COMPARATIVE DETERMINATION OF HUMAN HEALTH RISKS ASSOCIATED WITH CONSUMPTION OF CONTAMINATED GROUNDWATER WITH LEAD IN SELECTED AREAS SURROUNDING THE FORMER LEAD MINE IN KABWE AND NON-MINING AREAS IN LUSAKA, ZAMBIA.

By

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The University of Zambia

Lusaka

Copyright Declaration

I, **TASHA SIAME** do hereby declare that the contents of this thesis represent my work and have not been previously submitted for a degree, diploma, or any other academic qualification at this or any other University.

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Certificate of Approval

This dissertation submitted by **Tasha Siame** is approved as fulfilling the requirements for the award of the Master of Science in Ecological Public Health by the University of Zambia.

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Abstract

Human exposure to Lead (Pb) through the ingestion of contaminated groundwater with Pb has been associated with countless health effects. The current study aimed to determine the Pb levels in groundwater and assess the associated human health risks of exposure to Pb through the consumption of groundwater in selected areas surrounding the former lead mine in Kabwe and non-mining areas in Lusaka. A comparative cross-sectional study design was used to determine the levels of Pb and other physicochemical parameters in groundwater of former Pb mining areas in Kabwe and non-mining areas in Lusaka. The human health risk assessment was conducted by estimating the Daily intakes of groundwater in adults and children from mining areas and non-mining areas. A total of 61 groundwater samples were collected from boreholes, that is 34 from mining areas in Kabwe, and 27 samples from non-mining areas in Lusaka. The samples were anlaysed for Pb using Atomic Absorption Spectrometry (AAS). Results showed the Pb levels in groundwater samples from the former Zinc-Lead mining areas in Kabwe (median= 0.131 mg/L) were significantly higher ($p< 0.05$) than the Pb levels from non-mining areas (median= 0.071mg/L) in Lusaka. Overall, 91% of the groundwater samples from mining and 74% from non-mining areas were above the maximum acceptable limit of 0.010 mg/L of Pb in borehole drinking water (WHO, 2011). The study showed that physicochemical parameters like temperature (median= 23-24.8), Total Dissolved Solids (median= 303-601ppm), and pH (6-7.27) were within the WHO-acceptable levels. However, electricity conductivity from mining areas (585 µS/cm) and non-mining areas (1100 µS/cm) indicated levels that exceeded the WHOs permissible limits of $\leq$ 400 µS/cm. This could be attributed to the influence of the leachate from the former mining waste in the mining areas. Spearman's rank correlation analysis test showed that the levels of Pb in groundwater were not influenced by the concentration of the other measured physicochemical parameters. The Estimated Daily Intake (EDI) for adults and children from mining areas recorded significantly higher ($p< 0.05$) values than non-mining areas. The median EDIs for adults (0.004 mg/L) and children (0.013 mg/L) from mining areas as well as children (0.007mg/L) from non-mining areas surpassed the WHOs recommended daily intake of 0.003 mg/L in drinking water. The estimated Target Hazard Quotients (THQs) in children (4.333) and adults (1.333) from mining areas as well as children (2.333) from non-mining areas were > 1. This suggests that health risk complications are likely to accumulate in the future if control measures are not laid in place. Additionally, the estimated cancer risk (CR) was in the range of 5.6×10^{-5} to 1.0×10^{-4} which is within the EPAs threshold risk value (1×10^{-6}) and residual level (1×10^{-4}), therefore, the cancer risk was unlikely. Collectively, drinking groundwater from boreholes in areas surrounding the former Zinc-Lead mine in Kabwe and non-mining areas in Lusaka are a source of exposure to waterbourne Pb in Kabwe and Lusaka. Therefore, ensuring that groundwater sources are monitored for heavy metal levels in accordance with WHO guidelines should be considered. Lastly, investigating the source of Pb contamination of groundwater in non-mining areas of Lusaka is required.

Dedication

This work is dedicated to my mother, Irene, the core of love and a personal source of encouragement, and the cause for my ardent commitment to realizing my full potential. To the Kabwe district's children, adults, and students practicing environmental toxicology all over the world.

Acknowledgement

A reputable parcel of thank you is presented to my supervisor, Dr. Kaampwe Muzandu for the guidance, ideas, and uncountable efforts. You are an icon to me that anything is possible if you work hard in life.

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Acronyms and Abbreviations

°C	Degree Celsius
>	Greater than
<	Less than
≤	Less than or equal to
%	Percentage
AAS	Atomic Absorption Spectrometer
BW	Body Weight
CSF	Cancer Slope Factor
EC	Electrical Conductivity
ED	Exposure Duration
EDI	Estimated Daily Intake
EF	Exposure Frequency
FAO	Food and Agriculture Organisation
GIS	Geographical Information System
GPS	Global Positioning System
IngR	Ingestion Rate
MWDSEP	Zambian Ministry of Water Development, Sanitation and Environmental Protection

NSA	National Statistics Agency
Pb	Lead (Plumbum)
pH	Potential of Hydrogen
PWTI	Provisional Weekly Tolerable Intake
RfD	Reference Dose
SPSS	Statistical Package for the Social Sciences
TCR	Target Cancer Risk
TDS	Total Dissolved Solids
THQ	Target Hazard Quotient
USEPA	United States Environmental Protection Agency
WHO	World Health Organisation

CHAPTER ONE: INTRODUCTION

1.1 Background information

Groundwater is a vital constituent of the ecological and geological environment which significantly impacts biotic development (Mohammadi et al., 2019). However, inadequate regulated industrial development especially in developing countries has been associated with the contamination of groundwater by heavy metals (Liang et al., 2017).

