# ASSESSMENT OF SUNFLOWER (HELIANTHUS ANNUUS L) FOR PHYTOREMEDIATION OF HEAVY METAL POLLUTED MINE TAILINGS- A CASE STUDY OF NAMPUNDWE MINES TAILINGS DAM.

**BY**
**KAELA BEVERLY CHILESHE**

A DISSERTATION SUBMITTED TO THE UNIVERSITY OF ZAMBIA IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE DEGREE OF MASTER OF SCIENCE IN SUSTAINABLE MINERAL RESOURCE DEVELOPMENT.

**THE UNIVERSITY OF ZAMBIA**
**LUSAKA**

**2023**

ASSESSMENT OF SUNFLOWER (HELIANTHUS ANNUUS L) FOR PHYTOREMEDIATION OF HEAVY METAL POLLUTED MINE TAILINGS- A CASE STUDY OF NAMPUNDWE MINES TAILINGS DAM.

BY
KAELA BEVERLY CHILESHE

A DISSERTATION SUBMITTED TO THE UNIVERSITY OF ZAMBIA IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE DEGREE OF MASTER OF SCIENCE IN SUSTAINABLE MINERAL RESOURCE DEVELOPMENT.

THE UNIVERSITY OF ZAMBIA
LUSAKA

2023

# DECLARATION

I, **Kaela B Chileshe** hereby declares that this submission is my work towards the Master of Science in sustainable mineral resource development and that to the best of my knowledge it has not been submitted for any other degree at this or any other university except where due acknowledge has been made in the text.

Signed: _______________________________________________

Date: _________________________________________________

# APPROVAL

This dissertation of Kaela B Chileshe is approved in partial fulfillment of the requirements for the award of the degree of Master of Science in Sustainable Mineral Resource Development by the University of Zambia.

Supervisor

Name_____________________________________________
Signature ___________________________________________
Date_______________________________________________

Examiners' Signatures
Examiner 1
Name_____________________________________________
Signature___________________________________________
Date_______________________________________________

Examiner 2
Name_____________________________________________
Signature___________________________________________
Date_______________________________________________

Examiner 3
Name_____________________________________________
Signature___________________________________________
Date_______________________________________________

Board of Examiners chairperson
Name
Signature
Date

# ABSTRACT

Mining is the main source of export income and contributes significantly to the Zambian gross domestic product. Besides its contributions to exports, the mining industry plays a pivot role in the economic and socio-political development of Zambia. It also provides essential mineral based raw materials to the local industry.

However, mining activities have led to a generation of heavy metals laden wastes which are released into the environment in an unsustainable way causing the contamination of the ecosystems and posing a risk to human health. Most mining companies have not employed any rehabilitation or remediation program for the heavy metal laden wastes.

For this purpose, this study was conducted to assess the potential of sunflower for phytoremediation of heavy metal polluted Pyritic mine tailings. Phytoremediation is an emerging technology in the remediation of mine tailings that uses tolerant plants species to clean up contaminated sites. It uses plants with high biomass and sunflower has been identified as such. These plants can extract, transfer, sequester and stabilize a variety of metals through mechanisms such as phytoextraction, phytostabilization, phytoaccumulation and phytovolatilization.

In this study, pot experiment was conducted by growing sunflower (Helianthus annuus L) in pyrite mine tailings and in agricultural soil as a control. The study showed that the concentration of Cu reduced from 40.76mg/kg to 36.59mg/kg, Zn reduced from 3.58mg/kg to 3.49mg/kg and Fe reduced 23.70mg/kg to 10mg/kg respectively in the mine tailings after six (6) weeks. Analysis of harvested sunflower (roots, stems, leaves) showed that sunflower could remove heavy metals from the tailings and the highest removal efficiency was 56.16% and the highest translocation factor was 0.25.

Based on the results obtained it can be concluded that sunflowers have the potential to remediate contaminated pyritic mine tailings and phytoremediation is a viable and efficient technology to treat soils contaminated with heavy metals.

# DEDICATION

I humbly dedicate this work to God Almighty, who has made this endeavour fruitful.

To my lovely children, Mapalo Namwinga, Zewelanji Simwinga and Joshua Simwinga who have been my support and inspiration during my study period.

To my beloved Husband Mr. Abiya Simwinga for his moral support throughout my education.

# ACKNOWLEDGEMENTS

Thanks to Jehovah God who has given me life, divine wisdom, and strength to finish this research.

Firstly, I would like to thank my supervisor Dr. Koonda Mususu for the tireless guidance, outmost support, and never-ending inspiration throughout the research work. Iam so grateful for her patience, motivation, and immense knowledge. Her excellent guidance and timely response to my queries has made it possible for this work to be completed.

My sincere appreciation goes to all lecturers dedicated to this program in the School of Mines for their support. I would also like to say thank you to the staff at the School of Agriculture laboratory for their support in analysing my samples.

My unreserved thanks to the Management of Nampundwe Mine for their maximum co-operation and assistance towards the success of this research work.

Lastly, I would like to express my gratitude to the University of Zambia for providing me with the opportunity and resources to conduct my research and complete the research.

Table of Contents

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF ACRONYMS

| **ABBREVIATION** | **DESCRIPTION** |
|---|---|
| SDGs | Sustainable development goals |
| UNZA | University of Zambia |
| AMD | Acid mine drainage |
| KCM | Konkola Copper Mines |
| ZEMA | Zambia Environmental Management Agency |
| EPA | Environmental protection Agency |
| EEA | European Environmental Agency |
| WHO | World Health Organization |
| SPSS | Statistical package for social sciences |
| ZCCM | Zambia Consolidated Copper Mines |

# CHAPTER ONE

# INTRODUCTION

## 1.1 Introduction

Although potentially toxic elements occur naturally in the soil, anthropogenic and geologic activities have increased the concentration of these elements to amounts that are harmful to both plants and animals (Zehra *et al.*, 2020). Some of these activities include mining, smelting of metals, burning of fossil fuels, use of fertilizers, pesticides and insecticides for agriculture, production of batteries and other metal products in industries, sewage sludge, and municipal waste disposal (Liu *et al.*, 2018). With increased industrialization and population growth, soils have become contaminated with toxic elements which cause threats to  ground water, food safety and human health (Ding *et al.*, 2017).

Soil contamination with toxic elements has now become a growing challenge in developing countries. Not only does it hinder sustainable development but also poses a threat to the local environment, ecosystems, and human health ( Rungwa *et al.*, 2013). Potentially toxic elements such as copper (Cu), iron (Fe), cadmium (Cd) and lead (Pb) are the most common and dangerous contaminants (Khalid *et al.*, 2017). Contaminated soils create lack of arable land, depriving local communities of land for economic agriculture activities as well as posing a health risk (Zehra *et al.*, 2020).

Zambia is an example of a developing country where industrial activities have polluted the soil and continue to do so (Ntengwe, 2006). The most polluting industrial activities are exploration, mining extraction and mineral beneficiation processes such as smelting, concentrating and refining (Mbewe *et al.*, 2016). Mining in Zambia spans over 100 years with the mining sector playing an important role in the country's economic development (Sikamo *et al.*, 2016). It is the main economic backbone of Zambia and contributes about 80% to the gross domestic product (Sikamo *et al.*, 2016). Zambia produces a  wide spectrum of metals which include Copper, cobalt, iron, manganese, uranium, gold, gemstones, coal, and industrial minerals (Ikenaka *et al.*, 2014). The mining and beneficiation processes generate mine waste and the oxidation of sulfide mine waste generates acid mine drainage (AMD) which contaminate the soil and ecosystems (Fellet *et al.*, 2007). The global demand for metals and minerals observed in the recent past has also led to an increased generation of mine waste. The decreasing metal ore grades in Zambia (Ntengwe, 2006) are also increasing the amount of mine waste generated hence increasing soil contaminants (Masaka *et al.*, 2017). Mine waste includes overburden and waste rock from mining as well as tailings and slag from mineral processing plants and smelting respectively. Currently mine waste accounts for 90% of the total solid waste generated annually in Zambia (Ntengwe, 2006). Mine waste also occupies large volumes of land making it unavailable for other uses such as agriculture (Fellet *et al.,* 2007). Mine wastes are toxic and harmful to both human health and the environment. They contains heavy metals such as lead (Pb), arsenic (As), Zinc (Zn), copper (Cu), nickel (Ni),chromium (Cr), cobalt (Co), cadmium (Cd) and mercury (Hg) (Li *et al.,* 2019) which contaminates the soils and freshwater ecosystems.

Waste from mining activities creates environmental problems such as fertile land loss, landscape disruption and habitat loss (Liu *et al.*, 2018) and the oxidation of sulphide waste leads to the generation of mine acid drainage (AMD) which contaminates both soil and water. The AMD is highly acidic and contains heavy metals which contaminates surface and ground water (Nyquist & Greger, 2009). Mine acid drainage (AMD) negatively impacts on the freshwater ecosystems causing acidification, high concentrations of iron and sulphates and increased levels of soluble toxic metals (Ji *et al*., 2008) .This renders most aquatic ecosystems unsafe for human consumption and agriculture purposes (Aguinaga *et al.*, 2018) .

Some elements are considered as toxic pollutants because they are persistent in the environment (Huang *et al.*, 2017) and not only pollute the atmosphere, food crops, degrade the quality of freshwater ecosystems but also affects health of human beings through accumulation in the food chain (Li *et al.*, 2019). Freshwater ecosystems are a pathway of heavy metal contamination to both human beings through drinking water and to agricultural crops through irrigation. Considering the adverse effects of mine waste on the terrestrial and aquatic ecosystems there is a need for the remediation of heavy metal polluted waste from mining activities.

To mitigate the effects of mine waste, different soil remediation technologies have been developed in the last couple of decades. These technologies aim at reducing the bioavailability fractions of heavy metals in soils and their consequent accumulation in the food chain (Bhargava *et al.*, 2012).The conventional techniques of remediating soils are mostly based on physical and chemical techniques. Physical techniques entails covering mine waste with waste rock from mining operations, gravel, topsoil, or clay capping, to reduce wind and soil erosion. While chemical techniques which include chemical oxidation, soil washing and flushing, adsorption and ion exchange, flocculation and precipitation aim at changing the chemical properties of heavy metals so that their toxicity can be reduced. Most of these technologies are costly, take time and lead to environmental degradation (Khalid *et al.*, 2017). There financial and environmental complexities make the implementation of conventional soil remediation technologies a challenge. Currently alternative methods for remediation of mine waste have been prescribed and adopted by various countries and these include bioremediation methods.

Phytoremediation, a form of bioremediation is an innovative and green technology that uses plants to clean up contaminated environments (Ullah *et al.*, 2015). This is an emerging technology that has proven to be less expensive than the conventional technologies and is also more sustainable in that it encourages site restorations (Forte & Mutiti, 2017). Phytoremediation technologies includes phytoextraction, Phytostabilization, Phytofiltration and Phytovolatilization (Song *et al.,* 2019). This technology uses plants species with the following characteristics: a profuse root system, ability to grow fast, heavy biomass, tolerance to high concentrations of metals and high metal-accumulation capability (Adesodun *et al.*, 2010).This enables adsorption, absorption and accumulation of contaminants in their tissues for the remediation (Materac, Wyrwicka & Sobiecka, 2015). These plants are known as hyperaccumulators because of their ability to accumulate high concentrations of metals in their tissues (Adesodun *et al.*, 2010). According to Lasat ( 1999) approximately 400 plant species from at least 45 families have been identified as hyperaccumulators of metals.

Some plants used for remediation include Indian mustard which remediates Cd, Pb, Se, Zn, Hg and Cu , white willow remediates Cd, Ni and Pb and sunflower which remediates Pb, Zn, Cu and Mn (Rungwa *et al.*, 2013) . Poplar tree is used to remediate chlorinated Solvents (Materac, Wyrwicka & Sobiecka, 2015) and Indian grass is used to remediate pesticides and herbicides ( Rungwa *et al.*, 2013).

Sunflower (helianthus annuus L) has been identified as a fast growing industrial oil crop with high biomass and has the ability to hyper accumulate heavy metals in its harvestable parts such as roots leaves and stems.(Jadia & Fulekar, 2008). Sunflower is one of the most studied species for phytoremediation of heavy metals and is considered as the most ideal plant because of its greater potential for heavy metal uptake and tolerance (Rizwan *et al.*, 2016).This plant grows in different soil types and the stem can grow as high as 3m tall with the flower head growing up to 30 centimetres in diameter with very large seeds (Adesodun *et al.*, 2010).

### 1.2 Description of study area

Nampundwe mine is in a typical rural set-up in Shibuyunji District of Central province about 50Km west of the Capital City of Zambia, Lusaka in Figure 1.1. The major socio-economic activities in the district are mining and agriculture. The district is one of the major producers of cotton in the country. Other major crops grown in the district include maize and ground nuts. Livestock reared in the district include cattle, goats, and chickens.

The district has a pyrite mine, iron mine and currently there is a company prospecting mining licenses to do mining in copper. Apart from mining, sugar production is also another industrial activity in the district.

