ASSESSMENT OF ENVIRONMENTAL RISKS ASSOCIATED WITH REPROCESSED TAILINGS FROM VAT LEACHING AT SEKENKE GOLD MINE, IRAMBA DISTRICT, TANZANIA

PRISCUS ROMAN

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENVIRONMENTAL STUDIES (MES)

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CERTIFICATION

I, the undersigned, certify that I have read and hereby recommend for acceptance by the Open University of Tanzania a dissertation entitled; "**Influence of Vat Leach Reprocessed Tailings on the Environments around Sekenke Gold Mine, Iramba District, Tanzania"** in partial fulfilment of the requirements for Master of Environmental Studies (MES).

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Dr. Josephat Saria

(Supervisor)

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Date

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DECLARATION

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

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Signature

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Date

DEDICATION

I dedicate this work to my lovely family.

ACKNOWLEDGEMENT

The accomplishment of this dissertation comes from different sources. I greatly thank the almighty God for leading and keeping me healthy always and manage my research to be accomplished. My great thanks are given to my relatives basically my family members, my beloved wife Mrs. Theresia Mosile, my daughters Eminence and Harriet; and my son Godlisten for their prayers and passion when I was busy with studies basically this dissertation report preparation. My sponsors, friends and all other people in any way who supported me in any means to accomplish my studies.

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ABSTRACT

Soil pollution is a worldwide phenomenon which results from both natural and anthropogenic activities. This study aimed to assess the environmental risks associated with reprocessed tailings by determining the concentration of heavy metals (As, Pb, Cd, Fe, Zn & Cr) by using XRF (Rigaku Nex CG) and atomic absorption spectroscopy (AAS, Varian 55B) for As. Eighteen (18) samples from both unprocessed and reprocessed tailing heaps, twelve (12) garden soils, nine (9) water samples and six (6) leafy vegetable samples collected and analysed in the laboratory to assess the heavy metals levels. The pollution load Index (PLI) values for unprocessed and reprocessed tailings were 2.440 and 1.858 respectively, indicating significant environmental pollution. In garden soils, the pollution index (PI) and contamination degree, (C_{deg}) values were 2.9889 and 27.082 respectively, confirming elevated contamination. As and Cr was higher in both children and adults consuming water. Cancer risk evaluation showed children consuming *Amaranthus spp* faced higher risk for As, Cd, Cr and Pb than in adults. In contrast, consuming *Cucurbita moschata* posed cancer risk from As, Cd and Cr in both groups though Pb related risk for children remained below US EPA life time cancer risk (LTCR) thresholds. However, further studies are required to assess levels of heavy metals in other green leafy vegetables and fruits around the process plants, health risks through dermal and inhalation and assess the levels of heavy metals dispersion in soils from the abandoned reprocessed tailings to a far distance.

Keywords: *Heavy Metals, Geoaccumulation Index (Igeo), tailings, Contamination, pollution load Index, Amaranthus spp, Cucubita moschata, Iramba.*

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LIST OF ABBREVIATION

ASGM	Artisanal and Small-Scale gold Miners
ATSDR	Agency for Toxic Substances and Diseases Registry
BW	Body weight
CDC	US Center for Diseases Control and Prevention
CDI	Chronic daily intake
CF	Contamination Factor
CWS	Contamination Warning standard
DNA	Deoxyribonucleic acid
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organisation
GDP	Gross Domestic Product
GST	Geological Survey of Tanzania
HI	Hazard Index
HM	Heavy Metals
HQ	Hazard Quotient
LTCR	Life Time Cancer Risk
MoM	Ministry of Minerals
PLI	Pollution Load Index
PML	Primary Mining Licence
SF	Slope factor
SSGM	Small Scale Gold Miners
TAMISEMI	*Tawala za Mikoa na Serikali za Mitaa*
US EPA	United States Environmental Protection Agency

WHO	World Health Organisation
XRD	X-ray Diffractometer

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Small-scale Mining is practiced worldwide in over 70 countries where around 10 to 15 million are miners including women and children approximately 4 to 5 million (WHO, 2016). In Tanzania, Small-scale Gold Mining (SSGM) is one of the economic activities that contribute to the household income and contribute to the national income which is expected to reach about 10% of Tanzania's GDP in 2025 (Biteko, 2023). As reported in the parliament of Tanzania during its budget sessions 2023/2024, the contribution comes from the mineral stakeholders including Large Mine companies, medium-scale miners and the Small-scale Gold Mining which contribute to around 40% of the total collections from this sector (MoM budget speech, 2023/2024).

Leaving aside large and medium scale mine, the Small-Scale Gold Mining sector employs over 1.5 million people involving mineral extraction, process plants including Vat (large tanks) leach and gravity separation methods, Mineral and chemical dealers, equipment businessmen and others (Maganga *et al*., 2023). In Tanzania, Small-scale Gold Mining is considered legally with a Primary Mining license (PLM). However, the majority of these miners involved in the activities operate informally.

The method of recovering gold by most of the small-scale miners is by gravity concentration using sluices of which the concentrate is amalgamated by mercury.

The amalgamation followed by smelting of the amalgam in an open space leaving the mercury to evaporate to the environment. Few mine sites small hats are built for smelting the amalgam, that make the mercury not to spread in a large area which then transmitted to unpolluted areas. Although mercury is still used, but from 2000s, a new business began by extending the scope of recovery to increase more production of gold by re-processing the tailing disposed after gravity concentration by using sluices. In this period, the Vat leaching technique for extracting gold from the tailings by the small-scale miners was established in Geita Region Tanzania.

According to Cope (1999) Vat leaching is also known as Sand leaching to recover precious metals which is a process used in metallurgy to extract metals from ores. It involves using vats or tanks to hold crushed ore and a leaching solution, such as a solvent or acid that helps dissolve the desired metal from the ore. The most serious health and safety hazards affecting the small-scale mining sector are associated with the use of chemicals in recovery. Small-scale miners for example in Tanzania, are engaged in unsafe and heavy manual labour and they frequently use unsafe and poor tools in mining and processing of gold as seen in figure 1.1. The Vat leach technology is safer in the context of extraction since it involves loading of materials and chemicals to the Vat leach tanks, loading carbon to tanks and conduct elution that finally produce gold by smelting of the concentrates. This flow activities minimize direct contact with dust and chemicals by the miners.

Figure 1.1: Tailings Produced by ASGM

The recovery of gold from ASM tailings is done all over the country in areas with gold mines and therefore metals are released to the environment through the abandoned tailings. For example, in Southern highlands several Vat leach plants are located in Chunya, the most active mining sites are Saza, Makongolosi, Itumbi, Lupa-Sira, Sengambi, Mabadaga and Iyai; and other areas in Mbeya and Songwe regions with ASM gold mine activities on which these tailings are produced.

In Lake Zone, historically the area is potentially having a several mines with many mine activities including reprocessing of tailings (Maganga, *et al*., 2023). The activity of recovery gold by reprocessing tailings produced by small scale miners using cyanide spread all over this zone in areas like Nyarugusu, Mgusu, Rwamgasa, Msasa to mention few in Geita region. Likewise, Shinyanga, Kagera and Mara regions in the lake zone practice the same as Geita whereby several Vat leach tailing processing plants established around the small-scale mining sites or a distance far from the mines (Merket, 2019).

In western regions the plants are found in the Mpanda gold field in Katavi region. The mines contain a complex ore with different heavy metals like Lead, iron, cadmium, chromium, copper zinc, silver and others in small scale miners of D-reef, Ibindi, Magula, Kapanda, Sikitiko and Chemchem (Stendol, *et al.*, 2004). In central regions most of these activities are done in Sekenke, Kirondatal and Mpambaa small scale mining areas in Iramba - Singida and Nholi in Bahi district in Dodoma. All these places which reprocessing tailings is done there is no proper management of tailings as after cyanidation as seen in Figure 1.2.

Figure 1.2: Vat Leach for Reprocessing Tailings in one of the Sekenke Process Plant

It can be seen that figure 1.3, tailings are offloaded from the Vat leach tanks, dropped around the process plants. There are no clear management of the tailings, since there are no tailing dams or any restriction to avoid movement of the materials to the uncontaminated environment. This mechanism is done like it is seen to all process plants at Sekenke ASM mines and other areas with these Vat leach plants.

Figure 1.3: Offloading of Reprocessed Tailings after Vat leach Cyanidation

The focus of the study is on the assessment of environmental risks due to increasing heavy metal pollution caused by reprocessed abandoned tailings on human health and other individuals at and around the Sekenke, Singida region in Tanzania where cyanidation processes by Vat leaching plants are taking place.

The miners, individuals around the mines and possibly the Decision makers are not aware on the risks that are associated with the contents of heavy metal in reprocessed tailings that can pollute the environment. Therefore, to build this awareness to these groups of people, it was necessary to conduct a study so that the findings can be used for their safety and establish regulation on handling reprocessed tailings.

1.2 Statement of the Problem

The reprocessing of Vat leach tailings in gold mining operations has introduced significant environmental concerns, necessitating a thorough investigation and assessment of its impact on the surrounding ecosystems. The Vat leaching technology used by the small-scale miners spread all over the mining sites in

Tanzania, leaving a number large abandoned heaps of reprocessed tailings without a proper care. The poor or mistreatment of these heaps results to drainage of chemical solutions during the rainy season or dusts during the dry seasons to the virgin environment. A result of the situation may cause environmental pollutions by heavy metals contained in the tailings.

Currently, there are no studies conducted in this region basically in Tanzania that addresses the proper treatment or abandon of the reprocessed tailings. Also, through literatures, there is no any study found that address the levels of heavy metals in the reprocessed tailings and the surrounding environment especially the soils that vegetables are grown. Therefore due to that concern, a study was required specifically to focus on the assessment of levels of heavy metals to soil and leafy vegetables around the mine and the potential risks to human health arising from the consumption of green leafy vegetables contaminated with the hazardous heavy metals.

1.3 Objectives of the Study

1.3.1 Main Objective

The purpose of this study was to assess the influence of Vat leach reprocessed tailings on the environments around Sekenke Gold Mine, Iramba District, Tanzania.

1.3.2 Specific Objectives

1. To determine the level of heavy metals (As, Pb, Cd, Cr, Fe and Zn) in unprocessed and reprocessed tailings, water and soils around the small-scale gold mining processing plants;

ii. To assess levels of heavy metals (As, Pb, Cd, Cr, Fe and Zn) in the green leafy vegetables irrigated by water from the small-scale gold mining;

iii. To evaluate human health risks due to the consumption of contaminated green leafy vegetables irrigated by water from the small-scale gold mining.

1.4 Research Questions

i. What are the levels of heavy metals in the soils, unprocessed and reprocessed tailings and water?

ii. What are the levels of heavy metals in the green leafy vegetables?

iii. What are the human health risks due to the consumption of contaminated green leafy vegetables?

1.5. Significance of the Study

VAT leaching is a method used to extract gold from their ores or unprocessed tailings. In extraction of gold from unprocessed tailings, results to other remaining materials which are termed as reprocessed tailings. The reprocessed tailings to all over the country are abandoned without special care on the environments around gold mines. . Understanding the impact of these tailings on soil and water is crucial to mitigate potential environmental damage. Also, the presence of contaminants from reprocessed tailings can adversely affect local flora and fauna by up taking the heavy metals over a period of time through bioaccumulation or any other pathway. Assessing their impact helps in understanding how ecosystems are being affected, allowing for measures to protect biodiversity and ecosystem health.

Assessing the environmental risks caused by reprocessed tailings in soil and on water is vital for safeguarding these resources. Nevertheless, understanding the potential health risks posed by exposure to contaminants from these tailings and leafy vegetables grown around the mine site is crucial. Local communities near mining areas might be at risk due to exposure to contaminated soil and water.

Assessment environmental risks caused by reprocessed tailings is now helpful in ensuring compliance with these regulations, guiding responsible mining practices and minimizing environmental impact. In this study, the influence of Vat leach reprocessed tailings on the environment will help the researchers and policymakers to develop effective long-term remediation strategies. The remediation involves the techniques to mitigate contamination or changes in mining practices to reduce environmental harm.

Overall, the study assessed the impacts Vat leach reprocessed tailings on the environment in gold mining areas which is critical to prevent potential environmental and health risks associated with mining activities.

1.6 Scope of the Study

The study covered the Vat leaching plants operated by small-scale gold miners at Sekenke in Iramba District, Singida region. The targeted area consists of nine plants and hence eighteen (18) heaps were used as sample population that include nine (9) heaps of unprocessed tailings and nine (9) heaps of reprocessed tailings. The garden soil was also an environmental media considered under the study covers around twelve (12) acres in which, one acre represented by one sample. Water and vegetable samples were also considered in the accomplish and fulfilment of the objectives. The study focused on the Vat leach method and hence, other gold small-scale miners with other methods of recovery such as gravity recovery, flotation method, magnetic separation and the other related methods were not targeted in the study.

1.7 Limitation of the Study

i. The abandoned tailings were big heaps of different sizes, so it was difficult to take samples in the inner part. Therefore, less than a meter opened into the heaps chisels to get samples. The different moisture contents and particle sizes of the tailings and affected the uniformity of quantity of samples from each heap.
ii. Small Scale Miners are sometimes not transparent to their operations. Some of them with process plants had given less cooperation during the collection of samples, fearing that they could expose the quantity of gold in their tailing heaps.

1.8 Definition of Key Terms

1.8.1 Mining

Mining is the extraction of any naturally occurring mineral substances (solid, liquid and gas) from the earth for utilization purposes (K Telmer, 2012). In this study, mining refers to the extraction of gold from the ground earth.

1.8.2 Small-scale Gold Mining

Small-scale gold mining is the activity of extracting gold from rocks or sediments that contain gold minerals. It involves various processes including mining, communication (crushing and grinding), washing or panning, amalgamation, and burning of the amalgam for gold recovery (Telmer, 2012). In this study, small-scale gold mining refers to the extraction of gold from its ore by individuals with little capital investment and poor technology.

1.8.3 Small-scale gold Miners

A small-scale gold Miner is a person that extract gold mineral from the ores with little capital investment. The result of the low capital is a low production of gold.

1.8.4 Tailings

They are the waste materials resulting from the recovery of the economic mineral from its ore after passing through the process plant or mill. In this case, the economic mineral is gold. In small-scale miners the tailings are the materials washed out from wooden board machines called sluices.

1.8.5 Unprocessed Tailings

They are the wastes resulted after recovery of the economic minerals but in this study regarded as the wastes that are not subjected into cyanidation, that are direct from the concentration of the gold ores on the sluices.

1.8.5 Reprocessed Tailings

They are the wastes resulted after recovery of the economic minerals from the unprocessed tailings, in this study are regarded tailings after cyanidation.

1.8.5 VAT Leaching

This is the method of recovering gold using chemicals such as cyanide, lime and other chemical whenever required for extraction of gold from its ore. Vat leaching is applied by large mines with a sophisticated knowledge, equipment and technology and by SSGM by locally made plants and moderate technological equipment. These are the byproducts, wastes resulting after extraction or recovery of gold from mine wastes, or tailings using the Vat leach method after chemical reactions take place for some hours. In this study, these tailings are the ones that are offloaded from the leach tanks and left.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

A review of literature related to this topic is presented in this chapter. The literature gave an organized overview of existing research undertaken on this topic. This introduction subchapter highlights the concept of gold processing and extraction, heavy metals in the mine sites and re-processing tailings. The other sub chapters presenting a review of related works on the specific objectives includes; A concept of heavy metal contamination in soil and water near gold mine sites, uptake of heavy metals by green leafy vegetables irrigated with contaminated water and Human health risks from consumption of heavy metals contaminated vegetables. The chapter discusses also the research gap that required to be fulfilled.