Based on 2015 data by WHO, lead (Pb) exposure accounted for 494 550 deaths and 9.3 million disability-adjusted life years (DALYs) due to long-term effects on health (WHO, 2017). Human exposure to lead from untreated ground drinking water and treated surface (tap) water in cities with lead installations, increases the comparative importance (Ul Haq et al., 2011). Lead may enter the body through ingestion, inhalation, or skin contact (WHO, 2001). In contrast, the most common route of entry is ingestion, and absorption of lead through the skin is rare (Fewtrell, et al., 2003).

Lead is a silvery grayish metal accounting for 13 mg/kg of Earth's crust, it exists in three stable isotopes including, in order of abundance, ^{208}Pb, ^{207}Pb, ^{206}Pb, and ^{204}Pb (Levin, 2014). The health effects associated with exposure to Lead may include; mental retardation and behavioural disorders in children, renal impairment, hypertension, immunotoxicity, and toxicity to the reproductive organs (WHO, 2017).

According to Zambia National Water Supply and Sanitation Council report, about 70% of water distributed in Kabwe is from groundwater obtained from deep boreholes (MWDSEP, 2019). In the case of Lusaka, about 55% of the water distributed comes from groundwater (Foster, 2017). Although drinking water is an important source of lead exposure, the comparative contribution of groundwater to the overall Pb-related disease burden in Kabwe has not yet been assessed.

Meanwhile, researchers in Zambia analysed the chemical composition and lead isotope ratios in seventeen shallow wells, five deep wells, three ponds and three borehole wells in the areas surrounding the lead mine in Kabwe. Researchers found low dissolved Pb ($<4 \times 10^{-5}$ mg/L) but high particulate Pb concentrations (0.002–0.1 mg/L) in seventeen shallow groundwater and five shallow wells exceeded the World Health Organization (WHO) guideline (0.01 mg/L) for total-Pb concentration (Toyoda *et al.*, 2022).

As a result, this study aimed to determine and compare the Pb levels in groundwater and assess the associated human health risks of exposure to Pb through the consumption of groundwater in selected areas surrounding the former Pb mine in Kabwe and non-mining areas in Lusaka.

1.2 Statement of the Problem

In Zambia, a decent number of scholars have researched primarily on lead intoxication in children and levels of Pb in the soil as well as drinking water in areas near the lead-zinc mine in Kabwe (Phiri, 2016; Bose-O'Reilly et al., 2018; Yabe et al., 2020). Hitherto, there has been less attention given to the comparative determination of lead levels in groundwater and the health risks associated with known mining areas and non-mining areas in Zambia.

Nonetheless, exposure to high levels of Pb is a real threat to public health, especially in developing countries (Cobbina et al., 2015). Hematopoietic, renal, reproductive, and central nervous systems are among the systems that are vulnerable to with deleterious effects of lead exposure to high levels of lead (Assi et al., 2016).

1.3 Significance of the Study

The study aimed to determine the Pb levels in groundwater and assess the associated human health risks of exposure to Pb through the consumption of groundwater in selected areas surrounding the former Pb mine in Kabwe and non-mining areas in Lusaka. The study has also generated new information on the status of lead contamination levels in groundwater in known mining areas and non-mining areas in Kabwe and Lusaka. In addition, the study recommended measures to lessen both ground and surface water contamination in so doing preventing health effects due to Pb poisoning.

1.4 Research Questions

1. What is the difference between lead levels in the groundwater of selected areas surrounding the former lead mine in Kabwe and non-mining areas in Lusaka?
2. What are the human health risks associated with the consumption of groundwater contaminated with lead in selected areas surrounding the former lead mine in Kabwe and non-mining areas in Lusaka?

1.5 Study Objectives

1.5.1 General Objectives

To compare human health risks associated with consumption of contaminated groundwater with lead in selected areas surrounding the former lead mine in Kabwe and non-mining areas in Lusaka, Zambia.

1.5.2 Specific Objectives

1. To determine and compare lead levels in the groundwater of selected areas surrounding the former lead mine in Kabwe and non-mining areas in Lusaka.

2. To determine and compare physicochemical water quality parameters (pH, electrical conductivity, temperature, and total dissolved solids) in groundwater of the selected areas surrounding the former mine in Kabwe and non-mining areas in Lusaka.
3. To establish the association between lead levels in groundwater and selected physicochemical water quality parameters of the selected areas surrounding the former mine in Kabwe and non-mining areas in Lusaka.
4. To determine and compare the risk of lifetime exposure to Pb through the consumption of groundwater of selected areas surrounding the former mine in Kabwe and non-mining areas in Lusaka.

1.6 Scope of the study

This study investigated the levels of lead contamination in the groundwater supply system of selected areas surrounding the former Pb mine in Kabwe and non-mining areas in Lusaka, Zambia. The study also determined the Hazard quotient for lead and carcinogenic risks to assess health risks to the Public. Further, other physicochemical parameters that were measured in the groundwater samples include; pH, electricity conductivity (EC), total dissolved solids (TDS), and temperature. Furthermore, Kabwe is a known high-risk area which is why the groundwater samples were drawn from the areas surrounding the former Zinc-Lead mine. For comparative purposes, Lusaka city was used as a non-mining area, and the areas that were selected include; Kanyama and Chelstone due to the presence of boreholes as a source for drinking.

1.7 Operational Definitions

1.7.1 Groundwater: Groundwater is water that has infiltrated the ground to fill the spaces between sediments and cracks in the rock. Groundwater is fed by precipitation (rain or snow) and can resurface to replenish streams, rivers, and lakes (Chilton, 1996).