Operations of the mine started in 1913 when it was known as King Edward Mine. It operates a concentrator and an underground mine. The concentrator produces pyrite as the main product and tailings as a waste product. The tailings are pumped to the tailings dump in the form of a slurry and water is then decanted and discharged into the Kacheta stream. which discharges its waters into the Kafue River. The tailings dump is located about 500m from the main plant. Since inception the mine has been operating the dump which has been expanding. Currently Nampundwe mine is mandated by ZEMA license to revegetate the tailings dump progressively. Considering the environmental challenges that tailings dumps poses, it is imperative that we employ a remediation method that is going to be environmentally sustainable and beneficial to the local communities.

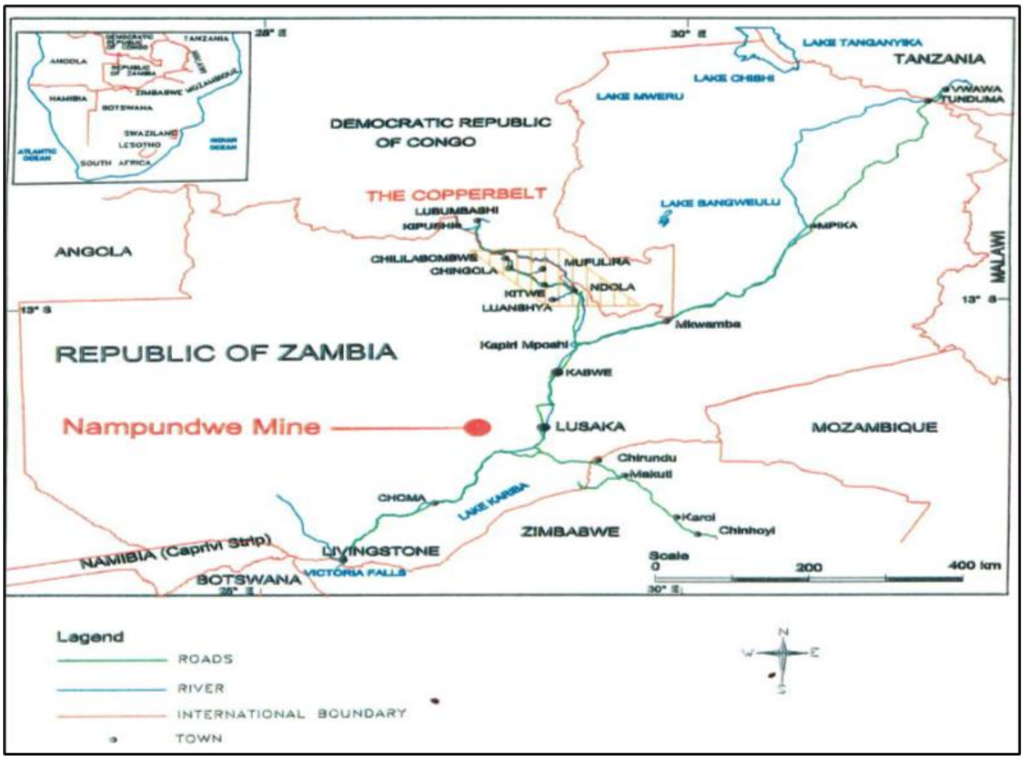

**Figure 1.1: Location of Nampundwe Mine in the Central Province of Zambia. (Source: www.kcm.co.zm accessed on 23 December 2023).**

### 1.2.1 Topography

The site lies within the watershed of the Kafue River, which flows through the Kafue Flats, approximately 30km south of the mine. Locally, drainage and runoff are into a series of the tributaries of the Kafue. The Kacheta stream is the most prominent of these tributaries and the topography of the site is gently undulating. The highest elevation around the mine is 1.060 meters above sea level (masl) on a small hill to the east of the site. From this point, there is a general slope westward to the valley of the Kacheta, which lies between 1,010 and 1,020 masl.

### 1.2.2 Geology

The geology at Nampundwe comprises of Pre-Cambrian basement rocks. The basement complex mainly consists of intrusive rocks, generally granites and gabbros, gneiss and quartz muscovite biotite schist. The Nampundwe orebodies are comprised of a series of strata bound massive sulphides hosted in massive dolomites and impure limestone. Sulphide account for 60% of the orebody and are comprised of pyrite and pyrrhotite. The other minerals are mainly calcite, dolomite and quartz.

## 1.3 Statement of the problem

Heavy metal pollution of terrestrial and aquatic ecosystems due to mining activities has become a global environmental problem. Considering the adverse effects of heavy metals in mine waste on the ecosystem and human health, there is need to remove them from the waste (Khalid *et al.*, 2017) for agro-ecological sustainability and human benefits (Bhargava *et al.*, 2012). But it is also crucial to use remediation techniques and technologies that would efficiently (Khalid *et al.*, 2017) and sustainably remediate heavy metals from Nampundwe mine tailings dam. Furthermore, the current world tread of promoting sustainable mining implores that we clean up the soil contaminated with mine waste in a sustainable way that will fit the local specifications in promoting sustainable development.

Konkola Copper Mines (PLC) Nampundwe Pyrite mine site has been in operation since 1931 and disposes its mine waste at a tailings Dam. Tailings are deposited in paddocks and the decant water drained from the supernatant pond using a small penstock pipe which flows down an unlined trench. The decant water flows down into a toll drain that discharges into the Kacheta stream. This water is usually utilized by the local farmers to water their vegetables and as well as drinking water for their animals.

These tailings contain toxic elements which have the potential of having adverse effect on humans and the environment. The most significant toxic elements in the tailings from Nampundwe mine are iron (Fe), Copper (Cu), Zinc (Zn), lead (Pb), Magnesium (Mg). However, the heavy metals that are abundant in the tailings and have potential to affect human health and the environment are Fe, Cu and Zn.

These toxic elements pose a great risk to humans in Nampundwe through drinking of the contaminated water and the food chain. With increased production from the mine over the years the amount of mine waste has increased leading to fertile land loss and landscape disruption and causes habitat loss while the loose tailings pollute the atmosphere.

During the past decade several studies have been carried out to develop mine waste remediation methods that are aimed at improving the ecological environment of mining areas. Scientists have come up with an inexpensive method called phytoremediation which uses plants called hyper accumulators to remediate contaminated mine waste sites. However, they is little knowledge in Zambia about remediation of pyritic mine waste using Phytoremediation.

It is against this background that this study seeks to assess the possibility of using sunflower for phytoremediation of contaminated mine tailings at Nampundwe mine tailings dam.

## 1.4 Aim of the study

The purpose of this study was to investigate the possibility of using sunflower as a green technology for the phytoremediation of mine tailing’s dumps contaminated with toxic elements from a pyrite mine. This study will use Nampundwe Mine Tailings Dam as a case study.

## 1.5 Study Objectives

### 1.5.1 Main Objective

To investigate the possibility of using sunflower as a green technology for phytoremediation of mine tailings at Nampundwe.

### 1.5.2 Specific Objectives

The specific objectives for this study were to:

(i). Evaluate the potential and efficiency of sunflower for the remediation of mine tailings contaminated with pyritic toxic elements.

(ii). Recommend which phytoremediation technique will be most suitable for the remediation of pyrite mine tailings dumps.

(iii). Identify the opportunities and limitations of implementing phytoremediation of toxic elements contaminated tailings.

## 1.6 Research questions

In this study I will answer the following research questions to fulfil my objectives:

(i). Can sunflower be used for the remediation of mine tailings from a pyrite mine contaminated with potentially toxic elements?

(ii). What conditions encourage the growth of sunflower and its extraction ability?

(iii). What are the barriers that prevent further implementation of phytoremediation?

(iv). Which phytoremediation technology does sunflower implore for remediation?

## 1.7 Significance of study

This study will provide Konkola Copper Mines (KCM) Nampundwe Mines and other mining companies in Zambia with information on an environmentally friendly and cost-effective method to treat the mine waste generated from their operations. Currently most mining companies in Zambia do not remediate the mine waste generated from their mining activities due to high costs, technical challenges, and regulatory compliance challenges (Sandell, 2020).

Hence this study is crucial in that it will enable mining companies to use remediation techniques that would cost effectively and sustainably remediate heavy metals from mine waste (Khalid et al., 2017). This will also help the government regulatory agencies such as Zambia Environmental Management Agency (ZEMA) to implement policies that will encourage the use of green technology in remediation of mine waste. Zambia as a country will also be on course in achieving sustainable development goals number 3, 6 and 11 by the year 2030.

## 1.8 Scope of study

The aim of this study is to investigate the possibility of using sunflower for phytoremediation of pyritic mine waste contaminated with potentially toxic elements. This study will focus on the remediation of tailings from Nampundwe pyrite mine. In this study tailings will be analysed for toxic elements before planting sunflower and after harvesting. Sunflower plants will also be analysed for toxic elements. The study will also highlight the challenges of phytoremediation and suggest possible ways to ensure successful remediation.

## 1.9 Ethical Considerations

The researcher obtained concert from KCM before conducting the study. The study was done with the help of KCM tailings dam employees. This was to ensure that there is accuracy, intellectual honest and protection of the organization involved in this case KCM Nampundwe mine. This study also ensured that data collected is reported accurately. The researcher was cleared by Natural and Applied Sciences Research Ethics Committee (NASREC) from the University of Zambia (UNZA).

## 1.10 Limitation of the study

Collection of representative composite samples from the tailings dump was challenge because it has 21 paddocks and covers an area of about 578.673m$^2$. However, paddocks 1 to 16 are filled to capacity and closed while 17 and 18 are currently being prepared for deposition. Paddocks 19 and 20 are the ones which were used in the last ten (10) years and still have space for deposition while paddock 21 is the one currently in use. Samples for this study were collected from paddocks 19 and 20 because historical data on dam monitoring was readily available. The toxic elements to be analysed in the tailings are limited to the ones that are commonly found in the tailings based on the historical analysis data.

## 1.11 Gap of knowledge

This study will help to bridge the gap of knowledge in sustainable mine waste remediation methods in the mining industry. It will also help mining companies in achieving sustainable developing goals by promoting sustainable mining.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Introduction

This section reviews literature on sources of heavy metals, impacts of mine waste on the environment, soil, and humans. This section will also review literature on the different types of remediation methods as well as focus on both the global and Zambian scenario of heavy metal pollution by mine waste.

## 2.2 Heavy metal pollution

With the increased development in industrialization and urbanization, the abundance of heavy metals in the environment has increased tremendously in the past decades, raising significant concerns globally. This contamination of soil by heavy metals has become a global problem for both human health and safe food production (Liu *et al.*, 2018).

Globally there are five (5) million soil contaminated sites by different heavy metals covering about five hundred (500) million hectares of land (Liu *et al.*, 2018). Most of these contaminated sites are in the developed countries such as China, Australia, and the United States of America. This is due to their huge growth in industrialization and advanced technological processes. According to the US EPA 600,000 hectares (ha) of land in the USA has been contaminated with heavy metals (Khalid *et al.*, 2017). In China , 100 million ha of land which is equivalent to about 25% of its arable land is contaminated with heavy metals(Liu *et al.*, 2018). In Europe there are about three (3) million polluted sites and about 250,000 sites are heavy metal polluted sites (EEA 2007).

Research by an environmental action group (ENS, 2006) based in the US, indicated that the world most contaminated areas pose health risks to more than 10 million people in different countries (Song *et al.*, 2019). In the Dominican Republic, the town of Haina is well known for automobile battery recycling industries which has resulted in people suffering from lead poisoning (Screening *et al.*, 1999); Kyrgyzstan is also severely polluted by radioactive uranium waste from mining activities(Fernández-Luqueño *et al.*, 2013); the city of Ranipet in India has about 3.5 million people affected tannery waste (Fernández-Luqueño *et al.*, 2013) and in Zambia the mining town of Kabwe millions of people are affected by lead pollution from an old mine (Hamvumba, Mataa & Mweetwa, 2014).

## 2.3 Sources of heavy metal pollution

Increased industrialization and Anthropogenic activities (Ullah *et al.*, 2015) such as burning fossil fuels, mining, mineral beneficiation processes, agriculture chemicals ,sewage, poor municipal waste disposal mechanisms and warfare are the major contributors to heavy metal soil contamination (Marques, Rangel & Castro, 2009). However, waste from mining and mineral beneficiation processes remains the world's largest waste streams (Bian *et al.*, 2012) containing metals. A typical example is North America which produces 10 times more solid waste from mining activities as compared to municipal solid waste (Khalid *et al.*, 2017).

Heavy metals are a group of metallic chemical elements that have relatively high densities, atomic weights, and atomic numbers. The most common heavy metals include cadmium (Cd), mercury (Hg), lead (Pb), arsenic (As), zinc (Zn), copper (Cu), nickel (Ni) and chromium (Cr). These heavy metals originate from either natural or anthropogenic activities. Heavy metals are non- biodegradable and persist in the environment hence posing a long-term threat for the environment. According to their role in the environment, heavy metals can be classified as essential and non-essential. Essential heavy metals such as Cu, Fe, Mn, Ni and Zn are needed (in small amounts) for the physiological and biochemical processes of living organisms however, they become toxic when available in excess concentrations. Non- essential heavy metals such as Pb, Cd, As, and Hg are highly toxic even in small amount with no known physiological functions in living organisms. Subsequently, non-essential heavy metals are known to cause environmental pollution and severely affect the physiological and biochemical functions in crops/plants resulting into reduced agricultural productivity.