2.1.1 Gold Processing and Extraction

Gold extraction methods vary depending on the mining location, and they can involve open-pit or deep shaft mining, often accompanied by the presence of other heavy metals (HM) like copper (Cu), silver (Ag), iron (Fe), cadmium (Cd), Zinc (Zn) and lead (Pb) (Kevin *et al.,* 2012). The mining process used and the quantity of waste generated are determined by the specific location. In the past, mining activities produced relatively small amounts of waste due to the exploitation of higher-grade ores.

Additionally, the capacity to handle large quantities of materials was limited, resulting in waste being discarded near the mine opening or pit. However, open-pit mining generates significantly more waste compared to underground mines, as a larger volume of topsoil, overburden and unproductive rock (gangue) needs to be removed. Over centuries, gold mining in Tanzania has led to the accumulation of numerous extensive tailings dumps scattered throughout the country, posing potential adverse impacts on the environment (Dold, 2010).

During Vat leaching chemicals like Sodium cyanide (NaCN) and quick lime (CaO) are mainly used in the processes of dissolution. The significance of Sodium cyanide is to dissolve gold to get a gold complex compound and sometimes other metals like copper, silver and others (Wills and Finch, 2015). Lime is required for raising pH since cyanidation can be operated under alkaline conditions to avoid the evolution of hydrogen cyanide gas which is toxic. Although lime can be used for the reduction of acid in the soil, the long-term use or discharge can lead to negative effects on plant growth and soil properties like a decrease in phosphorus and Manganese, in some other cases generates heat that leads to the loss of water which then left the soil with low moisture thus the increased plastic limit of soil (Ahmad & Tan, 1986; S. Kumar et al., 2019).

Jordan (2023) described that gold exists in the form of natural gold for about 70 to 75 % of the total gold ore in the world, 20% formed in the form of telluride, and 5% to 10% in the form of invisible gold. The author further describes eight (8) groups of gold ore including quartz gold ore, silver gold ore, iron oxide copper gold ore, gold sulphide ore, blue clay gold ore, tellurium gold ore, gold in arsenopyrite and granite gold ore.

In the process of extracting gold (Au) by ASM from mineral-bearing rock, a technique called mercury amalgamation is employed. This involves mixing mercury with the ores obtained from the ground or stream beds to create an amalgam, where the gold binds with the mercury. Subsequently, the burning of the amalgam takes place, causing the elemental mercury to vaporize into a toxic plume, while the gold is left behind. Mercury amalgamation has been utilized as the primary method for gold processing for centuries and continues to be practiced today in artisanal and small-scale gold mining (ASGM). Remarkably, ASGM represents the second largest contributor to atmospheric mercury pollution worldwide, following coal combustion (Kevin, *et al.*, 2012).

In Africa, Ghana is a country where the mining activities began earlier compared to other African countries except South Africa. Tailings are reprocessed in regions like Western region in areas like Asankragua, Bogoso, Prestea, Wassa-Akropong, and Tarkwa. The cyanidation technique used in test works indicated that the highest gold recovery was 81.5% in Asankragua while the lowest at Tarkwa with 38.5% (Cobbinah, et al., 2021). In Zimbabwe reprocessing of tailings is done in some mines including the Isabella Mine Located in Bubi District which is a run-of-mine leach situated in the dry western part of Zimbabwe and the Hopefield Gold which relies on the agglomerating the heap leaching of old mine tailings (Channon, 2023). Therefore, heap leaching is done in these areas for colonial tailings but not vat leaching technique.

In Misisi Eastern Congo, the Vat leach operation is practiced where the ASGM recover gold using the cyanide from the mine wastes and tailings. Belagamire et al., (2022) after observing the situation of tailing storage conducted a study that come up with production of concrete pavers to incorporate tailings on them because they were stored carelessly in the nature without respect for environmental and sanitary standards, leading to soil and underground pollution. Although the Authors explained the properties of tailings and possible harmful substances that can be released to the environment, their study ended up in production of pavements for storage of tailings before reprocessing.

In Tanzania, the gold mineralization deposits have always been associated with other heavy metals in quartz ore, silver ore, pyrite, pyrrhotite, sphalerite, gangue, arsenopyrite, gangue, and other minerals. According to Jordan (2023), various gold mine, minerals experts and other gold prospectors in their studies found that about 70%-75% of the gold deposits are natural gold and 20% are Au-Ag tellurides. The remaining 5% -10% is invisible gold ore and symbiotic in Gold-bearing minerals containing tellurium. The gold Tellurides contain calaverite, mayenite ($AuTe_2$), potash-zinc ore ($AuAgTe_4$) and green feldspar. For example, a study conducted in analysis of the ratio of metals in the arsenopyrite gold mine, the gold (Au) content is 72.27%, the silver (Ag) content is 27.73%, the Arsenic (As) content is 38.79%, the Sulfur (S) content is 24.29%, and the Iron (Fe) content is 36.92%.

2.1.2 The Concept of Re-processed Tailings

According to Bhanbhro (2014) it is the waste material from the mine, which is crushed, milled and stored as impoundments after extraction of materials of interest and Ikotun, et al., (2022) discussed tailings as waste produced from processes of excavation, extraction, physical and chemical treatment of mineral ores. The tailings are composed of mixture of silica, heavy metals, water and fine solids and are generally deposited in a pond or accumulated in proper-selected areas (Araya, et al., 2019; Zhong, et al., 2020). Fleming (2010), conducted a study of reprocessing the tailings from number of historic gold tailings dams in the Witwatersrand area of South Africa. The objective of the study was to investigate the possibility of recovering uranium and residual gold.

Reprocessing of tailings is also conducted in other countries like Portugal in which tungsten mineral is recovered from the tailings (Figueiredo, et al., 2018). In Zimbabwe sands and mine tailings are reprocessed in Mazowe Mine (Bantshi & Makuvise, 2017). Likewise, in DR Congo, cobalt and copper are recovered by reprocessing tailings from flotation of oxidized ores. Lutandula and Maloba (2013), conducted a study in Tanzania for tailings collected from the SSGM after the gold ore was processed by gravity concentration using sluices to the Vat leach plant for reprocessing. The arsenic levels study conducted in Ghana, where a maximum concentration of 8305 mg/kg was reported (Ahmad and Carboo, 2000), and in another study with a maximum concentration of 1752 mg/kg in gold mine tailings Distribution of Arsenic and heavy metals from Tailings dams at Obuas Municipality of Ghana (Bempah, et al., 2013).

2.1.3 Alternative Method of Extracting Gold Using Cyanide

An alternative method for extracting gold (Au) involves the use of cyanide in a two-stage process known as extraction and recovery. In the extraction stage, gold is initially dissolved by employing cyanide. Subsequently, the dissolved gold is recovered from the cyanide solution through two methods: cementation with zinc or adsorption onto activated carbon. The specific cyanide extraction processes employed can be either heap leach or vat/tank leach, depending on the quality of the ores being processed.

For ores with higher gold content, vat/tank leaching is utilized. This process entails leaching the crushed and ground ore within large enclosed tanks equipped with agitators, allowing for the gold to dissolve. The dissolved gold then adheres to pieces of activated carbon present in the tanks. The activated carbon, along with the gold, is subsequently separated from the solution, whiles the solution devoid of gold, as well as the leached ore, and is discarded. The heap leach is used for low-grade ore and involves the extraction of crushed oxide gold ore piled onto plastic-lined pads with leaching solvents such as acids or cyanide to dissolve the gold which is collected at the bottom of the pad (Lottermoser, 2007).

The equation below explains how cyanide dissolves gold:

$$4Au_{(s)} + 8NaCN_{(aq)} + O_{2(g)} + 2H_2O_{(l)} \rightarrow 4Au(CN)_{2(aq)} + 4NaOH_{(aq)} \quad (1)$$

Tailings, which are the primary byproducts of extracting gold, consist of substantial quantities of heavy metals (HM) (Fashola, et al., 2016). When exposed to water or dispersed by wind, these metals leach into the surrounding environment in an uncontrolled manner. The existence of heightened concentrations of HM in the environment poses a significant global health concern, as these metals are non-degradable and persist for extended periods, thereby exerting long-term impacts on the ecosystem (Singh, *et al.*, 2011).

In some cases, gold may be present in a complex ore that is not easy to be extracted by cyanide directly. Sometimes can occur in sulphide ores like pyrite, chalcopyrite, arsenopyrite, thus dissolution of gold and other metals is possible by oxidizing the ores with pressure oxidation and cyanidation simultaneously (Soto-Uribe *et al.,* 2023). In Other cases, pre-leaching techniques are used to condition the ore use alkaline materials before cyanidation processes in order to lower the activity of complex metals associated with gold. The pre leaching is done by taking into account the effects of solution pH and ionic strength, along with the type and amount of sulphide or complex minerals present on cyanide consumption as a function of time (Kianinia *et al.,* 2018).

Therefore, worldwide the techniques of recovering gold from tailings have been practiced. The literatures highlighted some countries that reprocess tailings using cyanidation technology including Brazil, Colombia, Ecuador, Indonesia, Venezuela, South Africa, Zimbabwe, Ghana and others including Tanzania.

2.2 Heavy Metal Contamination in Soil and Water near Gold Mining Sites

Gold is leached from its ores by using a number of chemicals depending on the nature of elements contained in the ore. Sometimes Sodium cyanide and lime are used in gold processing plants for the recovery of the metal. The function of Cyanide is to dissolve the metal gold and other metals with affinity to cyanide whereas the lime is used to raise the pH of the slurry between 9.5 and 11. The complex ores may require other chemicals like lead nitrate and others to speed up the decomposition of gold using sodium cyanide (Deschenes, et al. 2000).

In some other cases, techniques are employed to decompose the activity of cyanide by application of other chemicals usually released to the environment. Hou, et al.,

(2020) used sodium meta-bisuphide ($Na_2S_2O_5$) and hydrogen peroxide (H_2O_2) in the decomposition of cyanide leaching of gold. According to the study, the chemicals used to increase the alkalinity of the slurry by raising pH to 9 helped in decreasing the activity of cyanide in the tailings which were then used as material for backfilling.

Kholmurodov, et al., (2021) conducted a Mineralogical analysis of a gold ore and found that the main rock comprises quartz, feldspars, micas, hydromica and clay minerals whereas the ore minerals accompanied are pyrite and arsenopyrite. It is further found that hypergene minerals are represented by products of sulfide oxidation, iron oxides and hydroxides which include hematite, limonite, goethite and hydro goethite; and the iron arsenates which are scorodite and sulfates like gypsum in the soil.

In Southern Ecuador, a study conducted to assess the strategies to reduce environmental risk due to leaching the mercury rich tailings from the artisanal and small-scale miners. In this study the Authors (Lopez et al, 2010) described those countries such as Brazil, Colombia, Ecuador, Indonesia, Venezuela and Zimbabwe use the cyanidation technology to leach the amalgamated tailings to recover remaining gold. Sousa, et al. (2010) conducted a study look alike to that of Western Ecuador at Tapajos River basin in Brazil in which mercury was reduced from 22,000kg to 980kg per year and gold was recovered to 98%.

Sousa, et al., (2010) at Tapajos River Basin in Brazil in sighted strategies for reducing the environmental impact of reprocessing mercury-contaminated tailings in the artisan and small-scale gold mining sector by concentrating gold using cyanidation method in a ball mill. Several researchers conducted studies on the impact of the toxic heavy metals associated with gold when leached into the soil. They cause irritation of soil, decrease the production of crops and kill the fauna and other flora on the soil. Other minerals cause acid mine drainage due to the presence of sulphur that causes soil pollution, the result is plant metal intake, low productivity and disturbance of the ecosystem (Koo, Lee, & Kim, 2012; Sandeep, et al., 2019; Zhong, et al., 2020). In another study (Velásquez-López, et al., (2011) indicated that leaching of amalgamated tailings has a proportionality by which 10 g/ton of cyanide; approximately 42% of mercury was leached.

A study conducted in Colombia to determine the pollution agents during the leaching process and from the tailing's solutions after the gold extraction. It was reported that, spillages of Cyanide solutions containing heavy metals drained into the surrounding water-bodies and soil (Knoblauch *et al.,* 2020).

In Gorontalo, Indonesia heavy metals contamination study conducted in river Bone which is used as a source of water for inhabitants living around this river. The river passes through the artisanal and small-scale gold mines on which Arsenic (As), Mercury (Hg) and Lead (Pb) were the metal aimed at the study. The results of the study indicated that the concentrations of As, Hg and Pb in water ranged from 66 to 82,500µg/l, 17 to 2080 µg/l and 11 to 1670 µg/l respectively (Gafur *et al.,* 2018).

A study conducted in Loumbila and Ouagadougou, Bukina Faso (Bambara et al., 2015) the mean concentration level of Cr was 0.116 ±0.028 mg/l. Shahin et al.

(2019) conducted the alike study on iron concentration in Egypt ground water used for irrigation and revealed a concentration of Fe that ranged from 4.9mg/l to 8.8mg/l. Gafur et al., (2018) in Indonesia in their study of heavy metals pollution in water of Bone River by Artisanal small - scale Gold Mine Activities, found Pb to be ranged from 11 to 1670 µg/l. According to WHO, the permissible limit of heavy metal in drinking water is Arsenic (0.05 mg/kg), lead (0.05 mg/kg), Cadmium (0.005 mg/kg), iron (0.3 mg/kg), zinc (5.0 mg/kg) and Chromium (0.05 mg/kg).

Study of soil contamination with heavy metals conducted in South of Bukinafaso in Bissa village to evaluate the impact of tailings from an old mining site on heavy metal contamination of soil. The elements of study were Cr, Zn, As, Mn, Cu, Pb, Ni, Sr and Hg. The concentration of the metals decreased sequentially in the indicated order from Cr to Hg. Since soil samples were taken on top and others deeper to more than 15cm, the concentration of As, Hg, Cr, and Mn were higher on the top than in the deeper soils (Olobatoke & Muthuthu, 2016).

Presence of heavy metals in mines soils was also observed by Akoto et al. (2022).
A study was conducted on heavy metal concentration in Nangodi community (Ghana), the community that mine gold illegally. The study revealed that, the heavy metals concentrations for six elements (Hg, Cr, Cd, As, Pb, Fe) in the soil samples determined, the mean and standard deviations levels of Mercury ranged from 2.20 ± 0.14 to 7.46 ± 2.96 mg/kg in soils of certain zone. Lead (Pb) concentration in the soil samples was highest (21.65 ± 0.21 mg/kg) and lowest (1.45 ± 0.21 mg/kg) in another different zones. Likewise, the average concentrations of cadmium (Cd) recorded from the different zones during the study ranged from 2.0 ± 0.28 mg/kg to 14.60 ±

0.28 mg/kg. For Arsenic (As), the levels recorded highest (21.7 ± 0.57 mg/kg) to lowest (0.35 ± 0.07 mg/kg) at certain areas.

