MINING INDUCED HEAVY METAL SOIL AND CROP CONTAMINATION IN CHILILABOMBWE ON THE COPPERBELT OF ZAMBIA

By

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A dissertation
Submitted to the University of Zambia
in partial fulfillment of the requirements of the Degree of
Master of Science in Geography

THE UNIVERSITY OF ZAMBIA
LUSAKA

2017

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Declaration

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CERTIFICATE OF APPROVAL

This dissertation by Mulonga Namweemba Gertrude is approved as fulfilling the partial requirements for the award of the degree of Master of Science in Geography by the University of Zambia.

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Abstract

Mining is considered to be the world's most valued anthropogenic activity. For instance, in Zambia, mining is one of the most important economic sectors and contributes significantly to its Gross Domestic Product.On the other hand, it is recognised as being responsible for heavy metal soil and crop contamination. Mining induced heavy metal soil contamination is of concern because of its toxicity and accumulative power in soil and plants. These heavy metal contaminants eventually enter the food chain and endanger the health of human beings. Contamination of soils, water, air and food crops due to mining activities has been reported from other mining towns on the Copperbelt. Chililabombwe had hitherto been ignored by researchers due to the perception that heavy metal pollution was not a problem as the district did not have a smelter. This study makes an important contribution by showing that soil and food contamination can happen through other means. Therefore, this study investigated on heavy metal soil and food crop contamination in the mining district of Chililabombwe in the Copperbelt Province, Zambia.

The aim of this study was achieved by collecting 96 triplicated soil samples from the surface layer (0 – 30 cm) and 80 samples of selected food crops (cassava, pumpkin, sweet potato leaves and white egg-plants) were collected. The levels of heavy metals such as copper, cobalt and iron were determined in each sample using the Atomic Absorption Spectrometer (AAS) PE 400. The study highlighted the actual levels of heavy metal contaminants in soil and food crops consumed in Chililabombwe. Simple regression analysis indicated that there is a strong significant relationship between distance and heavy metal soil concentration with $p<0.05$ at 0.95 confidence level (copper R^2 at 90 percent, cobalt 80 percent and iron 86 percent). Pearson's Product moment correlation also displayed a moderate negative correlation between distance and levels of copper in soil with r above 0.3 (copper and distance r= - 0.5340212, cobalt with distance r = - 0.453402, iron and distance r = - 0.026407). The trends of heavy metal concentrations in soil revealed that Fe>Cu>Co and in food crops Fe>Cu>Co. It is also important to note that 80 percent of samples for copper and 100 percentfor iron in soil exceeded the World Health Organisation (WHO), Food and Agriculture Organisation (FAO) and Canadian thresholds with an exception of cobalt. Additionally, the study indicated 100 percent of heavy metal contamination in food crops in comparison with the FAO thresholds.

These results indicate that the levels of heavy metals in soil and food crops are above thresholds. This entails that Chililabombwe suffers from heavy metal soil and food crop contamination. Therefore, it can be concluded that there is heavy metal contamination of soil and food crops in Chililabombwe on the Copperbelt of Zambia. The contamination of soil and food crops imply that heavy metals enter the food chain and pose potential risks to human life which leads to chronic illness and eventually death. It is therefore, recommended thatinformation from this study be used by the relevant authorities to develop appropriate measures for monitoring and control of heavy metal soil and food crop contamination in mining areas in Zambia. This study was conducted in March, 2013 towards the end of the rain season. Therefore, it is important that a comparative study on heavy metal soil and food crop contamination be conducted during thedry seasons.

Acknowledgements

This dissertation would not have been possible without the support of many people. Many thanks to my supervisor Dr. Mulenga M. C. who read my numerous revisions and helped refine the document. I valued your comments and insights. Also thanks to the Academic Staff in the Department of Geography and Environmental Studies, Mr. Musukwa G. of the Department of Agriculture and Professor NyambeI. of the School of Mines who offered guidance and support. Thanks to the University of Zambia for providing the necessary facilities. Thanks to my children Mpundu and Kapya, other family members and friends for moral and spiritual support. And finally, thanks to everyone who made positive contributions to this dissertation. I can only say no one can live a life untouched by others. May God abundantly bless you all.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAS	Atomic Absorption Spectrometer
AMD	Acid Mine Drain
ATSDOR	Agency for Toxic Substances and Disease Registry
DEFRA	Department of Environment, Food and Rural Affairs
DTPA	Department of Environmental
ECZ	Environmental Council of Zambia
EIA	Environmental Impact Assessment
ESSC	Environmental System Science Centre
EU	European Union
FAO	Food and Agriculture Organisation
FQA	Footwall Quartzite Aquifer
FWA	Footwall Aquifer
GDP	Gross Domestic Product
GRZ	Government of the Republic of Zambia
HWA	Hanging Wall Aquifer
HIV	Human Immunodeficiency Virus
AIDS	Acquired Immune Deficiency syndrome
KCM	Konkola Copper Mine
KDM	Konkola Deep Mining
KONOC	Konkola North Copper Mine
MRL	Minimal Risk Level
PMTDI	Provisional Maximum Tolerable Daily Intake
SPSS	Statistical Package for Social Science
UK	United Kingdom
USA	United States of America

UNZA	University of Zambia
UNEP	United Nations Environmental Programme
WHO	World Health Organisation
ZCCM	Zambia Consolidated Copper Mines
ZEMA	Zambia Environmental Management Agency

CHAPTER ONE

INTRODUCTION

1.1 Background

Mining has always been conceived as a paradigm of wealth in the history of humankind, while its marketing conceals its environmental consequences, such as soil and water contamination. According to Allan (1997), mining generates large amounts of wastes at various stages of metallurgical processing. Marcus (1997) also asserts that mine wastes contain various poisonous elements that lead to soil contamination. These include heavy metals such as copper, cobalt, and iron to mention but a few. Furthermore, Ripley *et al.,* (1996) add that mining is responsible for causing irreversible environmental consequences such as soil pollution which deter life. This makes mining one of the most depredatory anthropogenic activities in the world that compromises the quality of soil and food crops in agricultural areas.

In the past, mining had not been as massive as what has been witnessed in the 21^{st}century. Generally, there has been an increase in mining activities throughout the world due to the increase in mineral demand in the western and eastern countries such as America, China and India (ECZ, 2008). Such an increase has triggered a number of environmental concerns which include soil and food crop contamination. The current increase in mining activities causing soil contamination in the world does not leave out Chililabombwe as a mining district in the Copperbelt Province of Zambia. For instance, the EIA report that the re-opening and expansion of shaft two in Konkola, the sinking of Konkola Deep Mining (KDM) and Fitwaola open-pit has increased mining activities in Chililabombwe (KCM, 2001). In the year 2012, Konkola North Copper Mine (KONOCO) popularly known as Lubambe Copper Mine, sunk another shaft west of Lubengele tailings dump which entails an increase in waste production, which eventually leads to soil contamination in the study area.

It is also worth mentioning that mining activities that contaminate soil in Chililabombwe can be categorised as excavations, metallurgical processes, waste rocks, and tailing dumps. Others are leakages of effluents and acids, erosion from the waste dumps, irrigation of crops using waste water discharged from the mines, dust from the crusher and transportation of ore for processing at the concentrator.

There are a number of trace metals that contaminate soil and food crops in mining areas such ascopper, zinc, lead, cobalt, nickel, manganese, cadmium, and chromium. However, according to the Environmental Impact Assessment report of 2001, three indices are likely to contaminate soil in the study area and these are copper, cobalt and iron (KCM, 2001). Waste products such as heavy metals are critical factors in the field of soil pollution because they spread widely in soil due to their immutable nature. Therefore, this denotes that mining has the potential to pose heavy metal soil contamination, destruction to agricultural land and production of contaminated food crops unfit for human consumption. The study therefore, assessed the levels of heavy metal contamination in soil. Additionally, it also assessed the levels of heavy metals in food crops such as Pumpkin (*Cucurbita maxima*), Cassava (*Manihot esculenta*), Sweet potato leaves (*Ipomoea atata*) and golden white eggplants (*Solanum melongena*) because they are commonly grown and eaten as vegetables by all classes of people in Chililabombwe (GRZ, 2010). In this study, eggplants have been considered as fruits. Additionally, Odukoya *et al.*, (1987) asserts that pumpkin, cassava and sweet potato leaves have high transpiration rates, absorb heavy metals through their leaves and have a long period of maturing which enhances contamination from the soil. Hence, it was important that a study on heavy metal mining induced soil and food crop contamination be undertaken.

1.2 Statement of the Problem

Chililabombwe, like any other mining town in Zambia,suffers from the effects of mining induced soil and food crop contamination. Even though it has no refinery, the existing mining shafts and the increased mining activities such as; clearing of forests, excavation, metallurgical processing, depositing of waste rock in free air space, expansion of the Lubengele tailings dump, Fitwaola open pit and Konkola Deep Mining (KDM) augment heavy metal soil contamination through the production of heavy metal contaminated wastes. Contaminants induced by mining such as heavy metals include;

copper, cobalt, and iron. Additionally, other sources of heavy metal soil and food crops contamination in Chililabombwe include seepage, leakage and discharge of contaminated effluents near cultivated areas, use of seepage from tailing dumps for crop irrigation and heavy metal contaminated dust from the tailing dumps and haulage roads settle on the food crops. Although minute quantities of heavy metals are important for plant growth and other biological processes, high concentrations in soils have an adverse effect on the quality of food crops and the health of the people.

Studies on heavy metal soil, water, air, and food crop contamination in various mining districts with fully-fledged metallurgical plants in the Copperbelt Province have been undertaken in the past, while in Chililabombwe where there is no refinery, the extent to which mining induced heavy metals contaminate soil and food crops has not been studied comprehensively. Therefore, it is important that a study on the extent of mining induced heavy metal soil and food crop contamination in Chililabombwe be conducted. For instance, Kribek *et al.*, (2010) attributes heavy metal soil and food crop contamination in Mufulira, Kitwe, Chambishi and Chingola to the presence of the metallurgical plants through particulate matter and sulphur dioxide. Basing on the poorly quantified data on mining induced heavy metal soil and food crop contamination in Chililabombwe, this study assessed heavy metal soil and food crop contamination in the mining district of Chililabombwe to show that soil and food crop contamination can take place through other means. It is important that this study had to be undertaken in order to fill the gap of the missing knowledge on the levels and extent of mining induced heavy metal soil contamination and its effects on selected food crops such as Pumpkin, Cassava and Sweet potato leaves as well as golden white eggplants in Chililabombwe.

1.3 Aim

To investigate mining induced heavy metal soil and food crop contamination in the mining town of Chililabombwe.

1.4 Objectives

1. To determine levels of heavy metal soil contaminants in Chililabombwe.
2. To assess the levels of heavy metal contamination in food crops in Chililabombwe.

1.5 Hypothesis

There is a significant relationship between the extent and levels of some heavy metals like copper, cobalt and iron in soil from point source (concentrator).

1.6 Significance of the study

Mining activities produce wastes that lead to soil and food crop contamination. Therefore, an assessment of heavy metal soil and food crop contamination was necessary in order to enable the local authorities and the Department of Agriculture and Livestock determine land available for urban agriculture and the local authorities will also use the results of this study as a foundation for improved decision making in allocating land use zones.

The results of this study will enhance the efforts of the Zambia Environmental Management Agency (ZEMA) in minimizing environmental deterioration in areas affected by mining.

The findings will provide base line data for further studies on heavy metal soil and food crop contamination for researchers. Non - governmental organisations and the Public Health Department will also use these findings to promote public awareness on the health risks to the local community.

The findings from this study will also provide new data in the gap of knowledge for missing information in related studies conducted by other Researchers since the dissertation will also be availed to the University of Zambia (UNZA) and Zambia ZEMA for public interest.

1.7 Organization of Dissertation

The study is organised as follows: Chapter one is the introduction and it outlines the background to the study. Chapter two reviews the literature for this study. Chapter three describes the study area in terms of location, physical characteristics, social and economic activities. Chapter four presents research methods used in the study and chapter five presents the findings. Chapter six discusses the findings in relation to reviewed literature and chapter seven presents the conclusion and recommendations on the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews world and Zambian literature on mining induced heavy metal contamination. Mining is the extraction of valuable minerals or other geological materials from the earth, usually (but not always) from an ore body, vein, or (coal) seam (Hartman, 1984). Materials recovered by mining among others include copper, cobalt and iron.

Mining is one of the most valued anthropogenic activity worldwide, occurring only in places where the ore naturally exists. The contribution of mining to economic development is immense. Acheampong (2004) argues that the mining industry has been key to the development of civilisation, underpinning the iron and bronze ages, the industrial revolution and the infrastructure of today's information age. For example, in Peru, mining accounts for 50 percent of the country's annual export earnings, and over 11 percent of the Gross Domestic Product(GDP) (Acheampong, 2004).Awudi (2002) reports that in Ghana, the mining sector accounts for 41 percent of the country's foreign exchange.

Mining is one of the most important economic sectors in Zambia and contributes significantly to its Gross Domestic Product. It is the major foreign exchange earner and provides employment both directly and indirectly through contracts. Mining contributes positively to the nation and the social welfare of the community in Chililabombwe. Konkola Copper Mine is currently the second largest copper producing company in Zambia. KCM is the major employer in Chililabombwe providing 7 804 jobs and 9 549 jobs through contractors(ECZ, 2008). Additionally, ECZ(2008) states that Zambia's mining industry accounts for 60 percent of foreign exchange, 10 percent Gross Domestic Product and five percent employment. In Chililabombwe, Konkola Copper Mine has been highly involved in corporate social responsibility activities such as sponsoring of deserving students in Chililabombwe to higher institutions of learning, construction of classrooms and health facilities. Other Corporate social responsibility activities are; distribution of livestock to subsistence farmers, sponsoring adult learning, sinking boreholes and encouraging good sanitation in the peri-urban, sponsorship of sporting activities, provision of education and health services such as sensitisation programmes on Human Immune Virus/Acquired Immune Deficiency Syndrome (HIV/AIDS), malaria, eye and diabetes screening to the community, distribution of mosquito nets and indoor spraying of mosquitoes before the onset of rains (KCM, 2001).

However, mining is one of the industries, which produces a lot of wastes that contaminate soil (ECZ, 2008). High demand for copper on the world market for industrial development taking place in Asia (China and India) and the western world is an additional challenge on soil contamination (ECZ, 2008). Furthermore, hunger for economic development in most developing countries, like Zambia, has increased investment opportunities in the mining sector in order to improve the country's economic status (ECZ, 2008). Additionally, as more easily accessible mineral deposits get extracted, the more the hunger for new cheap sources. Hence, this has driven the industry into more intensified explorations in reserved indigenous forests (ECZ, 2008). Likewise, an increase in the production of wastes widens the sphere of soil contamination.

In Zambia, Norman *et al.*, (2007) ascribe rapid economic development backed by the mining industry to be the most significant cause of environmental problems. These include heavy metal soil and food crop contamination through excavations, deposition of waste rock in free air space and discharge of contaminated effluents.

2.2 Heavy Metal Soil Contamination

Significantly, heavy metal soil contamination emanates from various mining activities at various stages of copper, cobalt and iron production. Zambian like Finland (Plate 2.1), mining activities such as excavations in open-pit or underground mining, metallurgical processing, transportation and dumping sites such as tailings dumps, waste dumps make soil vulnerable to heavy metal contamination Heavy metal contamination renders soil unproductive by decreasing its quality and upsetting its natural balance (Ripley *et al.*, 1996). Other sources of soil contamination in mining areas include seepage from waste rock, leakages of gasses and effluents, discharge of effluents into the natural water and emissions of gases into the atmosphere(Kribek, *et al.*,2010). Details on the sources of heavy metal soil contamination are given in the sections below.

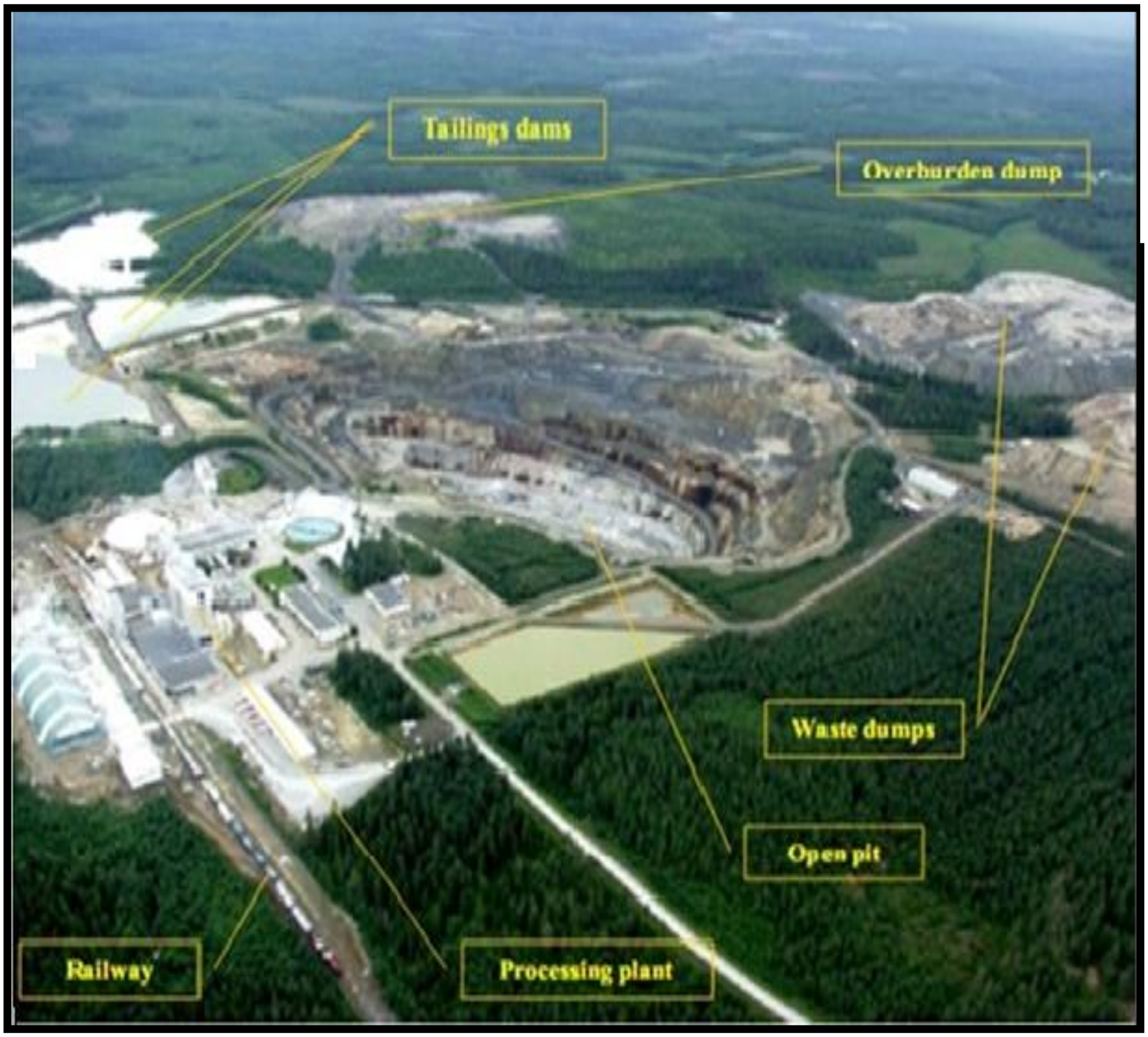


Plate 2.1: Lahraslampi Open – Pit – Finland

Source: Mineo, (2000)

2.2.1 Excavation

Excavation is one of the mining activities that contaminate soil (Oelofse, 2008).According to Marcfalen (2009) this stage produces a lot of dust particles, hydro-sulphides, nitrates, methane and silica which eventually settle on the ground and contaminate soil. This deprives soil of its nutrients for agricultural purposes. For instance, in Kitwe, Chingola, Mufulira, Chililabombwe and other mining towns, large tracts of land have had their top soils removed and others covered with waste rock and debris from mining activities (Kribek *et al.*, 2010).

Heavy metal soil contamination also destroys ecosystems, making it difficult for wildlife to adapt itself to the new environment *(*Middleton, 2003). For instance, according to UNEP (2006) the rich diversity of wildlife which brought fame for Africa has been altered by heavy metal soil contamination. It either dies or migrates to marginal lands where it succumbs to predators or starves and dies *(*Middleton, 2003). In this study area, KCM (2001) reveals that frogs and other aquatic creatures that inhabited Lubengele stream in Chililabombwe have disappeared due to heavy metal soil contamination from mining activities at shaft three, and the leakages of discharge of mine effluents from the Lubengele tailings dam to the north east and the old Kakoso tailings dump to the south. Furthermore, Kelly (1998) argues that on a broader scale, mining may affect biodiversity by changing species composition and structure due to heavy metal soil contamination and only plant species that withstand heavy metal contaminated soils thrive as observed in mining areas.

Studies conducted by UNEP (2000) reveal that dust released to the environment contains harmful particles which contaminate soil. For instance, dust produced during clearing of the forests, crushing, transportation of mining materials and ore to the processing plants, and windblown dust from the tailings in Chililabombwe, whose characteristics are unknown, also destroys vegetation and alters the characteristics of soil around the mining area (UNEP, 2000).Unlike Chililabombwe, the western side of Kabwe mine has poor vegetation due to heavy metal contaminated dust produced from mining activities. Additionally the western side of the copper mine in Mufulira, sulphur dioxide and heavy metal contamination make vegetation and food crops difficult to survive (Kribek, *et al.*,2010).

2.2.2 Waste Rock

Waste rock also contributes to heavy metal soil contamination. According to ECZ (2008) mining generates large quantities of waste rock with different characteristics emanating from different compound metals that co-exist with copper. Waste rock from the mines have unknown characteristics which present challenges to soil deriving from its contents such as heavy metals and harmful acid-forming sulphides. The world over, mining areas have mountains of accumulated waste rock resulting from extraction of minerals as in Paupa New Guinea. For instance, UNEP (2000) states that Western Europe generates 4700 metric tons of waste rock, Australia produces 1750 metric tons per year, USA 2000 metric tons, South Africa over 1100 metric tons, China 34840 metric tons. ECZ (2008) also highlights that in Chililabombwe, more than 1840 metric tons of waste rock is generated per year covering an area of 33.5 hectares of land (Plate 2.2).

Plate 2.2: Mine Waste Rock Pile at Shaft 3, Konkola Mine, Chililabombwe.
Source: Field Data (2013)

Waste rock, usually stored above the ground in large free- draining piles, contain acid-generated sulphides, heavy metals and other contaminants that have the potential to pollute soil and retard plant growth (Ripley *et al.,* 1996). Additionally, ESSC (2003) contends that, there is massive soil contamination from waste rock in areas surrounding mining activities because of the potential damaging compounds that co-exist with the ore.Ripley*et al.*,(1996) further states that, acids leach from the waste rock liberating other heavy metals such as copper, cobalt, cadmium, lead, arsenic and mercury. These metals and acids find their way into soil, creating a serious effect on the micro-organisms that barrow and improve soil nutrients (Ripley *et al.*, 1996).

The acid-generated sulphides and heavy metals contaminate soil through run off from waste rock and leach into the soil (Smith, 1979). In the absence of adequate control strategies, run-off carries loose contaminated soil and sediments from waste rock which increases heavy metal soil contamination. Smith,(1979) further contends that these substantial amounts of contaminated soil and sediments discharged into nearby areas, streams and rivers cause a change in the soil and inhibit plant growth in wetlands. Furthermore, Smith (1979) adds that deposition of these contaminated soil sediments also destroy the beauty and the breeding areas for organisms that decompose materials and improve soil fertility for plant growth.

2.2.3 Metallurgical processes

Metallurgical processes are considered to be the most significant mining activity that contaminates soil. Hence, the mining industry is often blamed for some of the biggest soil pollution disasters of heavy metals and chemicals (Alkorta *et al*., 2004). During processing, toxic chemicals such as mercury, cyanide and sulphuric acid are added to the slurry to separate the target minerals from the wastes (Hartman, 1984). These highly toxic chemicals together with other effluents are discharged through steel pipes into the Lubengele tailing dumps where they are stored in free air open spaces. These contaminants overflow, percolate through the soil and contaminate food crops in nearby agricultural areas. For example, effluents from metallurgical processes also contaminate ponds and streams, causing toxicity to water, irrigated agricultural soil and crops in the flood plains. These effluents do not only affect water and aquatic life but also soil in the flood plains and wetlands for arable agriculture (Oelofse, 2008). For example, Oelofse, (2008) asserts that in 1995 more than four billion litres of wastewater that contained cyanide and sulphuric acid contaminated the Essequibo River when the tailings dam collapsed in Guyana. Other than destroying life and soil, the flood plains were heavily poisoned, and lost their value for agriculture.

ZCCM (1995) contends that mining induced heavy metals in sediments and soils along the Kafue River were above the thresholds set by the FAO with copper at 5000mg/kg and cobalt at 60mg/kg on average. Besides polluting water in the Kafue River, animals that graze in the Kafue flats had accumulations of heavy metals in the livers and kidneys resulting from contaminated water and grass in the flood plains. ZCCM, (1995) further argues that investigations on heavy metal contamination along the Kafue River indicated that soil in the Kafue flats was also contaminated and unfit for food production. This is because heavy metals have a serious effect in the food chain and human health especially those whose local diet includes food crops grown along the Kafue Flats.

2.2.4 Spillages and Leakages

Spillages and leakages of chemicals transported to the mining sites for use is also another possible way of soil contamination. Some of these pollutants get into the soil when pipes containing toxic chemicals leak or chemicals spill during transportation. For example, Kribek *et al.,* (2006) asserts that in 2005 leakages of chemicals from the acid plant in Mufulira polluted the Mushishima stream and soil along the banks. This incidence resulted into deaths of animals that drunk the water and fed on the grass along the bank.

Despite measures taken by mining companies to release the chemical wastes into tailing dumps, large amounts of chemicals leak to the ground (KCM, 2001). This changes the chemical composition of soil and makes it unsuitable for plant growth. Organisms that live in the soil also find polluted environments hostile for their survival. According to Davis *et al.,* (2003) when sulphuric acid (often used to separate copper from other metals) leaks and spills into the environment, it has wide spread effects of poisoning that destroy all forms of life. For instance, ZCCM (1995) confirms that in Mufulira, leakages and spills of sulphuric acid caused wide spread deaths of aquatic, terrestrial plants and animal lives. This also resulted into the poisoning and contamination of arable land and the main source of drinking water for thousands of people.

2.2.5 Tailings Dump

Tailing dumps contain heavy metals and toxic effluents discharged from metallurgical processes that contaminate soil. Toxic effluents are usually impounded in tailings dump and cover large tracts of land. However, when pressure in the tailings dump build up more especially when heavy rain falls, water in the dumps has to be decanted or risk dam burst or collapse. In either case, it contaminates the adjacent agricultural land. For instance, the Mankayan mine tailings dam in the Philippines collapsed in 1992 and 1994 and polluted the Verdant rice paddies. Fruit trees and animals died and rice crops were stunted (Raipon, 2007). Furthermore, UNEP (2000) reported that on the 10thMarch2000 a tailing dam in Borsa Romania weakened and failed to hold after a heavy rain. The heavy metals and chemicals from the tailings spread over hundreds of meters causing soil contamination. In South Africa, at the Wonder Fontein Spruit and the Loop Spruit mine, then tailing dump collapsed and the contaminated tailings spread on the farmland and contaminated agricultural soil after a heavy storm (UNEP, 2000).

Technical problems in the tailings dam can also cause soil contamination. For instance, in Sweden, UNEP (2000) reported that on the 24th of July 2000,the tailings dam failed due to a filter failure and the tailings contaminated agricultural land. On the other hand, water is also a mode of heavy metals soil contamination in the tailing dumps. Toxic chemicals in the tailings percolate into the ground through normal natural processes such as osmosis and this contaminates soil (Miller, 2001). Oelofse (2008) also contends that toxic wastes from these processes leach the ground. Hence, tailings dumps are also points of heavy metal soil contamination to the surrounding areas.