## 2.4 Heavy Metal pollution in Zambia

Zambia is in the southern part of Africa. It is known not only for its rich diversity of wildlife including birds, reptiles, and large mammals but also for its minerals. It is endowed with mineral resources such as Copper, Cobalt, Zinc and Lead among others. In 1997, 3% of the world's annual copper production and 20% of the annual cobalt production was mined in Zambia. Between 2021 and 2022, Zambia accounted for 4% of the global copper production while the production of cobalt has reduced and Zambia only accounts for 0.26% of the global production (Statista,2024) .The core mining areas in Zambia are central, Copperbelt, Northwestern and Eastern Province.

Despite the economic benefits of income and employment that mining has offered the Zambians, it has impacted negatively on the environment and its citizens. According to recent research by ZEMA (2021), 90% of solid waste generated in Zambia is mining waste. Mining pollution in Zambia is because of unsustainable mining processes such as discharging toxic effluent into fresh water sources and the fact that they are no progressive rehabilitation of mine dumps during operations and after closure of mine sites. This is evident in the Copperbelt province where communities near the Copper mines are highly polluted while the town of Kabwe which had a lead mine is now known as the most contaminated town in the world (Hamvumba, Mataa & Mweetwa, 2014). This pollution is mainly from the tailings and mining residue left when the mine was abandoned.

Different mining processes produce different types of wastes such as tailings, waste rock stockpiles, wastewater, overburden, open- pit stopes, leach residues and underground workings as shown in figure 2.1.

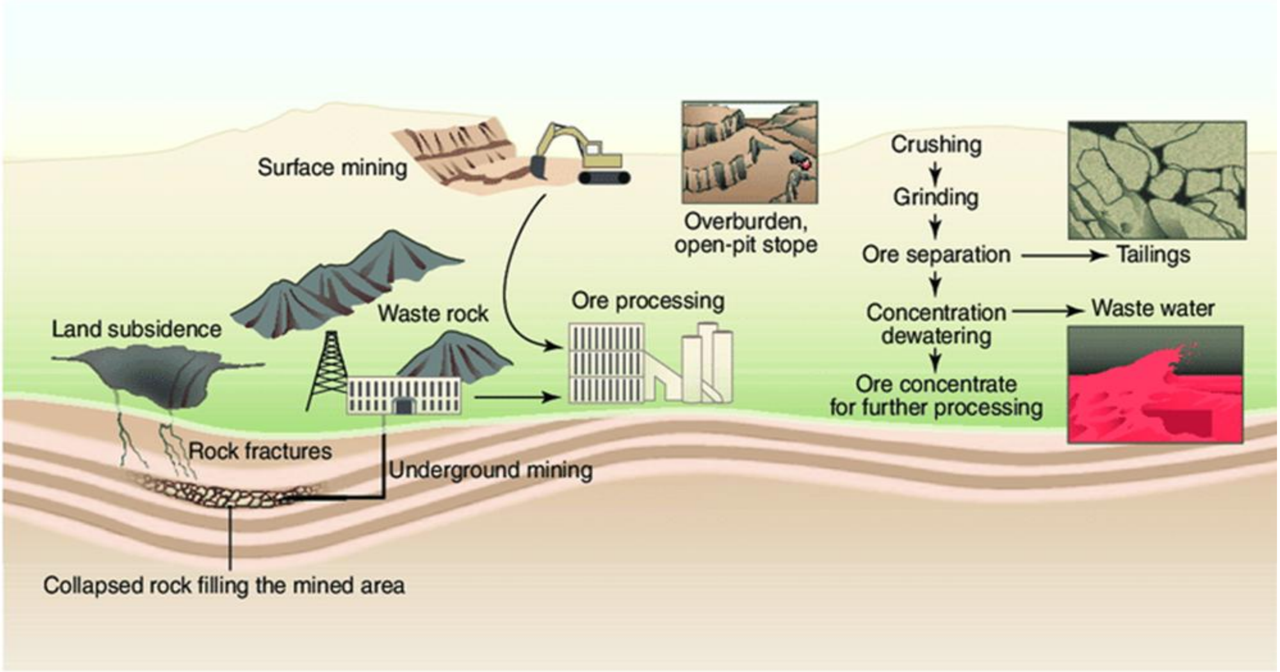

**Figure 2.1: Shows the different types of waste generated from different mining processes (Bian et al., 2012)**

The waste rock is the low-grade material generated in underground mining that must be excavated to reach the ore body and it is usually not profitable to process. Zambia has approximately twenty-one waste rock dumps which cover an area estimated to be about 388 hectors(Nyambe & Phiri, 2010). The overburden is the near surface soils and rocks from open pits stripping operations and research has shown that it covers an area of 206,465 hector from the Zambian's mining industry(Nyambe & Phiri, 2010). The tailings are gauge material from the concentration of ore that has been processed in an enrichment/concentrator plant before the deposition of waste tailings. In an enrichment plant the ore is crushed and grinded to reduce the size hence increasing the surface area of the ore which increases the recovery of the valuable mineral. Crushing is followed by ore separation process such as flotation which is a milling process by which mineral particles are chemically induced to get attached to bubbles and float while the gangue sinks. In this way the valuable minerals are concentrated and separated from the low-grade gangue. The valuable product from the enrichment plant is transported to the smelter for further treatment while the wastewater and the tailings are disposed of at the tailing's dams.

Tailings are the waste material that remain after the extraction of the valuable mineral from a concentrator plant and mostly consist of finely ground ore, the waste minerals that occur in the ore and small amounts of ore valuable minerals that cannot be recovered economically. These tailings are disposed in impoundments that are usually constructed by tailings and in some cases from waste rock (Edraki *et al.*, 2014). The design and construction of tailings impoundments/dams are meant to provide retention of tailings solids, protection from dam failure(Edraki *et al.*, 2014), prevention of air pollution and prevention of the release of contaminated water to ground water and surface water system(Wang *et al.*, 2017a). The release of contaminated water from tailings dams can compromise the quality of downstream water and destroy aquatic environments(Sheoran & Sheoran, 2006).

There are several environmental impacts connected with tailings including surface and ground water contamination, soil contamination, air pollution and land degradation(Donkor *et al.*, 2009). For example, the Copperbelt province has about forty-five tailings' dams covering an area of around 9125 hectares(Nyambe & Phiri, 2010) and this has deprived the local communities of land for economic activities such as farming, forestry, and housing. The use of tailings ponds for water supply, fishing and crop irrigation has potential to cause harmful health impacts(Afonso *et al.*, 2020).Tailings are loose in nature; flow easily and hence collapse easily when stacked leading to tailings dam failures which release large amounts of acidic water and toxic mud containing heavy metals(Afonso *et al.*, 2020).This results in the loss of lives, property, and contamination of surrounding landscape. Soil contamination by heavy metals is also because of wind-borne dust from the tailing's dams. The tailing's discharge from Nampundwe concentrator contain high concentration of toxic elements or organic contaminants that are harmful to the environmental and humans(Wang *et al.*, 2017b).

Most of these tailings dams in Zambia are linked to historical mining operations when the mines were owned by government through Zambia Consolidated Copper Mines (ZCCM). In the late 1990 when the mining industry faced several challenges due to lack of investment, falling copper prices and poor technology mines were privatized and the new owner did not take up the responsibility of the environmental impacts resulting from historical mining. Hence no remediation or rehabilitation has been done on these tailings' dams making them a hazard to the environment and humans. Currently the mines have been revived through massive investments by the new owners and new mines have also been opened. But as mining operations are scaling up production to make profits from invested capital the environmental obligations and concerns are being overlooked and, in most cases, remediations methods are said to be unsustainable economically for mine owners.

## 2.5 Impacts of heavy metals pollution from mine tailings

### 2.5.1 Soil contamination

Accumulation of heavy metals in soils are usually a result of wind-blown dry tailings from tailings dams. High concentrations of heavy metals in soil are a problem due to their toxicity to soil microorganisms and impairment of ecosystems functions (Huang *et al.*, 2017). Heavy metals affect microorganisms ability to decompose certain compounds by regulating substrate available in the soil (Ding *et al.*, 2017).They tends to affect the important microbial processes in soil and reduce on the microorganisms activities and population in the soil (Jiwan & Ajay, 2011).Microbial communities are cardinal in soil because they play an important role in nutrient cycling, maintenance of soil structure and the detoxication of chemicals used in agriculture for controlling weeds and pests (Nannipieri et al,2003; Huang *et al.*, 2017). Heavy metals also affect the amount of useful bacteria in the soil and can modify soil biological properties and affect plant yields. A study on soil contamination done on the Copperbelt by Czech geological survey (1999) showed a higher concentration of non- essential elements in mining towns like Kitwe, Mufulira and Chingola (Norrgren *et al.*, 2000)

### 2.5.2 Water contamination

Most mining operations in Zambia lie within the catchment of the Kafue River, which is used for domestic water supply, irrigation and is also a source of livelihood through fishing to the local communities (Kambole, 2003). Recently the river has come under threat from pollution by mining activities and has been classified as the most polluted river in Zambia (Ntengwe, 2006). The waste water discharged from tailings dams into freshwater ecosystems has results into the accumulation of heavy metals in the food chain (Mbewe *et al.*, 2016).Therefore, freshwater ecosystems which are polluted by mining waste waters have now become a pathway of heavy metal contamination to both human being through drinking the water and to agricultural crops through irrigation(Ntengwe, 2006; Ikenaka *et al.*, 2014). Ecological the heavy metals in fresh water ecosystems reduce the fish stocks in rivers which are major sources of fish hence affecting the source of income for households whose livelihood depend on fishing (Mbewe *et al.*, 2016).

### 2.5.3 Human

As heavy metals concentrations increase is agricultural land, their levels also increase in food crops posing a serious risk to human health (Khalid *et al.*, 2017). For example accumulation of lead in the food chain can cause serious health problems in humans such as high blood pressure, joint and muscle pains and difficulties with memory and concentration (Zehra *et al.*, 2020). This is evident in Kabwe district which is one of the most polluted towns in the world due to lead contamination (Hamvumba, Mataa & Mweetwa, 2014). Another example is the accumulation of cadmium in rice grains in China which has had harmful effects on human beings consuming it (Huang *et al.*, 2017).The effects of heavy metals on human health include cancer, bone and lung diseases (Jiwan & Ajay, 2011). The health of humans is at risk because they consume fish which has bioaccumulated heavy metals that are discharged or washed into freshwater aquatic environments (Huang *et al.*, 2017)

## 2.6 Remediation of heavy metals polluted mine Tailings.

### 2.6.1 Remediation Methods

Various techniques are available for soil remediation but it is crucial to use remediation technologies that would efficiently (Khalid *et al.*, 2017) and sustainably remediate heavy metals from contaminated tailings .Several technologies have been developed to resolve the issue of soil contamination and can be categorized into two main technologies that is in-situ remediation and ex-situ remediation. In situ remediation is the treatment of the contaminated soil in its original place where it has been found while in ex-situ remediation the contaminated soil is moved to another place for treatment. Remediation can be carried out by physical, chemical, and biological methods (Figure 2.2) and sometimes these methods can be used in combination for effective remediation.