1.7.2 Lead (Pb): Lead is a naturally occurring element with an abundance of 0.0016% in the earth's crust. It is a member of Group 14 of the periodic table. Natural Lead is a mixture of four stable isotopes: ^{204}Pb (1.4%), ^{206}Pb (24.1%), ^{207}Pb (22.1%), and ^{208}Pb (52.4%), (Levin, 2014).

1.7.3 pH: pH is a measure of hydrogen ion concentration, a measure of the acidity or alkalinity of a solution. pH is measured on a scale that ranges from 1 (strongly acidic) to 14 (strongly basic). In the middle is 7, where the pH is "neutral" like in pure water (Kelley and Wheat, 2016).

1.7.4 Health Risk Assessment: A human health risk assessment is the process to predict the nature and probability of undesirable health effects in individuals who may be exposed to chemicals in contaminated environmental media, now or in the future (EPA, 2014).

1.7.5 Temperature: Temperature is the physical quantity characterizing the state of thermodynamic equilibrium of a system or the degree of heat and coldness of a place or object (Melker, Starovoitov and Vorobyeva, 2010).

1.7.6 Electrical Conductivity (water): Conductivity is a measure of the ability of water to pass an electrical current (Herschy, 2012).

1.7.7 Total dissolved solids (TDS): This is the term used to describe the inorganic salts and small amounts of organic matter present in solution in water. The principal constituents are usually sodium, magnesium, calcium, and potassium cations and hydrogen carbonate, carbonate, chloride, sulfate, and nitrate anions (WHO, 1996).

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

A lot of literature has been written about lead contamination in drinking water and groundwater worldwide. It is a subject that has received the attention of scholars globally, on the contrary, a research gap has been identified because studies on comparing the human health risks associated with consumption of groundwater contaminated with Pb in groundwater between mining areas and non-mining areas are limited. In Zambia, a few scholars have researched on the current trends of blood lead levels, lead and cadmium excretion in feces and urine of children (Ikenaka et al., 2010; Yabe et al., 2015; Yabe, et al., 2020). As a result, this research focused on the comparative assessment of lead contamination in groundwater, quantifying the exposure, and conducting a human health risk assessment from ingestion of groundwater contaminated with Pb.

2.2 Overview of lead across the globe

In 2016, Pb exposure accounted for 63.2% of the global burden of idiopathic developmental intellectual disability, 10.3% of the global burden of hypertensive heart disease, 5.6% of the global burden of ischaemic heart disease, and 6.2% of the global burden of stroke (WHO, 2017). According to the EPA guideline, the levels of Pb in blood should not exceed the threshold of 3.5 µg/dL (USEPA, 2021). On the contrary, a recent study in the United States of America revealed that children under the age of 5 years with high Pb levels reached 4.9% in 2015 (Pieper et al., 2018). Similarly, nearly 5% of children in Flint were exposed to high Pb due to the failure of treating the lead-contaminated water properly (Santucci and Scully, 2020). While estimates differ, a study in Australia found water Pb concentrations derived for plumbing components range from 108 µg/L to 1440 µg/L (Harvey et al., 2016).

Additionally, another study done in coastal Madagascar revealed that concentrations of lead in water exceeded the World Health Organization's provisional guideline for drinking water of 0.01 mg/L (Akers et al., 2015).

However, researchers from Iran's semi-arid regions studied the geochemical mechanisms causing lead enrichment in groundwaters and discovered that 68% of the groundwater samples exceeded WHO guidelines (Pazand et al., 2018). As shocking as the percentages may appear in Iran, it is important to know that it may be just the tip of the iceberg globally. In this regard, it is, therefore, safe to say that the lead problem is global and catastrophic.

2.3 Overview of lead in Africa

The World Health Organization estimates that 240 million people are overexposed and 99 % of those with blood levels above 20 µg/dl are in the developing countries (WHO, 2017). Contaminated groundwater is a concern in developing countries of Africa that demands immediate action (Giri and Singh, 2015). However, groundwater influences daily life because it is essential for daily activities such as industrial, agriculture, drinking, and domestic use that contribute to firming the economic growth of developing countries (Khalid et al., 2020).

Nonetheless, in Africa, studies have shown that low-income and middle-income countries are at particular risk of undetected exposures to lead in groundwater due to less extensively regulated and monitored water systems (Cobbina et al., 2015; Trémolet, 2015; Chowdhury et al., 2018).

A study in Addis Ababa, Ethiopia showed a mean concentration of Pb in drinking groundwater that exceeded the WHOs guideline of 0.01mg/L, the study further revealed that above 50% of the 80 water samples collected exceeded the WHO guideline (Tesfaye et al., 2017).

Another study in Ghana assessed the level of heavy metals in groundwater sources of two mining communities of northern Ghana, the study showed that Pb levels from Nangodi and Tinga exceeded the WHO stipulated limits of 0.01mg/L (Cobbina et al., 2015).

The WHO guidelines for drinking water quality note that lead in drinking water principally results from the corrosion of plumbing systems (WHO, 2011). Nonetheless, African countries are currently being assisted by the United States Agency for International Development (USAID) to strengthen the capacity of monitoring and regulating water systems (USAID, 2020).