Bitala, *et al.*, (2009) study at a large mine; North Mara in Tanzania reported levels of toxic metal Cadmium in gold mine tailings, concentrations ranging between 6.4 and 11.7 mg/kg. The tolerance levels required in the soil as observed by WHO (2007) are between 0.07 to 1.1 mg/kg. The minimum level for agricultural soil of this metal as sighted by Zulfiqar et al. (2022) is 100mg/kg. Another study on heavy metals contamination in soils and water conducted in Londoni and Sambaru Gold Small Scale Mines by Herman and Kihampa (2015). The study targeted four metals, Hg, Pb, Zn and Cu on which it revealed that the concentration of the heavy metals range from 1.7 to 53.8 mg/kg, 8.7 to 22.24 mg/kg, 0.42 to 2.61 mg/kg and 3.19 to 29.42 mg/kg respectively. For surface and ground water analysis, the concentration of both heavy metals ranged from 0.013 to 0.17 mg/l.

The averaged electrical conductivity analyzed in water ranges from 586.75±493.32 µs/cm. According to Atlas scientific report of September 2022, the waters are contaminated by salt ions since their electrical conductivity are more than 200 µs/cm.

2.3 Uptake of Heavy Metals by Green Leafy Vegetables Irrigated by Contaminated Water

According to Lim, *et al.* (2008), on study of vegetables grown in contaminated soil with heavy metal in Bengal India, indicated a higher concentrations heavy metals detected were As, Hg, Pb, Cd, Zn and Cu and all mean concentrations in the soil were higher than the permissible level and led to easy uptake of vegetables grown in such areas. In another study (Zhou, *et al.,* 2016), revealed that there were much higher heavy metals in the leafy part of vegetables than other parts. This indicates that as vegetables grow, the heavy metals increase and accelerate from the roots through stems and are highly concentrated in the leaves.

In another study (Tun, et al., 2020), a major placer gold mining area in the Sagaing. Region of Myanmar, the highest heavy metal concentrations were generally found in the amalgamation stages across all the gold mining sites. Across the three mining sites, the maximum heavy metal concentrations in the amalgamation stage were 22.170 mg/kg for As, 3.070 mg/kg for Cd, 77.440 mg/kg for Hg, and 210.000 mg/kg for Pb. This stage is the final stage in gold recovery by small scale miners and the final tailings produced in the process of recovery.

In Bangladesh by Ahmed et al (2016) conducted a study on heavy metals that revealed that, the range of chromium concentration in wastewater irrigated vegetables was ND (Not detected) to 4.14 mg/kg and which is higher than the permissible limit. A study conducted by Ongon’g et al, (2020) on Amaranthus dubuis Thel, revealed that Chromium (IV) and Chromium (III) mean concentration was 0.2±0.1mg/kg and 1.0±0.2mg/kg respectively.

Likewise, Siame (2016) conducted a study on heavy metal contamination (Cu, Ni, Zn, Co, Pb and Fe) in copper belts for vegetables and fruits brought to the markets from different locations in Kitwe district, Zambia. The study revealed that there were many concentrations of heavy metals higher than the allowable concentration set by the Food and Agricultural Organization (FAO). Jaishankar *et al.* (2014) discussed the toxicology and mechanism of heavy metals in vegetables around the mine sites to the human body through their study and citations from other authors. The contamination of heavy metals can destroy the brain, lungs, kidney, and liver functions, lower energy levels, and disturbs blood composition and other important organs.

Geita Gold Mine (GGM) conducted a study in the mine site to investigate the contamination of heavy metals in the environment on which shoots and roots of selected plants and soil samples were taken for analysis of these metals. The Authors reported that there were higher concentrations of Lead (Pb) in some plants like giant rat tail grass, Cadmium (Cd) in creeping Blepharis, higher manganese (Mn) in Leaceana plants, higher chromium (Cr) Leucophala and Copper in Camara plant (Kahangwa, *et al.,* 2021). Another study conducted in Geita district in irrigation water and vegetables to determine the heavy metal contamination revealed that lead (Pb) was much higher in the vegetable leafy than the tolerance level, the same applied to arsenic by 0.1mg/kg (John, 2021). In Ruangwa, Koleleni and Mbike (2018) conducted a study on heavy metals in Soil and Maize Grown around Namungo Gold Mine. The authors have reported that soil and maize were accumulated with Cd, Pb, Hg, Cu, V, Fe and U at different concentrations.

Mnali (2001), conducted a study in Lupa gold field, SW Tanzania found that the mean concentrations of As: 0.44 ppb (water), 1.2 mg/kg (sediments) and 0.44 mg/kg (soil); Cd: 0.03 ppb (water), 0.03 mg/kg (sediments) and 0.03 mg/kg (soil) Cr: 1.4 ppb (water), 70 mg/kg (stream sediments), 250 mg/kg (soil) and 270 mg/kg (tailings); Cu: 30 ppb (water), 68 mg/kg (sediments), 66 mg/kg (soil) and 455 mg/kg (tailings); Hg: 0.25 ppb (water), 1.1 mg/kg (sediments), 0.10 mg/kg (soil) and 8.70 mg/kg (tailings) and Pb: 0.50 ppb (water), 85 mg/kg (sediments), 22 mg/kg (soil) and 275 mg/kg (tailings).

Philip, (2021) in his study on heavy metal contamination in irrigation water and vegetables in areas around gold mining areas in the Geita reported respectively the mean concentration values of As and Pb in Amaranthus spp such that 145.73±10.79 µg/kg and 165.11±60.74 µg/kg for samples collected from Nyarugusu, 172.19±14.77 µg/kg and 86.75±5.31 µg/kg for samples collected Magenge and Nyamalimbe, 106.69±10.90 µg/kg and 208.10±58.87 µg/kg at Nyamatondoo and Kaseme, 179.10±18.24 and 125.42±25.57 µg/kg Ojiego B.O et al., (2022) in their study in Health risk assessment for selected heavy metals in Telfairia occidentalis (fluted pumpkin) leaf sampled from damp sites found leaves with concentration of heavy metals like Cd (0.18 ± 0.02) mg/kg, Pb (0.08 ± 0.11) mg/kg and Zn (1.82 ± 0.04) mg/kg.

The studies of heavy metals by the authors indicated there were contamination levels in Amaranthus spp and Cucurbita moschata grown in areas where vegetatbles irrigated by contaminated water or in contaminated soils. The literatures were helpful in fulfillment of the objective for the leafy vegetables grown in Sekenke Gold mine.

2.4 Human Health Risks from Consumption of Heavy Metal Contaminated Vegetables

The process of gold production is accompanied by the discharge of chemicals like cyanide, mercury and other toxic elements as waste to the environment (Bansah, *et* *al.,* 2016). A study conducted on small scale miners in Indonesia indicated that people were affected by mercury after the analysis of mercury in the urine of process plant workers, miners and nearby residents. The concentrations of mercury in their urines recorded up to 0.20265 mg/L for the processing plant workers, the miner's analysis was up to 0.18264 mg/L and nearby residents' data was up to 0.03455 mg/L (Whitehouse, *et al.,* 2006).

In mines with arsenic gold bearing the process, involves the dissolution of metals from its ore. Arsenic discharges to the environment associated with gold mining at levels >1000 mg/kg As, which either produces phytotoxic effects in sensitive species or growth in a few tolerance animals (Eisler, 2004). Contaminations can spread from the soil to water used for drinking, food preparation and irrigation of food crops and pose the greatest threat to public health.

According to US EPA (2023), the tolerable value that set by this agency is 1×10^{-6}, that means one person among million of them can face cancer risk. The reference dose set by USA EPA are as cited by Osae et al, (2023) were, As (0.000), Cd (0.001), Pb (0.04), Fe (0.7), Zn (0.3) and Cr (1.5) while the cancer risk factor (CRF) were 0.0061, 0.041, 0.0085 for Cd, Cr and Pb respectively. In a study conducted by Liu et al, (2021) on Arsenic in leafy vegetables, the Consumption of the vegetables investigated area poses a significantly potential human health risk with a hazard quotient (HQ) of 2.7.

In a study conducted by Singovszka, et al., (2020) in five sites at Smolnik creek in Slovakia to investigate the impact of heavy metals in water from abandoned mine on human health, revealed ingestion pathways measured for adults, DI of the As for adults ranged from $1.13x10^{-5}$ to $4.00\ x10^{-4}$ while for children ranged from $1.11x10^{-1}$ to 8.06×10^{-1}. For Cd, adults ranged from 9.59×10^{-3} to 5.39×10^{-1} while for children ranged from 2.24×10^{-2} to 1.26×10^{0}. DI for Zn ranged from 2.53×10^{-2} to 2.08×10^{0} in adults while for children ranged from 5.91×10^{-2} to 6.17×10^{0}.

The non-carcinogenic hazard quotients of heavy metals at the sites were higher among children than among adults. The HQ values for dermal exposure for adults were<1 at all five measured sites. The HQ value for children was>1 for As. The Authors revealed that specific carcinogenic risk evaluation of the various samples indicates that there was a significant cancer risk from arsenic by ingestion exposure at of pumpkin leaves (Cucurbita moschata), where the arsenic cancer risk values were 0.07 (CRing adult) and 0.17 (CRing child).

According to WHO (2020) a daily recommendation of vegetables for adults is at least 400 g (i.e. five portions) of fruit and vegetables per day excluding roots food like potatoes, sweet potatoes, cassava and other starchy roots. Daily recommendation for children aged 2 - 3 years is at least 2.5 serves and with age 4 - 8 years is at least 4.5 serves equivalent to 337.5 g.

Knoblauch, *et al.,* (2020) conducted studies to three individuals that are likely to be exposed to cyanide. These were those directly use cyanide, non-using cyanide and others around the mining sites. The study conducted in order to the purpose of creating awareness to local actors, health and sustainable development stakeholders and covered also on the health effects, environmental burden and societal effects of cyanide use in SSGM of Burkina Faso. It was concluded that the ASGM using cyanide in Burkina Faso’s face a potential negative health effect. Although the study did not touch directly ways that the groups used to take in cyanide, it is hopeful that the intake of cyanide by the groups comes from sources like spillages in the soil, water and perhaps in air.

Individuals around some mine sites where the process plants are also situated claims to be sick and sometimes feel disorder to their health. Flora and Pachauri (2015) conducted a cross sectional study on 340 pregnant women ranging from 15 - 49 years old in Geita to examine geophagy practices of pregnant women in gold Mining. The study come up with conclusion that pregnant women who eat soil are exposed from high levels of chemical elements on the area collected, amount and frequency of consumption.

2.5 The Current Observed Research Gap

Numerous studies conducted on heavy metal contamination and accumulation in soils and plants around gold mining areas as indicated in this chapter. Authors explain that the causes of the contaminations in soils and vegetables due to mining sector but the majority of the available studies have focused on large mine and on medium mine operations and not in reprocessed tailings in small scale mining areas. In this case reprocessed tailings, which are the leftover materials after the extraction of minerals from unprocessed tailings, might contain heavy metals. Though reprocessing of tailings to extract valuable minerals employed in various countries worldwide, including Tanzania very few studies have been done on the impact of the heavy metals to the environment.

Tanzania, known for its rich mineral resources, has various mining operations where tailings reprocessing occur all over the country. For instance, gold mining in Tanzania has seen efforts to reprocess tailings to extract gold particles that might have been missed during initial extraction processes. Assessing the environmental impact of VAT leaching on reprocessed tailings from small scale gold mining operations to soils, water and vegetables is important.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

The research is permitted by the Open University of Tanzania as partial fulfilment of the requirement in the degree of Master of Environmental Studies. It was supported by the Iramba, Singida District Director who allowed the research to be carried in the small-scale Miners of Sekenke in May 2024. The area chose because the mining operations are practised before 1914 and therefore it is a proper area of study to represent other mining sites.

The chapter comprised of six sub-chapters that explain the way the study was conducted. It comprises with study area subchapter, research design, sampling population, sampling techniques and instruments used in data collection and analysis and health risk assessment. The chapter includes some models and formulas that managed some evaluations which made this research to succeed.

3.2 Area of the Study

The study conducted at Sekenke small scale gold mine in Iramba District Tanzania in which mining activities are operated there for over one hundred (100) years. This mine is situated on a low rise in the Wembere depression. The mines have long been known to be auriferous. It extend on the west to Kinyeleli on the east of the Iramba plateau, trending approximately south-east for a distance of about thirty miles along the line of the broken belt of ancient rocks of the Ubendian belt. The mine contains over 2,000 tons of colonial tailings abandoned on the site and over 17,000 of both unprocessed and reprocessed tailings. The longtime operation of the mine found to be a good site for study of the heavy metals in the tailings

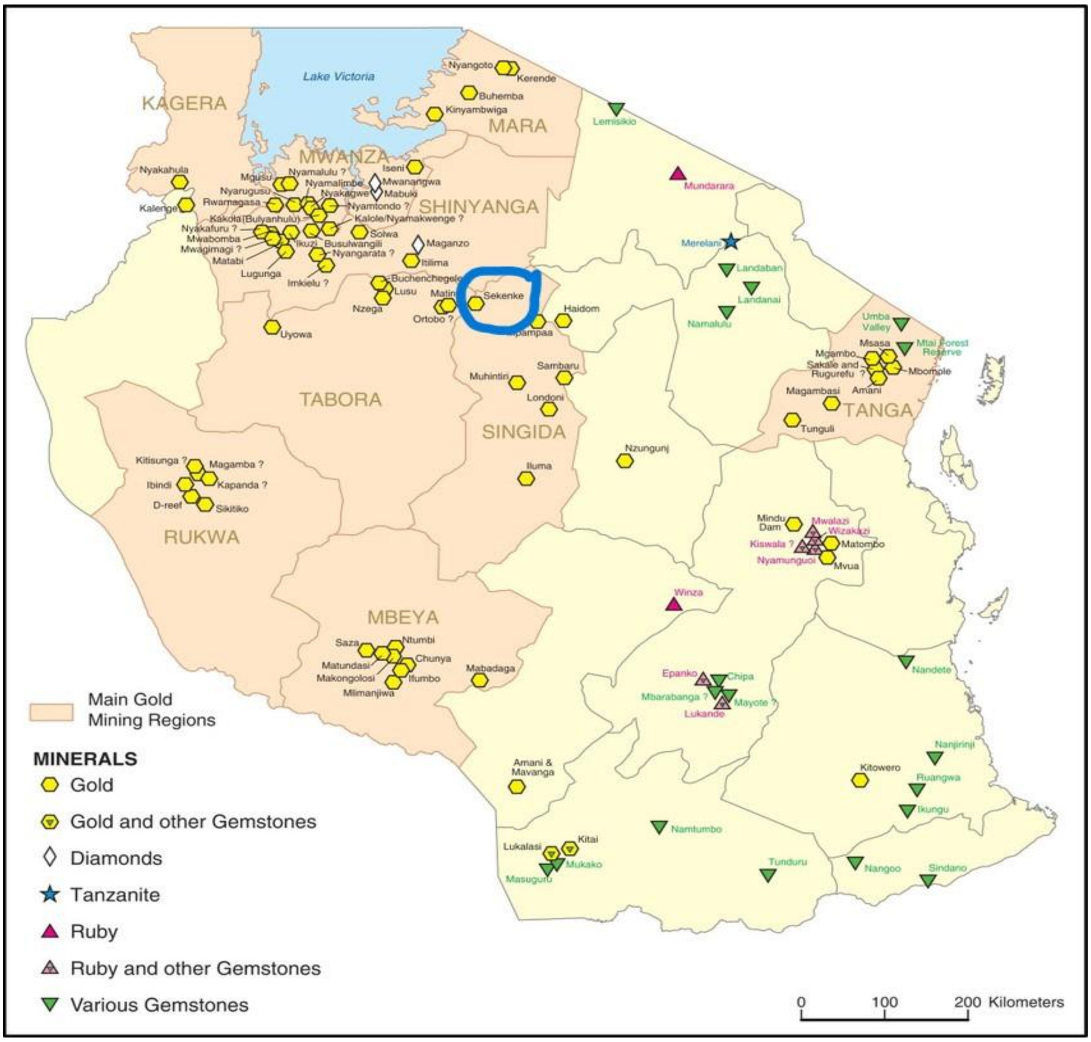

Figure 3.1: The Circle indicates the Location of Sekenke SSM on the Map of Tanzania

3.3 Sampling Design and Procedures

3.3.1 Sampling of Soil Samples

The soil samples focused from the mining site to accomplish the study were the soil samples in the gardens around the mine sites, the unprocessed tailings that are not treated by cyanide for gold recovery and those from the reprocessed tailings. The unprocessed tailings obtained from the miners after the concentration processes in the sluice boxes and that possibly mixed with amalgamated tailings. The reprocessed tailing found in the mine site usually disposed after being offloaded from the leach tanks. No proper disposal dam or unrestricted area of these tailings rather than left them in the surround around the tanks and compacted leaving a heap.