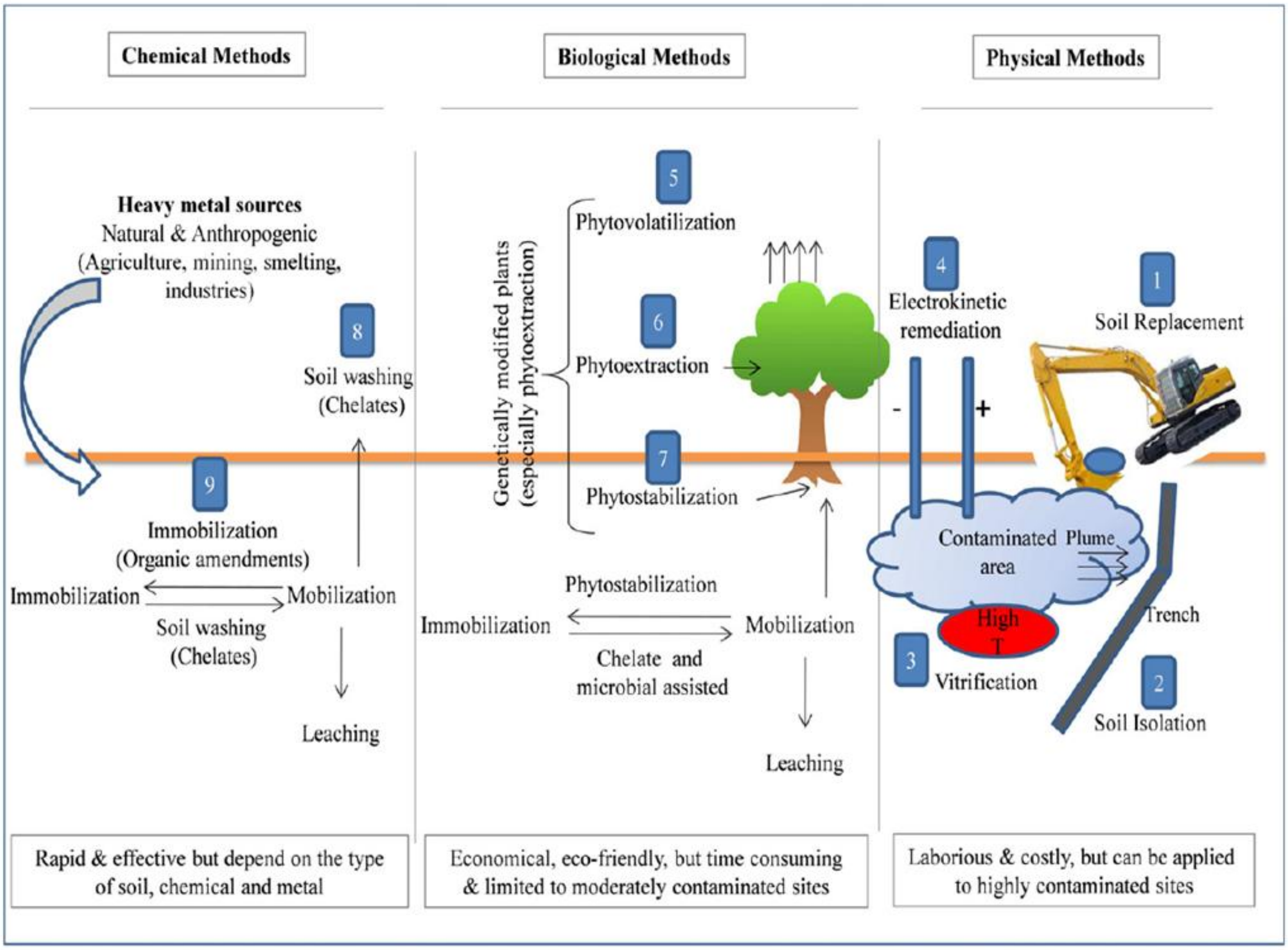

**Figure 2.2: Shows the different remediation methods which are categorized into three that is chemical, biological, and physical methods (Khalid et al., 2017**).

### 2.6.1.1 Physical methods

The physical remediation technique involves the removal of the contaminant from the tailings using physical technology such as soil replacement, isolation, covering and containment method .(Yao *et al.*, 2012).Soil replacement is the mixing or covering of contaminated soils with large volumes of uncontaminated soils (Yao *et al.*, 2012). The mixing of contained soil with uncontaminated soil will effectively dilute the contaminant concentration and improve the soil's ability to support plant life. But this methods is only suitable for small areas considering the fact that it involves heavy work such as excavation and is costly (Li *et al.*, 2019) . Contaminants can also be isolated and contained in a specific area by putting barriers around the contaminated sites to prevent it from spreading to other areas. This remediation method can be used for tailings however it is not suitable for huge amounts of contaminated tailing because it is costly, and efficiency of treatment is low.

#### 2.6.1.2 Chemical methods

The chemical remediation techniques are methods that use chemical reagents, reactions principles to remove contaminants (Li *et al.*, 2019). The soil remediation techniques include solidification and stabilization, soil flushing, soil washing and electrokinetic(Marques, Rangel & Castro, 2009). Solidification use cement, bitumen and asphalt to physically encapsulate the contaminants into a solid while stabilization technology is used by mixing contaminated soils with reagents that will reduce on the solubility of the heavy metals (Fawzy, 2008). Soil flushing involves the extraction of heavy metals through the injection of a fluid into the contaminated soil. This method is effective compared to the physical method and can also be used for small tailings dams that are heavily polluted. However, this method degrades the land because of the chemicals used and introduces other pollutants into the environment.

#### 2.6.1.3 Biological methods

Bioremediation uses plants and microorganisms to remove heavy metals from the soil. The bioremediation techniques that uses plants is phytoremediation (Khalid *et al.*, 2017) and microbial bioremediation is carried out using microorganisms (Ding *et al.*, 2017).

### 2.6.2 Phytoremediation

Phytoremediation is the biological method that uses plants to clean up contaminated sites and restore the sites (Bhargava *et al.*, 2012). It is an inexpensive and environmentally friendly method that can remove organic and inorganic contaminants. The efficiency of phytoremediation is dependent on several plant and soil factors. Plants used for phytoremediation should have the following factors: ability to grow fast, a good root system, tolerance to high concentration of metals and high metal-accumulation capability(Wang *et al.*, 2017b). Soil factors include physio-chemical properties of the soil and bioavailability of metals in the soil (Rahman, Azirun & Boyce, 2013). Phytoremediation includes different techniques which differ in the process by which plants remove, immobilize, or degrade the metals. Phytoremediation technology include phytostabilization, phytovolatilization and phytoextraction (Khalid *et al.*, 2017).

#### 2.6.2.1 Phytoextraction

Phytoextraction uses plants that grow fast and produce large amounts of biomass and are tolerant to high concentrations of heavy metals (Materac, Wyrwicka & Sobiecka, 2015). This technique is based on the plant root’s ability to take-up translocate and concentrate heavy metals from the soil to the biomass of the plant(Jadia & Fulekar, 2008). This plant biomass can easily be disposed of as compared to large amounts of tailings.

### 2.6.2.2 Phytovolatilization

For phytovolatilization the plants absorb the contaminants from the soil and after metabolization releases them to the atmosphere in a less toxic form (Materac, Wyrwicka & Sobiecka, 2015). In this method the plants take up the contaminants including the organic contaminants with water and then release them into the atmosphere through the stomata. This method is used mainly to remediate mercury by converting it into gaseous form which is less toxic. Once these gases are released into the atmosphere studies have shown that they become diluted and do not pose any environmental hazard. Phytovolatilization does not involve disposal of contaminated biomass but prevents soil erosion and can be used for large tailings dam's site(Nehnevajova *et al.*, 2009).

### 2.6.2.3 Phytostabilization

Phytostabilization is where plants are used as vegetation cover to not only reduce the mobility and bioavailability of contaminants in the environment but also to ensure that there are not available for uptake by crops. Phytostabilization does not reduce the concentrations of contaminants (Khalid *et al.*, 2017) but prevents them from sipping further into the groundwater and migrating to surface soils with rainwater runoff (Materac, Wyrwicka & Sobiecka, 2015). Hence it prevents soil erosion and immobilize heavy metals. This method is best for large tailings dams' stockpile because it can stabilize the tailings therefore preventing further environment impacts.

## 2.7 Plants used for phytoremediation.

This technology uses plants with good root system that enables adsorption, absorption and accumulation of contaminants in their tissues for the remediation (Materac, Wyrwicka & Sobiecka, 2015).Research indicates that Phytoremediation improves the quality of contaminated soil unlike the physical and chemical technologies that irreversibly alter soil properties (Liu *et al.*, 2018). The plants used in phytoremediation are known as hyperaccumulators because there accumulate high concentrations of metals in their tissues (Adesodun *et al.*, 2010). According to Lasat( 1999),approximately 400 plant species from at least 45 families have been identified globally as hyperaccumulators of metals. Below are some plants that are used for remediation and the metals they remediate.

- Indian mustard – remediate Cd, Pb, Se, Zn, Hg, Cu
- White willow – remediate Cd, Ni, Pb
- Poplar tree – remediate chlorinated solvents.
- Sunflower – remediate Pb, Zn, Cu, Mn,
- Indian grass – remediate pesticides/ herbicides.

For sub-Saharan Africa several plant species have been identified as possible plants for phytoremediation. A study by Van Der Ent *et al* (2019) revealed that Central African Copperbelt of the DR Congo and Zambia have over 30 species of hyperaccumulators and these include Cyperus dives and Pteris Vittata L among others (Sinkala, 2018).

Previous studies on phytoremediation in Zambia have focused on maize, Indian/lemon grass and sunflower (Mbuki & Mbewe, 2017). For example a study carried out in Chingola, Mufulira, Kitwe and Mwekera in the Copperbelt region of Zambia indicated that grass has several beneficial characteristics for phytoremediation however, due to its shallow root system its survive rates are low (Sandell, 2020). In a study conducted by Mbuki & Mbewe (2017) in Kabwe central province of Zambia, it was observed that sunflower was able to accumulate heavy metals easily as compared to maize.

Most studies have also recommended the use of indigenous trees or plants those that are grown locally for remediation/rehabilitation of mine dumping site (Sandell, 2020; Lee *et al.*, 2021). The benefits of using locally occurring plants include.

- Locally available/grown plants can adapt to the local soils and climate.
- Introductions of foreign species can create a conflict in the local eco-system or introduce invasive species into the environment.

Sunflower is one of the cash crops grown locally by farmers in Nampundwe for socio-economic benefits. The sunflower seeds are used to produce vegetable oil and the residual cake is used as poultry and other animal feed. This study will focus on the use of sunflower because it is one of the most studied species for phytoremediation of heavy metals in Zambia and is considered as the most ideal plant because of its greater potential for heavy metal uptake and tolerance (Rizwan *et al.*, 2016).The main pathway through which heavy metal gain access to sunflower are the roots and the uptake of these heavy metals varies with soil properties and sunflower cultivars (Yang *et al.*, 2017). Most studies agree that the most important factor in heavy metal uptake by plants is the concentration of heavy metals in soil (Yang *et al.*, 2017). High concentration of heavy metals in soil and water negatively affects plant growth as the metals interfere with metabolic functions such as physiological and biochemical processes, inhibiting photosynthesis and respiration, degeneration of main cell organelles in plants (Mukhtar *et al.*, 2010). Rizwan *et al.*, (2016), however argues that heavy metal uptake and translocation increases in sunflower with increasing metal concentration in the growth medium.

Some studies have argued that the physicochemical characteristics of tailings such as high Ph, low water retention, high concentration of heavy metals and deficiencies in soil organic matters (Mukhtar *et al.*, 2010) are not conductive for plant growth. However other studies have shown that the addition of amendments to the tailing to enhance plant growth also introduces heavy metals to the soil (Boonyapookana *et al.*, 2005). It has also been argued that the addition of organic amendments to the tailings not only improves the tailings conditions but also leads to a higher uptake of contaminants from the tailings(Sun *et al.*, 2018). However, for this study no amendments will be added to the tailings as we are trying to establish the potential of sunflower for phytoremediation in tailings.

# CHAPTER THREE

# METHODOLOGY

## 3.1 Introduction

This chapter outlines the methods which were used for sampling, laboratory analysis and data analysis. It will also outline the method used for establishing sample size and the tools used for sampling.

## 3.2 Research design

A research design is a plan, structure and strategy of investigation concerned so as to obtain answers to research questions and control variables. It provides a holistic picture for the whole work earlier before starting work (Convery, 2003). This study aims at collecting information that will help establish whether sunflower has the potential to phytoremediate pyritic mine waste contaminated with heavy metals. Quantitative research methodology was used to collect data on the possibilities of using sunflower flower for phytoremediation of pyritic mine tailings.

Primary data collected from sampling and analysis of the tailings, agriculture soil and analysis of heavy metals in harvested sunflower plants. Secondary data was collected from similar studies reports, books, internet and observations noted during the growing process of the sunflower.

Secondary data was analysed using one-way anova to compare the concentrations of heavy metals in the tailings and soil.

## 3.3 Study site

The study site is Nampundwe mine tailings dam situated in shibuyunji district in central province of Zambia. Shibuyunji district was moved from Lusaka province to central province in 2018 and is situated about fifty km from Lusaka. It has a population of about 70,000 (CSO 2010).

The tailings dam is about 500 meters from the plant and has 21 paddocks at an elevation of 1208 meters above sea as shown in Figure 3.1. The walls of the dam are built up with tailings and earth fill material (figure 3.2). It has a toe drain (figure 3.3) which discharges water into the Kacheta stream, and it is surrounded by indigenous trees on the northern side while the other areas are bare. The top surface and wall slopes of the tailings dam are mostly bare with small patches of grass and trees.

