfer Factor (TF) is a parameter used to describe the movement of trace elements from soil to plants, and it is influenced by both soil and plant properties (Opaluwa, *et al.*, 2012). Soil-to-Plant Transfer Factor was calculated to evaluate the ability of vegetables to accumulate heavy metals from the soil into their edible tissues. The TF provides an essential link between environmental contamination and dietary exposure, as it reflects the efficiency of metal uptake by crops relative to soil concentrations. Plant metal concentration (Conc. Veg) and soil metal concentrations (Conc. Soil) were compared to calculate the transfer factor (Jalali and Meyari, 2022). Examining Transfer Factors (TFs) in short-term or fast-growing vegetables (like *Cucurbita* sp., *Vigna* sp. *and Ipomoea* sp.) provides critical insight into how quickly contaminants in soil can enter the human food chain. TF was calculated by dividing the concentration of heavy metals in vegetables by the total heavy metal concentration in the soil (Equation 1).

$$TF = \frac{Conc_{.Veg}}{Conc_{.Soil}} \tag{1}$$

3.8 Assessment of Heavy Metal Health Risks

Human health risk assessment involves evaluating the potential adverse effects on human health resulting from exposure to environmental hazards (USEPA, 2019). This process integrates scientific, engineering, and statistical approaches to identify hazards, assess exposure pathways, and quantify risks through numerical estimates (Nguyen and Lee, 2020). In this study, the potential health risks associated with heavy metal ingestion through vegetable consumption were assessed using multiple indicators. Subsequently, consumer exposure was assessed through the Average Daily Intake (ADI), while the Hazard Quotient (HQ) and the Hazard Index (HI) were applied to estimate the non-carcinogenic health risks (Khan et al., 2018; Li et al., 2019).

3.7.1 Average daily intake (ADI)

Exposure to heavy metals via vegetable consumption is expressed as the average daily intake (ADI) also referred to as estimated daily intake (EDI). ADI is the estimated amount of a contaminant (e.g., a heavy metal) ingested daily through food consumption, normalized to body weight. The ADI values indicate the amount of each heavy metal that a person is estimated to ingest daily through consumption of *Cucurbita* sp., *Vigna* sp., and *Ipomoea* sp. vegetables, while PMTDI values represent the maximum safe intake levels recommended by health authorities like WHO and FAO. The RfD is typically derived from toxicological studies, incorporating uncertainty factors to protect sensitive populations (Lee *et al.*, 2020). It is a key parameter used to evaluate human exposure to toxic substances via dietary intake and is expressed in milligrams per kilogram of body weight per day (mg/kg bw/day). The ADI of each heavy metal Pb, Cr, Cu, Zn and Fe was calculated as a product of heavy metals concentration in vegetables and the amount of the respective vegetable consumed, using the formular (2).

$$ADI = \frac{C*EF*ED*IR}{AT*LT*BW} \quad (2)$$

Where: C is the average heavy metal concentration in GLV (mg/kg); EF is the exposure frequency (365 days/year); ED is the exposure duration [Tanzanian life expectancy 67.3 years and 6.7 year for children] (URT, 2019); IR is the ingestion rate (GLV consumption rate; g/person/day). According to Weinberger and Swai (2006) vegetable consumption values for Tanzanian adult are 0.280 kg/person/day). AT is the average time (365 × ED for non-carcinogens); LT is the lifetime (equal to exposure duration; years) and BW is an average body weight of Tanzanian adult is 60.7 kg for adults.

3.7.2 Non-Carcinogenic risk (Hazard Quotient)

The Hazard Quotient (HQ) is a risk assessment parameter used to evaluate the potential non-carcinogenic health risks associated with long-term exposure to environmental contaminants, particularly heavy metals, through ingestion. It represents the ratio between the Average daily intake (ADI) of a contaminant and its corresponding oral reference dose (RfD), which is the maximum acceptable daily exposure level without appreciable health risk over a life (USEPA, 2011).

HQ value less than 1 is generally considered to indicate no significant health risk to the consumer, while HQ greater than 1 indicates potential health risks that warrant further investigation (Chen *et al.*, 2018; USEPA, 2021). HQ values provide important insight into the likelihood and extent of non-carcinogenic health effects resulting from exposure to environmental pollutants. The non-carcinogenic risk associated with individual metals, expressed as the hazard quotient (HQ), was evaluated using Equation (3) as proposed by Granero and Domingo (2002), as shown below:

$$HQ = = \frac{ADI}{RfD} \tag{3}$$

Where Reference Dose (RfD) is defined as the estimated daily amount of a chemical substance (e.g., a heavy metal or pollutant) that a person can ingest over a lifetime without experiencing significant adverse health effects (USEPA 2011). Reference Doses (RfDs) are scientifically derived values that estimate a safe daily exposure level for a chemical such as a heavy metal that is not expected to cause harmful (non-carcinogenic) health effects over a lifetime, even in sensitive individuals. Regulatory agencies such as the World Health Organization (WHO) and the U.S. Environmental Protection Agency (USEPA) through comprehensive toxicological evaluations most commonly establish reference Doses (RfDs). Each heavy metal has its own established RfD based on scientific evidence and risk assessment protocols. Thus, THQ serves as a crucial screening tool in human health risk assessments to prioritize contaminants based on their potential for non-carcinogenic effects (Nguyen and Lee, 2020).

3.7.3 Hazard Index (HI)

The Hazard Index (HI) is a health risk assessment tool used to evaluate the combined non-carcinogenic health risks from exposure to multiple hazardous substances, such as heavy metals, through ingestion, inhalation, or dermal contact. The HI is simply expressed as the sum of individual THQs for substances that may affect the same target organ or system. Hazard Index helps to determine whether simultaneous exposure to multiple contaminants could pose a health risk. This is very useful tool since exposure to more than one contaminant has contributed additive effects. The hazard index (HI) as per by USEPA (2021) was calculated as the summation of the THQ arising from all the heavy metals examined. Health index was determined by the following equation (Kacholi and Sahu 2018);

$$HI = \sum_{i=1}^{n} HQi = HQ_{Pb} + HQ_{Zn} + HQ_{Cu} + HQ_{Fe} + HQ_{Cr} \qquad (2)$$

The value of the hazard index is proportional to the magnitude of the toxicity of the vegetables consumed. If HI is less than 1 (< 1), it suggests that the combined exposure is unlikely to cause adverse health effects. In other words, the risk is considered acceptable or negligible. If HI is equal to or greater than 1 (≥ 1), it signals a potential health concern, meaning the combined exposures may pose a risk of harmful effects to human health, and further investigation or intervention might be needed.

3.8 Data Analysis

Descriptive statistical analysis was conducted using the Data Analysis Toolpak in the current version of Microsoft Office Excel to compute the mean, standard deviation, minimum, and maximum concentrations of heavy metals in vegetable, soil, and wastewater samples. This provided an initial overview of the distribution and central tendency of the measured parameters. To determine whether the differences in heavy metal concentrations were statistically significant across different vegetable species and metal types, a two-way Analysis of Variance (ANOVA) with interaction was involved.

CHAPTER FOUR

RESULTS AND DISUSSION

4.1 Introduction

This chapter provides a comprehensive presentation and analysis of the study's findings. It discusses the results in depth, explores their broader implications, and critically compares them with findings from existing literature. The collected data have been analyzed and interpreted using tables and charts, which are clearly organized and aligned with the study's research objectives and questions.

4.2 Levels of Heavy Metals (Pb, Cr, Cu, Zn and Fe) in Vegetables

The concentrations of five heavy metals Pb, Cr, Cu, Zn and Fe were quantified in the edible parts of three green leafy vegetables (*Cucurbita* sp., *Vigna* sp., and *Ipomoea* sp.) grown in proximity to the Ikwiriri slaughterhouse. The results, presented as mean ± standard deviation in mg/kg dry weight, are summarized in Table 4.1.

Table 4.1: Heavy Metal Concentration in Vegetables

Heavy Metal	**Vegetable Samples (Metal Concentration in mg/kg)**			**FAO / WHO (2019) Limits, (mg/kg)**
	***Cucurbita* sp.**	***Vigna* sp.**	***Ipomoea* sp.**	
Pb	0.120 ± 0.082	0.073 ± 0.011	0.158 ± 0.071	0.3
Cr	0.405 ± 0.161	0.437 ± 0.181	0.182 ± 0.096	2.3
Cu	2.307 ±0.335	1.212 ± 0.208	1.220 ± 0.147	73
Zn	7.618 ± 0.082	7.740 ± 0.928	2.933 ± 0.305	100
Fe	58.991 ± 17.196	96.109 ± 29.265	15.543 ± 1.649	425

Source: Field Research Data, (2024).

Heavy metal contamination Pb, Cr, Cu, Zn and Fe was detected in all vegetable samples (*Ipomoea* sp., *Cucurbita* sp. and *Vigna* sp.) analyzed. Some vegetable exhibits a higher concentration of a particular metal compared to others. *Cucurbita* sp. has the highest level of heavy metal accumulation among the studied vegetables grown near abattoir. The concentrations of five heavy metals (Pb, Cr, Cu, Zn and Fe) measured in *Cucurbita* sp., *Vigna* sp., and *Ipomoea* sp. grown near the Ikwiriri slaughterhouse reveal important insights into contamination patterns, species-specific accumulation, and potential health risks.

4.2.1 Lead (Pb) Levels in Green Leafy Vegetables

The findings reveal notable differences in lead accumulation among the three studied green vegetables. The concentration of Pb ranged between 0.073 ± 0.011 mg/kg in *Vigna* sp. to 0.158 ± 0.071 mg/kg in *Ipomoea* sp. in order of decrease *Ipomoea* sp. > *Cucurbita* sp. > *V. unguiculata* sp. These results suggest that Pb uptake varies significantly depending on species-specific physiological traits, as well as environmental and soil interactions. These values are well below the maximum permissible limit of 0.3 mg/kg for leafy vegetables set by the Codex Alimentarius (FAO/WHO, 2019). This finding suggests that the consumption of these vegetables does not currently pose a significant health risk in terms of Pb exposure.

Despite being within acceptable safety margins, the variation in Pb concentrations among the species highlights species-specific differences in metal uptake and accumulation capacities. *Ipomoea* sp. recorded the highest Pb concentration (0.158 ± 0.071 mg/kg), more than double that found in *Vigna* sp. (0.073 ± 0.011 mg/kg). This aligns with previous observations that some species of *Ipomoea* possess traits that may facilitate greater metal uptake, including a more extensive root system, higher transpiration rates, and physiological adaptations for metal sequestration in aerial tissues (Sharma, *et al.*, 2019). These traits may explain *Ipomoea*'s relatively high accumulation despite all samples being collected from the same environmental conditions. The higher Pb concentration observed in *Ipomoea sp*. may result from root-mediated changes in rhizosphere chemistry such as acidification and organic acid exudation, which increase Pb solubility and bioavailability (Chen, et al., 2017; Liu, Ma, & Zhou, 2019). Conversely, *Cucurbita* sp. may limit Pb uptake by promoting metal immobilization through complexation and adsorption processes in the rhizosphere influenced by soil properties and root exudates (Mishra & Tripathi, 2016; Luo, *et al.*, 2018).

In contrast, *Vigna* sp. Like other leguminous plants form symbiotic associations with nitrogen-fixing rhizobia, a process that significantly alters the physicochemical properties of the rhizosphere. This symbiosis leads to the formation of root nodules and the release of microbial metabolites such as exopolysaccharides, siderophores, and organic acids which can chelate, immobilize, or sequester heavy metals in the soil matrix. These rhizospheric modifications effectively reduce the bioavailability and translocation of toxic metals like Pb into aerial plant tissues, thereby mitigating metal accumulation and associated phytotoxicity (Meng, *et al*., 2023).

Comparable findings were reported by Kumar, *et al.* (2017), who investigated leafy vegetables irrigated with abattoir effluents in Saharanpur, India. Their study showed that Pb levels remained below international safety thresholds, yet varied between plant species, indicating that uptake is strongly plant-dependent, even under similar exposure conditions. Similarly, Osu and Okereke (2015) documented Pb accumulation in vegetables cultivated near slaughterhouses in Nigeria, noting values within safe limits, though still higher than those in non-contaminated control sites emphasizing that proximity to pollution sources plays a role, but plant physiology also mediates risk.

Once in the soil, Pb is not easily degraded and can persist for long periods, gradually accumulating in plant tissues especially in leafy vegetables, which tend to absorb and store more heavy metals in their foliage due to large surface areas and direct contact with contaminated soils. Lead is a non-essential, highly toxic heavy metal with no beneficial role in human biology. Even minimal exposure over time can cause neurological and cognitive damage, particularly in children and fetuses (e.g., developmental delays, lowered IQ), chronic kidney damage, hypertension and cardiovascular problems, anemia, by interfering with hemoglobin synthesis, reproductive toxicity and hormonal disruptions (WHO, 2023). The public health concern is especially critical in areas where leafy vegetables are consumed frequently and form a dietary staple as is the case in many Tanzanian households. Long-term ingestion of Pb-contaminated vegetables like *Ipomoea* sp. and *Cucurbita* sp. can contribute to chronic lead exposure, which accumulates in bones and soft tissues, leading to long-lasting health effects.

These findings indicate that crop selection could be an important mitigation strategy to minimize dietary lead exposure in contaminated. These findings also reinforce the conclusion that abattoirs, if unmanaged, can significantly contribute to heavy metal contamination, especially lead, in nearby food crops. The elevated Pb in vegetables near the Ikwiriri slaughterhouse suggests that poor waste management practices may be contaminating the local agricultural environment.