The mine area is almost 252 hectares with 9 unprocessed heaps of tailings each of approximately 5,000 tons of materials and 9 heaps of reprocessed tailings of about 12,000 tons around the separate process plants. Soil samples collected randomly at each heap in a circumference of 200metres in which vegetables and other plants are found. Eight (8) samples collected randomly at the top and the bottom around each heap which were then stationed around each heap, mixed homogeneously to get one (1) composite sample.

The soil samples around these process plants were collected randomly from 0-30cm depth where the roots of grown vegetables penetrate during the absorption of water and minerals. These were collected in one growing season of one to two months from May to June, 2024 in which the green leafy vegetables grown. Nine (9) samples were collected systematically at the interval of 35metres and stationed in each respective acre for homogenisation and produce a composite sample from each acre. In this case, twelve (12) composite soil samples were collected.

For the case of tailing samples, one (1) sample was collected before reprocessing and one (1) after reprocessing from all the available nine (9) heaps that make a total of 18 samples. The samples were taken by opening small trenches/holes with spade and using chisels for sampling. The collected 12 soil and 18 tailing samples sealed in labelled Teflon bags separately in order to avoid contaminations and were analysed in the Geological Survey of Tanzania (GST) Laboratory.

3.3.2 Sampling of Green Leafy Vegetables Samples

In this case the samples considered here were the green leafy vegetables that are edible in day to day by the individuals in the mine site. Samples of each green leafy vegetable collected by picking randomly making a one sample batch of not less than 2 kg before drying for each type of vegetables *Amaranthus spp* and *Cucurbita moschata* respectively. All samples collected in one growing season via systematic intervals of one week in order to observe the accumulation of heavy metals with time of growth since other gardens had small vegetables that were difficult to handle or picked. Hence, a total of six (6) samples collected and kept in Teflon translucent bags separately, three (3) for *Amaranthus spp* and three (3) for *Cucurbita moschata.* All samples were taken to Geological Survey of Tanzania (GST) Laboratory for analysis.

3.3.3 Sampling of Irrigation Water

The irrigation water is from different sources like the mine pits water that penetrate the underground rocks during mining. This is the mine water contains waste materials that is pumped from the pits to the surface for gold recovery and sometimes watering the ground to reduce mines dusts and others released to the environment as means of disposing it or for irrigation. Water is the deep well water. This is underground around all PMLs used for domestic uses like cooking, washing and sometimes for drinking and irrigation purposes. This water is different from pit water since it is not contaminated with soils and other waste materials and kept in tanks and Wells.

The barren water, which is resulted from Vat leach processes in the mine. This water contains barren chemical substances used in the process of gold recovery in the Vat the leach tanks. Like the pit water, this water contains wastes from the tanks and even chemicals remained after mineral recovery.

The physical determination of parameters like pH, turbidity and conductivity was done on-site by pH, turbidity meter and conductivity meter. In this mine site the irrigation water come from underground water, process water (barren water) and tape water sources which was from deep Wells located in the mine site. Nine (9) samples collected at an interval of one week for three weeks in different sources such as the pumped underground water to the process plants (barren water) and the deep well water. The samples kept in a clean Teflon container and stored at a temperature of less than 6ºC for laboratory examination of heavy metals.

A 0.05M Nitric acid used to preserve them from not to change its state for some hours because of transportation time to the laboratory. A 3ml of dilute HNO_3 per litre of a water sample was added in the samples for preservation to maintain it in acidic level.

3.4 Preparation of Samples

3.4.1 Preparation of Soil Samples

During preparation of the samples, division technique was done in order to reduce the large quantity collected to smaller portion such that approximately 500gram of each sample so as to give a wide spread or surface area of contents in the soil. The activity conducted by using riffle instrument for splitting the samples. The obtained samples dried at a temperature between 50-105°C for 12-24 hours to remove the moisture. The oven-drying was preferred since it can accelerate the speed of drying and limit changes in the sample condition due to microbial activity (Weinfurtner & Kördel, 2012). The samples ground and then sieved to remove coarse debris and rubbles with a size greater than 75microns. A non-metallic sieve was used to avoid contamination of metals. A 10g of each fine soil sample pressed in special plastic cups, then covered well with polypropylene thin film and taken for analysis of five heavy metals (Pb, Cd, Fe, Zn and Cr) by XRF Rigaku Nex CG instrument. Arsenic (As) in tailings and soils was analysed by AAS since the potential spectra overlaps with other elements, like Lead (Pb) and have relatively high detection limits in XRF such that the detection limit of AAS use was 0.003mg/kg.

Determination of As was conducted using acid digestion method on which a 1g of each fine soil sample undergo strong acidic digestion in aqua regia (HCl/HNO3: 3/1) to attack a wide range of soil and geological materials Hossner (1996) heated slowly near dryness. After the process of digestion, 20ml of distilled water was added to each sample, filtered and kept in 100 ml volumetric flask, which then diluted to the mark. The sample solutions sealed in labelled Teflon examined by Atomic Absorption spectrometry (AAS) equipped with Vapour Generator Accessory (VGA).

3.4.2 Preparation of Vegetable Samples

The collected samples of all green leafy vegetables washed with pure water twice, on which the dusts and other air-borne pollutants removed (Mubofu, 2012). The samples sliced and oven-dried at 60-80°C for 12 to 24 hours. The dried vegetable samples ground with a grinder and then homogenized carefully in a plastic bottle. One (1) gram of ground sample of the two vegetables in triplicate weighed and transferred to 150 ml conical flask followed by adding 15 ml di-acid mixture (Nitric acid and Perchloric acid in the ratio of one to one) and thereafter kept for 12hours for partial digestion.

The mixture heated at 160^0C for 1 hour in a fume hood and then cooled to room temperature followed by addition of 20ml of distilled water. The solution filtered by filter papers Whatman No. 42 and then the filtrate transferred to a 50ml volumetric flask diluted to the mark. The solution was again left to settle for 15 hours (Singh et al, 2012). The black samples of green vegetable leafy collected at different places in Dodoma undergo the same process of preparations and then analysed simultaneously with samples collected in soils around the tailings reprocessing plants.

3.4.3 Preparation of Water Samples

The water samples collected in different three points that observed to be sources of the water for irrigating the green leafy vegetables. The portion of the collected nine (9) samples aspirated directly in the Atomic Absorption Spectrometry (AAS) machine and then the concentrations were recorded from the machine readout. For samples that contained suspended materials were first filtered by Whatman No. 42 filter paper and then the filtrate aspirated directly in the AAS.

2.4.4 Quality Control

In order to maintain the accuracy of the machine, three blank samples of silica sand collected from Coastal region prepared to the size below 75microns and then analysed simultaneously with the collected soil samples from the mine site by XRF.

The AAS machine was calibrated using a series of calibration standards of different concentration from Agilent technology in 0.5M HNO_3 matrix.

Ranges of calibration standard for each element analyzed was as follows, for zinc concentration ranges from 0.5 up to 2mg/kg, for Lead concentration ranges from 5 to 40mg/kg, for Chromium concentration ranges from 2 to 20mg/kg, for Iron concentration ranges from 5 to 40mg/kg, for Arsenic concentration ranges from 20 to 200mg/kg and for Cadmium concentration ranges from 0.5 to 2mg/kg. In order to ensure the validity of results all samples ran parallel with the following set of quality control samples, one Duplicate, one Blank (Distilled water with conductivity less than 3 µmhos/cm) and 1internal CRM.

AAS machine was used in analysing heavy metals in solutions. The machine performance checked during calibration by using intermediate check (Standard) and replicate sample during analysis. The machine was first calibrated by a blank solution followed by solutions with known amounts of respective element of analysis. The detection limit for this machine is 0.003ppm.

3.5 Soil Contamination Assessment

3.5.1 Contamination factor

In the study, the soil contamination was determined by using the contamination factor (CF) as indicated by Calmano, et al., (1993) and Jimoh, et al., (2020), that was calculated as,

$$CF = \frac{\mathrm{Cm}}{\mathrm{Cb}} \qquad (2)$$

Where C_m is the concentration of the metal in the soil and C_b is the concentration of the metal in the background.

3.5.2 Pollution Load Index

The Pollution Load Index (PLI), as proposed by Thomlinson et al. (1980), was used to assess the quality of soil in a polluted site. Therefore, the pollution load index was estimated as;

$$PLI = (CF_1 X CF_2 X CF_3 \ldots CF_n)^{1/n} \quad (3)$$

Where n is the number of metals considered in the study and CF_i is the contamination factor for each metal.

In a study conducted in South Korea by Suwanmanon and Kim (2021), the Authors quoted that the pollution index classified as if PI<1 the soil is termed as uncontaminated, if 1≤PI< 2 the soil is Slightly polluted, if 2≤PI<3 the soil is Moderately polluted and if 3<PI is termed as Highly polluted.

3.5.3 Contamination Degree

Hakanson, (1980) proposed the contamination degree (Cdeg) of the soil and was computed based on the sum of all contamination factors using the formula (equation 4) The contamination degree of soil is divided into four groups: low (Cdeg<8), moderate (8≤Cdeg<16), considerable (16≤Cdeg<32), and very high contamination degree (Cdeg ≥32).

The degree of contamination was analyzed by three indices for environmental assessment of soil in small scale mining of Sekenke Singida Municipality.

$$C_{\deg} = \sum_{i=1}^{n} Cf \quad (4)$$

3.5.4 Geo-accumulation Index (I_{geo})

The I_{geo} is a pollution degree evaluation index proposed by Müller (1979) and is widely used to evaluate the metal pollution degree in water, ocean, and soil environments (Banu, et al., 2013). The calculation formula can be expressed as follows:

$$I_{geo} = Log_2\left(\frac{C_i}{1.5B_i}\right) \qquad (5)$$

Where C_i represents the concentration of heavy metals measured in the soil (mg/kg), and B_i refers to the geochemical background values based on the Average Composition of Shales as proposed by Wedepohl (1995). These shale values were chosen for calculating pollution indices as they allow for meaningful comparisons across different regions, aiding in the understanding of global trends in element enrichment and contamination (Turekian and Wedepohl, 1961; Ali, *et al*., 2016). Shale values offer a consistent, standardized reference point and are relatively stable, minimizing significant variations in elemental composition over time. The background values adopted from Edori and Kpee (2017) where: As= 13; Fe = 47,200; Cr = 90; Pb = 20; Cd = 0.3 and Zn = 95 both in mg/kg.

The indices are Geo-accumulation index (I_{geo}), Pollution load Index (PLI) and Contamination degree (C_f).

3.6 Human Health Risk Assessment

According to US EPA (2005), the human health risk assessment estimates the human health effects that could arise from the combined exposure to carcinogenic and non-carcinogenic chemicals. The risk assessment performed on the basis of exposure doses (D) to heavy metals by ingestion, using Equations (6) and (v).

$$D_{ing} = \frac{C_{ing} xIRxEFxED}{BWxAT} \tag{6}$$

Where D_{ing} is the exposure dose through water ingestion (µg/kg/day); C_{ing} is the measured metal concentration in water (µg/L); IR is the ingestion rate per unit time (L/day) estimated to be 2.2 L/day for adults, 1.8 L/day for children; EF is the exposure frequency (350 days/year); ED is the exposure duration (70 years for adults, 6 years for children); BW is the average body weight (70 kg for adults, 15 kg for children); AT is the average life expectancy of people.

3.6.1 Non-Carcinogenic Risk Assessment

For the non-carcinogenic risk, the hazard quotient (HQ) calculated by dividing the exposure value by the reference dose (Custodio, et al., 2020). Health risks from consuming vegetables can be expressed by the hazard quotient.

$$HQ_{ing} = \frac{D_{ing}}{RfD_{ing}} \tag{7}$$

Where HQ_{ing} is the hazard quotient for ingestion or skin contact, D_{ing} is daily intake ingestion or contact, RfD is dermal reference dose.

The general potential for non-carcinogenic effects has been assessed by integrating the HQs calculated for each element and expressed as a hazard index.

$$HI = \sum_{i=1}^{n} HQ_{ing(derm)} = HQ_{Pb} + HQ_{Cd} + HQ_{Zn} + \mathrm{HQ}_{As} + HQ_{Fe} + \mathrm{HQ}_{Cr} \tag{8}$$

Where $HI_{ing/derm}$ is the hazard index for ingestion or dermal contact, and *n* is the total number of chemical elements considered.

3.6.2 Carcinogenic Risk Assessment

The chronic daily intake (CDI) the formula used for calculating the cancer risks (Li and Zhang, 2010):

$$CDI \quad = \frac{CvegxDI}{BW} \tag{9}$$

C_{veg}, DI, and BW represent the concentration of metal trace in the water or vegetable (mg/kg), mean daily water intake and body weight, respectively.

According to Moghaddam *et al.*, 2022, the life time cancer risk (LTCR) can also be expressed as the product of chronic daily intake and slope factor. This is time that an individual may develop cancer during the course of a life time.

$$LTCR = SFxCDI \tag{10}$$

Where CDI is chronic daily intake while SF is a cancer slope factor. The total cancer risk (TCR) is expressed as:

$$\text{TCR} = \sum_{p=1}^{n} CDI_p xSF_p \tag{11}$$

Where CDI_p is a chronic daily intake of a certain element and SF_p is slope factor of respective element.

Where CDI is the daily chronic intake while CSF is cancer slope factor

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The tailings around the process plant are from the gold ores mined at the Sekenke mines after the recovery of gold by gravity concentration method. The mining activity conducted underground to a depth of approximately more than 70 to 150m below the ground. The study conducted by analyzing six heavy metals (As, Pb, Cd, Fe, Zn and) concentrations in the unprocessed tailings, reprocessed tailings, garden soils, water and leafy vegetables such as *Amaranthus spp* and *Cucurbita moschata*.

The evaluation of results was conducted by statistical methods through using Microsoft excel worksheet. These statistical data include mean and standard deviations values. The findings fulfil the three objectives and they are described based on the analytical results from the tailings, garden soils, water and leafy vegetables. Levels of pollution by both tailings and garden soils are well evaluated in this chapter by considering the geo-accumulation index, pollution load index and Contamination degree.