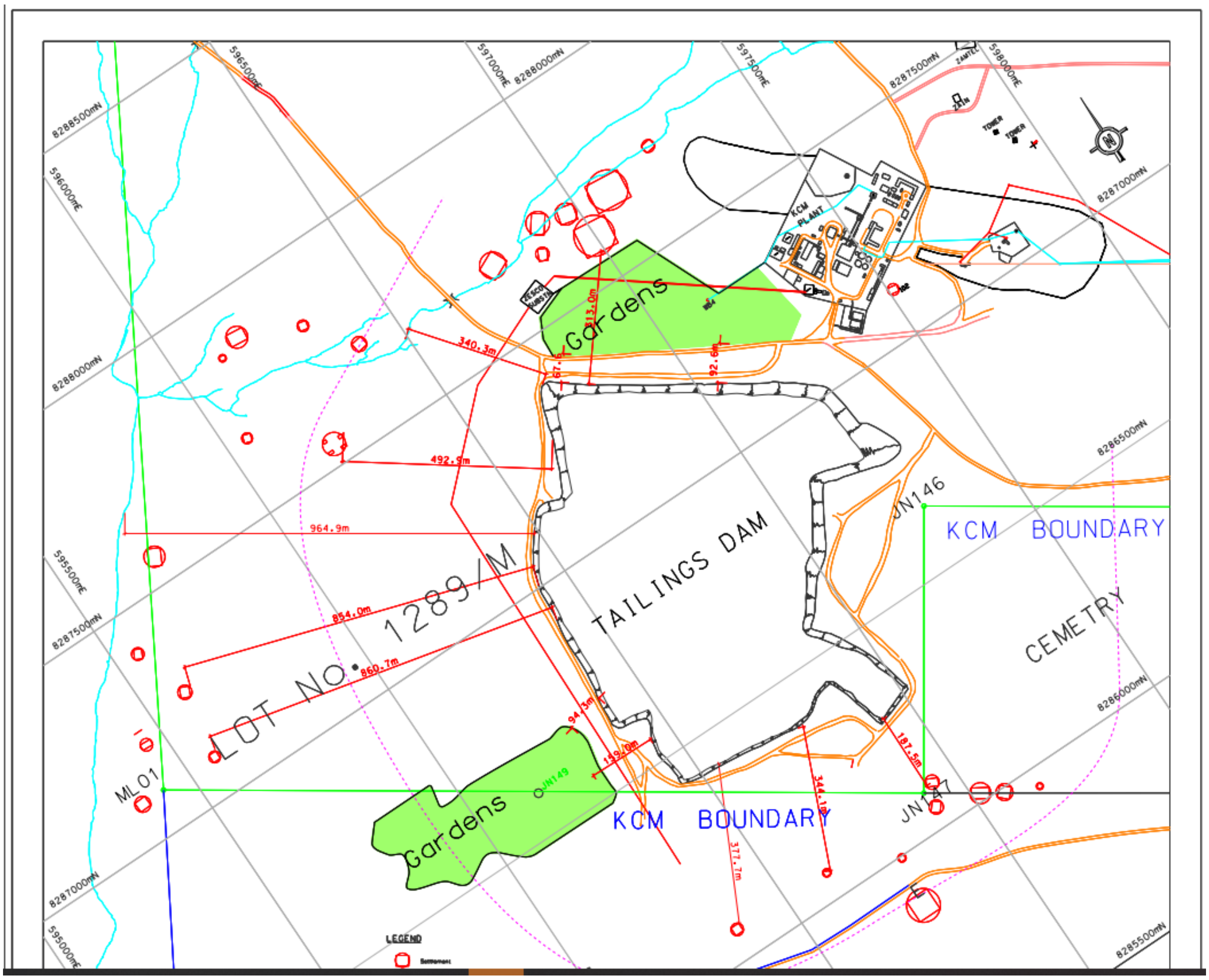

**Figure 3.1: Shows the Nampundwe tailings dam and surrounding areas (KCM 2019).**

**Figure 3.2: Tailings dam walls.**

**Figure 3.3 Toe drain discharging water**.

## 3.4 Study samples

Study samples were tailings, agricultural soil, and sunflower seedlings. The specific species of sunflower used was Helianthus Annuus L. Tailings were collected from the Nampundwe tailings dam which comprises of 21 paddocks. It covers a total footprint area of approximately 578,673m$^2$ with just over 10.6 million tons of stored tailings. The total volume of the store tailings is approximately 4.1 million m$^3$. Out of the 21 paddocks 16 are filled up to capacity and closed while 17 and 18 are yet to be used for deposition. Paddocks 19 and 20 are the ones which were used in the last ten (10) years and still have space for deposition while paddock 21 is the one currently in use. Tailings samples for this study were collected from paddocks 19 and 20 because these paddocks were easily accessible and historical data on dam monitoring was readily available. The sample size calculator was used to determine the sample size for administering the questionnaires (https://www.surveymonkey.com/mp/sample-size-calculator)

Agricultural soil was obtained locally from an area not affected by mining activities. The agricultural soil was reddish – orange to brown and texture was mostly sandy clay. The area where the soil was collected is about 5 km from the tailings dam. Fifty (25) Sunflower seedlings were obtained from Seedco, a local company which deals in seeds.

## 3.5 Sampling techniques

In this study, the method of sampling was grid sampling, a technique where soil samples are taken at locations spaced in a uniform pattern. The reason for choosing this technique was that samples were taken in a regularized pattern, and this ensures an even spatial coverage of the tailings dam. The sampling area was divided into five uniform sampling sites of about 50m * 50m and 50 samples were collected from each site. The tailings samples were collected at every 5 m interval with a closed soil auger down to 100 cm depth, mixed together and 20 kilograms of composite sample was collected.

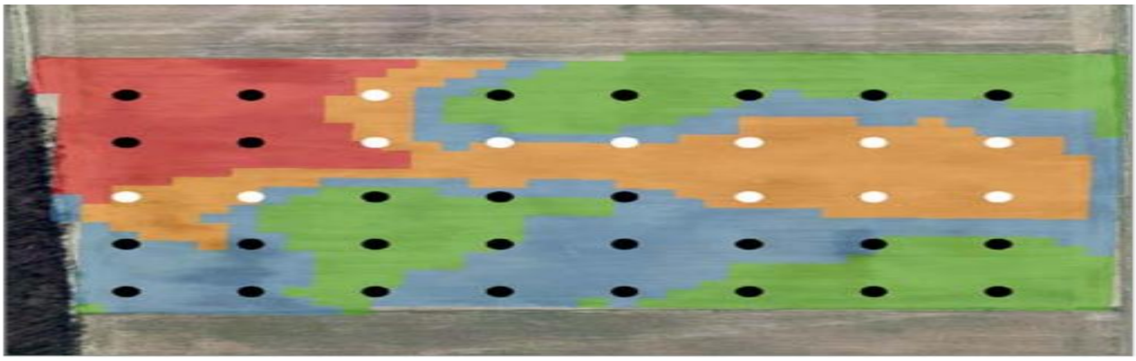

**Figure 3.4: An example of grid-based soil sampling with sampling points (dots) located on an evenly distributed grid**.

**Figure 3.5 Actual sampling points at Nampundwe tailings dam.**

Similarly for soil, the sampling area was divided into five uniform sampling sites of about 50m * 50m and 50 samples were collected from each site. The soil samples were collected at every 5 m interval with a closed soil auger down to 100 cm depth, mixed together and 20 kilograms of composite sample was collected. Soil samples were taken from an area not affected by mining activities to help determine the baseline concentrations of heavy metals in the environment. This area was about five (5) km from the tailings dam.

## 3.6 Data collection equipment

The equipment that were used for data collection included shovels and scoops to clean the sampling areas and scoop the samples. The soil probe was used to collect samples at a depth of 100cm and stored in buckets before taking to the laboratory for analysis.

**Figure 3.6: Soil Probe**

## 3.7 Data analysis

Bernard (2002) states that analysis is the search for patterns in data and for ideas that help explain the observed patterns.  Data collected were summarized and stored in statistical tables and graphs. These included bar charts and using SPSS software. One-way ANOVA was used for analysing the differences in heavy metal concentration in the tailings and agricultural soil.

### 3.7.1 Tailings and Agricultural Soil

For this study 20 kg of soil and tailings composite samples were collected. These samples were then put into black polyethylene (i.e. 5 for tailings and 5 for soil samples) and samples picked from the polyethylene for laboratory analysis. All samples were collected and stored in sampling envelops and  taken to the School of Agriculture Analytical Laboratory for analysis. Concentrations of Copper, Zinc and Iron were analyzed in the tailings and agricultural soil before planting and after harvesting sunflower with an Atomic Absorption Spectrophotometer (AAS) machine.

### 3.7.2 Sunflower

Sunflower was planted in the black polyethylene containing 100% tailings and 100% agricultural soil as a control and their growth monitored. It was planted on the 14th of September 2021 and harvested on the 25th of October 2021 making it a period of six weeks. The species of sunflower planted was Helianthus Annuus L and it was watered three times a week. After six weeks the sunflower was harvested from both the tailings and the agricultural soil. The leaves, roots and shoots were separated and put in sampling envelops and taken to the school of Agriculture Analytical Laboratory for analysis. Concentration of Copper, Zinc and Iron were analyzed in the roots, leaves and shoots with an Atomic Absorption Spectrophotometer (AAS) machine.

**Figure 3.7: Sunflower planted in tailings in black polyethene plastics.**

After determination of heavy metal concentrations in the roots, leaves, and shoots as well as mining tailings and soil through laboratory analysis, the metal removal efficiency (MRE) was determined using Equation 1.

$$MRE = C_1 - C_2/C_1 * 100 \qquad (1)$$

Where C1 is the concentration of heavy metals in soil/tailings before planting and
C2 is the concentration of heavy metals in soil/tailings after harvesting.

This will help determine the efficiency of sunflower for the remediation of mine tailings contaminated with pyritic heavy metals. In order to establish which method of phytoremediation sunflower implored, the translocation factor (TF) was determined. The translocation factor (TF) is the capability of the plant to move a metal throughout the plant(Zadeh *et al.*, 2008). The greater the value the more ease with which the plant moves the metal.TF is determined by the concentration of metals in the shoots of the sunflower in relation to the roots(Zehra *et al.*, 2020).

TF = concentration of heavy metals in shoots / concentration of metal in roots (2)

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1 Introduction

This chapter outlines the results that were obtained from the analysis of the Nampundwe tailings and agricultural soils.

## 4.2 Mineralogical Examination for Nampundwe Ore and Tailings

Nampundwe host rock comprises of dolomites, impure limestone, pyrite with minor pyrrhotite, Chalcopyrite and covellite (Nchanga Mineralogy Department, 2020) . Small amounts of malachite and galena occur in its folded zones on surface and traces of silver, gold, nickel lead cobalt, zinc antimony and bismuth have been identified (Nchanga Mineralogy Department, 2020) .

**Table 4.1: Mineralogical Composition for Nampundwe Ore.**

| Mineral Group | | Chemical Formula |
|---|---|---|
| Chalcopyrite | xx | CuFeS2 |
| Bornite | x | Cu5FeS4 |
| Chalcocite | x | Cu2S |
| Covellite | x | CuS |
| Pyrite | xx | FeS2 |
| Carrollite | xx | Cu(Co,Ni)2S4 |
| Pyrrhotite | xx | FeS |
| Sphalerite | x | (Zn,Fe)S |
| Malachite | x | Cu2(CO3)(OH)2 |
| Pseudomalachite | x | Cu5(PO4)2(OH) |
| | | |

XX= Major amount X= Trace amount

**Table 4.2: Mineralogical Composition for Nampundwe Tailings**

| Group | Mineral | Final Tails |
|---|---|---|
| **Cu Sulphides** | **Chalcopyrite** | Major |
| | **Bornite** | Trace |
| | **Chalcocite** | Trace |
| | **Covellite** | Trace |
| | **Carrollite** | Trace |
| **Iron sulphide** | **Sphalerite** | Minor |
| | **Pyrrhotite** | Major |
| | Pyrite | Major |
| **Copper Oxides** | **Malachite** | Trace |
| | **Pseudomalachite** | |

### 4.3 Assessment of metal concentration in the tailings and agricultural soils

The agricultural soil is reddish – orange to brown and texture was mostly sandy clay while the texture of the tailings was dominated by sand. The pH value differed between sites; the tailings had an average of pH 8.4 while the soil had an average of pH 5.05. Table 4.3 below shows the heavy metal concentrations(mg/kg) in tailings and soil samples collected from selected sites.

**Table 4. 3: The Concentrations, mean and standard deviation (±SD) of Cu, Zn and Fe in the tailings and soil before planting sunflowers.**

| Concentration of heavy metals in tailings and soil before planting (mg/kg) | | | | | | |
|---|---|---|---|---|---|---|
| **Sample** | **Tails** | | | **Soil** | | |
| | Cu | Zn | Fe | Cu | Zn | Fe |
| 1 | 41,92 | 2,46 | 16,4 | 14,38 | 0,3 | 24,14 |
| 2 | 43,66 | 3,08 | 17,64 | 19,84 | 0,96 | 26,56 |
| 3 | 35,24 | 1,88 | 17,06 | 14,48 | 1,76 | 24,78 |
| 4 | 42,52 | 4,96 | 16.1 | 19,38 | 1,02 | 24,32 |
| 5 | 40,48 | 5,56 | 51,3 | 18,76 | 1,76 | 30,56 |
| Mean and (±SD) | 40,76 ± 3,29 | 3,58 ± 1,60 | 23,70 ±15,44 | 17,37 ± 2,71 | 1,16 ± 0,62 | 26,07 ±2,69 |

### 4.3.1 Concentration of Copper (Cu)

From this study the concentration of Cu in the tailings (40.76mg/kg) was significantly higher as compared to the soil (17.37mg/kg). From the mineralogical analysis the ore in Nampundwe contain copper and that is the source of copper in the tailings.