2.4 Overview of lead in Zambia

Zambia has a history of mining lead in Central Province, specifically in the Kabwe town formerly known as Broken Hill Town. The lead-zinc mine in Kabwe started operating in 1906 and closed in 1994 (Burga and Saunders, 2019). Furthermore, Kabwe remains one of the most lead-contaminated towns in the world (Toyoda *et al*., 2022). Studies done in Zambia have shown that lead levels in soil, water, and sediment far exceed permissible limits set by the World Health Organization (Ikenaka *et al.*, 2010; Nambeye., 2013; Burga and Saunders, 2019). Similarly, a high level of lead has also been recorded in livestock in the same town (Yabe et al., 2011, 2013). Further, investigations have been done on lead intoxication in children, with evidence revealing alarming levels of lead in their blood from townships in areas near the former lead-zinc mine in Kabwe (Yabe *et al.*, 2015; Bose-O'Reilly *et al.*, 2018).

All things considered, this study closed the gap between lead exposure and human health risks because it further investigated the actual situation of groundwater lead contamination and the extent to which the residents of areas near the former lead-zinc mine in Kabwe are exposed.

2.5 Physicochemical properties of groundwater and lead (Pb) concentration

The physicochemical properties of groundwater are defined as the intrinsic physical and chemical characteristics of groundwater (WHO, 2011). The physicochemical properties are essential indicators used in human health risk assessment due to exposure to a toxic substance through the ingestion of groundwater (USEPA, 2005). On the other hand, the characteristics may be associated with the environment, such as the geology, or contamination from surface run-off from fields (Vespasiano *et al*, 2021).

The physical parameters of groundwater may include; temperature, total dissolved solids (TDS), taste, turbidity, odour, taste, electrical conductivity (EC), and colour (WHO, 2011). In contrast, the chemical parameters can include; pH, lead (Pb), arsenic, fluoride, nitrate, phosphate, chlorine, and total hardness (WHO, 2011; Omer, 2019). For the current study, among the physicochemical parameters, only EC, temperature, total dissolved solids, and lead were analysed.

Different studies have investigated the relationship between the physicochemical of water and the concentration of heavy metals in groundwater. However, results differ depending on the geographic location and the levels of contamination due to natural and anthropogenic activities (Vespasiano et al., 2021). For instance, a study in India investigated the heavy metals in correlation with the physicochemical properties of drinking groundwater, the study showed that pH did not correlate with heavy metal content including lead, and also observed a positive correlation between TDS and heavy metals (Kanmani and Gandhimathi, 2013).

In comparison with other studies, researchers from Ghana showed that TDS and pH correlated positively with the heavy metals in groundwater (Seyram, 2018). Another study also revealed that the pH of groundwater was reducing the solubility of heavy metals, therefore, the pH significantly correlated with heavy metals in water but on the other hand, EC had no significant correlation with the heavy metals (Akoto *et al*., 2008).

Additionally, researchers in Algeria revealed that EC, Temperature, and pH had a weak positive correlation with lead and other heavy metals in the groundwater of the south of setif area, east Algeria (Belkhiri et al., 2018). Generally, the evidence above clearly indicates the critical influence of these physicochemical parameters on the concentration of heavy metals in groundwater.

2.6 Human Health Risk Assessment

A human health risk assessment can be is defined as the process of estimating the nature and likelihood of adverse health effects in humans who may be exposed to chemicals in contaminated environmental media, now or in the future. The process of risk assessment involves four steps which include; hazard identification, exposure assessment, dose-response assessment, and risk characterization.

2.6.1 Hazard identification

This step involves the evaluation of whether a chemical substance will exert adverse health impacts on people at risk (USEPA, 2014). The assessors will now examine if the chemical substance has the potential to cause harm and also ways in which the hazard will cause harm to the health of humans and the environment (Mirzabeygi *et al*., 2017). The current study for example focused on lead, as the potential hazard to cause harm to human health

2.6.2 Dose-Response Assessment

The USEPA defines this stage as the determination of the relationship between the magnitude of an administered, applied, or internal dose and a specific biological response (USEPA, 2014). This stage describes the effect change based on the differing levels of doses of a chemical substance. The stage further incorporates the estimation of the daily intakes (EDIs) depending on the children's and adults' body weight (Tesfaye *et al*., 2017). This can be simplified by assessing how residents from Kabwe and Lusaka will respond due to exposure to lead through drinking groundwater.

2.6.3 Exposure Assessment

At this stage, the assessors will now establish the relationship between exposure and adverse health outcomes under investigation (WHO and IPCS, 2020). This stage is very vital to the assessors because it provides the basis for risk characterization by further analysing the frequency, timing, and levels of contact with the hazard (Sharma, et al., 2005).

2.6.4 Risk Characterization

In this stage, the Reference dose (RfD) of a chemical substance is compared with the estimated daily intakes (EDIs) (WHO and IPCS, 2020). However, this permits risk managers to classify which chemical substance requires regulatory actions and may be necessary for public health protection (Giri and Singh, 2015). In addition, this stage also estimates the risk and compares exposure levels for the hazard under investigation including the population, environment, and adverse health effects (USEPA, 2014).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Research Design

The study employed an analytical comparative cross-sectional study to determine the Pb contamination of drinking groundwater sources found in the surrounding communities of the former Zinc-ead mine in Kabwe as mining areas and compare the results with those from the non-mining areas in Lusaka.

Groundwater samples were collected from hand pump boreholes and all functional hand pump boreholes where residents drew their drinking water were considered.

3.2 Study Area

The study was conducted in the Kabwe district located at (14.4285° S, 28.4514° E) as a mining area, and the Lusaka district located at (15.3875° S, 28.3228° E) as a non-mining area. Areas that were selected in Kabwe included; Chowa and Makululu. These areas are located around the former Zinc-lead mine in Kabwe (Figure 3.1).