The hazard quotient, hazard index and life time cancer risks were the indices used in the evolution of human health risk assessment for two groups such that children with average age of 6 years and adults of average age of 70 years. The human health risk assessment based on ingestion of water and the leafy vegetables.

4.2 Heavy Metals Concentration in Unprocessed and Reprocessed Tailings

The concentration of heavy metals in unprocessed and reprocessed tailings is presented in Table 4.1.

Table 4.1: Concentration of Heavy Metals in Unrepressed and Reprocessed Tailings (mg/kg)

S/N	Concentration in Unprocessed Tailings						S/N	Concentration in Reprocessed Tailings					
	As	**Pb**	**Cd**	**Fe**	**Zn**	**Cr**		**As**	**Pb**	**Cd**	**Fe**	**Zn**	**Cr**
1	13.782	31.681	4.413	22960.03	43.617	182.332	10	9.267	27.287	5.978	22011.47	40.200	179.174
2	23.161	119.427	6.261	24463.80	169.589	220.024	11	21.341	77.013	4.112	23414.64	171.118	118.321
3	26.567	20.181	3.833	25307.94	76.251	179.467	12	15.413	18.219	1.468	24000.12	66.726	137.226
4	75.978	23.138	3.528	30089.13	80.408	148.881	13	61.116	26.871	2.973	26242.00	78.842	142.474
5	13.922	28.864	3.913	22864.25	50.064	204.119	14	11.519	24.172	2.242	20177.43	44.221	144.387
6	23.199	97.233	6.230	24476.98	147.219	196.354	15	22.011	97.233	3.104	25221.25	74.544	124.933
7	25.726	21.386	3.877	25323.16	78.341	188.739	16	18.252	21.386	2.711	22824.77	81.663	110.439
8	80.531	24.188	4.148	30102.12	69.961	214.638	17	53.347	24.188	1.988	23446.43	52.194	178.642
. 9	12.993	30.014	4.418	23003.28	44.784	216.183	18	7.243	29.248	3.229	23684.40	44.007	199.573
Mean	32.873	44.012	4.513	25398.96	84.470	194.526	Mean	24.390	38.402	3.089	23446.95	72.613	141.352
STD (±)	26.284	37.091	1.022	2827.729	44.641	22.670	STD (±)	19.394	28.270	1.329	1748.619	40.240	30.726
WHO/FAO(2001)	20.0	50.0	3.0	5000	300	50	WHO/FAO(2001)	20.0	50.0	3.0	-	300	50

4.2.1 Arsenic in Unprocessed and Reprocessed Tailings

Arsenic was detected in both unprocessed and reprocessed samples, as well as in all heaps. In unprocessed samples, arsenic concentrations ranged from 12.993 to 80.531 mg/kg, with a mean of 32.873 ± 26.284 mg/kg. Approximately 67% of the unprocessed tailings samples had arsenic levels exceeding the WHO/FAO (2001) maximum acceptable limit of 20.0 mg/kg. In reprocessed tailings, arsenic levels ranged from 7.243 to 61.116 mg/kg, with a mean of 24.390 ± 19.394 mg/kg. About 44% of the reprocessed tailings samples exceeded the WHO/FAO acceptable limit.

Overall, arsenic concentrations were lower in reprocessed tailings compared to unprocessed tailings. Previous studies (Tóth et al., 2016) have indicated a strong correlation between arsenic (As), cadmium (Cd), mercury (Hg), lead (Pb) and gold (Au) mining activities. The arsenic levels in this study were lower than those found in earlier research in Ghana, where a maximum concentration of 8305 mg/kg was reported (Ahmad and Carboo, 2000), and in another study with a maximum concentration of 1752 mg/kg in gold mine tailings (Bempah et al., 2013). High levels of arsenic contamination are concerning due to its potential health impacts, with several epidemiological studies (Tchounwou et al., 2004) highlighting a strong link between arsenic exposure and an increased risk of both carcinogenic and systemic health effects.

4.2.2 Lead in Unprocessed and Reprocessed Tailings

Lead has many different industrial, agricultural and domestic applications. It is currently used in the production of lead-acid batteries, ammunitions, metal products (solder and pipes), and devices to shield X-rays (Gabby, 2003; 2006). Lead is the most systemic toxicant that affects several organs in the body including the kidneys, liver, central nervous system, hematopoetic system, endocrine system, and reproductive system (Pirkle, et al., 1998). Lead concentration in unprocessed tailing ranges from 20.181 to 119.427 mg/kg with mean of 44.012 ± 37.091mg/kg. The concentration in reprocessed tailing ranges from 18.219 to 97.233 mg/kg with mean of 38.402 ± 28.270 mg/kg. The detected levels in both unprocessed and reprocessed are higher than the maximum acceptable limit (WHO/FAO (2011). The concentration in reprocessed tailing is lower than in unprocessed tailing by the factor of 1.15. The values obtained in this study are lower than the one detected in similar study (Ogola, et al., 2002) where the level of Pb in gold mining soils have been reported to be 510 mg/kg of Pb concentrations in Kenya.

4.2.3 Zinc in Unprocessed and Reprocessed Tailings

Zn plays a key role during physiological growth and fulfills an immune function. It is vital for the functionality of more than 300 enzymes, for the stabilization of DNA, and for gene expression (Costa, et al., 2023). Although some iron enzymes are sensitive to iron deficiency (Dallman, 1990), their activity has not been used as a successful routine measure of iron status. The most significant and common cause of anemia is iron deficiency (WHO/CDC, 2008). If iron intake is limited or inadequate due to poor dietary intake, anemia may occur as a result.

Zinc concentration in unprocessed tailing ranges from 43.617 to 169.589 mg/kg with mean of 88.470 ± 44.641 mg/kg. The concentration of analyzed samples is lower than maximum acceptable limit by WHO/FAO (2011). The concentration in reprocessed tailing ranges from 40.200 to 171.118 mg/kg with mean of 72.613±

40.240 mg/kg. Surprisingly, the concentration in unprocessed tailing is lower than of the tailings reprocessed tailing. This is due to the existing in geochemical environment where mostly in mining sites acid is and they mobilize zinc from sulfide minerals, concentrating it in the reprocessed tailings. This redistribution leads to increase zinc concentrations in the reprocessed material (Gleisner and Herbert, 2002). The values obtained in this study are higher than the value detected earlier in Ghana (Osae, et al., 2023), where the mean Zn concentrations in the sand soil samples ranged between 4.17±1.23 mg/kg and 43.17±4.75 mg/kg.

4.2.4 Iron in Unprocessed and Reprocessed Tailings

Iron concentration in unprocessed tailing ranges from 22844.250 to 30102.120 mg/kg with mean of 25398.96 ± 2827.729 mg/kg. The concentration in reprocessed tailing ranges from 22011.470 to 26242.00 mg/kg with mean of 23446.95± 1748.619 mg/kg. The concentration observed in this study in line with similar study in Nigeria (Fagbenro, et al., 2021) where the mean concentration was 20,560.4 ± 84.30 mg/kg. The mean values of iron at Sekenke exceed the WHO/FAO threshold value that indicates that the site top soils might be contaminated with iron mined from underground.

4.2.5 Cadmium in Unprocessed and Reprocessed Tailings

Cadmium concentration in unprocessed tailing ranges from 3.528 to 6.261 mg/kg with mean of 4.513 ± 1.022 mg/kg. About 100% of the analyzed samples have higher level than maximum acceptable limit by WHO/FAO (2011). The concentration in reprocessed tailing ranges from 1.988 to5.978 mg/kg with mean of 3.089 ± 1.329 mg/kg. About 44% of the samples analyzed have higher level than maximum acceptable limit by WHO/FAO (2011). The values obtained in this study is lower than one detected in similar study (Bitala, et al., 2009) where the level of Cd in gold mining soils have been reported to range between 6.4 to 11.7 mg/kg of Cd concentrations in Tanzania.

Cadmium compounds are classified as human carcinogens by several regulatory agencies (IARC, 1993). Cadmium is a severe pulmonary and gastrointestinal irritant, which can be fatal if inhaled or ingested. After acute ingestion, symptoms such as abdominal pain, burning sensation, nausea, vomiting, salivation, muscle cramps, vertigo, shock, loss of consciousness and convulsions usually appear within 15 to 30 min (Baselt. and Cravey, 1995). Acute cadmium ingestion can also cause gastrointestinal tract erosion, pulmonary, hepatic or renal injury and coma, depending on the route of poisoning (Baselt, 2000).

4.2.6 Chromium in Unprocessed and Reprocessed Tailings

Chromium (Cr) is a naturally occurring element present in the earth’s crust, with oxidation states (or valence states) ranging from chromium (II) to chromium (VI) (Jacobs and Testa 2005). Industries with the largest contribution to chromium release include metal processing, tannery facilities, chromate production, stainless steel welding, and ferrochrome and chrome pigment production. The main health problems seen in animals following ingestion of chromium (VI) compounds are irritation and ulcers in the stomach and small intestine, anemia, sperm damage and male reproductive system damage. Also, it connected with cardiovascular, gastrointestinal, hematological, hepatic, renal, and neurological effects as part of the sequelae leading to death or in patients who survived because of medical treatment

(ATSDR, 2008).

Chromium concentration in unprocessed tailing ranges from 148.881 to 220.024 mg/kg with mean of 194.526± 22.670 mg/kg. The concentration in reprocessed tailing ranges from 110.439 to 199.573 mg/kg with mean of 141.352 ± 30.726 mg/kg. All samples analyzed detected higher level than maximum acceptable limit by WHO/FAO (2011). The concentration in reprocessed tailing is lower than in unprocessed tailing by the factor of 1.38. The values obtained in this study are lower than the one detected in similar study in Oman (Abdul-Wahab and Marikar, 2012) where the level of Cr in gold mining soils reported to be 486 mg/kg in gold mine tailings.

4.2.7 Implications of Heavy Metals in Unprocessed and Reprocessed Tailings

The mean concentrations of the six heavy metals (As, Cd, Fe, Pb, Zn and Cr) analysed in unprocessed and reprocessed tailings at Sekenke Mine are higher than the WHO/FAO acceptable limits of studied heavy metals in soils. Iron analyzed highest than the acceptable limit to at least five (5) times, chromium higher to at least four (4) times and hence cause more effect than other element to the Sekenke environment especially in garden soils. The mean concentrations of heavy metals in reprocessed tailings are slightly lower than that of unprocessed tailings because of leching processes took place that caused either partial reaction of metals with chemicals or dissolution of the metals from unprocessed tailings.

4.3 Heavy Metals Pollution Levels

4.3.1 Geo-Accumulation Indices

The calculated index of geo-accumulation (*Igeo*) of the investigated trace metals in the tailings are illustrated in Figures 4.1.

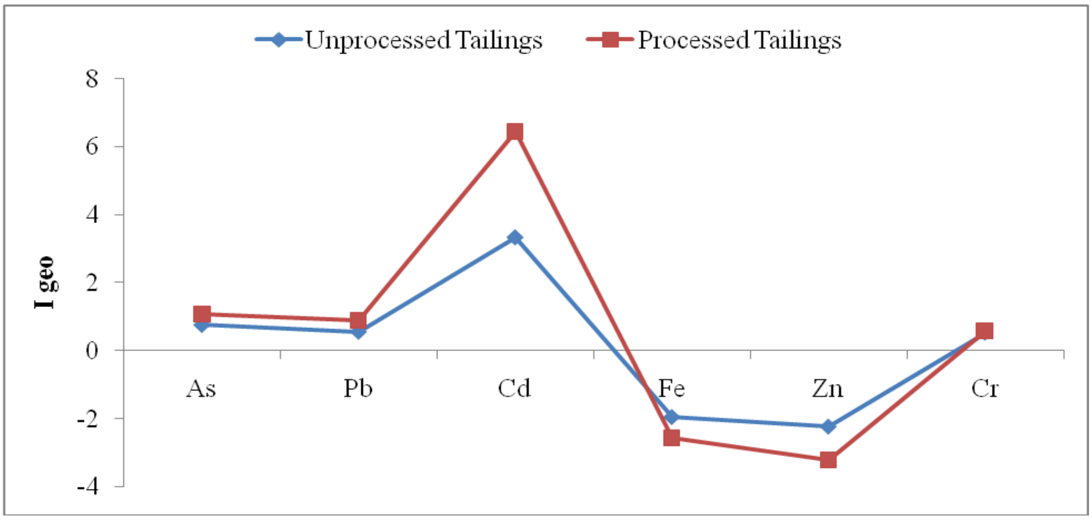

Figure 4.1: Geo-accumulation Indices Values for Unprocessed and Reprocessed Tailings

The *Igeo* values obtained range from -2.237 to 3.326 in unprocessed tailing and -0.970 to 3.3116 in reprocessed tailings. The index of geo-accumulation (Igeo) was assessed based on the values proposed by Müller (1969) and their Igeo values estimated is found in the following increasing order in unprocessed tailing Zn < Fe < Pb < Cr < As < Cd while in reprocessed tailing was in the following increasing order Zn < Fe < Cr < As < Pb < Cd. According to the Muller scale (Muller, 1981), the calculated results of Igeo values (Figure 4.1) indicate that Cd can be classified in class 4 (strong pollutes) for both unprocessed and reprocessed tailings. Other studied trace metals exhibited a zero class that correspond to contamination intensity that indicating unpolluted soil quality since all the values are less than zero.

4.3.2 Contamination Factor (C_f)

Figure 4.2 shows the Contamination Factors (Cf) for unprocessed tailings and reprocessed tailing. The C*f* for unprocessed tailings and reprocessed tailing for As, Pb, Cd, Fe, Zn and Cr were observed in the ranges of 2.529 to 1.876, 2.201 to 1.920, 15.043 to 10.297, 0.538to 0.497, 0.889 to 0.764, and 2.161 to 1.571 respectively (Figure 2). Accordingly, tailing samples can be classified as exhibiting low or no contamination with respect to Zn and Fe for all sampling tailings. For As, Pb, and Cr the Cf is in the range $1 \leq CF < 3$ indicating moderate contamination Cd, the Cf is in the range $CF \geq 6$ indicating very high contamination.