### 4.3.2 Concentration of Zinc (Zn)

The concentration of Zn in the tailings (3.58mg/kg) was higher as compared to the soil (1.16 mg/kg). In the ore, which is the source of Zn in the tailings, the concentration of Zn is low hence the low concentration in the tailings.

### .4.3.3 Concentration of Iron (Fe)

From this study the Fe concentrations in agricultural soil (26.07mg/kg) were significantly higher than that found in the tailings (23.70mg/kg). Nampundwe is within the geographically area which has iron deposits as can be seen from the predominantly iron mining activities in the district. Hence this higher concentration of Fe in the soil can be attributed to contamination from windblown iron concentrate from nearby iron mines.

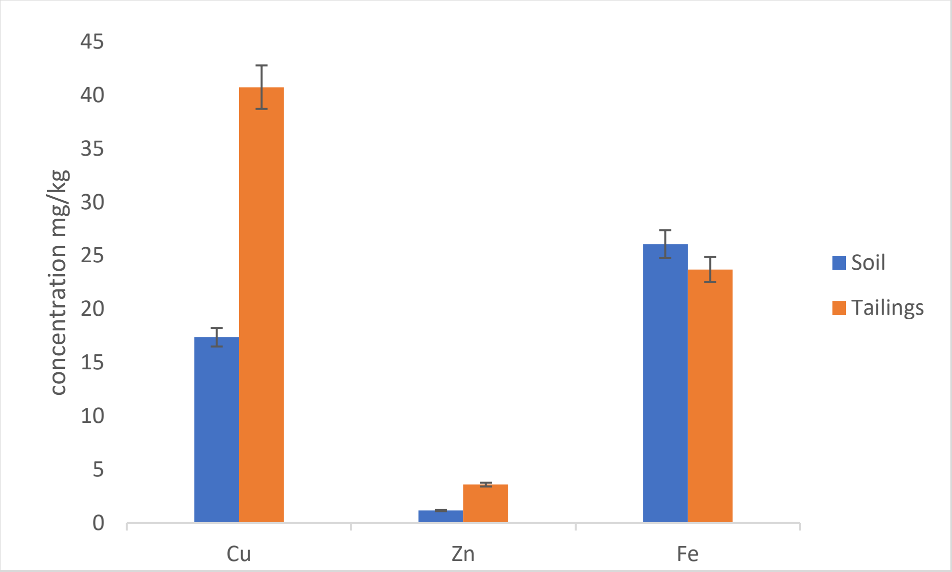

**Figure 4.1: Comparison of concentration of Heavy metals in soil and tailings before planting of sunflower.**

The results from this study were consistent with metal concentration found in soils and water in mining areas of Zambia (Ntengwe, 2006) . Most studies conducted in mining towns in Zambia showed the presences of heavy metal pollution in agricultural soils (Sandell, 2020). Geographical areas where mining activities take place have a higher concentration of heavy metals in soils while areas which are distant from mining activities have moderate or low heavy metals in their soils (Ikenaka *et al.*, 2010).

### 4.4 Evaluation of the potential and efficiency of sunflower for the remediation of mine tailings contaminated with pyritic heavy metals.

This research was carried out to assess the potential of sunflower (Helianthus annuus L) to phytoremediate contaminated pyritic tailings. The data obtained shows that the sunflower was able to uptake heavy metals from the contaminated tailings. The concentration of heavy metals in tailings reduced after harvesting of the sunflower. The concentration of copper reduced from 40.76mg/kg to 36.59mg/kg while zinc reduced from 3.58mg/kg to 3.49mg/kg and iron reduced from 23.70mg/kg to 10.97mg/kg (Table4. 2) respectively, after six weeks. The reduction of heavy metal concentration was also observed in the soil which was a control in this research. The concentration of Cu in the soil reduced from 17.37mg/kg to 10.39mg/kg while concentration of Zn reduced from 1.16 mg/kg to 0.68mg/kg and Fe reduced from 26.07mg/kg to 12.16mg/kg respectively. These findings were consistent with other studies which showed a reduction in heavy metals concentration after harvesting sunflower (Doncheva *et al.*, 2013). A study conducted by Mahardika, Rinanti & Fachrul, ( 2018) showed that the concentration of heavy metals is soil decreased weekly due to the absorption by sunflower and this resulted into the translocation of heavy metals into the plant organs.

**Table 4.4: Concentrations of Cu, Zn and Fe in tailings before planting and after harvesting sunflower**.

| **Concentration of heavy metals in tailings before planting and after harvesting (mg/kg)** | | | | | | |
|---|---|---|---|---|---|---|
| **Sample** | **Tails (before planting)** | | | **Tails (after harvesting)** | | |
| | Cu | Zn | Fe | Cu | Zn | Fe |
| 1 | 41,92 | 2,46 | 16,4 | 38,78 | 2,96 | 11,2 |
| 2 | 43,66 | 3,08 | 17,64 | 38 | 3,24 | 7,6 |
| 3 | 35,24 | 1,88 | 17,06 | 38,04 | 3,08 | 7,76 |
| 4 | 42,52 | 4,96 | 16.1 | 35,88 | 3,98 | 12,98 |
| 5 | 40,48 | 5,56 | 51,3 | 32,26 | 4,22 | 15,3 |
| | | | | | | |
| | **40,76 ± 3,29** | **3,58 ± 1,60** | **23,70 ±15,44** | **36,59 ± 2,65** | **3,49 ± 0,57** | **10,97 ± 3,34** |

**Table 4.5: Concentrations of Cu, Zn and Fe in the Soil before planting and after harvesting sunflower.**

| **Concentration of heavy metals in soil before planting and after harvesting (mg/kg)** | | | | | | |
|---|---|---|---|---|---|---|
| **Sample** | **Soil (before planting)** | | | **Soil (after harvesting)** | | |
| | Cu | Zn | Fe | Cu | Zn | Fe |
| 1 | 14,38 | 0,3 | 24,14 | 12,12 | 0,74 | 13,42 |
| 2 | 19,84 | 0,96 | 26,56 | 11,16 | 0,58 | 12,6 |
| 3 | 14,48 | 1,76 | 24,78 | 11,18 | 0,64 | 13 |
| 4 | 19,38 | 1,02 | 24,32 | 9,26 | 1,22 | 10,68 |
| 5 | 18,76 | 1,76 | 30,56 | 8,24 | 0,24 | 11,1 |
| | | | | | | |
| | **17,37 ± 2,71** | **1,16 ± 0,62** | **26,07 ±2,69** | **10,39 ± 1,59** | **0,68 ±0,35** | **12,16 ±1,20** |

After harvesting the sunflower, the soil and tailings were analysed again for heavy metals. Figure 4.2 and 4.3 shows the concentration of heavy metals in the soil and tailings before planting and after harvesting the sunflower. It was observed that the concentration of heavy metals reduced significantly in the tailings and soil after harvesting the sunflower.

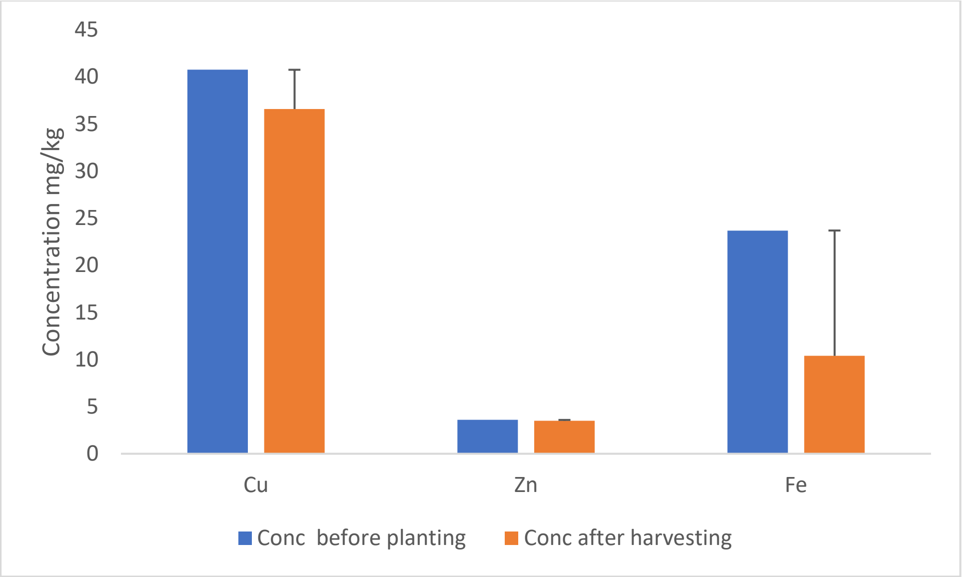

**Figure 4.2: Shows the concentration of heavy metals in the tails before planting and after harvesting sunflowers.**

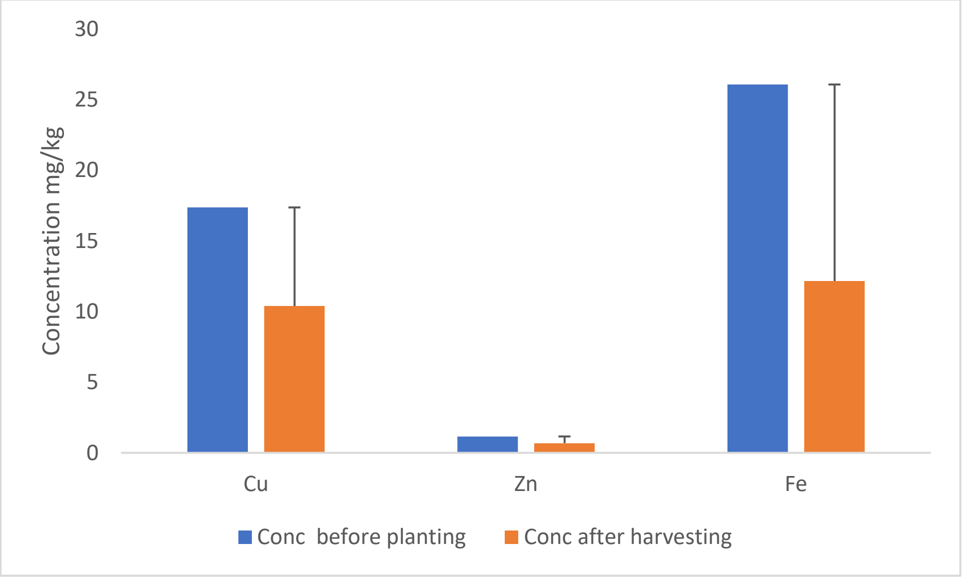

**Figure 4.3: shows the concentration of heavy metals in the soil before and after harvesting the sunflower.**.

### 4.5 Metal recovery efficiency

After the concentration of heavy metals in the tailings before and after harvesting is known the metal removal efficiency (MRE) is determined. This will determine the efficiency of sunflower to remediate mine tailings contaminated with heavy metals. Table 4.4 and 4.5 shows the metal recovery efficiency of sunflower planted in the tailings and soil respectively.

**Table 4. 6: MRE for sunflower planted in the tailings.**

| Element | Concentration before planting ($C_1$) | Concentration after harvesting ($C_2$) | MRE % |
|---|---|---|---|
| Cu | 40,764 | 36,592 | 10,23 |
| Zn | 3,588 | 3,496 | 2,56 |
| Fe | 23,7 | 10,39 | 56,16 |

**Table 4.7: MRE for sunflower planted in agricultural soil.**

| Element | Concentration before planting ($C_1$) | Concentration after harvesting ($C_2$) | MRE % |
|---|---|---|---|
| Cu | 17,368 | 10,392 | 40,17 |
| Zn | 1,16 | 0,684 | 41,03 |
| Fe | 26,07 | 12,16 | 53,36 |

From these results we can conclude that sunflower is effective in removing heavy metals from tailings. The highest removal efficiency of 56.16% for iron happened in the tailings which shows that sunflower can effectively remove iron from pyritic mine waste.

### 4.6 Heavy metal concentrations of plant (sunflower) tissue

After harvesting the sunflower plants copper and iron were found to be the most accumulated in the plant parts after the six weeks (6) weeks planting period. It was also observed that most of the heavy metals were absorbed in the roots and leaves. This is evident in both the control (soil) and the tailings. Results of metal concentration in individual plant parts showed a higher concentration in the roots followed by leaves and lastly the stems. Tables 3 and 4 show the concentrations in the roots, stems, and the leaves after harvesting from the soil and the tailings.

.

**Table 4.8: The average concentrations of heavy metals in the roots, stems, and leaves of harvested sunflower from tailings.**

| Tailings | Roots | Leaves | Stems |
|---|---|---|---|
| Copper (Cu) mg/kg | 1.8 | 0.8 | 0.4 |
| Zinc (Zn) mg/kg | 0.04 | ND | ND |
| Iron (Fe) mg/kg | 6 | 2 | 1.5 |

**Table4.9: The average concentrations of heavy metals in the roots, stems, and leaves of harvested sunflower from tailings**

| Soil | Roots | Leaves | Stems |
|---|---|---|---|
| Copper (Cu) mg/kg | 3.7 | 1.1 | 0.6 |
| Zinc (Zn) mg/kg | 0.13 | ND | 0.03 |
| Iron (Fe) mg/kg | 8 | 3 | 1.8 |

### 4.7 Translocation Factor (TF)

The translocation of Cu, Fe and Zn from roots of sunflower planted in tailings and soil to the shoots can be seen in Table 4.6. Translocation factor was calculated by dividing the concentration of heavy in the shoots by the concentration of heavy metals in the roots (TF = concentration of heavy metals in shoots / concentration of metal in roots). From the table it can be seen that the largest translocation factor is 0.25 after 6-weeks absorption.