Simple random sampling specifically the lottery method was used to select two mining areas (Makululu and Chowa) around the former lead mine in Kabwe. Areas that were considered in Kabwe include; Chowa, Makululu, Mutwewansofu, Kasanda, and Makandanyama. Purposeful sampling was used to select two non-mining areas in Lusaka. The areas that were selected in Lusaka include; Kanyama and Chelstone-Obama. This is because the areas are known to use boreholes as the source of water for drinking as well as other domestic and household chores.

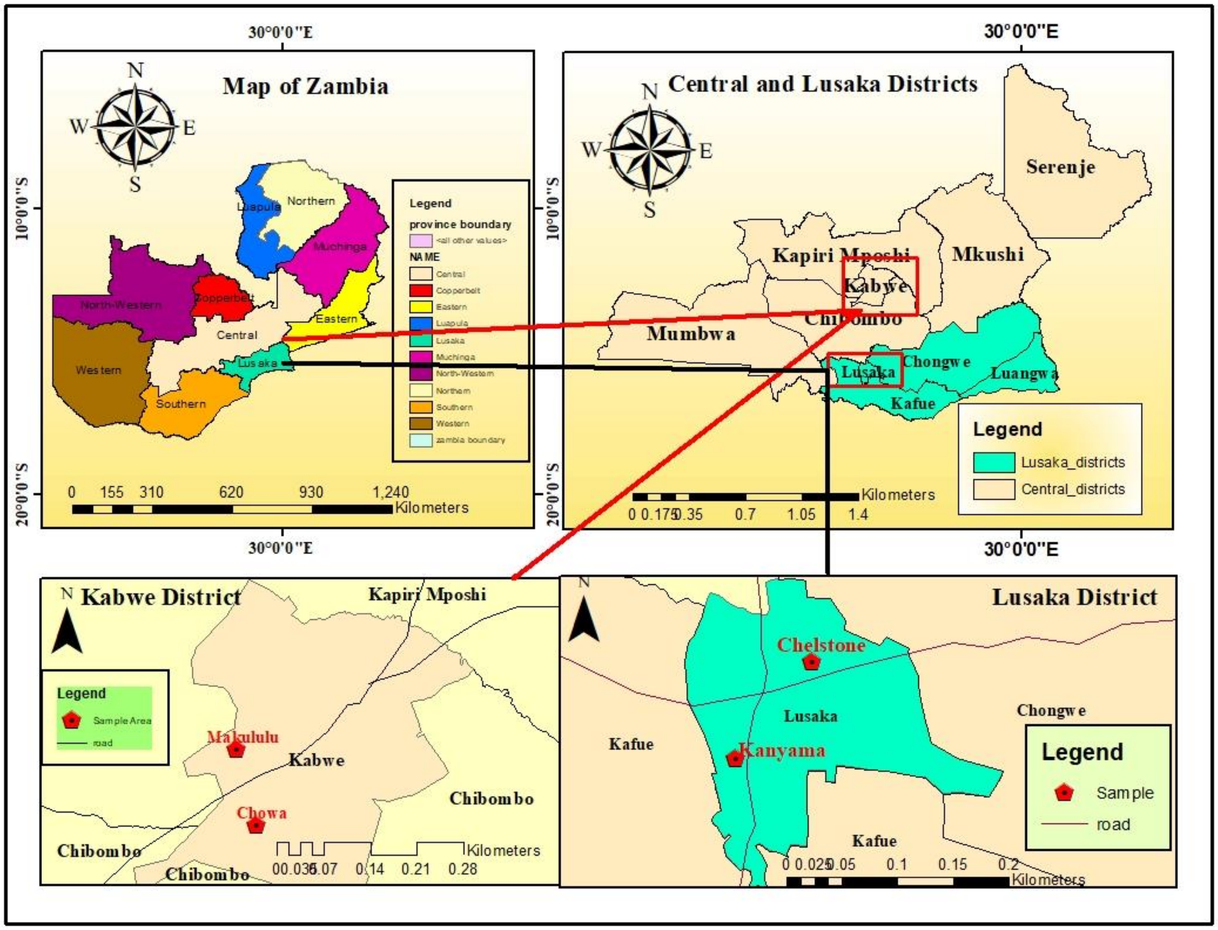

Figure 3.1: Location map of mining areas in Kabwe and non-mining areas in Lusaka

3.3 Study Sample

To determine the sample size where the number of boreholes is known, the following formula was used (Krejcie and Morgan, 1970). The degree of accuracy was at 0.05 whilst the prevalence of possible contamination was estimated at 0.5 (50%) of the total number of boreholes.

$$\mathbf{S} = \frac{x^2 NP(1-P)}{d^2(N-1)+x^2P(1-P)} \tag{1}$$

Where:

S = Required sample size, N= Given population size (number of boreholes) under consideration

P = Estimated Prevalence/proportion of contamination, d^2= Degree of accuracy, X^2= 1.96 Confidence level

Table 3.1: Total number of Boreholes found in the selected study areas

Sampling site	Number of Boreholes
a. Makululu	30
b. Chowa	18
Kabwe sites total	48
a. Kanyama	40
b. Chelstone-Obama	60
Lusaka sites total	100
Grand total	**148**

Source: (Zambian Ministry of Health, 2018; MWDSEP, 2019)

Therefore,

$$\mathbf{S} = \frac{1.96^2 * 148 * 0.5(1-0.5)}{0.05^2(148-1)+1.96^2 * 0.5(1-0.5)} = 107.041 = \mathbf{107}$$

Therefore, **107** is the sample size for the non-infinite population

To adjust for the target population [N(adj)]:

$$\text{N(adj)}= \frac{\mathbf{N}}{\mathbf{1+(N-1)/population}} \tag{2}$$

$$\text{N(adj)} = \frac{\mathbf{107}}{\mathbf{1+(107-1)/148}} = \mathbf{62.346 = 63}$$

However, the study sampled 61 boreholes, that is 34 boreholes from mining areas in Kabwe and 27 boreholes from non-mining areas in Lusaka. This is because a few boreholes were not functioning during the collection of groundwater samples.

3.4 Collection of Groundwater Samples and preparation

The collection of groundwater samples was done between May and June 2022, during which period the water table had risen and stabilised. Groundwater samples were drawn from hand pump boreholes, and sterile 100 ml capacity high-density polyethylene (HDPE) tubes were used. After collection, the bottles were labelled, placed in a cooler box with ice packs, and transported to the laboratory for filtration and preservation (Vail, 2013). To prevent the absorption of Pb to the walls of the 100 ml HDPE bottles, about 1 ml of 60% nitric acid (HNO_3) was added to 100ml of groundwater to maintain a pH of about 2 (Cobbina *et al*., 2015). Then the prepared groundwater samples were maintained at 4°C until laboratory analysis.

3.5 Metal Analysis and Quality control

Groundwater samples were drawn from boreholes and analysed for total Pb levels using Atomic Absorption Spectrometry (AAS, Perkin Elmer, A-Analyst 400 series, USA) at the school of Agricultural Sciences laboratory, University of Zambia. Contamination was reduced by directly collecting groundwater from hand pump boreholes into 100 ml sterile tubes, packaging the samples in a cooler box and changing of gloves at each site.

All materials used in the laboratory were washed and soaked for 24 hours in 2% diluted Nitric acid (HNO_3), then rinsed by distilled water from a milli-Q-Element (18 MΩ .cm, Millipore®, Milford, MA, USA) and oven dried (Zyambo *et al.*, 2022). To increase sensitivity of metal detection by AAS, the metal extraction was conducted by using a microwave digester (Berghof, SpeedWave®ENTRY, Eningen, Germany). Then 10 ml of 30% HNO_3 was added to 90 ml of groundwater sample under automated temperature conditions for 30 minutes, cooled for 20 minutes and then transferred into 50 ml tubes for analysis (Toyomaki *et al.*, 2020).

Direct measurement was used and the calibration curve was prepared by using the known standard levels of Pb (0, 5, and 10 mg/L) which was prepared from 1000 mg/L of Lead (II) nitrate (Pb $(NO_3)_2$). The quality control of the analytical methodology was monitored by using the reference Pb standard of known concentration at regular interval of the first and last three as well as the thirtieth sample in the middle. Therefore, to ensure the accuracy of analysis, analytical duplicates were made for each groundwater sample.

The other water quality parameters (pH, electrical conductivity (EC), total dissolved solids (TDS), and temperature were measured using a portable Hanna pH meter (HI 98129 and HI 98130, pH/EC/TDS/Temperature, D462,024, USA). The portable meter was calibrated for pH by using a two-point pH calibration for better accuracy. Firstly, the meter electrode was placed in the buffer of pH 7.01 followed by the second buffer value of pH 4.01 for automatic value settings. Secondly, for the calibration of the EC and TDS was carried out by the immersion of the meter probe into the EC calibration solution according to standardized parameters as guided in the manufacturer's manual.

3.6 Human Health Risk Assessment

A human health risk assessment is the process to estimate the nature and probability of adverse health effects in humans who may be exposed to chemicals in contaminated environmental media, now or in the future (USEPA, 2007). Risk assessment is a method used to estimate people's increased risk of health problems as a result of exposure to toxic pollutants in the environment (USEPA, 2014).

3.6.1 Estimated daily intake of Pb through groundwater consumption

The estimated daily intake (EDI) of Pb through water consumption depended on; IngR which is the approximate daily water ingestion rates, CW= the median concentration of Pb in drinking water from the study sites, and BW= the person's body weight. The ingestion rates (IngR) for water were 2L/day and 1L/day in adults and children respectively, as the average ingestion rate of water (EPA, 2014).

The formula below was used to calculate EDIs:

$$\text{EDI} = \frac{\text{IngR x CW}}{\text{BW}} \tag{3}$$

Furthermore, an average body weight of 60 kg estimated for African adults was used to calculate the exposure and risk (Walpole *et al.*, 2012). This was supported by the accessible body weight data in Zambia (Yamauchi, 2009; NSA, 2019). In the category of children aged 5 and below, an average body weight of 10 kg was used based on average weight reports (Yamauchi, 2007; NSA, 2019).

3.6.2 Carcinogenic and non-carcinogenic health risks

The determined levels of Pb in groundwater samples were the source for calculating the estimated daily intake of Pb through the consumption of groundwater. The calculated EDIs were attributed to carcinogenic risk assessments from exposure to Pb in children and adults. The assessed potential health risks from exposure to Pb among sites near the Zinc-lead mining area in Kabwe were compared to those groundwater samples from the non-mining sites in Lusaka.

3.6.3 Non-carcinogenic health risk assessment

The study used the Target Hazard Quotient (THQ) to calculate the risk of non-carcinogenic effects for Pb. The target Hazard quotient is the ratio of the potential exposure to a substance and the level at which no adverse effects are expected. The method of assessing health risk using THQs was calculated according to the USEPA Region III risk-based concentration table as displayed below; (USEPA, 2015).

$$\mathrm{THQ} = \frac{\mathrm{EF\ x\ ED\ x\ EDI}}{\mathrm{RfD\ x\ AT}}\ \mathrm{x}\ 10^{-3} \qquad (4)$$

The EF is the exposure frequency (365 days/ year); ED is the exposure duration (64 years) equivalent to life expectancy in Zambia, and EDI was determined by formula (3). The Oral RfD in this study was estimated to be 0.003 mg/kg/day, established from the Provisional Weekly Tolerable Intake (PWTI) of 0.025 mg of Lead (Pb) per kg of body weight, which corresponds to 0.003 mg/kg/day, as recognized by the Joint FAO/WHO Expert Committee. However, the AT is lead's chemical toxicity due to the averaging lifetime Pb exposure (365 days*64 years) and 10^{-3} is the unit conversion factor. By the rule of thumb, the greater the value of THQ above unity, the greater the level of concern. Meaning if the THQ exceeds 1, then there is the possibility of non-carcinogenic effects on health, whereas THQ less than or equal to 1 means no possibility of any adverse health effects resulting from the consumption of groundwater contaminated with Pb. The following are the details of the parameters used for human health risk assessment:

Table 3.2: Parameters of human health risk assessment

Parameter	Unit	Value used	References
AT- Averaging time	Days	365 days x 64 yrs	(EPA, 2014)
BW- Bodyweight	Kg	Adults=60 Children=10	(Yamauchi, 2007; Walpole

			et al., 2012; Hoffman *et al*., 2017)
CSF- Cancer Slope factor	mg/kg/day	0.008	(USEPA, 2005)
CW - Site Concentration of Pb in groundwater	mg/l	Ranged from 0- 0.379mg/L	
ED- Lifetime Exposure Duration	Years	64	(NSA, 2019)
EF- Exposure frequency	Days/year	365	(USEPA, 2005)
IngR - Ingestion rate	Litres/day	Adult=2L Children=1L	(EPA, 2014)
RfD- Oral Reference dose	mg/kg/day	0.0035	(FAO/WHO, 2013)

3.6.4 Carcinogenic health risk assessment

The target cancer risk (TCR) calculation of Pb from the ingestion of groundwater from boreholes was calculated according to the equation provided in USEPA Region III Risk-Based Concentration Table (USEPA, 2015).

$$\mathrm{TCR} = \frac{\mathrm{EF \ x \ ED \ x \ EDI \ \ x \ CSF}}{\mathrm{AT}} \ \mathrm{x} \ 10^{-3} \qquad (5)$$

Cancer risk is estimated as the likelihood of an individual developing cancer over a lifetime. As a result, the Cancer Slop factor (CSF) in this study was based on the intake dose conversion factor (0.008 mg/kg/day) as stipulated by the USEPA (USEPA, 2005).

3.7 Data Analysis Instruments and Procedures

Quantitative statistical analysis with Microsoft Excel and STATA 21 was used to test each hypothesis. Since the data were not normally distributed, a Mann-Whitney U test was used to compare the medians between lead levels from mining areas in Kabwe and non-mining areas in

Lusaka. Descriptive statistics were also calculated for categories created for the hypothesis. The association between lead levels in groundwater and selected physicochemical parameters in the study areas was determined using Spearman's rank correlation coefficient statistical test.

CHAPTER FOUR: RESULTS

4.1 Lead levels in the groundwater of Kabwe (mining area) and Lusaka (non-mining area)

From the 61 samples that were obtained from boreholes, 21 samples were collected from Makululu, 13 samples from Chowa, 13 samples from Kanyama, and finally 14 samples from Chelstone-Obama. The lead levels from the mining areas in Kabwe were significantly higher ($p<0.05$) than levels from non-mining areas in Lusaka. This was determined by the Mann-Whitney U test ($p=0.028$), the highest Pb levels were recorded in Makululu with a median of 0.147mg/L, followed by Kanyama (median=0.103 mg/L) then Chowa (median=0.056 mg/L**)** and the least was Chelstone-Obama (median=0.103 mg/L) (Table 4.1, Figure 4.1, and figure 4.2).

Further, the Pb levels in samples from mining areas ranged from 0 to 0.379 mg/L with a median of 0.130 mg/L. Meanwhile, samples from non-mining areas recorded Pb levels ranging from 0 to 0.197 mg/L with a median of 0.071 mg/L (Table 4.1). The groundwater samples from the Zn-Pb mining areas recorded a less wide variation of Pb levels with an interquartile range of 0.110 mg/L than the areas in Lusaka with an interquartile range of 0.138 mg/L. Despite the higher levels of Pb in groundwater samples from mining areas, Kanyama recorded higher Pb levels than Chowa and yet Chowa is one of the areas near the Zn-Pb mining area in Kabwe (Table 4.1, Figure 4.1, and figure 4.2).

Table 4.1: Pb (mg/L) levels in the groundwater water of specific sampling sites

Sampling site	n	Median	Minimum	Maximum	Q1	Q3
Makululu	21	0.147	0.047	0.379	0.112	0.2
Chowa	13	0.056	0	0.144	0.017	0.134
Kabwe sites total	**34**					
Kanyama	13	0.103	0	0.183	0.048	0.14
Chelstone-Obama	14	0.038	0	0.197	0	0.111

Lusaka sites total	**27**

n represents sample size, Q1 is the lowest quartile and Q3 is the upper quartile respectively. Then 0 mg/L denotes that the Pb levels were below the atomic absorption spectrophotometer (AAS) detection limit.

Table 4.2: Pb (mg/L) levels in the groundwater of mining and non-mining areas

Sampling site	n	Median	Minimum	Maximum	Q1	Q3
Mining area (Kabwe)	34	0.131*	0	0.379	0.054	0.164
Non-mining area (Lusaka)	27	0.071*	0	0.197	0	0.138

*Statistically significant at $p<0.05$.

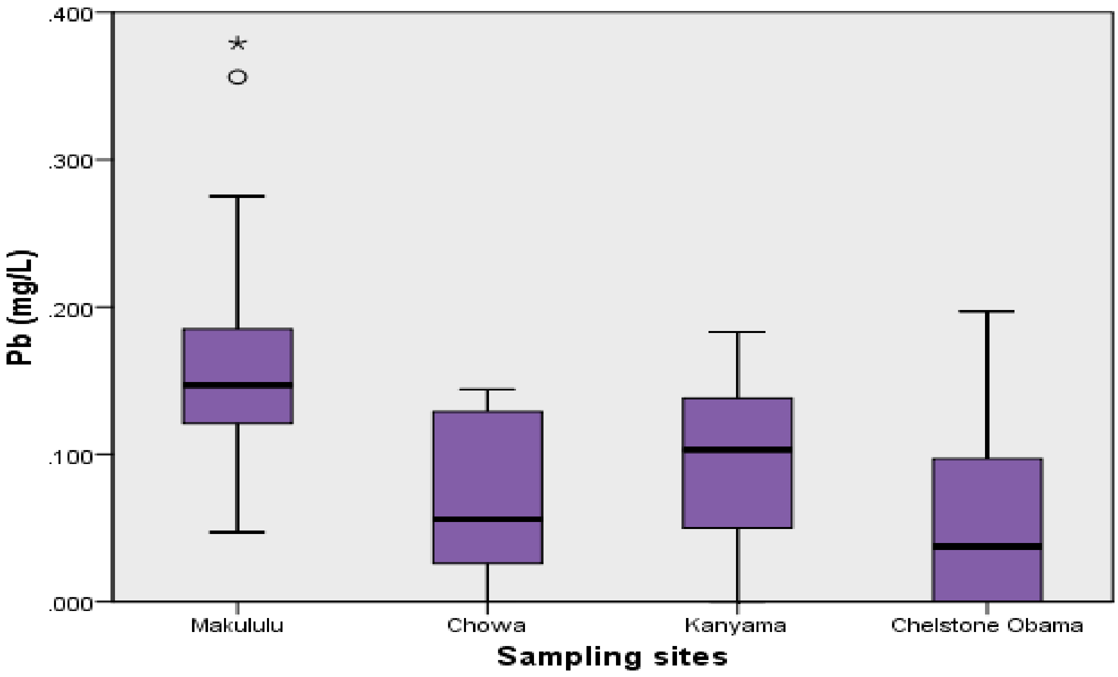

Figure 4.1: Median Pb levels in groundwater samples of specific sampling sites

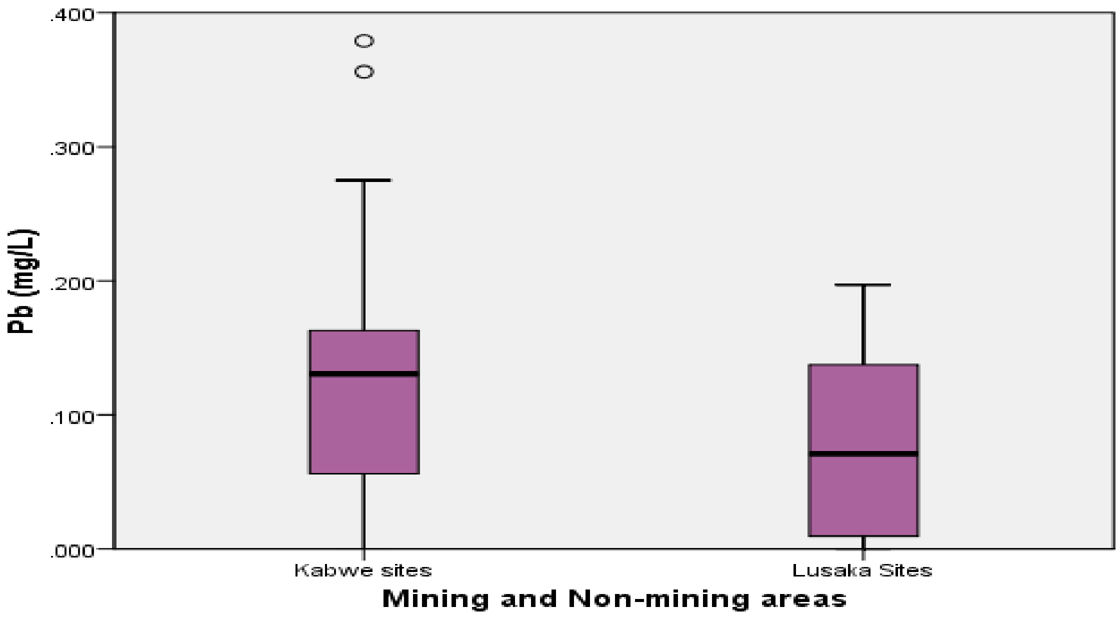

Figure 4.2: Median Pb levels in groundwater samples of mining and non-mining areas

4.2 Comparison of Pb (mg/L) levels in groundwater with WHO limit

Comparisons of Pb concentrations with the WHO limits showed that 100% groundwater samples collected in Makululu were above the WHO limit of 0.01 mg/L. On the other hand, