

**ASSESSMENT OF HEAVY METAL CONCENTRATION IN
AGRICULTURAL LAND NEAR HEAVY INDUSTRIAL AREAS IN
WELKOM, FREE STATE**

LEBOHANG KLAAS LETSITSA

A thesis submitted in fulfilment of the requirements for the degree

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Supervisor: Dr K. Lebelo

DECLARATION

DECLARATION WITH REGARD TO INDEPENDENT WORK

I, Lebohang Klaas Letsitsa, student number (_____), do hereby declare that this research report is my work. It is submitted for the master's degree in environmental health at the Central University of Technology, Free State. It has not been submitted before for any degree or examination at this or any other university.

SIGNATURE OF STUDENT

DATE

ABSTRACT

Background: Food safety concerns arise from heavy metal contamination in the environment. This contamination comes from anthropogenic sources like urban and industrial waste, mining, and metallurgy. Through food consumption, toxic trace metals such as lead, cadmium, arsenic, and mercury can enter the human diet, causing health problems with prolonged exposure. People collecting vegetables near waste sites are at greater risk. Crops like maize, which are staples for millions worldwide, can absorb heavy metals from soil contamination from industrial pollution, mining, and contaminated fertilizers and pesticides. This study aims to assess the level of heavy metal exposure and potential health risks associated with consuming maize grown on agricultural land near mines in the Welkom area.

Methodology: A human health risk assessment was conducted to determine the hazard quotient and hazard index for the non-carcinogenic effects of the selected maize crops. This was achieved through an experimental method that helped to determine the exposure limits of the detected heavy metals in the selected samples. A quantitative research technique was applied to prioritize quantification in data collection and analysis. Sixteen maize samples were collected separately from four distinct groups of farmlands, and an ICP-OES Spectrometer was used to determine the target metals in the maize samples.

Results: The health risk assessment was conducted using EDI and THQ to assess the potential health risks associated with heavy metal exposure. The Hazard Index estimate indicates that consuming maize poses a non-carcinogenic risk. The concentration of Arsenic (As) in maize was above the maximum limit of 0.1 mg/kg in all farm groups. The concentration of Cadmium (Cd) in maize was below the maximum limit for all farm groups except one. The Lead (Pb) concentration in Farm Group 2 slightly increased, which may have been caused using fertilizers and pesticides. The average HQ of heavy metals in all farm groups was lower than 1, indicating no potential adverse carcinogenic health effects. This may be due to good agricultural practices, location away from heavy industries and polluted land, and the use of treated water, environmentally friendly fertilizers, and pesticides.

Conclusion: This study has both experimental and theoretical implications. The study can guide government policymaking, inform farming practices, and educate consumers about food safety, thereby promoting public health and sustainable agriculture. It serves as a call to action for researchers, practising Environmental Health Practitioners, and environmentalists to delve deeper into environmental exposures, particularly focusing on food safety at the early stages of

the food production chain. Furthermore, assessing heavy metal exposure in maize crops grown on agricultural land near heavy industrial areas is a critical issue that demands attention.

RESEARCH DRAFT MANUSCRIPTS

Journal articles:

1. Heavy metal degradation and catalysis on various media in polluted agricultural land: A food safety and human health perspective. A review (*Draft manuscript*).
2. The heavy metal compliance assessment of maize samples from selected farms in the Welkom area using ICP-OES: Human health risk assessment (*Draft manuscript*).

DEDICATION

To God, my source of strength and guidance, you have been my constant companion throughout this difficult journey. In times of doubt and uncertainty, you have provided me with the resilience to persevere. Your divine presence has given me solace and the courage to face each challenge head-on.

To my late aunt Lerato and cousin Kenny Khoarane, whose vibrant spirits continue to resonate within me, I dedicate this dissertation to honour your memory and the profound impact you had on my life.

To my loving parents, your belief in my abilities and unconditional love has been my foundation. To my dearest partner, you have been my pillar of strength throughout this demanding journey.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CDC	Centre for Disease Control
CDI	Chronic Daily Intake
CNS	Central Nervous System
EDI	Estimated Daily Intake
EHP	Environmental Health Practitioner
FDA	Food and Drug Administration
HI	Hazard Index
HM	Heavy Metals
HQ	Hazard Quotient
ESA	Eastern and Southern Africa
ICP-OES	Inductively coupled plasma optical emission spectrometry
NM	Nanomaterials
NP	Nanoparticles
POP	Persistent Organic Pollutants
SSA	Sub-Saharan Africa
SEM-EDS	Scanning Electron Microscopy with Energy Dispersive X-Ray Spectrometer
THQ	Total Hazard Quotient
WHO	World Health Organization

CHAPTER 1: INTRODUCTION

1.1. Background

Pollution is a major global issue that impacts air, water, and soil negatively through physical, chemical and biological changes. This affects the lives of both people and animals (Al-othman, Ali, Al-othman & Ali 2016). Environmental pollution causing heavy metal contamination accumulation is a serious food safety issue (Gebeyehu, Danno & Id 2020; Srivastava et al. 2017). One serious food safety issue caused by environmental pollution is the accumulation of heavy metal contamination. Heavy metal toxicity poses a significant environmental health problem due to its potential to bioaccumulate through the food chain, affecting both livestock and humans (Sathyamoorthy *et al.*, 2016; Xiao *et al.*, 2018). In recent years, heavy metals have been detected in soil, water, aquatic life, vegetables, fruits, and other food crops due to population growth, urbanization, and other anthropogenic activities. Heavy metals can cause serious health problems in humans, particularly young children, due to their long-term accumulation in the body and organs. As a result, it is important to take the necessary steps to mitigate the effects of heavy metals in the environment (Ohiagu, Chidoka & Ahaneku 2022; Dessie, Robele, Mihret, Desta & Mehari 2021).

Mines, metallurgical industries, urban and industrial wastes, and mining contaminate urban vegetable cultivation (Kumar, Soo, Zhang, Fai & Kim 2019; Singbo 2012). A significant amount of harmful trace metals can be ingested through the food we eat, and over time this can lead to disruptions in the human body. To reduce the risk of exposure to toxic trace metals, it is important to be mindful of the food one consumes and where it comes from. Eating locally sourced, organic food and avoiding processed foods can help to reduce the risk of exposure to these metals. Additionally, investing in a water filter can help to reduce the amount of these metals present in drinking water (Lion and Olowoyo, 2013; Jaishan et al., 2014). Vegetables are a vital part of human diet and nutrition, consumed both raw and cooked, and play a vital role in African households' customs, traditions, and food culture (Lion and Olowoyo, 2013; Lv et al., 2019; Gebeyehu et al., 2020; Danno and Id, 2020). Vegetables are eaten as a primary food source and can be consumed raw or cooked (Sharma & Kaur 2019; Moura et al. 2015).

As the population grows, there is an urgent need to balance it with increased food production, particularly in developing nations (Muedi 2018; Lam, Remais, Fung, Xu & Sun 2013). However, in urban areas, agricultural lands are often located near industrial sites. People living

nearby may rely on backyard farming for household vegetables or collect vegetables near waste sites. (Lion & Olowoyo 2013). This can lead to the accumulation of heavy metals such as lead, cadmium, arsenic, and mercury in the soil. These metals can be taken up by plants like maize through their roots and leaves, potentially contaminating the food chain (Aladesanmi, Oroboade & Osisiogu 2019; Ekpa, Palacios-rojas, Kruseman, Fogliano & Linnemann 2018). Contamination of maize and agricultural soil with heavy metals is a food safety concern (Afonne & Ifediba 2020; Gu et al. 2019), and this can lead to the accumulation of toxic heavy metals in food crops, which can cause serious health problems such as neurological disorders, organ damage, and cancer (Jabeen, Aslam and Salman, 2018; Liang et al., 2019; Ohiagu et al., 2022).

Agricultural soil can become contaminated with heavy metals from various sources, including industrial pollution, mining activities, and the use of contaminated fertilizers and pesticides (Cuo, Peñaloza, Orellana & Aguilar-cáceres 2021; Liang et al. 2019; Ebadi, Shariatifar, Moazzen & Nazmara 2018). Once in the soil, these metals can be taken up by crops like maize, which is a staple food for millions of people worldwide (Balconi et al. 2022; Huma, Yuesuo, Hussain & Ning 2019; Stevens & Madani 2016; Suleiman & Rosentrater 2015). In addition, heavy metal contamination in maize and other food crops can also lead to trade restrictions and impact the economy of the affected regions (Amponsah, Kong & Abendin 2021; Haggblade, Me-nsope & Staatz 2017). It is crucial to ensure that agricultural soil is free from heavy metals and that crops are regularly tested for safety. Heavy metal contamination in maize can lead to reduced yield, poor quality, and toxicity concerns for human consumption (Romdhane et al. 2021).

1.2. Problem statement

Heavy metal pollution is a major environmental and food safety concern caused by industrialization processes. Agricultural heavy metal pollution poses a threat to human health. Ideally, food-producing farms should be monitored regularly to measure their exposure to contaminants. However, the extent of heavy metal pollution in industrial towns such as Welkom is uncertain. This requires robust studies to compare concentrations of heavy metals concerning the permissible limits as per the regulations on the maximum allowable limits for heavy metals in food. Therefore, efforts to address heavy metal contamination in maize and agricultural soil include improving soil management practices, reducing industrial pollution, and promoting the safe disposal of hazardous waste.

1.2.1. Aim

The study aimed to assess the level of heavy metal exposure and potential health risks associated with consuming maize crops grown on agricultural land near mines in the Welkom area. Additionally, it aimed to carry out an assessment of the risk to human health to determine the hazard quotient and hazard index for the non-carcinogenic effects of the selected maize crops.

1.2.2. Hypothesis

Hypothesis (H_0): Maize crops grown on agricultural land near industrial areas exceed permissible limits for heavy metal concentrations in food. The permissible limits for these heavy metals are as follows: Arsenic is 0.1mg/kg, Cadmium is 0.1mg/kg, Lead is 0.2mg/kg, and Copper is 4.0mg/kg. Any values above these limits are considered non-permissible.

Null hypothesis (H_a): Maize crops grown on agricultural land near industrial areas have heavy metal concentrations below the permissible limits for heavy metals in food.

(Human health risk assessment)

Null hypothesis (H_0): The hazard quotient and hazard index for the non-carcinogenic effects of the selected maize crops are within safe limits.

Alternative hypothesis (H_a): The hazard quotient and hazard index for some maize crops' non-carcinogenic effects exceed acceptable levels, suggesting possible health hazards.

1.2.3. Research Questions

What are the concentrations of heavy metals and what are their toxicological effects in selected farmlands within the Welkom area?

Sub-Questions

- What are the concentrations of heavy metals in maize crops selected from four farmlands located near industrial areas?
- How do the concentrations of heavy metals found in these maize crops compare to the exposure limits set by South African health and safety regulations?
- What are the potential toxicological effects on humans due to exposure to these heavy metals through the consumption of the selected maize crops?

1.2.4. Objectives

- Determine heavy metal concentrations in selected maize crops grown on the four farmlands near industrial areas.
- Compare the heavy metal concentrations found with the South African exposure limits.
- Examine the toxicological effects of human exposure to heavy metals from the intake of selected maize crops.

1.2.5. Inclusion and Exclusion criteria

Inclusion criteria

- Maize farms located near industrial areas of Welkom with a high risk due to the runoff of heavy metals that can finally accumulate on the farm.
- Maize farms that produce white and yellow types of maize.

Exclusion criteria

- Maize farms that are far from the industrial areas are not included. The focus is primarily on agricultural lands near mines, as these areas are more likely to be affected by heavy metal contamination due to industrial activities.
- Farms that produce poultry and meat products.

1.3. Significance of the research

This study examines the excessive accumulation of heavy metals in agricultural soil from mining regions, which can lead to diminished maize quality and safety. It also identifies measures to eradicate agricultural soil contamination, which is crucial, since plant uptake is a major pathway for heavy metals to invade the food chain. The research highlights the need for effective, efficient, low-cost, and eco-friendly absorbents for heavy metal removal from waste and soil due to industrial and anthropogenic activities that contaminate crops. Moreover, this study emphasizes the importance of ensuring permissible concentrations of elements in agricultural soil to protect crops and the food chain.

1.4. Thesis structure

This thesis consists of six chapters. The chapter titles are listed in Table 1 below.

Table 1: Titles of the research.

<i>Chapters</i>	<i>Titles</i>
<i>Chapter 1</i>	Introduction
<i>Chapter 2</i>	Literature Review
<i>Chapter 3</i>	Methodology
<i>Chapter 4</i>	Results
<i>Chapter 5</i>	Discussion
<i>Chapter 6</i>	Conclusion

1.5 References

- Afonne, OJ & Ifediba, EC. 2020. Heavy metals risks in plant foods – need to step up precautionary measures. *Current Opinion in Toxicology*. 22:1–6. doi.org/10.1016/j.cotox.2019.12.006.
- Al-othman, ZA, Ali, R, Al-othman, AM & Ali, J. 2016. Assessment of toxic metals in wheat crops grown on selected soils , irrigated by different water sources. *Arabian Journal of Chemistry*. 9:S1555–S1562. doi.org/10.1016/j.arabjc.2012.04.006.
- Aladesanmi, OT, Oroboade, JG & Osisiogu, CP. 2019. Bioaccumulation Factor of Selected Heavy Metals in Zea mays. 9(24).
- Amponsah, R, Kong, X & Abendin, S. 2021. The Impact of Maize Trade on the Development of the Maize Industry in Ghana. 1906–1931. doi.org/10.4236/ojbm.2021.94103.
- Balconi, C, Dinis, I, Revilla, P, Alves, ML, Andelkovi, V, Mendes-moreira, P, Redaelli, R, Ignacio, J, et al. 2022. Traditional Foods From Maize (Zea mays L .) in Europe. 8(January). doi.org/10.3389/fnut.2021.683399.
- Cuo, M, Peñaloza, R, Orellana, E & Aguilar-cáceres, MA. 2021. Heavy Metals and Arsenic in Soil and Cereal Grains and Potential Human Risk in the Central Region of Peru Heavy Metals and Arsenic in Soil and Cereal Grains and Potential Human Risk in the Central Region of Peru. (January). doi.org/10.12911/22998993/129255.
- Dessie, BK, Robele, S, Mihret, A, Desta, AF & Mehari, B. 2021. Heliyon Determination and health risk assessment of trace elements in the tap water of two Sub-Cities of Addis Ababa , Ethiopia. *Heliyon*. 7(April):e06988. doi.org/10.1016/j.heliyon.2021.e06988.
- Ebadi, A, Shariatifar, N, Moazzen, M & Nazmara, S. 2018. Determination of heavy metal content of processed fruit products from Tehran ’ s market using ICP- OES : A risk assessment

study. 115(March):436–446.

Ekpa, O, Palacios-rojas, N, Kruseman, G, Fogliano, V & Linnemann, AR. 2018. Sub-Saharan African maize-based foods : Technological perspectives to increase the food and nutrition security impacts of maize breeding programmes. *Global Food Security*. 17(January):48–56. doi.org/10.1016/j.gfs.2018.03.007.

Gebeyehu, HR, Danno, L & Id, B. 2020. Levels of heavy metals in soil and vegetables and associated health risks in Mojo area ,. 1–22.

Gu, Q, Yu, T, Yang, Z, Ji, J, Hou, Q, Wang, L & Wei, X. 2019. Prediction and risk assessment of five heavy metals in maize and peanut : A case study of Guangxi , China. *Environmental Toxicology and Pharmacology*. 70(March):103199. doi.org/10.1016/j.etap.2019.103199.

Haggblade, S, Me-nsope, NM & Staatz, JM. 2017. Food security implications of staple food substitution in Sahelian West Africa. *Food Policy*. 71:27–38. doi.org/10.1016/j.foodpol.2017.06.003.

Huma, B, Yuesuo, Y, Hussain, M & Ning, C. 2019. Scholar Journal of Applied Sciences and Research Human Benefits from Maize. 2:2(2).

Jabeen, F, Aslam, A & Salman, M. 2018. Heavy Metals Toxicity and Associated Health Risks in Vegetables Grown under Soil Irrigated with Sewage Water. 6(5):173–180. doi.org/10.13189/ujar.2018.060505.

Kumar, P, Soo, S, Zhang, M, Fai, Y & Kim, K. 2019. Heavy metals in food crops : Health risks , fate , mechanisms , and management. *Environment International*. 125(February):365–385. doi.org/10.1016/j.envint.2019.01.067.

Lam, H, Remais, J, Fung, M, Xu, L & Sun, SS. 2013. Food supply and food safety issues in China. *The Lancet*. 381(9882):2044–2053. doi.org/10.1016/S0140-6736(13)60776-X.

Liang, G, Gong, W, Li, B, Zuo, J, Pan, L & Liu, X. 2019. Analysis of heavy metals in foodstuffs and an assessment of the health risks to the general public via consumption in Beijing, China. *International Journal of Environmental Research and Public Health*. 16(6). doi.org/10.3390/ijerph16060909.

Lion, GN & Olowoyo, JO. 2013. South African Journal of Botany Population health risk due to dietary intake of toxic heavy metals from *Spinacia oleracea* harvested from soils collected in and around Tshwane , South Africa ☆. *South African Journal of Botany*. 88:178–182. doi.org/10.1016/j.sajb.2013.07.014.

Moura, FF De, Miloff, A, Boy, E, Moura, FFDE, Miloff, A & Boy, E. 2015. Retention of Provitamin A Carotenoids in Staple Crops Targeted for Biofortification in Africa : Retention

of Provitamin A Carotenoids in Staple Crops Targeted for Biofortification in Africa : Cassava , Maize , and Sweet Potato. 8398. doi.org/10.1080/10408398.2012.724477.

Muedi, L. 2018. Environmental Contamination Environmental Contamination by by Heavy Heavy Metals Metals. doi.org/10.5772/intechopen.76082.

Ohiagu, FO, Chidoka, P & Ahaneku, CC. 2022. Human exposure to heavy metals : toxicity mechanisms and health implications. doi.org/10.15406/mseij.2022.06.00183.

Romdhane, L, Panozzo, A, Radhouane, L, Cortivo, CD, Barion, G & Vamerali, T. 2021. Root Characteristics and Metal Uptake of Maize (*Zea mays* L .) under Extreme Soil Contamination.

Sathyamoorthy, K, Sivaruban, T & Barathy, S. 2016. Assessment of heavy metal pollution and contamination in the cattle meat. 32(1):350–355.

Sharma, A & Kaur, A. 2019. Contamination of vegetables with heavy metals across the globe : hampering food security goal. *Journal of Food Science and Technology*. doi.org/10.1007/s13197-019-04053-5.

Singbo, A. 2012. *Analyzing Efficiency of Vegetable Production in Benin*.

Srivastava, V, Sarkar, A, Singh, S, Singh, P, de Araujo, ASF & Singh, RP. 2017. Agroecological responses of heavy metal pollution with special emphasis on soil health and plant performances. *Frontiers in Environmental Science*. 5(OCT):1–19. doi.org/10.3389/fenvs.2017.00064.

Stevens, T & Madani, K. 2016. Future climate impacts on maize farming and food security in Malawi. *Nature Publishing Group*. (November):1–14. doi.org/10.1038/srep36241.

Suleiman, R & Rosentrater, K. 2015. Current maize production, postharvest losses and the risk of mycotoxins contamination in Tanzania’.

Xiao, W, Ye, X, Zhang, Q, Chen, D, Hu, J & Gao, N. 2018. Evaluation of cadmium transfer from soil to leafy vegetables: Influencing factors, transfer models, and indication of soil threshold contents. *Ecotoxicology and Environmental Safety*. 164(March):355–362. doi.org/10.1016/j.ecoenv.2018.08.041.

CHAPTER 2: LITERATURE REVIEW

Heavy metal degradation and catalysis on various media in polluted agricultural land: A food safety and human health perspective: A review.

L.K. Letsitsa¹ and K. Lebelo¹

¹Central University of Technology, Free State, Department of Life Sciences, Private Bag X20539, Bloemfontein, 9301, South Africa

ABSTRACT

Heavy metal pollution is associated with environmental contamination and is a global public health concern. Studies have shown high levels of heavy metal soil contamination on land in the vicinity of heavy metal industries such as mining and petroleum industries. Vegetables are irrigated with untreated wastewater discharged from industries and these heavy metals move to plant tissues and the surface of fresh vegetables. In this review, data from 1,056 documents published between 2019 and 2023 was independently extracted and sourced from the Web of Science core collection databases. The documents, which included original articles, reviews, proceedings papers, and early-access papers, were searched using specific terms. The heavy industry's impact on the environment is significant, with mining being a major economic activity that changes the local landscape significantly. Catalysis processes can be used to mitigate the presence of heavy metals in food. Today, catalytic technology continues to evolve and expand through evolving technologies. This review aims to explore the impact of heavy metals from heavy industries on human health and further discusses how catalytic technologies can be used to protect the environment.

Keywords: agriculture, catalysis, heavy metals, industries, maize, mining, photocatalysis, vegetables

Corresponding author: lletsisa@cut.ac.za

2.1. Introduction

In recent decades, heavy metal pollution in the environment and food has emerged as a significant concern due to its harmful effects on human health and ecosystems (Briffa, Sinagra

& Blundell 2020; Zhang, Zhong, Liu & Ouyang 2015). Metals such as lead, cadmium, mercury and arsenic can accumulate in living organisms, leading to severe health complications and ecosystem disruption. Human activities, including mining, smelting and other metal-based industries, are the primary sources of heavy metal pollution. Metals can also leach from landfills, waste dumps, and excretion from livestock and poultry, as well as runoff from automobiles and roadworks (Suhani, Sahab, Srivastava & Singh 2021; Kumar, Prasad, et al. 2019; Sandeep, Vijayalatha & Anitha 2019). Pesticides, insecticides, and fertilizers in agriculture are another source of heavy metal pollution (Briffa et al., 2020; Qin et al., 2021). Heavy metals may enter the body through a variety of routes, including ingestion, skin contact, inhalation, and intake of contaminated food. When soil is utilized to cultivate crops or grains, the main route of exposure is through eating (Qin et al. 2021; Zhang et al. 2015). Plants absorb heavy metals from contaminated soil through their roots and transfer them to their seeds. The combination of soil contamination with heavy metals and the decreasing availability of arable land poses a significant threat to food security (Qin et al. 2021; Zhang et al. 2015).

Nanotechnologies have been used to improve food safety and quality in the food industry. For example, antibacterial essential oil emulsions and films have been developed to sterilize food (P.L. Wang et al., 2019; Nong et al., 2020). In addition, nano-assembly has been used to create high-efficiency preservatives and growth regulators for controlling food shelf-life and ripening. Sensitive nano-sensors have also been designed to detect potentially dangerous or unknown chemicals in food, hence increasing food preservation and safety (P.L. Wang et al., 2019; Nong et al., 2020; Qin et al., 2021).

Another way to mitigate heavy metal pollution is catalytic technologies. These technologies employ catalysts, which facilitate chemical reactions without consumption. Catalysts can be made from organic or inorganic materials and are often engineered on the nanoscale to enhance their efficiency (P.L. Wang et al., 2019; Hou et al., 2020). By using catalytic processes, it is possible to remove heavy metals from contaminated environments and reduce their levels in food, thereby protecting human health and maintaining ecological balance (Hou et al. 2020).

Pollutants in soil, water, and groundwater can accumulate and enter the human body through the food chain (Briffa et al., 2020; Rajmohan, Chandrasekaran and Varjani, 2020). Therefore, it is essential to efficiently remove pollutants from water to protect the environment and human health. Various techniques, including precipitation, membrane filtration, adsorption, oxidation-reduction, degradation, ion exchange, and transformation, are used to remove pollutants from

water or to solidify or immobilize them (Lyu, Zhang & Shen 2020; Rawtani, Khatri, Tyagi & Pandey 2018).

Photocatalytic degradation is an effective strategy for in-situ decontamination of persistent organic pollutants (POPs) and the reduction of metal ions. This reduces the concentration of organic contaminants and immobilizes heavy metal ions on solid particles. Fixation of heavy metals in soil can reduce bio-availability and harm from human exposure (De Andrade et al., 2015; Bhavya et al., 2021; Lu et al., 2022). Biochar, which is made by burning organic resources including wood, chicken manure, and agricultural residues, can be used as a soil supplement to lessen environmental concerns associated with polluted locations (Lu et al. 2022; Qin et al. 2021). Its application is simple and can increase soil carbon content, improving soil fertility. Green nanotechnology advances have shown the potential to degrade or detoxify pollutants using bio-fabricated nanomaterials (Bhavya et al. 2021). Nano remediation is the use of various techniques and nanomaterials (NMs) to remove or immobilize heavy metals (HMs) from polluted soils. Different types of nanoparticles (NPs) have been effective in this process (Ahmed et al. 2021). This provides a viable alternative to conventional environmental remediation methods. In addition, the detection of POPs and heavy metals in the environment is typically done using chemical, enzyme, ELISA, and biosensor methods that involve sophisticated instruments such as LCMS, ICPMS, AAS and GS-MS. These methods require a high level of energy and technology (Bhavya et al. 2021).

Physical soil remediation involves two methods, which are soil replacement and thermal desorption areas (Yao et al., 2012). Soil replacement entails using clean soil to replace contaminated soil partially or completely. This is done to reduce pollutant concentration and increase environmental capacity. Soil replacement is classified into three types: soil replacement, soil spading, and rebuilt soil import. Soil replacement entails removing contaminated soil and replacing it with fresh soil that is suited for regions with little pollution (Yao, Li, Xie & Yu 2012). The process of digging deep into contaminated soil spreads pollutants and allows natural degradation. An original soil import consists of adding clean soil to contaminated soil, either by covering it or mixing it in to decrease pollutant concentrations. Chemical leaching is the process of washing polluted soil with clean water, reagents, or other fluids or gases that remove contaminants from the soil. Heavy metals in soil are transported from the solid phase to the liquid phase by processes such as ion exchange, precipitation, adsorption, and chelation. They are then recoverable from the leachate (Yao et al. 2012). However, research into the production and application of nanoparticles for sensing and

detecting heavy metals, dyes, herbicides, insect pests, diseases, and other pollutants in food and agricultural goods is underway (Yao et al. 2012).

Catalytic technologies can also reduce energy consumption and greenhouse gas emissions, making them a key tool for sustainable development. These processes are cost-effective, resulting in more efficient resource use. Catalysis, the process of increasing the rate of a chemical reaction by the presence of a catalyst, has had a significant impact on society since ancient times (Kakaei, Esrafilii & Ehsani 2019). As the science of accelerating chemical transformations, catalysis has become an integral part of modern society (Chen, Xu & Mavrikakis 2020). According to Stephan (2020), catalysis did not begin to evolve rapidly from fundamental scientific research to advanced chemical technologies until the early 1900s, leading to significant transformations in our lives. Today, catalytic technology continues to evolve and expand through evolving technologies. It plays a crucial role in the production of fertilizers that feed millions of people worldwide and in the efficient processing of petroleum for fuel and chemicals (Kakaei et al., 2019; Stephan, 2020).

Catalysts have become increasingly important in recent years as industries have developed rapidly. Catalysts play an essential role in the petroleum refining industry for producing fuel. Additionally, catalysis has allowed for the precise production of drugs, materials, and agrochemicals. In recent decades, synthetic organic chemistry laboratories have been increasingly using transition-metal chemistry, contributing to its continued growth and expansion (Stephan, 2020).

Catalytic technologies mitigate heavy metal pollution. For example, catalyst converters in cars reduce emissions by converting pollutants into less harmful substances, which improves air quality (Kritsanaviparkporn, Baena-Moreno & Reina 2021; Steiner, Malashchuk, Kubinski, Hagen & Moos 2019). In wastewater treatment, catalyst oxidation changes metal ions into safer forms, which purifies water more efficiently. Catalytic technologies extract and accumulate heavy metals, making removal easier (Eskandari et al. 2020). Using catalyst nanomaterials in air filtration systems captures and breaks down heavy metal particles, which makes the environment cleaner and reduces emissions (Ahmed et al. 2021; Nishiori, Wadsworth & Moore 2021). These examples show how catalytic technologies can address heavy metal pollution in different areas.