**Table 4.10: Sunflower Translocation Factor (TF)**

| Translocation Factor (TF) (Root to Shoot) | | |
|---|---|---|
| **Element** | **Tailings** | **Soil** |
| Copper | 0.22 | 0.162 |
| Iron | 0.25 | 0.225 |
| Zinc | - | 0.23 |

Plants have a natural ability to uptake elements from soil through biological processes(Vangronsveld *et al.*, 2009) and translocate them between roots and shoot systems (Ximenez-Embun et al. 2002). Heavy metals can also be taken up and transported to different parts of the plant and findings from this research indicate that sunflower has the capability to heavy metals throughout the plant(Forte & Mutiti, 2017). Relative to copper and iron, zinc was not taken up as much from the soil and this can be attributed to its low concentration in the tailings. According to previous studies low concentrations of heavy metals affect the rate of translocation (Mahardika, Rinanti & Fachrul, 2018).

### 4.8 Sunflower growth in tailings

It was also observed during the study that the sunflower planted in tailings exhibited a slow growth rate as compared to the one planted in agricultural soil after six weeks. Several studies have shown that heavy metals impact negatively on biomass yield and sunflower growth (Rizwan *et al.*, 2016).

Similarly, it was observed that the shoot length of sunflower differed significantly between the sunflower in the tailings and that planted in agricultural soil. It was therefore concluded that an increase in heavy metal concentration affects the growth of the sunflower(Zadeh *et al.*, 2008)(Rizwan *et al.*, 2016). Increased concentrations of heavy metals reduced the leaf area, plant height and biomass of sunflower seedlings (Rizwan *et al.*, 2016) as observed between the plant in the tailings and those in the soil. Below are pictures of the sunflower after a period of three weeks.

**Figure 3 sunflower planted in tailings.**

**Figure 4 Sunflower planted in soil**

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

The remediation of mine waste globally is extremely poor and in most cases the mine waste is just piled up in huge heaps with no measures in place to prevent run-off or fugitive dust from the mine waste piles. This mine waste contains heavy metals which are carried by rainwater into nearby watercourses or land and pollutes both. Physical and chemical remediation methods are not only expensive but also reintroduces other harmful chemicals into the environment leading to further contamination of the ecosystem.

Presently, most countries have adopted alternative methods for remediation of mine waste which are less expensive and more environmentally friendly. These methods include bioremediation and phytoremediation which was the focus for this research. This research at Nampundwe mine has established that phytoremediation of mine tailings is urgently needed due to the threat to human health and the environmental however, there is need to understand the type and physio-chemical characteristic of the heavy metal contamination before deciding on the plants to use for remediation.

It can be emphasized that the research has contributed immensely to the existing knowledge on phytoremediation of pyritic mine waste and Phytoremediation offers a sustainable green solution for the remediation of contaminated pyritic mine tailing dumps as it is an effective method with no negative impact on the environment.

This research has established from the differences in concentration of copper, zinc, and iron in tailings before planting sunflower and after harvesting, that sunflower has the potential to remediate contaminated soils (table 4.3 and 4.5). Sunflower also showed that it was effective in removing multiple heavy metals from the mine tailings as the highest removal efficiency of 56.16% (Table 4.5) attained was that of the removal of iron by sunflower planted in the tailings after six weeks.

This research also established that the methods of phytoremediation that sunflower remediated heavy metals from pyritic tailings at Nampundwe were phytostabilization and phytoextraction. This was evident by the concentration of heavy metals were found to be in the roots (signifying phytostabilization) and in the shoot and leaves (signifying phytoextraction) of the sunflower (table 4.2).

Difference in shoot lengths and leaf area were observed between the sunflower planted in the tailings and agricultural soil. The sunflower planted in the tailings had smaller leaves and short shoots as compared to the sunflower planted in agricultural soil. This was attributed to the fact that higher concentrations of heavy metals and lack of nutrients affected the growth of the sunflower in the tailings.

### 5.2: Recommendations

After a thorough study and analysis of the findings as indicated in the preceding chapters, the following recommendations were made to ensure a successful restoration of post mining waste damps:

The Nampundwe mine management should revise its rehabilitation plan allocate some fund to it in their budget. This will ensure that an economically sound and environmentally method is implemented as soon as possible, and that degraded land is rehabilitated and restored to its original state. This will not only reduce the negative environmental and health impacts on the people but also land would be available particularly to farmers for agricultural purposes.

Extensive mineralogical analysis should be carried out as well as the physio-chemical characteristics of the tailings. By having knowledge of the total heavy metal content in the tailings, estimation can be done of how the concentrations may hinder establishment and growth of many plant species.

Further screening of plant and trees species should be undertaken as trees might be more beneficial for long-term restoration. The use of native species suitable for phytoremediation should be encouraged especially those that are grown locally, growing near mine waste dump or plants already established and growing on the tailing’s dumps. A breeding program to promote promising species that have shown tolerance for elevated levels of heavy metals should be initiated.

The use of organic amendments should be evaluated, in particular those that are readily available in Nampundwe such as poultry or cow manure. This will increase the survival rate of the plants.

As the mining industry strives to become greener through sustainable mining and reduce its negative environmental footprint, collaboration with the local community and forest department in Nampundwe is key in ensuring the success of remediation programs.

# 6.0 REFERENCES

Adesodun, J.K., Atayese, M.O., Agbaje, T.A., Osadiaye, B.A. (2010) Phytoremediation potentials of sunflowers (Tithonia diversifolia and Helianthus annuus) for metals in soils contaminated with zinc and lead nitrates. *Water, Air, and Soil Pollution*. [Online] 207 (1–4), 195–201. Available from: doi:10.1007/s11270-009-0128-3.

Afonso, T.F., Demarco, C.F., Pieniz, S., Quadro, M.S. (2020) Bioprospection of indigenous flora grown in copper mining tailing area for phytoremediation of metals. *Journal of Environmental Management*. [Online] 256 (July 2019). Available from: doi:10.1016/j.jenvman.2019.109953.

Aguinaga, O.E., McMahon, A., White, K.N., Dean, A.P. (2018) Microbial community shifts in response to acid mine drainage pollution within a natural wetland ecosystem. *Frontiers in Microbiology*. [Online] 9 (JUN), 1–14. Available from: doi:10.3389/fmicb.2018.01445.

Bhargava, A., Carmona, F.F., Bhargava, M. & Srivastava, S. (2012) Approaches for enhanced phytoextraction of heavy metals. *Journal of Environmental Management*. [Online] 105, 103–120. Available from: doi:10.1016/j.jenvman.2012.04.002.

Bian, Z., Miao, X., Lei, S. & Chen, S. (2012) *The Challenges of Reusing Mining*. (August), 702–704.

Boonyapookana, B., Parkpian, P., Techapinyawat, S., DeLaune, R.D. (2005) Phytoaccumulation of lead by sunflower (Helianthus annuus), tobacco (Nicotiana tabacum), and vetiver (Vetiveria zizanioides). *Journal of Environmental Science and Health - Part A Toxic/Hazardous Substances and Environmental Engineering*. [Online] 40 (1), 117–137. Available from: doi:10.1081/ESE-200033621.

Department, N. mine M. & Mp, M. (2020) *NCHANGA MINE Mineralogy Department Identification and Quantification of Main Copper / Cobalt Sulphide and Oxide Minerals*.

Ding, Z., Wu, J., You, A., Huang, B. (2017) Effects of heavy metals on soil microbial community structure and diversity in the rice (Oryza sativa L. subsp. Japonica, Food Crops Institute of Jiangsu Academy of Agricultural Sciences) rhizosphere. *Soil Science and Plant Nutrition*. [Online] 63 (1), 75–83. Available from: doi:10.1080/00380768.2016.1247385.

Doncheva, S., Moustakas, M., Ananieva, K., Chavdarova, M. (2013) Plant response to lead in the presence or absence EDTA in two sunflower genotypes (cultivated H. annuus cv. 1114 and interspecific line H. annuus × H. argophyllus). *Environmental Science and*

*Pollution Research*. [Online] 20 (2), 823–833. Available from: doi:10.1007/s11356-012-1274-5.

Donkor, A., Nartey, V., Bonzongo, J. & Adotey, D. (2009) Artisanal mining of gold with mercury in Ghana. *West African Journal of Applied Ecology*. [Online] 9 (1), 1–8. Available from: doi:10.4314/wajae.v9i1.45666.

Edraki, M., Baumgartl, T., Manlapig, E., Bradshaw, D. (2014) Designing mine tailings for better environmental , social and economic outcomes : a review of alternative approaches. *Journal of Cleaner Production*. [Online] 84, 411–420. Available from: doi:10.1016/j.jclepro.2014.04.079.

Van Der Ent, A., Malaisse, F., Erskine, P.D., Mesjasz-Przybyłowicz, J.(2019) Abnormal concentrations of Cu-Co in: Haumaniastrum katangense, Haumaniastrum robertii and Aeolanthus biformifolius: Contamination or hyperaccumulation? *Metallomics*. [Online] 11 (3), 586–596. Available from: doi:10.1039/c8mt00300a.

Fawzy, E.M. (2008) Soil remediation using in situ immobilisation techniques. *Chemistry and Ecology*. [Online] 24 (2), 147–156. Available from: doi:10.1080/02757540801920154.

Fellet, G., Marchiol, L., Perosa, D. & Zerbi, G. (2007) The application of phytoremediation technology in a soil contaminated by pyrite cinders. *Ecological Engineering*. [Online] 31 (3), 207–214. Available from: doi:10.1016/j.ecoleng.2007.06.011.

Fernández-Luqueño, F., López-Valdez, F., Gamero-Melo, P., Luna-Suárez, S. (2013) Heavy metal pollution in drinking water - a global risk for human health: A review. *African Journal of Environmental Science and Technology*. [Online] 7 (7), 567–584. Available from: doi:10.5897/AJEST12.197.

Forte, J. & Mutiti, S. (2017) Phytoremediation Potential of Helianthus annuus and Hydrangea paniculata in Copper and Lead-Contaminated Soil. *Water, Air, and Soil Pollution*. [Online] 228 (2). Available from: doi:10.1007/s11270-017-3249-0.

Hamvumba, R., Mataa, M. & Mweetwa, A.M. (2014) Evaluation of Sunflower (Helianthus annuus L.), Sorghum (Sorghum bicolor L.) and Chinese Cabbage (Brassica chinensis) for Phytoremediation of Lead Contaminated Soils. *Environment and Pollution*. [Online] 3 (2), 65–73. Available from: doi:10.5539/ep.v3n2p65.

Huang, X., Zhao, F., Yu, G., Song, C. (2017) Removal of Cu, Zn, Pb, and Cr from Yangtze Estuary Using the Phragmites australis Artificial Floating Wetlands. *BioMed Research International*. [Online] 2017. Available from: doi:10.1155/2017/6201048.

Ikenaka, Y., Nakayama, S.M.M., Muzandu, K., Choongo, K.(2014) Heavy metal contamination of soil and sediment in Zambia. *Heavy Metal Contamination of Water* *and Soil: Analysis, Assessment, and Remediation Strategies*. [Online] 4 (11), 109–128. Available from: doi:10.1201/b16566.

Jadia, C.D. & Fulekar, M.H. (2008) Phytoremediation: The application of vermicompost to remove zinc, cadmium, copper, nickel and lead by sunflower plant. *Environmental Engineering and Management Journal*. [Online] 7 (5), 547–558. Available from: doi:10.30638/eemj.2008.078.

Ji, S., Kim, S. & Ko, J. (2008) The status of the passive treatment systems for acid mine drainage in South Korea. *Environmental Geology*. [Online] 55 (6), 1181–1194. Available from: doi:10.1007/s00254-007-1064-4.

Jiwan, S. & Ajay, K. (2011) Effects of Heavy Metals on Soil, Plants, Human Health and Aquatic Life. *International Journal of Research in Chemistry and Environment*. [Online] 1 (January), 15–21. Available from: www.ijrce.org.

Kambole, M.S. (2003) Managing the water quality of the Kafue River. *Physics and Chemistry of the Earth*. [Online] 28 (20–27), 1105–1109. Available from: doi:10.1016/j.pce.2003.08.031.

Khalid, S., Shahid, M., Niazi, N.K., Murtaza, B. (2017) A comparison of technologies for remediation of heavy metal contaminated soils. *Journal of Geochemical Exploration*. [Online] 182, 247–268. Available from: doi:10.1016/j.gexplo.2016.11.021.