In Zambia, on the 25th of September, 1970 the tailings dam in Mufulira collapsed through a sink hole which opened on the surface allowing surface water to pour into the underground mine and 89 people died (ZCCM, 1971**).**KCM (2001) reveals that the tailing dumps in Chililabombwe contain heavy metals and other toxic substances that contaminate soil. Miller (2001) argues that dry tailings are usually blown-off by wind and settle on the soils around the tailings depending on the direction of the wind. For instance, if the North-East Trade winds blow over a tailing dump the contaminated tailing dust will settle on the South-Western direction of tailing dump. For instance, KCM (2001) states that in Chililabombwe the North-East Trade wind blows over the Lubengele tailings dump and the tailings settle on soil on the western side of the dam contaminating food crops in the gardens. ESSC (2003) also reported that in Cyprus dust containing heavy metals from tailing dumps, usually blown off side by wind, contaminates soil in agricultural lands on the western side of the mine.

2.2.6 Air Pollution

During metallurgical processes, toxic particulate matter and gases released into the atmosphere pollute the air. MINEO (2000) states that primary air pollutants at mining sites such as particulate matter resulting from heavy metal processing are of concern because it is composed of noxious materials such as arsenic, sulphur dioxide, cadmium, and lead. These noxious materials settle on the ground and contaminate soil.

A number of mining operations emit particulate matter commonly known as fugitive dust. MINEO (2000) stresses that fugitive dust originating from ore crushing, loading of ore and other mine materials, blasting, vehicle travels on haulage roads, dry tailing dumps and mine wastes contains heavy metals. Other sources of fugitive dust are spoil piles and access roads. KCM(2001) contends that fugitive dust contains various heavy metals and toxins that contaminate soil. In Zambia, Kribek *et al*., (2002) reported that 99 percent of soil samples collected in Kitwe, Mufulira and Chambishi mining districts exceeded the Canadian thresholds for copper contamination emanating from fugitive dust.

Mining activities also attract transport for the movement of mining materials. Indirectly, mining pollutes soil through emissions of carbon monoxide by automobiles. Outsole (1993) argues that heavy metals such as copper, lead and zinc from additives used in gasoline and lubricating oils deposited in the highways contain heavy metals and contaminate soils on the sides of the road.

According to Davis and Tilton (2003), Brazil, China and the United States are the worst affected countries of the world in soil contamination through air pollution. These toxic particles in the air eventually settle on the ground and pollute the soil. Warthrust (1994) also confirms that the Copper Hill Smelters in Tennessee destroyed 7000 hectares of land such that no vegetation or fish populations survived up to 70 kilometres away from the smelting plants due to air and soil pollution. Additionally, Steinborn *et al.*, (1999) states that the Department of Ecology in Washington reported that air borne smelter pollutants contaminated 1000 square mile of land in Tacoma and destroyed valuable soils for growing food crops. Furthermore, in Zambia, Kribek *et al.,* (2006) argues that on the western sides of Mufulira, Kitwe, Kabwe and Chingola mining areas, air pollution has destroyed large hectares of land.

In mining areas, it is also important to note that, although high concentrations of copper originate from within and near the mining activities, the parent rock material properties also contribute to high concentrations of heavy metals in the soil. For example, Terelark *et al.,* (1994) note that although Czestochowa and Beala provinces in Poland have high concentrations of copper in soils, these provinces are not exposed to any emissions or discharge from the mines. Just as in Poland, ECZ (2001) confirms that soil in the Copperbelt of Zambia contain high levels of copper because of the characteristics of the parent rock.

Heavy metals also contaminate soil through a natural release to the environment. Terelark *et al.,* (1994) contend that heavy metals like copper, cobalt, iron and others are deposited on the soil by natural sources such as wind-blown dust and decaying vegetation. Therefore, heavy metals spread widely in the environment because they are also released through natural processes.

2.2.7 Acid Mine Drain

Acid mine drain also contaminates soil. Minerals occur in compounds (Hartman, 1987). For instance, copper occurs with cobalt, zinc, iron, manganese, lead, sulphate and gold. Acid Mine Drain (AMD) is potentially a severe soil pollutant. The formation of acid mine drain is a function of geology, hydrology, and mining technology employed at a mine site.

Holdings (2008) argue that mining activities expose the once buried metals and sulphides to water and atmospheric oxygen producing strong sulphuric acid that contaminates soil. The primary sources for acid generation are sulphide minerals, such as pyrite (iron sulphide)from waste rock or tailings. These sulphide minerals decompose in air and water. The water that infiltrates pyrite-laden rock acidifies in the presence of air often at a pH level of two or three rendering soil unsuitable for food crops. This is because increased acidity in soil destroys living organisms and plants rendering land unsuitable for food production. Holdings, (2008) states that heavy metals also immobilize and react with other minerals such as phosphates and carbonates to produce toxic materials, which contaminate soil. In the Copperbelt Province of Zambia, Acid Mine Drain is a rare feature except for a two hectares large former stockpile in Chibuluma west of Kitwe. Drainage from this area holds a pH of 2-3with high contents of copper and cobalt (Lindah, 2014).

Heavy metal soil pollution also causes serious economic and social consequences associated with reduction in agricultural produce, which results into poverty, diseases and deaths (De Echave and Torres, 2005).For instance, MINEO (2000) reported that, cattle and sheep are more sensitive to copper in their diet. For example, during the 1980's about 20 percent of the sheep and 80 percent of Hereford cattle died after eating grass contaminated with copper at the farms between eight and 30 kilometres away from the smelter. Additionally, soil fertility in these farms declined from 90 percent to 42 percent (MINEO, 2000). Mishira *et al.,* (2008), states that villages in India found that agricultural productivity decreased due to heavy metal contamination from mining activities.

2.3 Effects of Heavy Metal Contamination in soil and Food crops

Heavy metal soil contamination resulting from mining activities is one of the most serious environmental challenges in the world today (Jinadasa *et al.,* 1997). Although, heavy metals are essential for the functioning of biological systems, higher concentrations can be detrimental because they block essential functioning groups, displace other ions or modify active conformations of biological molecules in soil (Alkorta, 2004). According to UNEP(2000) heavy metals are a threat to agriculture and other food sources for humans. Furthermore, Eddy (2004) asserts that heavy metal contaminated soil retard plant growth and reduce food production threatening food security.

Heavy metals in the food chain are a health hazard to consumers (Odoh and Adebayo, 2011) because they contribute to increased toxic build up in people's bodies. Heavy metals such as copper and cobalt do not decompose but bio-accumulate in soil and food crops, which include; fruit trees, maize (*Zeal Mays ssp.mays*), cassava (*Manihot exculanta*), soyabeans (*Glycinemax*),sweet potatoes (*Ipomoea batatas*), groundnuts (*Arachishy pogaema*), sugar cane (*Saccharum officinarum*), sorghum (*Sorghum bicolor*), beans (*phaseolus vulgaris*), and varieties of vegetables (Marcus, 1997).

Mining induced heavy metals accumulate and adhere to crops through contaminated soil, aerial particulate matter, ground and surface water. Odukoya *et al.,* (1987) indicated that food crops that grow on heavy metal contaminated soil have greater chances of accumulating heavy metals. Some food crops have a greater potential to accumulate higher concentrations of heavy metals than others. For instance, Odukoya *et al.*,(1987) state that food crops such as spinach (*Tetragonia expansa*), cauliflower (*Brassica oleraceavar botrytis*), cabbage (*Brassica oleraceavar. acephala*), amaranthus(Amaranthus hypochondriacus), cassava (*Manihot exculanta*),chinese cabbage (*Brassica rapasubsp .pekinensis*) andrape (*Brassicnapus*) to mention a few, are high bio-accumulators of heavy metals because they absorb these metals through their broad leaves. Heavy metals also accumulate in soil and crops hence, get into the food chain and cause chronic illness and eventually death. Studies conducted by Lindahl, (2014) on the Copperbelt concluded that vegetables and fruits grown on heavy metal contaminated areas become toxic when consumed by humans.

However, some food crops such as cassava, eggplants and sweet potatoes take long to mature making them more vulnerable to heavy metal contamination. For instance, Kribek *et al.,* (2010) also add that variability in nutrient concentrations in crops also depend on the age of the crop. Lindahl (2014) argues that cassava leaves and sweet potato leaves in the Copperbelt Province have elevated levels of copper and cobalt hence, crops such as maize, which indicated lowest levels of heavy metals, is grown on heavy metal contaminated soil. Kribek *et al.*,(2002) in their report also revealed that cassava is hyper-cumulative to heavy metals and attributed it to long periods of growth and maturing. Hence, crops like cassava, eggplants, sweet potatoes and pumpkins which take more than six months are vulnerable to heavy metal accumulations and toxicity.

Heavy metal contamination in food crops can also be caused by irrigation of crops with heavy metal contaminated water discharged into the streams.

For instance, Odoh *et al.*,(2011) assert that heavy metal contaminated water from the Benue River is used for irrigation of food crops in Makurdi, which is a dominant source of vegetables in Nigeria. Wu *et al.,* (2010) also revealed that food crop irrigation water from a stream near a Manganese mine was heavily polluted by the discharge of untreated mining wastewater in the Hunan Province of China, posing a threat to agricultural crops. In their study, Wu *et al.,* (2010) indicated that heavy metal concentrations in stream water, sediments, soils and vegetables along the stream exceeded FAO thresholds by more than 50 percent. In addition, heavy metals in contaminated water used for irrigation were copper 72.7 mg/kg and cobalt 34.8 mg/kg, which were significantly higher than the FAO thresholds.

The concentrations of copper, nickel, manganese and chromium in the soil irrigated by the stream water were 6.2mg/kg, 9.7mg/kg, 40.9mg/kg and 17.0mg/kg respectively and they were three times higher than the local background values. Furthermore, Wu *et al.*, (2010) add that the edible parts of vegetables growing on the soils with stream water irrigation contained higher concentrations of heavy metals than those in the soils irrigated by unpolluted water in Hunan Province. Heavy metal contents in the food crops exceeded FAO recommended values. This suggests that heavy metal contaminated stream water contaminated soil and food crops posing severe health risks to the local people.

In Zambia, the results of the study conducted by Kribek *et al.,* (2002) on the extent of industrial pollution of the stream sediments, soils and agricultural products from the local community on the Copperbelt showed that 99 percent of soils exceeded the Canadian thresholds (used in default because currently Zambia does not have thresholds)for copper in agricultural land. Kribek *et al*., (2002) further assert that sampled food crops in the same area showed that in areas near the smelter and the tailing dump, yams had the highest metal uptake of 376 mg/kg copper and19.70mg/kg cobalt while cassava had 263.83 mg/kg copper and 13.79 mg/kg cobalt. KCM (2001) also reports that the concentration of heavy metals in soil exceed the WHO thresholds in Chililabombwe.

Heavy metal concentration ranges of copper, cobalt and iron were 36–24 960 mg/kg, 7–2 057 mg/kg and < 1–1 038 mg/kg respectively. Such contaminated soils are a hazard to the health of humans.

In reference to the literature reviewed in this study, mining contaminates the environment. The effects of various mining activities (Figure.2.3) are very remarkable on soil and food crops. Consequently, they alter the soil composition and structure making land for farming unproductive. This scenario increases agricultural production costs compromising food security and, disturbs the social and economic status of the people.

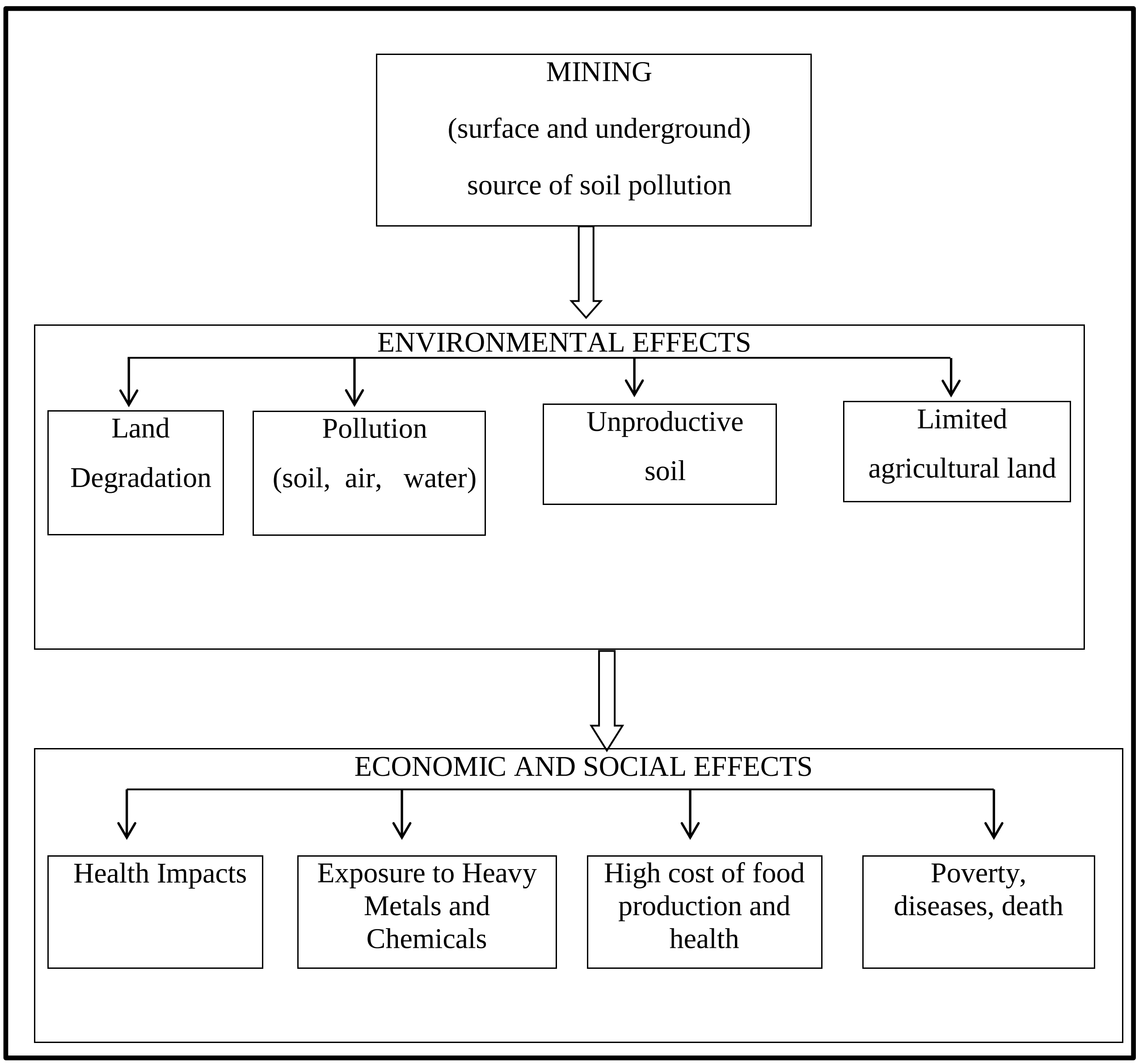


Figure 2.1: Effects of Mining Induced Soil Contamination
Source: De Echave and Torres, (2005)

2.4 Implications of Heavy Metal Food Crop Contamination on Human Life

As human activities such as mining increase, pollution and contamination of the human food chain become inevitable. The effects of mining on soil are increasingly worrying throughout the world because of its implications on the quality of food and human health. (Eddy and Ndibuke, 2004). Odukoya and Ajayi, 1987) assert that heavy metals accumulate in both edible and non-edible parts of vegetables. Hence, food safety issues and potential human health risks make such topics to be more important in environmental studies (Odukoya and Ajayi, 1987).

Trace metals such as cadmium, lead, gold and others in food crops are deadly to humans and animals (Alkota *et al.*, 2004). Odoh *et al.*, (2011) also affirm that metals that act as biological poisons are deadly even in parts per billion (ppb) levels. However, Odoh *et al.*, (2011) add that heavy metals such as zinc, manganese, nickel, and copper that act as micro- nutrients in the food chain become hazardous at higher concentrations.

Vegetables constitute a significant part of the local diet hence ingestion thereof may be an important pathway for human exposure to elevated concentrations of harmful and toxic metals. Furthermore, ZCCM (2005) states that, on the Copperbelt Province, vegetables are often grown near or on the tailings dam as well as on the downwind side of the metallurgical plant. Such food crops are of concern if consumed by either animals or humans.

However, the health risks will depend on the chemical composition of the mine waste materials, its physical characteristics, the vegetables cultivated and the consumption rate. Odukoya *et al.*, (1987) also suggested that bio-toxic effects of heavy metals depend upon the concentrations and oxidation states of heavy metals, and modes of deposition such as acid rain, or wind depositing the toxics on the leaves of vegetables. Either way heavy metal contamination in food crops is hazardous to human health.

Implications related to heavy metal contamination in food crops is of great concern to human health. According to Gupta and Gupta (1998) heavy metals can pose a significant health risk to humans, particularly in elevated concentrations. For instance, prolonged consumption of unsafe concentrations of heavy metals through foodstuffs, may lead to the chronic accumulation of heavy metals in the kidney and liver of humans causing disruption of numerous biochemical processes that make people vulnerable to incurable diseases such as cardiovascular, gastrointestinal cancer, nervousness, kidney and bone diseases and eventually death (WHO, 1992).

Kachenko and Singh (2006) also add that, dietary exposure to heavy metals like, cadmium, lead, zinc and copper through consumption of vegetables is a risk to human health. For instance, consumption of heavy metal contaminated food deplete some essential nutrients in the body, causing a decrease in immunological defences, intrauterine growth retardation, impaired psychosocial behaviour, disabilities associated with malnutrition and a high prevalence of upper gastrointestinal cancer (Arora *et al*., 2008). Therefore, mining deserves special attention in sustaining the environment and the health of the people.

There is an opinion among the consumers that, green and big leaves are characteristics of good quality leafy vegetables. Recent reports in literature indicate that heavy metals take driver's seat among the chief contaminants of leafy vegetables (Wilberforce and Nwabue, 2013). Heavy metals are non-biodegradable and thermo-stable and thus readily accumulate to high toxic levels even in such green and health looking vegetables (Sharma *et al.,* 2007).

In developing countries like Zambia, vegetables constitute an important part of the human diet. However, it is argued that, diets of the majority of the people in developing countries comprise of vegetables not because of the benefits, but are affordable compared to other foodstuffs. Furthermore, people are aware that vegetables contain certain nutritionally important compounds necessary for human survival and often called protective food due to their functions of preventing diseases in humans. Furthermore, vegetables contain carbohydrates, proteins, minerals, and fibres required for human health(Wilberforce and Nwabue, 2013). They also act as neutralising agents for acidic substances formed during digestion. The commonly available food crops in developing countries like Zambia are; maize, cassava, soya beans, sweet potatoes, groundnuts, sorghum, beans, pumpkins, eggplants and varieties of vegetables. They are only vulnerable to heavy metal contamination if they grow in contaminated soil.

It is also important to note that heavy metal soil contamination causes serious economic and social consequences associated with agricultural produce (De Echave and Torres, 2005). This situation results into poverty, diseases and deaths. For instance, Marcus (1997) reported that the geological and economic survey undertaken in Western Virginia revealed that people who live near the mines have higher risk of kidney diseases, chronic obstructive memory diseases and high blood pressure. Additionally, these chronic illnesses have claimed a number of lives in the same area. When people’s health deteriorates, their ability to work and earn money is reduced and eventually leads to death with the old and the young being particularly more vulnerable.

Literature indicates that the irreversible confounding environmental, health costs and damages caused by mining activities far outweigh their economic and social benefits (Kachenko and Singh, 2006; Gupta and Gupta; 1998, De Echave and Torres, 2005; Marcus, 1997). The delirious effects of mining on the soil can make the earth uninhabitable if not checked. Hence, sustainable development is the key to environmental problems experienced on planet earth. Therefore, it is a moral duty to protect the environment amidst the hunger for extraction of more minerals that contaminate soil.

Additionally, in as much as it is important to acknowledge the benefits of mining, it is equally important that its challenges to soil, food crops and life be addressed. Environmental hazards and risks such as heavy metal soil contamination should be minimized by constant monitoring and use of more sustainable methods of metal extraction. For instance, because soil is the substance of all life, its contamination culminates into a number of effects in the ecosystem, which includes the health of humans. Soil pollution also leads to limited land for food production and compromises food security within the municipality. In view of this, it is important to promote sustainable development by being sensitive to the conservation of natural resources such as soil.

CHAPTER THREE

DESCRIPTION OF THE STUDY AREA

3.1 Introduction

This chapter describes the study area which includes location and size, physical characteristics such as relief, drainage, climate, vegetation, and geology. Social characteristics comprise population and livelihoods and the economic characteristics include mining, farming and trade.

3.2 Location and Size

Chililabombwe is located in the northern part of the Copperbelt. It extends from latitudes 12° 25´S to 12° 29´S and longitudes 27°47´E to 27°53´E (Fig 3.1). It is 129km northwest of Ndola, the Copperbelt Provincial capital. In the North, Chililabombwe shares the border with the Democratic Republic of Congo, to the south is Chingola district, Mufulira district in the East and Solwezi district to the West. Chililabombwe covers an area of 102700 hectares with 13 966 hectares under KCM surface rights (GRZ, 2005).

3.3 Physical Characteristics

The physical characteristics of Chililabombwe include relief, Drainage, climate, soil, vegetation, geology and mineralisation.

3.3.1 Relief and Drainage

Chililabombwe lies on the Zambia and the Zambezi–Congo watershed at an average altitude of 1372 meters above sea level. The topography is gently undulating between elevations of 1250 m to1400m, with low hills along the border with the Democratic Republic of Congo. The highest peak is Kamenza Hill at a height of 1, 405 me above sea level and the land slopes gently to the south at 1 220 m towards the Kafue River and 1 340 m down the Milyashi Stream (Figure 3.1). The gentle sloping land makes it easy for run-off from the mines to drain into the Kafue River and to spread soil contaminants to a wider area (GRZ, 2005).

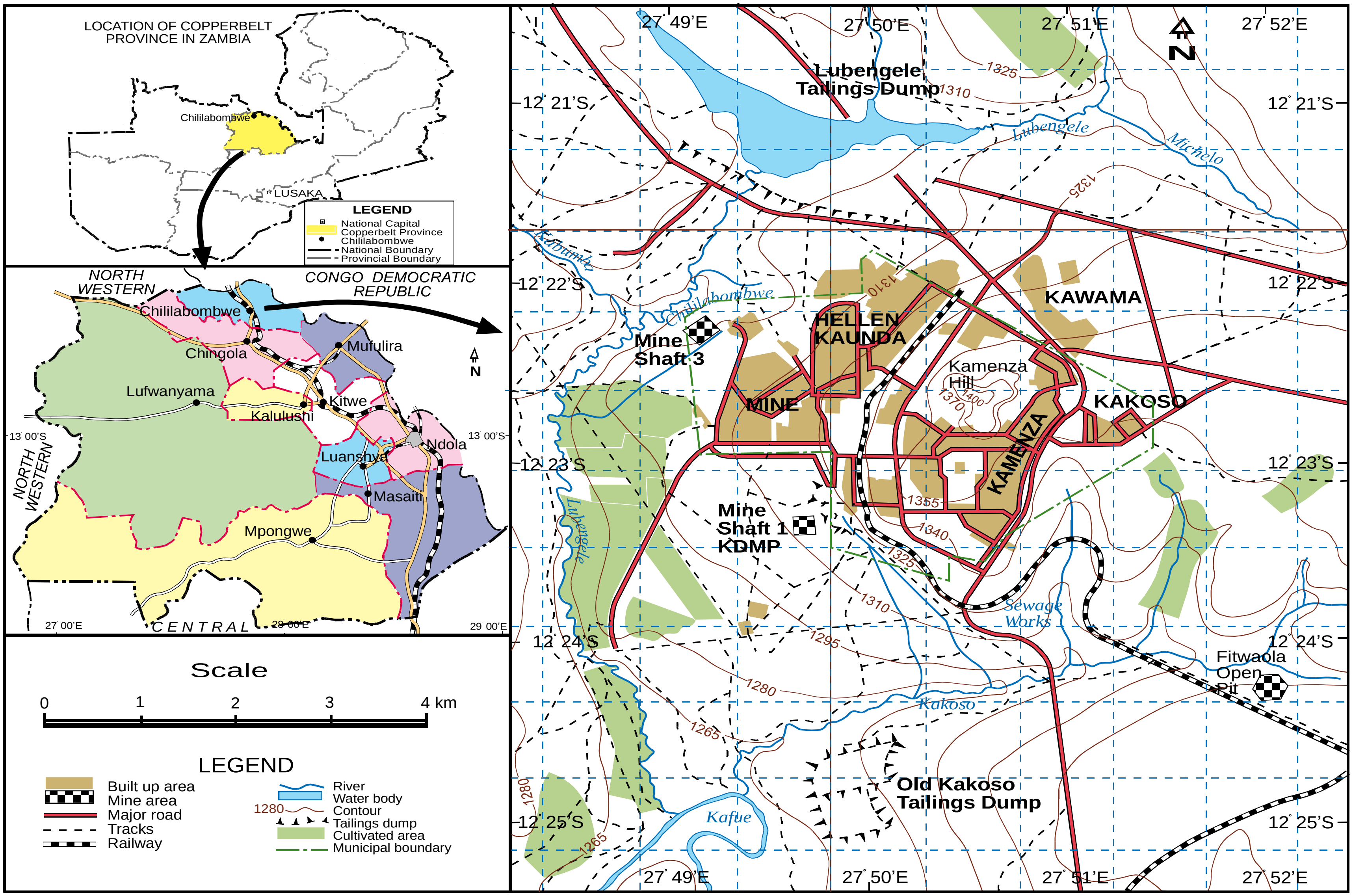


Figure 3.1: Location of Chililabombwe

Source: GRZ, Map Sheet 1227 B4 (2012)

There are several water courses that surround the mine-licensed area. These include the Kafue River which is the major river that drains Chililabombwe District and is also the boundary between Chingola and Chililabombwe districts (GRZ, 2005). The others are the tributaries of the Kafue River such as Ming'omba, Kasapa, Michelo, Miyanda, Kabumba, Lubengele, Milyashi, Kakoso, and Kamenza streams. Most of these streams dry up during the dry season except for the Ming'omba stream which is dammed by the Lubengele tailings storage facility and the Kakoso stream because it is the recipient of underground water which is discharged into the Kafue River (KCM, 2001).

There are also several wetlands or *dambos* in the South, East, West and North that exist in the mining licensed areas, some of which are used for the growing of maize, vegetables and other food crops consumed by local people (KCM 2001. Shallow wells are used during the dry season by communities living and farming in the *dambos*, along the banks of the river and streams for both domestic and irrigation of vegetables (GRZ, 2005). In the urban area, water from underground and the Kafue River is purified for domestic use and irrigation of vegetables in the backyard gardens (KCM 2001). The Lubengele tailings storage dam is at the confluence of the Ming'omba and Lubengele streams and the water is used for watering food crops such as sugarcane and vegetables on the western side of the tailings dump (KCM 2001).

According to ZCCM (1995) these streams are perennial because of their being found in the high rainfall belt area. KCM (2001) asserts that the drainage pattern of the Kafue River and its tributaries form a dendritic pattern characterised by irregular branching off due to the uniform resistance of the geology (Figure 3.1). However, there is some structural control over the Kafue River and Kakoso Stream evidenced by the drainage flow through Kakoso Fault.

According to Peterson (2001) the discharges from the local streams are highly varied with a difference between rain and dry season. During the rainy season, the discharge is higher than the dry season due to heavy rainfall experienced in the study area. The drainage pattern of the Kafue River is so well developed that the run-off from KCM containing heavy metals and other toxics substances such as oil, sulphur and other chemicals flow freely (Peterson, 2001). Furthermore, the abundant water discharged from underground is also drained into the Kafue River through the Kakoso stream.

3.3.2 Underground Water

According to KCM, (2001), underground water systems that affect mining come from three main aquifers found in the Lower and Upper Roan. KCM, (2001) states that the water systems that surround the ore body at Konkola mine and cause the high groundwater flows into the mine include:

i. The Footwall Quartzite Aquifer (FQA) occurring just above the basement rocks at about150 m thick where most mine development takes place.
ii. Footwall Aquifer (FWA) where the Footwall Sand stone is the most permeable at 50 m thick and directly underlies the ore body.
iii. The Hanging Wall Aquifer (HWA) which directly overlies the ore body, comprising of the Hanging Wall Quartzite, the Shale-with-grit and the Upper Roan Dolomite with about 700 m thick.