2.2. Bibliometric analysis and visualization

Bibliometrics is a statistical technique that is used by many fields of study to analyse knowledge databases. It allows researchers to identify patterns and influential countries within a specific subject area (Qin et al. 2020; Sweileh & Moh'd Mansour 2020). In this review, the authors used the Web of Science core collection databases to retrieve data from 1 056 documents published between 2019 and 2023, using search terms as follows: "Heavy metal toxicity*" OR "Heavy metal exposure*" OR "Metals in agricultural land*" OR "trace metals in crops*" AND Health effects*. As noted by various researchers, WoS is reputable in documenting scientific studies across different disciplines (Zyoud 2019). The study followed the guidelines suggested by Munn et al. (2018) to sort and analyse search results based on significant themes related to the connection between heavy metal contamination, toxicity, agricultural land and health effects. To be included in the study, the articles had to meet specific requirements, such as being published in English and containing specific information requested by the researcher.

The types of publications that were obtained included original articles, reviews, proceedings papers and early-access papers. Relevant data such as the study title, authors, and publication date were extracted from these records by the researcher for quality assessment purposes, and the data extraction was performed independently. The data were processed using the VOS viewer software for visualization and mapping as recommended by Eck and Waltman (2010) and Dhital and Rupakheti (2019). The analysis as shown in Figure 2.1 shows a significant surge in publication from 2019 to 2020. This is followed by a plateau observation from 2020 to 2022. The drop in publications in 2023 is likely due to the timing of the bibliometric analysis. The year 2023 had fewer publications because the year was not complete enough to let all publications tally accurately.

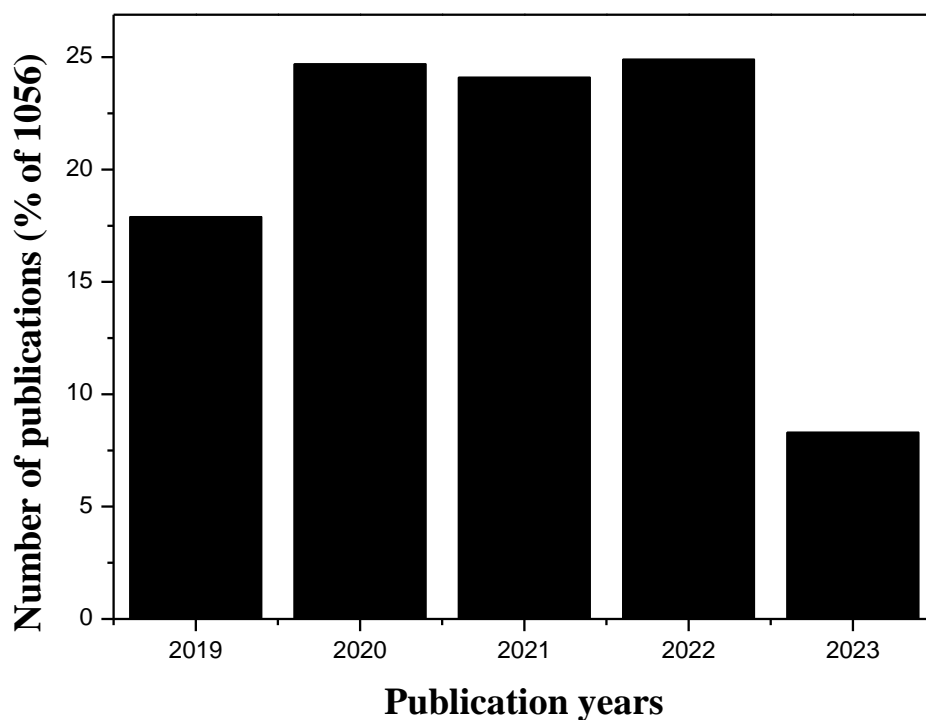


Figure 2.1: Graphical representation of the publication trends in heavy metal and health effects studies in the last 5 years (2019-2023): Data retrieved from the Web of Science core collection databases.



Figure 2.2: Tree Map chart depicting the top 10 research areas in heavy metal and health effects research in the last 5 years (2019-2023).

Figure 2.2 shows that the leading research area in this research topic is Environmental Sciences Ecology (432), followed by plant Sciences (127) and Toxicology (111). In respect of the

leading countries in heavy metal research, the People’s Republic of China is dominant (31.6%), followed by India (17.7%) and the United States of America (14.9%), respectively, as shown in Figure 2.3. The bibliometric network presented in Figure 2.4 indicates the co-occurrence of keywords in publications where the size of the frame is proportionate to the number of co-occurrences. The clusters (red, yellow, purple, blue, and green) further show that keywords of the same colour have often occurred together in publications. Figures 5 and 6 show that the People’s Republic of China, India, and Pakistan are the most-cited countries, respectively. Moreover, the thickness of the connection line between India and China shows a strong collaborative relationship. In addition, Figure 6 depicts that the most recent citations have come from Germany, Malaysia, Bangladesh, the United Arab Emirates, Romania, and Indonesia.

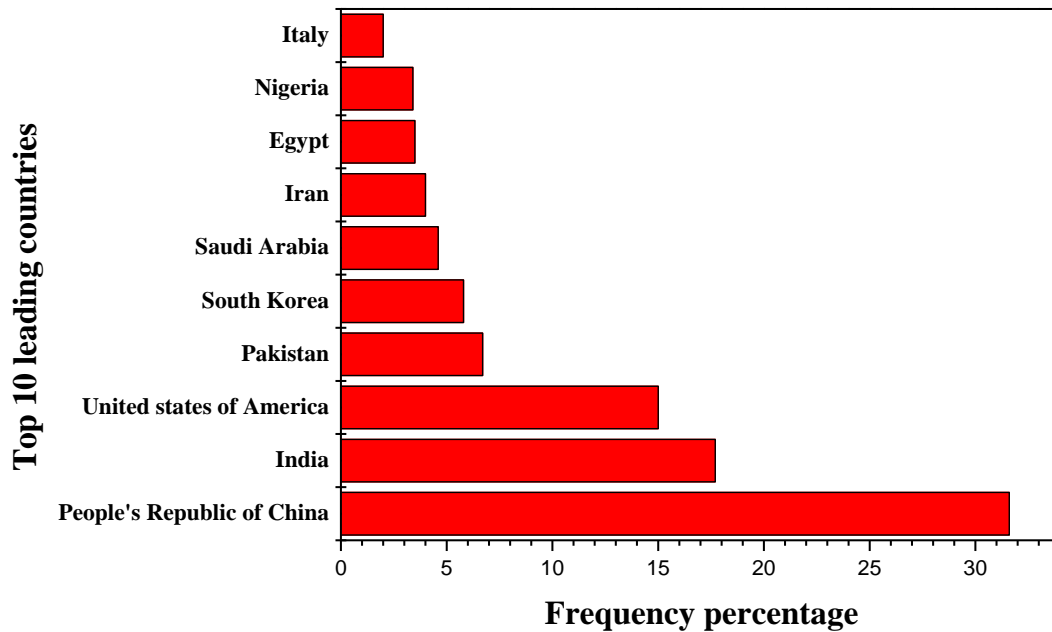


Figure 2.3: Graphical depiction of the top 10 leading countries in heavy metals and health effects research in the last 5 years (2019-2023).

land. It provides food security and economic prosperity for approximately 208 million people, with more than 1.2 billion Africans depending on maize as their primary food source. In addition to being used for food production, maize is also utilized for non-food products. Low-income African households spend between 30% and 50% of their income on maize, which accounts for 20% to 30% of their caloric intake and occupies 13% of SSA's cultivated land (Berge et al. 2019; Ragasa 2017).

Maize grains are in high demand due to an increasing population and the growing consumption of animal-derived foods. In the SSA region, over 90% of farmers grow maize, although their productivity varies widely. Maize also plays a significant role in food security, as it is the most important cereal crop in all countries of Sub-Saharan Africa (SSA) in terms of both production and area covered (Jena 2021). In terms of area and total output, maize, wheat, and rice are three of the most important staple cereals in the world (Du Plessis, 2015; Adiaha, 2020a).

In developed countries, maize is mainly consumed as a secondary product and serves as a staple food for around 200 million people. It is an important raw material for producing livestock and poultry feed, as well as for the manufacturing of cornflakes. However, the existing units that use maize are small and limited in their capacity (Karmakar & Gouraha 2018). Maize is commonly known as a breakfast cereal, but it can also be found in other forms such as fuel (ethanol) and processed starch. Starch can be transformed by enzymes into products like sorbitol, dextrin, sorbic acid, and lactic acid, which are found in a wide range of products, including beer, ice cream, syrup, shoe polish, glue, fireworks, ink, batteries, mustard, cosmetics, aspirin, and paint. Maize meal and by-products such as flour and oil are also derived from maize (Du Plessis, 2015; Hefferon, 2015; Adiaha, 2020a; Jena, 2021; Balconi et al., 2022).

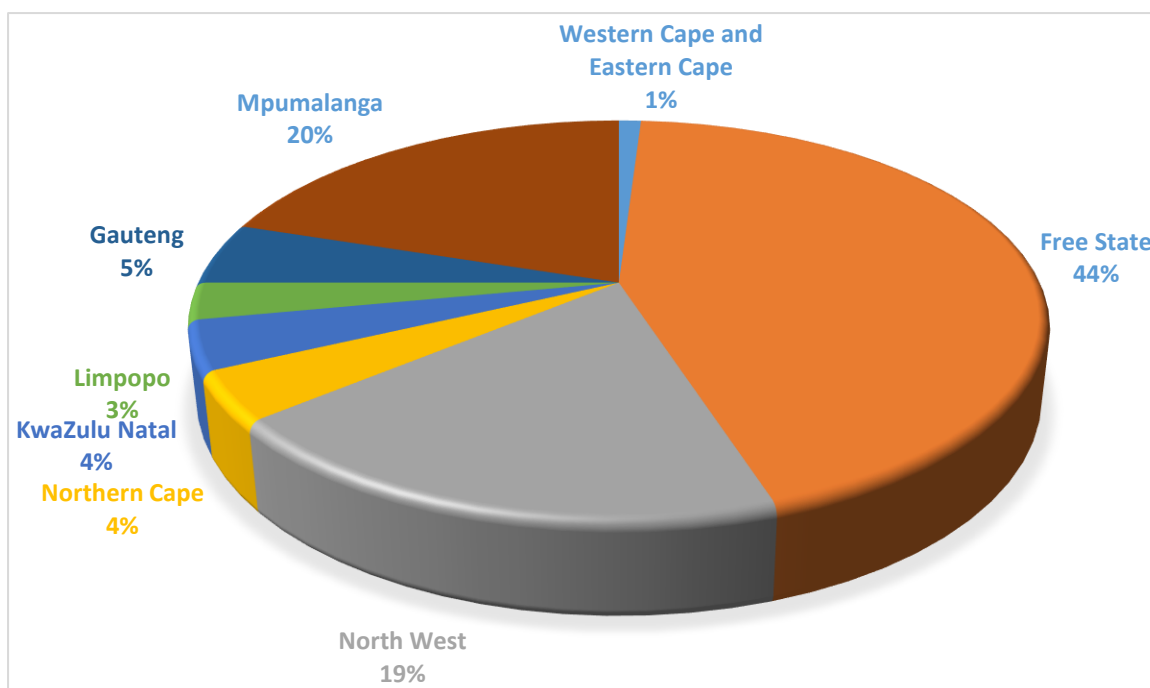


Figure 2.7: Contribution of the nine provinces to the 2016/2017 maize crop production in South Africa (source: NPC, 2017).

Induced agricultural production such as maize enhances the country's economy. Figure 2.7 shows the contribution of the nine provinces to the 2016/2017 maize crop production in South Africa. Agriculture has always been a significant source of foreign exchange earnings. By the grading regulations, a representative sample of each maize delivered at the various silos during harvest was taken during the harvesting season. A study conducted by the South African Grain Laboratory (SAGL) collected composite samples of white and yellow maize, totalling 1,000 in number from every production region, and subsequently analysed for quality. About 549 samples of white maize and 451 samples of yellow maize were collected (Southern African Grain Laboratory, NPC 2017) As a result, successful maize production requires the correct inputs both for the environment and agricultural production to be sustained (Du Plessis, 2015; Adiaha, 2020).

2.3.1 Maize import and export

In South Africa, maize is the most widely grown field crop and is central to global food security as one of the most widely consumed cereal crops in both human and animal diets worldwide (Ekpa, Palacios-rojas, Kruseman, Fogliano & Linnemann 2019; Wu & Guclu 2014). It is the mainstay of most of the population, especially the poor. The maize industry contributes significantly to the economy, both upstream to the input industries and downstream to the

milling, animal feed, and food processing industries. In addition, soy, cooking oil, and other processed foods are examples of imported foods (Eckert et al., 2018; Amponsah et al., 2021). Yellow maize makes up 90% of the global maize trade, with white maize making up the remaining 10% mainly in South Africa, Zimbabwe, Zambia, Malawi, Uganda, Tanzania, and Kenya (Kapuya & Sihlobo 2022; Grote, Fasse, Nguyen & Erenstein 2021). Most of the maize produced in Mozambique is consumed locally. However, some of the maize produced in northern Mozambique is exported. Some of the maize imported from South Africa meets some of the local demand in the south (De Araújo and Chabite, 2022). The majority of key staple foods essential to the diet in Africa are produced and transported across a food landscape, including rural areas, according to estimates (Wegerif & Wiskere 2017).

Most trade analysis literature focuses on maize as a homogenous product, without much consideration of its heterogeneity, particularly in a more general context. The focus of more focused and region-specific studies tends to be more on trade flows, while they do not take into account product heterogeneity as well (Kapuya & Sihlobo 2022; Wu & Guclu 2014). This approach is partly due to systemic limitations. Trade databases do not provide detailed product differentiation, resulting in the conflation of yellow and white maize statistics into a single product category (Wu & Guclu 2014). In Tanzania, small farmers produce most of the maize and potatoes. They also produce nearly all the rice. Tanzania imports some rice and maize, but it also exports some to neighbouring countries. (Wegerif & Wiskere 2017; Mboya, Tongoona, Derera & Mudhara 2011).

2.3.2 The versatility and nutritional value of maize

In developing countries, maize is a staple food, particularly in Latin America and Africa. An essential ingredient in local drinks and food, its high energy content, low fibre content, and ease of digestion make it an excellent feed for livestock (Verheye 2015). As a source of starch, it is widely used in industrial food products. Maize is one of the most widely consumed cereal grains in the world, along with rice and wheat. It is used to produce a wide range of products including starch, oil, protein, alcoholic beverages, food sweeteners, and fuel. Maize also provides essential nutrients for both humans and animals (Pingali 2015; Wu & Guclu 2014). A variety of products are made from corn kernels, such as bread, porridge, gruel, cakes, and alcoholic beverages. These products are consumed off the cob, dried, boiled, fried, roasted, ground, and fermented. Their popularity is largely due to their versatility as a food source for both humans and animals (Grote et al. 2021). Additionally, it thickens food, sweeteners, and

oils, but it is not edible. More than 200 million people consume maize as a staple of their diet, providing 15% of their protein and 20% of their calories (Rosa-Castor, Guzmán-Mar, Hernández-Ramírez, Garza-González & Hinojosa-Reyes 2014). As the global population is approaching 8 billion in 2025, this number is expected to increase, demonstrating maize's importance as a vital nutritional crop (Grote et al. 2021; Nuss & Tanumihardjo 2010). As a result of successful efforts to increase food security in many developing countries, the challenge has evolved (Pingali 2015). It is no longer sufficient simply to consume enough calories; addressing malnutrition in all its forms has become necessary. Agricultural policy continues to prioritize increasing the productivity of staple grains such as rice, wheat, and maize (Dias 2013). However, the needs of the middle and lower classes for dietary diversity remain unsatisfying. As a result of the 2008 food price crisis, most countries still define food security as self-sufficiency in staple grains (Dube & Garc 2016).

In addition to being edible, maize kernels are also nutrient rich (Shah et al., 2016). They are a rich source of both macro and micronutrients essential for human metabolism (Adiaha, 2020). Maize kernels provide many essential macro- and micronutrients for human metabolism. Sweetcorn (*Zea mays (L.) var. saccharata*) is a cultivated plant grown for human consumption and is used as a raw or processed food ingredient worldwide (Swapna, Jadesha & Mahadevu 2020). Sweetcorn is an essential component of the human diet due to its valuable nutritional properties. Maize also contains several health benefits. It is a rich source of B-complex vitamins, which are beneficial to the skin, hair, heart, brain, and digestion. Additionally, maize may improve joint motility and reduce symptoms related to rheumatoid arthritis. (Shah et al., 2016; Swapna et al., 2020). It contains vitamins A, C, and K, as well as beta-carotene and selenium, which are beneficial to the thyroid and immune systems (Nuss & Tanumihardjo 2010). Maize silk contains a significant amount of potassium, which has diuretic properties. In many countries such as India, China, Spain, France, and Greece, maize silk offers several benefits such as the treatment of kidney stones, urinary tract infections, jaundice, and fluid retention (Adiaha and Bat, 2017). Additionally, it may assist in lowering blood pressure, supporting liver function, and producing bile (Shah et al., 2016).

2.3.3 Common contaminants and diseases associated with maize.

Aflatoxins, a set of toxic substances produced by several staple foods such as maize, groundnuts, and tree nuts can be contaminated by the fungi *Aspergillus flavus* and *Aspergillus parasiticus*. It is believed that approximately 5 billion people across the globe consume

unregulated aflatoxin in their diets. These toxins can occur in the crops during growth and after harvest when not stored under optimal conditions. The prevalence of aflatoxin is particularly high in crops grown in tropical and subtropical areas (Stevens & Madani 2016). Several foodborne fungi, including *Aspergillus flavus* and *Aspergillus parasiticus*, colonize tropical and subtropical crops worldwide and produce aflatoxins as secondary metabolites (Wu, Groopman & Pestka 2014).

Maize is not only a major source of human exposure to aflatoxin, but also a susceptible crop to the toxic substance. Mycotoxins are widespread worldwide and commonly coexist in crops, leading to a varied diet exposing people to combinations of mycotoxins. This makes them highly relevant contaminants in agriculture. The primary producers of mycotoxins, such as *Aspergillus*, *Fusarium*, and *Penicillium*, generate them in response to shifting environmental conditions. Despite decades of research and the implementation of secure agricultural and manufacturing practices, mycotoxin occurrence persists as a global problem. Mycotoxins have a significant impact on human health, animal welfare and productivity, as well as both domestic and international trade (Wu & Guclu 2012). To safeguard public health, many countries have set food safety standards that specify the maximum allowable levels of certain contaminants in food. These standards have a considerable influence on the global food trade (Santpoort 2020). It would be valuable to explore the impact of national food safety regulations on global food trade patterns.

2.3.5. Heavy metals in maize crops

Heavy metals such as cadmium (Cd), copper (Cu), zinc (Zn), nickel (Ni), lead (Pb), and arsenic (As) are often found in agricultural soils throughout the world (Adekiya, Oloruntoba, Ojeniyi & Ewulo 2018). This is because cereals, *Zea mays L* (maize), are effective accumulators of heavy metals (Ali & Al-qahtani 2012). Contamination can be attributed to several factors, such as the application of phosphatic fertilizers and sewage sludge, smelter dust, industrial waste, and substandard irrigation practices. These practices lead to the absorption of heavy metals from water runoff by maize roots. (Yaqub, Khan, Ahmad & Irshad 2021). In addition to soil pollution caused by weathering processes, the total concentration of metals in the soil affects their bioavailability and bioaccumulation potential (Gunalan & Vijayalatha 2020).

People and communities are affected by the environment, including air, water, and soil. As a result, they are exposed to chemical, biological, and physical agents (Adekiya et al. 2018).

Additionally, heavy metals in soil can harm the environment due to their non-biodegradability. Heavy metal contamination is caused by mining and smelting metal ores (Gunalan & Vijayalatha 2020; Adekiya et al. 2018). Heavy metals are metallic chemical elements that are found naturally in the earth's crust. Some of these are biologically essential. There are certain heavy metals, such as arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), and lead (Pb), that are not necessary for plant growth. They can be harmful even in small amounts (Adekiya et al., 2018; Balali-mood et al., 2021).

2.4. Type of catalysts

Catalysts can be classified in different ways based on their structure, use, or composition. Catalysis is divided into three subdisciplines: heterogeneous catalysis, homogeneous catalysis, and bio-catalysis. Homogeneous catalysts are often soluble in the reaction medium and used in liquid-phase reactions (Bender, Dabrowski & Gagné 2018). The term 'phase' refers to solid, liquid, gas, or immiscible liquids, like oil and water. They are in the same phase as the reactants, and examples include acids, bases, and transition metal complexes. Catalysis is crucial in converting biomass to energy and functionalizing petroleum and developing effective catalytic methods offers many benefits and goals. Heterogeneous catalysts are usually solids, while their reactants are gases or liquids (Chen et al., 2020). Heterogeneous catalysts can be made from metals, metal oxides, metal salts, or organic materials like hydroperoxides, ion exchangers, and enzymes. Bio-catalysis involves using natural substances such as enzymes or cells as catalysts in chemical reactions. Enzymes are protein catalysts that perform different functions, including aiding in digestion, producing essential nutrients, and facilitating muscle movement (Lamoureux, Winther and Garrido, 2019; Chen et al., 2020).

Bio-catalysts have a crucial role in regulating biological reactions for protein and DNA synthesis, molecule decomposition, and energy storage in sugars (Kakaei et al., 2019; Yi et al., 2021). Compared to traditional chemical methods, bio-catalytic processes offer various advantages, such as minimal toxic byproducts, low energy requirements, and standard temperature and pressure conditions (Kakaei et al., 2019). Moreover, bio-catalysis is increasingly utilized in various applications, including the production of renewable fuels, pharmaceuticals, and value-added chemicals, even in cases where traditional chemical methods are not yet efficient (Bell et al. 2021).

2.5. Enzyme catalytic activities

Enzymes are catalysts that accelerate chemical reactions by reducing the amount of activation energy needed. Each enzyme is highly specific and only catalyses one particular reaction (Zeymer and Hilvert, 2018; Kakaei et al., 2019). Enzymes are made up of proteins and often require additional molecules called cofactors, which help the enzyme perform its catalytic activity. Enzymes catalyse reactions in living organisms by binding to a substrate, converting it into a product and releasing it (Nishiori et al. 2021). Enzymes are involved in a wide range of biochemical processes, including metabolism, digestion, and DNA replication. Without enzymes, most biochemical reactions would occur too slowly to support life (Choudhary, Gupta, Dhar & Kaul 2021). Table 2.1 below shows the types of enzyme activities and examples.

Table 2.1: Enzymes activities

Type of activities	Definition and examples	References
Hydrolases	These enzymes catalyse the breakdown of large molecules into smaller ones by adding water. Examples: include lipases, proteases and amylases.	(Burek, Dawood, Hollmann, Liese & Holtmann 2022; Hanefeld, Hollmann & Paul 2022)
Oxidoreductases	These enzymes catalyse the transfer of electrons between molecules, leading to oxidation or reduction reactions. Examples include dehydrogenases, oxidases and reductases.	(Verasoundarapandian et al. 2022; Zhu, Chen & Wei 2018)
Transferases	The transfer of a functional group from one molecule to another is catalysed by these enzymes. Kinases, methyltransferases, and transaminases are a few examples...	(Bell et al. 2021; Yi et al. 2021)
Isomerases	These enzymes catalyse the transfer of a functional group from one molecule to another. Kinases, methyltransferases, and transaminases are among examples.	(Zhu et al., 2018; Yi et al., 2021)
Ligases	These enzymes catalyse the joining of two molecules together, usually using energy from ATP. Examples include DNA ligase and RNA ligase.	(Zhu et al., 2018; Yi et al., 2021)

2.6. Biological and natural catalysts

Enzymes are a type of protein that catalyse biochemical reactions in living organisms (Choudhary et al. 2021). They are highly specific in their interactions with substrates, efficient in performing reactions quickly, and can be regulated to control the rate and direction of chemical reactions (Su et al., 2018; Zhu et al., 2018). Enzymes have many roles, including breaking down food molecules (digestive enzymes) producing energy and aiding cellular processes (metabolic enzymes). Natural catalysts are found in natural environments like soils, water bodies, and the atmosphere. They can be either organic or inorganic and play a crucial role in the chemical reactions of these environments (Yi et al. 2021; Zeymer & Hilvert 2018). For example, microorganisms in soil use natural catalysts to break down organic matter, and sunlight and atmospheric oxygen act as natural catalysts during photosynthesis in plants.

2.7. The heavy industry's impact on the environment

Mining involves excavation into the earth to obtain minerals that are found naturally (Worlanyo & Jiangfeng 2021). Mines are an important economic activity in many developing nations. Furthermore, they are one of the few businesses that drastically alter the surrounding landscape by destroying land resources and leaving them unsuitable for other purposes, such as agriculture and forestry (Oluwayemisi 2020; Werner, Bebbington & Gregory 2019). Inappropriate and inefficient work methods and restoration efforts harm the environment, including pollution and biodiversity loss. Additionally, there have been consequences such as soil erosion and contamination of various types of food, surface water, groundwater, and soil (Haruna, Musa & Ayinla 2021). The quality of water, soil, and agricultural production is affected by extraction activities. Mining operations produce drainage that results in elevated levels of specific metals in the soil, potentially causing severe problems like impeding vegetation growth through pollution.



Figure 2.8. The copper smelting plant (Slukovskii 2023).

Mining activities can release significant amounts of both particulate matter and gaseous pollutants into the environment. This, combined with the large quantities of water used in mining processes, increases the risk of mine discharges into nearby streams and rivers (Haruna et al. 2021; Oluwayemisi 2020; Rivera 2020).

2.8. Impact on water

Water is crucial to the mining industry and serves a variety of functions. Mineral processing, metal recovery, cleaning, pumping, and transportation are examples of these. Water is also used for cooling, dust control and to meet the needs of workers. These water-intensive activities take place throughout the entire life cycle of a mine, from exploration to rehabilitation (Jain & Domen 2016). Mining activities can have a negative impact on both the quality and quantity of water in a region. This can lead to contamination of water resources, destruction of aquatic habitats and a reduction in regional water supplies (Jain & Domen 2016). Research has shown that irrigation is used to grow 40% of the world's food supply and that industrial processes also rely on water (Islam, Prabal & Belal 2017).

According to Jain (2016), mine dewatering and persistent pumping can also have an impact on groundwater, resulting in a reduction in the local water table around the mine. Approximately half of the global population's drinking water comes from groundwater. There is an increasing worry that mining and mineral operations are depleting local water resources in an unsustainable manner. Groundwater quantity is also affected by groundwater withdrawals for mining activities and it lowers the water table elevations (Jain 2016). According to Agboola et al. (2020), erosion of mine waste affects the quality of surface water, particularly tailing and waste rock.



Figure 2.9 Diagram illustrating heavy metal in water (Mitra et al. 2022).

2.9. Impact on soil

Many research studies indicate that surface mining impacts the environment negatively. During the mineral's extraction, the use of heavy machinery and blasting destroy the critical soil organisms, having a significant adverse impact on the land and the vegetation, disrupting the stability of the soil aggregates, and eventually depriving the soil of organic matter (Mensah et al. 2015).

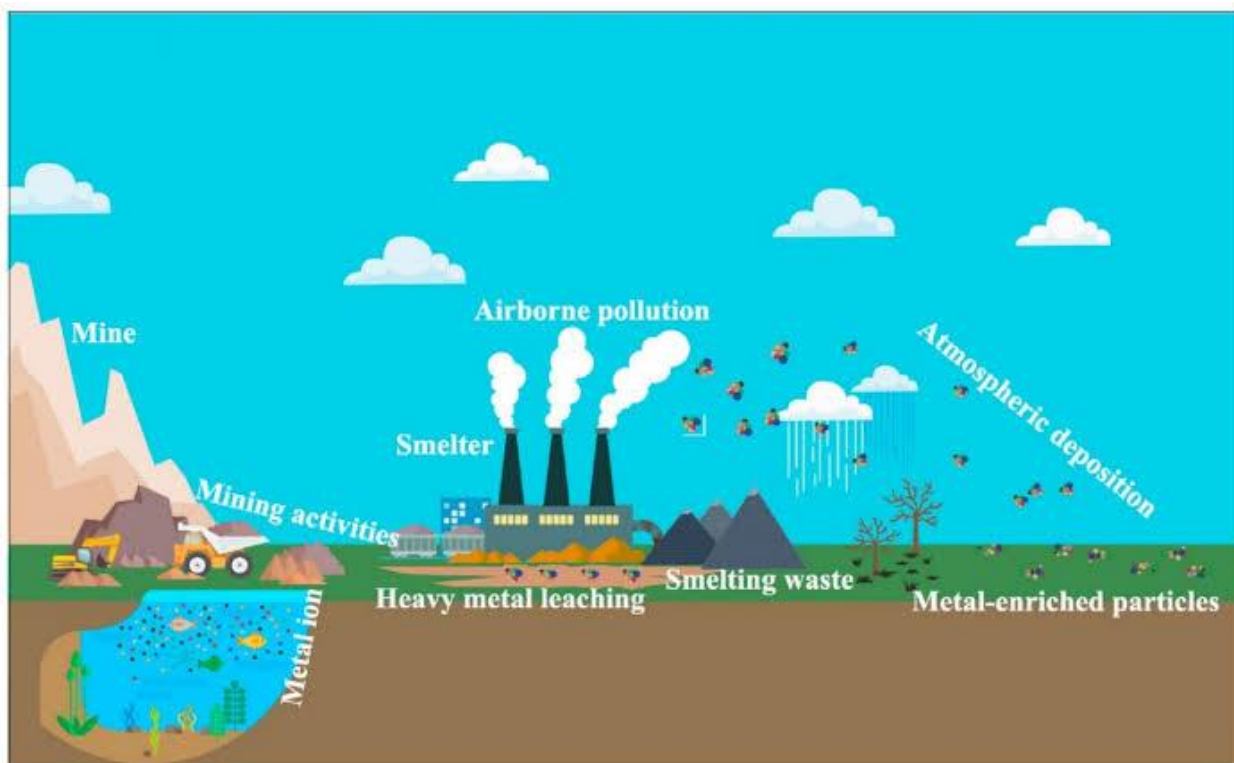


Figure 2.10 Illustration of the smelting procedures polluting the soil (Adnan et al. 2022).

2.10. Impact on human health and air quality

Heavy metal contamination from mining and industrial activities can adversely affect local communities and pose potential health risks. Table 2.2 summarizes the pollutants associated with these activities. Coal mining is associated with the release of large quantities of emissions that are a potential health hazard. The pollutants are transported and distributed into the surface environment by dust (Kumar & Masto 2013). According to Rostami, Kamani and Shahsavani (2021), industrial chemicals can have serious consequences for human health, including heart and bone diseases, infertility, and nerve damage. Even at low levels, heavy metals such as mercury, cadmium and arsenic are poisonous and hazardous. Studies show the burning of fuels produces greenhouse gases and other byproducts, including H_2O , CO_2 , CO , CH_4 , H_2S , H , SO_2 , SO_3 , HCl , and NH_4 . Additionally, gaseous materials are emitted from active dumps and mining can cause environmental damage through various mechanisms (Agboola et al., 2020). Study results revealed that living near mine dumps or being exposed to mine dust are high-risk factors for asthma in South Africa. In addition, in areas near mine dumps, asthma incidence in children exposed to dust particles is between 10% and 13%. This figure rises to 17.3% among older individuals (Agboola et al., 2020). Furthermore, lead poisoning has been reported to affect

children due to exposure to wind-blown dust in an abandoned Pb–Zn mine dump in Zambia. Their blood lead levels were beyond the reference value of 5 $\mu\text{g}/\text{dL}$ (Omutiti, 2013; Agboola et al., 2020).

Table 2.2: Air pollutants associated with mining activities.

Air pollutants	Impact on health and environment	Source	References
Carbon dioxide	Atmospheric/climate change and increase in temperature.	Industrial and coal mining	(Agboola, Babatunde, Isaac Fayomi, et al. 2020)
Carbon monoxide	At low concentrations, CO causes neurological symptoms and has effects on the cardiovascular system.	Inadequate ventilation systems in mining activities	(Jain 2016; Kumar & Masto 2013)
Hydrocarbons	Exposure can cause sinus irritation. Major soil pollutant.	Mining equipment	(Agnello, Bagard, van Hullebusch, Esposito & Huguenot 2016)
Nitrogen oxides	NO ₂ damages the respiratory system. Outdoor exposure to smog.	Mining	(Jain 2016)
Methane	Respiratory hazard to underground workers. Methane is highly explosive. Can displace oxygen and act as an asphyxiant.	Coal mining	(Agboola, Babatunde, Isaac Fayomi, et al. 2020; Kumar & Masto 2013)
Sulphur dioxide	Exposure can cause chronic bronchitis. High concentration levels pollute the atmosphere.	Mining and Industrial	(Agboola, Babatunde, Isaac Fayomi, et al. 2020)
Particulate matter	Can get trapped in the lungs and cause chronic shortness of breath.	Mining and industrial activities	(Anyanwu, Ezejiyor, Igweze & Orisakwe 2018)

2.11. Heavy metal

Elements on the periodic table with a density over five are known as heavy metals and are part of an ill-defined group of inorganic chemical hazards. Lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), copper (Cu), mercury (Hg), and nickel (Ni) are commonly found in contaminated locations (Abdu, Abdullahi & Abdulkadir 2016; Wuana & Okieimen 2011). In recent years, heavy metal pollution has been associated with environmental contamination and also a global public health concern due to these metals (Abdu et al., 2016; Tchounwou et al., 2016). According to Abdu et al. (2016), heavy metals consist of two sources natural and anthropogenic.

Arsenic ingestion can have rapid harmful consequences on human health, including gastrointestinal symptoms such as severe vomiting, blood and circulation problems, nervous system damage, and even death (Mahurpawar 2015). Even at low concentrations, arsenic can cause diseases. High concentrations of arsenic can affect the kidney, liver, and bladder, reduce blood cell production, and break up red blood cells in circulation (Izah, Inyang & Angaye 2017; Mahurpawar 2015).

Cadmium can accumulate in the human body throughout life once absorbed. Inhalation and ingestion are the primary routes of exposure, and humans can suffer from acute and chronic intoxications (Jaishan, Tseten, Anbalagan, Mathew & Beeregowda 2014). Cadmium does not break down into hazardous compounds in the environment, which contributes to its bioaccumulation in vertebrate and invertebrate kidneys and livers (Mahurpawar 2015). Cadmium is a very hazardous, non-essential heavy metal found mostly in fruits and vegetables. It can harm cell enzymatic systems, produce oxidative stress, and cause nutritional deficits in plants (Jaishan et al. 2014).

Mercury is another toxic heavy metal that can be retained in lung tissue, even at low concentrations. It can penetrate the blood-brain barrier and cause neurological effects (Mahurpawar, 2015; Izah et al., 2017). Depending on the exposure and concentration, mercury toxicity can interfere with several cellular metabolisms in humans and can affect children and adults (Izah et al., 2017). High mercury exposure has led to death, but the critical effects are neurotoxic and renal (Mahurpawar 2015).

Nickel is a chemical that exists in extremely low concentrations in the environment and is used by humans as a constituent in steel and other metal goods. Nickel is also widely used in metal

items such as jewellery. Nickels exist naturally and in modest amounts in meals, however, chocolate and fats contain extremely high levels (Mahurpawar 2015). According to Oyewo et al. (2020), people consume large quantities of vegetables grown in polluted soils. Plants are known to accumulate nickel, resulting in significant nickel uptake from vegetables. Nickel may be ingested by humans by breathing air, drinking water, eating food, or smoking cigarettes (Mahurpawar 2015).

2.12. Heavy metal contamination on soil and water

The physical, chemical, and biological properties of water can be used to characterize its quality. High-quality water is essential for life's survival and is required for agricultural, industrial, recreational, and home use (Jain & Domen 2016) and according to Islam et al. (2017), water is vital for humans, food production, economic development and crucial for other living organisms (Sun, Li, Guo, Semple & Jones 2019).

According to Rostami et al. (2021), soil contamination is one of the most significant environmental problems worldwide. Soil contaminants include heavy metals, which enter the environment through industrial activities, fertilizer use, and urban sewage. These contaminants can directly and indirectly endanger human health. The increase in solid waste generation due to urbanization and industrialization has become a global concern. It is increasing day by day due to anthropogenic activities throughout the world (Ahmad et al. 2021). Fast economic development and industrialisation in Iran have resulted in significant levels of heavy metal pollution in soil and water (Mohammadi et al. 2019). Soil plays an important role in food safety, and the negative impacts of pollutants such as heavy metals on crop quality have put human health at risk (Qin et al. 2021).

Heavy metal pollution in the environment can result from wastewater generated by sources such as vehicle exhaust, poor waste disposal, fossil fuel combustion, municipal waste, sewage, pesticides, metal mines, and smelting. These large quantities of heavy metals can affect human health and pollute rivers, groundwater, and soil (Qin et al. 2021; Mohammadi et al. 2019; Vareda, Valente & Durães 2019). Heavy metals are natural elements of the earth's crust that can be released into water through natural processes or human activities. Weathering and decomposition of metal rock and ores can transfer heavy metals into groundwater, leading to human exposure (Mohammadi et al. 2019). Water quality is vulnerable to pollution from

sources such as untreated industrial effluents, runoff from chemical fertilizers and pesticides, and oil spillage from operational processes in coastal areas and river ports (Islam et al., 2017).

According to Marrugo-negrete, Pinedo-hernández and Díez (2017), the accumulation of metals in agricultural soils as a result of human activity is becoming a growing problem. Although fertilizers are necessary for optimal nutrient supply and good harvests, they have the potential to accumulate in less soluble forms and be transported into soil solution. This can result in potentially harmful levels of metals in soils. Heavy metals in soil can be hazardous to human health and ecosystems even at low concentrations, due to their ubiquity, toxicity, and persistence. Studies have shown that about 98% of health-related illnesses from heavy metal contamination in soil result from the ingestion of home-grown produce, particularly in rural areas (Jiang, Chao, Liu, Yang & Chen 2017).

According to studies, heavy metal build-up has caused water levels in African countries to reach unsafe levels. Heavy metals in drinking water can cause cancer of the liver, lung, kidney, or bladder in 13 out of every 1000 persons who consume one litre of water per day with an arsenic content of 50 micrograms per litre (Anyanwu et al. 2018) and heavy metals may enter the human body through a variety of routes, including direct ingestion, skin contact, and inhalation through the mouth and nose, if they are released into drinking water (Mohammadi et al. 2019).

2.14. Effects of heavy metals on agriculture

Heavy metal contamination is a worldwide problem that harms the environment and endangers human health. This problem has also accelerated urbanization and industry in highly populated and emerging countries (Afonne & Ifediba 2020a). The release of heavy metals into the environment through various anthropogenic activities has proven to be problematic. Heavy metal elements can be found in sewage sludge from industrial wastewater outlets and surface runoff water (Sandeep, Vijayalatha and Anitha, 2019) and the introduction of the industrial revolution and economic globalization has led to an increase in countless anthropogenic contaminants in the environment (Kumar et al., 2019). According to Edogbo et al. (2020), agricultural activities pollute water in rural regions in many developing countries. This may increase the concentration of soil particles washed into bodies of water because of erosion.

The inefficient release of man-made wastes into adjacent waterways, particularly those created by industry can lead to these water bodies becoming major recipients of these wastes. The use

of low-cost irrigation systems such as wastewater, treated effluent, and sludge can contaminate the soil with heavy metals, affecting the quality of food and leading to the deterioration of health (Edokpayi, Odiyo, Edokpayi, Odiyo & Durowoju 2017; Srivastava et al. 2017). Crops irrigated with contaminated water that contains heavy metals such as cadmium, arsenic, lead, mercury and nickel can have toxic concentrations. These heavy metals have been found in both ground and surface water all over the country (Pakistan) (Rehman, Sajid & Akash 2018). According to Afonne and Ifediba (2020a) and Linu-chibuezeh and Ugwunnadi (2020), because leachates from solid waste dumps can include significant quantities of heavy metals and metalloids, improper waste disposal system management can also pollute the soil-crop system. Furthermore, the growing use of chemicals, mineral fertilizers, and pesticides in agriculture contributes to heavy metal disruption of the soil-plant system.

According to Sandeep et al. (2019), sewage sludge can serve as a nutrient carrier for plant growth and development. However, because of the presence of organics, long-term usage of sewage sludge can affect the environment and plants. Heavy metals are naturally occurring in the earth's crust and have a persistent and stable nature. Heavy metals cannot be broken down or destroyed. Heavy metal pollution, like other metals and metalloids, is a major environmental hazard that endangers plants and animals as well as the quality of the environment (Srivastava et al. 2017). Heavy metals can be left in the open during ore extraction and mineral processing and transferred to other locations by wind and flood processes, posing serious environmental risks. Farming pollution has resulted from the degradation of the ecosystem and the environment caused by the growing use of agrochemicals and inorganic fertilizers in current agricultural methods (Srivastava et al., 2017) and Heavy metals can have an immediate impact on plant biochemical and physiological processes, limiting growth, damaging cell organelles, and blocking photosynthesis. Heavy metals are a major problem in agricultural plants owing to the possibility of food contamination via the soil-root interface (Sandeep et al., 2019).

When plant food is harvested from polluted soils, the heavy metal content in the food can be affected due to the high levels of toxic metals in the soil (Afonne & Ifediba 2020a). According to Kumar et al. (2019), it can be asserted that indoor cultivation of crops is not an absolute way to ensure food safety. Even in a controlled environment, greenhouse-grown vegetables can still be contaminated with heavy metals, mostly through anthropogenic sources. In a study by Mihaileanu et al. (2019), reports have shown that home-grown vegetables near industrial sites have higher levels of heavy metal concentration compared to vegetables from groceries and supermarkets.

Studies conducted in residential areas near former industrial sites in Romania have shown high levels of heavy metal contamination in soil and home-grown vegetables. In particular, lead (Pb) and cadmium (Cd) were found to be present at high levels (Mihaileanu et al. 2019). When vegetables are irrigated with untreated wastewater discharged from industries, heavy metals can move into plant tissues and the surface of fresh vegetables intended for consumption. This can result in adverse health effects (Edogbo et al. 2020).

2.14. Effects on red meat and poultry

Meat is defined by the Codex Alimentarius as "any portions of an animal that are intended for or have been determined safe and acceptable for human consumption" (Yakup, Sabow, Saleh & Mohammed 2018). Meat from cattle and lamb constitutes a significant portion of human diets globally due to its palatability and nutritional value. Meat products are primary sources of essential nutrients such as protein, minerals, vitamins, and fats (Wang et al., 2019). However, they are exposed to and polluted in the same way as other food materials (Yakup et al. 2018). Heavy metals are considered chemical contaminants in meat and edible offal and are among the primary contaminants in our food supply (Hashemi, 2018; Sciences, 2013). The risk of exposure to heavy metals present in meat and meat products is a concern for human health and safety due to their toxicity (Yakup et al. 2018). In recent decades, heavy metal contamination of meat and meat products has increased at an unprecedented rate (Yakup et al. 2018). However, it is important to note that animal products can contain high levels of toxic elements. These elements primarily originate from sources such as feed, water, litter, and the environment (Korish & Attia 2020).

Pollutants produced by air, chemical pollution and an unhygienic way of selling meat can contaminate the meat with heavy metals during processing, storage and transportation, and heavy metal contamination in meat has been closely associated with contaminated livestock feed and grazing livestock near polluted areas in some cases (Yakup et al. 2018). Heavy metals including lead (Pb), cadmium (Cd), and mercury (Hg) are poisonous even at low concentrations and serve no physiological role in the human body. Cadmium, arsenic (As), and lead can enter the food chain and endanger both animal and human health (Korish & Attia 2020).

Copper (Cu) and zinc (Zn) are important metals required by living organisms at low amounts for normal growth, development, and maintenance. Their absence, on the other hand, might result in major health issues or even death in cattle. Exposure to levels greater than ideal, on

the other hand, can endanger human health (Hashemi 2018). Lead is a neurotoxin that can cause metabolic harm and adversely affect renal function and hemopoiesis. It can also have negative effects on the nervous and gastrointestinal systems (Korish & Attia 2020). Heavy metals that animals take orally through their food and water, or that they get from their environment, can accumulate in organ tissue such as the liver and kidney. Humans utilize these organs as a source of animal protein all around the world (Oymak 2017).

Cadmium contamination in the diet can come from various food sources and the environment. It can travel through the food chain to animals and ultimately humans, causing kidney dysfunction, hypertension and damage to the lungs and liver (Korish & Attia 2020). When an excessive amount of copper (Cu) is consumed, it can harm the kidneys and liver. An excess of copper in the liver can even lead to cirrhosis or hepatitis (Oymak 2017). Both frozen and fresh meat contain essential elements and heavy metal contents (Korish & Attia 2020). However, except for chromium, which has higher levels in fresh meat than in frozen meat, most information comes from studies on chickens. Little or no attention has been paid to the concentration of heavy metals in red meat imported into Iraq, such as beef and mutton (Yakup et al. 2018).

2.15. Human health effects

Food contamination with heavy metals, such as beef and meat products, vegetables, and fish, has become a danger to food security and a global issue for human health (Kumar et al., 2019). The rate of contamination has increased at an unprecedented rate due to exposure to toxic metals (Wang et al., 2019). Heavy metals may enter the human body through food, drinking water, and inhalation. In significant quantities, certain metals can become hazardous. Environmental pollutants such as heavy metals and metalloids, according to some research, may have a major influence on the prevalence of bad birth outcomes (Mihaileanu et al. 2019).

Continuous heavy metal exposure might cause an internal imbalance in the body. These metals can build up in the body and begin to be utilized as replacements for critical components, affecting normal biological activities even further (Rehman et al., 2018; Wang et al., 2019) report that the intake of heavy metals is a major health concern. These metals can have an impact on the structural and functional integrity of the ecosystem, and their presence in meat products is a severe food safety problem. Heavy metals can endanger human health since they are hazardous even at low concentrations. They can build up in key organs including the liver,

heart, and kidney, interfering with normal biological operations and affecting the body's metabolic processes (Rehman et al., 2018). Heavy metal deposition in food crops produced in polluted locations can have several deleterious impacts on human health. These include decreased psychological abilities, malnutrition-related impairments, and a high frequency of upper gastrointestinal cancer rates (Afonne & Ifediba 2020b).

The consumption of food contaminated with aflatoxins can cause a variety of adverse reactions. These include death from acute aflatoxicosis, liver damage (hepatotoxicity), and liver cancer from chronic aflatoxicosis (Yang et al., 2020). High levels of arsenic can lead to poisoning through the consumption of contaminated food. This can occur from eating food containing pesticides or food grown in soil with high levels of arsenic. Ingesting food crops contaminated with excessive amounts of arsenic can result in acute intoxication, causing gastrointestinal disturbances and affecting the cardiovascular system. This can also lead to toxicity in the central nervous system (CNS) (Illia, Ruzaidy & Amid 2020; Rehman et al. 2018).

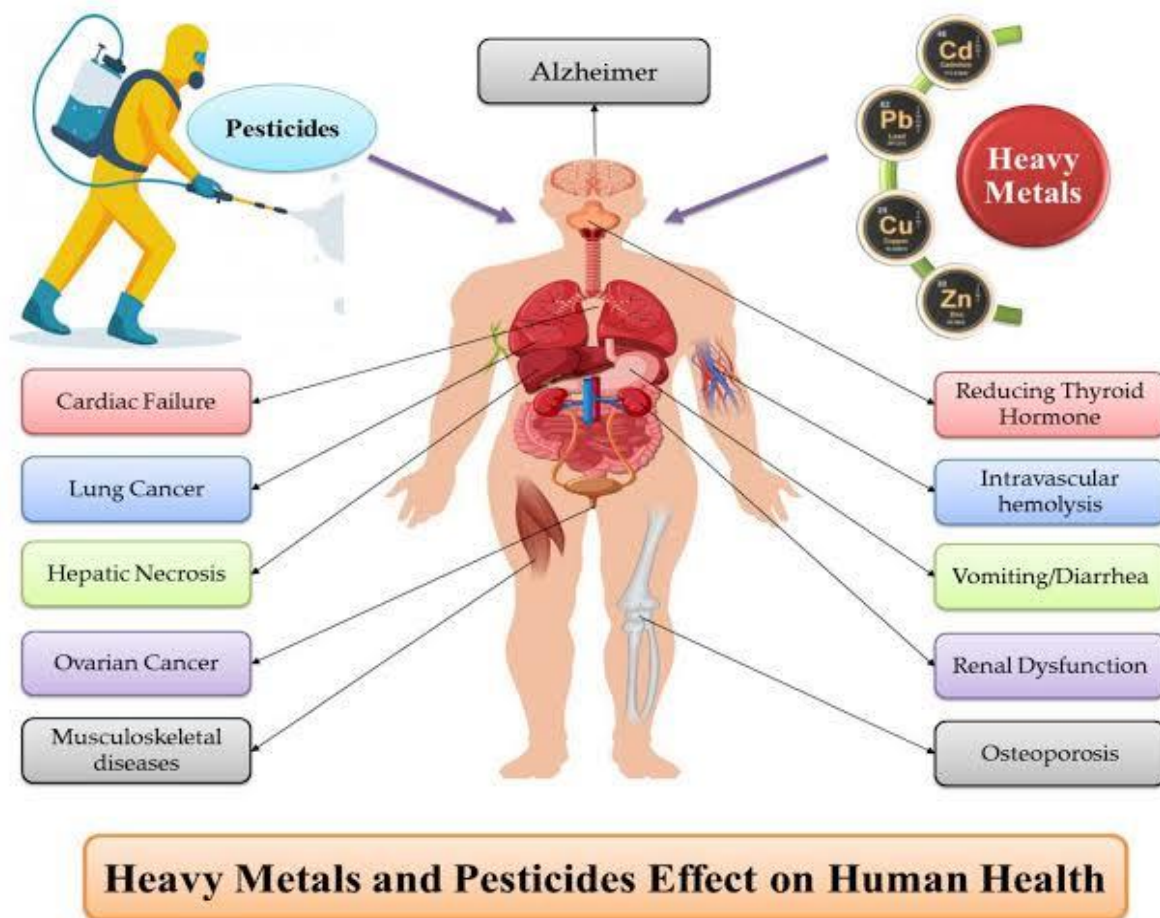


Figure 2.11 Heavy metal effects on human health (Ahmed et al. 2021)

Arsenic exposure has been linked to acute gastrointestinal disorders, according to research. Symptoms may include a garlic-like taste on the tongue and burning lips, followed by a dry mouth and trouble swallowing. Severe vomiting may ensue, perhaps leading to blood vomiting (hematemesis) (Rehman et al. 2018). The biological systems, once heavy metals are within a body, block their vital activities in the body. If the body is exposed to an excessive number of base metals for a long period, it can be toxic to the body.

Cadmium (Cd) is a toxic heavy metal and an important environmental pollutant. In humans, exposure to Cd can cause multiple adverse effects, including renal and hepatic dysfunction and testicular damage (Balali-mood et al. 2021; Rehman et al. 2018). Severe exposure to Cd can also result in pulmonary effects such as bronchiolitis, emphysema, and alveolitis (Yang et al. 2020; Kamunda, Mathuthu & Madhuku 2016). Cadmium is harmful even in low quantities and is thought to be a potential carcinogen. Lead toxicity has also been shown to interfere with the normal function of enzymes. Heavy metal exposure can cause kidney damage and elevated blood pressure (Yang *et al.*, 2020; Xiao et al., 2018), while Chen et al. (2021) state that the accumulation of heavy metals in humans can cause toxicity and major health issues due to the bio-magnification effect.

Long-term exposure to arsenic in food can result in skin, lung, and bladder cancer (Yang et al. 2020). In China, the agricultural cultivation system for food and vegetable crops is critical. The eating of these crops may result in the buildup of excessive quantities of heavy metals in people. Long-term exposure can cause gradual neurological and muscular deterioration, resulting in illnesses such as Parkinson's disease, muscular dystrophy, Alzheimer's disease, and multiple sclerosis (Chen et al. 2021). Heavy metal exposure has increased globally in recent years because of industrialisation. This has increased the negative health consequences connected with metal exposure. In South Carolina, mothers living near industrial zones with high levels of Cr and Pb pollution gave birth to low-birth-weight infants, according to research done in the United States. This shows that soil metals may constitute a health risk to pregnant women. Additionally, the surfaces of vegetables can become contaminated by heavy metals in soil and dust, leading to exposure through ingestion and uptake into tissues (Mihaileanu et al. 2019). Similarly, in Nigeria, there have been reports of high lead concentrations in women and children due to the consumption of food contaminated with heavy metals (Edogbo et al. 2020).

2.16. Photocatalysis of heavy metals

The agenda on the clean and green economy and sustainability is a global movement that is supported by technological advancements such as photocatalysis to remediate polluted environments. These polluted environments are potentially catastrophic to humans and the ecosystem at large. Photocatalysis technologies are widely applied in fields such as energy, conservation, health, pollution control, environment, and chemical synthesis (Saianand et al. 2022; Gao & Meng 2021). Historically, the sun's energy has been used for the removal of organic compounds, thus mitigating pollution due to its low-cost energy source.

Over the last five years, research has focused on using photocatalysis to remove heavy metals from wastewater. Various photocatalysts, such as bismuth vanadate, titanium dioxide, and graphitic carbon nitride, have been tested for their effectiveness in removing heavy metals like lead, cadmium, and mercury. Table 2.3 below provides a summary of environmental contaminants and their corresponding remediation techniques. According to the study, photocatalysis can be used for treating heavy metal-contaminated wastewater (Ren et al. 2021; Xing et al. 2018). The choice of photocatalyst is important, and specific heavy metals may require different photocatalysts. In summary, these recent advances in photocatalysis research offer potential for the development of efficient and sustainable wastewater treatment methods (Das & Mohanty 2019).

Table 2.3: Environmental contaminants and remediation techniques.

Pollutant types	Sources	Decontamination strategies	Major decontamination strategies	References
Water	Pharmaceutical waste	Physicochemical	Advanced oxidation	(Giri & Golder 2018)
Soil	Infectious materials	Chemical	Photo-catalysts	(Jadoun et al. 2022)
Air	Agricultural pesticides and herbicides	Biological	UV radiation	(De Andrade et al., 2015)
Pesticides	Inorganic and organic	Chemical	Incineration	(Tahir, Kiran & Iqbal 2019)
Landfills	Electronic waste	Physical	Air filtration	(Ghosh et al. 2015)
Dust	Particulate matter	Physical	Filtration	(Das & Mohanty 2019)
Plastics	Industrial waste	Chemical	Adsorption	(Yang et al. 2019)
Organic solvents	Domestic sources	Bioremediation	Oxidation	(Gao & Meng 2021)
Smoke	Industrial activities	Chemical	Electrostatic precipitation	(Wang, Li & Cui 2020)

2.17. Conclusion

In conclusion, catalysis, photocatalysis, and enzyme technologies have shown significant potential in addressing environmental challenges related to heavy metal pollution in air, water, and other environmental resources. Photocatalytic and enzyme-based approaches have proven to be effective in degrading heavy metals from industrial and domestic wastewater. This can help prevent their accumulation in the environment and mitigate the risks they pose to human health and the ecosystem. Furthermore, these technologies provide a sustainable and eco-friendly solution for the treatment of heavy metal-contaminated waste streams. However, more research is needed to develop cost-effective and efficient technologies that can be scaled up for large-scale industrial applications. The ongoing advancement in catalysis, photocatalytic, and enzyme-based research hold the potential to introduce innovative solutions to minimize the adverse effects of heavy metal pollution on the environment and human health. Furthermore, catalysis has proven successful in various domain, including small library synthesis, industrial process optimization, and biocatalysis.

2.18. References

- Abdu, N, Abdullahi, AA & Abdulkadir, A. 2016. Heavy metals and soil microbes. *Environmental Chemistry Letters*. doi.org/10.1007/s10311-016-0587-x.
- Adekiya, AO, Oloruntoba, AP, Ojeniyi, SO & Ewulo, BS. 2018. Heavy metal composition of maize and tomato grown on contaminated soils. 414–426.
- Adiaha, M. 2020a. Economics of Maize (*Zea mays* L .) Production in Nigeria and Maize Traditional Utilization. (June 2017). doi.org/10.14419/ijsw.v5i2.7819.
- Adiaha, M. 2020b. The impact of Maize (*Zea mays* L .) and it uses for human development : A review. (May 2017):9–12. doi.org/10.14419/ijsw.v5i1.7585.
- Adnan, M, Xiao, B, Xiao, P, Zhao, P, Li, R & Bibi, S. 2022. Research Progress on Heavy Metals Pollution in the Soil of Smelting Sites in China. 1–30.
- Afonne, OJ & Ifediba, EC. 2020a. Heavy metals risks in plant foods – need to step up precautionary measures. *Current Opinion in Toxicology*. 22:1–6. doi.org/10.1016/j.cotox.2019.12.006.
- Afonne, OJ & Ifediba, EC. 2020b. Heavy metals risks in plant foods – need to step up

precautionary measures. *Current Opinion in Toxicology*. 22:1–6. doi.org/10.1016/j.cotox.2019.12.006.