Lasat, M.M. (1999) Phytoextraction of Metals from Contaminated Soil: A Review of Plant/Soil/Metal Interaction and Assessment of Pertinent Agronomic Issues. *Journal of Hazardous Substance Research*. [Online] 2 (1). Available from: doi:10.4148/1090-7025.1015.

Lee, J., Kaunda, R.B., Sinkala, T., Workman, C.F. (2021) Phytoremediation and phytoextraction in Sub-Saharan Africa: Addressing economic and social challenges. *Ecotoxicology and Environmental Safety*. [Online] 226 (July), 112864. Available from: doi:10.1016/j.ecoenv.2021.112864.

Li, C., Zhou, K., Qin, W., Tian, C. (2019) A Review on Heavy Metals Contamination in Soil: Effects, Sources, and Remediation Techniques. *Soil and Sediment Contamination*. [Online] 28 (4), 380–394. Available from: doi:10.1080/15320383.2019.1592108.

Liu, L., Li, W., Song, W. & Guo, M. (2018) Remediation techniques for heavy metal-contaminated soils: Principles and applicability. *Science of the Total Environment*. [Online] 633, 206–219. Available from: doi:10.1016/j.scitotenv.2018.03.161.

Mahardika, G., Rinanti, A. & Fachrul, M.F. (2018) Phytoremediation of heavy metal copper (Cu2+) by sunflower (Helianthus annuus l.). *IOP Conference Series: Earth and*

*Environmental Science*. [Online] 106 (1). Available from: doi:10.1088/1755-1315/106/1/012120.

Marques, A.P.G.C., Rangel, A.O.S.S. & Castro, P.M.L. (2009) *Remediation of heavy metal contaminated soils: Phytoremediation as a potentially promising clean-Up technology*. [Online]. Available from: doi:10.1080/10643380701798272.

Masaka, J., Mutambu, M., Mhindu, R. & Muringaniza, K. (2017) Pyritic metals sequestration on mine dumps treated with oyster mushroom (Pleurotus ostreatus, Jacq.et Fr.). *Chemical and Biological Technologies in Agriculture*. [Online] 4 (1), 1–14. Available from: doi:10.1186/s40538-017-0108-6.

Materac, M., Wyrwicka, A. & Sobiecka, E. (2015) Phytoremediation techniques in wastewater treatment. *Environmental Biotechnology*. [Online] 11 (1), 10–13. Available from: doi:10.14799/ebms249.

Mbewe, G., Mutondo, M., Maseka, K. & Sichilongo, K. (2016) Assessment of Heavy-Metal Pollution in Sediments and Tilapia Fish Species in Kafue River of Zambia. *Archives of Environmental Contamination and Toxicology*. [Online] 71 (3), 383–393. Available from: doi:10.1007/s00244-016-0295-3.

Mbuki, R. & Mbewe, G. (2017) Phytoremediation of Lead and Zinc Metals Using Sunflower : Sampled From An Abandoned Mine Tailing Dump Site In Kabwe , Zambia . *International Journal of Multi-Disciplinary Research*. 1–11.

Mukhtar, S., Bhatti, H.N., Khalid, M., Anwar Ul Haq, M. (2010) Potential of sunflower (Helianthus annuus l.) for phytoremediation of nickle (Ni) and lead (Pb) contaminated water. *Pakistan Journal of Botany*. 42 (6), 4017–4026.

Nehnevajova, E., Herzig, R., Bourigault, C., Bangerter, S. (2009) Stability of Enhanced Yield and Metal Uptake By Sunflower Mutants for Improved Phytoremediation. *International Journal of Phytoremediation*. [Online] 11 (4), 329–346. Available from: doi:10.1080/15226510802565394.

Norrgren, L., Pettersson, U., Örn, S. & Bergqvist, P.A. (2000) Environmental monitoring of the Kafue River, located in the Copperbelt, Zambia. *Archives of Environmental Contamination and Toxicology*. [Online] 38 (3), 334–341. Available from: doi:10.1007/s002449910044.

Ntengwe, F.W. (2006) Pollutant loads and water quality in streams of heavily populated and industrialised towns. *Physics and Chemistry of the Earth*. [Online] 31 (15–16), 832–839. Available from: doi:10.1016/j.pce.2006.08.025.

Nyambe, I. & Phiri, C. (2010) Database of mineral resources of Zambia. *International*

*Workshop on UNFC-2009 - Theory and Practice*. (June), 29.

Nyquist, J. & Greger, M. (2009) A field study of constructed wetlands for preventing and treating acid mine drainage. *Ecological Engineering*. [Online] 35 (5), 630–642. Available from: doi:10.1016/j.ecoleng.2008.10.018.

Rahman, M.M., Azirun, S.M. & Boyce, A.N. (2013) Enhanced Accumulation of Copper and Lead in Amaranth (Amaranthus paniculatus), Indian Mustard (Brassica juncea) and Sunflower (Helianthus annuus). *PLoS ONE*. [Online] 8 (5). Available from: doi:10.1371/journal.pone.0062941.

Rizwan, M., Ali, S., Rizvi, H., Rinklebe, J. (2016) Phytomanagement of heavy metals in contaminated soils using sunflower: A review. *Critical Reviews in Environmental Science and Technology*. [Online] 46 (18), 1498–1528. Available from: doi:10.1080/10643389.2016.1248199.

Sandell, E. (2020) *Post-Mining Restoration in Zambia: screening native tree species for phytoremediation potential*. [Online]. Available from: http://urn.kb.se/resolve?urn=urn:nbn:se:slu:epsilon-p-105117%0Ahttps://pub.epsilon.slu.se/16846/1/sandell_festin_e_200409.pdf.

Screening, F., Near, L.C., Kaul, B., Sandhu, R.S. (1999) *Artcles*. 107 (1), 917–920.

Sheoran, A.S. & Sheoran, V. (2006) Heavy metal removal mechanism of acid mine drainage in wetlands: A critical review. *Minerals Engineering*. [Online] 19 (2), 105–116. Available from: doi:10.1016/j.mineng.2005.08.006.

Sikamo, J., Mwanza, A. & Mweemba, C. (2016) Copper mining in Zambia - History and future. *Journal of the Southern African Institute of Mining and Metallurgy*. [Online] 116 (6), 491–496. Available from: doi:10.17159/2411-9717/2016/v116n6a1.

Sinkala, T. (2018) Integrated phytomining and ethanol production in the Zambian Copperbelt to minimize mine decontamination costs and environmental and social impacts: A review. *Journal of the Southern African Institute of Mining and Metallurgy*. [Online] 118 (8), 815–824. Available from: doi:10.17159/2411-9717/2018/v118n8a4.

Song, Y., Kirkwood, N., Maksimović, Č., Zhen, X. (2019) Nature based solutions for contaminated land remediation and brownfield redevelopment in cities: A review. *Science of the Total Environment*. [Online] 663, 568–579. Available from: doi:10.1016/j.scitotenv.2019.01.347.

Stanley Rungwa, Arpa, G., Sakulas, H., Harakuwe, A. (2013) Phytoremediation – An Eco-friendly and Sustainable Method of Heavy Metal Removal from Closed Mine Environments in Papua New Guinea. *Procedia Earth and Planetary Science*. [Online] 6, 269–277. Available from: doi:10.1016/j.proeps.2013.01.036.

Sun, Y., Wen, C., Liang, X. & He, C. (2018) Determination of the phytoremediation efficiency of Ricinus communis L. and methane uptake from cadmium and nickel-contaminated soil using spent mushroom substrate. *Environmental Science and Pollution Research*. [Online] 25 (32), 32603–32616. Available from: doi:10.1007/s11356-018-3128-2.

Ullah, A., Heng, S., Munis, M.F.H., Fahad, S. (2015) Phytoremediation of heavy metals assisted by plant growth promoting (PGP) bacteria: A review. *Environmental and Experimental Botany*. [Online] 117, 28–40. Available from: doi:10.1016/j.envexpbot.2015.05.001.

Vangronsveld, J., Herzig, R., Weyens, N., Boulet, J. (2009) Phytoremediation of contaminated soils and groundwater: Lessons from the field. *Environmental Science and Pollution Research*. [Online] 16 (7), 765–794. Available from: doi:10.1007/s11356-009-0213-6.

Wallace, K.B. (2002) Mechanisms of pyrethroid neurotoxicity: Implications for cumulative risk assessment. *Toxicology*. [Online] 171 (1), 1. Available from: doi:10.1016/S0300-483X(01)00574-1.

Wang, L., Ji, B., Hu, Y., Liu, R. (2017a) A review on in situ phytoremediation of mine tailings. *Chemosphere*. [Online] 184, 594–600. Available from: doi:10.1016/j.chemosphere.2017.06.025.

Wang, L., Ji, B., Hu, Y., Liu, R. (2017b) A review on in situ phytoremediation of mine tailings. *Chemosphere*. [Online] 184, 594–600. Available from: doi:10.1016/j.chemosphere.2017.06.025.

Yang, Y., Zhou, X., Tie, B., Peng, L. (2017) Comparison of three types of oil crop rotation systems for effective use and remediation of heavy metal contaminated agricultural soil. *Chemosphere*. [Online] 188 (June 2014), 148–156. Available from: doi:10.1016/j.chemosphere.2017.08.140.

Yao, Z., Li, J., Xie, H. & Yu, C. (2012) Review on Remediation Technologies of Soil Contaminated by Heavy Metals. *Procedia Environmental Sciences*. [Online] 16, 722–729. Available from: doi:10.1016/j.proenv.2012.10.099.

Zadeh, B.M., Savaghebi-firozabadi, G.R., Alikhani, H.A. & Hosseini, H.M. (2008) Effect of Sunflower and Amaranthus Culture and Application of Inoculants on Phytoremediation of the Soils Contaminated with Cadmium. *American-Eurasian J. Agric. & Environ. Sci.,*. 4 (1), 93–103.

Zehra, A., Sahito, Z.A., Tong, W., Tang, L. (2020) Assessment of sunflower germplasm for phytoremediation of lead-polluted soil and production of seed oil and seed meal for human and animal consumption. *Journal of Environmental Sciences (China)*. [Online] 87, 24–38. Available from: doi:10.1016/j.jes.2019.05.031.

# APPENDICES

## APPENDIX 1: LABORATORY REPORT FOR TAILINGS AND SOIL ANALYSIS

### Tailings and Soil analysis Results

| Date of Analysis | Sample id | Cu | Zn | Fe |
|---|---|---|---|---|
| | | mg/kg | | |
| Aug-22 | Sunflower leaves T1 | 0.8 | ND | 2 |
| | Sunflower roots T2 | 1.8 | 0.04 | 6 |
| | Sunflower stems T3 | 0.4 | ND | 1.5 |
| | Sunflower leaves S1 | 1.1 | ND | 3 |
| | Sunflower roots S2 | 3.7 | 0.13 | 8 |
| | Sunflower stems S3 | 0.6 | 0.03 | 1.8 |
| | | | | |
| | Tails 1 | 41.92 | 2.46 | 16.4 |
| | Tails 2 | 43.66 | 3.08 | 17.64 |
| | Tails 3 | 35.24 | 1.88 | 17.06 |
| | Tails 4 | 42.52 | 4.96 | 16.1 |
| | Tails 5 | 40.48 | 5.56 | 51.3 |
| | Soil 1 | 14.38 | 0.3 | 24.14 |
| | Soil 2 | 19.84 | 0.96 | 26.56 |
| | Soil 3 | 14.48 | 1.76 | 24.78 |
| | Soil 4 | 19.38 | 1.02 | 24.32 |
| | Soil 5 | 18.76 | 1.76 | 30.56 |
| | Namp T1 | 38.78 | 2.96 | 11.2 |
| | Namp T2 | 38.00 | 3.24 | 7.6 |
| | Namp T3 | 38.04 | 3.08 | 7.76 |
| | Namp T4 | 35.88 | 3.98 | 12.98 |
| | Namp T5 | 32.26 | 4.22 | 15.3 |
| | Namp As 1 | 12.12 | 0.74 | 13.42 |
| | Namp As 2 | 11.16 | 0.58 | 12.6 |
| | Namp As 3 | 11.18 | 0.64 | 13.00 |
| | Namp As 4 | 9.26 | 1.22 | 10.68 |
| | Namp As 5 | 8.24 | 0.24 | 11.1 |

## APPENDIX 2: PROTOCOL USED FOR SOIL SAMPLING

**Protocol for soil Sampling.**

| |
|---|
| Site name: |

Sample number: ______________________________
Sample location (paddocks number): ______________________________
Coordinates: ______________________________
Date sample was collected: ______________________________
Sample depth: ______________________________
Type of soil (sand, clay, loam, others): ______________________________
Topography (hilly, plain): ______________________________

Description of locality: if anything in particular is noticed (garbage dumped, strange smell, many tracks of humans, wildlife or other random factors observed): ________________
______________________________________________________________

Landcover in % (to the nearest 5, approximation) in a radius of 100 m from the sampling point (m):
water: ______________________ forest: ______________________
grassland: ______________________ buildings & roads: ______________________
agricultural fields: ______________________ gardens: ______________________
industrial activities: ______________________ residential: ______________________
open soil or cut down forest: ______________________
Not of the above: ______________________