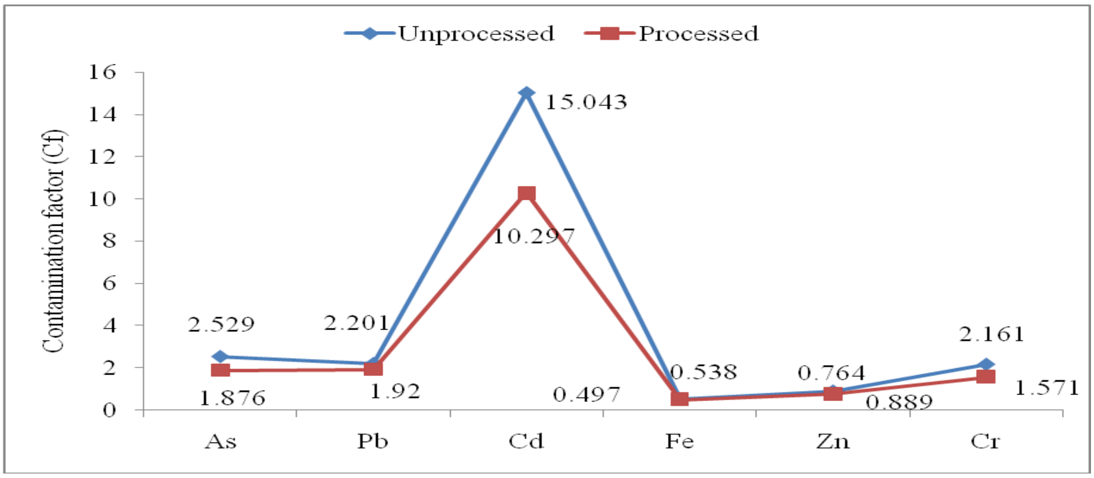

Figure 4.2: Contamination Factors for Unprocessed and Reprocessed Tailings

The degree of contamination for unprocessed and reprocessed tailing samples were 23.361 and 16.925 respectively. This indicates the tailings are considerable contaminate. For the modified degree of contamination, the unprocessed tailing has the value of 4.671 which shows high degree of contamination and reprocessed tailing has the value of 3.385 which shows moderate degree of contamination

4.3.3 The Pollution Load Index

The Pollution Load Index (PLI) was calculated to better assess the level of pollution in the area, providing valuable data to decision-makers. The PLI values for the tailing samples were found to be 2.440 for unprocessed tailing and 1.858 for reprocessed tailing, indicating that the soils are polluted and the environmental quality has deteriorated. This reflects the strong impact of mining activities, with soils in the region being heavily contaminated by heavy metals. A PLI of 2.44 for heavy metals in soil indicates that the concentration of heavy metals is more than twice the baseline or background level. These findings are consistent with a previous study by Jimoh et al. (2020), which reported PLI values greater than 1 for all study sites, while the control site had a PLI of 1. The elevated PLI values suggest significant contamination from sources such as industrial activities, mining, waste disposal, and vehicular emissions.

4.4. Heavy Metal Concentration in Garden Soils around the Process Plants

The concentration of heavy metals in the soil samples are summarized in Table 4.2. The concentration of Arsenic (As) in garden soils ranges from 10.287 to 41.191 mg/kg while the mean concentration As sampled around the gardens is 21.331±7.503 mg/kg. This concentration is slightly higher than WHO/FAO permissible limits in soils of 20 mg/kg. This finding is higher than the one detected eelier (Mnali, 2001) in Lupa gold field SW Tanzania in which As analysis was 0.44 mg/kg in soil. The presence of higher concentration of the As in the tailings that spread to the garden soils could be attributed by the arsenal pyrite (FeAsS), which is one of the gold ore. The higher value of Arsenic may pose environment concern.

Cadmium (Cd) for all sampling gardens ranges from 2.203 mg/kg to 4.961 mg/kg with a mean concentration of 3.018± 0.842 mg/kg. The mean concentration of cadmium in the garden soils is higher than the WHO (2001) maximum permissible value of 0.8 mg/kg in the soil. Comparatively to studies conducted in soil of Lupa

Gold field by Mnali (2001), the concentration of Cd found to be 0.03mg/kg which is lower than the mean concentration analyzed in this study. In London and Sambaru, Singida the concentration of Cd analyzed was also lower than that analyzed at Sekenke soil with concentration of 0.26 mg/kg.

Table 4.2: Concentration of Heavy Metals in Garden Soils (mg/kg)

Sample No.	As	Pb	Cd	Fe	Zn	Cr
1	21.214	78.333	4.961	144.886	73.930	168.107
2	18.829	10.872	3.033	202.862	37.870	165.894
3	41.191	23.419	3.258	240.614	33.640	150.483
4	10.287	14.326	2.226	206.261	36.734	142.232
5	16.424	12.414	3.116	186.644	69.958	177.402
6	19.699	18.694	4.218	217.201	64.512	159.646
7	26.178	17.386	2.472	160.186	78.846	189.818
8	22.420	16.138	2.279	216.867	42.144	176.920
9	18.617	29.841	2.825	204.677	44.346	172.651
10	20.332	18.268	3.176	234.285	56.717	128.372
11	24.574	22.771	2.448	211.289	48.649	164.683
12	16.206	18.246	2.203	229.974	41.486	161.183
Max.	41.191	78.333	4.961	240.614	78.846	189.818
Min.	10.287	10.872	2.203	144.886	33.640	128.372
Mean	21.331	23.392	3.018	204.646	52.403	163.116
Std (±)	7.503	18.049	0.842	28.671	15.806	16.658

Source: Research Data, (2024).

Lead (Pb) is another metal analysed and it is a heavy metal that can cause concern to the human life. The concentration of this metal varies from 10.872 to 78.333 mg/kg in garden soils with a mean value of 23.392±18.049 mg/kg. The mean concentrations of the lead in garden soils of Sekenke mine is lower than the (WHO, 2001) permissible concentrations (85 mg/kg) in the soil. This value diverges from a study conducted by Herman and Kihampa (2015) in Sambaru and Londoni Singida Tanzania in which Pb ranged from 8.7 to 22.24 mg/kg, which shows that the soil was less contaminated with this metal. Therefore, lead in Sekenke mining area is higher than in Sambaru and London almost to three times in the maximum level but the minimum levels is likely to be the same.

Iron (Fe) was also a heavy metal under study in this mine. The analytical values ranged from 144.886mg/kg to 240.614 mg/kg with a mean concentration of 204.646±28.671 mg/kg. Likewise, According to WHO (2011) the concentration of the Iron in soils of all gardens around Sekenke lower than the permissible levels (5000 mg/kg) and hence there is no environmental concern with iron metal in this area.

Zinc concentration in gardens soil 33.640 to 78.846 mg/kg with mean of 52.403± 15.806 mg/kg. The concentration of analyzed samples is lower than maximum acceptable limit by WHO/FAO (2011). The values obtained in this study are higher than the value detected earlier in Ghana (Koranteng, et al., 2011), where the mean Zn concentrations in the sand soil samples ranged between 4.17±1.23 mg/kg and 43.17±4.75 mg/kg. Likely to a study conducted by Herman and Kihampa (2015) in Sambaru and Londoni Singida Tanzania where Zn ranged from 0.42 to 2.6mg/kg. Chromium concentration in garden soils ranges from 128.372 to 189.818 mg/kg with mean of 163.116 ± 16.658 mg/kg. All samples analyzed detected higher level than maximum acceptable limit by WHO/FAO (2011). The values obtained in this study are lower than the one detected in similar study in Oman (Abdul-Wahab and Marikar, 2012) where the level of Cr in gold mining soils reported to be 486 mg/kg in gold mines.

4.5 Garden Soil Contamination

Heavy metal concentrations in soils were higher than the levels of soil baseline survey at this area and Contamination Warning Standard (CWS). Soil contamination assessed by calculating the pollution index (PI). If PI<1, the soil is termed as uncontaminated, if 1≤PI<2, the soil is slightly contaminated, if 2≤PI<3 the soil is moderately contaminated and if 3<PI, the soil is highly contaminated. The background values adopted from Shine et al (2015) where: As= 7.708; Fe = 16.889; Cr =163.453; Pb = 10.04; Cd = 0.393 and Zn = 44.003 both in mg/kg. This was a study conducted in Sekenke Mine soils by Geological Survey of Finland (GTK) in cooperation with Geological Survey of Tanzania (GST).

Hakanson, (1980) suggested four categories of Cf to assess the metal contamination levels as when Cf < 1: Indicates low contamination (or no contamination). The concentration of the contaminant is less than the background level. When 1 ≤ Cf < 3 indicates moderate contamination while 3 ≤ Cf < 6, indicates considerable contamination and Cf ≥ 6: Indicates very high contamination. The contamination degree (Cdeg) of the soil and was computed based on the sum of all contamination factors using the formula (equation 4) and the results are as indicated in Table 4.3

Table 4.3: Contamination Factor (CF) for Six Heavy Metals and Pollution Index for Garden Soils

HM	**Cb**	**Cm**	**CF**	PLI	**C(deg)**
As	7.708	21.331	2.767		
Pb	10.04	23.392	2.330		
Cd	0.393	3.018	7.679	2.9889	27.082
Fe	16.889	204.646	12.117		
Zn	44.003	52.403	1.191		
Cr	163.453	163.116	0.998		

Source: Research Data, (2024).

Therefore, the pollution index (PI) and contamination degree, C(deg) values of all six heavy metals (As, Pb, Cd, Fe, Zn and Cr) are 2.9889 and 27.082 respectively (Table 4.3). Since the pollution index is between 2 and 3; and the contamination degree, C(deg) is between 16 and 32, the soil is moderately polluted and considerable contaminated by considering the classifications of degree of contamination proposed by Hakanson (1980) in his study. These results suggest that the place is moderately safe for agricultural activities especially vegetable production relying the PLI classification values indicated by Suwanmanon and Kim (2021).

4.6 Heavy Metal Levels in Water

Water in these study areas is used for domestic purposes as well as to irrigate vegetables. The concentration of heavy metals is summarized in Table 4.4.

4.6.1 Arsenic in Water

The concentration of Arsenic (As) in water ranges from 0.68 mg/l to 3.76 mg/L while the mean concentration As was 2.707±1.7556 mg/l. This concentration is higher than WHO/FAO permissible limit of heavy metal in drinking water is Arsenic (0.05 mg/kg). The finding is contrary to a study conducted by Gafur *et al.*, (2018) in Gorontalo, Indonesia where the analysis of As ranged from 66 to 82,500 µg/l. The mean value is also higher than that obtained by Mnali (2001) in Lupa gold field with the concentration of as in water which was 0.44 µg/l.

Table 4.4: Heavy Metal Concentration in Irrigation Water (mg/l)

HM	As	Pb	Cd	Fe	Zn	Cr
Max.	3.760	1.109	0.008	59.870	25.130	0.008
Min.	0.680	0.042	0.007	3.652	5.443	0.005
Mean	2.707	0.750	0.008	39.147	13.864	0.006
Std (±)	1.756	0.613	0.001	30.883	10.147	0.001
WHO/FAO	0.05	0.05	0.005	0.3	5	0.05

Source: Research Data, (2024).

4.6.2 Cadmium in Water

The maximum value of Cadmium (Cd) determined in water was 0.008 mg/l with a mean concentration of 0.008 ± 0.001 mg/l. The values obtained in this study are much higher compared to a study conducted by Mnali (2001) in which Cd concentration was 0.03 µg/l. The mean concentration of cadmium in irrigation water at Sekenke is slightly higher than the WHO (2001) maximum permissible value of 0.0067 mg/l.

4.6.3 Lead in Water

The concentration of Pb in water ranged from 0.042 to 1.109 mg/l with a mean concentration of 0.750± 0.613 mg/l. The mean concentrations of the lead in water used for irrigation at Sekenke mine is lower than the (WHO, 2001) permissible limit of 1.0994 mg/l and the maximum value is also lower than that obtained by Gafur et al., (2018) in Indonesia with a concentration range from 11 to 1670 µg/l. Likewise, Mnali (2001) in his study in Lupa gold field in Tanzania, the Pb concentration (0.5 µg/l) found to be lower than that obtained in this study and WHO permissible limit.

4.6.4 Iron in Water

Iron (Fe) in water was also a heavy metal under study in this mine. It was observed that the metal concentration ranged from 3.652 to 59.870 mg/kg with a mean concentration of 39.147±30.884 mg/kg. According to WHO (2001), the maximum permissible limit of Fe metal concentration in drinking water is 0.3 mg/kg. The mean value of iron in water is very high almost 7 times higher than that obtained by Shahin et al. (2016) in Egypt on ground water used for irrigation with a concentration range from 4.9 to 8.8 mg/kg. This indicates a danger in the health of the individuals if this irrigation water will be taken for human consumption as drinking water.

4.6.5 Zinc in Water

Zinc concentration in gardens soil was 5.443 to 25.130 mg/kg with mean of 13.864± 10.147 mg/kg. According to WHO (2011), the maximum permissible limit of Zinc in drinking water is 11.02 mg/kg. Unlikely to a study conducted by Herman and Kihampa (2015) in Sambaru and Londoni Singida Tanzania Zn concentration was very low that ranged from 0.013 to 0.17 mg/l.

4.6.6 Chromium in Water

Chromium concentration in irrigation water ranges from 0.005 to 0.008 mg/l with mean of 0.006±0.001 mg/l. All samples analyzed detected lower level than maximum acceptable limit set by WHO/FAO (2011) which is 0.1 mg/l but lower than the one detected (0.116±0.028 mg/l) in Loumbila and Paspanga, Bukina Faso (Bambara, et al., 2015). The Cr detected by Mnali (2001) in water was very low with concentration 0.0014 mg/l compared to the mean value of Cr concentration at Sekenke irrigation water.

4.6.7 Implications of Heavy Metals in Water

The mean concentrations of the six heavy metals (As, Cd, Fe, Pb, Zn and Cr) at Sekenke Mine are higher than the WHO/FAO acceptable limits of studied heavy metals in water. Iron analyzed highest than the acceptable limit to at least one hundred and thirty (130) times and hence cause effect to individuals using/consuming water with this element. Cadmium in Sekenke Mine is higher than the acceptable limit but to the marginal, that is considered negligible for individuals using the water at the site.

4.7 Physical Parameters Analyzed in Water

The physical parameters analyzed for three different portions of water samples were pH, electrical conductivity and turbidity. The average pH of irrigation water 7.85 and this shows that the water is slightly basic due nature of ore materials and spillage of lime in the environment and that applied during processes. The water with this measured pH values causes no effect to the environment since the water seems not acidic. The average turbidity value of irrigation water at Sekenke was 2.372 ±1.052NTU above the recommended level of the WHO/US EPA (2024); (Table 4.5) for drinking water but below for irrigation purposes. The higher turbidity causes cloudiness and hence hinders oxygen in water and therefore cause danger to aquatic life.

Table 4.5: Physical Parameters analysed in Irrigation Water

	pH				EC(μohm/s)				Turbidity(NTU)
Sample ID	P1	P2	P3	Average	E1	E2	E3	Average	T1
Max	11.23	11.22	11.25	11.25	1108	1111	1109	1109.33	3.69
Min	5.32	5.36	5.28	5.28	34	31	36	33.67	1.12
Mean	7.85	7.86	7.85	7.85	586	587	587.25	586.75	2.372
Std (±)	3.05	3.02	3.07	2.49	492.76	494.72	492.50	493.32	1.052
US EPA/WHO									10 -50

Source: Research Data, (2024)

4.8 The Heavy Metals Concentration in *Amaranthus Spp* and *Cucurbita Moschata*

Analysis of heavy metals in the two green leafy vegetables conducted for samples collected at an interval of three weeks. The actual concentration of the heavy metals in the vegetables expressed as the product of the absorbance and volume used in dilution per mass used for digestion. The volumetric flask used was 100 ml and mass of vegetable samples used was 1g each test. Therefore, Table 4.7 shows the actual concentration of the heavy metals in the vegetables (Amaranthus spp and Cucubita moschata) as analysed in the laboratory.

4.8.1 Arsenic in *Amaranthus spp* and *Cucurbita moschata*

The study of metal concentration of Arsenic (As) in *Amaranthus spp* leaves ranges from 1.860 to 2.5 mg/kg with the mean concentration of 2.153±0.264 mg/kg while the concentration of As in *Cucurbita moschata* leaves ranges 0.400 to 1.6 mg/kg. These concentrations are higher than WHO/FAO permissible limits in vegetables as indicated in table 4.6. Philip J (2021) in his study in Geita reported lower concentration values of As in *Amaranthus spp* such that 0.14573±0.01079 mg/kg for samples collected from Nyarugusu, 0.17219±0.01477 mg/kg for samples collected Magenge and Nyamalimbe, 0.10669±0.01090 mg/kg at Nyamatondoo and Kaseme, 0.17910±0.01824 mg/kg.