KCM (2005) adds that these porous aquifers make Konkola Copper Mine to be one of the wettest mines in the world and this has been a threat to mining. This is because the excavations have reached the major aquifer which is not cemented hence the bad wet conditions that occur at shaft one. However, according to KCM (2005) the mines have been dewatering at a rate of between 237 000m^3/day to 340 000 m^3/day. This water is not as clean as per say, it contain toxics and heavy metals from underground and contaminates soil. Some of the underground water is channelled to the water works for domestic and industrial use and the rest into the Kafue River (KCM (2005).

3.4 Climate

Chililabombwe, like any other district in the Copperbelt Province, experiences a tropical savannah type of climate comprising three principal seasons namely; a rainy season from November to April, a dry-cool season from May to July accompanied by a cool breeze with no rain and a hot dry season from August to October (KCM, 2001).GRZ (2005) states that, the factors that influence climate in Chililabombwe include; latitude, altitude, North- East Trade Winds and the Congo moist air.

3.4.1 Temperature

According to the Zambia Meteorological Department (2012) at Kafironda weather report the mean temperatures experienced in the study area in 2012 were 20.3ºC with an annual temperature range of 10ºC. This signifies that temperatures in Chililabombwe are moderate. The mean monthly variations in temperature are as shown in Figure 3.2. The highest temperatures experienced were in October and November of 25.30^{o}C and 24.4^{o}C respectively. Figure 3.2 also shows that the pattern of temperatures experienced in Chililabombwe for the period 2006 to 2012 is constant. The lowest temperatures from 2006 to 2012 were in the months of June and July while the hottest were from October to December. However, from January to April temperatures were also high. According to Once *et al.*, (2016), heavy metal toxicity in soil increase parallel with rising temperatures. Hence, high temperatures in the Copperbelt contribute to heavy metal soil contamination.

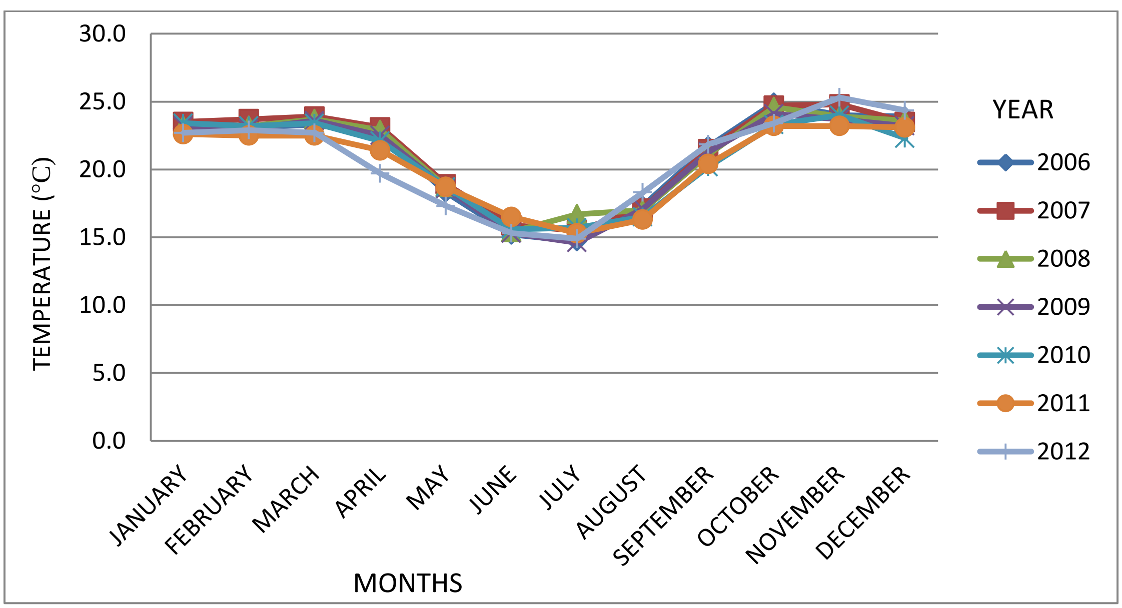


Figure 3.2: Annual Average Temperature of Chililabombwe from 2005- 2012
Source: Zambia Meteorological Department (2012)

3.4.2 Rainfall

Chililabombwe lies in the high rainfall belt of Zambia. The rain season is accompanied by lightning and frequent thunderstorms at the beginning of the wet season due to high temperatures (ZRZ, 2005).The district experienced a total average annual rainfall of 1567.3 mm in 2012 (Figure 3.3) mainly coming from the north-west trade winds and Congo air masses. These heavy rains are a mode of heavy metal soil distribution and causes leaching of toxics from the mines in the soil and some deposited into rivers such as the Kafue River by run-offs, resulting into the sludge contaminated with heavy metals on the Kafue flats (ZCCM, 2005). Additionally, heavy metals like copper enter the air mainly through combustion for a long period of time and ends up mainly in soil during the rainy season. The rain season varies from year to year and according to the meteorological report of 2012-2013, the rain days were 190 as shown in Figure 3.3.

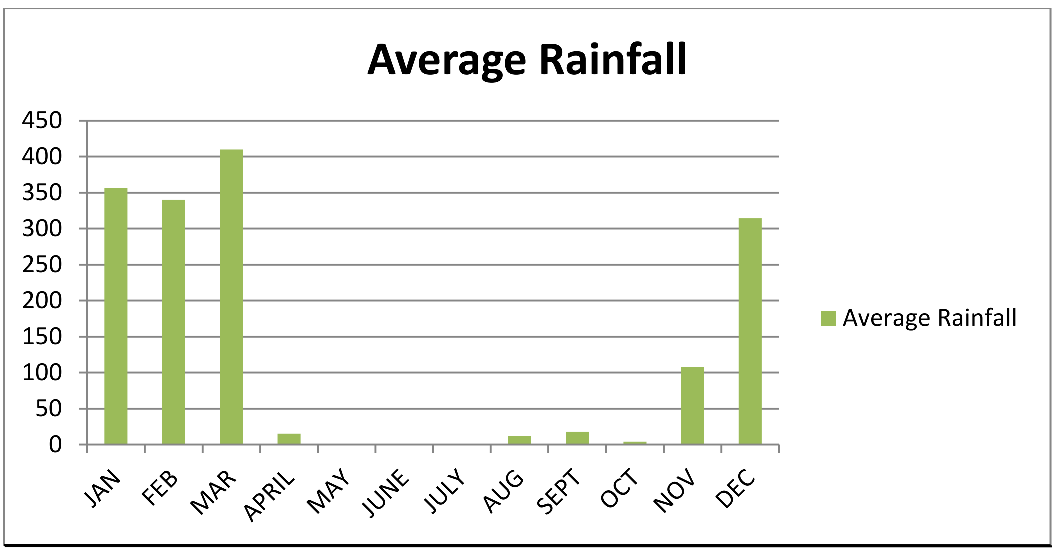


Figure 3.3: The Monthly Average Rainfall of Chililabombwe for 2012
Source: Zambia Meteorological Department; Weather Forecasting for 2012

3.4.3 Wind

The wind that blows in Chililabombwe is usually dominated by the North-East, South-East and the South-West Trade wind. In the year 2012, the strongest velocity of wind recorded was in the months of May, June, July, August and September at 14.7, 16.83, 12.63, 17.13 and 13.92 knots respectively (Zambia Meteorological Department, 2013). These are the months when dust from the haulage roads, crusher and the tailings dump is blown off to the surrounding areas by wind affecting backyard gardens in the mine township and gardens near Lubengele tailings dam (KCM, 2001).

3.5 Soils

The major types of soils are Ultisols, Entisols, Hostisols and Oxisols. Konkola mining site is dominated by the Oxisols, (50 percent) of which are found on the crests and upper slopes, Ultisols (41 percent) on the middle and upper slopes. Hostisols (eight percent) are found in water saturated lowlands and river valleys. Entisols are mineral soils with no generic zone taking one percent of the soils in the study area (ZCCM, 1989). Most of the soils in Chililabombwe are deeply weathered Lateritic soils. Top- soils are generally sand with heavy textured sub-soils (KCM, 2001).

The Oxisols are strongly leached, strongly acidic, red to reddish, clayey and slightly silt soils with clay to fine loamy topsoil (Mendelssohn, 1961). Oxisols are derived from local bedrock with a low retention capacity and are characterized by the *Miombo* vegetation. The Ultisols are strongly leached, strongly acidic, reddish to brownish, clay to loamy soils with coarse to fine loam top soils (Mendelssohn, 1961).These soils derived from the bedrock are also characterised by the *Miombo* vegetation. The other soils include the Entisols and the Hostisols. They may have medium to fine textures and are usually limited by soil depth and clay content (Mendelsohn, 1961).

The Hostisols or tissue soils are the recent alluvium, flood plain soils developed in a water saturated environment. These soils are very poorly drained, deep, yellowish, and grey to greyish yellow brown stratified soils (KCM, 2001).According to Kribek *et al*.,(2010) soils on the Copperbelt are freely drained and are in the Ferral soil group which are usually acidic, poor in carbon and nitrogen and displays low cation exchange capacity. The soils in the study area originate from the parent rock which is mineralised with copper, cobalt and iron.

3.6 Vegetation

The natural vegetation in Chililabombwe is characterised by open forest or woodlands with tall trees and tall grass whose growth is influenced by high temperatures and heavy rainfall experienced in the district. Forests in the study area have been largely affected by anthropogenic activities such as mining, small-scale farming and charcoal production (GRZ, 2005). Mining affects vegetation through cutting of trees for props and clearing of areas where mining activities would take place. The indigenous vegetation around the tailings dump reduces wind speed that blows off the dry tailings that contaminate soil in the study area (KCM, 2001). GRZ, (2005) also states that, the district has an area of 102 600 hectares of forests and 24 535 hectares of woodland.

3.6.1 Forest Reserves

Chililabombwe has nine forest reserves occupying an area of 48 767 hectares. Forests include national reserves such as Kirila, Kamenza, Nsato, Dome, Border, Konkola, Kafwila and Hippo Pool (GRZ, 2005).

Forests are important because they reserve land for future development in form of industries, which includes mining, farming and permanent buildings. However, some of these reserved indigenous forests have been de-gazetted for farmland and mining activities which include the Fitwaola open pit in the Kamenza forest widening the sphere of soil contamination (GRZ, 2005). They also provide commercial tree species such as; *Pericopsis angolensis, Faurasaligna, Ethypheeoma forcanum, Brachystegia longifolia, Brachystegia microphylla, Julbernadia globiflora, Albezia adiafifolia, Marquesia aacroura, Afzelia quaauzesis, Strychnos cocculoides,* and *Albezia viscolor.*, (Storrs, 1997)

3.7 Geology

The Zambian Copperbelt ore deposit forms a belt of about 50 km wide, extends 150 km from Chililabombwe in the North West, to Luanshya in the South- East. The Konkola Copper Mine complex is located at the northern end of the Copperbelt, bordering the Democratic Republic of Congo. The major geological structural feature of the study area (Figure 3.4) is the Kafue Anticline, the core of which consists of the granites, schist and gneisses of the Basement Complex (ZCCM, 1995). These features are overlain by the deformed meta-sedimentary rocks of the Katanga Super group, wrapped around the flanks of the Kafue Anticline. The Mine Series consists of the Lower Roan, Upper Roan and Mwashia Groups. The main ore bodies occur within the Ore Shale of the Lower Roan (KCM, (2001).

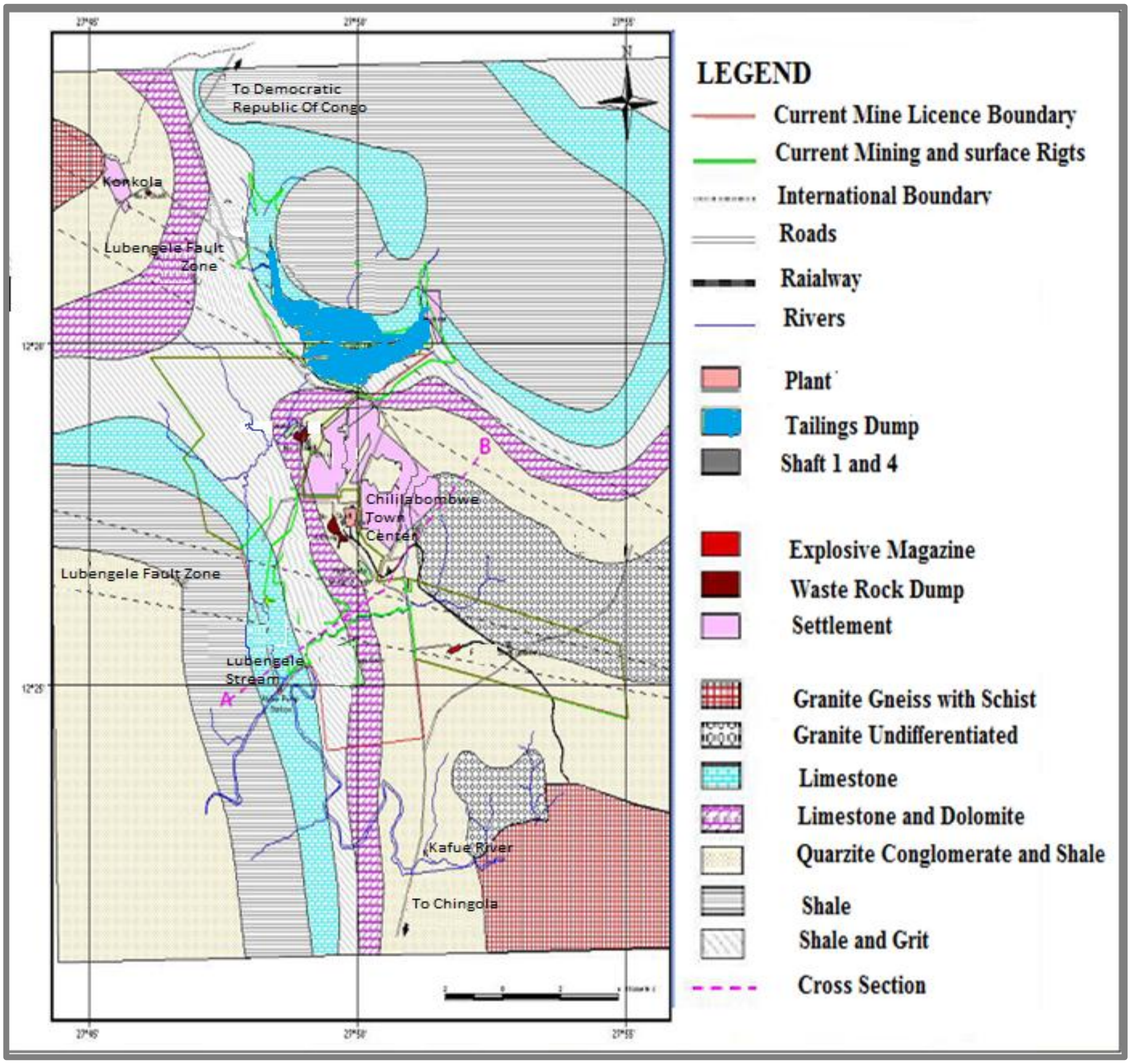


Figure 3.4: Geological Map of Chililabombwe
Source: KCM (2001)

According to Binda (1994) the basement complexes and the Lower Roan Group occur on a higher ground. The Shales and the Dolomite lay in the Upper Roan, Mwanshia and Kundelungu series. Mandelson (1961) states that this region was subjected to numerous periods of deformation which led to a compressive stress acting from North-west and South-west which resulted into folding of the rock structure. The Roan Group comprises the Lower Roan, Upper Roan and Mwashia subgroups with economically important copper and cobalt deposits. The Upper Roan Subgroup comprises mostly dolomites and argillites with quartzite intercalations. The Mwashia Group contains mostly carbonaceous shale's and the Kundelungu series comprise limestone, shale and sandstone. The carbonaceous shales and limestone act as a buffer against acidification from the effluents in the Lubengele tailings dump. In the lowest formation is the boulder conglomerate overlain by pebbles, which has been leached and weathered. The basalt footwall overlain by argillaceous sandstone forms the aquifer, which is porous causing bad wet conditions underground at number one shaft KCM (2001).

ZCCM (1995) asserts that the Shale formation consists of a series of inter-bedded silt stones, fine sand stone and dolomite sand stone which contain impure dolomitic silt stone, grey stone, silt-stone inter-bedded with dolomite sandstone, less regular dolomite and arkose. The underlain rock which is the parent rock relates to the rich minerals such as copper, cobalt and gold, which contaminate the environment in Chililabombwe.

3.8 Mineralisation

The ore body in Chililabombwe is one of the largest in the world with ore reserves and resources exceeding 300 Metric tonnes (Mt) ranging from 4 m to 17 m thick with dips from 10° to 70° (ZCCM, 1995). The existing drilled reserves and resources contain in excess of over 13 000 000Mt of copper and 232,000 Mt of cobalt. The deposit has an in situ grade of 3.8 percent copper and 0.067 percent cobalt. The main ore minerals present are chalcocite, bornite, chalcopyrite, malachite and carrolite (KCM, 2001). The principal metals present in the ore body are copper, cobalt and iron, which exist mostly as sulphides (ZCCM, 1995). The geologic setting (Figure 3.4) occurs in sedimentary host rocks with high carbonate content, and a correspondingly high acid neutralising capacity (KCM, 2001). The craving for extraction of high grade copper contributes to heavy metal soil contamination in the study area.

3.9 Copper Processing Methods

Mining in Chililabombwe is underground except for the Fitwaola Open Pit. The excavated ore from number one, two and four shafts is transported to the concentrator at number one (1) shaft where it is crushed into smaller pieces and ground into fine powder in the ball mills. The slurry that is the product of the ball mill passes through the floatation process where the collector is added to separate wastes from the mineral particles. The coke and limestone is added to the copper concentrate at 45 to 47percent to further remove the slag and the molten copper called matte raising it to 60 percent. Other metals such as iron sulphides are blown off in the converter where blister copper is produced at 99.5 percent pure (ZCCM, 1995). The slag or waste is discharged into the tailings dump or back into the shaft for back filling through iron pipes. This processing method up to this stage occurs in Chililabombwe (Figure 3.6). Heavy metal soil contamination at this stage is through dust fall outs from the trucks carrying the ore to the concentrator and during crushing of the ore into fine powder in the ball mills.

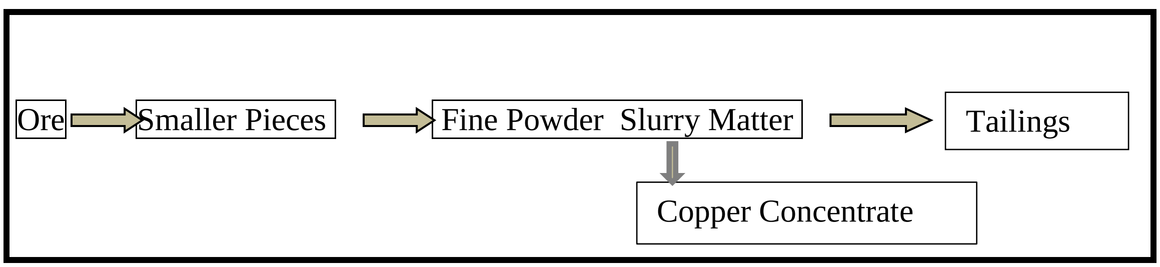


Figure 3.6: Stages of Copper Processing in Chililabombwe
Source: Ntalasha et al., (2004), Page73.

The existing concentrator (commissioned in 1957) consists of the following stages: crushing, milling and flotation circuit (Figure 3.7) with a production capacity of 2.1 Metric tonnes per annum of ore to produce a high-grade copper sulphide Mining concentrate. A new modern concentrator next to shaft number four commissioned in 2010 is capable of processing up to 6 Metric tonnes per annum. This is an indication that the higher the production of copper using the modern concentrator the more the production of wastes containing heavy metals. The tailings are discharged at the Lubengele tailings disposal facility (KCM, 2001).The Concentrate produced from Konkola is transported to the smelters in Kitwe and Mufulira for refining.

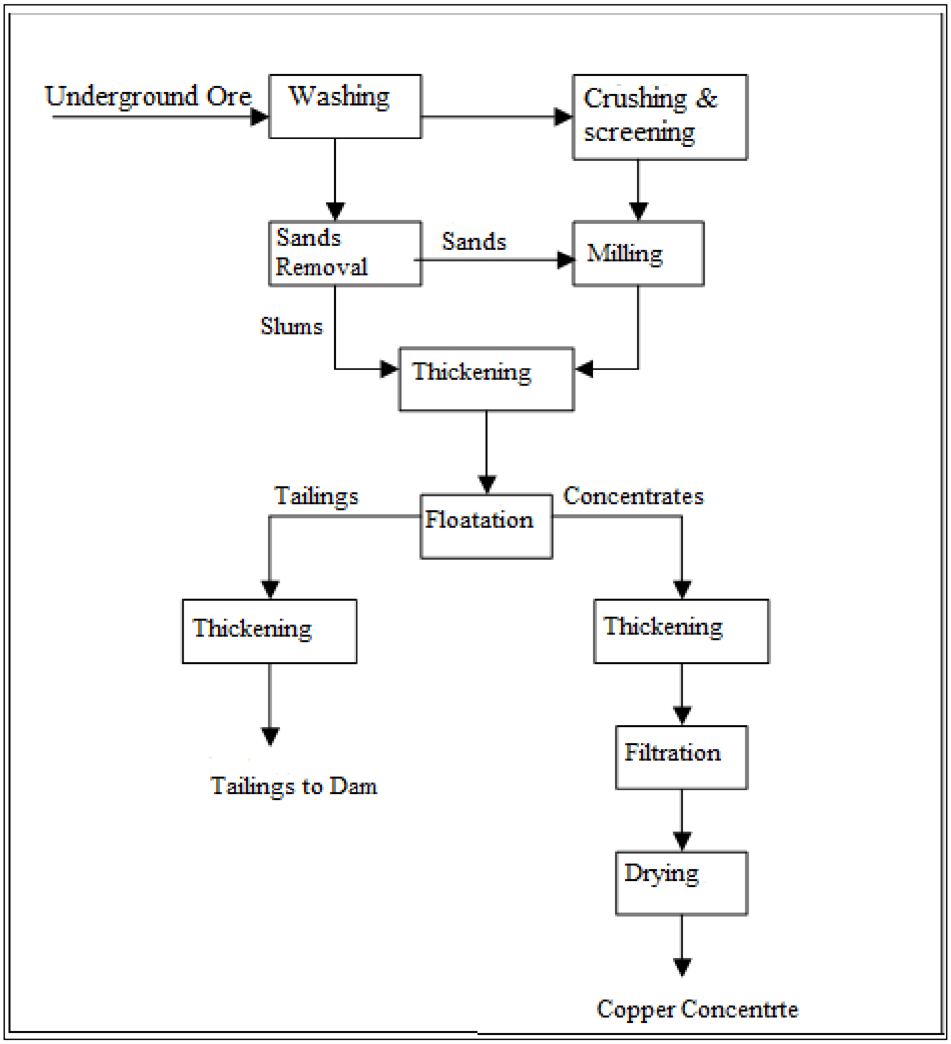


Figure 3.7: Copper Processing Floatation Circuit
Source: KCM (2005)

3.10 Social Characteristics

The socio–economic characteristics of the study area include population, livelihood and land use.

3.10.1 Population

According to the 2010 population census, Chililabombwe district has 17 326 households with a total population of 91 834 of which 45 042 are males while 46 792 are females (GRZ, 2012). GRZ (2012) further states that the total peri-urban population was at 14 015 and the urban had 77 818 people with a growth rate of 3.1. These are the numbers of people likely to be affected by mining induced heavy metal soil and vegetable contamination in the study area.

3.11 Land use

Chililabombwe district has 102 700 hectares of land divided into the following categories; Reserve Forests for future use (40.12 percent), State land (28.38 percent), Mining Industry (KCM and ZCCM land) (28.36 percent), under Municipal Council (28.38 percent) and land for cultivation (3.15 percent) (Figure 3.8). However, other than land allocated for cultivation, people still cultivate food crops even on KCM land and reserved forests due to the fast growing population.

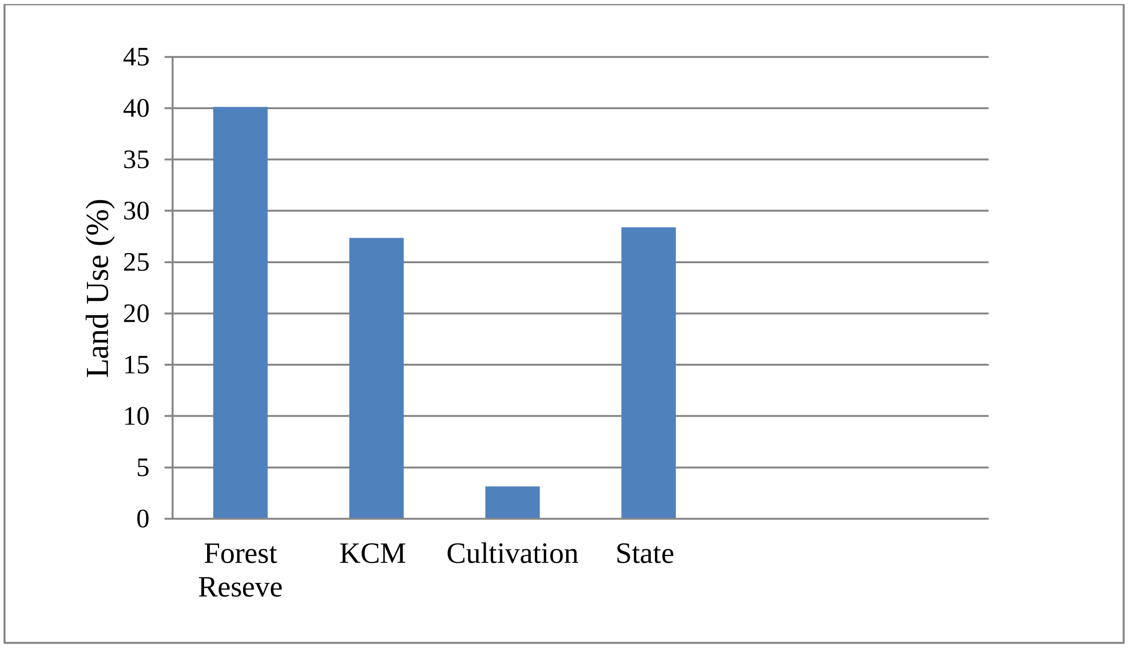


Figure 3.8 Land Use Categories in Chililabombwe

Source: GRZ, (2005)

3.11.1 State land

This area under the state land include; gardens, parks, residential areas, administrative offices for government, companies and service providers, schools, the post office and hospitals (GRZ, 2005).

3.12 Economic Activities

Chililabombwe has a number of economic activities which have drawn a number of people from all parts of Zambia and neighbouring countries. These include mining, both wholesale and retail trading, cross border–trading and farming.

3.12.1 Livelihood

A large portion of the population in Chililabombwe depends on mining and small scale farming for their livelihood. Farming is one of the main-stay of livelihood among the residents and the poor community in the study area. According to the key informants, the average size of the total area under farming by each household was half a hector. The residents in the study area also practise small-scale agriculture and grow vegetables in their backyard gardens. Some of the crops including vegetables are also grown under irrigation with water from heavy metal contaminated streams. The typical crops grown in the study area include maize, beans, groundnuts, sweet potatoes, pumpkins, golden white eggplants, among others. All crops produced by the households are for both consumption and for sale at the local markets.

3.12.2 Farming

The agriculture sector involves people from all walks of life including miners, retirees, government employees and traders. These economic activities improve the economic status of the study area and supply food staffs and other needs to the community. Farming is an important economic activity in Chililabombwe with 5 086 people involved in it whose majority are retirees (GRZ, 2005). According to GRZ, (2005), the major types of farming in Chililabombwe district are; commercial farming on 1500 hectares of land located at Kanenga, Mingomba, Chimfunshi and Lubansa. Small-scale farming in the study area is practised on 4 450 hectares of land in different areas such as Kamenza, Kafue, Lubengele, Chimfunshi, Fitwaola, Kebumba, Mwananshiku, Lubansa, Kanenga and Mingomba (GRZ, 2005).

According to GRZ (2005) the major food crops that face the challenge of induced mining soil contamination are; Fruit trees, Maize, Cassava, Soya Beans, Sweet potatoes, groundnuts, sugar cane, sorghum, beans and varieties of vegetables. Livestock include cattle, goats, chickens, pigs and sheep. Some of these farming activities take place in heavy metal soil contaminated areas such as gardening near Lubengele and Kakoso tailing dumps, along the haulage road from shaft one to shaft three and the townships surrounding the mining activities.

3.12.3 Mining

Chililabombwe district is one of the major mining districts on the Copperbelt occupying 34, 498 hectares of land with 9, 050 employees and 10, 950 employed by contractors (GRZ, 2001). Copper is the key mineral which attracted mining in Chililabombwe(KCM, 2001). Copper exists as a compound mineral with cobalt, iron and zinc among others. Although soil on the Copperbelt province, naturally has heavy metals mining activities such as explorations, metallurgical processes, transportation of materials and the tailing dumps being conducted in the study area increase the risk of soil and food crop contamination (Kribek *et al.*, 2005). The mining industry has also attracted a number of investors and has drawn a large number of people who seek employment from all provinces of Zambia (GRZ, 2005).

Mining is the major source of heavy metals contamination in the study area Kribek *et al*., 2002). Mining activities that contaminate soil in this study area include; Lubengele tailings dump, old Kakoso tailings dump, Fitwaola open–pit, shafts one, three and four. These mining activities produce waste materials that contain heavy metals which contaminate soil and food crops (KCM, 2001). These contaminants are a risk to the health of the people in Chililabombwe. Therefore, it prompted the study.

CHAPTER FOUR

RESEARCH METHODS

4.1 Introduction

This chapter presents the methods used in the collection of both primary and secondary data. Furthermore, it outlines the sampling procedures, validation of sampling procedures, analytical procedures for elements in soil and selected vegetables. Finally, it also outlined the limitations of the study.

4.2 PrimaryData

The main sources of primary data were fieldwork, which involved observation on effects of heavy metal contamination on crops and interviews of key informants. Data sheets were prepared for both quantitative and qualitative primary data(Appendices7 and 8).Quantitative techniques analysed concentrations of heavy metals in soil and food crops while qualitative techniques involved observation. Fieldwork involved random collection of 96 replicated soil samples, 17mature pumpkin leaves, 17 sweet potato leaves, 17 cassava leaves and 17 golden white egg-plants from selected sampling points. Both soil and food crops were tested and statistically analysed for heavy metal contamination using the Perkin Elmer AAnalyst 400 Atomic Absorption Spectrometer. Additionally, the relationship between heavy metal soil and food crop contamination was statistically determined using laboratory results which generated new information on patterns and concentration of heavy metals in soil and food crops in the study area.

4.3 SecondaryData

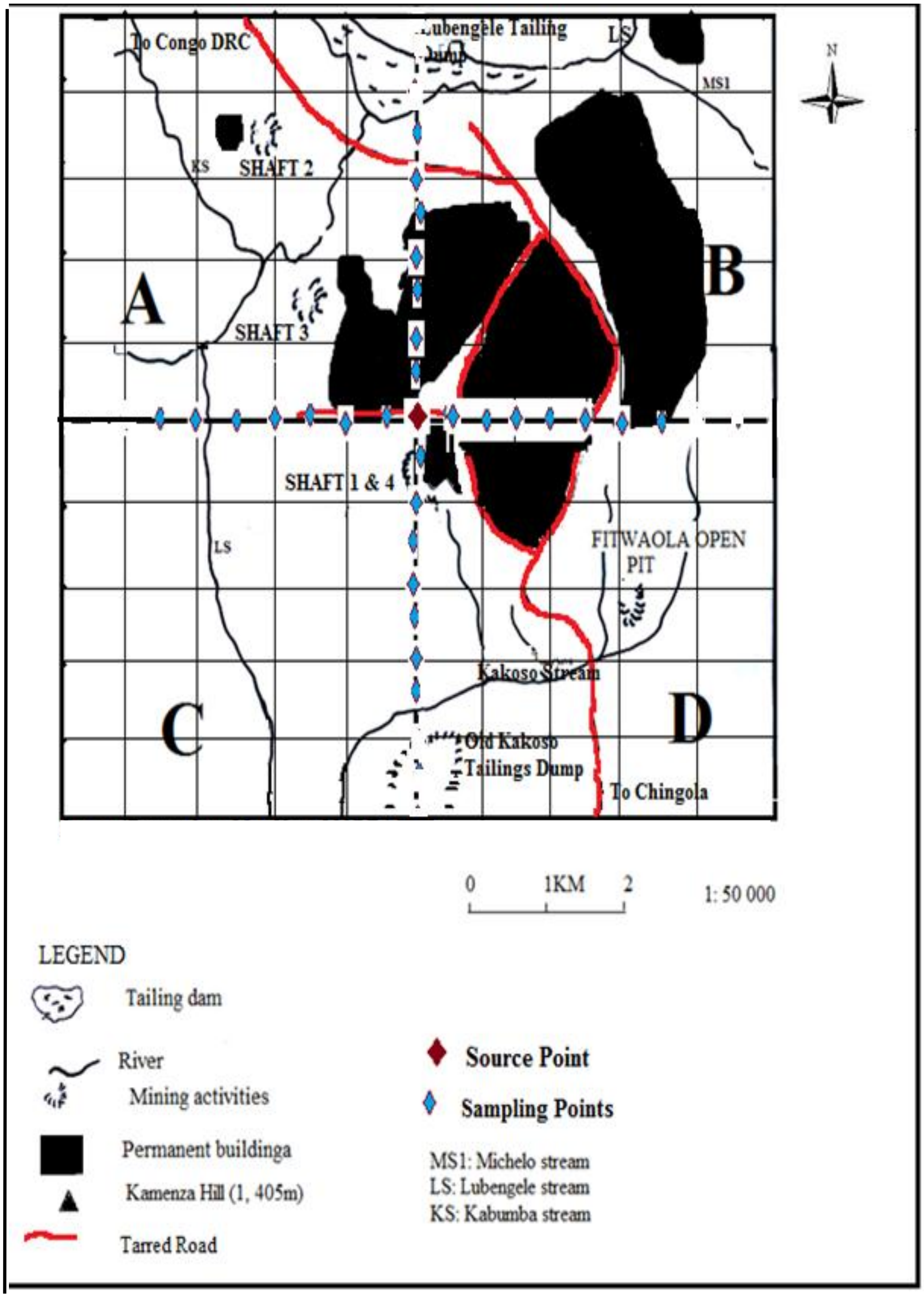
Secondary sources of data involved a review of the existing literature on heavy metal soil pollution, its effects on food crops and the health of human beings from various archival sources. This provided an insight on the past status of mining induced heavy metal soil contamination and its effects on food crops in the study area. Additionally, findings of this study were compared with the literature reviewed in order to assess the degree of heavy metal soil and food crop contamination. The Zambia Meteorological Department provided the 2012weatherdata for the study area.

4.4 Sampling Site

An area of 100 km² was selected for sampling because the distance between each mining activity was less than 5km. The area was sub-divided into quadrants A,B, C and D of 25km² using longitude 27° 50´ E and latitude 12° 23´ S (Figure 4.1) because there were mining activities in each quadrant which could have contributed to heavy metal soil and food crop contamination. Each quadrant had 24 sampling points along longitude 27° 50´ E and latitude 12° 23´ S. The quadrant technique was used in this study because of the uniformity and even distribution of units in a study area. All individuals in each quadrant were counted fairly giving a good representation of the entire study area. The study was conducted in a multi-contaminated area (Kribek et al., 2010). The point source was at shaft one where the metallurgical processing plant is located. The other mining activities such as shafts two and three, Fitwaola open-pit and tailings dumps were regarded as other factors that would have contributed to heavy metal soil and food crop contamination in either of the quadrants.

4.5 Soil Sampling Procedure

Soil samples were collected towards the end of the rainy season between March 2013 and April 2013. Sampling points were at a distance of 500 metres apart along the intersecting transects longitude 27° 50´E and latitude 12° 23´S. In this study, a systematic sampling technique was used for determining sampling points because there is an assurance that the population would be evenly sampled since sampling has to be at uniform levels (Kothari, 2004). Sub-samples were randomly collected at a radius of 100 meters from each sampling point to allow homogeneity of elements in each area (Gupta and Varshney, 1989). Soil samples were collected in a concentric model of a radius of 500m between the circles. Soil was collected from each sampling point at a plough depth of 0 - 30 cm where the rooting system of plants develop, using a stainless steel Ekman Grab Sampler (Gupta and Varshney, 1989).



j-ip.Figure 4 .1: Soil Sampling Points in the Study Area
Source: Extract from Map Sheet 1227 B 4 (2013)

Approximately, three samples of 500 g of soil were collected within a 100 meter radius from each of the 32 sampling points (Figure 4.2). Okalebo *et al.,* (2013) recommends the use of replicate sets of samples to determine the final composite sample because cultivated soils are less homogeneous than virgin soils. Hence, 96replicated soil samples above Kothari’s (2004) recommended minimum of 30 samples were collected.

These sub-soil samples were used for determining the statistical significance of the results of the final composite sample. These results were also used for analysing the extent of heavy metal soil contamination from point source. The 96 soil samples were stored in labelled polythene bags and taken for analysis to the Department of Soil Science Laboratory at the School of Agricultural Sciences at University of Zambia in Lusaka.

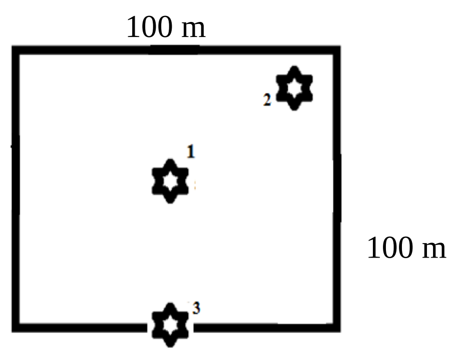


Figure 4.2: Sketch of Composite Sampling points
Source: Field Data (2013)

4.6 Procedures for Soil Analysis

Soil samples were air-dried at 25˚ C for 2 days in order to obtain a constant weight. The dry soil samples were mechanically ground using an electrical mill to make it homogeneous (Wilberforce *et al*., 2013). Samples passed through a standard steel sieve mesh to obtain <2 mm fraction and separated stones and roots from the soils required for analysis of elements. The stones and roots that remained in the sieve were disposed off. Sample bulk reduction was carried out. A final representative sample of approximately 125 grams was obtained by conning and quartering each sample (Wilberforce *et al*., 2013). The soil samples were pulverised in 2 minutes. The index number of the samples, elements under investigations and date were labelled on the containers.

4.6.1 Total Copper, Cobalt and Iron Analysis in Soil

In this experiment, 1g of each soil sample was weighed and digested in 30 mls Aqua Regia (mixture of 3 part concentrated HCL to 1 Part Concentrated Nitric Acid) (Demirezen, and Ahmet, 2000). The mixture was heated for 30 minutes and 50 mls of distilled water were added to the mixture. The residue was filtered through a Whatman no. 42 filter paper for the analysis of heavy metal concentrations of copper, cobalt and iron (Demirezen, and Ahmet., 2000). The ions of copper, cobalt and iron were analysed in the filtrate using the Perkin Elmer A Analyst 400 Atomic Absorption Spectrometer (AAS) manufactured by Perkinelmer Wallac 5100 model 2001.

The spectrometer was calibrated for each of the heavy metals using certified standards from the Natural Institute of Standards and Technology (Kapungwe, 2013). For copper the blank extracts and the standard series were aspirated in the air-acetylene flame of the AAS and the absorbance measured at wavelength of 324.7 nm. Iron was analysed using a specified hollow cathode lamp at a wavelength of 248.3 nm, while cobalt was analysed at a wavelength of 479.5 nm as in Table 4.1 Samples that read higher than the highest standard, a dilution was done to bring to the right volume (Kachenko and Singh, 2006). A blank sample was read whose volume was used to correct the readings of the sample. The machine was re-calibrated after taking readings for 20 samples for each element. The mean values of the readings were recorded and the formula that was used for calculating the concentrations per kg in the original sample is; **Element mg/kg = mean value reading (mg/l) x 50mls (Volume of concentrate) (**Kachenko and Singh, 2006)**.**

Table 4.1: Perkin Elmer A Analyst 400 Atomic Absorption Spectrometer parameters

Element	**Band width (nm)**	**Wavelength (nm)**	**Lamp current (mΛ)**	**Detection limit mg/kg**	**Flame Type**
Cu	0.2	324.7	1.5	0.001	Nitrous oxide-acetylene
Co	0.2	479.5	0.2	0.006	Nitrous oxide-acetylene
Fe	0.2	248.3	30	0.002	Nitrous oxide-acetylene

Source: wwwperknelmer.com

4.6.2 pH

The pH of the soil was also tested. In this analysis, 10 g of soil were weighed in a beaker and 25mls 0.01M $CaCl_2$ solution was added. The mixture was shaken for 30 minutes using a mechanical shaker after which the sample was allowed to settle for 10 minutes to allow the suspension to settle (Knesl, 2002). The pH-meter was calibrated with two buffers that bracket the expected pH of the soil (pH 4.0 and 7.0 buffers) (McKnight,1984). In every sample, the electrode junction was placed at the same distance above the surface of the soil in order to maintain uniformity in pH reading (Knesl, 2002). The pH value was analysed using a HANNA (HI 98129) pH - meter. The pH value was recorded and compared to the standard pH Scale (Table 4.2).

Table 4:2 The Standard pH Scale

ACIDIC					ALKALINE		
Strongly	Medium	Slightly	Very slightly	Very slightly	Slightly	Medium	Strongly
5.5	6.0	6.5	7.0	7.5	8.0	8.5	

Source: McKnight, (1984)

4.6.3 Available Heavy Metal Plant Intake in Soil

These are available nutrient elements or trace metals in soil for plant up take. In this experiment, 20mg of each soil sample was weighed and 40mls DTPA was added (Kribeke *et al*, 2010). The mixture was mechanically shaken for 2 hours. Samples were filtered and the Perkin Elmer A Analyst 400 Atomic Absorption Spectrometer in the filtrate determined the ions of copper, cobalt and iron. The formula used in calculating the copper, cobalt and iron concentrations was; **Element mg/kg =mean value (mg/l) x 40 mls.**

4.6.4 Validity of Soil Samples and analysis

The most important prerequisite in sampling was that, samples were both valid and representative. Okalebo *et al.*,(2013) adds that in scientific research it is important that the sample reflect the properties of the larger system of interest. This means that for a sample to be representative, it should have a composition identical to that of the medium from which it was collected. In other words, it should have the same chemical characteristics as the sampled medium at the site and time of sampling. A valid sample is one that has been randomly selected and in this study, 3 sub-samples were randomly selected at each sampling point to make a representative sample. Therefore, the sampling method was valid and representative.

Soil zone 0-30 was chosen because that is where the main rooting and development of a plant rooting system takes place for the extraction of nutrients and other important elements for plant growth (Gupta and Varshney, 1989). Therefore, it is also called an agriculture soil zone. The sampler was examined and cleaned with ambient water for possible cross–contamination after each sample collection. .

During the analysis of heavy metal concentration, specific lamps for each element and standardised blank samples were used to correct readings of samples where detection limits were higher than the standard**.** During the reading of the pH meter, the electrodes were wiped dry using filter paper in order to avoid polarization (Krishna *et al*, 2006).Distance Decay Function was applied in the soil sample analysis in order to establish the relationship between extent and heavy metal soil contamination in the study area (Descombe, 2003).

4.6.5 Heavy Metal Soil Laboratory Analysis

The laboratory results were presented in Tables and graphs. Hence, the mean values of heavy metals in soil and food crops were compared to the UK, EU, Canadian and FAO thresholds (Table 4.3) which were used in previous studies conducted in Zambia (Kapungwe, 2013).

Table 4.3: Guidelines for Heavy Metals in Soil

Heavy Metals	Soil Thresholds (Mg/kg dry weight)
Cu	130 [b] -140 [a]
Co	240 [c]
Fe	400 [c] – 1000 [a]

Source: [a] FAO soil guidelines (Ayers and Westcot, 1985); [b] UK Soil guidelines (DEFRA-UK, 1989; 2002); [c]EU Soil Guidelines (Papapreponis et al.., 2006);Ministry of Environment Ontario Canada, (2011), [d]Marshall et al. (2004)

4.6.6 Quantitative Analysis

This study confirmed the distance decay function on heavy metal concentration using simple linear regression analysis. Quantitative data were analysed by Statistical Package for Social Sciences (SPSS) 16.0,2007 Microsoft excel software package to generate descriptive statistics. Pearson's product moment correlation analysis was used to describe the strength and direction of the linear relationship and correlation between distance and heavy metals using Cohen, (1988) guidelines (Table 4.4).

Table 4.4: Standards for Direction of a Linear Relationship

r = .10 to .29 or - .10 to -. 29	Small
r = .30 to .49 or -.30 to -.49	Medium
r = .50 to .59 or - .50 to -.59	above Strong

Source: Cohen, (1988)

4.6.7 Heavy Metal Soil Analysis

Simple regression analysis explores the relationship between continuous dependent variables and the independent variables or predictor (Pallant, 2005). In this context, simple regression was used to determine the relationship that exists between distance (independent variable) from point source and heavy metal concentrations (dependent variables) in soil. Therefore, simple regression analysis determined extent of heavy metal soil contamination of copper (Y_1), cobalt (Y_2), and iron (Y_3) with distance X from point source.

Regression equation:Equation 1

$$\hat{y} = b_o + b_1x + b_2x + b_3x$$

However, the simple regression equation used was and elements substituted as below:

Equation 2

$$\hat{y}_{Cu} = b_o + b_1x$$

$$\hat{y}_{Co} = b_o + b_2x$$

$$\hat{y}_{Fe} = b_o + b_3x$$

Where $\hat{y}$ is the elements; copper, cobalt, and iron, and x is distance from point source. The regression coefficient was calculated in order to find the intercept using the formulae:

Equation 3

$$b = r \times \frac{s_y}{s_x}$$

Where b is the regression coefficient, r is the correlation between x (element) and y (distance) variables, $s_x$the standard deviation from y and is th $s_y$andard deviation from x. The intercept was calculated in order to get the regression line using the formulae;

$$b_0 = \bar{Y} - b\bar{X}$$

Equation 4

Where b_0 the regression coefficient, is the $\bar{Y}$ average value of Y and is the $\bar{X}$ average value of X. The two formulae produced the regression equation which analysed the data to determine the relationship between distance and heavy metal soil concentration in the study area.

4.7 Sampling Procedure for Food Crops

Food crops of dietary importance were selected for sampling because they are the immediate health risk that can be evaluated and controlled. These include; cassava leaves, sweet potato leaves, pumpkin leaves and golden white eggplants. The selected food crops have the potential to readily accumulate toxic metals (ZCCM, 2005). For instance, according to Wilberforce and Nwabeu (2013) variability in nutrient concentrations in plant tissue is dependent on the part of the plant sampled and the age of the plant. In this study mature cassava leaves, sweet potato leaves, pumpkin leaves and eggplants were collected for testing heavy metal concentration.

To evaluate the uptake of trace metals by plants in the study area, 68 samples of mature leaves and 17 from each type (pumpkin leaves, sweet potato leaves, cassava leaves) and 17 fruit samples (eggplants) were collected. Vegetable samples were picked along transects at a distance of a kilometre apart. Each sample had10 leaves of a particular food crop and 10 fruits of eggplants were taken per sample at each sampling point within a 100 m radius. Additionally, Jinadasa *et al.,* (1997) assets that mature leafy food crops are preferable for sampling because they accumulate heavy metals at a greater capacity than other parts of the crop.

Although Kothari(2004) recommends a minimum of 30 samples, this study used a minimum sample size of 68 for food crops with at least 17 samples of each type.

Sampled food crops were picked along the transects at a distance of 1km (Figure 4.3) within a radius of 100 m because not all the four types of food crops may be found at each sampling point.

4.7.1 Sample Preparation of Food Crops

Sampled food crops were rinsed in distilled water in order to remove heavy metal contaminated dust from the surface of the leaves (Chary *et al*., 2008). Samples were cut into small pieces and dried in the oven at about 60 °C(to avoid loss of boron and the decomposition process) until they became brittle(Chary *et al*., 2008). In order to obtain homogeneous powder, the samples were finely ground into powder using a pestle and mortar (Kachenko and Singh, 2006). The sample passed through a 2mm steel mesh sieve. Between samples, the mill and the sieve were washed thoroughly to avoid cross contamination (Kachenko and Singh, 2006). The ground samples were sealed, labelled in polyethylene bags and taken for digestion.

4.7.2 Total Copper, Cobalt and Iron in Food Crops

In this study, the ground food crop sub-samples were digested by heating the dried 1.00g of each sample in clean crucibles(Miyazawa *et al*., 2009). The sub-samples were ashed in a Muffle furnace at 550℃ for 2 hours until they turned grey whitish. The crucibles with ash were cooled in desiccators and the ash was transferred quantitatively into a 100 ml conical flask and 30 ml 1 N HNO_3 was added (Odoh, and Adebayo, 2011). The suspension was digested and heated for 15 minutes to allow the dissolution of organic matter until white fumes were observed. After cooling, 50 ml of distilled water were added and the suspension was filtered using Whatman No. 42 filter paper into volumetric flask (Odoh, and Adebayo, 2011).

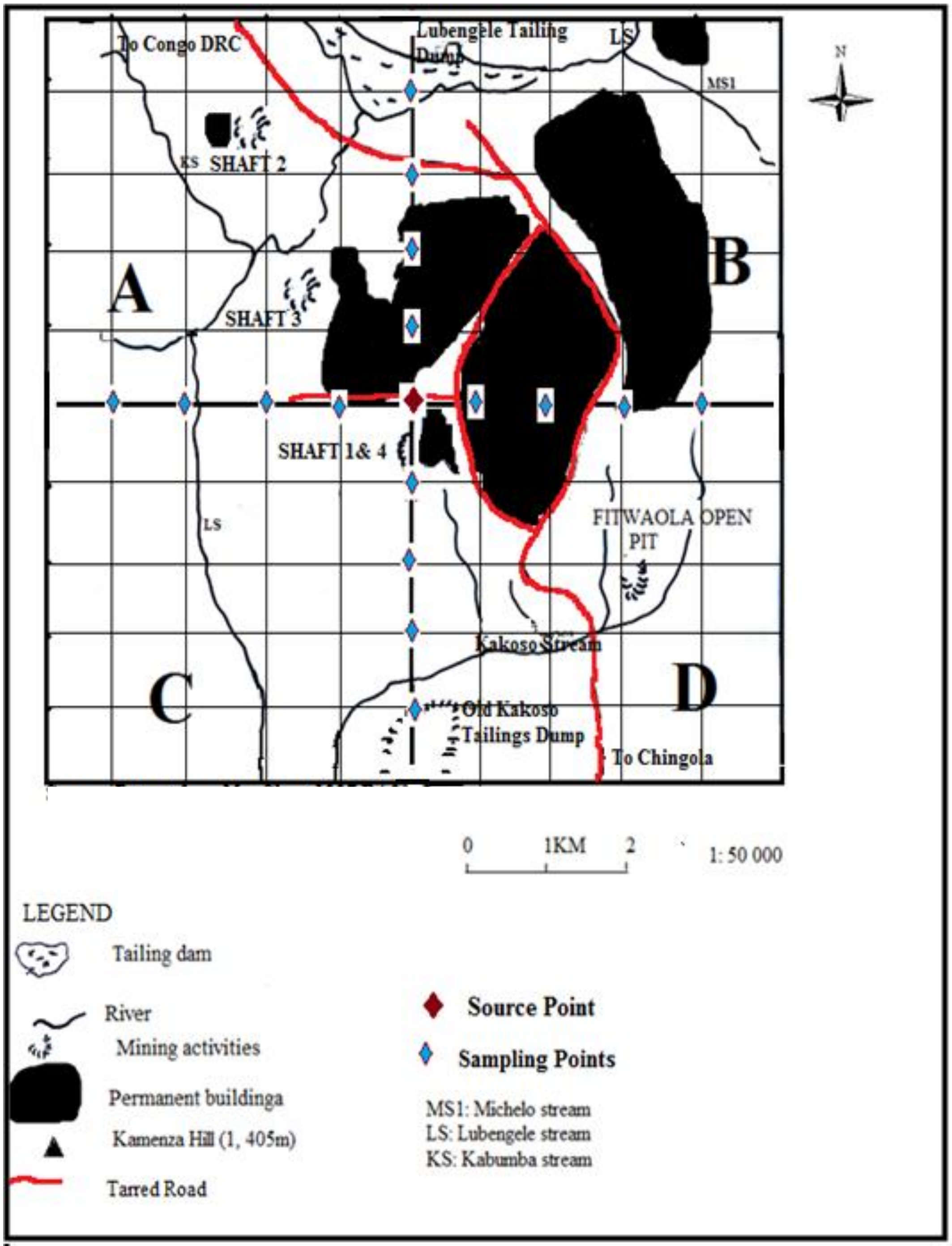


Figure 4.3: Sampling Points for Food Crops
Source: Extract Map from Map Sheet 1227 B 4 (2013)

The Atomic Absorption Spectrophotometer was calibrated with standard concentrations suitable for each element (copper, cobalt and iron) at five percent nitric acid. This stage was followed by the aspiration of each sample. Each element was read using specified lamps for their analysis (Kapungwe, 2013).Samples that read higher than the highest standard, a dilution was done to bring to the right volume. A blank sample was read whose volume was used to correct the readings of the sample. The AAS was recalibrated after taking readings for 17 samples for each element (Kapungwe 2013). The flames, wave lengths and detection limits used are indicated in Table 4.1. The concentrations in each sample for each trace element were determined by AAS. The values for the original were calculated using the formulae; **Element mg/kg=mean reading mg/lx 20 mls (volume of extractant).**

4.8 Heavy Metal Contamination in Selected Food Crops

In Zambia there are no thresholds for heavy metal oral intake of food crops grown in Zambia, hence, FAO thresholds were used. The results of the levels of heavy metals in selected food crops(Chinese cabbage, sweet potato leaves, cassava leaves and eggplants) were compared with the FAO Oral intake threshold used by ZCCM (2005) and Marshall *et al.,* (2009) in Table 4.4. This established the contamination levels of heavy metals in vegetables grown in the study area.

Table 4.5: Thresholds for Heavy Metal in Food Crops

Elements	Critical Limits (mg/kg)
Cobalt	0.01
Copper	0.2
Iron	5.0

Source: Marshall et al. (2004)

4.9 Limitations

The study encountered limitations during data analysis. It was difficult to find the Zambian thresholds for heavy metals. Hence, thresholds from the FAO, US-Environmental Protection Agency, UK, EU, Ministry of Environment Ontario Canada, and Soil Guideline were used.

4.10 Assumptions

The assumption for this study was that mining induced heavy metals in soil contaminate food crops and risks the health of humans through the food chain in Chililabombwe.

4.11 Principal of Distance and Contamination

In this study, a geographical concept has been applied to show the extent of heavy metal contamination. Distance-Decay Curve or Function which states that values of variables(copper, cobalt and iron) tend to decrease as distance increases (Thoman and Corbin, 1974). In this study, the Distance-Decay Curve or Function has been applied to assess an assumption that heavy metal contamination decreases with increasing distance from the point source. Furthermore, Ayras and Kashulina (2000) state that these toxics decrease with distance until background concentrations are established usually in tens of kilometres from the point source.

CHAPTER FIVE

PRESENTATION FINDINGS AND DISCUSSION

5.1 Introduction

This chapter addresses the findings on the levels of some selected heavy metal soil contaminants and heavy metal contamination of selected food crops in Chililabombwe.

5.2 Some selected Heavy Metal Soil Contaminants

The results for heavy metal soil contaminants obtained from the study area are presented in Tables 5.1 to 5.4 and the pH of soil in the study area is presented in Table 5.5. These results are means of the 32 triplicated samples collected from the study area and the Tables present the levels of heavy metal soil contamination specific to copper, cobalt and iron.

5.2.1 Copper

Table 5.1 summarises the levels of copper in soil from point source. The results in Table 5.1 indicate that 99.6 percent of the samples recorded above 100mg/kg of copper in the study area.