4.2.2 Chromium (Cr) in Green Leafy Vegetables

The concentrations of chromium (Cr) in the three vegetable species cultivated near the Ikwiriri slaughterhouse exhibited clear variation. *Vigna* sp. recorded the highest mean Cr level at 0.437 ± 0.181 mg/kg, closely followed by *Cucurbita* sp. with 0.405 ± 0.161 mg/kg. In contrast, *Ipomoea* sp. had the lowest Cr concentration, measured at 0.182 ± 0.096 mg/kg. The overall trend in Cr accumulation followed the order: *Vigna* sp. > *Cucurbita* sp. > *Ipomoea* sp. This pattern highlights distinct species-specific differences in Cr uptake, with *Ipomoea* sp. accumulating less than half the amount observed in *Vigna* sp.

The WHO/FAO (2011) maximum allowable limit for Chromium in leafy vegetables is 2.3 mg/kg. All three vegetable species had Cr concentrations well below this threshold, indicating that there is currently no immediate health risk associated with chromium exposure from the consumption of these vegetables, even if they were cultivated near a potential pollution source like an abattoir. This compliance with safety standards is reassuring, especially when compared with more toxic elements like lead.

Patel, *et al.*, (2023), in a study on vegetables irrigated with slaughterhouse wastewater in Gujarat, India, also reported low Cr concentrations in leafy greens, attributing it to low metal mobility and strong soil binding. This pattern of variability suggests that chromium accumulation is influenced by physiological and morphological differences between plant species. Studies have shown that factors such as root structure, metal transporter activity, and transpiration rates contribute to differing metal uptake capacities across plant species (Sharma *et al.*, 2020). Plants with deeper or more fibrous root systems, like *Vigna* sp. and *Cucurbita* sp., may access Cr more efficiently from contaminated soils, resulting in higher bioaccumulation.

The relatively lower accumulation in *Ipomoea* sp. might be due to either a lower root absorption efficiency or a greater exclusion ability for Cr at the root-soil interface. This aligns with findings from a study by Cuéllar *et al.,* (2021), where variations in Cr uptake among different leafy vegetables were attributed to their species-specific physiological responses to Cr stress. Their results demonstrated that leafy vegetables such as arugula accumulated significantly more Cr under the same exposure conditions compared to others like spinach. Chromium can be introduced into soils via abattoir wastewater including cleaning agents, disinfectants and animal residues, the low concentrations of Cr observed in the vegetables suggest that contamination from the Ikwiriri slaughterhouse may be limited, or that natural soil immobilization processes are effectively reducing Cr bioavailability (Tripathi *et al.,* 2017).

Chromium in soils predominantly occurs in two forms: Cr (III) which is relatively insoluble, less toxic, and strongly adsorbed by soil components and Cr (VI) which is more soluble, highly toxic, and mobile (Zulfiqar *et al*., 2023). In well-structured agricultural soils, the prevalence of Cr (III) likely contributes to the low chromium concentrations observed in edible plant tissues. This effect is amplified when soil organic matter is high, since increased organic carbon enhances the reduction of Cr (VI) to Cr (III) and reduces Cr bioaccessibility (Jardine *et al.*, 2013).

Chromium (Cr) is recognized as a trace micronutrient in its trivalent form (Cr III), which plays an essential role in human metabolism by supporting glucose and lipid regulation. Cr III is required in small quantities (typically 50–200 µg/day), and toxicity is rare at normal dietary levels (Vincent, 2020). In contrast, hexavalent chromium (Cr VI) is highly toxic, more mobile, and has been classified as a known human carcinogen due to its oxidative properties and ability to penetrate biological membranes (UK Health Security Agency, 2022). Despite this toxicity, Cr VI is generally unstable in soil environments and is often reduced to the less toxic Cr III form, particularly under conditions with sufficient organic matter or reducing agents. This explains why, in most agricultural soil-plant systems, Cr III tends to predominate.

In the present study, the observed Cr concentrations in all three vegetables were well below the WHO/FAO permissible limits, suggesting limited bioavailability and a correspondingly low risk to human health from dietary exposure. Nevertheless, continuous or long-term exposure to low concentrations of Cr particularly if environmental inputs from sources such as abattoir wastewater persist could lead to gradual accumulation and increased risk over time, especially if soil buffering capacity becomes overwhelmed (Abdullahi *et al.,* 2019). Therefore, while immediate health risks for Cr appear minimal, preventive environmental monitoring and sustainable waste management practices are still essential to ensure long-term agricultural and public health safety, particularly as abattoirs continue to operate near vegetable production zones.

4.2.3 Copper (Cu) Levels in Green Leafy Vegetables

The concentration of Cu in the analyzed leafy vegetables cultivated near the Ikwiriri abattoir ranged from 1.212 ± 0.208 mg/kg in *Vigna* sp., 1.220 ± 0.147 mg/kg in *Ipomoea* sp., to the highest value of 2.307 ± 0.335 mg/kg in *Cucurbita* sp. in order of

Cucurbita sp. > *Ipomoea* sp. > *Vigna* sp. Although these values reflect the presence of Cu in the edible parts of the vegetables, the concentrations are relatively low and fall within a typical range for vegetables cultivated in uncontaminated or slightly contaminated soils.

All measured values are substantially below the WHO/FAO (2011) recommended maximum permissible limit for Cu in vegetables, which is 73 mg/kg. The concentration of Cu in vegetable species which is significantly below permissible limit indicating no immediate threat to human health from copper exposure through consumption of these vegetables, even though they were cultivated near a known pollution source (the Ikwiriri abattoir). Patel, *et al.*, (2023) highlighted that while Cu was detectable in vegetables grown with wastewater irrigation, levels were generally within safe limits unless industrial waste was also mixed into the irrigation source. These findings reinforce the interpretation that copper is not a priority contaminant in vegetables grown near abattoirs unless accompanied by additional industrial inputs.

Copper is a micronutrient essential for plant growth and human nutrition, playing key roles in enzymatic functions, photosynthesis, and cellular metabolism. However, excessive Cu can become toxic, affecting soil microbial activity and can lead to oxidative stress, inhibition of root growth, chlorophyll degradation, and reduced crop productivity (Adrees *et al.*, 2015). Abattoirs can contribute Cu to the environment through various waste streams such blood, organs, and offal may release trace metals during decomposition, cleaning chemicals and detergents used in abattoir operations may also contain trace levels of copper compounds (Elemile *et al*., 2019).

The Recommended Dietary Allowance (RDA) for adults is about 0.9 mg/day, and consumption of these vegetables could contribute beneficially to daily Cu intake, without posing toxicity concerns. However, excessive long-term exposure to Cu through food (e.g., >10 mg/day) can lead to gastrointestinal disturbances and, in rare cases, liver or kidney damage, especially in individuals with underlying conditions like Wilson's disease (NIH, 2022). In this case, the low Cu levels in the vegetables indicate minimal risk of toxicity, and moderate consumption can actually support essential nutrient intake. While Cu is essential for plant and human health, the observed levels reflect a favorable balance between nutritional benefit and safety.

4.2.4 Zinc (Zn) levels in green leafy vegetables

The analysis of zinc levels in the leafy vegetable samples revealed a distinct pattern in accumulation among the species. *Vigna* sp. exhibited the highest Zn concentration at 7.740 ± 0.928 mg/kg closely to *Cucurbita* sp. which recorded a moderate level of 7.618± 0.082 mg/kg and *Ipomoea* sp. had the lowest Zn content, measured at 2.933 ± 0.305 mg/kg in the order of *Vigna* sp. > *Cucurbita* sp. > *Ipomoea* sp. This gradation suggests species-specific differences in zinc uptake and translocation, possibly influenced by root structure, soil-metal interactions, and physiological zinc requirements.

The WHO/FAO permissible limit for Zn in edible vegetables is 100 mg/kg. All three vegetable species in this study had zinc concentrations well below this threshold, with the highest observed value (in *Vigna* sp.) being only about 13% of the limit. This indicates that there is no immediate risk of zinc toxicity from the consumption of these vegetables and zinc levels fall within a nutritionally beneficial range, supporting their role in healthy diets.

The results are in line with findings from similar environments. Ali, *et al.,* (2019) found elevated Zn concentrations in vegetables grown near industrial area in Nigeria but noted that levels rarely exceed permissible thresholds unless industrial waste is mixed with abattoir runoff. These studies reinforce the conclusion that zinc exposure through vegetables grown near abattoirs is generally low-risk, and the nutrient can even play a beneficial role in addressing local dietary deficiencies.

Abattoirs can act as point sources of environmental zinc, stemming from several inputs: animal feed supplements enriched with Zn, veterinary pharmaceuticals and hormone residues, and decomposing animal parts like bones, hair, and organs all of which release zinc into nearby soils. Despite these potential sources, the zinc concentrations found in the vegetable samples suggest that contamination from the abattoir is limited. This moderation may be due to soil buffering characteristics, such as neutral to slightly alkaline pH, organic matter content, and cation-exchange capacity (CEC), which collectively reduce zinc's solubility and bioavailability in the root zone. In particular, alkaline soil pH encourages Zn sorption onto soil particles, thereby inhibiting plant uptake (Mossa, *et al.*, 2021).

The zinc concentrations in all three vegetable species *Cucurbita* sp., *Vigna* sp., and *Ipomoea* sp. remain well within safe and beneficial limits according to international food safety standards. However, the tendency of *Cucurbita* sp. and *Vigna* sp. to also accumulate toxic metals like Pb suggests that nutritional benefits must be weighed against contamination risks. Monitoring zinc and other heavy metal levels in vegetables grown near abattoirs is therefore crucial.

4.2.5 Iron (Fe) Levels In Green Leafy Vegetables

The study found significant variation in iron content across the three leafy vegetables sampled near the Ikwiriri abattoir. *Vigna* sp. had the highest Fe concentration at 96.109 ± 29.265 mg/kg, followed by *Cucurbita* sp. with 58.991 ± 17.196 mg/kg, *Ipomoea* sp. recorded the lowest Fe levels, at 15.543 ± 1.649 mg/kg. The order of iron concentration was *Vigna* sp. > *Cucurbita* sp. > *Ipomoea* sp. Despite their proximity to a potential contamination source, all three species had Fe levels far below the WHO/FAO (2011) permissible limit of 425 mg/kg, indicating that iron accumulation does not pose a food safety risk in the studied context.

The observed Fe concentrations align with values reported in other studies conducted near slaughterhouses or similar environments. Eze *et al.,* 2018 recorded Fe levels average of 14.96±0.86 mg/kg in leafy vegetables irrigated with wastewater in Abuja Nigeria, particularly in areas with high organic input from slaughterhouse waste. Aliyu, *et al.,* (2021) emphasized that Fe is abundant in most tropical soils, yet often limited in bioavailability due to chemical fixation or plant exclusion mechanisms, which aligns with the moderate levels found in *Cucurbita* sp. and *Ipomoea* sp. in this study.

The variation in Fe concentration among the studied vegetables likely reflects species-specific physiological traits. *Vigna* sp. showed the highest iron content, possibly due to more efficient uptake mechanisms such as secretion of root exudates (e.g., phenolic compounds, flavins, coumarins) that enhance Fe solubility via chelation or reduction (Rodríguez-Celma *et al.*, 2013; Mimmo *et al.*, 2014) and increased ferric-chelate reductase activity at the root epidermis that reduces Fe^{3+} to more bioavailable Fe^{2+} (Waters *et al.*, 2002). Additionally, more effective rhizosphere acidification through proton extrusion and organic-acid release could increase Fe availability. Transpiration-driven transport of soluble iron in the xylem, facilitated by polarized localization of the IRT1 transporter in root epidermal cells, also supports enhanced root-to-shoot iron movement (Dubeaux, *et al.*, 2015).

Cucurbita sp., although known to accumulate multiple metals, had only moderate Fe levels, suggesting either selective uptake or limitations in Fe availability in its rhizosphere. *Ipomoea* sp., with the lowest Fe accumulation, may have restrictive root transport proteins that limit Fe movement to aerial parts and a defensive adaptation to avoid oxidative stress from excess Fe, which can catalyze harmful free radical formation if not tightly regulated (Fan *et al.*, 2017). These patterns reflect an exclusionary strategy consistent with low metal accumulation tendencies seen in non-hyperaccumulator species like *Ipomoea* sp. (Hanafiah, *et al.*, 2020).

Abattoirs can influence iron (Fe) concentrations in nearby soils through various environmental pathways. Organic-rich wastes such as blood, manure, and decomposing animal tissues often contain substantial amounts of iron, which may be released into the soil matrix during decomposition (Fan, *et al.*, 2017). However, the bioavailability of Fe in soil is governed by several physicochemical factors. Soil pH plays a major role: in alkaline soils, Fe commonly precipitates as insoluble oxides and hydroxides, reducing its plant availability; while in acidic soils, Fe becomes more soluble and readily absorbed by plant roots (Zhao *et al.*, 2023). Redox potential also influences Fe speciation: under aerated (oxidizing) conditions, Fe is present as Fe^{3+}, which tends to form insoluble compounds; whereas in anoxic or waterlogged soils, Fe remains in the more soluble Fe^{2+} form, increasing its bioavailability. Additionally, soil organic matter and microbial activity affect Fe dynamics through the production of organic acids and chelating compounds, which can increase Fe solubility and mobility (Zhao, *et al.*, 2023).

These findings reinforce that although abattoir activities may increase iron concentrations in surrounding soils, the bioavailability of iron to plants is often constrained by soil chemistry factors, making iron toxicity in vegetables uncommon under typical agricultural conditions (Alloway, 2013; Kabata-Pendias, 2010; Rengel, 2015). While organic matter from abattoir waste can increase soil iron levels through decomposition and nutrient cycling, current evidence suggests that this does not lead to excessive Fe accumulation in edible crops (Kabata-Pendias, 2010;). Nevertheless, ongoing soil and waste management near agricultural areas is crucial to mitigate risks, especially considering the potential for synergistic toxicity when Fe co-occurs with other heavy metals such as lead, which may amplify contamination effects (Alloway, 2013).

Iron concentrations in *Vigna* sp., *Cucurbita* sp., and *Ipomoea* sp. cultivated near abattoirs are generally below toxic levels while still contributing valuable micronutrients to human diets (Mensah *et al.*, 2019; Kabata-Pendias, 2010). However, Fe availability to plants is influenced by soil parameters such as pH and redox conditions, which may vary with waste management practices at abattoirs, thus warranting regular soil and crop monitoring to prevent contamination risks

(Alloway, 2013; Rengel, 2015).

4.3 Heavy Metal Concentrations in Abattoir Wastewater and Soil

The mean concentrations of selected heavy metals (Pb, Cr, Cu, Zn, and Fe) in abattoir wastewater and the surrounding agricultural soils of the Ikwiriri slaughterhouse are presented in Table 4.2. These concentrations were evaluated against the permissible limits established by the World Health Organization (WHO, 1996) and the Tanzania Bureau of Standards (TBS, 2003) for wastewater, as well as WHO (2011) and TBS (2006) guidelines for soils intended for agricultural use. This comparison allows for an assessment of potential contamination levels and the suitability of the soil and wastewater for crop production.

Table 4.2: Concentrations of Selected Heavy Metals in Soil and Wastewater

Heavy metals	Conc. In soil (mg/kg)	Soil standard (WHO 1996 /TBS 2003)	Conc. in wastewater (mg/L)	Wastewater standard (WHO 2011)
Pb	0.373 ± 0.011	85.0	0.099 ± 0.076	0.065
Cr	31.232 ± 2.487	100.0	0.030 ± 0.001	0.55
Cu	14.683 ± 2.019	36.0	0.027 ± 0.012	0.05
Zn	98.325 ± 58.941	50.0	0.121 ± 0.030	3.0
Fe	16656.144 ± 1330.350	50000	2.098 ± 0.479	0.50

Source: Field Research Data, (2024).

4.3.1 Concentration of Heavy Metals in Wastewater

The mean concentrations of heavy metals in abattoir wastewater samples are summarized in Table 4.2. Among the analyzed metals, Fe exhibited the highest concentration (2.098 ± 0.479 mg/L), followed by Zn (0.121 ± 0.030 mg/L), Pb (0.099 ± 0.076 mg/L), Cr (0.030 ± 0.001 mg/L), and Cu (0.027 ± 0.012 mg/L). The overall decreasing trend of heavy metal concentrations can be described as Fe > Zn > Pb > Cr > Cu.

The Fe concentration of 2.098 mg/L significantly exceeds the WHO limit of 0.50 mg/L. This elevated level is concerning as Fe is not an essential element for plants at high concentrations and can lead to soil acidification and nutrient imbalances (Parveen *et al.*, 2015). Similar findings were reported by Jegede *et al.* (2022), who observed Fe concentrations up to 15.44 mg/L in abattoir wastewater, indicating a potential risk of environmental contamination. The Pb concentration of 0.099 mg/L exceeds the WHO limit of 0.065 mg/L. Pb is a non-essential and highly toxic metal that can accumulate in soils and plants, posing serious health risks to humans through the food chain (Ukom *et al.*, 2023). Similar concentrations have been reported in other studies, highlighting the need for stringent wastewater management practices.

The Cr concentration of 0.030 mg/L is well below the WHO limit of 0.55 mg/L. Cr is an essential element for plants in trace amounts; however, higher concentrations can be toxic. The current level does not pose an immediate risk but warrants monitoring. For Cu Concentration of 0.027 mg/L is below the WHO limit of 0.05 mg/L. Cu is an essential micronutrient for plants, but excessive levels can be toxic. The current concentration does not pose an immediate risk. The Zn concentration of 0.121 mg/L is well below the WHO limit of 3.0 mg/L. While Zn is an essential micronutrient for plants, excessive levels can be toxic. However, the current concentration does not pose an immediate risk.

Comparing these results with previous studies reveals a concerning trend. Kashua and Shanu (2010) reported Fe concentrations of 0.10 mg/L and Pb concentrations of 0.36 mg/L, both of which are lower than the levels observed in the current study.

However, more recent studies have reported higher concentrations. For instance, Oladipo, *et al.*, (2022) found Fe concentrations up to 3.806 mg/L and Cu up to 1.070 mg/L in abattoir wastewater, indicating deterioration in wastewater quality over time. The elevated concentrations of Fe and Pb in the abattoir wastewater from Ikwiriri raise significant concerns regarding environmental contamination. When used for irrigation, such wastewater can lead to the accumulation of these metals in soils and crops, posing health risks to humans through the food chain. The persistence of Pb in the environment and its potential for bioaccumulation make it particularly concerning (Majumder, *et al*., 2021).

The findings underscore the need for effective wastewater management practices at the Ikwiriri slaughterhouse. Without appropriate treatment, the discharge of untreated or partially treated wastewater can lead to environmental contamination and pose health risks to the local population. Implementing stringent wastewater treatment protocols and regular monitoring of heavy metal concentrations are essential to mitigate these risks.

4.3.2 Concentration of Heavy Metals in Soil

The concentrations of selected heavy metals (Pb, Cr, Cu, Zn, and Fe) in soils around the Ikwiriri slaughterhouse are summarized in Table 4.2. The results demonstrate a clear decreasing trend in mean concentrations in the following order: Fe > Zn > Cr > Cu > Pb. This pattern reflects the impact of abattoir effluent discharge on soil contamination and highlights the potential for uptake of these metals by edible plants cultivated nearby.

The mean concentration of chromium in the current study was 26.90 ± 4.03 mg/kg, which, although still below the WHO permissible limit, is significantly higher than the values reported in previous studies ranging from 0 to 4.5 mg/kg by Olusola *et al.* (2020), and 4.25 to 5.86 mg/kg by Chukwu and Anuchi (2016) in abattoir-contaminated soils. The elevated Cr levels in the current study suggest contamination from the use of cleaning agents, animal waste, and hide processing residues. Chromium is non-essential and toxic at elevated levels, its accumulation in the soil increases the risk of plant uptake and subsequent food chain transfer. The mean Cu concentration in the soil was 14.05 ± 2.53 mg/kg, falling within WHO limits slightly lower than the 18.88 ± 3.22 mg/kg reported by Helen *et al.* (2019). While copper is essential for plant metabolism, elevated levels often from blood and organ waste can become toxic over time. Although not immediately hazardous, its accumulation in soil warrants regular monitoring due to the risk of uptake by food crops.

Iron displayed the highest concentration in the soil, with a mean of 14,693.25 ± 2,203.99 mg/kg, substantially exceeding the levels reported previously 560.40 – 676.60 mg/kg by Chukwu and Anuchi (2016). Despite remaining below WHO permissible limits, such elevated Fe levels suggest significant accumulation from slaughterhouse activities, particularly blood and offal disposal. To contextualize, Kobbe, *et al.*, (2022) found similarly elevated iron concentrations in abattoir-impacted sub-soils in Nigeria, ranging from 556 to 739 mg/kg, compared to just 34.60 mg/kg in control soils. This underscores the need for regular monitoring, as excess iron while essential can disrupt soil microbial communities and long-term fertility.

The mean Pb concentration was 3.43 ± 0.65 mg/kg, higher than the levels reported by Ubwa, *et al.*, (2013) (0.185 – 1.676 mg/kg) and Helen, *et al.*, (2019) (0.91 ± 0.28 mg/kg), but lower than the concentrations observed by Yahaya, *et al.*, (2009) (15.60 – 30.09 mg/kg). Although within WHO's permissible limits, the non-degradable and toxic nature of lead is worrisome. Historical data from sediment cores in Dar es Salaam's Msimbazi estuary demonstrate that lead can accumulate and persist in soils over decades (Sawe, *et al.*, 2021). Prolonged exposure through consumption of contaminated vegetables may pose chronic health risks, particularly to vulnerable populations such as children and pregnant women. Continuous monitoring is essential to prevent potential bioaccumulation in the soil over time and to mitigate associated environmental and health risks.

The mean concentration of Zn in abattoir soil was 113.32 ± 21.53 mg/kg, exceeding WHO/TBS recommended limits for agricultural soils. This level is significantly higher than ranges reported in recent studies for example, Olatunji, *et al.*, (2018) recorded Zn concentrations between 20.5 and 35.7 mg/kg in abattoir soils, while Adeolu, *et al.*, (2020) found levels ranging from 5.3 to 12.8 mg/kg in similar environments. Although zinc is an essential micronutrient, elevated concentrations can cause phytotoxicity and increase uptake by vegetables through root and foliar absorption pathways (Mwamba, *et al.*, 2019). Persistent Zn contamination in abattoir-affected soils thus poses risks of bioaccumulation in crops and potential dietary exposure for nearby communities.

The concentration of heavy metals in soils surrounding abattoirs is influenced by various secondary wastes produced during slaughtering, including blood, fat, stomach contents, and processing chemicals. These contaminants can lead to elevated levels of metals such as zinc, copper, and iron in the soil. For instance, a study by Kobbe, *et al.,* (2022) reported increased concentrations of heavy metals in soils near the Bauchi Main Abattoir, Nigeria, highlighting the impact of abattoir waste on soil quality. Such elevated metal concentrations can adversely affect soil microbial communities, leading to reduced biodiversity and impaired soil fertility (Ogun, *et al.*, 2023). Furthermore, these metals can be absorbed by plants, entering the food chain and posing potential health risks to humans (Abbas *et al.*, 2023).

The analysis of vegetables cultivated near the Ikwiriri slaughterhouse revealed detectable concentrations of Pb, Cr, Cu, Zn, and Fe across all three species (*Cucurbita* sp., *Vigna* sp., and *Ipomoea* sp.) (Table 4.5). When compared against the FAO/WHO (2019) permissible limits, the results indicate that all heavy metal concentrations in vegetables remained below the recommended thresholds. Nevertheless, the observed variations among the different vegetables point to a potential influence of wastewater and soil contamination on heavy metal uptake.

The abattoir wastewater analysis revealed elevated concentrations of Pb (0.099 mg/L) and Fe (2.098 mg/L), both exceeding WHO (2011) permissible limits for irrigation water (0.065 mg/L and 0.5 mg/L, respectively). These elevated levels strongly suggest that wastewater used for irrigation is a major source of contamination for soils and subsequently vegetables. For instance, the relatively high Fe accumulation in *Vigna* sp. (96.109 ± 29.265 mg/kg) and *Cucurbita* sp. (58.991 ± 17.196 mg/kg) aligns with the high Fe content detected in wastewater. Similarly, Pb was present in vegetables at concentrations up to 0.158 ± 0.071 mg/kg (*Ipomoea* sp.), which, although below the FAO/WHO limit (0.3 mg/kg), reflects the elevated Pb in wastewater. This finding corroborates the view of Oladipo, *et al.,* (2022), who observed that abattoir effluent containing Pb and Fe significantly influenced vegetable uptake in downstream farms.

Soil analysis around the abattoir (Section 4.3) demonstrated elevated concentrations of Zn (98.325 ± 58.941 mg/kg) above the WHO/TBS permissible limit (50 mg/kg), while Pb, Cr, Cu, and Fe remained within allowable limits. This elevated Zn in soils corresponds directly with the relatively high Zn uptake in vegetables, particularly *Cucurbita* sp. (7.618 ± 0.082 mg/kg) and *Vigna* sp. (7.740 ± 0.928 mg/kg). Although these values remain well below the FAO/WHO threshold (100 mg/kg), they indicate bioaccumulation potential due to excessive Zn loading in the soil.

Interestingly, Cr levels in soils (31.232 ± 2.487 mg/kg) were below the permissible limit (100 mg/kg), yet vegetables still exhibited measurable Cr uptake (0.405–0.437 mg/kg). This suggests that even sub-threshold concentrations in soils, when combined with continuous exposure from wastewater, can lead to detectable accumulation in crops. Comparable findings were reported by Mapanda *et al.* (2007), who observed that irrigation with wastewater containing trace Cr concentrations led to measurable accumulation in edible plants.

Taken together, the results demonstrate that both abattoir wastewater and surrounding soils exert a significant influence on heavy metal levels in vegetables. Wastewater contributes more directly to Pb and Fe accumulation, while soil contamination plays a greater role in Zn uptake. The consistency of these findings with previous research (Jegede, *et al.*, 2022; Oladipo, *et al.*, 2022) reinforces the conclusion that continued irrigation with untreated abattoir effluent is a critical pathway for heavy metal entry into the food chain. Although current levels in vegetables remain within international safety limits, the combined contribution of wastewater and soil contamination indicates a potential long-term risk of bioaccumulation and subsequent health hazards if mitigation measures are not implemented.

4.4 Soil to Vegetable Transfer Factor (TF)

The soil to plant transfer factor for heavy metals Pb, Cr, Cu, Zn and Fe are summarized in the Table 4.3.

Table 4.3: Soil to Vegetable Transfer Factors of Selected Vegetables

Metal	**Soil to Vegetable Transfer Factor**		
	***Cucurbita* sp.**	***Vigna* sp.**	***Ipomoea* sp.**
Pb	0.322	0.196	0.423
Cr	0.018	0.014	0.006
Cu	0.157	0.082	0.083
Zn	0.077	0.079	0.031
Fe	0.004	0.007	0.001

Source: Field Research Data, (2024).

The TF values calculated in this study (Table 4.3) reflect the extent to which heavy metals from abattoir-contaminated soils are accumulated by the three selected vegetables *Cucurbita* sp., *Vigna* sp., and *Ipomoea* sp. The transfer factor heavy metals within each vegetable sample in descending order was *Cucurbita* sp. Pb > Cu > Zn > Cr > Fe, *Vigna* sp. Pb > Cu > Zn > Cr > Fe and *Ipomoea* sp. Pb > Cu > Zn > Cr > Fe.

Chromium recorded the lowest average TF (0.017), indicating limited mobility from soil to plant tissues. The low translocation rate may be attributed to Cr’s strong affinity to soil particles and low solubility in its trivalent form. This suggests that despite elevated Cr concentrations in the soil; its uptake by the studied vegetables is relatively restricted. However, caution is warranted as Cr can accumulate over time, especially in soils continuously irrigated with contaminated wastewater.

Lead exhibited a moderate TF on average 0.099, with the highest uptake in *Cucurbita* sp. (TF = 0.176) and the lowest in *Vigna* sp. (TF = 0.018). Lead (Pb) is typically known for its low bioavailability due to strong binding to organic matter and soil particles. Nevertheless, the moderate TF values observed here suggest potential uptake pathways, especially in soils with poor pH buffering or organic matter degradation from abattoir waste. Since Pb is highly toxic even at low concentrations, this warrants concern for chronic dietary exposure.

Coppe r (Cu) demonstrated a moderate TF value across all three vegetables with mean value 0.101. Although Cu is an essential micronutrient for both plants and humans, elevated levels may lead to phytotoxicity and oxidative stress in plants. *Cucurbita* sp. again showed the highest TF (0.131), suggesting its greater tendency for Cu uptake. The results imply that continuous cultivation in Cu-rich abattoir soils could increase its concentration in edible plant parts over time, emphasizing the need for routine monitoring.

Despite being the most abundant metal in soil, Fe showed a very low average TF (0.004). This supports the general understanding that iron, although essential, tends to remain bound in soil matrices and is poorly Tran located into above-ground tissues. The low TFs observed for Fe across all vegetable types suggest that the elevated soil Fe levels are unlikely to significantly influence Fe content in the edible portions of these vegetables. Zinc had a moderate TF of 0.067 on average, with *Cucurbita* sp. showing the highest uptake (0.116). Zn is an essential micronutrient, but excessive accumulation in plant tissues can lead to nutritional imbalances and toxicity, especially in humans consuming these vegetables regularly. The moderate TF values suggest active uptake from contaminated soils, highlighting Zn as a metal of concern where long-term soil accumulation and food chain transfer are involved.

Transfer factors (TFs) are pivotal in evaluating the bioavailability of heavy metals to plants, indicating the extent of metal mobility within soil-plant systems (Ali *et al.*, 2022). In this study, all calculated TF values were below 1, suggesting that the selected green leafy vegetables (*Cucurbita* sp., *Vigna* sp., and *Ipomoea* sp.) currently pose minimal risk of heavy metal contamination. Generally, TF values equal to or greater than 1 indicate a high potential for metal uptake by plants, which can lead to significant health risks upon consumption. In contrast, TF values below 1, as observed in this study, indicate limited translocation of metals from soil to plant tissues, implying relative safety for human dietary intake (Mwamba, *et al.*, 2019; Mirecki, *et al.*, 2015).

The efficiency of metal uptake, as represented by the TF, is influenced by a complex set of factors, including the physicochemical properties of the soil, the specific behavior of metals in the soil-plant interface, and local environmental conditions (Cervantes, *et al.*, 2018). Key soil characteristics such as pH, organic matter content, cation exchange capacity (CEC), soil texture, and clay content play critical roles in governing the mobility and bioavailability of heavy metals (Dube, *et al.*, 2011). For instance, acidic soils generally enhance metal solubility and uptake by plants, whereas alkaline conditions can reduce mobility through processes like precipitation and adsorption.

The results of this study revealed notable differences in the TF values among metals, pointing to varying levels of bioavailability. Lead showed the highest TF, followed copper suggesting these elements have a greater potential for uptake and accumulation in the edible parts of vegetables grown near the Ikwiriri slaughterhouse. Among the tested species, *Cucurbita* sp. exhibited the highest uptake potential across most metals, indicating a greater susceptibility to metal accumulation when compared to *Vigna* sp. and *Ipomoea* sp.

These findings underscore the significant influence of contaminated soil on metal levels in vegetables cultivated in close proximity to abattoirs. The observed trends emphasize the importance of proper soil management practices and the careful selection of crop species as potential mitigation strategies to reduce human exposure to heavy metals through dietary intake. Furthermore, the results highlight the necessity for ongoing monitoring of both soil and edible plants in areas where untreated abattoir wastewater is used for irrigation, to ensure food safety and protect public health.

4.5 Health Risk Assessments of Heavy Metals

This section evaluates the potential health risks associated with the consumption of *Cucurbita* sp., *Vigna* sp., and *Ipomoea* sp. by calculating the Average Daily Intake

(ADI) of selected heavy metals, Non-carcinogenic risk (hazard quotient) and hazard index (HI). This aligns with the third specific objective of the study: to determine human health risks due to consumption of vegetables contaminated by toxic heavy metals from abattoir waste.

4.5.1 Average Daily Intake (ADI) of heavy metals

The ADI values were calculated using metal concentrations in the edible portions of vegetables and standard consumption rates, and then compared to the Provisional Maximum Tolerable Daily Intake (PMTDI) recommended by WHO/FAO. The results are presented in Table 4.4.

Table 4.4: Average Daily Intake (ADI) for the Analyzed Vegetables (mg/day)

Vegetable	Cr	Cu	Fe	Pb	Zn
Cucurbita sp.	0.00187	0.01064	0.27212	0.00055	0.03514
Ipomoea sp.	0.00084	0.00563	0.07170	0.00073	0.01353
Vigna sp.	0.00202	0.00559	0.44334	0.00034	0.03570
MTDI (FAO/WHO (2011)) mg/day	0.3	30.0	45.0	0.0005	0.43

Source: Field Research Data, (2024).

In this study, the Average Daily Intake (ADI) of heavy metals was calculated solely through the ingestion pathway, based on the consumption of *Cucurbita* sp., *Vigna* sp., and *Ipomoea* sp. Among the three vegetables, the ADI for Pb decreased in the order: *Ipomoea* sp. > *Cucurbita* sp. > *Vigna* sp. The ADI of Pb, Cr, Cu, Zn and Fe ranged from 0.00073 to 0.00034 mg/kg/day, 0.00202 to 0.00084 mg/kg/day, 0.01064 to 0.00559 mg/kg/day, 0.03570 to 0.01353 mg/kg/day, and 0.44334 to 0.07170 mg/kg/day, respectively. Except for lead (Pb), the overall ADI through vegetable consumption remains largely within established safety thresholds as defined by the Maximum Tolerable Daily Intakes (MTDIs) from FAO/WHO (2011).

The ADI for lead (Pb) in this study ranged from 0.00073 to 0.00034 mg/day, in order of *Vigna* sp. > *Cucurbita* sp. > *Ipomoea* sp. The ADI for Pb in *Ipomoea* sp. (0.00073 mg/day) and *Cucurbita* sp. (0.00055 mg/day) exceeded the MTDI of 0.0005 mg/day by 46% and 10%, respectively. *Vigna* sp., with a Pb ADI of 0.00034 mg/day, remained within permissible limits. Although the absolute values are small, the fact that two of the three vegetables surpassed the recommended daily intake is of toxicological concern due to the cumulative nature and non-biodegradability of Pb (Li, *et al.*, 2017).

Similar ADI ranges have been reported in comparable environments impacted by abattoir activities. For instance, Adeolu, *et al.*, (2020) found Pb ADIs between 0.0005 and 0.0021 mg/day in vegetables irrigated with abattoir wastewater in southwestern Nigeria, reflecting comparable exposure levels. Likewise, Lema (2023) documented Pb ADIs up to 0.003 mg/day in urban vegetables from Dar es Salaam, Tanzania, reinforcing the risk of dietary Pb exposure near poorly managed wastewater facilities. These parallels underscore the importance of continuous monitoring and improved waste management to mitigate lead contamination and its associated health risks.

The ADI of chromium across the studied vegetables ranged from 0.00084 mg/day in *Ipomoea* sp. to 0.00202 mg/day in *Vigna* sp. all of which fall significantly below the FAO/WHO Maximum Tolerable Daily Intake (MTDI) of 0.3 mg/day (FAO/WHO, 2011). *Vigna* sp. exhibited the highest Cr uptake, but still contributed less than 1% of the MTDI. This indicates a negligible risk of chromium toxicity through the consumption of these vegetables. Comparable low-risk levels have been reported in urban farming studies across East Africa. Adeolu, *et al.*, (2020) found Cr ADIs in vegetables ranging from 0.0012 to 0.0029 mg/day in southwestern Nigeria, close to the findings of this study. Similarly, Mwamba, *et al.*, (2019) recorded Cr ADIs of up to 0.0025 mg/day in vegetables irrigated with wastewater. While Cr is an essential micronutrient in trace amounts, excessive intake particularly in the hexavalent form (Cr^{6+}) can be carcinogenic. However, the low levels observed in the current study suggest that the vegetables are safe for daily consumption with respect to Cr.

The ADI of copper (Cu) in this study ranged from 0.01064 to 0.00559 mg/day, which is significantly below the Provisional Maximum Tolerable Daily Intake (PMTDI) of 30 mg/day established by international guidelines. These levels suggest that the analyzed vegetables do not pose an immediate health risk from copper exposure. Copper is an essential trace element, playing critical roles in enzymatic functions, redox balance, iron metabolism, and connective tissue development (Skalnaya, *et al.*, 2018). Despite being well within the safe limit, continuous monitoring is still advised, especially near abattoirs, where bioaccumulation over time could alter exposure patterns. Comparable ADI levels have been documented in other recent studies. For example, Adeolu, *et al.*, (2020) reported Cu ADIs ranging between 0.006 to 0.010 mg/day in vegetables irrigated with wastewater from abattoirs in southwestern Nigeria, aligning closely with the present findings.

Similarly, Abbas, *et al.*, (2023) recorded Cu ADIs of 0.005 to 0.009 mg/day in vegetables grown in soils influenced by slaughterhouse discharge in Pakistan. These consistent results across diverse geographic locations affirm that Cu intake via vegetables is typically within acceptable limits, though site-specific risk assessments remain important for long-term public health safety.

Among the vegetables studied, *Vigna* sp. contributed the highest iron intake at 0.44334 mg/day, while the lowest intake was observed in *Ipomoea* sp. at 0.07170 mg/day. All values remain below the Provisional Maximum Tolerable Daily Intake (PMTDI) of 45.0 mg/day. Iron is crucial for hemoglobin formation, oxygen transport, and enzymatic activity; however, chronic overconsumption particularly in individuals with iron metabolism disorders such as hemochromatosis can lead to iron overload, resulting in liver, heart, and pancreatic damage (Abbaspour, *et al.*, 2014).

Comparable Fe exposure levels have been recorded in other studies near abattoir or industrial areas. Mwamba, *et al.,* (2019) reported Fe ADIs between 0.09 and 0.41 mg/day in leafy vegetables cultivated with wastewater in urban Zambia. Similarly, Abbas, *et al.,* (2023) found ADI values for Fe ranging from 0.07 to 0.49 mg/day in vegetables grown on abattoir-contaminated soils in Pakistan. These findings mirror the current study's outcomes and suggest that while Fe is not a critical concern at present levels, the potential for cumulative effects warrants periodic environmental and dietary risk assessments.

Zinc intake from the vegetables analyzed ranged between 0.03570 and 0.01351 mg/day, remaining significantly below the Provisional Maximum Tolerable Daily Intake (PMTDI) of 0.43 mg/day. Among studied vegetables *Vigna* sp. and *Cucurbita* sp. recorded the highest zinc intake at 0.0.03570 and 0.03514 mg/day respectively, while *Ipomoea* sp. showed the lowest intake at 0.01353 mg/day. All values remain below the PMTDI of 0.43 mg/day, indicating that the levels of Zn accumulated in these vegetables pose no immediate dietary risk. Zinc plays an essential role in immune regulation, enzyme activation, wound healing, and cell growth, making its presence in food vital for human health (Plum, *et al.*, 2010).

However, excessive accumulation can disrupt the balance of other trace elements like copper and iron, though this is not a concern at the current intake levels. Comparable findings have been reported in other recent studies. Abbas *et al.* (2023) found Zn ADIs ranging from 0.014 to 0.068 mg/day in vegetables grown on abattoir-impacted soils in Pakistan, which aligns closely with the present study. Similarly, Adeolu *et al.* (2020) observed Zn ADIs between 0.017 and 0.060 mg/day in leafy vegetables irrigated with abattoir wastewater in southwestern Nigeria. These consistent values across different geographical settings affirm that, despite the presence of Zn in abattoir wastewater and soils, bioaccumulation in edible crops remains within safe limits, provided that exposure is not prolonged or compounded by other environmental sources. It is important to note that while this study provides insight into the dietary exposure to heavy metals via vegetable ingestion, total human exposure may be higher if other routes such as inhalation or dermal contact with contaminated soil or water are considered. However, because the aim of this study was to assess health risks associated with consuming vegetables irrigated with abattoir wastewater, only the ingestion pathway was evaluated.

4.5.2 Hazard Quotient (HQ)

The non-carcinogenic health risks associated with exposure to the studied heavy metals through dietary ingestion of vegetables are presented in Table 4.5. This assessment focuses exclusively on the ingestion pathway, as the study did not evaluate other exposure routes such as dermal contact or inhalation.

Table 4.5: Non-carcinogenic Risk by Ingestion (HQ) of Heavy Metals in vegetables

Vegetable Species	Hazard Quotient (HQ)				
	Cr	**Cu**	**Fe**	**Pb**	**Zn**
Cucurbita sp.	0.6233	0.2660	0.3887	0.1375	0.1171
Ipomoea sp.	0.2767	0.1408	0.1024	0.1825	0.0451
Vigna sp.	0.6733	0.1398	0.6333	0.0850	0.1190
Mean HQ	0.5244	0.1822	0.3748	0.1350	0.0937

Source: Field Research Data, (2024).

The trend for Hazard Quotient (HQ) values for heavy metals via vegetable ingestion followed a descending order Cr > Fe >Cu > Pb > Zn. Lead (Pb) exposure through vegetable consumption shows moderate health concern, with HQ values ranging from 0.00850 to 0.1825 and an average of 0.1350. All these values remain below the non-carcinogenic risk threshold of 1. Lead is a persistent and highly toxic heavy metal known to adversely affect the nervous system, kidneys, and cardiovascular health, with especially detrimental effects in children and pregnant women due to its neurotoxic potential (Li, *et al.*, 2019).

Similar findings have been reported in recent studies: Tanzeem, *et al.*, (2022) observed Pb HQ values up to 0.65 in leafy vegetables irrigated with wastewater near slaughterhouses in Pakistan, highlighting comparable risk levels. Additionally, Okeke *et al.* (2021) documented Pb HQs ranging from 0.30 to 0.70 in vegetables from abattoir-affected soils in Southeast Nigeria, reinforcing concerns about Pb bioaccumulation in common food crops. These studies corroborate the potential health risks posed by Pb in areas affected by slaughterhouse effluents and emphasize the need for stringent monitoring and remediation efforts.

In this study, the non-carcinogenic health risk associated with Chromium (Cr) exposure through the consumption vegetables, HQ values were found to be 0.6233 for *Cucurbita* sp., 0.2767 for *Ipomoea* sp., and 0.6733 for *Vigna* sp., with a mean HQ of 0.5244 across the samples. According to the United States Environmental Protection Agency (USEPA), an HQ value less than 1 indicates that the estimated level of exposure is unlikely to cause adverse non-carcinogenic health effects over a lifetime of consumption. Thus, the observed HQ values suggest that consumption of these vegetables poses no immediate health threat from Chromium exposure. However, the relatively higher HQs observed for *Vigna* sp. and *Cucurbita* sp. (both >0.6) approach the threshold level and may be of concern under conditions of high consumption frequency, bioaccumulation, or combined exposure to multiple contaminants.

The consistently low HQ values across all vegetables point to either low total chromium levels in the soil or the prevalence of trivalent chromium (Cr^{3+}), which is essential in trace amounts for metabolic functions (Pavesi & Moreira, 2020). Similar findings were reported by Abbas, *et al.* (2023), who observed Cr HQ values ranging between 0.005 and 0.018 in vegetables cultivated near abattoir-contaminated fields in Pakistan. Additionally, Adeolu, *et al.* (2020) recorded Cr HQs from 0.006 to 0.021 in Nigerian vegetables irrigated with wastewater from slaughterhouses. These comparative studies support the current results, reinforcing that Cr intake through vegetables grown near abattoir sites is generally within safe limits, provided the contamination remains unchanged and chromium speciation favors less toxic forms. Nevertheless, because hexavalent chromium can occasionally form under oxidizing soil conditions, regular monitoring of both total chromium and its speciation is recommended to prevent potential long-term exposure risks especially in areas subject to industrial or slaughterhouse runoff.

Copper (Cu) exposure via vegetable consumption revealed low Hazard Quotient (HQ) values, ranging from 0.1398 to 0.2660, with a mean of 0.1822, which is well below the risk threshold of 1. These results suggest that Cu intake from vegetables poses minimal non-carcinogenic health risks to local populations. Copper is an essential micronutrient involved in enzymatic activity, iron metabolism, and immune function, but excessive intake may lead to gastrointestinal distress, liver toxicity, or disruptions in zinc absorption (WHO, 2021). However, the HQ values observed in this study indicate that current Cu levels in vegetables are within safe dietary limits and do not raise immediate health concerns. Similar findings were reported by Obi, *et al.,* (2022), who found Cu HQ values between 0.14 and 0.25 in leafy vegetables cultivated near a major abattoir site in Port Harcourt, Nigeria showing consistent patterns of low risk.

These studies suggest that copper presence in such environments is often influenced by natural background levels or moderate anthropogenic input, rather than acute contamination, especially in areas without heavy industrial activity. Although copper is less mobile in soil compared to other heavy metals, and its uptake by plants is generally well-regulated, continuous monitoring is still advised in abattoir-affected zones to detect any gradual accumulation that might result from prolonged effluent discharge or sludge deposition.

Zinc (Zn) showed the lowest Hazard Quotient (HQ) values among the analyzed heavy metals, ranging from 0.0451 to 0.1190, with a mean of 0.0937. These consistently low HQ values suggest a minimal health risk from zinc exposure through consumption of the studied vegetables. Zinc is an essential micronutrient crucial for immune function, enzymatic reactions, and growth, and its toxicity is generally low at dietary intake levels (Prasad, 2017).

The low HQ values observed imply that zinc contamination in these vegetables is not currently a cause for concern, likely reflecting natural background concentrations rather than contamination from abattoir activities. This pattern aligns with findings from Nkwunonwo *et al.* (2020), who reported relatively low HQ values for zinc in vegetables cultivated near abattoir waste disposal sites in Nigeria, contrasting with much higher HQs for lead and cadmium that often-exceeded safety thresholds, highlighting greater health risks from those metals.

Iron (Fe) exposure through vegetable consumption revealed moderate but acceptable HQ values, ranging from 0.1024 to 0.6333, with a mean of 0.3748. While all values are well below the non-carcinogenic risk threshold of 1, this range suggests a moderate level of exposure, particularly through *Vigna* sp., which exhibited the highest Fe accumulation among the analyzed vegetables. Iron is a crucial micronutrient involved in oxygen transport, enzymatic functions, and cellular metabolism, but excessive dietary intake especially in individuals with iron storage disorders like hemochromatosis can lead to organ damage, oxidative stress, and gastrointestinal disturbances (Pavesi & Moreira, 2020).

Comparable studies support these findings. Mohammed, *et al.* (2021) investigated iron exposure in vegetables grown near an abattoir in Kano, Nigeria, and reported HQ values ranging from 0.28 to 0.71, particularly elevated in legumes and leafy greens. Similarly, Dauda *et al.* (2022) observed HQs for Fe between 0.30 and 0.65 in vegetables irrigated with wastewater from a major slaughterhouse in Kaduna, Nigeria. These studies reinforce the idea that Fe accumulation is more likely in certain crop types, especially legumes and leafy vegetables, due to their efficient nutrient uptake systems.

The health risk assessment of heavy metals in vegetables grown near the abattoir revealed varying degrees of potential concern. While essential micronutrients such as copper, iron, and zinc were present at levels within safe limits and posed minimal risk, presence of non-essential and toxic metals like lead indicating significant long-term health risks, especially with chronic exposure. The likelihood of experiencing long-term carcinogenic effects increases with higher HQ values. This risk assessment method has been validated and deemed reliable by researchers (Tsafe *et al.,* 2012; Jena, *et al.,* 2012). However, the HQ method only considers exposure to heavy metals through vegetable consumption, excluding other routes such as dermal contact, soil ingestion, and the presence of agrochemicals and herbicides.

4.5.3 Hazard Index (HI)

The combined health risk from multiple heavy metals in the analyzed vegetable samples was assessed using the Hazard Index (HI). Table 4.8 presents the calculated overall HI values from hazard quotients and for each of the analyzed heavy metals (Pb, Cr, Cu, Zn and Fe) in the selected vegetables (*Cucurbita* sp., *Vigna* sp., and

Ipomoea sp.).

Table 4.6: Hazard Index (HI) Values for Heavy Metal Exposure from Selected Vegetables

Vegetable	**Hazard Index (HI)**
Cucurbita sp.	1.5327
Ipomoea sp.	0.7474
Vigna sp.	1.6504

Source: Field Research Data, (2024)

The non-carcinogenic health risks associated with heavy metal ingestion through vegetable consumption were evaluated using the Hazard Index (HI). The HI provides a cumulative measure of potential health impacts from simultaneous exposure to multiple metals. In this study, two analyzed vegetables exhibited HI values exceeding the safe threshold of 1, indicating potential health risks from long-term consumption.

Among the three vegetables assessed, *Vigna* sp. recorded the highest HI value of 1.6504 closely to *Cucurbita* sp. at 1.5327, and *Ipomoea* sp. has the lowest at 0.7474. The elevated HI in *Vigna* sp. and *Cucurbita* sp. was primarily attributed to chromium and iron. Although lead had lesser contributions, its presence further compounded the risk. These findings are consistent with studies from industrial and abattoir-adjacent areas in countries such as Pakistan, Ethiopia, Bangladesh, and Burkina Faso, where vegetables irrigated with contaminated water exhibited similar HI trends. For instance, Bambara, *et al.* (2023) reported HI values ranging from 0.8036 to 2.7064 in various vegetables grown near abattoirs in Burkina Faso.

In conclusion, the consistently elevated HI values across all analyzed vegetables suggest a significant health risk for consumers, particularly from lead and chromium contamination. The highest risk is associated with *Vigna* sp. and *Cucurbita* sp. than *Ipomoea* sp. grown in the area. These findings suggest that consumption of these vegetables may pose significant combined toxicity concerns requiring attention and mitigation measures.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the overall conclusion of the study, synthesizing the key findings related to heavy metal contamination in vegetables cultivated near abattoirs. It revisits the study's objectives, discusses the implications of the results, and evaluates whether the research questions have been adequately addressed. Additionally, the chapter provides practical recommendations for stakeholders including policymakers, farmers, and environmental agencies to help reduce exposure to heavy metals in food crops.

5.2 Conclusions

This study assessed the contamination levels of five heavy metals (Pb, Cr, Cu, Zn and Fe) in vegetables *Ipomoea* sp., *Cucurbita* sp. and *Vigna* sp., soils, and wastewater collected near the Ikwiriri slaughterhouse, and evaluated the associated human health risks due to vegetable consumption. The findings clearly demonstrate significant contamination and potential public health implications.

All three vegetable species *Cucurbita* sp., *Vigna* sp., and *Ipomoea* sp. accumulated heavy metals at varying levels. The presence of these metals in the edible portions of commonly consumed vegetables indicates bioaccumulation and potential dietary exposure risks. The abattoir wastewater contained excessively high concentrations of Pb, Cr, and Fe, all surpassing the permissible limits set by WHO for irrigation water. Although most heavy metal concentrations in the soil remained within acceptable limits, Zinc (Zn) exceeded the TBS threshold. Continued use of contaminated wastewater for irrigation is likely to cause long-term accumulation of heavy metals and soil degradation. The soil-to-plant transfer factors (TFs) revealed the highest uptake for Cd (average TF = 0.339) and the lowest for Fe and Cr, confirming the high mobility and bioavailability of Cd in the local environment.

The ADI values for Pb in *Ipomoea* sp. and *Cucurbita* sp. surpassed the Provisional Maximum Tolerable Daily Intake (PMTDI) recommended by WHO/FAO, indicating potential chronic exposure risks. Hazard Quotient (HQ) analysis identified Cr and Fe as the dominant contributors to health risks across all vegetables. Furthermore, the Hazard Index (HI) values for *Cucurbita* sp. and *Vigna* sp. exceeded the safe threshold of 1, indicating a cumulative non-carcinogenic risk from multi-metal exposure.

In conclusion, this research confirms that vegetables grown near the Ikwiriri slaughterhouse are significantly contaminated with toxic heavy metals particularly Pb posing a serious health risk to consumers due to cumulative exposure. The contamination primarily originates from untreated abattoir wastewater, which is used for irrigation of vegetables. These findings underscore the need for immediate interventions.

5.3 Recommendations

Considering the significant findings of this study and the prevalent practice of growing vegetables near the abattoir using abattoir waste and untreated wastewater for irrigation, it is essential to implement the following recommendations to safeguard environmental and public health:

i. To reduce heavy metal exposure, cultivation of vegetables that accumulate high levels of toxic metals, such as *Cucurbita* sp. and *Vigna* sp. should be restricted near the slaughterhouse. Focusing on crops which absorb fewer metals, can help lower health risks. Public education is important to encourage farmers to choose safer crops. Regular testing of vegetables in these areas must be conducted to monitor contamination levels. This approach helps limit the transfer of harmful metals to consumers.

ii. Regulatory authorities such as the National Environment Management Council (NEMC) and Ministry of Agriculture should enforce strict guidelines prohibiting the use of untreated abattoir wastewater for crop irrigation. Farmers should be educated and encouraged to use safe water sources or adopt rainwater harvesting where feasible.

iii. Proper treatment of slaughterhouse wastewater before irrigation is essential to protect the agricultural environment. Treatment must target the removal of heavy metals and other toxic substances to prevent contamination. Continuous monitoring of wastewater quality is needed to ensure safety standards are met. Additionally, exploring and promoting alternative irrigation water sources can further reduce contamination risks.

iv. Community health outreach programs should be conducted by responsible authorities to raise awareness about the potential risks associated with consuming contaminated vegetables. Awareness also must promote diversification of diet to reduce reliance on vegetables grown near the slaughterhouse, thereby lowering exposure risk.

5.4 Suggestion for Future Research

i. Future studies should investigate crop species that exhibit lower accumulation of heavy metals when grown in contaminated soils. Such research would help identify crops suitable for cultivation in areas affected by abattoir waste, thereby reducing human exposure and enhancing food safety.

ii. Future research should focus on developing and evaluating practical mitigation strategies to reduce heavy metal contamination in irrigation water, soils, and vegetables. Such studies would provide evidence-based approaches to manage contamination and protect environmental and human health in areas impacted by abattoir waste.

REFERENCES

Abbas, M. T., Wadaan, M. A., Ullah, H., Farooq, M., Fozia, F., Ahmad, I., Farooq Khan, M., Baabbad, A. and Ullah, Z. (2023). Bioaccumulation and mobility of heavy metals in the soil-plant system and health risk assessment of vegetables irrigated by wastewater. *Sustainability,* 15(21), 15321.

Abbaspour, N., Hurrell, R. and Kelishadi, R. (2014). Review on iron and its importance for human health. *Journal of Research in Medical Sciences,* 19(2), 164–174.

Abdullahi, A., Kadarman, N., Hassan, A. and Madobi, I. S. (2023). Negative impact of abattoir activities and management in residential neighbourhoods in Kuala Terengganu, Malaysia. *International Journal of Public Health Sciences (IJPHS),* 4(2), 124–130.

Abunna, F., Mideksa, C. and Terefe, G. (2017). Assessment of hygienic practices in meat handling and slaughterhouse operation in selected towns of Wolaita zone, southern Ethiopia. *Journal of Food Quality and Hazards Control,* 4(2), 35–42.

Achmad, R. T., Budiawan, B. and Ibrahim, A. E. (2017). Effects of chromium on human body. *Annual Research and Review in Biology,* 13, 1–8.

Adeniji, C. B., Sindiku, O. K. and Bakare, O. C. (2024). Quantification of heavy metals in soil and water samples from major abattoirs located in Ibadan, Oyo State, Nigeria. *Biological and Environmental Sciences Journal for the Tropics*, 21(3), 240–248.

Adeolu, O., Oladipo, O. and Alabi, O. (2020). Assessment of heavy metal contamination in soils and vegetables irrigated with abattoir wastewater in southwestern Nigeria. *Environmental Monitoring and Assessment,* 192(11), 729.

Adeyebo, O. K., Adeyemi, I. G. and Odunsi, O. O. (2019). Physicochemical, heavy metals, and microbial pollution of surface and ground water in Bodija municipal abattoir and its environments. *International Journal of Agriculture Environment and Biotechnology,* 4(6), 1720–1725.

Adeyemi, O. A., Oladipo, O. and Bello, T. S. (2019). Impact of abattoir waste on heavy metal contamination in soils and vegetables in Lagos, Nigeria. *Environmental Monitoring and Assessment,* 191(7), 437.

Adeyemo, O. K., Ayodeji, I. O. and Aiki-Raji, C. O. (2002). The water quality and sanitary conditions in a major abattoir (Bodija) in Ibadan, Nigeria. *Africa Journal of Biomedical Research,* 1-2, 51–55.

Adrees, M., Ali, S., Rizwan, M., Ibrahim, M., Abbas, F., Farid, M., Zia ur Rehman, M., Irshad, M. K. and Bharwana, S. A. (2015). The effect of excess copper on growth and physiology of important food crops: A review. *Environmental Science and Pollution Research,* 22(11), 8148–8162.

Agency for Toxic Substances and Disease Registry (ATSDR). (2007). Priority list of hazardous substances. U.S. Department of Health and Human Services, Public Health Service.

Agency for Toxic Substances and Disease Registry. (2007). *Toxicological profile for lead*. U.S. Department of Health and Human Services, Public Health Service.

Agoro, M. A., Adeniji, A. O. and Akinyemi, M. O. (2021). Human health risk assessment of heavy metals in vegetables cultivated with abattoir wastewater in Osogbo, Nigeria. *Environmental Nanotechnology, Monitoring and*

Management, 16, 100576.

Ali, H., Khan, E. and Ilahi, I. (2019). Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. *Journal of Chemistry*, 2019, 6730305.

Alloway, B. J. (Ed.). (2013). *Heavy metals in soils: Trace metals and metalloids in soils and their bioavailability* (3rd ed.). Environmental Pollution, **22**, 1–613. Springer.

Al-Wasify, R., Mahmoud, A., Ragab, S., Abdelaziz, I. and Hamed, S. (2019). A pilot model for slaughterhouse wastewater treatment using Moringaoleifera seed husks, pods and extract followed by aeration. *Journal of Engineering and Applied Science*, 14, 354–362.

Amoah, P., Drechsel, P., Henseler, M. and Abaidoo, R. C. (2007). Irrigated urban vegetable production in Ghana: Microbiological contamination in farms and markets and associated consumer risk groups. *Journal of Water and Health,* 5(3), 455–466.

Apostoli, P. and Catalani, S. (2011). Metal ions affecting reproduction and development. *Metal Ions in Life Science,* 8, 263–303.

Bambara, T. L., Derra, M., Kaboré, K., Tougma, K. A., Cissé, O. I. and Zougmoré, F. (2023). Levels of heavy metals in some vegetables and human health risk assessment in Loumbila area, Burkina Faso. *Open Journal of Applied Sciences,* 13(9), 1498–1511.

Burki, T. K. (2012). Nigeria's lead poisoning crisis could leave a long legacy. *Lancet,* 379(9818), 793.

Cervantes, C., Campos-García, J., Devars, S., Gutiérrez-Corona, F., Loza-Tavera, H., Torres-Guzmán, J. C. and Moreno-Sánchez, R. (2018). Interactions of heavy metals with plants: Physiological, biochemical and molecular responses. *International Journal of Molecular Sciences,* 19(8), 2240.

Chaoua, S., Boussaa, S., Gharmali, A. E. and Ennaji, M. M. (2019). Impact of irrigation with wastewater on accumulation of heavy metals in soil and crops in the region of Marrakech in Morocco. *Journal of the Saudi Society of Agricultural Sciences,* 18(4), 429–436.

Chen, H., Liu, W., Zhang, X., Chen, J. and Cao, Z. (2018). Human health risk assessment of heavy metals in vegetables grown in suburban areas of Xi'an, China. *Ecotoxicology and Environmental Safety,* 149, 45–51.

Chen, H., Teng, Y., Lu, S., Wang, Y. and Wang, J. (2020). Contamination features and health risk of soil heavy metals in China. *Science of The Total Environment,* 512, 143–153.

Chen, X., Liu, Y. and Guo, W. (2017). Effects of rhizosphere acidification and organic acid exudation on lead (Pb) bioavailability in contaminated soils. *Environmental Pollution,* 228, 1–9.

Chen, X., Liu, Y. and Huang, Y. (2022). Vulnerability of pregnant women and children to heavy metal toxicity: A systematic review. *Science of The Total Environment,* 807, 150785.

Chen, X., Yin, J., Wu, M. and Zhang, D. (2020). Long-term exposure to zinc oxide nanoparticles induces oxidative stress and inflammatory responses in rats. *Environmental Toxicology,* 35(3), 299–309.

Chowdhury, R., Ramond, A., O'Keeffe, L., Shahzad, S., Kunutsor, S. and Muka, T. (2018). Environmental toxic metal contaminants and risk of cardiovascular disease: Systematic review and meta-analysis. *BMJ,* 362, k3310.

Chukwu, U. J. and Anuchi, S. O. (2016). Impact of abattoir wastes on the physicochemical properties of soils within Port Harcourt metropolis. *International Journal of Engineering Science,* 5, 17–21.

Clottey, S. J. A. (1985). *Manual for the slaughter of small ruminants in developing countries* (3rd ed., FAO Animal Production and Health Paper No. 49, iii + 45 pp.). Rome: Food and Agriculture Organization of the United Nations.

Costa, M. (2019). Review of arsenic toxicity, speciation and polyadenylation of canonical histones. *Toxicology and Applied Pharmacology,* 375, 1–4.

Cuéllar, M. A., Hernández, L. M. and Rojas, A. (2021). Chromium uptake and tolerance mechanisms in leafy vegetables: Physiological and biochemical adaptations to chromium stress. *Environmental Science and Pollution Research,* 28(12), 14856–14868.

Damalas, C. A. and Eleftherohorinos, I. G. (2011). Pesticide exposure, safety issues, and risk assessment indicators. *International Journal of Environmental Research and Public Health,* 8(5), 1402–1419.

Dauda, M. A., Ibrahim, H. I. and Sulaiman, I. A. (2022). Risk assessment of heavy metal intake through consumption of vegetables grown near abattoir wastewater channels in Kaduna, Nigeria. *Tropical Environmental Research,* 10(1), 43–52.

Deng, Y., Wang, M., Tian, T., Lin, S., Xu, P., Zhou, L. and Zhu, Y. (2019). The effect of hexavalent chromium on the incidence and mortality of human cancers: A meta-analysis based on published epidemiological cohort studies. *Frontiers* *in Oncology,* 9, 24.

Dube, S., Ngole-Jeme, V. M. and Gushit, J. S. (2011). Heavy metal contamination in soil and vegetation around a cement factory in north-central Nigeria. *Journal of Environmental Chemistry and Ecotoxicology,* 3(1), 12–20.

Dubeaux, G., Neveu, J., Zelazny, E. and Vert, G. (2015). Polar localization of the iron transporter IRT1 in *Arabidopsis* roots is essential for efficient iron uptake. *The New Phytologist,* 208(4), 1104–1115.

Ebong, G. A., Ettesam, E. S. and Dan, E. U. (2020). Impact of abattoir wastes on trace metal accumulation, speciation, and human health–related problems in soils within Southern Nigeria. *Air, Soil and Water Research,* 13, 1–10.

Elemile, O. O., Raphael, D. O., Omole, D. O., Oloruntoba, E. O., Ajayi, E. O. and Ohwavborua, N. A. (2019). Assessment of the impact of abattoir effluent on the quality of groundwater in a residential area of Omu-Aran, Nigeria. *Environmental Sciences Europe,* 31, Article 16.

Elin, R. J. (2018). Assessment of zinc status in humans. *Journal of Trace Elements in Medicine and Biology,* 46, 232–237.

Eze, E. J. and Phil-Eze, P. O. (2020). Abattoir effluents and population health risks. *Journal of Environmental Science, Toxicology and Food Technology,* 14(4), 49–52.

Fan, M. Z., Wu, Y. F., Zhao, L. Y., Fu, L. N., Deng, L. L., Deng, J. R., … Peng, S. (2017). Physiological and transcriptional changes of three citrus rootstock seedlings under iron deficiency. *Frontiers in Plant Science,* 8, 1104.

FAO. (2001). *Guidelines for humane handling, transport and slaughter of livestock*. Food and Agriculture Organization of the United Nations. FAO.

FAO. (2013). *Water reuse for agriculture: The regional overview of practices, constraints, and perspectives in the Near East*. Food and Agriculture Organization of the United Nations. FAO.

FAO/WHO (Food and Agriculture Organization/World Health Organization). (2011). *Joint FAO/WHO Food Standards Programme – Codex Committee on Contaminants in Foods. Fifth Session, Working Document on Metals*, The Hague, Netherlands.

FAO/WHO. (2018). *Exposure assessment of chemical contaminants in food*. FAO Food and Nutrition Paper No. 112.

Food and Agriculture Organization and World Health Organization. (2019). General standard for contaminants and toxins in food and feed: Maximum levels of lead in leafy vegetables (Codex Alimentarius Standard).

Food and Agriculture Organization of the United Nations. (2001). Informal food sector and its implications for food safety management in Sub-Saharan Africa. In *Food safety in Africa: Issues and options* (pp. 45–59).

Grace, D., Mutua, F., Ochungo, P., Kruska, R., Jones, K., Brierley, L. and Randolph, T. (2015). *Mapping of poverty and likely zoonoses hotspots*. International Livestock Research Institute (ILRI).

Granero, S. and Domingo, J. L. (2002). Levels of metals in soils of Alcalá de Henares, Spain: Human health risks. *Environmental International,* **28**(3), 159–164.

Gupta, N., Yadav, K. and Kumar, V. (2021). Heavy metals and human health: Mechanistic insight into toxicity and counter defense system of antioxidants. *Environmental Science and Pollution Research,* 28(14), 17222–17232.

Hanafiah, M. M., Zainuddin, M. F., Mohd Nizam, N. U., Halim, A. A. and Rasool, A. (2020). Phytoremediation of aluminum and iron from industrial wastewater using *Ipomoea aquatica* and *Centella asiatica*. *Applied Sciences, 10*(9), 3064.

Hassan, J., Rajib, M. M. R., Khan, M. N., Khandaker, S., Zubayer, M., Ashab, K. R. and Rahman, M. M. (2024). Assessment of heavy metals accumulation by vegetables irrigated with different stages of wastewater for evaluation of food and health risk. *Journal of Environmental Management,* 353, 120206.

Hassana, A. and Nuradeen, L. T. (2021). Evaluation of the efficiency of constructed activated carbon for the treatment of abattoir wastewater. *Science World Journal,* 16(2), 172–178.

Helen, S. E., Ebong, G. A. and Dan, E. U. (2019). Metal accumulation and risk assessment of abattoir wastes in soil and leafy vegetables. *European Academic Research,* 6, 5806–5833.

Honest, A., Manyele, S. V., Saria, J. A. and Mbuna, J. (2020). Assessment of the heavy metal levels in the incinerators bottom-ash from different hospitals in Dares Salaam. *African Journal of Environmental Science and Technology,* 14(11), 347–360.

Jacobs, D. E., Wilson, J., Dixon, S. L., Smith, J. and Evens, A. (2009). The relationship of housing and population health: A 30-year retrospective analysis. *Environmental Health Perspectives,* 117(4), 597–604.

Jalali, M. and Meyari, A. (2022). Heavy metal contents, soil-to-plant transfer factors, and associated health risks in vegetables grown in western Iran. *Journal of Food Composition and Analysis,* 106, 104316.

Jardine, P. M., Kidd, R., Blowes, D. W. and Waska, H. (2013). Chromium redox transformations in contaminated soils and their influence on bioaccessibility. *Environmental Science and Technology,* 47(22), 12324–12332.

Jegede, A. V., Akinola, M. O. and Okeowo, M. A. (2022). Levels of selected heavy metals in abattoir effluents and their impact on water quality of Ogun River, Nigeria. *African Journal of Environmental Science and Technology,* 16(5), 198–208.

Jena, M. K., Lenka, S. and Mishra, M. (2012). Health risk assessment of heavy metals in vegetables from industrial areas of Odisha, India. *Environmental Monitoring and Assessment,* 184(9), 5957–5967.

Kabata-Pendias, A. (2010). *Trace elements in soils and plants* (4th ed., 548 pp.). Boca Raton, FL: CRC Press.

Kacholi, D. S. and Sahu, M. (2018). Levels and health risk assessment of heavy metals in soil, water, and vegetables of Dar es Salaam, Tanzania. *Journal of Chemistry,* 1402674, 9 pages.

Kacholi, D. S., Sahu, O. and Mtoni, Y. A. (2017). Heavy metal contamination and human health risk assessment in leafy vegetables grown in Temeke district, Tanzania. *International Journal of Environmental Research and Public Health,* 14(4), 381.

Kashua, D. A. and Shanu, S. O. (2010). Assessment of heavy metals in wastewater from abattoirs in Nigeria. *Nigerian Journal of Environmental Health,* **7**(2), 45–53.

Keraita, B., Jiménez, B. and Drechsel, P. (2008). Extent and implications of agricultural reuse of untreated, partly treated, and diluted wastewater in developing countries. *CAB Reviews: Perspectives in Agriculture, Veterinary*

Science, Nutrition and Natural Resources, 3(058), 1–15.

Khan, S., Cao, Q., Zheng, Y. M., Huang, Y. Z. and Zhu, Y. G. (2018). Health risk assessment of heavy metals in vegetables collected from production areas in Beijing, China. *Food Chemistry*, 263, 247–254.

Khan, S., Cao, Q., Zheng, Y., Huang, Y. and Zhu, Y. G. (2017). Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. *Environmental Pollution*, 152(3), 686–692.

Kianoush, S., Balali-Mood, M., Mousavi, S. R., Moradi, V., Sadeghi, M. and Dadpour, B. (2012). Comparison of therapeutic effects of garlic and d-penicillamine in patients with chronic occupational lead poisoning. *Basic and Clinical Pharmacology and Toxicology*, 110(5), 476–481.

Kianoush, S., Balali-Mood, M., Mousavi, S. R., Shakeri, M. T., Dadpour, B., Moradi, V. and Sadeghi, M. (2013). Clinical, toxicological, biochemical, and hematologic parameters in lead-exposed workers of a car battery industry. *Iranian Journal of Medical Sciences*, 38(1), 30–37.

Kianoush, S., Sadeghi, M. and Balali-Mood, M. (2015). Recent advances in the clinical management of lead poisoning. *Acta Medica Iranica*, 53, 327–336.

Kihampa, C. and Mwegoha, W. J. S. (2010). Assessment of heavy metal contamination in urban agricultural soils of Dar es Salaam, Tanzania. *Tanzania Journal of Science*, 36(2), 59–68.

King, J. C. and Cousins, R. J. (2014). Zinc. In A. C. Ross, B. Caballero, R. J. Cousins, K. L. Tucker, and T. R. Ziegler (Eds.), *Modern nutrition in health and disease* (11th ed., pp. 189–205). Baltimore, MD: Lippincott Williams and Wilkins.

Kobbe, A. I., Hassan, U. F., Baba, N. M. and Baba, H. (2025). Comparative evaluation of the levels of selected heavy metals and index of pollution status of the sub-soil of Bauchi Main Abattoir, Bauchi State, Nigeria. *Journal of Agricultural and Environmental Science Research*, **7**. Retrieved on 12th May, 2025 from; https://hummingbirdjournals.com/jaesr/article/view/303.

Kumar, V., Bharti, P. K., Talwar, M., Tyagi, A. K. and Kumar, P. (2017). Studies on high iron content in water resources of Moradabad district (UP), India. *Water Science*, 31(1), 44–51.

Lema, M. W. (2023). Heavy metal pollution in soil, water and vegetables in Dar es Salaam – Tanzania. *Tanzania Journal of Agricultural Sciences*, 22(2, Special Issue).

Li, X., Zhang, H. and Zhou, D. (2019). Heavy metal contamination and health risk assessment of vegetables from suburban areas of Shenyang, Northeast China. *Environmental Monitoring and Assessment*, 191(3), 159.

Li, Y., Chen, X., Zhang, X. and Zhang, X. (2020). Heavy metal contamination and human health risk assessment in vegetables grown in a wastewater irrigated area. *Environmental Science and Pollution Research*, 27, 21709–21720.

Li, Y., Ye, Z. and Tang, H. (2017). Lead exposure and its impact on health: A review. *Environmental Toxicology and Pharmacology*, 50, 1-10.

Li, Z., Li, H. and Zhang, H. (2019). Health risk assessment of heavy metals in vegetables from industrial areas in China. *Ecotoxicology and Environmental Safety*, 169, 59–66.

Liu, J., Ma, L. and Zhou, Q. (2019). Influence of root exudates on the bioavailability of heavy metals in the rhizosphere: A review. *Environmental Science and*

Pollution Research, 26(7), 6700–6713.

Liu, Y., Ma, L. and Zhou, Q. (2019). Effects of rhizosphere organic acids on lead mobility and plant absorption in contaminated soils. *Journal of Hazardous Materials*, 366, 721–728.

Loomis, D., Grosse, Y., Lauby-Secretan, B., El Ghissassi, F., Bouvard, V., Benbrahim-Tallaa, L. and Straif, K. (2018). The carcinogenicity of outdoor air pollution. *The Lancet Oncology*, 14(13), 1262–1263.

Loomis, D., Guha, N., Hall, A. L. and Straif, K. (2018). Identifying occupational carcinogens: an update from the IARC monographs. *Occupational and Environmental Medicine*, 75(8), 593–603.

Majumder, A. K., Nayeem, A. A., Islam, M., Akter, M. M. and Carter, W. S. (2021). Critical review of lead pollution in Bangladesh. *Journal of Health and Pollution*, 11(31), Article 210902.

Mapanda, F., Mangwayana, E. N., Nyamangara, J. and Giller, K. E. (2007). The effect of long-term irrigation using wastewater on heavy metal contents of soils under vegetables in Harare, Zimbabwe. *Agriculture, Ecosystems and Environment*, 118(1-4), 237–248.

Mensah, A. K., Nartey, D. and Tetteh, E. K. (2019). Influence of organic waste amendments on soil iron bioavailability and accumulation in vegetables. *Journal of Environmental Management*, 241, 421–428.

Mimmo, T., Schmid, C., Allegretta, I., Feller, U. and Cesco, S. (2014). Copper and iron uptake by wheat plants as affected by root exudates and their synthetic analogues. *Environmental and Experimental Botany*, 105, 105–112.

Mimmo, T., Schmid, C., Allegretta, I., Feller, U. and Cesco, S. (2014). Copper and iron uptake by wheat plants as affected by root exudates and their synthetic analogues. *Environmental and Experimental Botany*, 105, 105–112.

Mohammed, A. I., Ahmed, A. A. and Dauda, T. E. (2020). Determination of levels of heavy metals and physicochemical parameters in wastewater of Kasuwan Shanu abattoir, Maiduguri. *Journal of Chemistry Letters*, *1*(2), 84–88.

Mohammed, S. A., Umar, M. and Abdullahi, A. S. (2021). Assessment of heavy metals and associated health risks in vegetables cultivated with abattoir wastewater in Kano State, Nigeria. *Environmental Health Research*, 21(3), 198–208.

Mozhiarasi, V. and Natarajan, T. S. (2022). Slaughterhouse and poultry wastes: Management practices, feedstocks for renewable energy production, and recovery of value-added products. *Biomass Conversion and Biorefinery*, 12(2), 1705–1728.

Mwamba, V. L., Nyambe, I. and Phiri, E. (2019). Uptake of heavy metals by leafy vegetables grown in urban agriculture: Implications for human health. *Journal of Environmental Science and Health, Part B*, 54(4), 320–329.

Nagraj, S. K., Naresh, S., Srinivas, K., George, R. P., Shetty, N. and Levenson, D. (2017). Interventions for managing taste disturbances. *Cochrane Database of Systematic Reviews*, 12, CD010470.

Naves, L. C., Souza, G. M., Lima, L. D. M., Barbosa, L. L. and Dutra, F. (2020). Informal slaughter of animals and risks to public health: An integrative review. *Brazilian Journal of Veterinary Medicine*, 42(1), e00220.

Ng, M., Dalhatou, S., Wilson, J., Kamdem, B. P., Temitope, M. B., Paumo, H. K., Djelal, H., Assadi, A. A., Nguyen-Tri, P. and Kane, A. (2022).

Characterization of slaughterhouse wastewater and development of treatment techniques: A review. *Processes*, 10(7), 1300.

Nguyen, T. P. and Lee, J. (2020). Advances in environmental risk assessment methodologies for human health. *Science of the Total Environment*, 712, 136384.

Nkwunonwo, U. C., Ijeoma, C. N. and Chibueze, M. C. (2020). Heavy metal contamination and health risk assessment of vegetables cultivated around abattoir waste disposal sites in Nigeria. *Environmental Science and Pollution Research*, 27(30), 37632–37644.

Obi, C. J., Okonkwo, C. C. and Dike, E. A. (2022). Evaluation of heavy metal uptake and risk assessment in edible vegetables grown near Port Harcourt abattoirs. *Journal of Environmental Science and Public Health*, 6(2), 115–125.

Odetola, L., Sills, S. and Morrison, S. A. (2021). A pilot study on the feasibility of testing residential tap water in North Carolina: Implications for environmental justice and health. *Journal of Exposure Science and Environmental Epidemiology*, 31(6), 972 - 978.

Ogun, A. A., Ojo, O. A. and Akinmoladun, O. F. (2023). The impacts of abattoir waste on soil and water quality: A review. *International Journal of Research and Innovation in Applied Science*, 8(1), 1-6.

Okeke, P. U., Ogbu, U. C. and Ofor, C. M. (2021). Assessment of heavy metals contamination and health risk evaluation in vegetables grown near abattoir wastewater discharge in Nigeria. *Environmental Monitoring and Assessment*, 193(4), 234.

Oladipo, O. T. and Akinola, O. O. (2021). Assessment of heavy metal contamination in abattoir wastewater and associated soils: Implications for agricultural use. *Environmental Science and Pollution Research*, 28, 5548–5560.

Olatunji, O. O., Oyedele, D. J. and Akinola, O. (2018). Heavy metal pollution in soils surrounding abattoir wastewater discharge points in Nigeria. *Journal of Soil Science and Environmental Management*, 9(9), 158–166.

Olusola, J. A., Akintan, O. B. and Adeyemi, M. O. (2020). Index of pollution status in soil and health risk assessment of heavy metals in vegetable crops of a municipal abattoir. *Journal of Materials and Environmental Science*, 11(8), 1250 – 1263.

Oluwatosin, G., Adeoyolanu, A., Ojo, A., Are, K., Dauda, T. and Aduramigba-modupe, V. (2010). Heavy metal uptake and accumulation by edible leafy vegetable (Amaranthus hybridus) grown on urban valley bottom soils in Southwestern Nigeria. *Soil and Sediment Contamination*, 19, 1 - 20.

Oluwole, S. O., Makinde, O. S. C., Yusuf, K. A., Fajana, O. O. and Odumosu, A. O. (2013). Determination of heavy metal contaminants in leafy vegetables cultivated by the roadside. *International Journal of Engineering Research and Development*, 7(3), 1-5.

Olynyk, J. K. and Ramm, G. A. (2022). Hemochromatosis. *New England Journal of Medicine*, 387(23), 2159–2170.

Opaluwa, O. D., Aremu, M. O., Ogbo, L. O. and Oyekunle, J. A. O. (2012). Heavy metal concentrations in soils, plant leaves and crops grown around dump sites in Lafia Metropolis, Nasarawa State, Nigeria. *Advances in Applied Science Research*, 3(2), 780–784.

Oruonye, E. D. (2015). Challenges of abattoir waste management in Jalingo

Metropolis, Nigeria. *International Journal of Research in Geography*, **1**(2), 22 - 31.

Osibanjo, O. and Adie, G. U. (2007). Impact of effluent from Bodija abattoir on the physicochemical parameters of Oshunkaye stream in Ibadan City, Nigeria. *African Journal of Biotechnology*, 6, 1806 - 1811.

Osu, C. I. and Okereke, V. C. (2015). Heavy metal accumulation from abattoir wastes on soils and some edible vegetables in selected areas in Umuahia metropolis. *International Journal of Current Microbiology and Applied Sciences*, 4, 1127 - 1132.

Othman, O. C. (2001). Heavy metals in green vegetables and soils from vegetable gardens in Dar es Salaam, Tanzania. *Tanzania Journal of Science*, 27, 37 - 48.

Pavesi, T. and Moreira, J. C. (2020). Mechanisms and individuality in chromium toxicity in humans. *Journal of Applied Toxicology*, 40, 1183–1197.

Porter, J. L., & Rawla, P. (2023). Hemochromatosis. In *StatPearls*. Retrieved November 21, 2024, from https://www.statpearls.com/point-of-care/22724.

Prasad, A. S. (2017). Zinc in human health: Effect of zinc on immune cells. *Molecular Medicine*, 22(1), 1-10.

Sawe, S. F., Shilla, D. A. and Machiwa, J. F. (2021). Lead (Pb) contamination trends in Msimbazi estuary reconstructed from ^{210}Pb-dated sediment cores. *Environmental Forensics*, 22(1-2), 99-107.

Sharma, P., Mishra, R. and Kumar, V. (2019). Metal uptake mechanisms in plants: Root morphology, transpiration, and physiological adaptations for metal sequestration. *Environmental Pollution*, 245, 1071-1080.

Sharma, R. K. and Tripathi, B. D. (2017). Ecological and health risk assessment of heavy metals in urban soils and plants of Varanasi, India. *Environmental Monitoring and Assessment*, 189 (6), 286.

Sharma, V., Sharma, R. and Sharma, R. K. (2017). Zinc toxicity: A comprehensive review. *International Journal of Environmental Health Research*, 27(2), 98-106.

Singh, A., Agrawal, M., & Marshall, F. M. (2019). Impact of sewage sludge and wastewater irrigation on heavy metal accumulation in soil and plants. *Environmental Monitoring and Assessment,* 191(9), 618.

Skalnaya, M. G., Skalny, A. V., Grabeklis, A. R. and Tinkov, A. A. (2018). Copper: Contemporary scientific views on its role in human health. *Biological Trace Element Research,* 186(1), 8–17.

Tang, M., Lu, G., Fan, B., Xiang, W. and Bao, Z. (2021). Bioaccumulation and risk assessment of heavy metals in soil-crop systems in Liujiang karst area, southwestern China. *Environmental Science and Pollution Research,* 28, 9657–9669.

Tanzeem, A., Akhtar, N., & Hussain, A. (2022). Heavy metals accumulation in vegetables irrigated with wastewater near slaughterhouses: A case study from Pakistan. *Journal of Environmental Management,* 300, 113694.

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K. and Sutton, D. J. (2018). Heavy metal toxicity and the environment. *EXS,* 101, 133–164.

Tsafe, A. I., Tijjani, M. N., Abubakar, M. B. and Muhammad, F. S. (2012). Health risk assessment of heavy metals in food crops grown along major highways in Northwestern Nigeria. *International Journal of Science and Research,* **3**(3), 28–32.

Ubwa, S. T., Atoo, G. H., Offem, J. O., Abah, J. and Asemave, K. (2013). Effect of activities at Gboko abattoir on some physical properties and heavy metals levels of surrounding soil. *International Journal of Chemistry, 5*(1), 49–57.

Ullah, A. K. M. A., Maksud, M. A. S. R., Khan, L. N. and Lutfa, S. B. (2017). Dietary intake of heavy metals from eight highly consumed species of cultured fish and possible human health risk implications in Bangladesh. *Toxicology Reports, 4*, 574–579.

United Republic of Tanzania. (2019). Health data overview for the United Republic of Tanzania. Retrieved on 23rd 2023 from https://data.who.int/countries/834.

United State Environmental Protection Agency. (1996). Method 3015A: Microwave assisted acid digestion of aqueous samples and extracts. *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* (SW-846).

United States Environmental Protection Agency. (2011). *Exposure factors handbook: 2011 edition* (EPA/600/R-09/052F). Washington, DC: U.S. Environmental Protection Agency. .https://www.epa.gov/sites/default/files/2015-09/documents/exposure_factors_handbook_2011.pdf

United States Environmental Protection Agency. (2019). *Guidelines for human health risk assessment* (EPA/630/R-14/002F). .https://www.epa.gov/risk/guidelines-human-health-risk-assessment

United States Environmental Protection Agency. (2021). *Risk assessment guidance for superfund: Human health evaluation manual (Part A)* (EPA/540/1-89/002). Office of Emergency and Remedial Response. https://www.epa.gov/sites/default/files/2015-09/documents/rags_a.pdf.

United States Environmental Protection Agency. (2022). *Preservation and handling* *of water samples for metals analysis*. https://www.epa.gov/sites/default/files/2022-03/documents/preservation_ handling_water_samples_metals.pdf.

Vincent, J. B. (2017). New evidence against chromium as an essential trace element. *Journal of Nutrition,* 147(12), 2212–2219.

Vincent, J. B. (2019). Effects of chromium supplementation on body composition, human and animal health, and insulin and glucose metabolism. *Current Opinion in Clinical Nutrition and Metabolic Care,* 22(6), 483–489.

Wang, L. and Chen, H. (2019). Toxicity and bioaccumulation of heavy metals in aquatic organisms: A review. *Environmental Toxicology and Pharmacology,* 69, 90–97.

Waters, B. M., Blevins, D. G. and Eide, D. J. (2002). Characterization of iron-regulated transporter 1 (IRT1) in *Arabidopsis thaliana*: A dual role in iron and zinc uptake. *Plant Molecular Biology,* 50(6), 955–967.

World Health Organization, & Food and Agriculture Organization. (2013). *Guidelines for the safe use of wastewater and foodstuff* (Technical Report, Vol. 2, No. 1). WHO/FAO Joint Report, Geneva, Switzerland.

World Health Organization. (2015). *WHO estimates of the global burden of foodborne diseases*. https://www.who.int/publications/i/item/9789241565165.

World Health Organization, (2021). *Copper in drinking-water: Background document for development of WHO guidelines for drinking-water quality*. https://www.who.int/publications/i/item/9789240020668.

World Health Organization, (1996). *Permissible limits of heavy metals in soil and plants*. Geneva: World Health Organization.

World Health Organization. (2011). *Guidelines for drinking water quality* (4th Ed.).

WHO, Geneva, Switzerland.

World Health Organization. (2020). *Guidelines for food safety*. World Health Organization. https://www.who.int/news-room/fact-sheets/detail/food-safety

Xu, X., Xu, Y., Chen, H. and Zhou, D. (2018). Ecological and health risks of heavy metals in soil-vegetable systems near industrial areas. *Science of The Total Environment*, 613–614, 1183–1193.

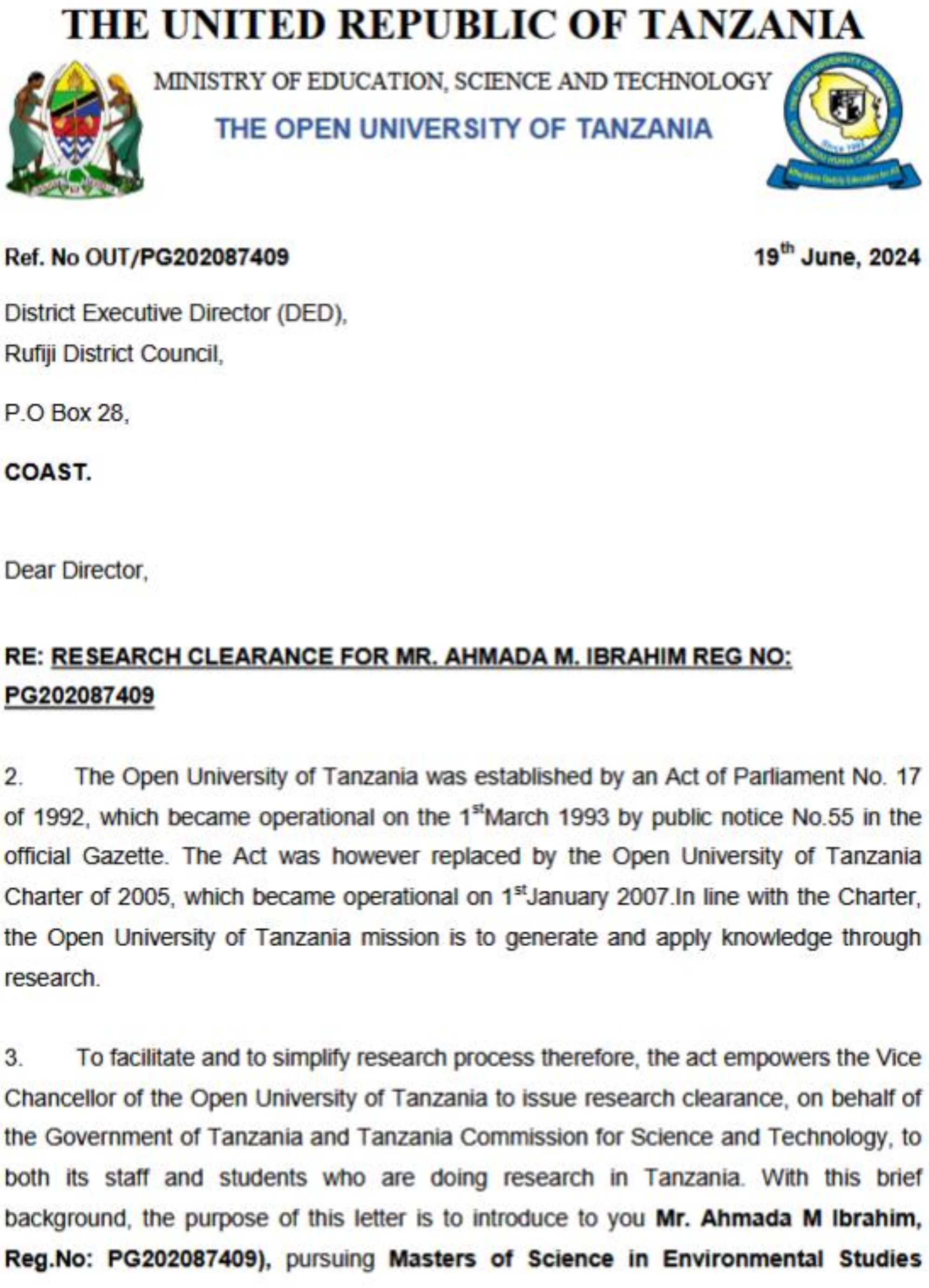
Yahaya, M. I., Mohammad, S. and Abdullahi, B. K. (2009). Seasonal variations of heavy metals concentration in abattoir dumping site soil in Nigeria. *Journal of Applied Sciences and Environmental Management*, 13, 9–13.

Zhang, W. and Wang, L. (2020). Toxic effects of heavy metals on human health and remediation approaches: A review. *Environmental Research*, 187, 109502.

Zulfiqar, U., Haider, F. U., Ahmad, M., Hussain, S., Maqsood, M. F., Ishfaq, M., Shahzad, B., Waqas, M. M., Ali, B., Tayyab, M. N., Ahmad, S. A., Khan, I. and Eldin, S. M. (2023). Chromium toxicity, speciation, and remediation strategies in soil-plant interface: A critical review. *Frontiers in Plant Science*, 13, 1081624.

APPENDIX

CLEARANCE LETTERS



THE UNITED REPUBLIC OF TANZANIA
MINISTRY OF EDUCATION, SCIENCE AND TECHNOLOGY
THE OPEN UNIVERSITY OF TANZANIA

Ref. No OUT/PG202087409 **19th June, 2024**

District Executive Director (DED),
Rufiji District Council,

P.O Box 28,

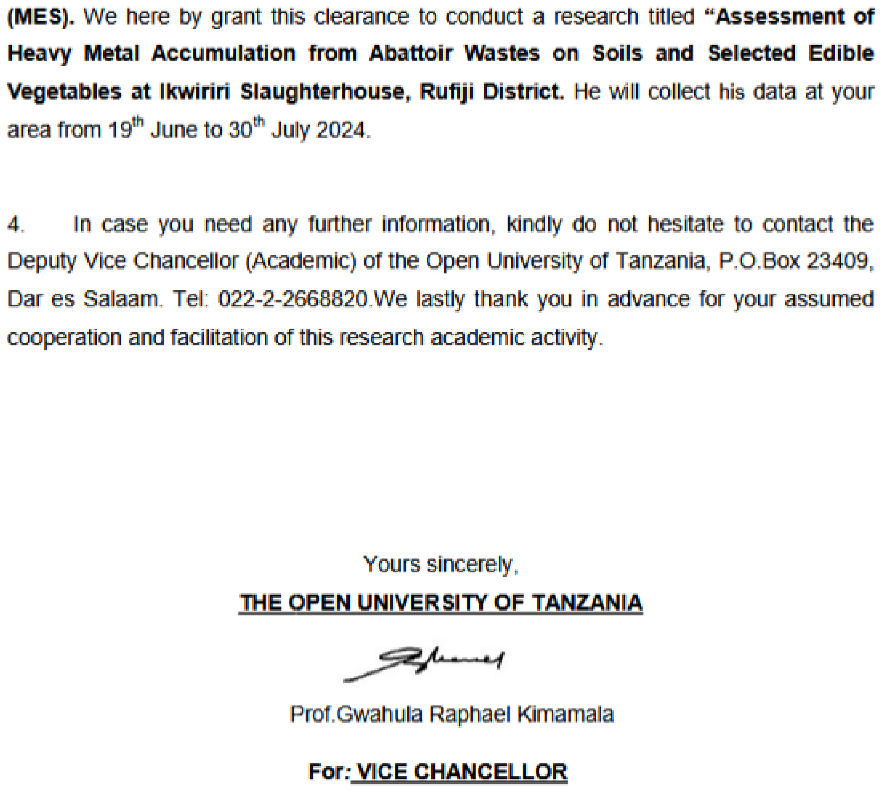
COAST.

Dear Director,

RE: RESEARCH CLEARANCE FOR MR. AHMADA M. IBRAHIM REG NO: PG202087409

2. The Open University of Tanzania was established by an Act of Parliament No. 17 of 1992, which became operational on the 1stMarch 1993 by public notice No.55 in the official Gazette. The Act was however replaced by the Open University of Tanzania Charter of 2005, which became operational on 1stJanuary 2007.In line with the Charter, the Open University of Tanzania mission is to generate and apply knowledge through research.

3. To facilitate and to simplify research process therefore, the act empowers the Vice Chancellor of the Open University of Tanzania to issue research clearance, on behalf of the Government of Tanzania and Tanzania Commission for Science and Technology, to both its staff and students who are doing research in Tanzania. With this brief background, the purpose of this letter is to introduce to you **Mr. Ahmada M Ibrahim, Reg.No: PG202087409)**, pursuing **Masters of Science in Environmental Studies**



(MES). We here by grant this clearance to conduct a research titled **"Assessment of Heavy Metal Accumulation from Abattoir Wastes on Soils and Selected Edible Vegetables at Ikwiriri Slaughterhouse, Rufiji District.** He will collect his data at your area from 19th June to 30th July 2024.

4. In case you need any further information, kindly do not hesitate to contact the Deputy Vice Chancellor (Academic) of the Open University of Tanzania, P.O.Box 23409, Dar es Salaam. Tel: 022-2-2668820.We lastly thank you in advance for your assumed cooperation and facilitation of this research academic activity.

Yours sincerely,

THE OPEN UNIVERSITY OF TANZANIA

Prof.Gwahula Raphael Kimamala

For: VICE CHANCELLOR