Table 4.6: Concentration of Heavy Metals in *Amaranthus Spp* and *Cucurbita Moschata* (mg/kg)

	Amaranthus spp						*Cucurbita moschata*					
HM	**As**	**Pb**	**Cd**	**Fe**	**Zn**	**Cr**	**As**	**Pb**	**Cd**	**Fe**	**Zn**	**Cr**
Max	2.500	0.988	0.852	61.100	156.300	0.655	1.600	0.921	0.924	90.400	181.400	0.512
Min	1.860	0.712	0.320	33.200	144.100	0.648	0.400	0.642	0.328	12.500	122.200	0.436
Mean	2.153	0.852	0.529	45.300	149.033	0.652	0.957	0.737	0.711	58.200	148.433	0.471
Std (±)	0.264	0.113	0.232	11.687	5.247	0.003	0.494	0.130	0.271	33.204	24.633	0.031
WHO/FAO	0.2	0.3	0.2	425.5	99.4	2.3	0.2	0.3	0.2	425.5	99.4	2.3

Source: Research Data, (2024).

4.8.2 Cadmium in *Amaranthus spp* and *Cucurbita moschata*

Cadmium (Cd) for all sampling *Amaranthus spp* ranges from 0.32 to 0.852 mg/kg (dry weight) with a mean concentration of 0.529±0.232 mg/kg while concentrations of Cadmium in *Cucurbita moschata* ranges from 0.328 to 0.924 mg/kg with a mean concentration of 0.711±0.271 mg/kg. The mean concentrations of cadmium in the vegetables are higher than the WHO (2001) maximum permissible value of 0.2mg/kg in the leafy vegetables. Yaradua et al., (2019) study on heavy metals in *Amaranthus spp* grown in illegal mining areas, the mean concentration of Cadmium was lower than that obtained in Sekenke with 0.0654 ± 0.0041 mg/kg. Another study by Ojiego, et al., (2022) revealed *Cucurbita moschata* with a Cd concentration of 0.18 ± 0.02 mg/kg also lower that obtained in Sekenke study.

4.8.3 Lead in *Amaranthus spp* and *Cucurbita moschata*

Lead (Pb) analyzed in *Amaranthus spp* ranged from 0.712 to 0.988 mg/kg with a mean value of 0.852±0.113 mg/kg while the concentration of Pb in *Cucurbita moschat*a ranges from 0.642 to 0.921 mg/kg with a mean concentration of 0.737±0.13 mg/kg. The mean concentrations of the lead in *Amaranthus spp* and *Cucurbita moschata* are higher than the (WHO, 2001) permissible concentrations (0.3mg/kg). Kahangwa, *et al.*, (2021) found the concentration of lead in vegetables leafy with a concentration of Pb 0.75778 mg/kg approximately equal to the mean concentration of Pb analysed in Sekenke mine.

4.8.4 Iron in *Amaranthus spp* and *Cucurbita moschata*

Iron (Fe) was also a heavy metal under study in Sekenke Small Scale mine. The analytical values in *Amaranthus spp* ranged from 33.2 to 61.1 mg/kg with a mean concentration of 45.3±11.687 mg/kg while the values for *Cucurbita moschata* ranges from 12.5 to 90.4 mg/kg with a mean concentration of 58.2±0.33.204 mg/kg. According to WHO the concentration of the Iron in *Amaranthus spp* around Sekenke is much lower than the permissible levels (425.5 mg/kg) and hence there is healthy effect with iron metal in the *Amaranthus spp*. The concentration of iron in *Amaranthus spp* leaves under this study revealed to be higher than that conducted by Yaradua et al., (2019) in Gadirge village, Jibia local Government area, Katsina State, Nigeria with mean concentration of 3000.1560 ± 0.0538 mg/kg. Iron concentration seems to be higher in *Cucurbita moschata* than in *Amaranthus spp* which indicates that there is high rate of iron up taking in *Cucurbita moschata*.

4.8.5 Zinc in *Amaranthus spp* and *Cucurbita moschata*

Zinc concentration in *Amaranthus spp* ranged from 144.1 to 156.3 mg/kg (dry weight) with mean of 149.033±5.247 mg/kg while Zn concentration in *Cucurbita moschata* ranges from 122.2 to181.4mg/kg with mean concentration of 148.433±24.633 mg/kg. The permissible levels of zinc in vegetables is 99.4 mg/kg, hence, the concentration of analyzed samples is higher than maximum acceptable limit by WHO/FAO (2011).

4.8.6 Chromium in *Amaranthus spp* and *Cucurbita moschata*

Chromium concentration in *Amaranthus spp* ranges from 0.648 to 0.655 mg/kg (dry weight) with mean of 0.652±0.003 mg/kg while the concentration of Cr in *Cucurbita moschata* ranges from 0.436 to 0.512 mg/kg with mean concentration of 0.471±0.031 mg/kg. The analyzed samples detected lower-level concentration which is within the maximum acceptable limit (2.3 mg/kg) by WHO/FAO by contrary to a study conducted in Bangladesh by Ahmed et al (2016) that revealed higher concentration of chromium but lower to a study conducted by Ongon'g et al, (2020). The concentration values are lower than the WHO/FAO permissible values and also lower that that analyzed in samples collected at Sekenke mine.

4.8.7 Implication of Heavy Metals in Leafy Vegetables at Sekenke Mine

The mean concentrations of five heavy metals (As, Cd, Fe, Pb and Zn) are higher than the WHO/FAO acceptable limits in *Amarathus spp* and *Cucurbita moschata*. Chromium analyzed lower than the acceptable limit to at least three times and hence cause no effect to individuals consuming vegetables with this element.

4.9 Human Health Risk Assessment

Risk assessment involves estimating the magnitude and nature of the harmful health impacts in humans exposed over a period. The assessment evaluated in both irrigation water and green leafy vegetables taken by adults with around 70 years and children with around 6 years. In this study, the green leafy considered were *Amaranthus spp* and *Cucurbita moschata*.

4.9.1 Exposure Dose through Irrigation Water

Health risk assessed by estimating the heavy metal contamination and potential carcinogenic and non-cancer health risk caused by the ingestion of heavy metals in the irrigation water from Sekenke Mine. The data obtained after analysis in the laboratory observed that cadmium has lowest value, 0.008±0.001 mg/kg in the water used for irrigation while other iron concentrations is the highest (39.147±30.883) mg/kg. The exposure dose of water due to ingestion of Iron to human health found to be higher both in Adults and Children. Exposure dose from cadmium was zero for both adults and children.

Table 4.7: Exposure Dose of Heavy Metals in Water

HM	**Adults** – D(ing)	**Children –** D(ing)
As	9.999	3.272
Pb	0.060	0.020
Cd	0.000	0.000
Fe	41.971	13.736
Zn	28.076	9.189
Cr	0.053	0.017

Source: Research Data, (2024).

4.9.1.1 Non-Carcinogenic Risk Aassessment through Irrigation Water

The Hazard quotient (HQ) used to assess the non-carcinogenic risks for As, Pb, Cd, Fe, Zn and Cr in adults and children in the study area. The HQ values for all metals under study were within the acceptable range of less than one. Although the values were within the range, Arsenic and Cadmium found to have, high values while Lead and Chromium with lowest values for both children and adults who take domestic water in the site. Likewise, the hazards indices HI values were less than one in in water indicating low health risk on long-term exposure and the non-cancer effect. The hazard index for adults was higher compared to that of the children implying that adults could be more disposed to non-cancer risks than children (Table 4.8 and 4.9) could.

The HQ is less than 1 like that obtained by Singovszka, et al., (2020) in a study of water in mines where the non-carcinogenic hazard quotients of heavy metals at the study sites were higher among children than among adults. The HQ values for ingestion of water to adults were<1 all five metals contrary children which was >1 for As, indicating that this group is highly in danger to non-carcinogenic risks in consuming water with arsenic.

Table 4.8: Non-Carcinogenic Risk Assessment – Hazard Quotients for Children in Water Ingestion

HM	D (ing)	Rf (Ding)	HQ (ing)	Hazard Index (HI)
As	1.79×10^{-6}	3.0×10^{-4}	5.97×10^{-3}	6.122×10^{-3}
Pb	1.37×10^{-8}	3.5×10^{-3}	3.91×10^{-6}	
Cd	n.d	1.0×10^{-3}	n.d	
Fe	1.72×10^{-5}	0.7	2.45×10^{-5}	
Zn	3.86×10^{-5}	0.3	1.29×10^{-4}	
Cr	1.21×10^{-7}	1.5	8.09×10^{-8}	

NB. n.d = not determined

Source: Research Data, 2024.

Table 4.9: Non-Carcinogenic Risk Assessment – Hazard Quotient for Adults through Water Ingestion

HM	D(ing)	Rf(Ding)	HQ(ing)	Hazard Index (HI)
As	1.05958×10^{-5}	3.0×10^{-4}	3.53×10^{-2}	
Pb	8.103×10^{-8}	3.5×10^{-3}	$2.31505 \times 10^{--5}$	3.62×10^{-2}
Cd	0	1.0×10^{-3}	0	
Fe	1.016×10^{-4}	0.7	1.451×10^{-2}	
Zn	2.284×10^{-4}	0.3	7.613×10^{-4}	
Cr	7.183×10^{-7}	1.5	4.7889×10^{-7}	

Source: Research Data, (2024).

4.9.1.2 Carcinogenic Risk Assessment through Water Ingestion

Chronic daily intake of water ingestion was used to assess the carcinogenic risks for As, Pb, Cd, Fe, Zn and Cr in adults and children in the study area. The results are shown in Table 4.10 & 4.11. The CDI values for the heavy metals were higher in children than in adults for the water source. The Life time cancer risk of 6 heavy metals exposure from ingesting water from Sekenke Small Scale Mines was estimated by Eq. (10) for both adults and children and the results presented in Table 4.6 & 4.7. Cancer slope factors ($SF_{ingestion}$) used in calculation of cancer risks for the heavy metals were 8.5×10^{-3} for Pb, 0.5 for Cr, 15 for Cd, and 1.5 for As (Oni et al.

(2022)). Other slope factors for metals, Zn and Fe were not found in the literatures reviewed.

The lifetime Cancer Risk (LTCR) of As and Cr on children were $8.57x10^{-3}$ and $2.7x10^{-3}$, for adults were $2.24x10^{-3}$ and $7.24x10^{-5}$ respectively. The CR values for adults were smaller than the CR value of children. According to US EPA, the tolerable value that set by this agency is 1×10^{-6}, that means one person among million of them can face cancer risk. In this case, the values of As and Chromium are very high for both children and adults consuming water at this area while lead values are in the acceptable value if ingested and hence the cancer risk is low. Cadmium pose no effect as the LTCR value is zero. The CR of three carcinogenic elements was As > Cr> Cd.

A lifetime cancer risk (LTCR) value between 10^{-6} and 10^{-4} considered to be of low health risk, and amounts greater than 10^{-4} is likely a high health risk according to US EPA. Based on this recommendation, the LTCR for arsenic in both children and adults are higher than 10^{-4} and hence these groups face a high cancer risk. Likely, for Chromium, children are in danger of facing cancer risk than adults whose value range between 10^{-6} and 10^{-4} that considered as low health risk.

Singovszka, et al., (2020) in five sites study at Slovakia on the impact of heavy metals in water from abandoned mine on human health, revealed that As daily intake (DI) through the ingestion pathway measured to adults ranges from $4.24x10^{-06}$ to $1.50x10^{-04}$, children from $5.58x10^{-06}$ to $7.09x10^{-02}$. For Cd, DI measured range from $1.01x10^{-06}$ to $4.43x10^{-05}$ for adults and from $2.68x10^{-06}$ to $1.18x10^{-04}$ for children.

DI for Zn, ingestion of water to adults ranges from $1.63\text{x}10^{-05}$ to $2.66\text{x}10^{-02}$ while for children ranges from $5.58\text{x}10^{-06}$ to $7.09\text{x}10^{-02}$.

Table 4.10: Chronic Daily Intake of Water for Children

HM	C(water) (mg/kg)	DI(L/day)	BW (kg)	CDI (mg/kg/day)	SF(mg/kg.d)/1	LTCR
As	$6.80\text{x}10^{-2}$	1.8	15	$8.16\text{x}10^{-3}$	$1.05\text{x}10^{0}$	$8.57\text{x}10^{-3}$
Pb	$5.20\text{x}10^{-3}$	1.8	15	$6.24\text{x}10^{-4}$	$8.50\text{x}10^{-3}$	$5.30\text{x}10^{-6}$
Cd	0	1.8	15	0	$5.01\text{x}10^{-1}$	0
Fe	$6.52\text{x}10^{-1}$	1.8	15	$7.82\text{x}10^{-2}$	-	-
Zn	$2.44\text{x}10^{0}$	1.8	15	$2.93\text{x}10^{-1}$	-	-
Cr	$4.60\text{x}10^{-3}$	1.8	15	$5.53\ \text{x}10^{-4}$	$5.00\text{x}10^{-1}$	$2.77\text{x}10^{-3}$
US EPA						10^{-6} to 10^{-4}

Source: Research Data, (2024).

Table 4.11: Chronic daily intake of Water for Adults

HM	C(water) (mg/kg)	DI(L/ day)	BW (kg)	CDI (mg/kg/day)	SF(mg/kg.d)/ l	LTCR
As	$6.8\text{x}10^{-2}$	2.2	70	$2.14\text{x}10^{-3}$	$1.05\text{x}10^{0}$	$2.24\text{x}10^{-3}$
Pb	$5.2\text{x}10^{-3}$	2.2	70	$1.63\text{x}10^{-4}$	$8.50\text{x}10^{-3}$	$1.39\text{x}10^{-6}$
Cd	0	2.2	70	0	$5.01\text{x}10^{-1}$	0
Fe	$6.52\text{x}10^{-1}$	2.2	70	$2.05\text{x}10^{-2}$	-	-
Zn	$2.44\text{x}10^{0}$	2.2	70	$7.68\text{x}10^{-2}$	-	-
Cr	$4.61\text{x}10^{-3}$	2.2	70	$1.45\text{x}10^{-4}$	$5.00\text{x}10^{-1}$	$7.24\text{x}10^{-5}$
US EPA						10^{-6} to 10^{-4}

Source: Research Data, (2024).

The findings in this study revealed that there is a significant cancer risk in consuming water contain concentrations of heavy metals likewise to the study conducted by Singovszka E et al., (2020) in their studies of heavy metals in water from abounded mine. Children are more at risk in consuming this water basically with chromium element.

4.9.2 Non-Carcinogenic Risk Assessment through consuming *Amaranths Spp*

In this study, health risk assessed by estimating the heavy metal contamination and potential carcinogenic and non-cancer health risk caused by the ingestion of heavy metals in *Amaranthus spp* from Sekenke Mine. Hazard Quotients (HQ) and Hazard Index (HI) used in assessing. In this case, Adults and children considered, hazard indices (HI) were used to assess the non-carcinogenic risks for As, Pb, Cd, Fe, Zn and Cr in adults and children who take *Amaranths spp* in the study area.

The HI values for the heavy metals were low in children than in adults for the *Amaranthus spp*. The HQ values for all heavy metals under study were within the acceptable range of less than one except As which was greater than 1. The HQ values of Arsenic for children consuming *Amaranthus spp* found to be lower than in adults and also greater than 1.