Table 5.1:Levelsof copper in soil

Distance from point source (m)	Levels of copper (mg/kg) in different Directions			
	North	South	East	West
500	1405	5812.5	940	1005
1000	830	635	765	730
1500	945	680	198.5	1685
2000	565	391	497	825
2500	113	397	295	675
3000	108	322.5	341.5	327
3500	149.5	225	126	209
4000	112.5	222	193.5	306

Source: Field Data (2013)

The highest levels of copper in soil were from samples at 500 m in all directions. For instance, from 500m north, copper was 1405mg/kg, in the south 5812.5mg/kg, eastwards 940mg/kg and westwards 1005mg/kg. However, it is also worth mentioning that some areas further away from the concentrator recorded high levels of copper. For instance, samples from 4000 m east and 4000 m south indicating 306 mg/kg and 222 mg/kg respectively. It is also important to mention that generally, in the eastern, northern and western sides of the point source, levels of copper in soil reduced with distance. The lowest levels of copper were 108 mg/kg and 112.5 mg/kg at 3000 m and 4000 m north of point source respectively.

The findings in this study show that all samples collected from the west, south and east indicate copper soil contamination ranging between 193.5 to 5812 mg/kg. In the north, soil contamination has been observed from 500 m to 2500 m ranging from 149.5 to 1405 mg/kg and at 3500 m with149.5 mg/kg. Tables 5.1 also show that there is copper soil contamination in the study area. For example, 87.5 percent of the soil samples collected are above the FAO and UK guide lines of about 130 to 140 mg/kg. These results indicate that copper is a soil contaminant in the study area.

In this study, there are a number of sources of copper soil contamination. This study has revealed that there are high levels of copper soil contamination near the concentrator, clearly showing that copper soil contamination originates from mining activities. Therefore, from these findings, it is evident that high concentrations of copper near the concentrator emanate from fugitive dust at ore crushing, loading and off-loading of materials and waste rock (Figure 5.1). Studies conducted by UNEP (2000) reveal that dust released to the environment contains harmful particles which contaminate soil. For instance, dust produced during clearing of the forests, crushing, transportation of mining materials and ore to the processing plants, and windblown dust from the tailings in Chililabombwe, contain copper and contaminate soil in the study area (UNEP, 2000).It is also important to mention that the according to Kribek *et al*, (2005) Copperbelt, by virtue of its name the Copperbelt has high levels of copper in soil.

Plate5.1: Dust during the off-loading of waste rock in Chililabombwe
Source: Field Data, (2013)

The findings have also shown that copper soil contamination reduced with increasing distance from point source in line with the distance decay function which states that values of variables tend to decrease with increasing distance. According to Ayras and Kashulina (2000) the surface enrichment that results from the atmospheric fall outs of particulate matter emissions is highest within 1-5 kilometres of the point source. Furthermore, Ayras and Kashulina (2000) state that these toxics decrease with distance until background concentrations are established usually in tens of kilometres from the point source. Therefore, the reduction in copper concentration in soil at 3000 m can be attributed to lack of mining activity.

However it is also important to note that the levels of copper at 4000 m away from the concentrator or point source in the east, south and west of the concentrator had a slight increase. According to Kribek et al (2005) the highest contents of copper and many other metals found in regions contaminated by ore processing. Contents of copper and cobalt exceed thresholds even in areas that are not affected by industrial activities. In these areas, increased amounts of copper and cobalt reflect bedrock lithology and are not associated with mining. However, other than this argument, Chililabombwe being a multi-contaminated area, this scenario can be attributed dust from a number of mining related activities found in the study area such as number three shaft north of the study area, Lubengele tailings dump in the north-east and Fitwaola Open-Pit mine in the south east.

The results of this study are similar to the results of the study conducted by Kribek *et al*., (2005) in the Copperbelt where dust fallouts from the processing plant and the Muntimpa tailing dumps in Chingola and on the western side of the plant indicated high levels of copper in soil exceeding WHO limits. Kriberk *et al*, (2005) asserts that by Canadian legislation on agricultural soil quality, 99.2 percent of soil samples from Chingola exceed the limit for copper and 32 percent of samples exceed the limit for cobalt.

The trend of copper levels in soil was also observed with slightly lower concentrations between 2000 m and 4000 m. The increase in copper concentration at 4000 m is attributed to the influence of the Old Kakoso tailings dump through run-off similar to the report on environmental copper contamination in Mufulira and Chambishi (Kribek *et al.,* 2005) which revealed that tailings dump contributes to copper soil contamination through dust and run-off.

In the study area, there is one concentrator where the metallurgical processes take place, hence, copper ore from number three shaft is transported using haulage roads (Figure 5.2) where the ore spills down and the cupriferous dust emanating from the haulage road spread in the environment contaminating soil in the study area.

Plate 5.2: Dust in Haulage roads transportation of Copper ore in Chililabombwe
Source: Field Data, (2013)

To the east of the concentrator, the levels of copper generally reduced with increase in distance. The copper contamination at 3000 m east to 341.5 mg/kg can be also attributed to the geochemistry of the parent rock. According to the findings, construction of residential and commercial business houses mandated by the Municipal Council stretching from Lubengele tailings dump to the area near Fitwaola open pit also contribute to copper soil contamination. Construction materials in the study area such as stones and concrete sand supplied by Crush-tech originate from waste rock containing some degree of copper, cobalt, iron and other elements that occur with copper underground (KCM, 2001). Therefore, it makes the soil east of point source vulnerable to copper contamination. However, it should also be noted that, wind-blown dust from Fitwaola open-pit and the Lubengele tailings dump are also sources of copper soil contamination in the study area.

The study indicated high levels of copper contamination on the western side of the concentrator compared to other directions. The findings of this study have revealed that the western side of the point source has high levels of copper soil contamination because of the wind-blown, dust from mining and other mining related activities. At 500 m west the level of copper concentration was at 1005 mg/kg that gently decreased to 306 mg/kg at 4000 m west. Similar the study conducted by Ikenaka *et al*., (2010) on heavy metal contamination of soil and sediment in Zambia indicated that the increase in levels of copper soil contamination are also caused by wind-blown dust.

Copper soil contamination on the west is attributed to the wind-blown dust from crusher, loading of copper ore, haulage roads, and the effect of the north-east trade winds that blow over the Lubengele tailings beach,(Plate 5.3) the fall-outs from number three shaft (Ikenaka *et al*., 2010) and other mining activities which play a prominent role in copper soil contamination. The findings of this study are similar to the results of the study conducted by Kribek *et al.,* (2005) and Kinesl *et al.,* (2002) in the Copperbelt mining towns and Krishna *et al*., (2007) on copper soil contamination due to heavy metals from an industrial area of Surat Western India which indicated copper soil contamination

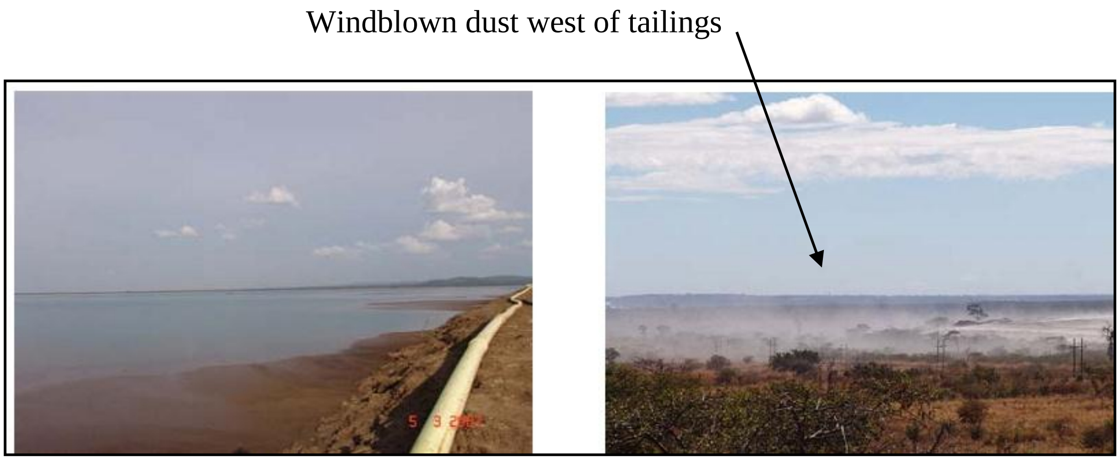


Plate 5.3: Dust fallouts from Lubengele Tailings Dump

Source: Field Work, (2013)

In contrast, according to KCM, (2010) in Kitwe, copper contaminations occur within 1500 m west of point source (smelter) with a maximum of 38 310 mg/kg, due north-west, at 1500 m concentrations of copper were 15 310 mg/kg due to the wind-ward effect. These values were extremely high compared to those obtained in Chililabombwe of 1685 mg/kg of copper at 1500 m west of the point source because Kitwe has an open pit with a fully fledged metallurgical plant while Chililabombwe has a shaft mine.

The studies by Kribek *et al.*, (2005), in Chingola, also indicated that the highest copper concentrations in soil were in the wind-ward side of the processing plant. Although concentrations of copper in the study area were above the threshold used in this study, they are lower than the report from KCM, (2010) in Kitwe because Kitwe has a fully-fledged metallurgical plant. This entails that, mining towns without a fully-fledged metallurgical plant contaminate soil although the levels of soil contaminants are also above the FAO and WHO thresholds.

The results near the point source are high in all direction with copper ranging from 565 mg/kg at 2500 to 1405mg/kg at 500 m from source point. Mining also involves removal of waste rocks from underground that contain various compound ions and sulphides that occur with copper. When rain falls on waste rocks, water dissolves the elements and form sulphides and ions which produce toxic acids. Run-off from waste rock collecting at low points infiltrate through the rock to the original ground surface leading to the formation of acid drain and soil contamination (KCM, 2001).

According to Ripley *et al.,* (1996), these acids and heavy metals destroy micro-organisms that barrow and through natural processes improve soil nutrients, which affects plant growth. Unlike Mufulira, Chambishi and Kitwe, there is also little evidences of acid mine in Chililabombwe. Additionally, by definition, waste rock in Chililabombwe contains low ore grade. Furthermore, KCM, (2001) asserts that the geologic setting of the Copperbelt is unusual compared to other deposits in the world in that it occurs in sedimentary host rocks with high carbonate content, and correspondingly has a high acid neutralising capacity. Hence, the study area does not generation of acid mine drain in the study area.

The other mining activity contributing to copper soil contamination in the study area is excavation, which involves the removal of debris and extraction of minerals from the depth of the earth. The debris contains various characteristics of heavy metals emanating from parent rock where copper originates change the chemical content of the soil where the overburden has been deposited. Therefore, the copper concentration levels are higher where there are anthropogenic activities such as excavation especially in the Copperbelt as stated by Kribek, (2010) and ZCCM, (1995). The findings indicate copper soil contamination similar to the results of the study conducted by Kribek, (2002) in Kitwe, Chambishi, Chingola and Mufulira and those conducted by ZCCM, (2004) in Chililabombwe.

The parent rock also may have an effect on the concentrations of copper in soil (Terelark *et al*., 1994) in the study area. For instance, the copper contamination of soil samples collected east of the point source at 3000 m with 341,5 mg/kg and 4000 m with 193.5 mg/kg (Appendix 1), away from mining activities may have been caused by the parent rock. According to Terelark *et al.,* (1994) in his studies in Beala provinces, the findings revealed that the parent rock also contributes to copper soil contamination in mining areas like the Copperbelt province which were named after the abundance of Copper in the province. Therefore, Chililabombwe being in the Copperbelt province the soil has high concentrations of copper. This is attributed to the parent rock (ZCCM, 1995) as exhibited by high level of copper in areas where there is no mining activity in the study area. For instance, at 3000 m east the level of copper is 341 mg/kg while at 1500 m the level of copper is 198.5 mg/kg. These findings are similar to the studies conducted by Krishna *et al*., (2007) on soil contamination due to heavy metals in industrial areas where he asserted that levels of copper in the soil reflect the concentration of copper in the parent rock where abnormal values of copper may not be caused by anthropogenic sources but attributed to a geogenic activity

During metallurgical processing effluents containing heavy metals are discharged and transported to the tailing dumps through steel pipes. Therefore, leakages of pipes (Plate 5.4) that discharge effluents containing heavy metals from the metallurgical process also contribute to soil contamination induced by mining (KCM, 2001) as exhibited by the sample at 4500 m north with 484 mg/kg.

Plate 5.4: Leakage of Effluents in the Study Area
Source: Field Data (2013)

The high concentrations of copper in Chililabombwe predominantly indicate anthropogenic contamination. The results show that 87.5 percent of samples were above thresholds used in this study indicating that there is copper soil contamination in Chililabombwe. Therefore, the findings of the study revealed that the levels of copper concentrations in all the 32 soil samples collected in the study area were high and exceeded the copper threshold of 130 -140 mg/kg established by the Food and Agricultural organisation and the United Kingdom for copper in agricultural lands. Similarly, the results of Kribek *et al*., (2005) on assessment of mining and processing of copper and cobalt ores on the environment in the Copperbelt province of Zambia which indicated that the levels of copper were higher than the Canadian thresholds at a depth of 0-30 cm as used in this study. This confirms heavy metal soil contamination in Chililabombwe.

According to the results in Table 5.1, this study identified Copper soil contamination in Chililabombwe. In this study, the degree of copper contamination was best evaluated by simple regression and correlation.

A simple regression analysis was used to determine the significance of the relationship between the dependent variable (copper) and independent variable (distance). The statistical results show an F – ratio of 6.750 and a P value of 0.0178 at 0.95 confidence levels. These results indicate that there is a difference in the mean of copper levels at different points from the source. This means that the research hypothesis is accepted and null hypothesis is rejected since the p value <.0.0178.This means that the levels of copper reduce as one move away from source point for instance, at 500 m from source point the level of copper was 1405 mg/kg while at 4000 m 112.5 mg/kg. The findings also indicated that the coefficient of determination (R^2) is 90%. This shows that, 90% of the variations of copper concentration in soil are explained by distance from the point source. The other seemingly small percentage (10%) is explained by other factors. These statistics indicate that there is an evidence of a significant linear relationship between the levels copper and distance. These statistics show that copper contamination is soils of the study area is caused by the point source and in some very few cases it is caused by natural environment.

In this study, correlation statistics also indicated a strong negative correlation between copper concentration and distance with r = - 0.53402. This statistic indicates that there is a significant negative correlation between copper and distance on the probability level of p –value 0.05 with at confidence level of 0.95. There is also a significant positive correlation between copper and cobalt (0.58827) while copper and iron showed an insignificant or weak correlation (-0.028835). The significant correlation between copper and distance and copper and iron indicate that copper is closely associated with distance and iron. Therefore, the levels of copper in soil correlate with distance. The further one moves away from point source the lesser the levels of copper.

5.2.2 Cobalt

Table 5.2 presents results for levels of cobalt in the soil of the study area. Table 5.2 reveals that levels of cobalt were higher near point source. For instance, at 500 m the levels of cobalt were 225.0 mg/kg in the north, south 157.95 mg/kg, east 50.10 mg/kg and 68.05 mg/kg in the west. Table 5.2 also reveals that levels of cobalt reduced with distance, with the lowest at 3000 m north with 18.40 mg/kg.

Cobalt was mined with copper in Chililabombwe until the early 90s. Krishna, *et al*., (2006) states that cobalt usually occurs copper, nickel, and arsenal. Like copper levels, cobalt concentrations are higher near the concentrator at 500 m compared to a distance of 4000 m away from the concentrator. In this study, levels of cobalt range from 225 mg/kg in the north, 157.95 mg/kg in the south, 50.1 mg/kg in the west and 68.05 mg/kg east at 500 m from the point source. These results are an indication that cobaltferous dust from crushing, screening, and handling of spillages near the concentrator during metallurgical processes.

One of the most important properties of cobalt is acidity. The more acidic the soil is the greater the potential for cobalt toxicity (Romic *et al.*, 2001). In this study the pH results in the study area indicate neutral to alkaline (4.5-6.62). Therefore, this makes cobalt results to be low from natural soils. In this study the presence of cobalt in soil is as a result of past mining activities or natural geochemical processes in soil. According to Ayeni, *et al.*, (2010) cobalt in soil exists with traces of many sulphides, and is released to the environment during metallurgical processes.

Table 5.2: Levels of cobalt in soil

Distance (m)from point source	Levels of cobalt (mg/kg)in Different directions			
	North'	South	East	West
500	225.0	157.95	50.10	68.05
1000	56.65	26.25	24.85	51.65
1500	75.10	30.30	19.10	34.10
2000	68.70	29.25	95.75	59.70
2500	21.30	27.60	40.05	36.90
3000	18.40	44.90	63.35	25.20
3500	25.25	35.05	79.35	23.05
4000	19.30	58.25	19.40	31.25

Source: Field Data (2013)

In this study cobalt was identified as a soil contaminant in Chililabombwe by studies conducted by KCM, (2001). In this study cobalt levels ranged from 18.4 mg/kg to 225 mg/kg of soil. It is also worth noting that the levels of cobalt in soil were below the threshold of 240 mg/kg established by the European Union. The lower cobalt levels were as a result of the low quantities of cobalt in the copper ore. Hence, cobalt is not a soil contaminant in the study area

Statistics from simple regression analysis shows a significant linear relationship between cobalt and distance with R^2 at 80 percent, a p value of 0.0 and the F ratio of 25.65 with the level of significant at 0.95. The F static show the there are variations in the mean cobalt levels at different points from source point. Therefore we reject the null hypothesis and accept the alternative. The coefficients of determination at 80 percent indicate that the relationship between the levels of cobalt in soil is explained by distance and the lesser percentage is explained by the natural causes in the environment. The 0.0 p value shows that there difference in mean levels of cobalt along the points for source points. Hence the null hypothesis is rejected and the alternative is accepted. Therefore, levels of cobalt reduced with distance. The results of the correlation statistics have also shown that there is a strong negative correlation between the levels of cobalt and distance (r = -453402) in soil. However, there was an insignificant correlation between cobalt and iron with r = 0.09212 and a positive significant association between cobalt and copper with r = 0.588275. In this study the levels of cobalt in soil reduce with distance from source point. Therefore, it is prudent to infer that iron contamination originates from point source.

The results of this study are similar to other studies which reported lower levels of cobalt in soil (Boluda *et al*., 1988) in the dry land of Valencia province, Spanish Mediterranean region and the fertile Granada valley (Campos, 1997) where cobalt was below thresholds established by EU, ranging between 7.9 and 10.1 mg/kg. Hence, a significant increase in levels of cobalt in soils as a result of mining activity has not occurred. Therefore, cobalt is not a soil contaminant in Chililabombwe cannot be linked to causing adverse biological effects to different organisms growing in the soil.

5.2.3 Iron

Table 5.3 indicates the levels of iron in the study area and reveals that the levels of iron in the study area are high. Furthermore, samples near the point source indicated highest levels of about 16, 375 mg/kg in the north, 23 750 mg/kg in the south, to the east 20 000 mg/kg and 26 875 mg/kg to the west.

Table 5.3: Levels of Iron in soil

Distance (m) from point Source	Levels of Iron(mg/kg) in Different Directions			
	North	South	East	West
500	16 375	23 750	26 875	20 000
1000	19 750	33 625.5	25 250	22 025
1500	11 812.5	33 375	11 762.5	8 9 37.5
2000	13 750	24 125	11 262.5	1 725
2500	9 500	31 000	39 375	2 8 75
3000	5 775	35 250	7 925	7 1 75
3500	2 025	9 237.5	7 250	4 0 93.7
4000	1 7875	9 575	13 125	4 112.5

Source: Field Data (2013)

Table 5.3 also showed that the levels of iron ranged from 2025 mg/kg to 19750 mg/kg in the north, 9235 mg/kg to 35250 mg/kg in the south, 7250 mg/kg to 26 875 mg/kg in the east and 1725 mg/kg and 22025 mg/kg in the west. However, the levels of iron reduced with distance from point source in all the directions except for samples from 4000 m away which indicated high levels of 13125 mg/kg to the east, 4112.5 mg/kg in the west. The west also recorded lowest levels of iron at 2000 m west.

The findings of the study reveal that the levels of Iron in Chililabombwe are very high ranging from1725 mg/kg to 41125 mg/kg. These levels of iron in the study area are beyond the FAO and European Union thresholds of between 400 and 1000 mg/kg. Therefore, there is iron soil contamination in the study area.

Like levels of copper in the study area, the levels of iron are high near the point source. The findings in this study show that there are high concentrations of iron from 500 m to 3000 m of between 5000 and 39 000 mg/kg in all directions. It is also important to note that concentrations of iron in soil reduced with distance an indication of the influence of mining activities in the study area. According to KCM (2001), land is contaminated or degraded in the vicinity of the mine facilities due to mechanical disturbance, chemical spills and dust fallouts among others. At 500 m north the levels of iron were 16375 mg/kg, in the south 23750 mg/kg, east 26875 mg/kg and in the west 20 000 mg/kg.

It has also been observed that the highest concentration of iron are mainly at 2500 m east and 3000 m south with 39 375 m and 35 250 mg/kg respectively which may not be as a result by mining activities. Eddy *et al.*,(2004) suggested that the iron contamination in the environment cannot be conclusively linked to waste mining materials alone but other natural sources of iron must be taken into consideration. Doberman and Fairhurst, (2000) explained that the iron toxicity in soil is due to the high form of iron available in the soil. Eddy *et al.,* (2004) also asserts that iron contamination can also be attributed to the parent rock where natural processes generate the formation of the element due to fast weathering of the rocks and the bonding of metals to organic matter also contribute to high levels of iron in soil.

Similarly, the findings of this study are like those of KCM, (2001) where the levels of iron exceeded the FAO and EU thresholds of400mg/kg and 1000 mg/kg used in the study. Additionally, the findings in the study area were also similar to the study conducted by Kribek (2005) in Mufulira, Chambishi, Kalulushi and Kitwe where the levels of iron were above 15 679 mg/kg and found to be higher than the FAO and EU thresholds.

In this study the statistical results for iron shows an F – ratio of 0.02145 with a P-value< 0.05 at 0.95 confidence levels. This meant that the research hypothesis is accepted and null hypothesis is rejected. Therefore, there is an evidence of a significant linear relationship between the levels of iron and distance affirming the decay function in that heavy metal contamination reduced with increasing distance in the study area.

The findings also indicated that the coefficient of determination (R^2) is 86 percent, F ratio at 26.60 and a p value of 0. The large F ratio indicates that there is a difference in the mean iron levels at different points from point source. Therefore, levels of iron reduce with increasing distance from point source. The further away the point is form source point the lesser the levels of contamination. The coefficient of determination shows that 86 percent the variations of in levels of copper in soil are explained by distance. The other seemingly small percentage (14%) is explained by other factors and natural causes. Therefore, it is prudent to infer that the iron contamination is caused by the point source.

In this study, correlation statistics also indicated a medium negative correlation between iron concentration in soil and distance with r = -0.44066. This statistic indicates that there is a negative moderate significant correlation between iron and distance on the probability level of 0.05 while iron and copper and, iron and cobalt showed an insignificant or weak correlation at = -0.176751 and 0.029929 respectively. The significant correlation between copper and distance, and iron and distance indicate that iron is closely associated with distance. In that as distance increase levels of iron decreased.

5.2.4 pH

Table 5.4 shows that the acidity levels in the soils of the study area. The acidity levels were high from 500 m to 2500 m north of point source indicating 4.5 to 4.65. To the east, the acidity level is high at 500 m with 4.6. Furthermore, it is important to note that all samples collected in the south indicate low acidity levels. However, the rest of the samples in the study area indicated neutral to alkaline.

The pH values near the copper concentrator and the tailing dump where there was high concentration of copper ranged between 4.61 at 500 m to 4.67 at 2500 m (Table 4.5). This study shows that the acidity levels are stronger near point source. The pH is the principle factor that governs the concentration of soluble available metals in soil and plants. When the pH is low metal solubility tends to increase and decreases at higher pH values (Bras. et al., 2016). Hence samples near mining activities were acidic and had higher levels of heavy metal concentration in soil and in food crops.

Table 5.4: pH Levels from point source

Distance from point source (m)	pH Levels in Different Direction			
	North	South	East	West
500	4.61	5.89	4.6	5.88
1000	4.56	5.09	5.46	5.6
1500	4.65	6.51	5.56	5.45
2000	4.5	6.58	6.61	6.33
2500	4.67	6.3	6.6	6.28
3000	5.22	6.31	6.57	6.37
3500	5.42	6.33	6.48	6.28
4000	5.73	6.4	5.8	6.54

Source: Field Data (2013)

It is also important to note that the underlining rock or host rock in the study area has high carbon content (limestone) which initiates alkalinity and tends to neutralise acidity in the soil of the study area (KCM, 2001). These findings clearly indicate that the high acidity values rebuff the lime content of the tailings material and the underlying rock by increasing the copper concentration levels in the soil. It is also important to note that, according to Chen *and Pu* (2000) the presence of the carbonaceous rocks in the geological structure of the study area indicates that there is a mitigation of soil copper contamination which significantly reduce the concentration of copper in soil derived from the increase in the acidity levels near the metallurgical plant. This indicates that the geology of the Copperbelt is enriched with carbonates which act as a buffer against acidification. Hence, acid mine drain waters is a rare feature in the Copperbelt (Kribek, 2011) and does not exist in the study area.

The pH values near the copper concentrator and the tailing dump where there was high concentration of copper ranged between 4.61 at 500 m to 4.67 at 2500 m. This study shows that the acidity levels are stronger near point source.

The pH is the principle factor that governs the concentration of soluble available metals in soil and plants. When the pH is low metal solubility tends to increase and decreases at higher pH values (Bras. *et al.*, 2016). Hence samples near mining activities were acidic and had higher levels of heavy metal concentration in soil and in food crops.

The study revealed that iron and copper are soil contaminants in the study area, with iron as the highest (Fe.>Cu>Co). However, this study shows cobalt is not a soil contaminant in the study area. Therefore, the study has shown that there is heavy metal soil contamination in the study area which may contaminate food crops grown Chililabombwe.

5.3 Trends of Heavy metal concentration in soil

Trends of heavy metal soil contamination in this study are indicated from Figure 5.1 to Figure 5.3.

5.3.1 Copper

Figure 5.1 shows the trend of copper concentration in the soil of the study area. The Figure generally shows a decrease of copper concentration in soil in all the four directions with increasing distance from point source. A rise in copper concentration has been observed at 500 m in the south, east and west with the west recording the highest Although there is an indication of a sharp rise in copper concentration at 1500 m west of point source, the trend line slightly dropped at 2500 m. Figure 5.1 also indicates a general decrease of copper concentration in all directions from 1000 m to 4000 m from point source. The north indicated lower concentration of copper at 1000 m and a slight rise at 1500 m and gently decreased with distance from point source.

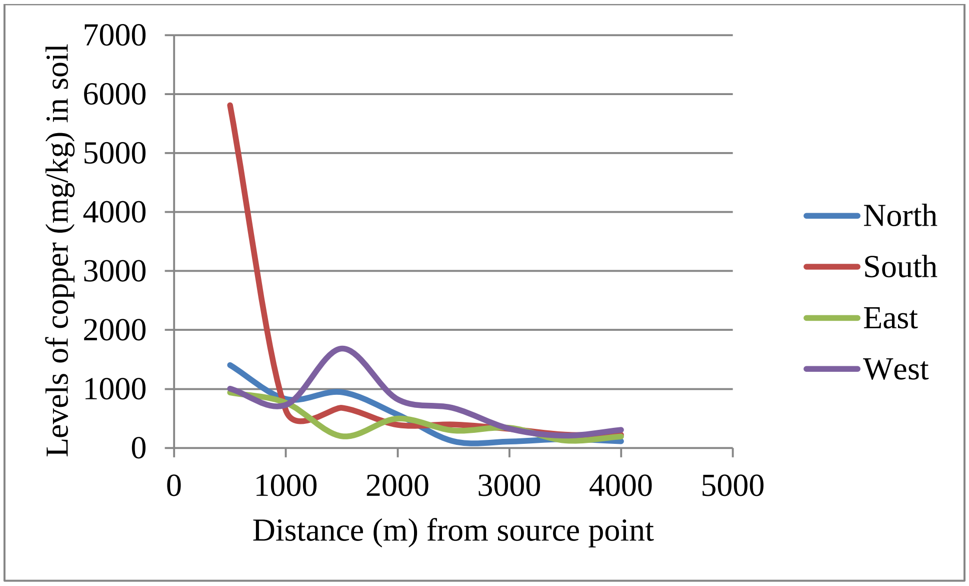


Figure 5.1: Trends of Copper in soil
Source: Field Data, (2013)

5.3.2 Cobalt

High levels of cobalt have been observed at 500 m from source point in all the four directions. Figure 5.2 shows variations in levels of cobalt in soil with distance from point source. For instance, in the north there is a sudden decrease of cobalt concentration in soil from point source at 1000 m with a slight rise at 1500 m and gradually decreased at 2500 m. Figure 5.2 also shows that south of the point source the concentration of cobalt suddenly decreased with increasing distance although there was a slight increase in the concentration of cobalt at 4000 m. Furthermore, to the east Figures 5.2 indicates a slightly different picture with a slight rise at 2000 m and 3500 m. However, the levels are below European Union thresholds at 240mg/kg and are not a danger to humans.