Agboola, O, Babatunde, DE, Isaac Fayomi, OS, Sadiku, ER, Popoola, P, Moropeng, L, Yahaya, A & Mamudu, OA. 2020. doi.org/10.1016/j.rineng.2020.100181.

Agboola, O, Babatunde, DE, Sunday, O, Fayomi, I, Rotimi, E, Popoola, P, Moropeng, L, Yahaya, A, et al. 2020. Results in Engineering A review on the impact of mining operation : Monitoring , assessment and management. *Results in Engineering*. 8(October):100181. doi.org/10.1016/j.rineng.2020.100181.

Agnello, AC, Bagard, M, van Hullebusch, ED, Esposito, G & Huguenot, D. 2016. Comparative bioremediation of heavy metals and petroleum hydrocarbons co-contaminated soil by natural attenuation, phytoremediation, bioaugmentation and bioaugmentation-assisted phytoremediation. *Science of the Total Environment*. 563–564:693–703. doi.org/10.1016/j.scitotenv.2015.10.061.

Ahmad, W, Alharthy, RD, Zubair, M, Ahmed, M, Hameed, A & Rafique, S. 2021. Toxic and heavy metals contamination assessment in soil and water to evaluate human health risk. *Scientific Reports*. (0123456789):1–12. doi.org/10.1038/s41598-021-94616-4.

Ahmed, T, Noman, M, Ijaz, M, Ali, S, Rizwan, M, Ijaz, U, Hameed, A, Ahmad, U, et al. 2021. Current trends and future prospective in nanoremediation of heavy metals contaminated soils: A way forward towards sustainable agriculture. *Ecotoxicology and Environmental Safety*. 227:112888. doi.org/10.1016/j.ecoenv.2021.112888.

Ali, MHH & Al-qahtani, KM. 2012. Assessment of some heavy metals in vegetables , cereals and fruits in Saudi Arabian markets. *The Egyptian Journal of Aquatic Research*. 38(1):31–37. doi.org/10.1016/j.ejar.2012.08.002.

Amponsah, R, Kong, X & Abendin, S. 2021. The Impact of Maize Trade on the Development of the Maize Industry in Ghana. 1906–1931. doi.org/10.4236/ojbm.2021.94103.

Andrade, FV De, Lima, GM De, Augusti, R, Silva, JCC, Coelho, MG, Paniago, R & Machado, IR. 2015. Journal of Water Process Engineering A novel TiO₂ / autoclaved cellular concrete composite : From a precast building material to a new floating photocatalyst for degradation of organic water contaminants. *Journal of Water Process Engineering*. 7:27–35. doi.org/10.1016/j.jwpe.2015.04.005.

Anyanwu, BO, Ezejiofor, AN, Igweze, ZN & Orisakwe, OE. 2018. Heavy metal mixture exposure and effects in developing nations: An update. *Toxics*. 6(4):1–32.

doi.org/10.3390/toxics6040065.

de Araújo, SMOO & Chabite, IT. 2022. Market Dynamics in Maize Production in the North Region of Mozambique. 12:55–61. doi.org/10.17265/2161-6264/2022.02.004.

Balali-mood, M, Naseri, K, Tahergorabi, Z & Khazdair, MR. 2021. Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic. 12(April):1–19. doi.org/10.3389/fphar.2021.643972.

Balconi, C, Dinis, I, Revilla, P, Alves, ML, Andelkovi, V, Mendes-moreira, P, Redaelli, R, Ignacio, J, et al. 2022. Traditional Foods From Maize (Zea mays L.) in Europe. 8(January). doi.org/10.3389/fnut.2021.683399.

Bell, EL, Finnigan, W, France, SP, Hepworth, LJ, Lovelock, SL, Hayes, MA, Osuna, S, Romero, E, et al. 2021. Biocatalysis. 0123456789:1–21. doi.org/10.1038/s43586-021-00044-z.

Bender, TA, Dabrowski, JA & Gagné, MR. 2018. Homogeneous catalysis for the production of low-volume, high-value chemicals from biomass. *Nature Reviews Chemistry*. doi.org/10.1038/s41570-018-0005-y.

Berge, HFM, Hijbeek, R, Loon, MP Van, Rurinda, J, Tesfaye, K, Zingore, S, Craufurd, P, Heerwaarden, J Van, et al. 2019. Maize crop nutrient input requirements for food security in sub-Saharan Africa. *Global Food Security*. 23(November 2018):9–21. doi.org/10.1016/j.gfs.2019.02.001.

Bhavya, G, Belorkar, SA, Mythili, R, Geetha, N, Shetty, HS, Udikeri, SS & Jogaiah, S. 2021. Remediation of emerging environmental pollutants: A review based on advances in the uses of eco-friendly biofabricated nanomaterials. *Chemosphere*. 275:129975. doi.org/10.1016/j.chemosphere.2021.129975.

Briffa, J, Sinagra, E & Blundell, R. 2020. Heavy metal pollution in the environment and their toxicological effects on humans. *Heliyon*. 6(9):e04691. doi.org/10.1016/j.heliyon.2020.e04691.

Burek, BO, Dawood, AWH, Hollmann, F, Liese, A & Holtmann, D. 2022. Process Intensification as Game Changer in Enzyme Catalysis. 2(March):1–18. doi.org/10.3389/fctls.2022.858706.

Chen, BWJ, Xu, L & Mavrikakis, M. 2020. Computational Methods in Heterogeneous Catalysis. *Chemical Reviews*. doi.org/10.1021/acs.chemrev.0c01060.

Chen, Z, Muhammad, I, Zhang, Y, Hu, W, Lu, Q, Wang, W, Huang, B & Hao, M. 2021.

Transfer of heavy metals in fruits and vegetables grown in greenhouse cultivation systems and their health risks in Northwest China. *Science of the Total Environment*. 766:142663. doi.org/10.1016/j.scitotenv.2020.142663.

Choudhary, M, Gupta, S, Dhar, MK & Kaul, S. 2021. Endophytic Fungi-Mediated Biocatalysis and Biotransformations Paving the Way Toward Green Chemistry. 9(June):1–10. doi.org/10.3389/fbioe.2021.664705.

Das, B & Mohanty, K. 2019. *A review on advances in sustainable energy production through various catalytic processes by using catalysts derived from waste red mud*. Elsevier B.V. doi.org/10.1016/j.renene.2019.05.114.

Dhital, S & Rupakheti, D. 2019. Correction to : Bibliometric analysis of global research on air pollution and human health : 1998 – 2017. (222):730000.

Dias, P. 2013. Analysis of incentives and disincentives for maize in Mozambique: Technical notes series, MAFAP, FAO, Rome. (March).

Dube, O & Garc, O. 2016. From maize to haze : Agricultural shocks and the growth of the Mexican. 14(October):1181–1224. doi.org/10.1111/jeea.12172.

Eck, NJ van & Waltman, L. 2010. Software survey : VOSviewer , a computer program for bibliometric mapping. 523–538. doi.org/10.1007/s11192-009-0146-3.

Eckert, CT, Frigo, EP, Albrecht, LP, Albrecht, AJP, Christ, D, Santos, WG, Berkembrock, E & Egewarth, VA. 2018. Maize ethanol production in Brazil : Characteristics and perspectives. *Renewable and Sustainable Energy Reviews*. 82(October 2017):3907–3912. doi.org/10.1016/j.rser.2017.10.082.

Edogbo, B, Okolocha, E, Maikai, B & Aluwong, T. 2020. Risk analysis of heavy metal contamination in soil , vegetables and fish around Challawa area in Kano State , Nigeria. *Scientific African*. 7:e00281. doi.org/10.1016/j.sciaf.2020.e00281.

Edokpayi, JN, Odiyo, JO, Edokpayi, N, Odiyo, JO & Durowoju, OS. 2017. Household Hazardous Waste Management in - Impact of Wastewater on Surface Water Quality in sub-Saharan Africa Developing Countries : A Case Study of South Africa.

Ekpa, O, Palacios-rojas, N, Kruseman, G, Fogliano, V & Linnemann, AR. 2019. Sub-Saharan African Maize-Based Foods - Processing Practices , Challenges and Opportunities Sub-Saharan African Maize-Based Foods - Processing Practices ,. *Food Reviews International*. 35(7):609–639. doi.org/10.1080/87559129.2019.1588290.

Eskandari, E, Kosari, M, Davood Abadi Farahani, MH, Khiavi, ND, Saeedikhani, M, Katal, R

- & Zarinejad, M. 2020. A review on polyaniline-based materials applications in heavy metals removal and catalytic processes. *Separation and Purification Technology*. 231:115901. doi.org/10.1016/j.seppur.2019.115901.
- Firoz, OPY, Karjagi, HCG & Zaidi, BKPH. 2015. Genetic Improvement of Maize in India : Retrospect and Prospects. *Agricultural Research*. doi.org/10.1007/s40003-015-0180-8.
- Gao, X & Meng, X. 2021. Photocatalysis for heavy metal treatment: A review. *Processes*. 9(10). doi.org/10.3390/pr9101729.
- Ghosh, S, Kouamé, NA, Ramos, L, Remita, S, Dazzi, A, Deniset-besseau, A, Beaunier, P, Goubard, F, et al. 2015. Conducting polymer nanostructures for photocatalysis under visible light. (March):1–7. doi.org/10.1038/NMAT4220.
- Giri, AS & Golder, AK. 2018. ScienceDirect Ciprofloxacin degradation in photo-Fenton and photo-catalytic processes: Degradation mechanisms and iron chelation. *Journal of Environmental Sciences*. 80:82–92. doi.org/10.1016/j.jes.2018.09.016.
- Grote, U, Fasse, A, Nguyen, TT & Erenstein, O. 2021. Food Security and the Dynamics of Wheat and Maize Value Chains in Africa and Asia. 4(February):1–17. doi.org/10.3389/fsufs.2020.617009.
- Gunalan, S & Vijayalatha, KR. 2020. Heavy metals and its impact in vegetable crops. (May).
- Hanefeld, U, Hollmann, F & Paul, CE. 2022. Biocatalysis making waves in organic chemistry. *Chem. Soc. Rev*. 594–627. doi.org/10.1039/d1cs00100k.
- Haruna, SA, Musa, A & Ayinla, GT. 2021. Trace and Heavy Metal Contamination Status of Soil and Water in Artisanal and Small Scale Gold Mining Vicinity in Kuchiko-Hausa , Gurara LGA, Niger State, Nigeria. 5(1):207–219.
- Hashemi, M. 2018. Ecotoxicology and Environmental Safety Heavy metal concentrations in bovine tissues (muscle , liver and kidney) and their relationship with heavy metal contents in consumed feed. *Ecotoxicology and Environmental Safety*. 154(February):263–267. doi.org/10.1016/j.ecoenv.2018.02.058.
- Hefferon, KL. 2015. Nutritionally Enhanced Food Crops ; Progress and Perspectives. 3895–3914. doi.org/10.3390/ijms16023895.
- Hou, D, O’Connor, D, Igalavithana, AD, Alessi, DS, Luo, J, Tsang, DCW, Sparks, DL, Yamauchi, Y, et al. 2020. Metal contamination and bioremediation of agricultural soils for food safety and sustainability. *Nature Reviews Earth and Environment*. 1(7):366–381. doi.org/10.1038/s43017-020-0061-y.

- Illia, N, Ruzaidy, M & Amid, A. 2020. Heavy Metal Contamination IN Vetetables And Its Detection. 4(1):1–5. doi.org/10.26480/gws.01.2020.01.05.
- Islam, MR, Prabal, NG Das & Belal, BM. 2017. Environmental assessment of water and soil contamination in Rajakhali Canal of Karnaphuli River (Bangladesh) impacted by anthropogenic influences : a preliminary case study. *Applied Water Science*. 7(2):997–1010. doi.org/10.1007/s13201-015-0310-2.
- Izah, SC, Inyang, IR & Angaye, TCN. 2017. A Review of Heavy Metal Concentration and Potential Health Implications of Beverages Consumed in Nigeria. 1–15. doi.org/10.3390/toxics5010001.
- Jadoun, S, Yáñez, J, Mansilla, HD, Riaz, U, Pal, N, Chauhan, S & Crystal, C V. 2022. Conducting polymers / zinc oxide - based photocatalysts for environmental remediation : a review. *Environmental Chemistry Letters*. 20(3):2063–2083. doi.org/10.1007/s10311-022-01398-w.
- Jain, R. 2016. *Environmental impact of mining and mineral processing : management, monitoring, and auditing strategies*.
- Jain, R & Domen, J. 2016. *Environmental Impact of mining and mineral*.
- Jaishan, M, Tseten, T, Anbalagan, N, Mathew, BB & Beeregowda, KN. 2014. Toxicity , mechanism and health effects of some heavy metals. 7(2):60–72. doi.org/10.2478/intox-2014-0009.
- Jena, PR. 2021. Development and Opportunities in the Maize Sector in Eastern and Southern Africa.
- Jiang, Y, Chao, S, Liu, J, Yang, Y & Chen, Y. 2017. Chemosphere Source apportionment and health risk assessment of heavy metals in soil for a township in Jiangsu Province , China. *Chemosphere*. 168:1658–1668. doi.org/10.1016/j.chemosphere.2016.11.088.
- Kakaei, K, Esrafil, M. & Ehsani, A. 2019. Introduction to Catalysis. Particles and catalysts. 1–21. doi.org/10.1016/B978-0-12-814523-4.00001-0.
- Kamunda, C, Mathuthu, M & Madhuku, M. 2016. Health risk assessment of heavy metals in soils from witwatersrand gold mining basin, South Africa. *International Journal of Environmental Research and Public Health*. 13(7). doi.org/10.3390/ijerph13070663.
- Kapuya, T & Sihlobo, W. 2022. South Africa’s maize exports: A Strategic Export Market Analysis model approach By Tinashe Kapuya 1 and Wandile Sihlobo 2. 1–31.
- Karmakar, S & Gouraha, AK. 2018. Economics of Value Added Products of Maize in

- Chhattisgarh. 11(December):889–893. doi.org/10.30954/0974-1712.12.2018.10.
- Korish, MA & Attia, YA. 2020. Meat , Meat Products , Liver , and Table Eggs.
- Kritsanaviparkporn, E, Baena-Moreno, FM & Reina, TR. 2021. Catalytic Converters for Vehicle Exhaust: Fundamental Aspects and Technology Overview for Newcomers to the Field. *Chemistry (Switzerland)*. 3(2):630–646. doi.org/10.3390/chemistry3020044.
- Kumar, T & Mastro, RRE. 2013. Assessment of human health risks from heavy metals in outdoor dust samples in a coal mining area. 347–356. doi.org/10.1007/s10653-012-9499-2.
- Kumar, P, Soo, S, Zhang, M, Fai, Y & Kim, K. 2019. Heavy metals in food crops : Health risks , fate , mechanisms , and management. *Environment International*. 125(February):365–385. doi.org/10.1016/j.envint.2019.01.067.
- Kumar, S, Prasad, S, Kumar, K, Shrivastava, M, Gupta, N, Nagar, S, Bach, Q, Kamyab, H, et al. 2019. Hazardous heavy metals contamination of vegetables and food chain : Role of sustainable remediation approaches - A review. *Environmental Research*. 179(June):108792. doi.org/10.1016/j.envres.2019.108792.
- Lamoureux, PS, Winther, KT & Garrido, A. 2019. Machine Learning for Computational Heterogeneous Catalysis. 1–22. doi.org/10.1002/cctc.201900595.
- Linu-chibuezeh, A & Ugwunnadi, NE. 2020. Determination of Heavy Metals in Some Fruits and Vegetables from Selected Market ' s in Anambra State. 4(4):163–171.
- Lu, Y, Cai, Y, Zhang, S, Zhuang, L, Hu, B, Wang, S, Chen, J & Wang, X. 2022. Application of biochar-based photocatalysts for adsorption-(photo)degradation/reduction of environmental contaminants: mechanism, challenges and perspective. *Biochar*. 4(1). doi.org/10.1007/s42773-022-00173-y.
- Lyu, H, Zhang, Q & Shen, B. 2020. Application of biochar and its composites in catalysis. *Chemosphere*. 240:124842. doi.org/10.1016/j.chemosphere.2019.124842.
- Macauley, H & Ramadjita, T. 2015. Cereal Crops: Rice, Maize, Millet, Sorghum, Wheat.
- Mahurpawar, M. 2015. Effects of heavy metals on human health. 0530.
- Marrugo-negrete, J, Pinedo-hernández, J & Díez, S. 2017. Assessment of heavy metal pollution , spatial distribution and origin in agricultural soils along the Sinú River Basin , Colombia. *Environmental Research*. 154(January):380–388. doi.org/10.1016/j.envres.2017.01.021.
- Mboya, R, Tongoona, P, Derera, J & Mudhara, M. 2011. The dietary importance of maize in Katumba ward , Rungwe district , Tanzania , and its contribution to household food security. (September 2014). doi.org/10.5897/AJAR10.891.

- Mensah, AK, Mahiri, IO, Owusu, O, Mireku, OD, Wireko, I & Kissi, EA. 2015. Environmental Impacts of Mining: A Study of Mining Communities in Ghana. 3(3):81–94. doi.org/10.12691/aees-3-3-3.
- Mihaileanu, RG, Neamtiu, IA, Fleming, M, Pop, C, Bloom, MS, Roba, C, Surcel, M, Stamatian, F, et al. 2019. Assessment of heavy metals (total chromium , lead , and manganese) contamination of residential soil and homegrown vegetables near a former chemical manufacturing facility in Tarnaveni , Romania.
- Mitra, S, Jyoti, A, Montakim, A, Bin, T, Nainu, F, Khusro, A, Idris, AM, Uddin, M, et al. 2022. Journal of King Saud University – Science Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. *Journal of King Saud University - Science*. 34(3):101865. doi.org/10.1016/j.jksus.2022.101865.
- Mohammadi, AA, Zarei, A, Majidi, S, Ghaderpoury, A, Hashempour, Y, Saghi, MH, Alinejad, A, Hosseingholizadeh, N, et al. 2019. MethodsX Carcinogenic and non-carcinogenic health risk assessment of heavy metals in drinking water of. 6:1642–1651. doi.org/10.1016/j.mex.2019.07.017.
- Munn, Z, Peters, MDJ, Stern, C, Tufanaru, C, Mcarthur, A & Aromataris, E. 2018. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. 1–7.
- Nishiori, D, Wadsworth, BL & Moore, GF. 2021. Perspective Parallels between enzyme catalysis , electrocatalysis , and photoelectrosynthesis. *Chem Catalysis*. 1(5):978–996. doi.org/10.1016/j.checat.2021.09.008.
- Nong, W, Liu, X, Wang, Q, Wu, J & Guan, Y. 2020. Metal-organic Framework-based Materials: Synthesis, Stability and Applications in Food Safety and Preservation. *ES Food and Agroforestry*. 1:11–40. doi.org/10.30919/esfaf0001.
- Nuss, ET & Tanumihardjo, SA. 2010. Maize : A Paramount Staple Crop in the Context of Global Nutrition. 9:417–436. doi.org/10.1111/j.1541-4337.2010.00117.x.
- Oluwayemisi, O. 2020. Evaluation of the Sustainability and Environmental Impacts of Mining in the Rustenburg Region Evaluation of the Sustainability and Environmental Impacts of Mining in the Rustenburg Region Olusola Oluwayemisi Ololade. (June).
- Omutiti, GM. 2013. Assessment of selected heavy metals concentrations in fresh fruits and health implications to consumers in Eldoret town, Kenya.
- Oyewo, OA, Adeniyi, A, Bopape, MF & Onyango, MS. 2020. *interactions*. LTD.

doi.org/10.1016/B978-0-12-818032-7.00004-7.

Oymak, T. 2017. Some Heavy Metal Contents of Various Slaughtered Cattle Tissues in Sivas-Turkey. 4(3):721–728.

Pingali, P. 2015. Agricultural policy and nutrition outcomes – getting beyond the preoccupation with staple grains. doi.org/10.1007/s12571-015-0461-x.

Du Plessis, J. 2015. Maize production.

Qin, F, Du, J, Gao, J, Liu, G, Song, Y, Yang, A, Wang, H, Ding, Y, et al. 2020. Bibliometric profile of global microplastics research from 2004 to 2019. *International Journal of Environmental Research and Public Health*. 17(16):1–15. doi.org/10.3390/ijerph17165639.

Qin, G, Niu, Z, Yu, J, Li, Z & Ma, J. 2021. Chemosphere Soil heavy metal pollution and food safety in China : Effects , sources and removing technology. *Chemosphere*. 267:129205. doi.org/10.1016/j.chemosphere.2020.129205.

Ragasa, C. 2017. Moving in the right direction ? The role of price subsidies in fertilizer use and maize productivity in Ghana. (26). doi.org/10.1007/s12571-017-0661-7.

Rajmohan, KS, Chandrasekaran, R & Varjani, S. 2020. A Review on Occurrence of Pesticides in Environment and Current Technologies for Their Remediation and Management. *Indian Journal of Microbiology*. 60(2):125–138. doi.org/10.1007/s12088-019-00841-x.

Ranum, P & Pe, JP. 2014. Global maize production , utilization , and consumption. 1312:105–112. doi.org/10.1111/nyas.12396.

Rawtani, D, Khatri, N, Tyagi, S & Pandey, G. 2018. Nanotechnology-based recent approaches for sensing and remediation of pesticides. *Journal of Environmental Management*. 206:749–762. doi.org/10.1016/j.jenvman.2017.11.037.

Rehman, K, Sajid, M & Akash, H. 2018. Prevalence of exposure of heavy metals and their impact on health consequences. (June 2017):157–184. doi.org/10.1002/jcb.26234.

Ren, G, Han, H, Wang, Y, Liu, S, Zhao, J & Meng, X. 2021. Recent Advances of Photocatalytic Application in Water Treatment : A Review.

Rivera, NM. 2020. *Is Mining an Environmental Disamenity? Evidence from Resource Extraction Site Openings*. Springer Netherlands. doi.org/10.1007/s10640-019-00397-w.

Rosa-Castor, J., Guzmán-Mar, JL., Hernández-Ramírez, A, Garza-González, MT & Hinojosa-Reyes, L. 2014. Science of the Total Environment Arsenic accumulation in maize crop (*Zea mays*): A review. *Science of the Total Environment, The*. 488–489:176–187. doi.org/10.1016/j.scitotenv.2014.04.075.

- Rostami, S, Kamani, H & Shahsavani, S. 2021. Human and Ecological Risk Assessment : An International Environmental monitoring and ecological risk assessment of heavy metals in farmland soils. *Human and Ecological Risk Assessment: An International Journal*. 27(2):392–404. doi.org/10.1080/10807039.2020.1719030.
- Saianand, G, Gopalan, A-I, Wang, L, Venkatramanan, K, Roy, VAL, Sonar, P, Lee, D-E & Naidu, R. 2022. Conducting polymer based visible light photocatalytic composites for pollutant removal: Progress and prospects. *Environmental Technology & Innovation*. 28:102698. doi.org/10.1016/j.eti.2022.102698.
- Sandeep, G, Vijayalatha, KR & Anitha, T. 2019. Heavy metals and its impact in vegetable crops. *International Journal of Chemical Studies*. 7(1):1612–1621. Available from: <http://www.chemijournal.com/archives/2019/vol7issue1/PartAB/7-1-229-742.pdf>.
- Santpoort, R. 2020. The Drivers of Maize Area Expansion in Sub-Saharan Africa . How Policies to Boost Maize Production Overlook the Interests of Smallholder Farmers.
- Shah, TR, Prasad, K & Kumar, P. 2016. Maize — A potential source of human nutrition and health : A review Maize — A potential source of human nutrition and health : A review. *Cogent Food & Agriculture*. 54(1). doi.org/10.1080/23311932.2016.1166995.
- Slukovskii, Z. 2023. Geochemical Indicators for Paleolimnological Studies of the Anthropogenic Influence on the Environment of the Russian Federation : A Review.
- Southern African Grain Laboratory, NP. 2017. South African Maize Crop.
- Srivastava, V, Sarkar, A, Singh, S, Singh, P, de Araujo, ASF & Singh, RP. 2017. Agroecological responses of heavy metal pollution with special emphasis on soil health and plant performances. *Frontiers in Environmental Science*. 5(OCT):1–19. doi.org/10.3389/fenvs.2017.00064.
- Steiner, C, Malashchuk, V, Kubinski, D, Hagen, G & Moos, R. 2019. Catalyst state diagnosis of three-way catalytic converters using di_ erent resonance parameters—a microwave cavity perturbation study. *Sensors (Switzerland)*. 19(16). doi.org/10.3390/s19163559.
- Stephan, DW. 2020. Perspective Catalysis , FLPs , and Beyond. *CHEMPR*. 6(7):1520–1526. doi.org/10.1016/j.chempr.2020.05.007.
- Stevens, T & Madani, K. 2016. Future climate impacts on maize farming and food security in Malawi. *Nature Publishing Group*. (November):1–14. doi.org/10.1038/srep36241.
- Su, T, Shao, Q, Qin, Z, Guo, Z & Wu, Z. 2018. Role of Interfaces in Two-Dimensional Photocatalyst for Water Splitting. doi.org/10.1021/acscatal.7b03437.

- Suhani, I, Sahab, S, Srivastava, V & Singh, RP. 2021. Impact of cadmium pollution on food safety and human health. *Current Opinion in Toxicology*. 27:1–7. doi.org/10.1016/j.cotox.2021.04.004.
- Sun, Y, Li, H, Guo, G, Semple, KT & Jones, KC. 2019. Soil contamination in China : Current priorities , defining background levels and standards for heavy metals. *Journal of Environmental Management*. 251(September):109512. doi.org/10.1016/j.jenvman.2019.109512.
- Swapna, G, Jadesha, G & Mahadevu, P. 2020. Sweet Corn – A Future Healthy Human Nutrition Food. 9(7):3859–3865.
- Sweileh, WM & Moh'd Mansour, A. 2020. Bibliometric analysis of global research output on antimicrobial resistance in the environment (2000–2019). *Global Health Research and Policy*. 5(1). doi.org/10.1186/s41256-020-00165-0.
- Tahir, MB, Kiran, H & Iqbal, T. 2019. The detoxification of heavy metals from aqueous environment using nano-photocatalysis approach : a review.
- Tchounwou, PB, Yedjou, CG, Patlolla, AK & Sutton, DJ. n.d. Heavy Metals Toxicity and the Environment. 1–30.
- Vareda, JP, Valente, AJM & Durães, L. 2019. Assessment of heavy metal pollution from anthropogenic activities and remediation strategies : A review. *Journal of Environmental Management*. 246(December 2018):101–118. doi.org/10.1016/j.jenvman.2019.05.126.
- Verasoundarapandian, G, Lim, ZS, Batrisyia, S, Radziff, M, Taufik, SH, Puasa, NA, Shaharuddin, NA, Merican, F, et al. 2022. Remediation of Pesticides by Microalgae as Feasible Approach in Agriculture : Bibliometric Strategies.
- Verheye, W. 2015. Growth and production of maize: Traditional low- input cultivation.
- Viljoen, AT & Gericke, GJ. 2001. Food habits and food preferences of black South African men in the army (1993-1994) *. 29:100–115.
- Wang, P, Chen, H, Kopittke, PM & Zhao, F. 2019. Cadmium contamination in agricultural soils of China and the impact on food safety *. *Environmental Pollution*. 249:1038–1048. doi.org/10.1016/j.envpol.2019.03.063.
- Wang, PL, Xie, LH, Joseph, EA, Li, JR, Su, XO & Zhou, HC. 2019. Metal-Organic Frameworks for Food Safety. *Chemical Reviews*. 119(18):10638–10690. doi.org/10.1021/acs.chemrev.9b00257.
- Wang, X, Zhang, Y, Geng, Z, Liu, Y, Guo, L & Xiao, G. 2019. Spatial analysis of heavy metals

in meat products in China during. *Food Control*. 104(April):174–180. doi.org/10.1016/j.foodcont.2019.04.033.

Wang, Y, Li, A & Cui, C. 2020. Chemosphere Remediation of heavy metal-contaminated soils by electrokinetic technology : Mechanisms and applicability. *Chemosphere*. (xxxx):129071. doi.org/10.1016/j.chemosphere.2020.129071.

Wegerif, MC. & Wiskere, JSC. 2017. Exploring the Staple Foodscape of Dar es Salaam. 1–16. doi.org/10.3390/su9061081.

Werner, TT, Bebbington, A & Gregory, G. 2019. The Extractive Industries and Society Assessing impacts of mining: Recent contributions from GIS and remote sensing. *The Extractive Industries and Society*. 6(3):993–1012. doi.org/10.1016/j.exis.2019.06.011.

Worlanyo, AS & Jiangfeng, L. 2021. Evaluating the environmental and economic impact of mining for post-mined land restoration and land-use : A review. *Journal of Environmental Management*. 279(September 2020):111623. doi.org/10.1016/j.jenvman.2020.111623.

Wu, F & Guclu, H. 2012. Aflatoxin Regulations in a Network of Global Maize Trade. 7(9). doi.org/10.1371/journal.pone.0045151.

Wu, F & Guclu, H. 2014. Global Maize Trade and Food Security: Implications from a Social Network Model. 33(12):1–18. doi.org/10.1111/risa.12064.Global.

Wu, F, Groopman, JD & Pestka, JJ. 2014. Public Health Impacts of Foodborne Mycotoxins. doi.org/10.1146/annurev-food-030713-092431.

Wuana, RA & Okieimen, FE. 2011. Heavy Metals in Contaminated Soils : A Review of Sources , Chemistry , Risks and Best Available Strategies for Remediation. 2011. doi.org/10.5402/2011/402647.

Xiao, W, Ye, X, Zhang, Q, Chen, D, Hu, J & Gao, N. 2018. Evaluation of cadmium transfer from soil to leafy vegetables: Influencing factors, transfer models, and indication of soil threshold contents. *Ecotoxicology and Environmental Safety*. 164(March):355–362. doi.org/10.1016/j.ecoenv.2018.08.041.

Xing, Z, Zhang, J, Cui, J, Yin, J, Zhao, T, Kuang, J & Xiu, Z. 2018. Applied Catalysis B : Environmental Recent advances in floating TiO₂-based photocatalysts for environmental application. *Applied Catalysis B: Environmental*. 225(October 2017):452–467. doi.org/10.1016/j.apcatb.2017.12.005.

Yakup, NY, Sabow, AB, Saleh, SJ & Mohammed, GR. 2018. Assessment of Heavy Metal in Imported Red Meat Available in the Markets of Erbil City. (6):177–183.

- Yang, B, Zhang, C, Zhang, X, Wang, G, Li, L, Geng, H, Zhang, C, Zhang, X, et al. 2020. Journal Pre-proof. doi.org/10.1016/j.foodcont.2020.107372.
- Yang, C, Miao, G, Pi, Y, Xia, Q, Wu, J, Li, Z & Xiao, J. 2019. Abatement of various types of VOCs by adsorption / catalytic oxidation: A review. *Chemical Engineering Journal*. doi.org/10.1016/j.cej.2019.03.232.
- Yao, Z, Li, J, Xie, H & Yu, C. 2012. Review on Remediation Technologies of Soil Contaminated by Heavy Metals. *Procedia Environmental Sciences*. 16:722–729. doi.org/10.1016/j.proenv.2012.10.099.
- Yaqub, G, Khan, A, Ahmad, MZ & Irshad, U. 2021. Determination of Concentration of Heavy Metals in Fruits , Vegetables , Groundwater , and Soil Samples of the Cement Industry and Nearby Communities and Assessment of Associated Health Risks. 2021:1–9.
- Yi, D, Bayer, T, Badenhorst, CPS, Wu, S & Bornscheuer, UT. 2021. Recent trends in biocatalysis. 50(14). doi.org/10.1039/d0cs01575j.
- Zeymer, C & Hilvert, D. 2018. Directed Evolution of Protein Catalysts. (February):1–27.
- Zhang, X, Zhong, T, Liu, L & Ouyang, X. 2015. Impact of Soil Heavy Metal Pollution on Food Safety in China. 1–14. doi.org/10.1371/journal.pone.0135182.
- Zhu, B, Chen, Y & Wei, N. 2018. Engineering Biocatalytic and Biosorptive Materials for Environmental Applications. *Trends in Biotechnology*. xx:1–16. doi.org/10.1016/j.tibtech.2018.11.005.
- Zyoud, SH. 2019. Global scientific trends on aflatoxin research during 1998-2017: a bibliometric and visualized study. *Journal of Occupational Medicine and Toxicology*. 14(1):1–11. doi.org/10.1186/s12995-019-0248-7.

CHAPTER 3: METHODOLOGY

3.1. Introduction

The purpose of this chapter is to make the process of developing a research framework for supporting an investigation or research study more accessible. A suitable research methodology was designed for this study to achieve the research objectives, supporting relevant data collection, and indicating the correct data analysis. In developing the methodology, researcher successfully applied the theoretical foundations, models, and concepts described in the previous chapter. (Madani 2019; Model & Essential 2018). To answer these problems, the researcher selected specific ideas, techniques, and methods.

3.2. Research methodology

The term ‘methodology’ refers to a general approach to conducting research that outlines the way the research should be conducted (Melnikovas 2019; Boru 2018). Methodology plays an important role in ensuring consistency between tools, techniques, and the underlying philosophy of a thesis (Boru 2018). Research methodology begins by defining the main philosophy, choosing approaches, methods, and strategies, and defining the period that connects the research design and research logic of the main methods and techniques for collecting and analysing data.

3.3. Research framework

Research Onion supports the development of appropriate frameworks that demonstrate appropriate strategies, approaches, and methods for processing research questions. Before undertaking any research, the researcher needed to consider and review the issues listed in the research process (Madani 2019; Tobi & Kampen 2018). This research framework model explains the directive approach to completing the research project. The research onion consists of five layers, the first of which is a positivistic approach in which samples are compared to one another to establish a relationship. Secondly, the deductive approach assists with testing hypotheses to operationalize concepts so that they can be measured and quantified. Thirdly, the quantitative approach facilitates the collection and analysis of data for representative samples. Since the study is based on the assessment of heavy metals in maize, the fourth-layer experimental approach assists with the comparison of the two samples. Measurements,

experiments, and observations form the last layer of data collection. Research timelines, data collection techniques, philosophical orientation, and research approach are all considered through the layers of the onion: philosophical orientation, research approach, appropriate research strategies, and research timelines (Lewis & Thornhill 2019). As shown in Figure 1, each layer of the framework contains a variety of study paradigm strategies and choices made by researcher during the study (Alturki 2021).

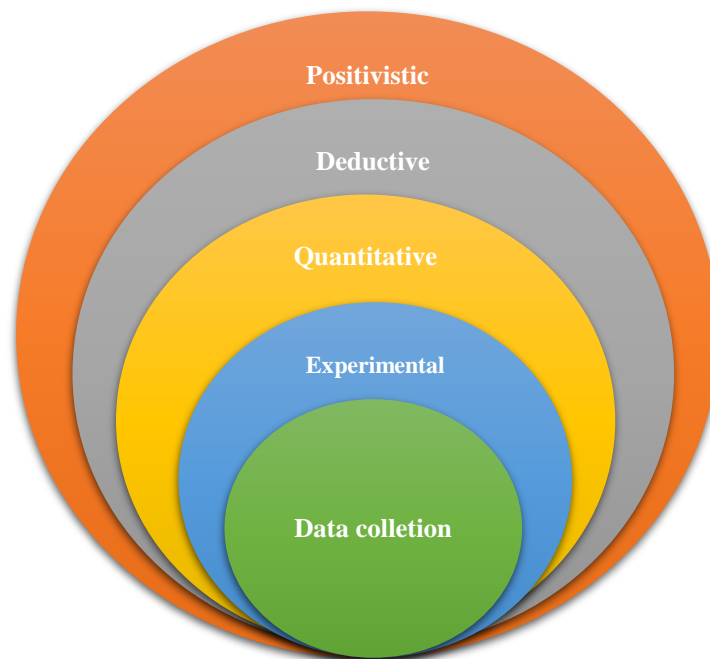


Figure 3.1: Research onion.

3.4. Research philosophy

The research philosophy outlines the beliefs and assumptions about the development of knowledge and provides guidelines for data collection, analysis, and application. The research philosophy adopted by the researcher determined the methodology to be used to answer the research question, the collection of data, the strategy, and the analysis of results (Madani 2019). Various philosophies could be implemented, but the researcher opted for a positivistic approach. A positivistic approach relies on scientific methods and provides a systematized method for generating knowledge by using quantification to enhance precision in describing parameters and their interrelationships (Alturki 2021). In this study, heavy metals in agricultural land and maize were assessed. Positivist approaches have helped identify and explain relationships and causality through quantitative approaches. Positivist science follows

the principles of generalizable reasoning, replication of evidence, and controlled experiments based on historical evidence obtained from large sample sizes (Park & Artino 2020).

3.5. Research approach

The research approach is both inductive and deductive, helping the researcher to collect, analyse, and interpret data (Alturki 2021; Casula, Rangarajan & Shields 2021). In this study, the researcher employed a deductive approach, a method frequently used in natural scientific research. This strategy entailed the rigorous testing of a theoretical framework or hypothesis, which was grounded in existing literature and theories. Specific propositions were examined as part of this process. In such a deductive study, the guiding theory is specified by the researcher, highlighting the key points and clarifies their connection to the research question. To present a balanced argument, one should include the main supporters and critics of the theory in the discussion (Imenda 2018; Sik 2015). Figure 3.2 demonstrates the use of top-bottom, deductive approaches facilitating the collection of data. It may be possible to test the theory based on existing literature, or by specifying the conditions under which it will hold. In addition, the deductive approach enables the generalization of information through inference and hypothesis testing (Alturki 2021; Lewis & Thornhill 2019).

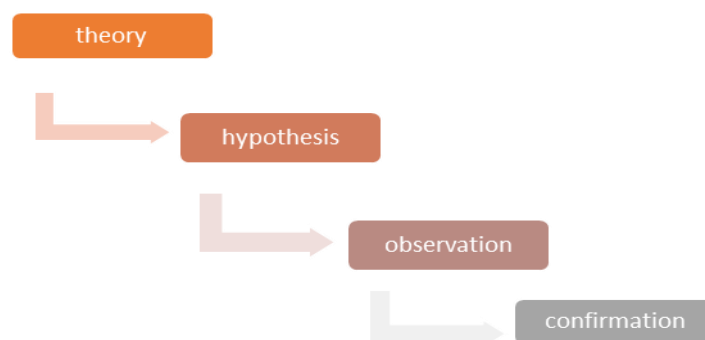


Figure 3.2 Top to bottom.

3.6. Research design

Researchers conduct quantitative research studies to describe the current situation, establish relationships between variables, and possibly explain causal relationships between variables. According to Rahman (2017), this research technique prioritizes quantification in data collecting and analysis. Random sampling is frequently used in quantitative data so that each individual has an equal chance of being chosen and the sample can be generalized to the larger population (Ishtiaq 2019; Creswell 2014). A quantitative study signifies the accumulation of something (Saunders 2020). This research approach seeks to find answers to queries such as how many, how much, and to what degree (Boru 2018). This type of research aims to describe and explain the phenomenon under investigation, sometimes in a definitive fashion. Using a quantitative approach in this study will assist in the selection of variables that are predetermined to be measurable. In this study, a quantitative approach was used to test the validate our hypotheses. The researcher began by examining the basic properties of the data, such as mean, median, mode, range, standard deviation, and variance to understand the data distribution. This was followed by data visualization using graphs and charts to identify trends. Depending on the research question, various statistical tests like t-tests, chi-square tests, ANOVA, or regression analysis were conducted to determine the significance of the results. The researcher then tested the initial hypothesis by comparing the p-value to a significance level, often 0.05, to ascertain if the results were statistically significant. Based on the statistical analysis and hypothesis testing, conclusions were drawn about the research question, considering the study's limitations and the existing body of knowledge. Finally, the findings were reported in a clear, concise manner, using tables and figures for data presentation, ensuring the interpretation was straightforward and backed by the data. This approach allowed the researcher to comparison of data points, identification of patterns, and the drawing of more accurate conclusions about the phenomena under study. By using this method, more accurate predictions were made. Quantitative research conducted to assist the researcher to answer

questions about the relationship between four farm groups and maize samples in relation to heavy metal exposure.

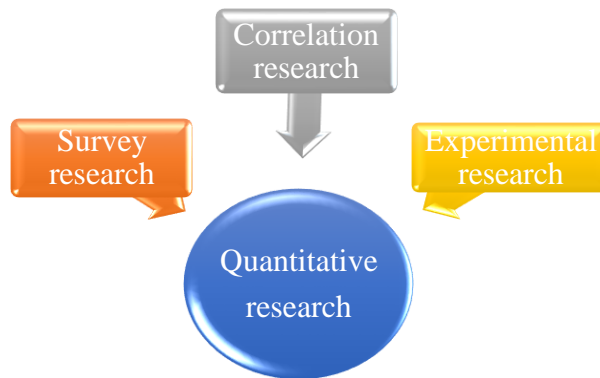


Figure 3.3 Quantitative research.

Figure 3.3 indicates the types of quantitative research methods. Researchers use experimental research to establish various treatments or conditions and then study their effects on participants (Drummond & Murphy-Reyes 2018). Experimental design is scientific and complex in its structure. It may make it difficult for others to replicate research (Model & Essential 2018). The process of collecting, analysing, interpreting, and testing hypotheses is known as experimental research (Patel & Patel 2019). To obtain quality results, researchers should establish their experimental designs and hypotheses before they begin their research. The experimental method in this study assisted in determining the exposure limits of the detected heavy metals in the selected samples. From the randomly selected sample of maize, an experiment was conducted to determine the effects, or if any heavy metals were detected. According to Objectives (2016), experimental studies are the best research design because of their ability to control the treatment conditions and control many external factors and variables can be manipulated under controlled conditions by the researcher to determine causality between one variable (the independent, or predictor variable) and another (Khaldi 2017).

3.7. Sample area.



Figure 3.4 Welkom town, South Africa.

In this study, a selected agricultural farmland situated at lat: S 27 55 7 long: E 26 51 24 was sampled in Riebeeckstad, a suburb 5 km east of Welkom, as indicated in Figure 3.4. The second-largest city in the Free State province, Lejweleputswa, is located within the Lejweleputswa District Municipality. It is 140 kilometres northeast of Bloemfontein, which is the provincial capital. Welkom is known as Matjhabeng. The rapid growth development made the city the second-largest city in the province. Welkom has many industries, including mining, slaughter, steelmaking, sawmilling and a variety of manufacturers.

3.8. Description of samples

Sixteen maize samples were collected separately from the four sample areas of the farm. The area is close to a mining area. Maize is the plant sample taken. Maize is cultivated on approximately 3.64 lakh hectares of land. It can be harvested year-round in regions with favourable climate conditions. However, it's crucial to note that the specific timing of the

harvest can vary. Factors influencing this include the local climate, the maize variety, and the intended use of the harvest. The most prevalent crop in the world is corn, *Zea mays L* (Ranum & Pe 2014). Maize is the most widely cultivated crop and is critical to food security and livelihoods in SSA (Berge et al. 2019). The origin of maize can be traced back 10,000 years to Latin America, specifically Mexico. From there, its cultivation expanded throughout the Americas, Europe, and Asia (Popescu 2018; Olaniyan 2015). Maize is the staple food crop farmed by the majority of South African smallholder farmers (Greyling & Pardey 2019).

3.9. Sampling strategy

3.9.1 Apparatuses and instruments

The researcher used clean and sterilized polyethylene bags to collect maize samples. A microwave oven was used to dry the samples, and an analytical balance was used to weigh them. Cylinders, pipettes, and disposable plastic syringes were used to measure different volumes of sample solutions, acid reagents, and metal standard solutions. The digested samples were filtered using Whatman No. 42 filter paper, and the digestion process was carried out in a laboratory fume hood. The ICP-OES spectrometer was employed to determine the target metals in the maize samples considered in this study.

3.9.2 Chemicals and reagents

In this study, all reagents and chemicals used were of analytical grade. Deionized water was used for all preparation and dilution purposes throughout the experimental procedures. During sample digestion, chemicals such as HNO₃ (69%), H₂O₂ (30%), and deionized water were used. Stock standard solutions of 1,000 ppm were prepared from the corresponding salts for the selected heavy metals (Cu, Zn, As, Fe, Mn, Ni, Pb, and Cd).

3.9.3 Maize sample collection and preparation

The researcher collected the edible parts of maize samples from privately owned farmlands with the consent of the owners. The researcher gathered 16 samples from four randomly selected subsampling sites and combined them to form a composite sample. The samples were collected for a period of a week. The rotten portions were removed, and the samples were transported to the laboratory for further processing. In the laboratory, as shown in Figure 3.5(a), the samples were washed with tap water and deionized water to remove dust and particulate

matter. They were then cut into small pieces, air-dried for two days, and further dried in a hot air oven at 50-60°C for 24 hours. As shown in Figure 3.5(b), the dried samples were ground into powder using a blender, sieved using a 2mm mesh-size sieve, and stored in polyethylene bags until digestion and analysis.



(a) Maize sample before grinding.



(b) powder grounded maize sample

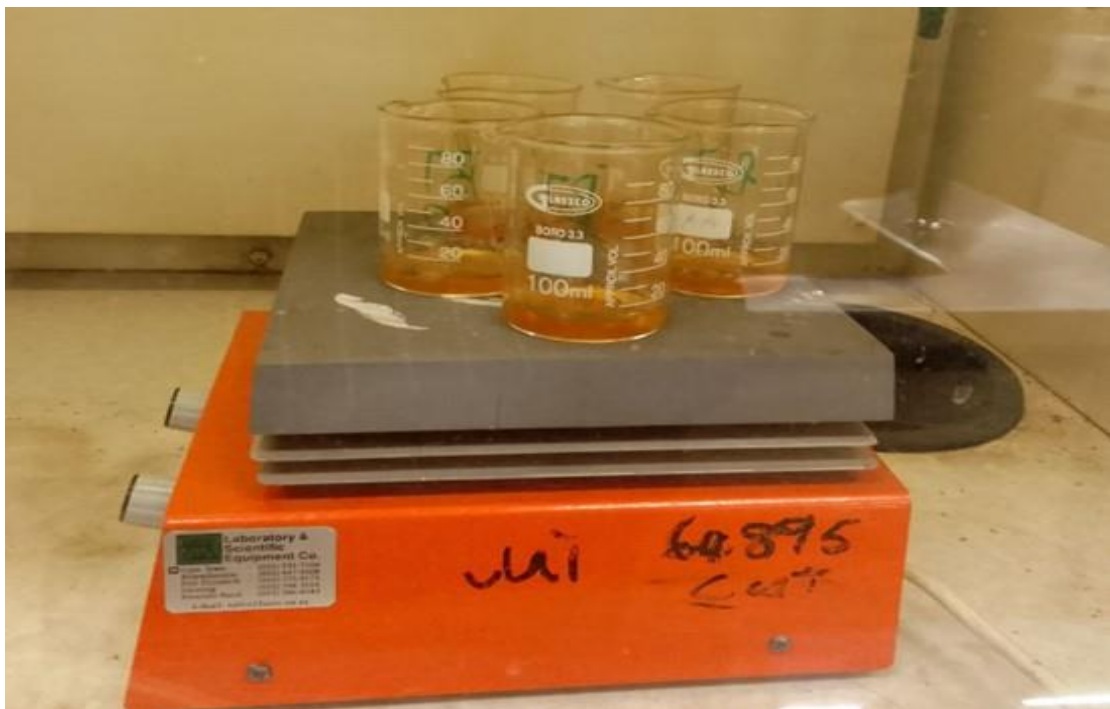
Figure 3.5: Maize samples before grinding and samples grounded into powder.

3.9.4 Digestion procedure of the samples

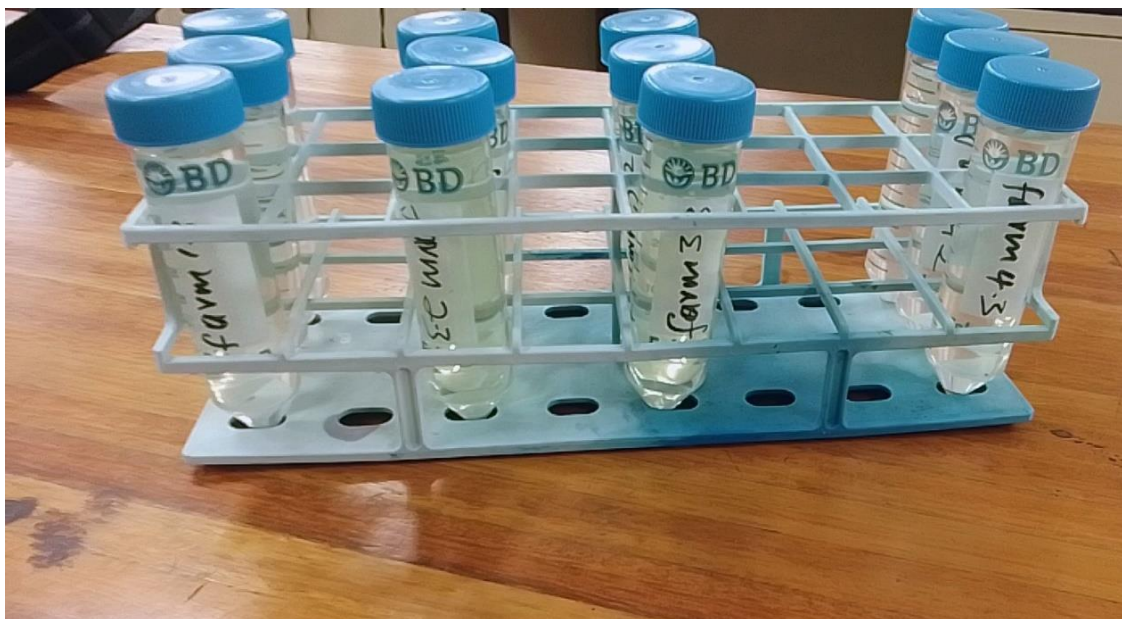
The concentrations of 8 trace elements (As, Cd, Cu, Fe, Mn, Ni, Pb, Zn) were analysed in the samples using an open vessel, acid digestion method. Approximately 0.5 g of the sample was mixed with 10 ml of 65% nitric acid (HNO₃) and 3 ml of 35% hydrogen peroxide (H₂O₂) in a polypropylene centrifuge tube (Nuapia, Chimuka & Cukrowska 2018). These reagents are known to be effective in the digestion of biological samples and minimizing sample loss (Bonemann et al. 2021). The mixture was left at room temperature for 24 hours as part of the pre-digestion process (Figure 3.6a). The mixtures were then heated on a hot plate at 180 °C for 15 minutes to complete the digestion process (Figure 3.6b). After cooling, the digested sample solutions were diluted with ultrapure deionized water, filtered, and transferred to polypropylene tubes that had been washed with ultrapure deionized water Figure 3.6c (Olowoyo, Okedeyi, Mkolo, Lion & Mdakane 2012).



(a) A group test tube in a rack



(b) A group beaker on a hot plate



(c) A group of test tube filled diluted with deionized water in a rack

Figure 3.6: Digestion process: (a) A group test tube in a rack (sample mixed with nitric acid and hydrogen peroxide) (b) A group beaker on a hot plate (sample mixed with nitric acid and hydrogen peroxide), and (c) A group of test tube filled diluted with deionized water in a rack.

3.9.5 Heavy metals analysis of the samples

The researcher determined the concentrations of Cd, Zn, Fe, Pb, As, Mn, Cu, and Ni in maize samples using Inductively coupled plasma optical emission spectroscopy (ICP-OES). The instrument was calibrated using a calibration blank and five working calibration standard solutions for each metal analysed. The calibration procedures were evaluated based on the correlation coefficients (r^2) of the calibration curves, which were found to be greater than 0.998. Additionally, the instrument's parameters, such as plasma power, pump speed, coolant flow, nebulizer flow, etc., were optimized for maximum signal intensity according to the manufacturer's manual.

3.9.6 Health risk assessments

The health risk assessment, which includes both non-carcinogenic and carcinogenic risks, of heavy metals present in fruit juices and canned fruit for consumers in both adult and children age groups, was determined using a specific model. The non-carcinogenic risk of heavy metals was calculated using the Target Hazard Quotient (THQ). In this context, the Chronic Daily

Intake (CDI) refers to the estimated daily intake of heavy metals per kilogram of body weight, while the oral reference dose (RfD) of the heavy metals (mg/kg.d) is determined via the oral exposure route.

$$THQ = \frac{CDi}{RfD} \quad (1)$$

The chronic daily intake (CDI mg/(kg/d)) value was calculated based on the equation below.

$$CDI = \frac{C \times IRi \times EFi \times EDi}{BWi \times AT}$$

The ingestion rate (IRi) per day differs for adults and children. The exposure frequency (EFi) is the same for both age groups, at 365 days for both adults and children. The exposure duration (EDi) is different for adults and children, being 70 and 6 years, respectively. The body weight (BWi) also differs, with children and adults weighing 20 and 70 years, respectively. The average lifespan (AT), calculated as the product of exposure frequency and duration (EF×ED), is 25550 days for adults and 2190 days for children. The Target Hazard Quotient (THQ) is used to assess potential risks. If THQ exceeds 1, there is a likelihood of adverse effects. Conversely, if THQ is less than or equal to 1, adverse effects are unlikely.

$$HI = \sum THQ = THQAs + THQCd + THQCu + THQPb$$

The Hazard Index (HI) estimate indicates the non-carcinogenic risk associated with maize consumption. When the Hazard Quotient (HQ) and HI exceed 1, it suggests potential adverse effects. The total HI is calculated by summing up multiple HQs. It's generally assumed that the severity of any adverse effect increases with the total of multiple exposures.

3.9.7 Statistical analysis

The researcher used Analysis of Variance (ANOVA) to analyse the data and determine if the origin of the samples had an impact on the concentration of heavy metals. They used a one-way ANOVA to check for significant differences between the means, as the level of contamination could vary depending on the sample size., they calculated correlation coefficients to examine the relationship between the target metals. However, given the equal sizes of all groups and only one group violating the normality assumption, it was deemed

appropriate to proceed with an ANOVA analysis. All statistical analyses were performed with a 95% confidence level, using SPSS software (Version 21).

3.10. Ethical considerations

The Faculty Research Committee and the Department of Life Sciences at the Central University of Technology approved this study. The study did not involve any human or animal subjects, and it would not subject anyone to danger.

3.11. References

- Alturki, R. 2021. Research Onion for Smart IoT-Enabled Mobile Applications. 2021.
- Berge, HFM, Hijbeek, R, Loon, MP Van, Rurinda, J, Tesfaye, K, Zingore, S, Craufurd, P, Heerwaarden, J Van, et al. 2019. Maize crop nutrient input requirements for food security in sub-Saharan Africa. *Global Food Security*. 23(November 2018):9–21. doi.org/10.1016/j.gfs.2019.02.001.
- Bonemann, DH, Luckow, ACB, Pereira, CC, Souza, AO de C, Nunes, SAM, Vieira, MA & Ribeiro, AS. 2021. Determination of total concentration and bioaccessible fraction of metals in tomatoes and their derivatives by MIP OES. *Journal of Food Composition and Analysis*. 96(November 2020).
- Boru, T. 2018. Chapter five research design and methodology 5 . 1 . Introduction Citation : Lelissa TB (2018); Research Methodology ; University of South Africa , PHD Thesis. (December). doi.org/10.13140/RG.2.2.21467.62242.
- Casula, M, Rangarajan, N & Shields, P. 2021. exploratory research. *Quality & Quantity*. 55(3):1703–1725. doi.org/10.1007/s11135-020-01072-9.
- Creswell, JW. 2014. *Research Design: qualitative, quantitative, and mixed methods approaches*. 4th ed.
- Drummond, KE & Murphy-Reyes, A. 2018. Quantitative Research Designs: Experimental, Quasi-Experimental and Descriptive.
- Greyling, JC & Pardey, PG. 2019. Measuring Maize in South Africa : The Shifting Structure of Production During the Twentieth Century , 1904 – 2015. 58(1):21–41.

- Imenda, S. 2018. Is There a Conceptual Difference between Theoretical and Conceptual Frameworks? Is There a Conceptual Difference between Theoretical. 8923(January). doi.org/10.1080/09718923.2014.11893249.
- Ishtiaq, M. 2019. Book Review Creswell , J . W . (2014). Research Design : Qualitative , Quantitative and Mixed Methods Approaches (4th ed .). Thousand Oaks , CA : Sage. 12(5):40–41. doi.org/10.5539/elt.v12n5p40.
- Khaldi, K. 2017. Quantitative , Qualitative or Mixed Research : Which Research Paradigm to Use ? 7(2):15–24. doi.org/10.5901/jesr.2017.v7n2p15.
- Lewis, P & Thornhill, A. 2019. “Research Methods for Business Students” Chapter 4: Understanding research philosophy and approaches to theory development. In: *Research Methods for business students*. 42.
- Madani, N. 2019. An Experimental Study to Examine the Teacher ’ s Self- efficacy in Implementing Inclusive Practice when Teaching Learners with Send in International Private Primary School. (October).
- Melnikovas, A. 2019. Towards an Explicit Research Methodology : Adapting Research Onion Model for Futures Studies. 23(January 2018). doi.org/10.6531/JFS.201812.
- Model, B & Essential, Y. 2018. Onion – Made easy to understand and follow. 1–22.
- Nuapia, Y, Chimuka, L & Cukrowska, E. 2018. Chemosphere Assessment of heavy metals in raw food samples from open markets in two African cities. 196.
- Objectives, SL. 2016. Quantitative Research Methods.
- Olaniyan, AB. 2015. Maize : Panacea for hunger in Nigeria. 9(March):155–174. doi.org/10.5897/AJPS2014.1203.
- Olowoyo, JO, Okedeyi, OO, Mkolo, NM, Lion, GN & Mdakane, STR. 2012. Uptake and translocation of heavy metals by medicinal plants growing around a waste dump site in Pretoria , South Africa. *South African Journal of Botany*. 78:116–121. doi.org/10.1016/j.sajb.2011.05.010.
- Park, YS & Artino, AR. 2020. The Positivism Paradigm of Research . 95. doi.org/10.1097/ACM.0000000000003093.
- Patel, M & Patel, N. 2019. Exploring Research Methodology : Review Article Exploring Research Methodology : Review Article. *review*. 6(3):48–55.
- Popescu, A. 2018. MAIZE AND WHEAT - Top Agricultural Products Produced , Exported and Imported by Romania. 18(3).

- Rahman, MS. 2017. The Advantages and Disadvantages of Using Qualitative and Quantitative Approaches and Methods in Language “ Testing and Assessment ” Research : A Literature Review. *Journal of Education and Learning*. 6(1):102–112. doi.org/10.5539/jel.v6n1p102.
- Ranum, P & Pe, JP. 2014. Global maize production , utilization , and consumption. 1312:105–112. doi.org/10.1111/nyas.12396.
- Saunders, MNK. 2020. Common and Key Issues in Mixed Methods Research Common and Key Issues in Mixed Methods Research.
- Sik, K. 2015. Tradition or Modernism in Grammar Teaching : Deductive vs . Inductive Approaches. *Procedia - Social and Behavioral Sciences*. 197(February):2141–2144. doi.org/10.1016/j.sbspro.2015.07.340.
- Tobi, H & Kampen, JK. 2018. Research design : the methodology for interdisciplinary research framework. *Quality & Quantity*. 52(3):1209–1225. doi.org/10.1007/s11135-017-0513-8.

CHAPTER 4: RESULTS

4.1. Introduction

This chapter outlines the results of the assessment of heavy metal contamination on maize crops grown in agricultural land. The study utilized ANOVA and Shapiro-Wilk tests to compare the levels of four heavy metals: arsenic, lead, cadmium, and copper in maize crops grown in different farmlands.

4.2. Description of the analysis procedures

Before an ANOVA analysis can be conducted, the assumptions need to be checked. The assumptions for conducting an ANOVA analysis are as follows:

Assumption 1- Observations should be independent.

Assumption 2- The dependent variable should be measured on at least an interval scale.

Assumption 3- Distributions within groups should be normally distributed. However, evidence suggests that when group sizes are equal ANOVA is quite robust to violations of normality.

Assumption 4- The variances in each experimental condition need to be fairly similar (discussed in the ANOVA section).

The assumptions were checked before an ANOVA analysis can be conducted. For the current study, Assumption 1 was met as the measurement in each data row came from an independent sample. Moreover, Assumption 2 was also met, as the dependent variable of the study was measured using an interval scale. To check Assumption 3, namely whether distributions within groups were normally distributed, the Shapiro-Wilk test was conducted on each group used in the ANOVA analysis.

4.3. The Shapiro-Wilk test

The Shapiro-Wilk test is a way to tell if a random sample comes from a normal distribution. If the p-value of the Shapiro-Wilk test is below 0.05, the group sample is not normally distributed.

The results of the Shapiro-Wilk test for each heavy metal used in the ANOVA analysis are shown in Table 4.1 to Table 4.4. When investigating the p-values in Table 4.1 of the heavy metal As, it can be seen that only the p-value of group 1 is lower than 0.05. As mentioned before, when group sizes are equal, ANOVA is quite robust to violations of normality. One sample was excluded from the analysis due to the presence of negative values in the raw data. This could have been a result of the sample being below the detection limit or a potential error in the standards or calibration. This situation led to significant variances among the samples, thereby restricting the types of post hoc tests that could be conducted. However, given the equal sizes of all groups and only one group violating the normality assumption, it was deemed appropriate to proceed with an ANOVA analysis.

Table 4.1: Shapiro-Wilk test for heavy metal As.

	GROUP	N	Shapiro-Wilk		
			Statistic	df	p-value
AVERAGE	1	3	.759	3	.021
	2	3	.800	3	.114
	3	3	.794	3	.100
	4	3	.933	3	.501

When investigating the p-values in Table 4.2 of the heavy metal Cd condition, it can be seen that none of the p-values are lower than 0.05, indicating that the measurements in each group are normally distributed. An ANOVA analysis can thereby be conducted on the Cd heavy metal data.

Table 4.2: Shapiro-Wilk test for heavy metal Cd.

	GROUP	N	Shapiro-Wilk		
			Statistic	df	p-value
AVERAGE	1	3	.931	3	.493
	2	3	.818	3	.159
	3	3	.853	3	.248
	4	3	1.000	3	.972

When investigating the p-values in Table 4.3 of the heavy metal Cu, it can be seen that only the p-value of group 4 is smaller than 0.05. As mentioned before, when group sizes are equal, ANOVA is quite robust to violations of normality. Due to the group sizes of all groups being equal, and only one group violating the normality assumption, the data were deemed appropriate to conduct an ANOVA analysis.

Table 4.3: Shapiro-Wilk test for heavy metal Cu.

	GROUP	N	Shapiro-Wilk		
			Statistic	df	p-value
AVERAGE	1	3	.795	3	.103
	2	3	.816	3	.154
	3	3	.907	3	.407
	4	3	.750	3	.001

When investigating the p-values in Table 4.4 of the heavy metal Pb, it can be seen that none of the values are smaller than 0.05, indicating that the measurements in each group are normally distributed. An ANOVA analysis can thereby be conducted on the Pb heavy metal data.

Table 4.4: Shapiro-Wilk test for Heavy Metal Pb.

	GROUP	N	Shapiro-Wilk		
			Statistic	df	p-value
AVERAGE	1	3	.822	3	.167
	2	3	.996	3	.872
	3	3	.990	3	.811
	4	3	.978	3	.713

4.4. ANOVA analysis

4.4.1 Arsenic heavy metal

The descriptive statistics for the As heavy metal farm groups are shown in Table 4.5. The assumption that must be met for running an ANOVA analysis is that the variances in each experimental condition need to be similar. The way to test this assumption is to conduct Levene's test of homogeneity of variances. The result of this test is shown in Table 4.6. The p-value of Levene's test is above 0.05. This means that the variances of the different groups are similar and that the assumption of homogeneity of variance for conducting an ANOVA analysis has been met. Consequently, a one-way, between-subjects ANOVA analysis for the As heavy metal condition was conducted and the result is shown in Table 4.7.

Table 4.5: Descriptive statistics for As heavy metal farm groups.

Farm Group	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
1	3	.946111	.1390533	.0802824	.600684	1.291539
2	3	.695000	.1090245	.0629453	.424168	.965832
3	3	.475333	.0095394	.0055076	.451636	.499030
4	3	.263933	.1600313	.0923941	-.133606	.661473
Total	12	.595094	.2837187	.0819025	.414828	.775361

Table 4.6: Levene's Test of Homogeneity of Variances.

Levene Statistic	df1	df2	p-value
3.821	3	8	.057

The results indicated in Table 4.7 show that there was a statistically significant difference between the different farm groups at the 0.05 significance level, $F(3,8) = 18.074$, $p = 0.001$. The effect size of the ANOVA was also calculated as shown in Table 4.8.

Table 4.7: ANOVA table for As heavy metal.

	Sum of Squares	df	Mean Square	F	Sig.
Between groups	.772	3	.257	18.074	.001
Within groups	.114	8	.014		
Total	.885	11			

Partial Eta squared (η_p^2) is a popular measure of effect size for ANOVA and Table 4.8 shows that $\eta_p^2 = 0.871$. This means that 87.1% of the variability of the average level of As in a sample can be accounted for by the farm group to which the sample belongs.

Table 4.8: Effect size of ANOVA.

	Eta	Eta Squared η_p^2
AVERAGE * GROUP	.934	.871

Post-hoc comparisons between all groups were also conducted to determine which groups had statistically significant differences in the level of As found in the samples. When group sizes are equal and group variances are similar (as is the case with this particular analysis), Tukey HSD post-hoc tests should be performed. Tukey's post-hoc tests revealed that there were statistically significant differences between the following groups:

Group 1 (M= 0.946, STD 0.139) and Group 3 (M=0.475, STD=0.009), $p = 0.006$.

Group 1 (M= 0.946, STD 0.139) and Group 4 (M=0.264, STD=0.092), $p = 0.001$.

Group 2 (M=0.695, STD=0.109) and Group 4 (M=0.264, STD=0.092), $p = 0.010$.

4.4.2 Copper heavy metal

The descriptive statistics for the Cu heavy metal farm groups are shown in Table 4.9. One assumption that must be met for running an ANOVA analysis is that the variances in each experimental condition need to be similar. The way to test this assumption is to conduct Levene's test of homogeneity of variances. The results of this test are shown in Table 4.10.

Table 4.9: Descriptive statistics for Cu heavy metal.

Farm Group	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
1	3	.269889	.0061674	.0035608	.254568	.285210
2	3	.260889	.0083022	.0047933	.240265	.281513
3	3	.246778	.0015753	.0009095	.242865	.250691
4	3	.244000	.0057735	.0033333	.229658	.258342
Total	12	.255389	.0121305	.0035018	.247682	.263096

Table 4.10: Levene's Test of Homogeneity of Variances.

Levene Statistic	df1	df2	Sig.
3.440	3	8	.072

As can be seen from Table 4.10, the p-value of Levene's test is above 0.05. This means that the variances of the different groups are similar and that the assumption of homogeneity of variance for conducting an ANOVA analysis has been met. Consequently, a one-way between-subjects ANOVA analysis for the Cu heavy metal condition was conducted and the result is shown in Table 4.11.

Table 4.11: ANOVA table for Cu heavy metal.

	Sum of Squares	df	Mean Square	F	Sig.
Between groups	.001	3	.000	12.449	.002
Within groups	.000	8	.000		
Total	.002	11			

The results indicated in Table 4.11 show that there was a statistically significant difference between the different farm groups at the 0.05 significance level, $F(3,8) = 12.449$, $p = 0.002$. The effect size of the ANOVA was also calculated, as shown in Table 4.12.

Table 4.12: Effect size of ANOVA.

	Eta	Eta Squared η_p^2
AVERAGE * Group	.908	.824

Partial Eta squared (η_p^2) is a popular measure of effect size for ANOVA and Table 4.12 shows that $\eta_p^2 = 0.824$. This means that 82.4% of the variability of the average level of Cu in a sample can be accounted for by the farm group to which the sample belongs.

Post-hoc comparisons between all groups were also conducted to determine which groups had statistically significant differences in the level of Cu found in the samples. When group sizes are equal and group variances are similar (as is the case with this particular analysis), the Tukey HSD post-hoc tests should be performed. Tukey's post-hoc tests revealed that there were statistically significant differences between the following groups:

Group 1 (M= 0.270, STD=0.006) and Group 3 (M=0.247, STD=0.002), $p = 0.006$.

Group 1 (M= 0.270, STD=0.006) and Group 4 (M=0.244, STD=0.006), $p = 0.003$.

Group 2 (M=0.261, STD=0.008) and Group 4 (M=0.244, STD=0.006), $p = 0.035$.

4.4.3 Lead heavy metal

The descriptive statistics for the Pb heavy metal farm groups are shown in Table 4.13. One assumption that must be met for running an ANOVA analysis is that the variances in each experimental condition need to be fairly similar. The way to test this assumption is to conduct Levene's test of homogeneity of variances. The results of this test are shown in Table 4.14.

Table 4.13: Descriptive statistics for Pb heavy metal.

Farm Group	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
1	3	.178111	.0152619	.0088115	.140198	.216024
2	3	.204556	.0287312	.0165880	.133183	.275928
3	3	.152778	.0048572	.0028043	.140712	.164844
4	3	.091122	.0256212	.0147924	.027476	.154769
Total	12	.156642	.0473575	.0136709	.126552	.186731

Table 4.14: Levene's Test of Homogeneity of Variances.

Levene Statistic	df1	df2	Sig.
1.615	3	8	.261

As can be seen from Table 4.14, the p-value of Levene's test is above 0.05. This means that the variances of the different groups are similar and that the assumption of homogeneity of variance for conducting an ANOVA analysis has been met. Consequently, a one-way between-subjects ANOVA analysis for the Pb heavy metal condition was conducted and the results are shown in Table 4.15.

Table 4.15: ANOVA table for Pb heavy metal.

	Sum of Squares	df	Mean Square	F	Sig.
Between groups	.021	3	.007	16.255	.001
Within groups	.003	8	.000		
Total	.025	11			

The results indicated in Table 4.15 show that there was a statistically significant difference between the different farm groups at the 0.05 significance level, $F(3,8) = 16.255$, $p = 0.001$. The effect size of the ANOVA was also calculated as shown in Table 4.16.

Table 4.16: Effect size of ANOVA.

	Eta	Eta Squared η_p^2
Average * group	.927	.859

Partial Eta squared (η_p^2) is a popular measure of effect size for ANOVA and Table 4.16 shows that $\eta_p^2 = 0.859$. This means that 85.9% of the variability of the average level of Pb in a sample can be accounted for by the farm group to which the sample belongs.

Post-hoc comparisons between all groups were also conducted to determine which groups had statistically significant differences in the level of Pb found in the samples. When group sizes are equal and group variances are similar (as is the case with this particular analysis), Tukey HSD post-hoc tests should be performed. Tukey's post-hoc tests revealed that there were statistically significant differences between the following groups:

Group 1 (M=0.178, STD=0.015) and Group 4 (M=0.091, STD=0.026), $p=0.004$.

Group 2 (M=0.205, STD=0.029) and Group 4 (M=0.091, STD=0.026), $p=0.001$.

Group 3 (M=0.153, STD=0.005) and Group 4 (M=0.091, STD=0.026), $p = 0.028$.

4.4.4 Cadmium heavy metal

The descriptive statistics for the Cd heavy metal vegetable groups are shown in Table 4.17.

Table 4.17: Descriptive statistics for Cd heavy metal.

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
1	3	.200222	.0058721	.0033903	.185635	.214809
2	3	.188889	.0140013	.0080837	.154108	.223670
3	3	.174222	.0102866	.0059390	.148669	.199776
4	3	.169889	.0133347	.0076988	.136764	.203014
Total	12	.183306	.0158627	.0045792	.173227	.193384

One assumption that must be met for running an ANOVA analysis is that the variances in each experimental condition need to be fairly similar. The way to test this assumption is to conduct Levene's test of homogeneity of variances. The results of this test are shown in Table 4.18.

Table 4.18: Levene's Test of Homogeneity of Variances.

Levene Statistic	df1	df2	Sig.
.870	3	8	.496

As can be seen from Table 4.18, the p-value of Levene's test is above 0.05. This means that the variances of the different groups are similar and that the assumption of homogeneity of variance for conducting an ANOVA analysis has been met. Consequently, a one-way between-subjects ANOVA analysis for the Cd heavy metal condition was conducted and the results are shown in Table 4.19.

Table 4.19: ANOVA table for Cd heavy metal.

	Sum of Squares	df	Mean Square	F	Sig.
Between groups	.002	3	.001	4.511	.039
Within groups	.001	8	.000		
Total	.003	11			

The results indicated in Table 4.19 show that there was a statistically significant difference between the different farm groups at the 0.05 significance level, $F(3,8) = 4.511$, $p = 0.039$. The effect size of the ANOVA was also calculated as shown in Table 4.20.

Table 4.20: Effect size of ANOVA.

	Eta	Eta Squared η_p^2
AVERAGE * group	.793	.628

Partial Eta squared (η_p^2) is a popular measure of effect size for ANOVA and Table 4.20 shows that $\eta_p^2 = 0.628$. This means that 62.8% of the variability of the average level of Cd in a sample can be accounted for by the farm group to which the sample belongs.

Post-hoc comparisons between all groups were also conducted to determine which groups had statistically significant differences in the level of Cd found in the samples. When group sizes are equal and group variances are similar (as is the case with this particular analysis), Field (2015) advises that Tukey HSD post-hoc tests should be performed. Tukey's post-hoc tests revealed that there were statistically significant differences between the following groups:

Group 1 (M=0.200, STD=0.006) and Group 4 (M=0.170, STD=0.013), $p=0.045$.

4.5. Conclusion

In conclusion, this study has provided crucial insights into the factors that contribute to heavy metal exposure in agricultural land. The findings have helped to identify areas with high levels of heavy metal exposure and potential sources of contamination. Specifically, heavy metals such as arsenic and cadmium were found to have high levels of concentration. Chapter 5 will cover the interpretation of the results for further understanding.

4.6. References

Field, A. (2015) *Discovering statistics using SPSS*. London, England: SAGE.

CHAPTER 5: DISCUSSION

The heavy metal compliance assessment of maize samples from selected farms in the Welkom area using ICP-OES: Human health risk assessment.

Lebohang Klaas Letsitsa¹ and Kgomotso Lebelo¹

¹Central University of Technology, Free State, Department of Life Sciences, Private Bag X20539, Bloemfontein, 9301, South Africa

ABSTRACT

A primary global concern today is environmental pollution due to heavy metals and food safety issues. Heavy metal concentrations in vegetables, fruits, and other food crops have increased due to population growth, urbanization, and other anthropogenic activities. Agricultural products cultivated on contaminated soils contain high levels of toxic metals, which affect the heavy metal content of food. Vegetables are a staple food and a fundamental component of modern agriculture. The Inductively Coupled Plasma Optical Emissions Spectrometry ICP-OES was used to analyse target metals in vegetable and soil samples. In addition, both adults' and children's exposure concentrations were assessed based on probabilistic risk assessments for health risks. In this study, 16 samples of maize crops from 4 selected farms were collected in Riebeeckstad, South Africa, and tested for the presence of arsenic (As), copper (Cu), lead (Pb), and cadmium (Cd). The results show that the mean concentration of As and Pb from the farm groups exceeds the maximum allowable limit for metals by the Food Authority Organization and World Health Organization. The hazard quotient values were ≥ 1 , which indicates that there is no likelihood of adverse health risks. The hazard index for adults was ≥ 1 , which suggests that there are no future cancer risks. The sequences of the concentrations were as follows: $As > Cd > Cu > Pb$. A low hazard quotient may be a result of the use of environmentally friendly fertilizers and pesticides in maize crops, as well as the location of the farms away from heavy industries and polluted land. Local farmers need to follow precautionary steps to prevent contamination of food sources.

Keywords: contamination, environmental pollution, food safety, toxic metals, ICP-OES, hazard index, health risk assessment

5.1. Introduction

In agriculture, grains are the seeds of cultivated grasses that provide a significant portion of human caloric intake. Wheat, maize, and rice account for 94% of the total cereal consumption, despite over a dozen cereals being grown for food.

Zea mays L. (maize) cereals can accumulate contaminants, making them vulnerable to heavy metal toxins like cadmium (Cd), copper (Cu), zinc (Zn), nickel (Ni), cobalt (Co), chromium (Cr), lead (Pb), and arsenic (As). These toxins are found in agricultural soils that are slightly or moderately contaminated in many regions of the world. There are several possible causes of this, including poor watering practices, phosphatic fertilizer, dust horn smelters, sewage sludge, and industrial waste. These are all contributing factors (Aladesanmi, Oroboade & Osisioigu 2019; Onakpa, Njan & Kalu 2018).

Heavy metal toxicity concerns have emerged as a significant concern in environmental health. These toxic substances pose a danger, as they accumulate and spread through the food chain. Research indicates that human activities, including agriculture, mining, and industrial processes, contribute to heavy metal release into the soil, water, and air. Consequently, heavy metals in urban soils are often associated with industrial sites and agricultural regions (Afonne & Ifediba 2020; Callistus & Afolayan 2012) and due to population growth, urbanization, and other anthropogenic activities, metal concentrations in vegetables, fruits, and other food crops have increased (Dessie, Robele, Mihret, Desta & Mehari 2021). Agriculture is a significant source of bioavailable heavy metals released to the environment by anthropogenic activities. Therefore, agricultural soils would also increase the uptake of heavy metals by crops and thus increase the consumption of heavy metals by humans (Zhang, Zeiss & Geng 2015; Malan, Cyster, Raitt & Aalbers 2014).

Due to their toxicity, ubiquity, persistence, non-biodegradability, and bioaccumulation, heavy metals have become a global health concern in recent years. Their presence in agricultural soils and vegetables makes them one of the world's most serious environmental problems (Kumar et al., 2019). If heavy metals are consumed more than their permissible limits, they are highly

toxic to plants and humans. Since the onset of the industrial revolution and the advent of economic globalization, there has been a remarkable proliferation of environmental pollutants, originating from an extensive array of anthropogenic sources (Kamunda, Mathuthu & Madhuku 2016). As a result, the global community has become increasingly concerned about the wide range of evolving challenges related to food security, recognizing their undeniable connection to human health (Wen-yan & De 2018).

Exposure to heavy metals from the consumption of contaminated vegetables and their toxicity is a serious concern. Vegetables grown in fields contaminated with heavy metals, or in fields near sources of heavy metal pollution, can accumulate higher levels of these metals (Zhang *et al.*, 2015). The application of wastewater over long periods results in the heavy metal build-up that affects soil functioning reduces vegetable nutritional quality, is toxic to crops, and contaminates the food chain due to its long-term application. The bioaccumulation of heavy metals occurs in vegetables, crops, and people due to continuous intake (Aladesanmi *et al.*, 2019). Soil's role in ensuring food safety is pivotal, as it directly influences the quality of food and acts as the foundation of the food chain. The presence of contaminants in soil poses a significant risk to human health, as they can enter the food chain and render crops unsafe for consumption (Wang, Chen, Kopittke & Zhao 2019). Heavy metals can cause disturbances in the body when they are consumed through food consumed from contaminated vegetables (Lull & Ram 2019).

Vegetables play a vital role in maintaining a healthy human diet by providing essential nutrients that support normal bodily functions. However, fertilizers and pesticides have resulted in heavy metal accumulation in vegetable gardens (Manzoor, Sharma & Wani 2018). When continuously exposed to heavy metals, the body begins to use them as a replacement for essential elements, leading to an internal imbalance (Rehman, Sajid & Akash 2018). According to research, scientists have found that food contains a high amount of toxic trace metals (Lion & Olowoyo 2013). The high levels of heavy metals in vegetables and fruits could pose a direct threat to human health (Kumar, Soo, Zhang, Fai & Kim 2019; Ramteke, Sahu, Dahariya & Patel 2016).

Global food security has become a major concern for human health because of the variety of threats it faces (Wang, Zhang, *et al.* 2019). As a result, people from poverty-stricken

communities find themselves having to resort to buying cheaper fruit and vegetables as a measure to ensure that they meet the minimum dietary requirements due to toxic metal exposure and heavy metal contamination that have increased at an unprecedented rate in meat, meat products, vegetables, and fish (Di Bella et al. 2020). Some food products may be more contaminated than others due to the nature of the contamination. This could be due to a variety of factors, including varying pesticide exposure, differences in plant uptake mechanisms from the environment, or contaminants from food packaging (Kumar, Prasad, et al. 2019). Individuals are exposed to these contaminants based on their dietary habits. As an example, nursing neonates are exposed to a high level of contaminants excreted in breast milk. Different toxic effects may also result from exposure at different stages of life. Childhood obesity and blood pressure have been linked to prenatal exposure to persistent organic pollutants (Thompson 2019).

The presence of high levels of heavy metals in the human body can result from contaminated food and water, as well as polluted air. Research indicates that environmental pollutants, including heavy metals and metalloids, can significantly impact negative pregnancy outcomes (Guo et al. 2019; Mihaileanu et al. 2019). Governments must address the potential health hazards linked to elevated levels of heavy metals in the human food chain. This concern is particularly significant for pregnant women and their unborn children due to their heightened vulnerability to such contaminants. Consequently, governments must implement measures aimed at reducing heavy metal levels in the environment to safeguard citizens' well-being. As these nations strive to sustain and improve their economies, food safety issues are undoubtedly a big challenge. World Health Organization data indicate that foodborne illnesses contribute to the disease burden in underdeveloped nations, which affects their economy. Food safety standards have been set by several nations worldwide for the maximum tolerable levels of certain contaminants in food (Wu & Guclu 2012). Therefore, a few regulatory limits of heavy metals found in grains and vegetables have been listed in Table 5.1.

Table 5.1: Grain and vegetables regulatory limits.

Foodstuff	Metal	Limit (mg/kg or mg/l)
Cereal grain	cadmium (Cd),	0.1
	lead (Pb)	0.2
Leafy vegetables	cadmium (Cd),	0.1
	lead (Pb)	0.3
Legumes vegetables	cadmium (Cd),	0.1
	lead (Pb)	0.1
Bulb vegetables	cadmium (Cd),	0.05
	lead (Pb)	0.1

Foodstuff cosmetics and disinfectants Act (Department of Health, 2011)

This research aimed to evaluate the trace metal contamination in maize in the region of Welkom in the Free State province, South Africa. The objective was to measure the heavy metal concentration in maize against the maximum allowable limits for heavy metals in vegetables as per the Codex Alimentarius and Foodstuff, Cosmetics and Disinfectants Act of South Africa.

Moreover, risk assessments were conducted for adults based on the hazard quotient and the estimated daily intake. This will assist in creating baseline data to understand the exposure levels of maize grown in an industrial area.

5.2. Material and methods

5.2.1 Sample collection

Maize (*Zea mays L.*), commonly known as corn, holds a significant position as the primary grain crop worldwide. Its productivity is of the utmost importance, as it serves as a staple crop, contributing to 20% of calorie intake and occupying 13% of the total cultivated land in Sub-Saharan Africa (SSA). For this study, field sampling was conducted on selected agricultural farmlands situated at coordinates (S 27 55 7; E 26 51 24) in Riebeeckstad, within the Lejweleputswa District Municipality. All collected samples were preserved in their original packaging.

5.2.2 Experiment Procedure

Apparatuses and instruments

To collect soil and maize samples, the researcher used clean and sanitized polyethylene bags. A microwave oven was employed to dry the maize samples. The processed samples were weighed using an analytical balance while measuring cylinders, pipettes, and disposable plastic syringes were used to measure various quantities of sample solutions, acid reagents, and metal reference solutions. The digestion was carried out under a fume hood in a laboratory. The ICP-OES Spectrometer was used in this study to analyse and evaluate the amounts of various metals in maize samples.

Chemicals and reagents

Chemicals such as (nitric acid (HNO₃), hydrogen peroxide (H₂O₂) and deionized water were used during sample digestion procedures.

Maize sample collection and preparation

Maize samples were obtained with the permission of farmers from privately owned farmlands and stored in Ziploc plastic bags. These samples were transported to the laboratory for further analysis, where they were washed with tap water and deionized water to remove any dust or particulate matter (Gebeyehu, Danno & Id 2020). The maize samples were sliced and diced into small pieces using a plastic knife to facilitate drying. They were then air-dried for two days and further dried in a hot air oven at 50-60°C for 24 hours to remove moisture and maintain a constant weight. The dried samples were ground into powder using a blender and sieved through a 2mm mesh-size sieve. Finally, the sieved samples were stored in polyethylene bags and kept in desiccators until digestion and analysis.

Digestion procedure and ICP OES analysis

The samples were analysed to determine the concentration of eight trace elements (arsenic, cadmium, copper, iron, manganese, nickel, lead and zinc). The samples were digested using an open-vessel acid digestion method. Approximately 0.5 grams of sample were weighed using an analytical balance and mixed with 10 ml of 65% nitric acid (HNO₃) and 3 ml of hydrogen peroxide 35% (H₂O₂) in a polypropylene centrifuge tube. To prevent contamination and analytic loss, the tubes were sealed with a small hole for oxygen release from the hydrogen peroxide reaction. The mixtures were left at room temperature for pre-digestion for 24 hours, resulting in most samples becoming transparent. Afterwards, the mixtures were transferred to

volumetric flasks and heated on a hot plate for 15 minutes at 180 °C under a fume hood until digestion was complete and the hydrogen gas had escaped. The digested sample solutions were then cooled to room temperature and brought to a volume of 50 ml with ultrapure deionized water. The solutions were filtered using a Nalgene filtration system with throttle bottles and a 0.2-micron nitrate membrane filter. The filtrate was transferred to 50 ml polypropylene tubes that had been washed with ultrapure deionized water. The same method was used to prepare blanks for each sample. The analysis of the vegetable samples was performed using a Plasma Atomic Emissions Spectrometer (Shimadzu, Model ICPE9820, made in Japan), with the instrument parameters listed in Table 5.2.

Table 5.2: Instrument parameters for ICP OES and SEM-EDS.

<i>ICP-OES</i>	Power (kW)	1.21
	Plasma Argon flow rate (L/min)	14.00
	OCD temperature (C)	-14.99
	Auxiliary Argon flow rate	1.20
	Nebulizer Argon flow rate	0.70
	Pump rate (rpm)	0
	Direction	Axial

Heavy metals analysis of the samples

The contents of Cd, Zn, Fe, Pb, As, Cu, and Ni in maize samples were measured using ICP-OES. The instrument was calibrated before analysis using a blank and five working calibration standard solutions for each metal. The effectiveness of the calibration procedure was evaluated by examining the correlation coefficients (r^2) of the calibration curves, which were found to exceed 0.998. To optimize the signal intensity of the instrument, parameters such as plasma power, pump speed, coolant flow, and nebulizer flow were adjusted according to the manufacturer's manual.

Statistical analysis

In this study, the researcher used the Statistical Package for Social Sciences (SPSS version 27) to perform statistical analysis. They used central tendency statistics such as the mean, range, and standard deviation in their analysis. A one-way analysis of variance (ANOVA) was

employed to evaluate significant differences, and the Shapiro-Wilk test was used to assess whether the samples were from a normal distribution.

Health risk assessment

Several research studies have shown that heavy metal exposure can occur via water, soil, and food consumption. In this study, EDI and THQ were used to assess the potential health risks associated with heavy metal exposure. THQ, according to Ramteke et al. (2016), is a non-cancer risk assessment formula that combines exposure and references oral dose (RfD). By calculating THQ (Real, Azam & Majed 2017), the non-carcinogenic risk of heavy metals can be estimated. A chronic daily intake of heavy metals is calculated as the amount of ingested heavy metals per kilogram of body weight. The (RfD) is the oral reference dose of metals measured in milligrams per kilogram per day (mg/kg/d) when ingested (Lebelo and Mochane, 2022).

$$THQ = \frac{CDi}{RfD} \quad (1)$$

The chronic daily intake (CDI mg/(kg/d)) value was calculated based on the equation below.

$$CDI = \frac{C \times IRi \times EFi \times EDi}{BWi \times AT} \quad (2)$$

Ci (mg/kg) represents the concentration of heavy metals in maize. IR represents the average daily intake (kg/d) of maize grains for adults in South Africa, and EDi is the exposure duration estimated to be 70 years for adults. EFi is the exposure frequency presented in 365 days for both adults and children. BWi represents the average body weight which is estimated as 70 kg, and the average exposure time is measured in days for adults and denoted as AT (EF × ED), 25550. The hazard index estimate signifies the consumption of maize with non-carcinogen risk (Yang, Ma & Zhou 2018). HQ and HI are greater than 1, and the exposure shows potentially adverse effects. The hazard index (HI) for the non-carcinogen risk of a variety of heavy metals was calculated using the equation denoted below.

$$HI = \sum THQ = THQ_{As} + THQ_{Cd} + THQ_{Cu} + THQ_{Pb} \quad (3)$$

The total hazard index is estimated by the sum of multiple hazard quotients. It is assumed that the severity of the adverse effect is positively correlated to the total of multiple exposures

(Lebelo and Mochane, 2022). Table 5.3 shows the input parameters characterising the CDI values.

Table 5.3: Input parameters to characterise CDI value.

Exposure parameters	Symbols	Units	Values
Concentration	Ci	mg/kg	-
Ingestion rate	IR	kg/day	0.015
Exposure frequency	EF	days/year	365
Exposure duration	ED	years	70
Adult BW	BW	kg	70
Child BW	BW	kg	16
Average time	AT	years	25 550 days

5.3. Results and discussion

5.3.1 Analysis of variance (ANOVA)

Assumptions were checked before an ANOVA analysis could be conducted. Observations should be independent for an ANOVA analysis to be conducted. Firstly, the assumption was met for the current study, since each data row represents measurements from an independent sample. Secondly, the assumption was also met, as the dependent variable was measured on an interval scale. Lastly, running an ANOVA analysis that the variances in each experimental condition need to be similar (Field, 2015).

On each group used in the ANOVA analysis, the Shapiro-Wilk test was conducted to determine whether the distributions within groups were normally distributed, as indicated in Table 5.4. If the p-value of the Shapiro-Wilk test is below 0.05, the group sample is not normally distributed. The results of the Shapiro-Wilk test for each heavy metal used in the ANOVA analysis are shown in Table 5.5. When investigating the p-values of the heavy metal Cu, it can be seen that only the p-value of Farm Group 4 is 0.05. Due to the group sizes of all groups being equal, and only one farm group violating the normality assumption, the data were deemed appropriate to conduct an ANOVA analysis. When investigating As, Cd, and Pb, it can be seen that none of the values are lower than 0.05, indicating that the measurements in each farm group are

normally distributed. An ANOVA analysis can thereby be conducted on the As, Cd, and Pb heavy metal data.

Table 5.4: Descriptive stats for Farm groups Trace.

Trace elements	Farm Group	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
						Lower Bound	Upper Bound
As	1	3	.946111	.1390533	.0802824	.600684	1.291539
	2	3	.695000	.1090245	.0629453	.424168	.965832
	3	3	.475333	.0095394	.0055076	.451636	.499030
	4	3	.263933	.1600313	.0923941	-.133606	.661473
	Total	12	.595094	.2837187	.0819025	.414828	.775361
Cu	1	3	.269889	.0061674	.0035608	.254568	.285210
	2	3	.260889	.0083022	.0047933	.240265	.281513
	3	3	.246778	.0015753	.0009095	.242865	.250691
	4	3	.244000	.0057735	.0033333	.229658	.258342
	Total	12	.255389	.0121305	.0035018	.247682	.263096
Cd	1	3	.200222	.0058721	.0033903	.185635	.214809
	2	3	.188889	.0140013	.0080837	.154108	.223670
	3	3	.174222	.0102866	.0059390	.148669	.199776
	4	3	.169889	.0133347	.0076988	.136764	.203014
	Total	12	.183306	.0158627	.0045792	.173227	.193384
Pb	1	3	.178111	.0152619	.0088115	.140198	.216024
	2	3	.204556	.0287312	.0165880	.133183	.275928
	3	3	.152778	.0048572	.0028043	.140712	.164844
	4	3	.091122	.0256212	.0147924	.027476	.154769
	Total	12	.156642	.0473575	.0136709	.126552	.186731

Table 5.5: The Shapiro-Wilk test for trace elements.

Shapiro-Wilk					
	FARM	N	Statistic	df	p-value
AVERAGE As	1	3	.759	3	.021
	2	3	.800	3	.114
	3	3	.794	3	.100
	4	3	.933	3	.501
AVERAGE Cd	1	3	.931	3	.493
	2	3	.818	3	.159
	3	3	.853	3	.248
	4	3	1.000	3	.972
AVERAGE Cu	1	3	.795	3	.103
	2	3	.816	3	.154
	3	3	.907	3	.407
	4	3	.750	3	.001
AVERAGE Pb	1	3	.822	3	.167
	2	3	.996	3	.872
	3	3	.990	3	.811
	4	3	.978	3	.713

The way to test this assumption is to conduct Levene's test of homogeneity of variances. The p-value of Levene's test shown in **Table 5.6** is above 0.05. This means that the variances of the different farm groups are similar and that the assumption of homogeneity of variance for conducting an ANOVA analysis has been met.

Table 5.6: Levene's test for As, Cu, and Pb.

	Tests	Statistics	df1	df2	p-value
As	Levene	3.821	3	8	.057*
Cu	Levene	3.440	3	8	.072*
Cd	Levene	.870	3	8	.496*
Pb	Levene	1.615	3	8	.261*

*= P value <0.05

Consequently, a one-way, between-subjects ANOVA analysis for As, Cd, Cu, and Pb heavy metal conditions was conducted, and the result is shown in **Table 5.7**. Furthermore, the results indicate that there was a statistically significant difference between the different farm groups at the 0.05 significance level.

Table 5.7: ANOVA table for heavy metals.

		Sum of Squares	df	Mean Square	F	Sig.
As	Between groups	.772	3	.257	18.074	.001
	Within groups	.114	8	.014		
	Total	.885	11			
Cd	Between groups	.002	3	.001	4.511	.039
	Within groups	.001	8	.000		
	Total	.003	11			
Cu	Between groups	.001	3	.000	12.449	.002
	Within groups	.000	8	.000		
	Total	.002	11			
Pb	Between groups	.021	3	.007	16.255	.001
	Within groups	.003	8	.000		
	Total	.025	11			

5.3.2 Human health risk assessment

The results of heavy metals concentration in maize grain are shown in Figure 5.1. The As concentration of maize was above the maximum limit of 0.1 mg/kg of FAO/WHO limits for all the farm groups, with values from 0.95 to 0.24 mg/kg (Cuo, Peñaloza, Orellana & Aguilar-cáceres 2021; Taghipour & Mosafiri 2013). The Cd concentration of maize was below the maximum limit of 0.1 mg/kg, except for Farm Group 1, with a concentration above the limit with a value of 0.2 mg/kg (Stan, 2009; FAO/WHO, 2016; Department of health, 2018). The Pb concentration was all below the maximum limit of 0.2 mg/kg for three farm groups

(Department of Health, 2016, 2018). The Pb concentration in Farm Group 2 has increased to a value of 0.21 mg/kg, which is slightly above the maximum limit of 0.2 mg/kg. Therefore, the increase in Pb concentration in Farm Group 2 might be caused by the administration of fertilizers and pesticides. The Pb concentration of maize was above the maximum limit of 0.1 mg/kg of FAO/WHO limits for three farm groups, with values from 0.18 to 0.21 mg/kg (Linuchibuezeh & Ugwunnadi 2020). The Pb for the other farm groups were below the maximum level of South African standards of 0.2 mg/kg, but some are above the FAO/WHO maximum limit of 0.1mg/kg. This could be that pesticides did not contain lead, or the water table linked to the mine pollution is far from the farm. In addition, studies have shown that lead is a toxic element that can be harmful to plants and for human consumption, especially when the Pb accumulation has exceeded the maximum limit.

The contamination of heavy metals and other farm groups in maize grains indicates that the concentration of Cd, Cu, and Pb was below the detection limits, but the concentration of As was above the permissible limit recommended by EPA (Liu, Li & He 2022). The results show that not all maize grains had high levels of toxicity. It is seen in Figure 1 that only Farm Group 1 has a Cd concentration in maize that is above the permissible limit of 0.1 mg/kg. In addition, heavy metals in maize grain can cause severe and destructive impacts on human health depending on the intake duration. Cd frequently harms both of these organs, as well as the lungs, bones, and testicles in humans (Al-othman, Ali, Al-othman & Ali 2016). It causes prostate, kidney, pancreas, and testicular cancer as a result of its carcinogenic effects (Rusin, Domagalska, Rogala, Razzaghi & Szymala 2021).

This element affects the skeletal system by altering the metabolism of calcium, magnesium, zinc, copper, and iron ions (Taghipour and Mosaferei, 2013; Adam, Sackey and Aurelia, 2022; Liu et al., 2022). The Cu concentration of maize was below the maximum limit of 4.0 mg/kg of FAO/WHO limits for all the farm groups with values from 0.27 to 0.24 mg/kg (Linuchibuezeh & Ugwunnadi 2020). While copper has many health benefits for the human body, a deficiency of copper can have adverse health effects as well. In infants and children, copper deficiency can cause anaemia, low white blood cells, osteoporosis, and defects in connective tissue.

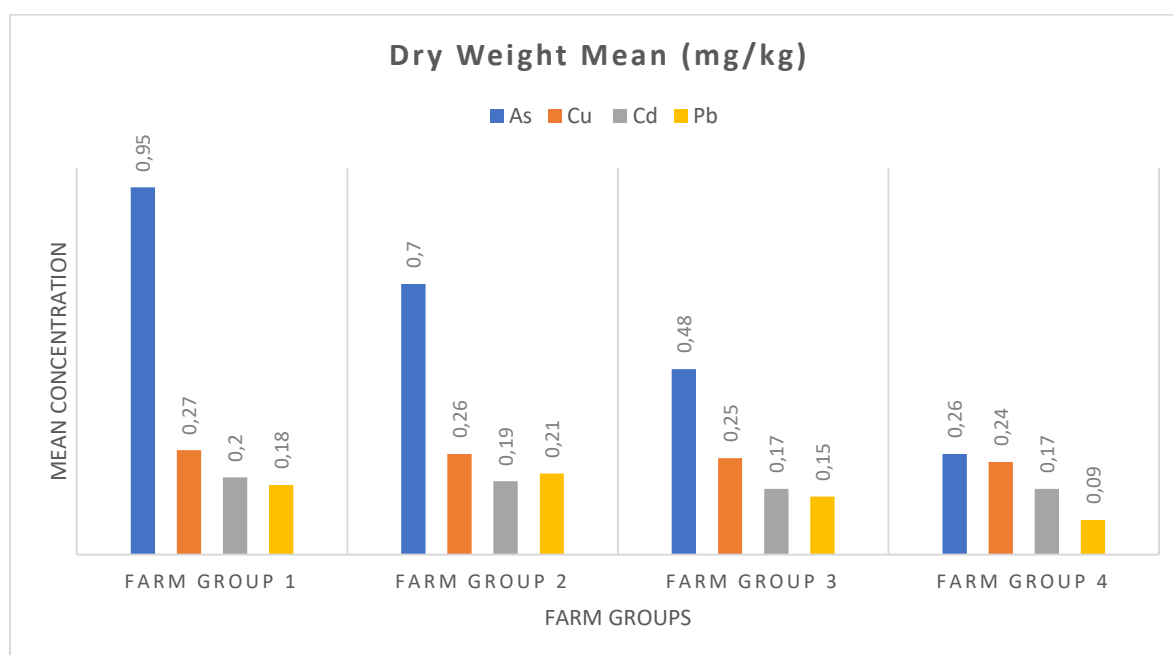


Figure 5.1: Concentration of heavy metals (mg/kg dry weight).

Table 5.8 shows the CDI and HQ of heavy metals in adults by the consumption of maize grain. We note that the CDIs of heavy metals in the farm groups decrease in the order of $Cu > As > Cd > Pb$. In adult consumption of maize grains, the average HQ of metals also decreased in the sequence As, Cu, Cd, and Pb. The average HQ of heavy metals in all the farm groups was lower than 1. According to several studies, a hazard quotient more significant than 1 indicates the likelihood of risk (Huang et al. 2019; Liang et al. 2019; Real et al. 2017).

The HI is the sum of every farm group's hazard quotient of the metals assessed from each maize grain. If the HI is greater than 1, there is potential for adverse carcinogenic health effects (Khezerlou, Dehghan, Moosavy & Kochakhani 2020; Ebadi, Shariatifar, Moazzen & Nazmara 2018). Figure 5.2. Shows the HI average of farm groups decreased in the sequence. The HI values of the farm groups were 0.057, 0.056, 0.042 and 0.038, respectively. The values were all lower than 1, meaning there were no potentially adverse carcinogenic health effects. Following good agricultural practices, farm groups reported low concentrations and hazard quotients, which might be related to their location away from heavy industries and polluted land, and the use of treated water, environmentally friendly fertilizers, and pesticides. There may be a link between the use of fertilizers, pesticides, and water management when growing maize and their accumulation of heavy metals (Tegegne 2017; Jaishan, Tseten, Anbalagan, Mathew & Beeregowda 2014; Jaishan et al. 2016). However, ICP-OES has proven reliable and

sensitive to detecting some heavy metals at low concentrations despite the results potentially affecting metal extraction techniques and sensitivity (Muller et al. 2014).

Table 5.8: Estimated hazard quotients (HQ) of the analysed trace metals.

Farms groups	Chronic daily intake (mg/kg)				Hazard Quotients			
	As	Cu	Cd	Pb	As	Cu	Cd	Pb
1	0.0002	0.0015	0.00004	0.00003	0.013	0.0375	0.003	0.002
2	0.0002	0.0015	0.00004	0.00004	0.013	0.0375	0.003	0.003
3	0.00005	0.0014	0.00004	0.00003	0.003	0.035	0.002	0.002
4	0.00005	0.0013	0.00004	0.00001	0.003	0.0325	0.002	0.0001

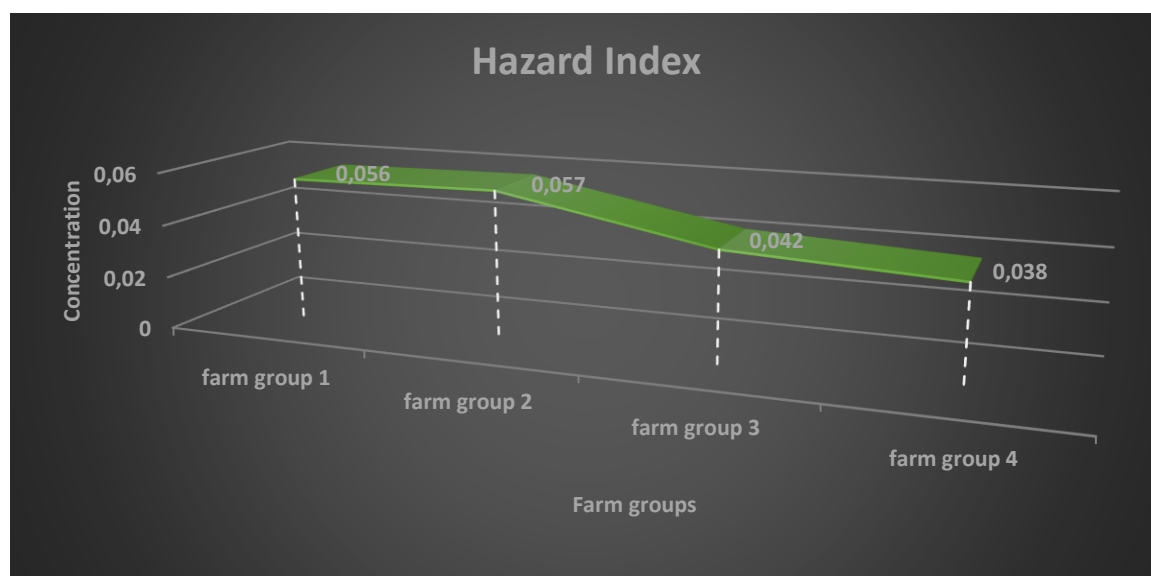


Figure 5.2: Hazard index (HI) for As, Cu, Pb and Cd.

The potential non-carcinogenic and carcinogenic health risks of maize heavy metals fell within the acceptable range. The concentration of As and Cu were the major contributors to the non-carcinogenic and carcinogenic health risks. In addition, this assessment indicates that the health risk of heavy metals was not determined by the metal concentration in the soil or maize, but also by metal consumption and human intake (Liu, Zhang, Feng, Zhu & Tian 2020; Luo, Ren, Hursthouse, Jiang & Deng 2019). Consuming maize contaminated with heavy metals poses severe risks to human health. These risks include gastrointestinal cancer, weakened immune

system function, impaired mental growth, and malnutrition (Kumar, Soo, et al. 2019; Yakup, Sabow, Saleh & Mohammed 2018).

Cadmium, even in low concentrations, as can be seen from Table 6, could be harmful to living organisms. Although cadmium is not very well absorbed, once it is absorbed, it can slowly be excreted, like other metals, which leads to kidney damage (Al Mashuk 2017; Series 2012). Cd presence in cultivation soils favours its transfer and accumulation in maize and could lead to anaemia, renal damage, bone disorder and cancer of the lungs (Rubio-armend et al. 2021; Tegegne 2017). Furthermore, food contamination contributes significantly, around 90%, to adverse health effects for both humans and animals. The concentrations of Pb detected in the maize samples analysed in this study fall within the acceptable limit, suggesting that this study does not reveal any potential health risks associated with lead exposure. However, it is worth noting that lead toxicity has been associated with various detrimental effects on the musculoskeletal system, kidneys, eyes, nervous system, immune system, and reproductive and developmental processes (Rubio-armend et al. 2021; Tegegne 2017). Pb can cause brain damage, paralysis (lead palsy), anaemia, and gastrointestinal symptoms if exposed to long-term (Series 2012).

Maize is an important food crop, but irrigated wastewater is a significant source of toxic metals (Cuo et al. 2021). The focus of this study was to measure the levels of As concentration, which could potentially be attributed to the use of pesticides and fertilizers containing arsenic, as well as the runoff from neighbouring agricultural areas (Adam et al., 2022). As a result of groundwater irrigation and soil additives contaminated with arsenic, the plants primarily take up arsenic that naturally occurs in the soil (Rosa-Castor, Guzmán-Mar, Hernández-Ramírez, Garza-González & Hinojosa-Reyes 2014). Crops can be exposed to heavy metals through various sources such as fertilizers, sewage sludge and municipal wastes. The release of industrial waste and fossil fuels can also contribute to the presence of heavy metals in the environment (Balkhair and Aqeel, 2016; Rehman et al., 2018; S. Kumar et al., 2019).

There are many uses for maize, including livestock feed and raw materials for industrial production. Maize is a nutritional powerhouse, abundant in a diverse range of vitamins and minerals. It boasts a high content of vitamins C, E, and K, along with a suite of B vitamins, namely thiamine (B1), niacin (B2), riboflavin (B3), pantothenic acid (B5), and pyridoxine (B6).

Folic acid and selenium further enrich its nutritional profile. Unique compounds such as N-p-coumaryl tryptamine and N-ferrulyl tryptamine can also be found in maize. In addition to these, it is packed with vitamins A and E, and a variety of trace elements (Manzoor et al. 2018; Kamunda et al. 2016). Since heavy metals can be absorbed through diet, their health implications are serious (Adam et al. 2022). The reduction in labour productivity has an adverse effect on economic growth. In addition, affected people are burdened with the cost of treating illnesses such as cancer, kidney disease, diminished intellectual capacity, heart disease, nerve damage, bone fractures, and gastrointestinal problems (Tegegne, 2017; Adam et al., 2022).

Minerals are essential for the growth and development of an organism. Several nutrients are essential for good health, including iron, zinc, copper, and manganese (Gunalan & Vijayalatha 2020). Food crops contaminated with heavy metals are a major source of human exposure, especially those that are continuously grown (Callistus & Afolayan 2012). Since vegetable tissues can accumulate heavy metals, cultivating such plants in contaminated soil presents a potential risk (Jabeen, Aslam & Salman 2018; Balkhair & Aqeel 2016).

Globally, heavy metals have been identified as significant contaminants of vegetables grown in contaminated soil by numerous scientific papers. Heavy metal deposition in humans causes a host of problems, including neuropathy, peripheral neuropathy, bone deterioration, poor immunity, lung cancer, skin cancer, osteoporosis, artery disease, kidney failure, and prostate cancer, by altering the oxidation and reduction (redox) potential of cells (Gupta et al. 2021; Yadav, Singh, Gupta & Kumar 2017).

As heavy metals accumulate in soft tissues, they become toxic when not metabolized by the body (Xiao et al., 2018; Liu et al., 2022). The body uses these nutrients to keep bones, muscles, the heart and the brain healthy. Even though living organisms require only a small amount of trace metals, huge concentrations can be harmful (Adam et al., 2022; Lebelo and Mochane, 2022). Copper, an essential mineral for human health, serves as a biocatalyst and plays a crucial role in pigmentation, maintaining a healthy central nervous system, preventing anaemia, and closely interacting with zinc and iron functions within the body. As well as for transportation (transportation, manufacturing, electricity transmission), copper is used in agriculture in the

form of fungicides, herbicides and fertilizers (Linu-chibuezeh & Ugwunnadi 2020; Kudirat & Funmilayo 2011).

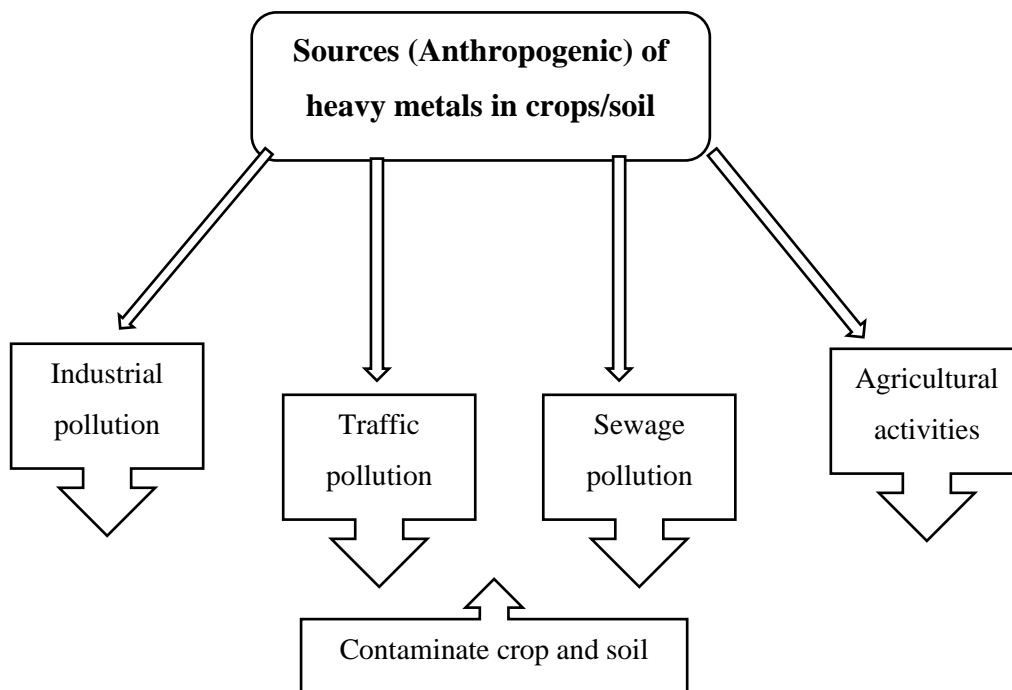


Figure 5.3. Anthropogenic sources of heavy metal contamination in food crops and soil.

The negative effects of chronic ingestion of toxic metals are not apparent for several years after exposure. Figure 5.3 shows the anthropogenic sources of heavy metal contamination in food crops and soil. In addition to posing a threat to agricultural product safety, heavy metal contaminants can harm organisms' immune, reproductive and nervous systems (Alain et al. 2021; Morais, e Costa & Lourdes Pereir 2012). In the different farm groups, high levels of arsenic were measured along with low levels of Pb, Cd, and Cu compared to the standard limit. In addition, regular consumption of Pb, Cu and Cd-contaminated vegetables increases the risk of upper-gastrointestinal cancer from long-term heavy metal deposition in maize-cultivated soil (Gupta et al. 2021; Yang 2019).

Consuming maize grain contaminated with arsenic can cause health issues. In contrast, other metal concentrations were relatively low, indicating no significant risks associated with them. The presence of arsenic in maize grain can be attributed to the use of pesticides and fertilizers containing arsenic. In addition, arsenic can be found in the runoff from nearby agricultural fields (Cao et al., 2020; Adam et al., 2022). Figure 5.3 demonstrates the significant soil disturbance caused by heavy metals originating from various point sources. These sources

include energy-intensive industries like thermal power plants and mines, chemical industries such as gold mines, smelting, electroplating, and textiles, as well as pollution from sewage and traffic. The elevated levels of arsenic found in maize grains from the four farm groups can be attributed to human activities such as the combustion of fossil fuels, the production of agricultural pesticides, and the utilization of machinery treatments. These activities result in direct soil contamination, leading to arsenic absorption by plants (Shah, Prasad & Kumar 2016). Arsenic levels in all maize grains exceed the WHO/FAO safe limit, of 0.1 mg/kg. Consequently, consuming these maize grains would likely lead to detrimental health consequences, including kidney and liver damage, gastrointestinal effects, and DNA damage. (Manwani et al. 2022; Linu-chibuezeh & Ugwunnadi 2020). Arsenic poisoning can result in both acute and chronic health issues. Acute symptoms may include nausea, vomiting, diarrhoea, cyanosis, confusion, and hallucinations. On a long-term basis, it can lead to keratosis, pigmentation/hypopigmentation of the feet, hands and fingers, as well as lung cancer, chronic bronchitis, chronic obstructive pulmonary disease, kidney cancer, and liver cancer (Ali et al. 2021; Linu-chibuezeh & Ugwunnadi 2020; Kudirat & Funmilayo 2011).

Cd is the seventh-most hazardous and noxious metal, causing indirect oxidative stress and having carcinogenic and mutagenic effects in the human body, resulting in severe health problems such as kidney damage, prostate dysfunction, bone diseases, and cancer (Ali et al. 2021). If Cd is exposed to the kidneys for an extended period, it can cause kidney dysfunction and proteinuria (Manwani et al. 2022; Ali et al. 2021; Jyothi 2020). Lead can also cause a decrease in intelligence quotient, memory loss, infertility, mood swings, joint weakness, nausea, insomnia, anorexia, and even death. Pb poisoning affects children and infants more than adults (Manwani et al. 2022; Ali et al. 2021; Jyothi 2020).

5.4. Conclusion

The purpose of the study was to assess the concentrations of heavy metals (arsenic, copper, cadmium, and lead) in maize grains obtained from four different farm groups. The findings revealed varying levels of heavy metals in the maize grains, with some samples exhibiting low levels, while others showed high levels. Comparing these results with the maximum allowable levels established by the World Health Organization/Food and Agricultural Organization and South Africa standards, it was observed that the levels of copper, cadmium, and lead in the

maize grains remained below the maximum permissible thresholds. However, the concentration of arsenic in the maize grains from Farm Group 1 exceeded the maximum allowable level, as defined by the WHO/FAO and the Environmental Protection Agency (EPA). The elevated levels of heavy metals found in maize grains from Farm Group 1 can be linked to the application of fertilizers during cultivation, as well as the use of agricultural pesticides and irrigation water. However, the hazard quotient values for all heavy metals were below 1, indicating a low probability of adverse health risks. Similarly, the hazard index for adults was below 1, signifying an acceptable level of non-carcinogenic effects and no significant future risks such as cancer. Nonetheless, the levels of cadmium detected in maize grains from Farm Group 1 exceeded the permissible limits, presenting a potential health concern. It is important to note that heavy metals generally exhibit toxic effects, but the impact on human health typically becomes significant only with prolonged consumption. To tackle these concerns, regular monitoring of heavy metal levels in maize grains and other food items is essential to prevent excessive accumulation in the food chain. Collaboration between the government and agricultural agencies is crucial to developing remedial strategies aimed at reducing the heavy metal content in maize grains. This can be achieved by collecting soil samples from the cultivation lands within the farm group. Such collaborative efforts will effectively minimize potential health hazards.

5.4. References

- Adam, A, Sackey, LNA & Aurelia, L. 2022. Heliyon Risk assessment of heavy metals concentration in cereals and legumes sold in the Tamale Aboabo market , Ghana. *Heliyon*. 8(January):e10162. doi.org/10.1016/j.heliyon.2022.e10162.
- Afonne, OJ & Ifediba, EC. 2020. Heavy metals risks in plant foods – need to step up precautionary measures. *Current Opinion in Toxicology*. 22:1–6. doi.org/10.1016/j.cotox.2019.12.006.
- Al-othman, ZA, Ali, R, Al-othman, AM & Ali, J. 2016. Assessment of toxic metals in wheat crops grown on selected soils , irrigated by different water sources. *Arabian Journal of Chemistry*. 9:S1555–S1562. doi.org/10.1016/j.arabjc.2012.04.006.
- Aladesanmi, OT, Oroboade, JG & Osisiogu, CP. 2019. Bioaccumulation Factor of Selected Heavy Metals in Zea mays. 9(24).

Alain, TK, Luc, BT, Ali, D, Moumoni, D, Zongo, I & Zougmore, F. 2021. Assessment of Heavy Metal Concentration and Evaluation of Health Risk of Some Vegetables Cultivated in Loumbila Farmland , Burkina Faso. 1019–1032. doi.org/10.4236/jep.2021.1212060.

Ali, MM, Hossain, D, Al-Imran, Khan, MS, Begum, M & Osman, MH. 2021. Environmental Pollution with Heavy Metals : A Public Health Concern.

Balkhair, KS & Aqeel, M. 2016. Field accumulation risks of heavy metals in soil and vegetable crop irrigated with sewage water in western region of Saudi Arabia. *Saudi Journal of Biological Sciences*. 23(1):S32–S44. doi.org/10.1016/j.sjbs.2015.09.023.

Di Bella, C, Traina, A, Giosuè, C, Carpintieri, D, Lo Dico, GM, Bellante, A, Del Core, M, Falco, F, et al. 2020. Heavy Metals and PAHs in Meat, Milk, and Seafood From Augusta Area (Southern Italy): Contamination Levels, Dietary Intake, and Human Exposure Assessment. *Frontiers in Public Health*. 8. doi.org/10.3389/fpubh.2020.00273.

Callistus, B & Afolayan, AJ. 2012. Heavy metal contamination of vegetables cultivated in home gardens in the Eastern Cape. 108:1–6.

Cao, L, Lin, C, Gao, Y, Sun, C, Xu, L, Zheng, L & Zhang, Z. 2020. Health risk assessment of trace elements exposure through the soil- plant (maize) -human contamination pathway near a petrochemical industry complex , Northeast China *. *Environmental Pollution*. 263:114414. doi.org/10.1016/j.envpol.2020.114414.

Cuo, M, Peñalosa, R, Orellana, E & Aguilar-cáceres, MA. 2021. Heavy Metals and Arsenic in Soil and Cereal Grains and Potential Human Risk in the Central Region of Peru Heavy Metals and Arsenic in Soil and Cereal Grains and Potential Human Risk in the Central Region of Peru. (January). doi.org/10.12911/22998993/129255.

Dessie, BK, Robele, S, Mihret, A, Desta, AF & Mehari, B. 2021. Heliyon Determination and health risk assessment of trace elements in the tap water of two Sub-Cities of Addis Ababa , Ethiopia. *Heliyon*. 7(April):e06988. doi.org/10.1016/j.heliyon.2021.e06988.

Ebadi, A, Shariatifar, N, Moazzen, M & Nazmara, S. 2018. Determination of heavy metal content of processed fruit products from Tehran ' s market using ICP- OES : A risk assessment study. 115(March):436–446.

Gebeyehu, HR, Danno, L & Id, B. 2020. Levels of heavy metals in soil and vegetables and associated health risks in Mojo area ,. 1–22.

Gunalan, S & Vijayalatha, KR. 2020. Heavy metals and its impact in vegetable crops. (May).

Guo, W, Pan, B, Sakkiah, S, Yavas, G, Ge, W & Zou, W. 2019. Persistent Organic Pollutants

- in Food : Contamination Sources , Health Effects and Detection Methods. 10–12.
- Gupta, N, Kumar, K, Kumar, V, Krishnan, S, Kumar, S, Derakhshan, Z, Khan, MAM & Alam, J. 2021. Evaluating heavy metals contamination in soil and vegetables in the region of North India : Levels , transfer and potential human health risk analysis. *Environmental Toxicology and Pharmacology*. 82(November 2020):103563. doi.org/10.1016/j.etap.2020.103563.
- Health, D of. 2011. Foodstuffs, Cosmetics and Disinfectants Act: Regulations: Hygiene requirements for milking sheds, transport of milk and related matters. 6(34198):4–18.
- Health, DO. 2016. Foodstuffs, Cosmetics and Disinfectants: Regulations: Maximum levels of metals in foodstuffs. (40252):9–17.
- Health, DO. 2018. Foodstuffs, Cosmetics and Disinfectants Act, 1972. (41704):28–46.
- Huang, Y, Wang, L, Wang, W, Li, T, He, Z & Yang, X. 2019. Science of the Total Environment Current status of agricultural soil pollution by heavy metals in China : A meta-analysis. *Science of the Total Environment*. 651:3034–3042. doi.org/10.1016/j.scitotenv.2018.10.185.
- Jabeen, F, Aslam, A & Salman, M. 2018. Heavy Metals Toxicity and Associated Health Risks in Vegetables Grown under Soil Irrigated with Sewage Water. 6(5):173–180. doi.org/10.13189/ujar.2018.060505.
- Jaishan, J, Nziguheba, G, Zingore, S, Coulibaly, A, Esilaba, A, Kabambe, V, Njoroge, S, Palm, C, et al. 2016. Agriculture , Ecosystems and Environment Understanding variability in crop response to fertilizer and amendments in sub-Saharan Africa. “*Agriculture, Ecosystems and Environment*”. 229:1–12. doi.org/10.1016/j.agee.2016.05.012.
- Jaishan, M, Tseten, T, Anbalagan, N, Mathew, BB & Beeregowda, KN. 2014. Toxicity , mechanism and health effects of some heavy metals. 7(2):60–72. doi.org/10.2478/intox-2014-0009.
- Jyothi, NR. 2020. Heavy Metal Sources and Their Effects on Human Health.
- Kamunda, C, Mathuthu, M & Madhuku, M. 2016. Health risk assessment of heavy metals in soils from witwatersrand gold mining basin, South Africa. *International Journal of Environmental Research and Public Health*. 13(7). doi.org/10.3390/ijerph13070663.
- Khezerlou, A, Dehghan, P, Moosavy, M & Kochakkhani, H. 2020. Assessment of Heavy Metal Contamination and the Probabilistic Risk via Salad Vegetable Consumption in Tabriz , Iran.
- Kudirat, LM & Funmilayo, DV. 2011. Heavy metal levels in vegetables from selected markets in Lagos , Nigeria . 2(1):18–21.
- Kumar, P, Soo, S, Zhang, M, Fai, Y & Kim, K. 2019. Heavy metals in food crops : Health risks

- , fate , mechanisms , and management. *Environment International*. 125(February):365–385. doi.org/10.1016/j.envint.2019.01.067.
- Kumar, S, Prasad, S, Kumar, K, Shrivastava, M, Gupta, N, Nagar, S, Bach, Q, Kamyab, H, et al. 2019. Hazardous heavy metals contamination of vegetables and food chain : Role of sustainable remediation approaches - A review. *Environmental Research*. 179(June):108792. doi.org/10.1016/j.envres.2019.108792.
- Lebelo, K & Mochane, MJ. 2022. Compliance sampling and monitoring of heavy metal accumulation in selected vegetables using ICP-OES: A probabilistic human health risk assessment. 21.
- Liang, G, Gong, W, Li, B, Zuo, J, Pan, L & Liu, X. 2019. Analysis of heavy metals in foodstuffs and an assessment of the health risks to the general public via consumption in Beijing, China. *International Journal of Environmental Research and Public Health*. 16(6). doi.org/10.3390/ijerph16060909.
- Linu-chibuezeh, A & Ugwunnadi, NE. 2020. Determination of Heavy Metals in Some Fruits and Vegetables from Selected Market ' s in Anambra State. 4(4):163–171.
- Lion, GN & Olowoyo, JO. 2013. South African Journal of Botany Population health risk due to dietary intake of toxic heavy metals from *Spinacia oleracea* harvested from soils collected in and around Tshwane , South Africa ☆. *South African Journal of Botany*. 88:178–182. doi.org/10.1016/j.sajb.2013.07.014.
- Liu, P, Zhang, Y, Feng, N, Zhu, M & Tian, J. 2020. Potentially toxic element (PTE) levels in maize , soil , and irrigation water and health risks through maize consumption in. 1–13.
- Liu, Q, Li, X & He, L. 2022. Health risk assessment of heavy metals in soils and food crops from a coexist area of heavily industrialized and intensively cropping in the Chengdu Plain ., (September):1–11. doi.org/10.3389/fchem.2022.988587.
- Lull, C & Ram, F. 2019. Legal measures to prevent and manage soil contamination and to increase food safety for consumer health : The case of Spain. 250:883–891. doi.org/10.1016/j.envpol.2019.04.074.
- Luo, X, Ren, B, Hursthouse, AS, Jiang, F & Deng, FJÁR. 2019. Potentially toxic elements (PTEs) in crops , soil , and water near Xiangtan manganese mine , China : potential risk to health in the foodchain. *Environmental Geochemistry and Health*. 9. doi.org/10.1007/s10653-019-00454-9.

- Malan, M, Cyster, L, Raitt, L & Aalbers, J. 2014. Heavy metals in the irrigation water, soils and vegetables in the Philippi horticultural area in the Western Cape Province of South Africa.
- Manwani, S, C.R., V, Vibha, J, Awasthi, KK, Yadav, CS, Sankhla, MS, Awasthi, G & Pandit, PP. 2022. Vegetables and Their Toxic Effects on Human Health.
- Manzoor, J, Sharma, M & Wani, KA. 2018. Heavy metals in vegetables and their impact on the nutrient quality of vegetables : A review. *Journal of Plant Nutrition*. 41(13):1744–1763. doi.org/10.1080/01904167.2018.1462382.
- Al Mashuk, H. 2017. Heavy Metal Contamination in Vegetables from Industrial Waste Water Polluted Soils.
- Mihaileanu, RG, Neamtii, IA, Fleming, M, Pop, C, Bloom, MS, Roba, C, Surcel, M, Stamatian, F, et al. 2019. Assessment of heavy metals (total chromium , lead , and manganese) contamination of residential soil and homegrown vegetables near a former chemical manufacturing facility in Tarnaveni , Romania.
- Morais, S, e Costa, FG & Lourdes Pereir, M de. 2012. Heavy Metals and Human Health. *Environmental Health - Emerging Issues and Practice*. (February). doi.org/10.5772/29869.
- Muller, CC, Muller, ALH, Pirola, C, Duarte, FA, Flores, EMM & Muller, EI. 2014. Feasibility of nut digestion using single reaction chamber for further trace element determination by ICP-OES. 116:255–260.
- Onakpa, MM, Njan, AA & Kalu, OC. 2018. A Review of Heavy Metal Contamination of Food Crops in Nigeria. 84(3):488–494.
- Ramteke, S, Sahu, BL, Dahariya, NS & Patel, KS. 2016. Heavy Metal Contamination of Vegetables. (June):996–1004.
- Real, MIH, Azam, HM & Majed, N. 2017. Consumption of heavy metal contaminated foods and associated risks in Bangladesh. *Environmental Monitoring and Assessment*. 1–14. doi.org/https://doi.org/10.1007/s10661-017-6362-z.
- Rehman, K, Sajid, M & Akash, H. 2018. Prevalence of exposure of heavy metals and their impact on health consequences. (June 2017):157–184. doi.org/10.1002/jcb.26234.
- Rosa-Castor, J., Guzmán-Mar, JL., Hernández-Ramírez, A, Garza-González, MT & Hinojosa-Reyes, L. 2014. Science of the Total Environment Arsenic accumulation in maize crop (*Zea mays*): A review. *Science of the Total Environment, The*. 488–489:176–187. doi.org/10.1016/j.scitotenv.2014.04.075.
- Rubio-armend, C, Paz, S, Guti, AJ, Furtado, VG, Gonz, D, Revert, C & Hardisson, A. 2021.

Toxic Metals in Cereals in Cape Verde : Risk Assessment Evaluation.

Rusin, M, Domagalska, J, Rogala, D, Razzaghi, M & Szymala, I. 2021. Concentration of cadmium and lead in vegetables and fruits. *Scientific Reports*. 1–10. doi.org/10.1038/s41598-021-91554-z.

Series, F. 2012. Mercury , Lead , Cadmium ,. (1):1–13.

Shah, TR, Prasad, K & Kumar, P. 2016. Maize — A potential source of human nutrition and health : A review Maize — A potential source of human nutrition and health : A review. *Cogent Food & Agriculture*. 54(1). doi.org/10.1080/23311932.2016.1166995.

Taghipour, H & Mosafiri, M. 2013. Heavy Metals in the Vegetables Collected from Production Sites. 3(2):185–193. doi.org/10.5681/hpp.2013.022.

Tegegne, WA. 2017. Assessment of some heavy metals concentration in selected cereals collected from local markets of Ambo City , Ethiopia. (March 2015). doi.org/10.5897/JCO15.

Thompson, LA. 2019. Environmental Chemical Contaminants in Food : Review of a Global Problem. 2019.

Wang, P, Chen, H, Kopittke, PM & Zhao, F. 2019. Cadmium contamination in agricultural soils of China and the impact on food safety *. *Environmental Pollution*. 249:1038–1048. doi.org/10.1016/j.envpol.2019.03.063.

Wang, X, Zhang, Y, Geng, Z, Liu, Y, Guo, L & Xiao, G. 2019. Spatial analysis of heavy metals in meat products in China during. *Food Control*. 104(April):174–180. doi.org/10.1016/j.foodcont.2019.04.033.

Wen-yan, Z & De, D. 2018. Structure Changes in Food System and China ' s Concerns with Food Safety Policy. 4(2). doi.org/10.18278/wfp.4.2.11.

Wu, F & Guclu, H. 2012. Aflatoxin Regulations in a Network of Global Maize Trade. 7(9). doi.org/10.1371/journal.pone.0045151.

Xiao, W, Ye, X, Zhang, Q, Chen, D, Hu, J & Gao, N. 2018. Evaluation of cadmium transfer from soil to leafy vegetables: Influencing factors, transfer models, and indication of soil threshold contents. *Ecotoxicology and Environmental Safety*. 164(March):355–362. doi.org/10.1016/j.ecoenv.2018.08.041.

Yadav, KK, Singh, JK, Gupta, N & Kumar, V. 2017. A Review of Nanobioremediation Technologies for Environmental Cleanup : A Novel Biological Approach. 8(2):740–757.

Yakup, NY, Sabow, AB, Saleh, SJ & Mohammed, GR. 2018. Assessment of Heavy Metal in Imported Red Meat Available in the Markets of Erbil City. (6):177–183.

Yang, G. 2019. Heavy Metals in Plants.

Yang, J, Ma, S & Zhou, J. 2018. Heavy metal contamination in soils and vegetables and health risk assessment of inhabitants in Daye , China. (182). doi.org/10.1177/0300060518758585.

Zhang, M, Zeiss, MR & Geng, S. 2015. Agricultural pesticide use and food safety : California ' s model. *Journal of Integrative Agriculture*. 14(11):2340–2357. doi.org/10.1016/S2095-3119(15)61126-1.

CHAPTER 6: CONCLUSION

6.1. Introduction

This chapter outlines the research study objectives and explains its implications for theory and practice. In addition, it summarizes the findings related to the contamination of maize crops grown on agricultural land. Furthermore, this thesis discusses its contributions, limitations, and potential future research questions.

6.2. Summary of the study and key findings

Heavy metal exposure in agricultural land near heavy industrial areas is a crucial issue, as it has significant implications for public health and the environment. Several studies have highlighted the elevated levels of heavy metals in agricultural land near heavy industrial areas, which pose a significant risk to human health and the environment. In this study, maize crops samples were collected from four farmlands and analysis were conducted to observe heavy metal concentration levels. Four heavy metals, namely arsenic, cadmium, lead, and copper were analysed in the sample determined by using ICP-OES.

Further analysis included Anova and Shapiro-Wilk tests to ascertain if the samples were from a normal distribution. A health risk assessment was conducted for heavy metal exposure from the selected maize crops that were predicted using the estimated daily intake (EDI) and the target hazard quotient (THQ). The HI values of the farm groups were all lower than 1, meaning there are no potential adverse carcinogenic health effects. Some heavy metal concentration levels were above the maximum allowable level when compared to the relevant governing bodies from foodstuff. The arsenic concentration levels for all farm groups were high. In addition, one farm group also had high lead and cadmium concentration levels. Factors that influence the high levels of heavy metal concentration in some of the farm groups included the link between the use of fertilizers, pesticides, and water management when growing maize. Exposure to high concentrations levels of heavy metals can have serious health consequences, including cancer, neurological disorders, and developmental problems, among others.

6.3. Limitation of study

Several factors limited the scope of the study. The researcher intended to explore various analytical techniques such as Inductively coupled plasma Mass spectrometry (ICP-MS), and X-ray fluorescence, atomic absorption spectrometry. However, due to the lack of financial constraints that techniques could not be utilized. Additionally, the inability to gain access to other farms further limited the sample size of the study. Limitations during analysis arose when one of the samples had a negative value, this could have been due to the possibility of the sample being below the detection limit or possibly an error in the standards or calibration. Furthermore, this led to great variances between samples which limited the type of post hoc test that can be conducted.

6.4. Evaluation of the hypothesis

In this study, the hypotheses were as follows:

Hypothesis (H₀): Maize crops grown on agricultural land near industrial areas exceed permissible limits for heavy metal concentrations in food.

Null hypothesis (H_a): Maize crops grown on agricultural land near industrial areas have heavy metal concentrations below the permissible limits for heavy metals in food.

Based on the research findings, the null hypothesis has been rejected. It was discovered that maize crops grown on agricultural land near industrial areas contained heavy metal concentrations above food permissible limits. However, only arsenic concentrations were found to exceed the permissible limit of 0.1 mg/kg of FAO/WHO limits for all the farm groups, with values from 0.95 to 0.24 mg/kg. Additionally, not all maize grown in agricultural areas or near industrial sites had heavy metal concentrations that exceeded food permissible limits.

For the human health risk assessment:

The null hypothesis (H₀): The hazard quotient and hazard index for the non-carcinogenic effects of the selected maize crops are within safe limits.

The alternative hypothesis (H_a): The hazard quotient and hazard index for the non-carcinogenic effects of the selected maize crops exceed safe limits, indicating potential health risks.

Based on the research findings, the alternative hypothesis has been rejected. The hazard index (HI) values for the farm groups were all below 1, indicating that non-carcinogenic risk is not

an issue. The hazard quotient (HQ) is used to evaluate the potential for non-carcinogenic health effects, and an HQ less than 1 suggests that no adverse health effects are expected due to exposure. Since the HI is the sum of HQs for multiple substances, an HI less than 1 also implies that no adverse health effects are expected from exposure to the substances being evaluated.

6.5. Implications for theory and practice

Research findings from this study have both practical and theoretical implications. They encourage researchers, environmental health practitioners (EHP's), and environmentalists to investigate environmental exposures further. A significant implication for future research is that heavy metal exposure in developing nations poses a challenge to food safety. Since contaminated environments are a source of contamination, they can have a significant impact on the food industry. Assessing heavy metal exposure in maize crops grown on agricultural land near large industrial areas is a critical issue that demands attention. The results presented in Chapter 5 support both the hypothesis that the hazard quotient and hazard index for the non-carcinogenic effects of the selected maize crops is within safe limits and the hypothesis that maize crops have heavy metal concentrations below the permissible limits for food. There is sufficient evidence demonstrating that some of the sampled maize crops comply with the Codex Alimentarius standards for metals in foodstuffs. Additionally, the hazard quotient (HQ) is used to evaluate the potential for non-carcinogenic health effects, and an HQ less than 1 suggests that no adverse health effects are expected due to exposure to the substances being evaluated.

6.6. Recommendations

The research study suggests that maize crops grown near industrial areas have acceptable levels of heavy metal concentrations in food and do not pose a significant risk of non-carcinogenic effects due to heavy metal exposure. EHPs play a vital role in addressing the impact of heavy metal exposure on agricultural land and food crops. Some recommendations for their roles include:

- EHPs can monitor agricultural land and food crops for heavy metal contamination. They can conduct soil tests and water quality tests to identify potential sources of contamination.
- EHPs can assess the risk posed by heavy metal exposure to humans. They can evaluate the likelihood and severity of adverse health effects based on the level of exposure.
- EHPs need to educate farmers and the public about the risks associated with heavy metal exposure in agricultural settings. They can provide guidance on best practices for preventing contamination, reducing exposure, and mitigating the impacts of contamination.
- EHPs can enforce regulations and policies related to heavy metal exposure in agriculture. They can conduct inspections, issue citations, and take legal action when necessary to protect public health and the environment.

6.7. Future studies and direction

- Analytical methods for detecting heavy metals in food.
- Mitigation strategies for reducing heavy metal contamination in food.
- Case studies of heavy metal contamination in specific food types
- Risk assessment and management of heavy metal contamination in food.
- Impact of heavy metal contamination on the environment and ecosystems
- Identification of vulnerable populations at risk of heavy metal exposure through food.

APPENDIX A: PLAGIARISM REPORT

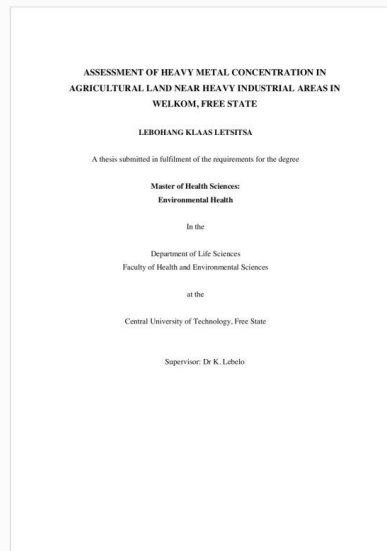


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APPENDIX B: LANGUAGE EDITING DECLARATION

CORNELIA GELDENHUYS

☎ 083 2877088
corrieg@mweb.co.za

20 August 2023

TO WHOM IT MAY CONCERN

Herewith I, **Cornelia Geldenhuys (ID 521114 0083 088)** declare that I am a qualified, accredited language practitioner and that I have translated the following thesis:

**ASSESSMENT OF HEAVY METAL CONCENTRATION IN
AGRICULTURAL LAND NEAR HEAVY INDUSTRIAL AREAS IN
WELKOM, FREE STATE**

by

LEBOHANG KLAAS LETSITSA

All changes were indicated by track changes and comments **for the author to verify, clarify aspects that are unclear, make the necessary adjustments and finalise.** The editor takes no responsibility in the instance of this not being done. The document remains the final responsibility of the author.



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Dear Mr Letsitsa

QUALIFICATION: Master of Health Sciences in Environmental Health

TITLE: "The assessment of heavy metal exposure in agricultural land near heavy industrial areas in Welkom: Free State"

It is my pleasure to inform you that the Faculty Research Committee of the CUT approved the above project title on 2021-11-30.

For any enquiries, contact 051 507 3068 or postgradadmin@cut.ac.za.

Kind regards,



Ms (Maki) Elizabeth Phantsi

Senior Administrative Officer
Assessment and Graduation Unit
Academic Administration

Tel: +27 51 507 3068 | **Fax:** +27 51 507 3409 | **E-mail:** rphantsi@cut.ac.za

Central University of Technology, Free State (CUT)
Private Bag X20539, Bloemfontein, 9300, South Africa

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