The HI values were greater than one for both adults and children consuming *Amaranthus spp* indicating high health risk on long-term exposure and the non-cancer effect is of no concern. The hazard index for children was lower compared to that of the adults implying that adults could be more disposed to non-cancer risks than children could. The results shown in Tables 4.12.

Table 6.12: Hazard Quotient and Hazard Index (HI) for Children and Adults Consuming *Amaranthus Spp*

	Children		**Adults**	
HM	**HQ (ing)**	**Hazard Index (HI)**	**HQ (ing)**	**Hazard Index (HI)**
As	5.062	6.003	14.998	17.787
Pb	0.172		0.509	
Cd	0.373		1.106	
Fe	0.046		0.135	
Zn	0.350		1.038	
Cr	3.0×10^{-3}		9.0×10^{-4}	

Source: Research Data, (2024).

The findings are in line with the findings by Yaradua et al., (2019) where the Hazard Quotient (HQ) associated with the evaluated heavy metals exposure through consumption of the vegetables by adults and children were below 1execpt for arsenic which is higher than 1. Therefore, since As>1, it poses higher risks to both children and adults. Similar study of heavy metals polluted vegetables with HQ or HI values for As > 1 have been reported previously (Qin, et al., (2021). The contribution of higher HI for adults was also from Zinc and Cadmium which have also higher HQ than 1 and poses higher non cancer risks in consuming *Amaranthus spp* with such elements.

4.9.3 Carcinogenic Risk Assessment through *Amaranthus Spp*

Like in water, the cancer risk in *Amaranthus spp* calculated for three elements that its slope factor obtained through the literatures. The cancer risk estimated by Eq. (10) for both adults and children and the results presented in Table 4.13. Likewise, the Cancer slope factors ($SF_{ingestion}$) used in calculation of cancer risks for the heavy metals were $8.5x10^{-3}$ for Pb, 0.5 for Cr, 15 for Cd, and 1.5 for As in $(mg/kg\text{-}day)^{-1}$. The lifetime cancer risk (CR) of As, Pb, Cd and Cr on children were $5.09x10^{-2}$, $1.63x10^{-4}$, $5.97x10^{-3}$ and $7.34x10^{-3}$ for adults were 0.01292, $4.14x10^{-5}$, $1.515x10^{-3}$ and $1.863x10^{-3}$ respectively in. The LTCR values for adults were smaller than LTCR for children. In this case, the values of as and Pb are high for both children and adults consuming *Amaranths spp* at this area. The order of LTCR of four elements was As > Pb>Cr> Cd.

According to US EPA, the tolerable value of a Lifetime cancer risk (LTCR) between 10^{-6} and 10^{-4} considered to be of low health risk, and amounts greater than 10^{-4} is likely a high health risk. Therefore, the LTCR for arsenic, Cadmium, chromium and slightly Lead in children are higher than 10^{-4} and hence the group face a high cancer risk. The adults face no cancer risks in consuming Lead since the LTCR is below 10^{-4}. Other elements are out of the range between 10^{-6} and 10^{-4} but higher and hence the adults are also at the cancer risk with consuming *Amaranthus spp* with As, Pb and Cr. In the two groups arsenic has high value LTCR than other metals and therefore is more dangerous for the groups in using this kind of vegetable at Sekenke (Table 4.13).

Table 4.13: Carcinogenic Risk Assessment of *Amaranthus Spp* for Children and Adults

	Children		Adults	
HM	**CDI (mg/kg/day)**	**LTCR**	**CDI (mg/kg/day)**	**LTCR**
As	$4.85x10^{-2}$	$5.09x10^{-2}$	$1.23x10^{-2}$	$1.29x10^{-2}$
Pb	$1.92x10^{-3}$	$1.63x10^{-4}$	$4.87x10^{-3}$	$4.14x10^{-5}$
Cd	$1.19x10^{-2}$	$5.97x10^{-3}$	$3.03x10^{-3}$	$1.52x10^{-3}$
Fe	$1.02x10^{0}$	-	$2.589x10^{-1}$	-
Zn	$3.35x10^{0}$	-	$8.52x10^{-1}$	-
Cr	$1.47x10^{-2}$	7.3410^{-3}	$3.73x10^{-3}$	$1.86x10^{-3}$
US EPA				10^{-6} to 10^{-4}

Source: Research Data, (2024).

The study rely on that conducted by Yaradua, et al., (2019) in areas with illegal mining at Katsina State, North west Nigeria on concentration and evaluation of cancer risks of heavy metals (Cr, Cd, Fe, Pb and Zn) in *Amaranthus spp* that revealed that the findings were greater than the US EPA limits (10^{-2} to 10^{-3}) and hence the population around this area exposed to cancer risk. The findings in this study are in line with findings of Sekenke where the cancer risk in consuming *Amaranthus spp* is high to the population around the area.

Therefore, the LTCR indicates that children consuming *Amaranthus spp*, chromium poses stronger cancer risks followed by Arsenic, cadmium and finally lead. In contrast to children, the trend of stronger cancer risks for adults is As>Cr>Cd>Pb. Hence Pb, poses lowest cancer risks than other heavy metals.

4.9.4 Non-Carcinogenic Risk Assessment through *Cucurbita Moschata* Ingestion

Like in other foods water and *Amaranths spp*, the Hazard quotients (HQ) and hazard indices (HI) were used to assess the non-carcinogenic risks for As, Pb, Cd, Fe, Zn and Cr both children and adults in the study area. The same as *Amaranths spp*, the HQ and HI values for the heavy metals were lower in children than in adults for the *Cucurbita moschata*.

Table 4.14: Hazard Quotient and Hazard Index (HI) for Children and Adults consuming *Cucurbita Moschata*

	Children		Adults	
HM	**HQ (ing)**	**Hazard Index (HI)**	**HQ (ing)**	**Hazard Index (HI)**
As	2.249	3.306	6.663	9.797
Pb	0.149		0.44	
Cd	0.501		1.485	
Fe	0.059		0.174	
Zn	0.349		1.034	
Cr	$2.0x10^{-4}$		$7.0x10^{-4}$	

Source: Research Data, (2024).

The HQ values for all elements under the study were within the acceptable range of less than one. The values for Arsenic in both adults and children were higher than other metals but do not cause any non-carcinogenic disease since is lower than 1 (Table 4.14). The hazard indices for adults found higher compared to those of the children implying that adults could be more disposed to non-cancer risks than in consumed by children.

4.9.5 Carcinogenic risk Assessment through *Cucurbita Moschata* Ingestion

In the study, the cancer risk of 6 heavy metals exposure from ingesting *Cucurbita moschata* in Sekenke Small Scale miners was also calculated and observed that both children and adults have also high risk in ingesting this vegetable. Table 4.15 shows the LTCR of four elements on which the As value is $2.26x10^{-2}$, Pb is $1.41x10^{-4}$, Cd is $2.40x10^{-1}$ and Cr is $5.30.x10^{-3}$ for children. The values of cancer risks for the heavy metals in children were obtained by using Cancer slope factors (SF_{ing}) which were $8.5x10^{-3}$ for Pb, 0.5 for Cr, 0.501 for Cd, and 1.5 for As. Hence, cadmium poses stronger cancer risks followed by Arsenic, chromium and finally lead for children consuming *Cucurbita moschata.*

The LTCR for adults consuming *Cucurbita moschata* were $5.74x10^{-3}$ for As, $3.16x10^{-5}$ for Pb, $6.09x10^{-2}$ for Cd and $1.35x10^{-3}$ for Cr. In contrast to children, the trend of stronger cancer risks for adults is Cd>As>Cr> Pb. Hence Pb, poses lowest cancer risks than other heavy metals.

Table 7.15: Carcinogenic Risk Assessment of *Cucurbita Moschata* for Children and Adults

	Children		Adults	
HM	**CDI (mg/kg/day)**	**LTCR**	**CDI (mg/kg/day)**	**LTCR**
As	$2.2x10^{-2}$	$2.26x10^{-2}$	$5.5x10^{-3}$	$5.74x10^{-3}$
Pb	$1.7x10^{-2}$	$1.41x10^{-4}$	$4.2x10^{-3}$	$3.16x10^{-5}$
Cd	$1.6x10^{-2}$	$2.40x10^{-1}$	$4.1x10^{-3}$	$6.09x10^{-2}$
Fe	$1.31x10^{0}$	-	$3.33x10^{-1}$	-
Zn	$3.34x10^{0}$	-	$8.48x10^{-1}$	-
Cr	$1.1x10^{-2}$	$5.30.x10^{-3}$	$3.0x10^{-3}$	$1.35x10^{-3}$
US EPA				10^{-6} to 10^{-4}

Source: Research Data, (2024).

Likewise, slope factor for Fe and Zn did not find in the literatures reviewed. However, in exceptional of lead metal in adults, the LTCR for the other three elements have high cancer risk for both children and adults because they all lie beyond 10^{-6} and 10^{-4} and hence are at all considered to be at high health risk.

Generally, the hazard question to children and adults consuming *Amaranthus spp* is both higher than those consuming *Cucurbita moshata*, hence poses higher non-carcinogenic risks. The LTCR for children consuming the two green leafy vegetable is higher than those consumed by adults. Hence, children are highly to cancer concern than adults consuming these vegetables. However, LTCR for Pb in the two kinds of vegetables is lower than other metals for both children and adults consuming *Cucurbita moschata*, and unlike to *Amaranthus spp*. This indicates that children and adults consuming these vegetables with Pb pose low cancer risks.

CHAPTER FIVE

CONCLUSIONS AND RECOMMANDATIONS

5.1 Overview

The chapter concludes and recommend on the findings of the study conducted in tailings, garden soils, water and leafy vegetables. Improper management of tailings containing heavy metals elevates levels of heavy metals in the garden soils around Sekenke mining site, thus high levels of heavy metals in vegetables grown in the soil. Human risk assessment was evaluated due to consumption of the leafy vegetables which draw the attention to individuals around the mine site.

5.2 Conclusion

The study reveals that there is high level of As, Pb, Cd, Fe, Zn, and Cr concentrations in both unprocessed and reprocessed tailings; and soils that crops are grown on it. The pollution index (PI) of heavy metals in the tailings was greater than one that pose a high pollution in tailings. Likewise, the contamination degree (C_{deg}) was between 16 and 32 for both unprocessed and reprocessed tailings that also pose a contamination.

The garden soil becomes moderately polluted since the PI was between 2 and 3 and the degree of contamination was between 16 and 32. The irrigation water found to be highly contaminated with five heavy metals except Cr that its mean concentration was below the WHO/FAO (2001) permissible limits.

In this study, the human health risk assessment conducted to children ingesting *Amaranthus spp* and *Cucurbita moschata* around the Sekenke mine indicated that the Life time cancer risk (LTCR) for As, Pb, Cd and Cr was higher than the tolerable limit and hence high cancer risk. Likewise, the cancer risk observed to adults consuming the vegetables with heavy metals As, Cd and Cr except Pb which was in the recommended limit.

Therefore, the environment is polluted with the heavy metals (As, Pb, Cd, Fe, Zn, Cr) due to mining activities that produces reprocessed tailings after recovery of gold from their ores and unprocessed tailings. The study also revealed that vegetables (*Amaranthus spp* and *Cucurbita moschata*) are highly contaminated by heavy metals due to contaminated tailings that spread to garden soils around the process plants through discharges from them.

5.3 Recommendations

Since the LTCR values are higher than the acceptable limits, measures are required to be taken so as to avoid transfer of heavy metals especially cadmium with higher LTCR to the environment. This can be done by encouraging the small-scale miners to establish tailing pits or any other mechanism that can prevent the movement of tailings from the process plants to the near environment.

Hence, further studies are proposed to

i. To asses heavy metal contamination levels from the mine site to soils distance by distance;
ii. To evaluate levels of heavy metal contamination in different fruits and leafy vegetables grown in gold mining areas so as to predict the possible human health hazards due to consumption of these vegetables;

iii. To compare levels of heavy metals which can be found in food consumed by miners due to contamination from vegetables as well as water used in cooking.

iv. To assess human risks due to dermal and inhalation of heavy metals in reprocessed tailings.

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APPENDICES

CLEARANCE LETTERS

THE UNITED REPUBLIC OF TANZANIA

MINISTRY OF EDUCATION, SCIENCE AND TECHNOLOGY

THE OPEN UNIVERSITY OF TANZANIA

Ref. No OUT/PG202086726 **21st May, 2024**

District Executive Director (DED),
Iramba District Council,
P.O.Box 155,
SINGIDA.

Dear Director,

RE: <u>RESEARCH CLEARANCE FOR MR. PRISCUS ROMAN, REG NO: PG202086726</u>

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

3. To facilitate and to simplify research process therefore, the act empowers the Vice Chancellor of the Open University of Tanzania to issue research clearance, on behalf of the Government of Tanzania and Tanzania Commission for Science and Technology, to both its staff and students who are doing research in Tanzania. With this brief background, the purpose of this letter is to introduce to you **Mr. Priscus Roman, Reg. No: PG202086726),** pursuing **Master of Environmental Studies (MES).** We here by grant this clearance to conduct a research titled **"Influence of Vat Leach Reprocessed**

Tailings on the Environments around Sekenke Gold Mine, Iramba District, Tanzania". He will collect his data at your area from 22nd May to 30th June 2024.

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

Yours sincerely,

THE OPEN UNIVERSITY OF TANZANIA

Prof.Gwahula Raphael Kimamala

For: VICE CHANCELLOR

JAMHURI YA MUUNGANO WA TANZANIA

OFISI YA RAIS

TAWALA ZA MIKOA NA SERIKALI ZA MITAA

HALMASHAURI YA WILAYA YA IRAMBA

Unapojbu tafadhalitaja:
Kumb. Na. DED/IRA/E10/30/VOLVI/91 **07 Juni 2024**

Mkuu wa Chuo,
Chuo Kikuu Huria,
S. L. P. 23409,
DAR ES SALA.

Yah: **MAOMBI YA KUFANYA UTAFITI MWANACHUO PRISCUS ROMAN**

Tafadhali husika na mada tajwa hapo juu,

2. Ofisi ya Mkurugenzi Mtendaji Wilaya ya Iramba Inakiri kupokea barua yako ya tarehe 21 Mei 2024 yenye Kumb. Na.OUT/PG202086726 ya kumwombea mtajwa hapo juu kufanya Utafiti katika Halmashauri ya Wilaya ya Iramba.

3. Kwa barua hii nakujulisha kuwa, ombi lako kuhusu Mwanachuo **Priscus Roman** kufanya utafiti katika Halmashauri ya Wilaya ya Iramba **limekubaliwa,** kuanzia tarehe **22 Mei 2024** hadi **30 Juni 2024.** Atakuwa chini ya uangalizi wa Afisa Mtendaji Kata ya Shelui.

Halmashauri haitahusika na gharama zozote kwenye zoezi hilo.

Nashukuru kwa ushirikiano wako.

Dorcas P.Kinyangadzi
Kny, MKURUGENZI MTENDAJI.

K.N.Y MKURUGENZI MTENDAJI
ALMASHAURI YA WILAYA YA IRAMBA

Nakala: 1/3 Mkurugenzi Mtendaji - Aione kwenye jalada
S.L.P. 155,
KIOMBOI – IRAMBA

2/3 Afisa Mtendaji Kata ya Shelui

3/3 Priscus Roman