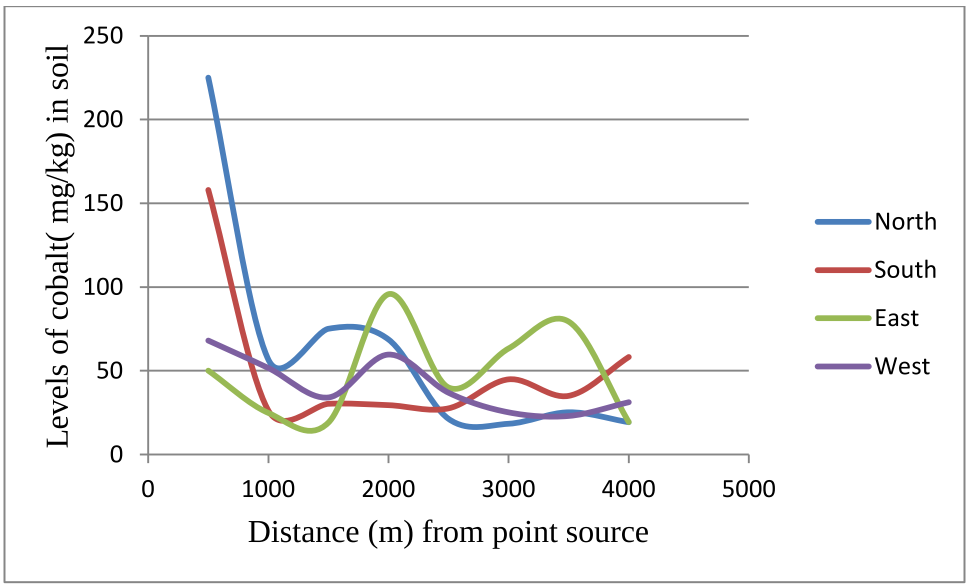


Figure 5.2: Trends of Cobalt in Soil

Source: Field Data, (2013)

5.3.3 Iron

Figure5.3 indicates fluctuations in levels of iron in soil from point source. Figure5.3 shows a sharp increase in iron at 1000 m in all directions to 19750 mg/kg. In the west the high levels of iron were also observed at 4000 m while to the north at 4000 m a sudden increase in the levels of iron has been observed.

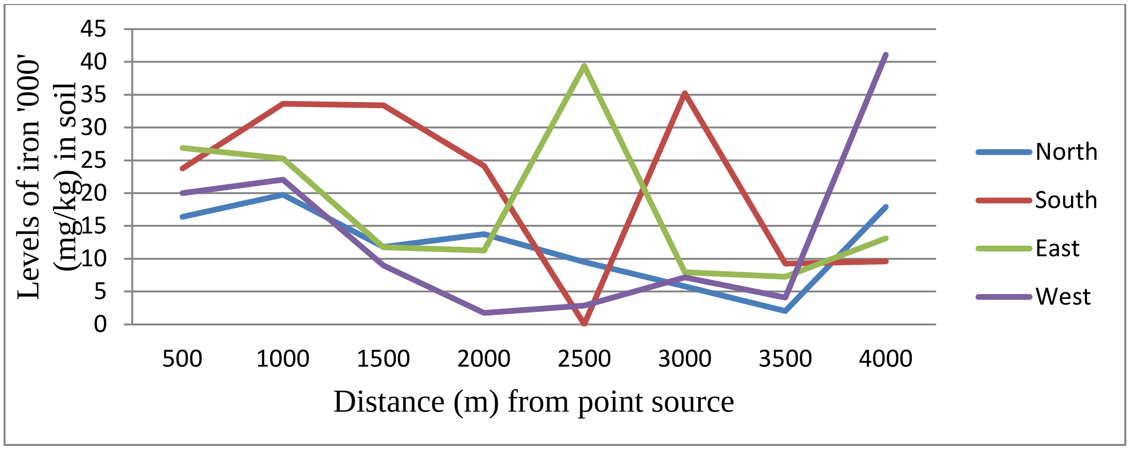


Figure 5.3: Trend of Iron in soil

Source: Field Data (2013)

The east had a sudden rise in iron levels at 2500 m south, 1000 m north and 3000 m south to 31 000 mg/kg, 19 750 mg/kg, and 35 250 mg/kg away from point source respectively. The lowest levels of iron in the study area were at 2000 m west with 1725 mg/kg and 3500 m. However, the levels of iron in soil fluctuated in all directions and the pattern for the distance decay function does not apply because the levels of iron in soil are not constant. The results of the statistics have indicated variations in the means of iron, copper and cobalt levels at different points from the source to 4000 m.

5.4 Heavy Metal Contamination in Selected Food Crops

Soil is the main link in the food chain. From soil, food crops can take up both nutrients and toxic elements, such as heavy metals, directly by root adsorption and indirectly through foliar absorption. According to Ma *et al*., (1994) high levels of the elements under study in soil and food crops are of concern because of their adverse effects on food quality, safety and marketability, crop growth and environmental health. In the study area, the local people grow food crops for consumption and for sale to the local market. Therefore, contamination in vegetables proves to be hazardous to the health of the consumer.

Table 5.5: Thresholds for oral intake of metals included in this study

Element	Dose	Unit
Cobalt	0.01	Mg/kg/day
Copper	0.2	Mg/kg/day
Iron	5.0	Mg/kg/day

Source: ZCCM, (2005) adapted from Marshall et al., (2004)

According to ZCCM (2005) a more direct way of determining whether heavy metals in food crops are present in high concentrations that may be hazardous to humans is through the comparison of estimated related food consumption with thresholds for oral intake (Table 5.5).

Like any other tropical country in Africa, Zambia like Nigeria a daily diet is dominated by starchy staple foods, vegetables (a cheap and readily available) a sources of proteins, vitamins, minerals and essential amino acids. However, recent studies have shown that most of these developing countries have a challenge of mining induced heavy metal contamination in soil and food crops, which is a challenge to food production. For instance, studies conducted by Wilberforce and Nuabe (2013) in Ebony State in Nigeria revealed that levels of heavy metals in soil and food crops were above US-EPA and WHO thresholds. Therefore the soil and food crops were contaminated with heavy metals. Nevertheless, developed countries also suffer challenges of heavy metal soil and food crop contamination like developing countries. For instance, in South Africa, Ayeni *et al.,* (2010)'s studies showed a significant degree of heavy metal contamination in soil exceeding thresholds. Cui *et al*., (2004), indicated that in both soil and vegetables at between 500m to 1500m away from the smelter were heavily contaminated compared to those at 5000m. This means that the food crops that grow on heavy metal contaminated soil are also contaminated and hazardous to the health of the consumer.

The findings of this study show that there is mining induced heavy metal contamination in food crops. The findings of this study show that there is copper, cobalt and iron contamination in food crops (Tables 5.5).Plants that grow on heavy metal contaminated soils are likely to be contaminated. In this study, the results of heavy metal contamination in the commonly eaten and cheapest vegetables such as cassava, pumpkin, sweet potato leaves and golden white eggplants are systematically displayed in Figures 5.4 to Figure 5.15.

5.4.1 Cassava Leaves

In this study area, Cassava leaves are one of the most commonly eaten food crops. Figures 5.4 to 5.7 indicate results of heavy metals (copper, cobalt and iron) contamination in cassava leaves, in Chililabombwe.

5.4.1.1 Copper

The results in Figure 5.4 indicate levels of copper in cassava leaves in the study area. Generally there were high levels of copper in cassava leaves in the west, south and east of the point source. The results in Figure 5.4 also show that samples near point source at 1000 m and further away at 4000 m indicate high levels of copper. For instance, at 1000 m north copper in cassava leaves was 26.10 mg/kg and 105.00 mg/kg respectively.

Additionally, at 4000 m the levels of copper in cassava were 35.53 mg /kg in the south, 150.00 mg/kg north and 57.55 mg/kg west. Samples that recorded highest levels of copper in cassava were at 4000 m east, 1000 m south and 2000 m west. The lowest levels of copper in cassava leaves were observed at 2000 m and 3000 m.

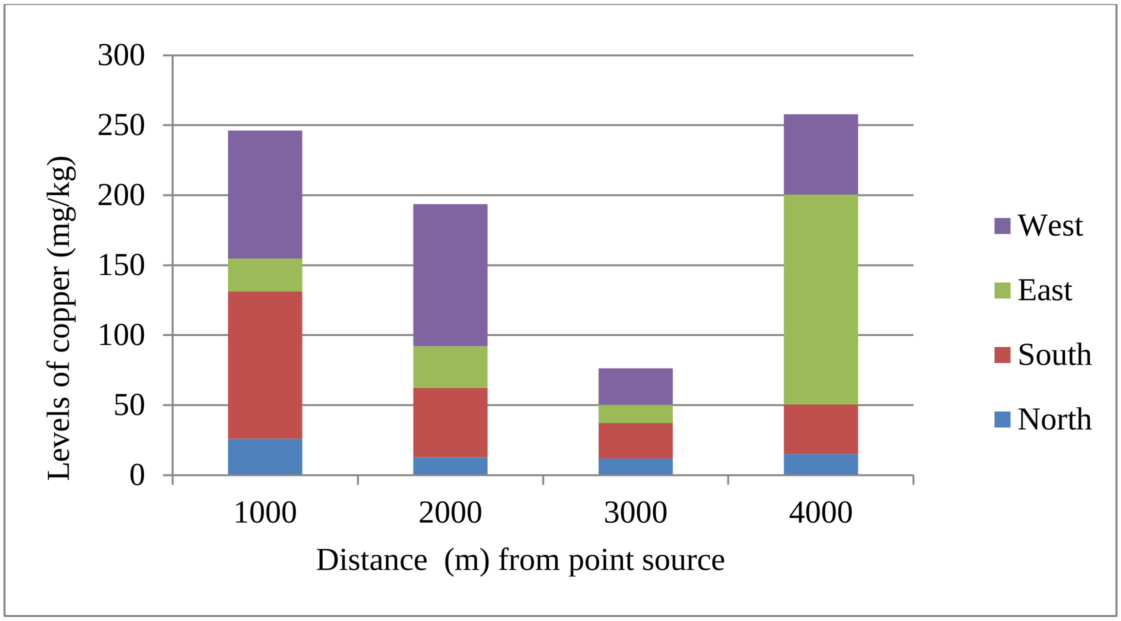


Figure 5.4: Copper in cassava leaves
Source: Field data (2013)

5.4.1.2 Cobalt

The results in Figure 5.5 indicated high levels of cobalt contamination in cassava leaves at 1000 m north at 27.95 mg/kg and at 2000 m east of point source with 33.40mg/kg. The sample that recorded the lowest levels copper in cassava leaves is at 1000 m east with 1.55 mg/kg of point source. However, all the samples indicated cobalt contamination in cassava leaves.

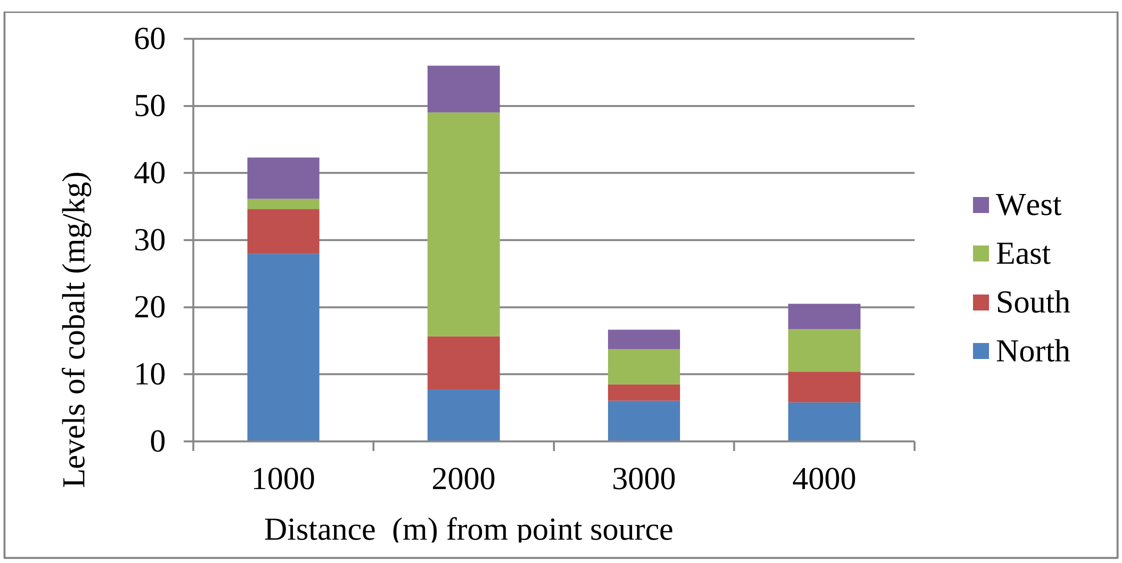


Figure 5.5: Cobalt in Cassava Leaves
Source: Field Data, (2013)

The results also indicated that three quarters of the samples at 2000 m were above 5 mg/kg. It is also important to note that samples at 1000 m east and 3000 m south and west recorded lowest levels of cobalt in cassava leaves. The lowest cobalt levels in cassava leaves were at 1000 m east and 3000 m south and west indicating low mining activities. The highest levels of cobalt in cassava leaves were at 1000 m north and 2000 m east. These samples indicate that the highest level of cobalt contamination was near the point source. Therefore, mining pollute cassava leaves.

5.4.1.3 Iron

The results of iron in Figure 5.6 indicate that samples in the south and east at 1000 m, 2000 m, 4000 m and 5000 m west indicated the highest levels of iron in cassava leaves. The lowest were in the northern and western side of point source. Figure 5.6 shows that in all samples, concentration levels of iron in cassava leaves were above 50mg/kg. The highest levels of iron were at 2000 m east with 335.5 mg/kg. It is also important to note that all samples in the south and east of the point source indicated that iron concentration was above 100 mg/kg in cassava leaves.

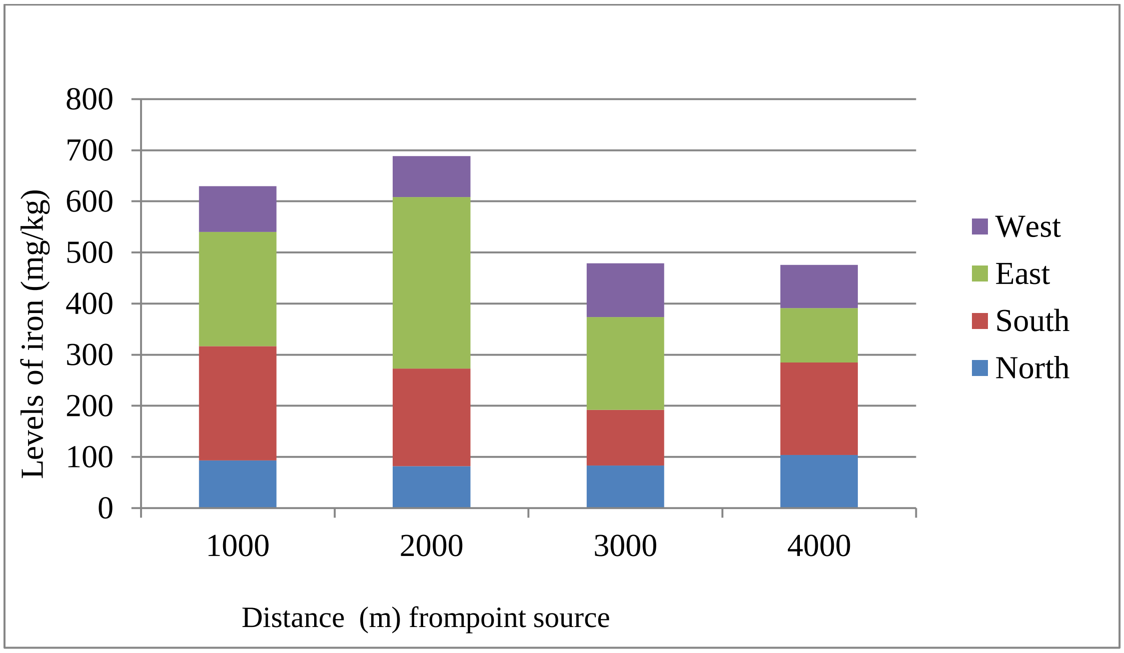


Figure 5.6: Iron in Cassava Leaves
Source: Field data, (2013)

The levels of iron in cassava leaves were 104 mg/kg at 4000 m north. At 3000 m and 5000 m west of the point source, iron concentration was 217 mg/kg and 105 mg/kg respectively. However, at 1000 m, 2000 m and 3000 m north and 1000 m, 2000 m and 4000 m west recorded below 100 mg/kg. These results indicate the abundance of iron in the soils of the study area emanating from both mining and natural processes.

5.4.2 Pumpkin Leaves

Pumpkin leaves are taken as vegetables in study area. The results of heavy metal contamination in pumpkin leaves are indicated from Figure 5.10 to 5.12.

5.4.2.1 Copper

Figure 5.7 shows the results of copper levels in pumpkin leaves. The results in Figure 5.7indicated decrease in levels of copper with increasing distance.

The highest levels of copper contamination in pumpkin leaves are 39.25 mg/kg at 500 m south, 19.20 mg/kg at 500 m East and 19.10 mg/kg at 3000 m west of point source. However, the lowest levels of copper in pumpkin leaves were 7.50 mg/kg at 1000 m north, 10.05 mg/kg at 4000 m south and 12.85 mg/kg at 4000 m east of the point source.

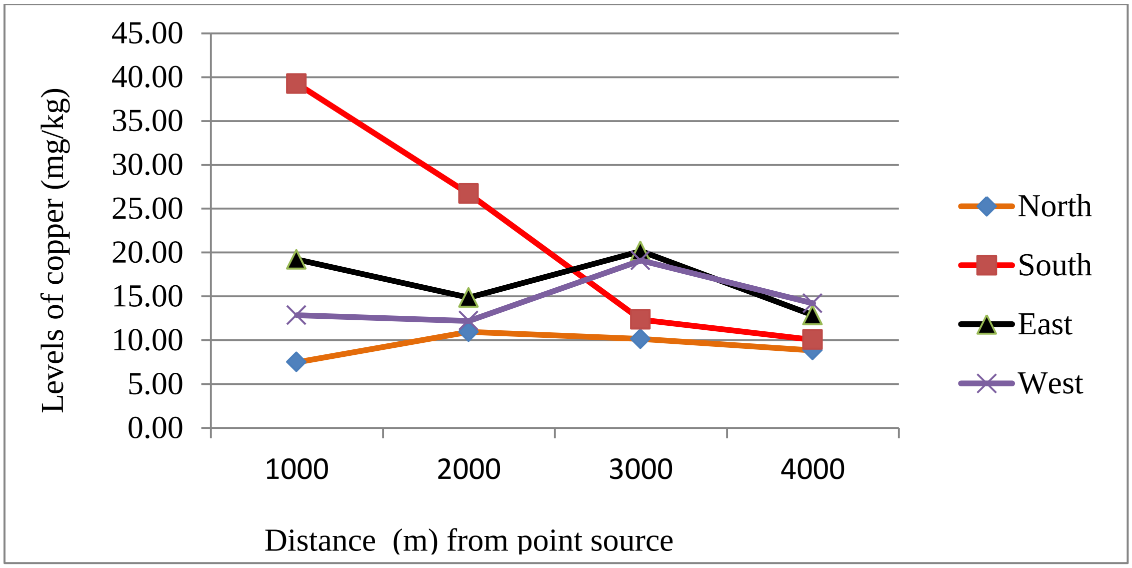


Figure 5.7: Copper in Pumpkin Leaves
Source: Field data (2013),

5.4.2.2 Cobalt

The levels of cobalt contamination in pumpkin leaves are indicated in Figure 5.8. The results of the levels of cobalt in pumpkin leaves were low and did not show a decrease with increasing distance from point source. There are disparities in the amounts of contamination from sample to sample in different directions. Therefore, the distance decay function did not apply. For instance, in the north, cobalt levels suddenly dropped from 3.05 mg/kg at 3000 m to 1.45 mg/kg at 4000 m. To the south the levels of cobalt decreased at 3000 m to1.60 mg/kg and slightly increased at 4000 m to 2.95 mg/kg due to the influence of the old tailings dump through run off. The east recorded slightly high levels of cobalt in pumpkin leaves with the highest at 3000 m indicating 4.50 mg/kg and the lowest at 2000 m west with 0.75 mg/kg. To the west the levels of cobalt were below 2 mg/kg an indication that the windblown dust from point source did not contain any cobalt. Hence the levels of cobalt ranged from 0.75 to 1.75mg/kg. Therefore, pumpkin leaves show highest contamination levels near point source and there is a reduction in levels of contamination with distance.

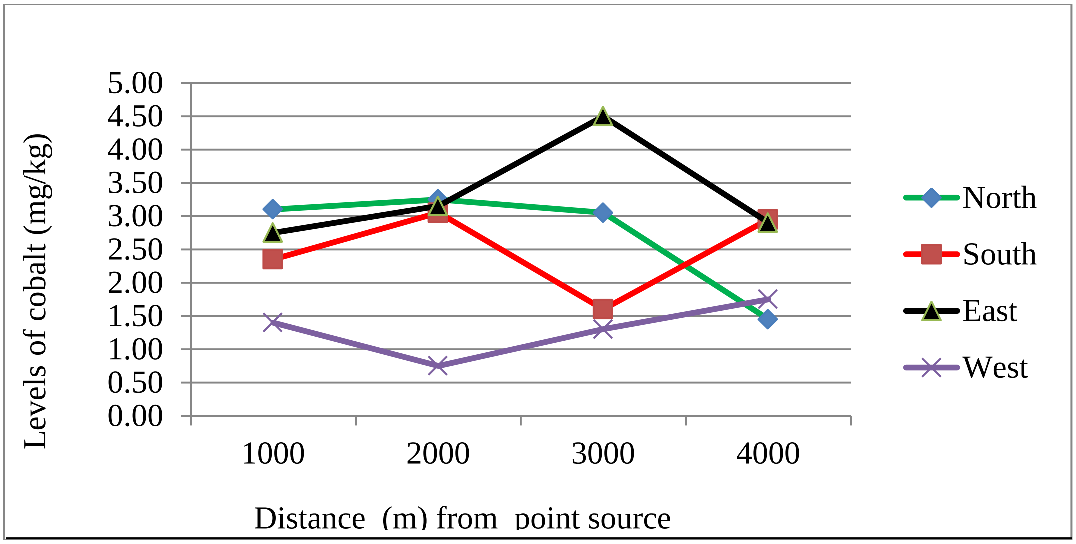


Figure 5.8: Cobalt in Pumpkin Leaves

Source: Field data (2013)

5.4.2.3 Iron

Figure 5.9 showed disparities in iron concentration in all directions in pumpkin leaves. For example, in the east the lowest concentrations were observed at 2000 m and 5000 m with the highest at 1000 m from point source. However, in the south highest levels of iron were at 2000 m and the rest at 4000 m with an abrupt rise at 5000 m. Samples from the west revealed an almost constant levels of iron from point source while in the north there was almost a constant level of concentration of iron in pumpkin leaves. At 3000 m and 5000 m a sharp increase was registered.

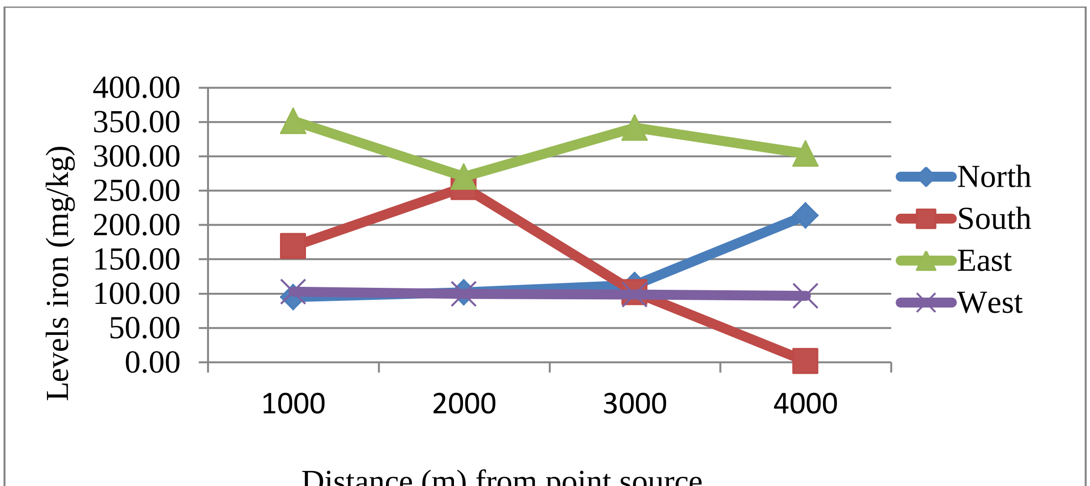


Figure 5.9: Iron in Pumpkin Leaves
Source: Field Data (2013)

The maximum level of iron concentration was in the eastern side of the point source at 1000 m with 351.Other levels included samples between 1000 m and 4000 m in the north with 247.50 mg/kg. In the south, the iron concentration was 255 mg/kg at 4000 m and the west recorded 103 mg/kg at 1000 m. However, the lowest in the north was 95 mg/kg at 500 m, to the south 1.49 mg/kg, in the east 82 mg/kg and 97 mg/kg west of point source. These results can only be explained by natural circumstances in the environment. These levels of iron in pumpkin leaves show that contamination of iron in pumpkin leaves is near the source point.

5.4.3 Sweet Potato Leaves

Sweet Potatoes are grown by many peasant farmers. The results of heavy metal contamination in sweet potatoes are indicated in Figures 5.13 to 5.15.

5.4.3.1 Copper

In sweet potato leaves, the results in Figure 5.10indicated that the concentration of copper at 3000 m north were exceptionally high while the south indicated low levels of copper in sweet potatoes at almost every sampling point with lowest at 1000 m. The highest levels in the west were at 2000 m from point source while the highest in the east was at 3000 m. These high levels of copper in sweet potato leaves are due to dust form the Lubengele tailings in the north and the old Kakoso tailings dump in the south. This entails that copper contaminates sweet potatoes in the study area.

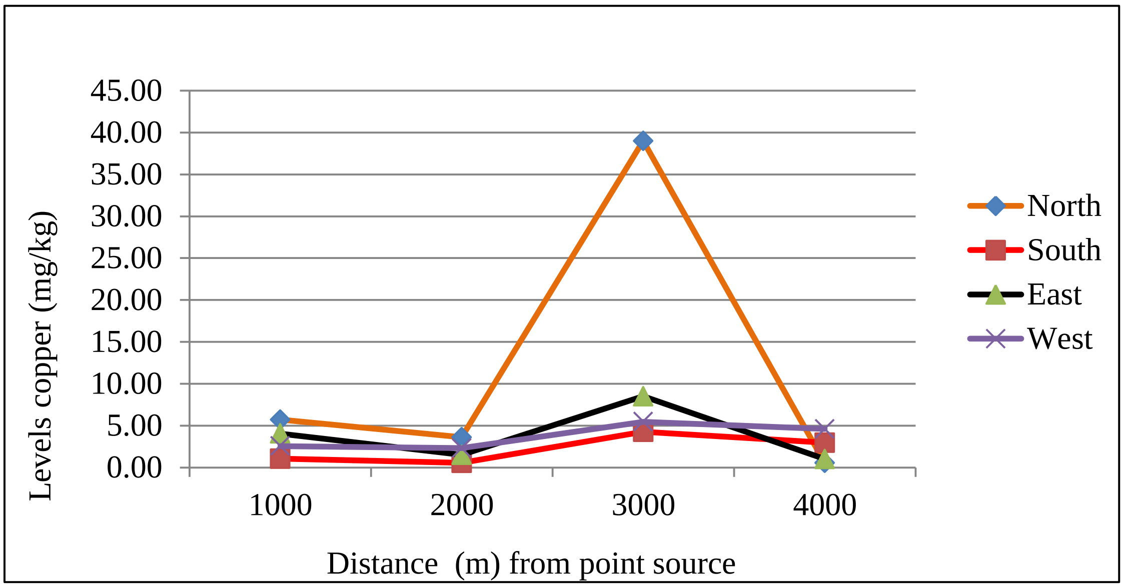


Figure 5.10: Copper in Sweet Potato Leaves
Source: Field Data (2013)

Other than the highest concentration at 3000 m north, generally copper concentration in sweet potato leaves was below 10 mg/kg in all directions. The maximum level of copper level was 39 mg/kg at 3000 m north and the least was 0.55 mg/kg at 2000 m.

5.4.3.2 Cobalt

The results in Figure 5.11 show a marked discrepancy in the presence of cobalt in sweet potato leaves in all directions. Figure 5.11also indicated lowest cobalt concentration in sweet potato leaves in the north at 2000 m. However, the south and the west registered highest concentration of cobalt in sweet potato leaves. Additionally, cobalt concentrations in the south and in the east at 1000 m and 3000 m recorded above 150mg/kg. Furthermore, Figure 5.11 indicates that the concentration of cobalt in sweet potato leaves were above 50 mg/kg in all directions. The highest being 335.5 mg/kg at 2000 m east. The results have showed that 98.6 percent of the samples had more than 100 mg/kg of cobalt and 1.4 percent was less than 100 mg/kg. The lowest levels were 80 mg/kg at 2000 m west of the point source. Therefore there is cobalt contamination in sweet potatoes.

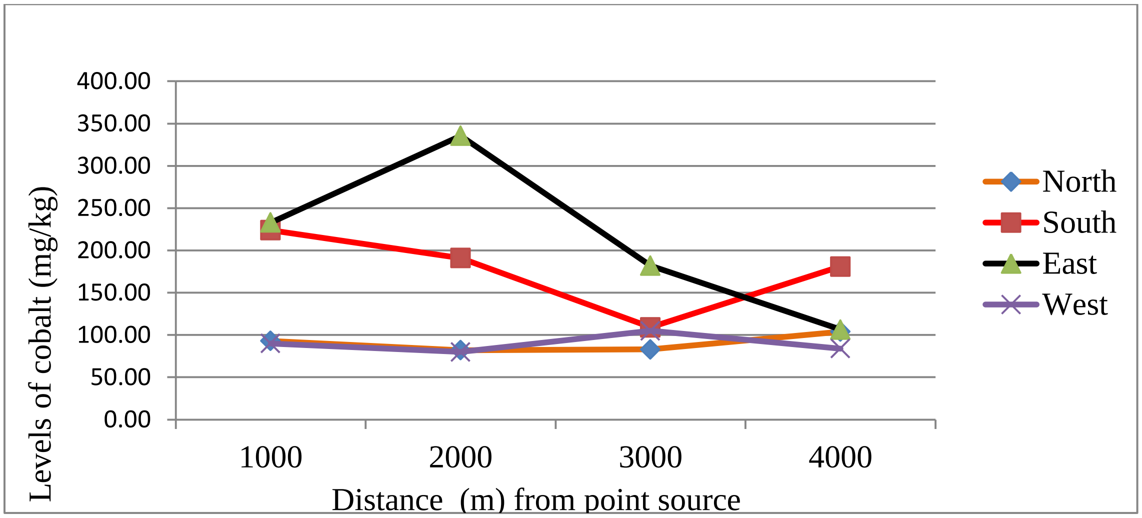


Figure 5.11: Cobalt in Sweet Potato Leaves
Source: Field data (2013)

5.4.3.3 Iron

In Figure 5.12 the levels of Iron in all samples were uniformly distributed in all directions regardless of distance from point source. According to Figure 5.12, samples at 2000 m north, 3000 m south and 4000 m west of point source indicated high concentrations of Iron in sweet potato leaves. The high levels of iron sweet potatoes can be attributed to both natural occurrence and mining because points near the point source also indicated high levels of iron in Sweet potatoes.

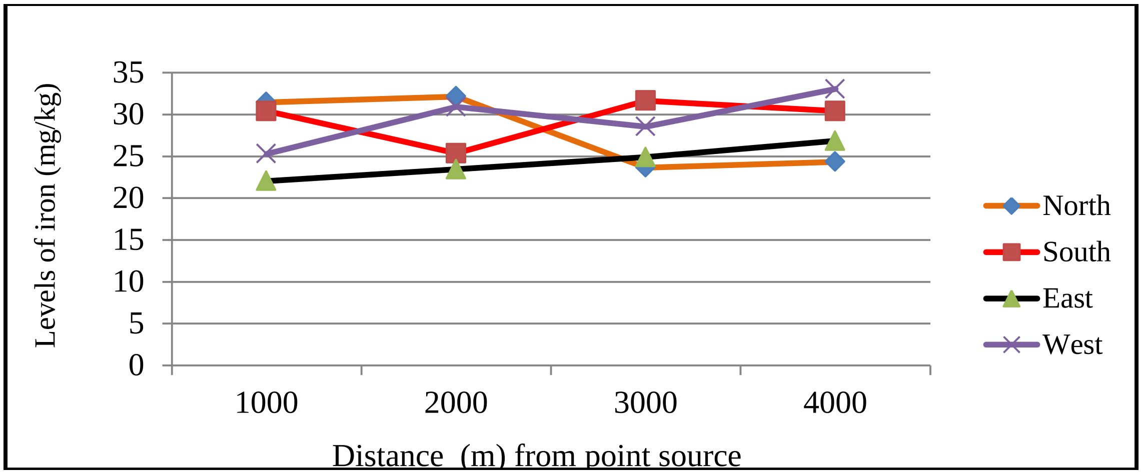


Figure 5.12 Iron in Sweet Potato Leaves
Source: Field data (2013)

The highest level was 33.05 mg//kg at 4000 m west of point source. The least was 22.05 mg/kg at 1000 m east of point source. The results also indicate that the concentration of iron in all samples was more than 20 mg/kg.

5.4.4 Golden White Eggplants

Golden white egg plants are either eaten raw or cooked for consumption in the study area. The results of heavy metal contamination in eggplants were indicated in Figures 5.13 to 5.15.

5.4.4.1 Copper

In Figure 5.16, the highest levels of copper concentration in golden white eggplants were at 5000 m east, 2000 m east and 3000 m south. The least copper contaminated areas were at 1000 m south and 2000 m west.

Figure 5.13 indicated that the levels of copper in golden white eggplants varied from sample to sample. For example, Figure 5.13 showed that the highest levels of copper in golden white eggplants are 70 .00 mg/kg at 3000 m south and 69.50 mg/kg at 2000 m east. Others were 44.30 mg/kg east and 38.35 mg/kg south of point source. The least copper concentration in eggplants was 7.55 mg/kg at 1000 m south followed by 8.40 mg/kg at 2000 m west of point source which shows that the mines do not affect the levels of iron in golden white eggplants.

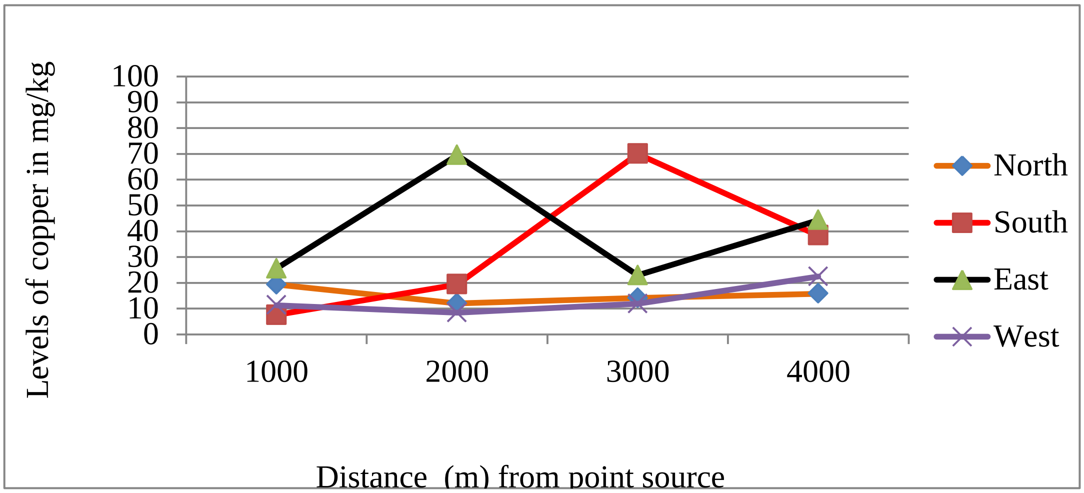


Figure 5.13: Copper in Golden White Eggplants
Source: Field Data (2013)

5.4.4.2 Cobalt

Figure 5.14 indicated that the highest cobalt concentrated sample in the study area was at 1000 m north of point source. The others were at 2000 m north and east, and 3000 m south of point source.

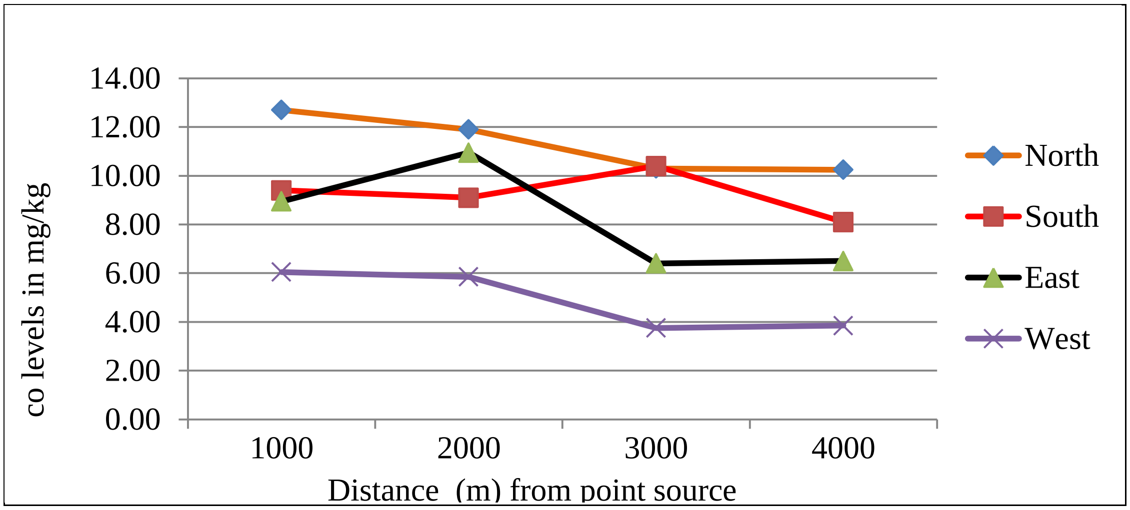


Figure 5.14: Cobalt in Golden White Eggplants
Source: Field data (2013)

The results in Figure 5.14 suggest that the highest level of cobalt concentration in golden white eggplants was 12.70 mg/kg north of point source. The others were 11.90 mg/kg and 10.95 mg/kg at 2000 m north and south of point source respectively, followed by 10.40mg/kg at 3000 m south of point source. The lowest levels of concentration were in the eastern side of the point source at 3.75 mg/kg. However, more than 50 percent of the samples recorded less than 10 mg/kg of cobalt in golden white eggplants. The results of the study indicate that the levels of cobalt in golden white eggplants reduce with distance implying that the point source has an effect on cobalt contamination in the golden white eggplants.

5.4.4.3 Iron

The results in Figure 5.15 showed that samples collected from the eastern side of the point source recorded high levels of iron contamination in golden white eggplants. The least iron concentrated samples were at 1000 m and 3000 m west of point source

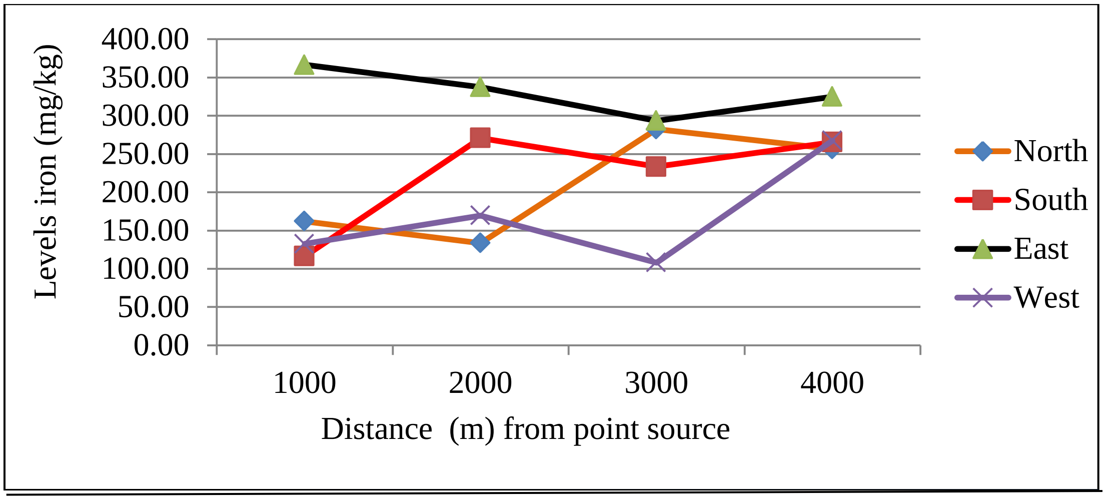


Figure 5.15: Iron in Golden White Eggplants
Source: Field data (2013)

Figure 5.15 indicated that the levels of iron in golden white eggplants ranged from 108mg/kg to 372.50 mg/kg. The highest recorded levels were 366 mg/kg at 1000 m east of the point source and the lowest was at 3000 m west with 108 mg/kg. Furthermore, Figure 5.15 showed that 100 percent of the samples were more than 100 mg/kg. The variations in the levels of iron in soil indicate that there is more than one factor controlling iron contamination which is the natural high presence of iron in the soil and the mining effect.

According to ZCCM (2005) a more direct way of determining whether heavy metals in food crops are present in high concentrations that may be hazardous to humans is through the comparison of estimated related food consumption with thresholds for oral intake (Table 5.5).

Like any other tropical country in Africa, Zambia like Nigeria a daily diet is dominated by starchy staple foods, vegetables (a cheap and readily available) a sources of proteins, vitamins, minerals and essential amino acids. However, recent studies have shown that most of these developing countries have a challenge of mining induced heavy metal contamination in soil and food crops, which is a challenge to food production. For instance, studies conducted by Wilberforce and Nuabe (2013) in Ebony State in Nigeria revealed that levels of heavy metals in soil and food crops were above US-EPA and WHO thresholds. Therefore the soil and food crops were contaminated with heavy metals. Nevertheless, developed countries also suffer challenges of heavy metal soil and food crop contamination like developing countries. For instance, in South Africa, Ayeni *et al.,* (2010)'s studies showed a significant degree of heavy metal contamination in soil exceeding thresholds. Cui *et al*., (2004), indicated that in both soil and vegetables at between 500m to 1500m away from the smelter were heavily contaminated compared to those at 5000m. This means that the food crops that grow on heavy metal contaminated soil are also contaminated and hazardous to the health of the consumer.

The findings of this study show that there is mining induced heavy metal contamination in food crops. The findings of this study show that there is copper, cobalt and iron contamination in food crops (Tables 5.6 to table 5.8).

5.4.5 Levels of Copper in Food Crops

In this study levels of copper in soil did not differ much with the levels in food crops because samples of food crops were collected from the same area where soil samples for copper were collected (Table 5.6). According to Kribek *et al.*,(2005) food crops that grow from copper contaminated soils are also contaminated with copper.

Therefore, high levels of copper in soil also have an effect on crops that grow on it. The findings of this study show that the levels of copper in cassava are above the FAO thresholds of 0.2 mg/kg. Therefore, cassava leaves in this study area are contaminated with copper.

The results in this study indicated that copper concentration was relatively high in cassava compared to sweet potato leaves, pumpkin leaves and eggplants. The concentration of copper in cassava ranged from 11.80 to 101.50 mg/kg. In the north, the highest levels of copper in cassava leaves were 26.10 mg/kg at 1000m from point source, in the south 105 mg/kg at 1000 m, east 150 mg/kg at 4000 m and 101mg/kg at 2000 m.

Table 5.6: Copper contamination in food crops

Food Crops	Copper Contamination (mg/kg)	
	From	To
Cassava leaves	11.80	150.00
Pumpkin Leaves	7.50	39.25
Sweet Potato Leaves	0.55	39.00
Eggplants	7.55	70.00
FAO Threshold	**0.2 mg/kg**	

Source Field Data (2013)(Marshall et al., (2004)

The cause of such high levels is the presence of mining activities in the north such as mainly the dust fallouts from the mining processes at number one shaft and dust from the from dry Lubengele tailings dump. In the south high levels of copper is also explained by dust fallouts from mining activities and the dry old Kakoso tailing dump. To the east the levels ranged from 29.55 mg/kg to 15.7 mg/kg. Basically, in the east the highest levels of copper in cassava at 150 mg/kg are explained constructions using waste rock products from the mines and the dust from Fitwaola open pit. West of the point source the levels of copper in cassava were above 50mg/kg with an exception of a sample at 3000 m being on the windward side. These findings are attributed to the north-east and south-east trade winds that blow over number one and three shafts and in the study area. It was also observed that cassava was observed to have had yellow tips and chlorosis an indication of excessive concentrations of copper, cobalt and iron (Plate 5.5).

Lindahl (2014) revealed that cassava leaves and sweet potato leaves in the in Mufulira have elevated copper levels at 253.90 mg/kg compared to those of the study area with the highest level at 150mg/kg. Lindahl (2014) preferred crops like maize to be grown because from the studies conducted maize had the lowest level of heavy metals of 1.5 to 2.6 mg/kg.

Plate 5.5 Cassava leaves affected by chlorosis.
Source: Field Data (2013)

According to the findings in the study, the levels of copper in pumpkin leaves were above the FAO standards of 0.2 mg/kg. Levels of copper in pumpkin leaves ranged from 7.5 to 39.25 mg/kg with a maximum at 1000m south attributed to dust falls from the metallurgical plant, in sweet potato leaves copper ranged from 0.55 to 39 mg/kg and eggplants from 7.55 to 86 mg/kg. The highest levels of copper accumulation were noted near mining activities. It is also important to note that sweet potato leaves had the lowest concentrations of copper at .55 mg/kg. According to Odukoya *et al.*, (1987) sweet potatoes leaves are too narrow to promote high transpiration rates and food crops such as spinach, Cauliflower, cabbage, Amaranthus, Chinese cabbage and rape are high bio-accumulators of heavy metals because of their broad leaves that initiate higher transpiration rates. Additionally, in all samples copper levels were below 10 except for the sample at 3000 m north which was at 39mg/kg near number three shaft due the effects of dust fallouts from the haulage road between number one and three shafts. In short, copper concentration trend in vegetables was; cassava > eggplants > pumpkin leaves > sweet potato leaves. It is also important to note that copper levels in all the food crops exceeded the thresholds in Table 5.5.

Similarly, studies conducted by Kribek *et al.*, (2005) in the Czech Geological Survey, in the Copperbelt confirmed that Cassava leaves accumulate more heavy metals (6.1 to 611mg/kg) than other food crops sampled. For instance in his study the levels of copper in maize grain was 1.5 to 2.6 mg/kg. This suggests that cassava is a hyper-cumulative plant in heavy metals. Kribek *et al.*,(2002) in his report also attributed cassava hyper-accumulation of heavy metals to long periods of growth and maturing. Hence, crops like cassava, eggplants, sweet potatoes and pumpkins which take more than six months to mature are vulnerable to heavy metal accumulations and toxicity. Furthermore, the results of copper concentration in cassava leaves were above the permissible levels in Table 5.5, which is also similar to the findings of the study conducted by Kapungwe (2013) which indicated very high copper concentration in pumpkin leaves of about 789mg/kg and sweat potato leaves in Mufulira. The findings have also indicated that like levels of copper in soil, there was a decrease in copper concentration level with distance from point source in food crops (Figure 5.16).

Figures 5.16 indicated high concentrations of copper in food crops between 0 and 20 mg/kg of soil where concentration in food crops is a function of heavy metal content in surface soil. In exception of pumpkin leaves levels of copper in cassava, sweet potatoes and eggplants the levels of copper were relatively high (Figure 5.16). These results reveal that food crops grown and consumed in the study area were contaminated with copper. Hence, the humans that consume these food crops are likely to suffer from cardiovascular, central nervous system, kidney, liver, and haematological effects which eventually will lead to death (WHO, 1992).

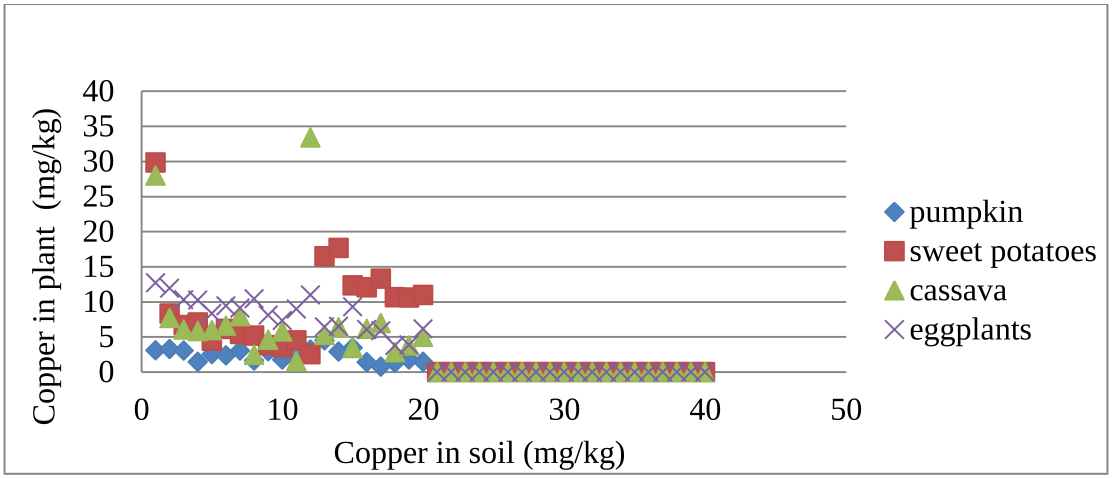


Figure 5.16: levels of Copper in soil and Food crops
Source: Field data (2013)

5.4.6 Levels of Cobalt in Food Crops

Table 5.7 shows that the results of cobalt in food crops are higher than the FAO limits (0.01 mg/kg) used in this study. Therefore, the findings of this study show that food crops in this study are contaminate with cobalt. In this study, cobalt concentrations ranged from 1.55 to 27.95 mg/kg in cassava leaves, 0.75 to 4.5 mg/kg in pumpkin leaves, 2.55 to 29.85 mg/kg sweet potato leaves and 3.75 to 12.70 mg/kg in eggplants. The highest concentrations of cobalt in cassava were 27.95 mg/kg, 4.5 mg/kg in pumpkin leaves, and 29.85 mg/kg in sweet potato leaves and 12.7 mg/kg in eggplants. These concentrations of cobalt in soil in the study area are higher than the acceptable levels (0.01 mg/kg) for oral intake hence, a threat to humans that consume these food crops.

Studies conducted by Kribek *et al.*, (2005) in Chambishi affirms the findings of this study in that when the results are compared with the guideline values of toxicity used by ZCCM (2005) presented in Table 5.7, cobalt in food crops exceeded the limits of the trace metals under study. In Mufulira, concentration levels of toxic metals such as cobalt were also found in food crops such as cassava leaves (1.0 to 77.9 mg/kg) and yams (Kriberk *et al.*, 2004). Therefore, consumption of such could cause harm to the health of consumers. Additional the report states that these two food crops can be used as good indicators of industrial contamination on the Copperbelt. Edward *et al.*, (2015) states that once cobalt makes its way to the environment, it cannot be destroyed and when humans are exposed to cobalt they would suffer from heart and lung problems, deafness, tinnitus, vertigo and blindness.

Table 5.7: Cobalt contamination in food crops

Food Crops	Cobalt Contamination (mg/kg)	
	From	To
Cassava leaves	1.55	27.95
Pumpkin Leaves	0.75	4.50
Sweet Potato Leaves	2.55	29.85
Eggplants	3.75	12.70
FAO	**0.01**	

Source: Field Data (2013)

Figure 5.17 showed the levels of cobalt in food crops as function cobalt in soil. Figure 5.17indicated the logic that where there is high concentration of cobalt in soil, food crops would also have high levels of cobalt. In this study, it has also been observed that levels of cobalt in soil and food crops reduced with distance from point source.

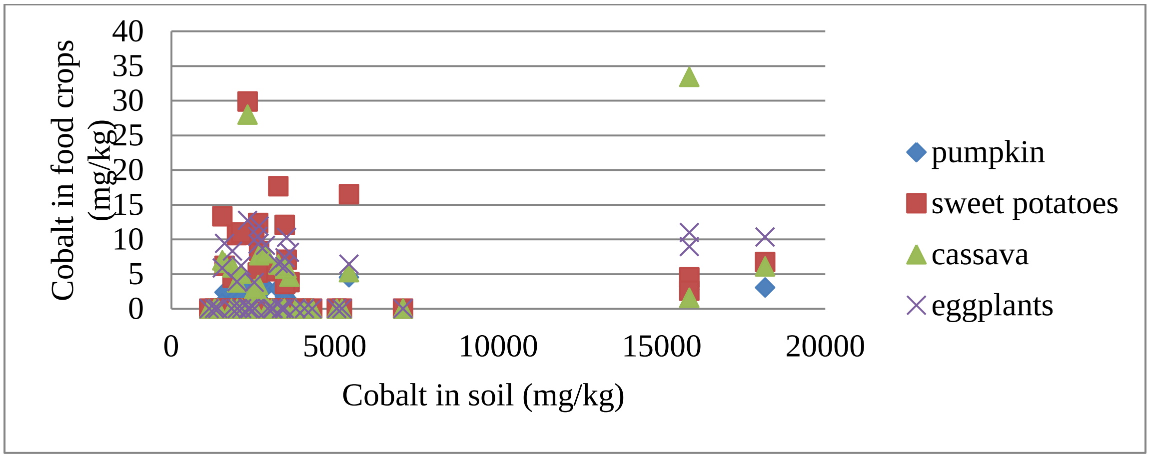


Figure 5.17: Levels of Cobalt in soil and Food Crops
Source: Field Data (2013)

5.4.7 Levels of Iron in Food Crops

The findings in this study in Table 5.8 show that iron concentrations in food crops are above the thresholds established by FAO at 5.0 mg/kg adapted from Marshall *et al.,* (2004). Hence, the food crops in this study area are contaminated with iron. In this study the highest level of iron in cassava were 335.50 mg/kg at 2000 m east and Pumpkin leaves 341.50 mg/kg at 3000 m east could have been caused by natural processes in the soil because there is no mining activity near these sampling points. In sweet potatoes the highest levels of iron were 33.05mg/kg at 4000 m west emanating from dust released from the metallurgical plant and haulage road, and for eggplants 366.00 mg/kg at 1000 m east due to dust originating from the metallurgical plant. It is also important to note that food crops like cassava, pumpkins, sweet potatoes and eggplants even in a natural environment accumulate high levels of iron (Ma and Logan, 1994).

Table 5.8: Iron contamination in food crops

Food Crops	Iron Contamination (mg/kg)	
	From	To
Cassava leaves	80	335.50
Pumpkin Leaves	1.49	351.50
Sweet Potato Leaves	22.05	33.05
Eggplants	108	372.50
FAO	**5.0**	

Source: Field Data (2013)

The lowest levels iron in food crops were 80.50 mg/kg at 2000 m west in cassava leaves, 1.49 mg/kg at 4000 m south in pumpkin leaves, 22.05 mg/kg at 1000 m east in sweet potato leaves and 108.00 mg/kg at 3000 m west of point source. These low levels of iron in food crops are due to natural processes and continuous cultivation in the same area. In this study, eggplants accumulated ostensibly higher concentrations of iron than the other food crops an indication that it naturally accumulates more iron than the other crops (Kribek et al., 2002). The trend in iron concentration in food crops in the study area was eggplants>pumpkin leaves>cassava>sweet potato leaves.

The results of the study are also found to be similar to the range of iron levels (2.11–336.9 mg/kg) reported by Kisku *et al.*, (2000) for iron in vegetables irrigated with water mixed with industrial effluents in India. However, the results from this study is typical of a developing economy with low industrial development indicating clear differences with heavy metal contaminants in food crops which includes iron, obtained from developed economies where studies have shown heavy metals more than the Indian and WHO thresholds (Sighn *et al.*, (2010) and Cui *et al.*, *(*2004). The reported results entail that, consumption of food crops with 2.11–336.9 mg/kg of Iron in China and India does not pose potential health risks to consumers while this study showed higher levels of iron in food crops above thresholds posing a health risk to consumers.

The results in Figure 5.18indicated that there are higher concentration of iron in food crops between 0 and5000 mg/kg of soil where heavy metal concentration in food crops is a function of iron concentration in the surface soil. These results show that food crops that are grown and consumed in study area were contaminated with copper, cobalt and iron. Therefore, it is likely that people who consume such contaminated food crops may suffer from cardiovascular, central nervous system, kidney, liver, and haematological effects which eventually lead to death (Kribek *et al*., 2002).

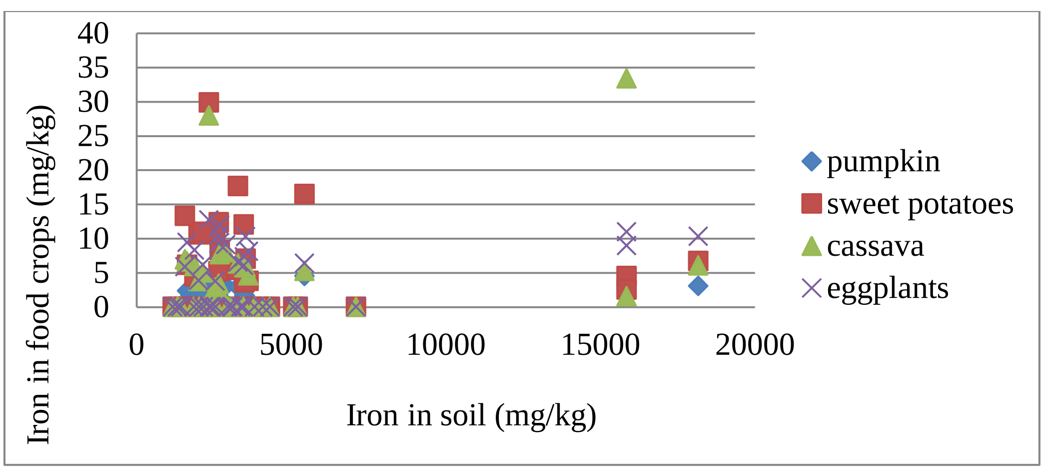


Figure 5.18: Levels of Iron in Soil and Food Crops
Source: Field Data (2013)

The results in this study are consistent with the conclusions of the Kribek *et al.*,(2002) which was characterized by high concentrations of heavy metals in soil of and food crops with copper at 101 mg/kg, cobalt above 4.3 mg/kg and iron above 756 mg/kg) at in Chambishi and Mufulira mining towns of the Copperbelt where there are fully-fledged metallurgical plants. According to Kribek *et al.*,(2002), levels copper in soil were ranging between 19210-63600 mg/kg and cobalt was between 29-490 mg/kg near the smelter while in food crops such as cassava, eggplants and maize levels of heavy metals were also above thresholds. For instance, copper in cassava leaves ranged from 6.1 to 611.0 mg/kg cobalt was 1.0 to 779 mg/kg while in eggplants copper was 250 mg/kg and cobalt was 3.3 mg/kg. Copper levels for maize were the lowest with copper ranging from 1.5to 2.6 and cobalt o.o3 to 0.30 mg/kg. In relation with the international threshold, most of the sampled food crops in the study area were contaminated with copper, cobalt and iron in contrast with sweet potato leaves which had lower copper concentration as below the threshold used in this study (Table 5.5). The results of this study were similar to the studies conducted in Kitwe, Chambishi and Chingola by Kribek e*t al.*, (2005). These

Plants require a continuous supply of iron for growth because it is an essential component of the many enzymatic functions and light energy transferring compounds in photosynthesis (Ma and Logan., 1994). In the human body, iron is mainly in the form of haemoglobin, which serves to transport oxygen. As a key element, iron deficiency causes abnormal growth and reproduction. However, iron thresholds in plants are quite high measuring 400 to 1000mg/kg (KCM, 2005). In humans, the acute toxicity of iron ingestion is unlikely to be encountered from any source other than medical iron (Committee on Medical and Biological Effects of Environmental Pollutants, 1979).

5.5 Summary of heavy metal contamination in food crops

The results of the levels of heavy metal concentrations of copper, cobalt and iron in the food crops in Figure 5.17 varied greatly. The results registered high concentration iron in food crops in all directions from point source. Copper was below 100mg/kg, recorded highest in cassava eggplants and pumpkin leaves and was lowest in sweet potato leaves while cobalt was the least contaminant in food crops.

Figure 5.19 showed that the highest iron concentration was 279 mg/kg in sweet potatoes followed by golden white eggplants at 255.53 mg/kg. In Cassava and pumpkin leaves iron was above 125 mg/kg. The least heavy metal concentration in food crops was cobalt especially in pumpkin leaves at 2.39 mg/kg.

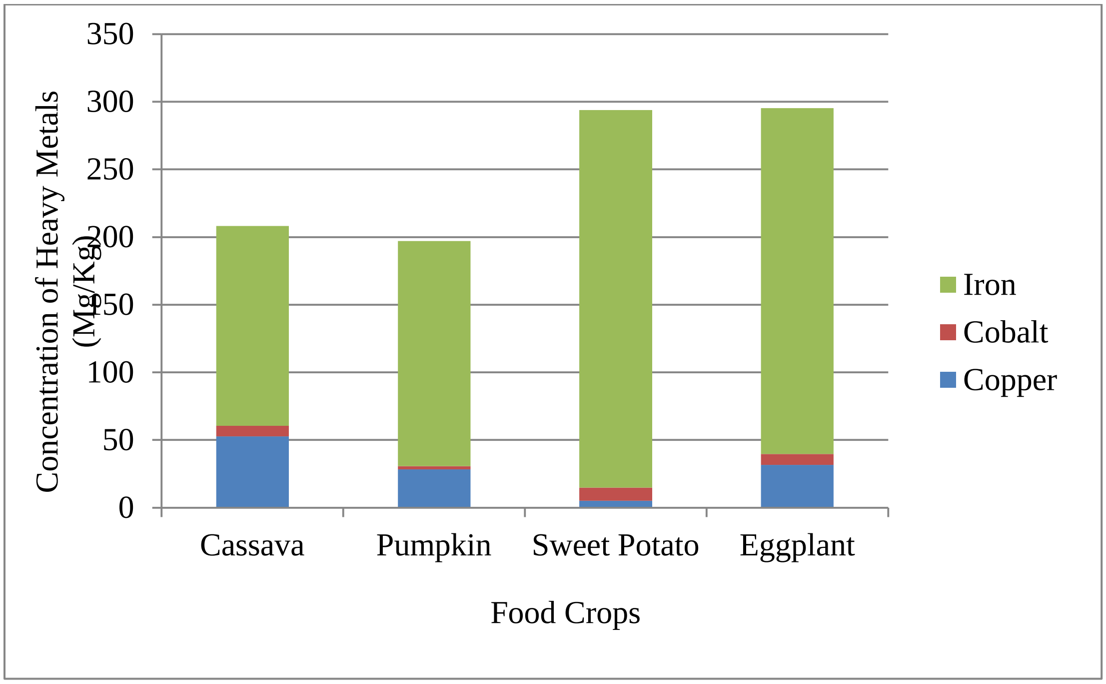


Figure 5.19: Heavy Metals in Food Crops
Source: Field Data, (2013)

The highest copper concentration was in cassava leaves at 52.8 mg/kg while copper in sweet potatoes was at 9.58 mg/kg. The study revealed that the trend of heavy metal concentration in food crops in Chililabombwe was iron > copper and cobalt. (Fe>Fe > Cu > Co).

5.6 Implication of Heavy Metal Food Crop Contamination to Humans

The results of this study showed heavy metal contamination in soil and food crops was above FAO thresholds in Tables 5.5. Therefore, prolonged consumption of such food crops of above years is unsafe because it is likely to caus**e** chronic accumulation of heavy metals in the kidneys and livers of humans causing disruption of numerous biochemical processes, leading to cardiovascular, gastrointestinal cancer, nervousness, haematological effects, heart and lung problems, deafness, tinnitus, vertigo, blindness, kidney and bone diseases that make people vulnerable to incurable diseases and eventually die (WHO, 1992).

According to Ma *et al., (*1994) higher levels of the elements under study in soil and food crops are of concern because of their adverse effects on food quality, safety and marketability, crop growth and environmental health. In the study area, food crops were grown for consumption and for sale to the local people. According to Geogopoulos *et al*., (2001) oral intake of more than 30mg/kg of copper daily for two to three years would cause gastrointestinal effects (O'Donohue *et al.*, 1993) Therefore, contamination in food crops in Chililabombwe may prove to be hazardous to the health of the consumers.

However, the scenario of heavy metal soil and food crop contamination by mining activities does not only take place in Africa. Demirezen and Ahmet (2006) obtained results of high copper contaminated soils and food crops in the industrial areas of Turkey. This observation agrees with Nwoko and Egunobi's (2001) findings, which revealed significantly high levels of heavy metal contamination in fruits grown in an industrialised area of Greece exceeding EU thresholds. Studies conducted by Rahman *et al.*, (2012) in Bangladesh also revealed high concentrations of heavy metals in agricultural soil exceeding the Indian standards where Cadmium levels were 3-fold higher than the thresholds and 9-times higher than the Chinese standards. Furthermore, Rahman *et al.*, (2012) assets that, even at low levels some heavy metals such as Cadmium, chronic exposure are a health hazard to humans and animals. In Australia, Kachenko and Singh (2005) observed high levels of heavy metals in soil and vegetables in Balaroo and Port Kembla in Australia. Heavy metals in foods exceeded the International food standard guidelines of the European Community. These findings highlight the dangers of growing food crops within the vicinity of mining activities.

According to Jinadasa *et al.,* (1997) high levels of copper in food crops are hazardous to humans because their accumulation in the body deteriorates the health of the consumer. Copper is both an essential element and a contaminant. Adverse effects from copper contamination can be observed with the recommended daily copper intake of 2–3 g for adults, or 0.03–0.05 mg/kg body weight for a 60kg adult, to ensure minimum biological requirements are met (FAO/WHO, 1992). High levels of copper in food crops are hazardous to humans because their accumulation in the body deteriorates the health of the consumer by causing critical illnesses such as gastrointestinal effects accompanied with nausea, vomiting, and diarrhoea as primary effects resulting from acute exposure to copper (WHO, 2004). Liver damage is the primary manifestation of copper toxicity in people with copper homoeostatic disorders (ZCCM, 2005) and leads to death.

According to Guerra *et al*., (2012)high levels of cobalt in food crops have effects in the life of a consumer. Guerra *et al*., (2012)states that the acute effects of Cobalt ingestion through foods causes cardiovascular effects, ventricular failure, gastrointestinal and blood effects, liver injury and allergic dermatitis which leads to death. Therefore the high levels of cobalt in vegetables in the study area are an indication that the people in the study are likely to suffer from cardiovascular effects, ventricular failure, gastrointestinal and blood effects, liver injury and allergic dermatitis and eventually cause death.

According to the findings, the adverse effects excessive iron intake from dietary sources, appears to be high in the general world population (O'Donohue *et al.*, 1993). The adverse effects may include acute toxicity with vomiting and diarrhoea, followed by cardiovascular, central nervous system, kidney, liver, and haematological effects. Others are gastrointestinal effects associated with high-dose supplements, such as constipation, nausea, vomiting, and diarrhoea.

Kachenko and Singh (2006) also add that, dietary exposure to heavy metals like copper, cobalt and iron through consumption is a risk to human health. Consumption of heavy metal contaminated food depletes some essential nutrients in the body. For instance, consumption of copper established thresholds can cause kidney failure, stomach pain, nausea, vomiting, bloody diarrhoea, fever, low blood pressure, anaemia intrauterine growth retardation, impaired psychosocial behaviour, and heart failure. The effects of cobalt include asthma, pneumonia, vision problems. Thyroid damage, heart problems, vomiting and nausea, bleeding, diarrhoea and loss of hair while intake of high iron concentrated food crops may cause abdominal pains failure causing a decrease in immunological defence, disabilities associated with malnutrition and high prevalence of upper gastrointestinal cancer (Arora *et al*., 2008). Therefore, people in Chililabombwe are likely to suffer from these chronic illnesses. Hence, mining deserves special attention in sustaining the environment for the health of the humans.

Therefore, this study revealed that all the food crops are contaminated with heavy metals in the study area. Heavy metal contamination in the study area contaminates food crops and ingestion thereof through consumption may affect human health and eventually leads to death.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This chapter gives conclusion of the findings of the study on an assessment of mining induced heavy metal soil and food crop contamination, implications and recommendations on heavy metal soil and food crop contamination thereof in Chililabombwe.

6.2 Conclusion

The aim of this study was to provide an assessment of mining induced heavy metal soil and crop contamination in Chililabombwe on the Copperbelt Province of Zambia. This study showed that the levels of heavy metals (copper, cobalt and iron) in soil were higher than thresholds used in this study.

The findings of the study in Chililabombwe indicate that the levels of heavy metals were high in soil and food crops. For, instance,86 percent of the soil samples for copper were above 140 mg/kg thresholds established by FAO and for iron 100 percent of the soil were above the EU thresholds used in the study. However the levels of cobalt were below the EU thresholds. This study also indicated that soil was acidic near the point source at 4.5 to 4.67. However, most of the samples showed alkalinity. Therefore, the soil in the study area is contaminated with copper and iron.

The findings of this study also show that the levels of copper, cobalt and iron in food crops exceeded the WHO thresholds used by ZCCM (2005). For instance, in all the food crops copper was above 0.2 mg/kg, cobalt was above 0.02 mg/kg and iron was above 5.0 mg/kg. These elements show the extent of heavy metal crop contamination in Chililabombwe. The levels of heavy metals in both soil and food crops depended on mining contamination and the bedrock geochemistry of the study area. Therefore, Dietary exposure to copper, cobalt and iron through consumption of food crops has been identified as a risk to human health.

Copper concentration in the study area was above thresholds and the highest concentrations were near the point source in the north, south, east and west directions. The analytical data also indicated significant concentrations of copper in the study area. Cobalt concentration in soil was below thresholds (FAO, EU, Canadian and UK thresholds) while in food crops it exceeded thresholds used in the study. Although iron is the most abundant mineral in the earth's crust, its concentrations were higher than threshold. Therefore, the study area has significant concentrations of heavy metals indicating toxicity and hazardous to the community.

The study also indicated that the coefficient of determination (R^2) revealed that the levels of heavy metal concentration in soil explained by distance for copper, cobalt and iron were at 90 percent copper with distance, 80 percent cobalt and distance and96 percent for iron and distance. Therefore, statistical coefficients indicated significant linear relationships between Heavy metal contamination (copper, cobalt and iron) and distance from point source with $p<0.05$ at confidence level of 0.95. Analysed data using Pearson's product moment correlation between distance and heavy metals showed a significant negative correlation between copper and distance with $r = -0.53402$. Copper and cobalt showed a significant correlation with $r = 0.58827$. However copper and iron had an insignificant correlation of -0.028835. The findings also indicated a significant correlation between distance and cobalt was $r = -0.453402$, cobalt and iron showed an insignificant correlation of $r = 0.09212$. Iron and cobalt also showed an insignificant association with distance.

Heavy metal food crop contamination in the study area was assessed. The results indicated that accumulations of copper, cobalt and iron were found to be higher than FAO thresholds used by ZCCM, (2005) in food crops such as cassava, pumpkin and sweet potato leaves, and eggplants cultivated in the study area. The concentrations of heavy metals in all the four food crops were found to be above 0.2 mg/kg thresholds for copper oral intake established by FAO. Cassava leaves ranged from 11.80 to 186.50 mg/kg, pumpkin leaves from 7.50 to 250.50 mg/kg, sweet potato leaves 0.55 to 39.0 mg/kg and eggplants from 7.55 to 86.66 mg/kg. The findings for cobalt also indicated levels above 0.2 mg/kg of FAO thresholds with Cassava leaves ranged from 1.55 to 27.95 mg/kg, pumpkin leaves from 0.75 to 4.50 mg/kg, sweet potato leaves 2.55 to 29.85 mg/kg and eggplants from 3.75 to 12.70 mg/kg. The findings for cobalt also indicated levels above 0.2 mg/kg. The findings for iron were also above 5.0 mg/kg of the FAO thresholds with cassava leaves ranging from 80 to 335.50 mg/kg, pumpkin leaves from 1.49 to 351.50 mg/kg, sweet potato leaves 22.05 to 33.05 mg/kg and eggplants from 108.00 to 372.50 mg/kg. The findings for iron also showed levels above 5.0 mg/kg. The findings also indicated that concentration of heavy metals in food crops were higher near point source. Cassava leaves proved to be hyper-cumulative because concentrations of the three elements proved to be higher compared to other food crops.

The high concentration of heavy metals in soil and vegetables beyond the FAO, EU and WHO thresholds used in this study is a risk to the health of humans and animals. The implications are that, prolonged consumption of heavy metal contaminated food crops may lead to chronic accumulation of heavy metals in kidneys and liver disrupting numerous biochemical processes causing cardiovascular, gastrointestinal cancer, nervousness, kidney and bone diseases which are incurable and eventually death. For instance, copper may cause cardiovascular, central nervous system, kidney, liver, and haematological effects which eventually will lead to death. Studies conducted on farms along Mushishima River and the Kafue flats confirmed the death of animals that consumed plants with heavy metal contamination.

However, heavy metals were also found to be significantly high in the food crops. The trend of heavy metal contamination in food crops was Fe > Cu > Co. These heavy metals are considered toxic for food crops consumed by humans and animals and eventually lead to death.

The statistics in this study have revealed that there is significant evidence to state that soil and food crops in Chililabombwe were found to have heavy metals above acceptable levels. Hence, soil and food crops in Chililabombwe are contaminated with heavy metals like copper, cobalt and iron. Therefore, the community that consume crops grown in the study area are likely to suffer from chronic illness resulting from heavy metal food crop contamination which may cause chronic illnesses and eventually death.

Mining is the major source of heavy metals contamination in the study area Kribek *et al*., 2002). Mining activities that contaminate soil in this study area include; Lubengele tailings dump, old Kakoso tailings dump, Fitwaola open–pit, shafts one, three and four. These mining activities produce waste materials that contain heavy metals which contaminate soil and food crops (KCM, 2001). These contaminants are a risk to the health of the people in Chililabombwe. Therefore, it prompted the study.

The findings of this study have demonstrated the apparent influence of heavy metal induced mining contamination in the study area. Therefore, Chililabombwe suffers from copper, cobalt and iron contamination which has contaminated food crops. Hence, it is likely to cause chronic illnesses and death to humans that consume the food crops.

6.3 Recommendations

In view of the findings of the study, the following recommendations were formulated:

1. Food crops that grow in heavy metal contaminated areas are a hazard to humans and animals. Therefore, food crops like maize which has been found not to be affected by heavy metal soil contamination can be grown in contaminated areas (Kribek *et al*., 2002).

2. Haulage roads are a source of dust that contaminates the backyard gardens in the mine townships therefore Konkola Copper Mine should ensure the haulage roads are wet always in order to suppress the dust.

3. The Local Authorities through the Department of Public Health, Department of Agriculture and KCM should hold sensitisation meetings in the community on heavy metal contaminated soil and food crop contamination.

6.4 Future Research Works

It is also important that in future a comparative study be conducted by researchers in Chililabombwe on heavy metal soil and food crop contamination during the dry season.

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Appendix 1

Mean Heavy Metal Data in Soil

Sample ID	Direction	Distance (m)	Cu (mg/kg)	Co (mg/kg)	Fe (mg/kg)	pH
SS 1	N	500	1405	225.0	16 375	4.61
SS 2	N	1000	830	56.65	19 750	4.56
SS 3	N	1500	945	75.10	11 812.5	4.65
SS 4	N	2000	565	68.70	13 750	4.50
SS 5	N	2500	113	21.30	9 500	4.67
SS 6	N	3000	108	18.40	5 775	5.22
SS 7	N	3500	149.5	25.25	2 025	5.42
SS 8	N	4000	112.5	19.30	1 7875	5.73
SS 8	S	500	5812.5	157.95	23 750	5.89
SS 10	S	1000	635	26.25	33 625.5	5.09
SS 11	S	1500	680	30.30	33 375	6.51
SS12	S	2000	391	29.25	24 125	6.58
SS 13	S	2500	397	27.60	31 000	6.30
SS14	S	3000	322.5	44.90	35 250	6.31
SS 15	S	3500	225	35.05	9 237.5	6.33
SS 16	S	4000	222	58.25	9 575	6.40
SS 17	E	500	940	50.10	26 875	5.88
SS 18	E	1000	765	24.85	25 250	5.60
SS 19	E	1500	198.5	19.10	11 762.5	5.45
SS 20	E	2000	497	95.75	11 262.5	6.33
SS 21	E	2500	295	40.05	39 375	6.28
SS 22	E	3000	341.5	63.35	7 925	6.37
SS 23	E	3500	126	79.35	7 250	6.28
SS 24	E	4000	193.5	19.40	13 125	6.54
SS 25	W	500	1005	68.05	20 000	4.60
SS 26	W	1000	730	51.65	22 025	5.46
SS 27	W	1500	1685	34.10	8 9 37.5	5.56
SS 28	W	2000	825	59.70	1 725	6.61
SS 29	W	2500	675	36.90	2 8 75	6.60
SS 30	W	3000	327	25.20	7 1 75	6.57
SS 31	W	3500	209	23.05	4 0 93.7	6.48
SS 32	W	4000	306	31.25	4 112.5	5.80

Source: Field data (2013)

Appendix 2

Available Heavy Metal Plant Intake in Soil

Sample ID	Direction	Distance	Cu	Co	Fe	pH
1	N	4000	24	118	0.668	4.6
2	N	3500	25	111	0.472	4.56
3	N	3000	20.2	25.8	0.2	4.65
4	N	2500	9.02	7.74	0	5.22
5	N	2000	16.12	11.5	0	5.73
6	N	1500	64.5	4.8	0	6.12
7	N	1000	65.8	6.4	0.082	6.25
8	N	500	58.9	7.36	0.074	6.51
9	S	5000	41.8	8.4	0	6.58
10	S	4500	53	4.2	0	6.3
11	S	4000	55.4	103	0.55	6.31
12	S	3500	47.7	10.9	0	6.33
13	S	3000	48	5.06	0	6.4
14	S	2500	144	0.618	0.822	6.51
15	S	2000	24	7.26	0	6.47
16	S	1500	19.54	8.96	0	6.13
17	S	1000	16.42	177	0	5.88
18	S	500	20.42	108	0	6
19	W	5000	5.2	13.28	0	6.33
20	W	3500	49.2	13.78	0	6.28
21	W	3000	12.34	6.74	0	6.54
22	W	2500	26.4	13.04	0	6.24
23	W	2000	56.6	4.74	0	6.41
24	W	1500	12.74	8.12	0	6.45
25	W	1000	63.6	3.18	0	6.56
26	W	500	55.8	3.88	0	6.61
27	E	4000	58.8	5.84	0	6.48
28	E	3500	53.6	13.12	0	5.8
29	E	3000	48.1	15.2	0	6.1
30	E	2500	4.18	17.64	0	6.13
31	E	2000	17.6	9.32	0	6.45
32	E	1500	18.48	119	0	6.51
33	E	1000	54	125	0	6.23
34	E	500	75	112	0	5.6

Source: Field data (2013)

Appendix 3

Vegetable heavy metal contamination in cassava Leaves

Sample No.	**Direction from point source**	**Distance (m)**	**cu mg/kg**	**co mg/kg**	**Fe mg/kg**
1	North	1000	26.10	27.95	93.00
2	North	2000	12.70	7.70	82.00
3	North	3000	11.80	6.05	83.00
4	North	4000	15.05	5.80	104.50
5	South	1000	105.00	6.60	224.00
6	South	2000	49.70	7.95	191.00
7	South	3000	25.25	2.45	109.00
8	South	4000	35.35	4.60	181.50
9	East	1000	23.55	1.55	233.00
10	East	2000	29.75	33.40	335.50
12	East	3000	12.95	5.25	182.00
13	East	4000	150.00	6.35	106.50
14	West	1000	91.50	6.15	90.50
15	West	2000	101.50	6.95	80.50
16	West	3000	26.00	2.80	105.00
17	West	4000	57.55	3.75	84.00

Appendix 4

Heavy metal contamination in Pumpkin Leaves

Sample No.	**Direction from point source**	**Distance (m)**	**cu mg/kg**	**co mg/kg**	**Fe mg/kg**
1	North	1000	7.50	3.10	95.00
2	North	2000	10.95	3.25	102.00
3	North	3000	10.15	3.05	112.50
4	North	4000	8.85	1.45	214.00
5	South	1000	39.25	2.35	169.00
6	South	2000	26.70	3.05	255.00
7	South	3000	12.35	1.60	102.00
8	South	4000	10.05	2.95	1.49
9	East	1000	19.20	2.75	351.50
10	East	2000	14.85	3.15	270.50
11	East	3000	20.15	4.50	341.50
12	East	4000	12.85	2.90	304.00
13	West	1000	12.85	1.40	103.00
14	West	2000	12.20	0.75	99.50
15	West	3000	19.10	1.30	98.50
16	West	4000	14.20	1.75	97.00

Appendix 5

Heavy metal contamination in Sweet Potato leaves

Sample No.	**Direction from point source**	**Distance (m)**	**cu mg/kg**	**co mg/kg**	**Fe mg/kg**
1	North	1000	5.70	29.85	31.45
2	North	2000	3.60	8.30	32.15
3	North	3000	39.00	6.70	23.65
4	North	4000	0.55	7.05	24.35
5	South	1000	1.05	6.15	30.40
6	South	2000	0.55	5.40	25.35
7	South	3000	4.25	5.20	31.65
8	South	4000	2.95	3.80	30.40
9	East	1000	4.95	4.50	22.05
10	East	2000	1.50	2.55	23.45
11	East	3000	8.50	16.50	24.90
12	East	4000	1.00	17.65	26.85
13	West	1000	2.55	12.05	25.30
14	West	2000	2.30	13.30	30.90
15	West	3000	5.45	10.65	28.55
16	West	4000	4.60	10.60	33.05

Appendix 6

Heavy metal contamination in Eggplants (IMPWA)

Sample No.	Direction from point source	Distance (m)	cu mg/kg	co mg/kg	Fe mg/kg
1	North	1000	19.30	12.70	162.00
2	North	2000	12.00	11.90	133.50
3	North	3000	24.10	10.30	282.50
4	North	4000	15.80	10.25	256.50
6	South	1000	7.55	9.40	116.50
7	South	2000	19.40	9.10	271.00
8	South	3000	70.00	10.40	233.50
9	South	4000	38.35	8.10	265.50
11	East	1000	25.55	8.95	366.50
12	East	2000	69.50	10.95	337.50
13	East	3000	22.90	6.40	293.50
14	East	4000	44.30	6.50	325.00
16	West	1000	11.35	6.05	132.50
17	West	2000	8.40	5.85	169.50
18	West	3000	11.90	3.75	108.00
19	West	4000	22.45	3.85	267.50

Appendix 7

LABORATORY RESULTS ON HEAVY METAL CONCENTRATIONS IN THE SOIL SAMPLES

TOWN: **STUDY SITE:**
STRATUM A. SITE DESCRIPTION
GPS: **ALTITUDE:** **TIME:**
SAMPLE ID:

METAL	CONCENTRATION	UN GUIDELINES

SAMPLED BY:

APPENDIX 8

LABORATORY RESULTS ON HEAVY METAL CONCENTRATIONS IN VEGETABLES SAMPLES

TOWN: **STUDY SITE:**

STRATUM A. SITE DESCRIPTION

GPS: **ALTITUDE:** **TIME:**

SAMPLE ID:

METAL	CONCENTRATION	INTERNATIONAL GUIDELINES ON VEGETABLES

SAMPLED BY: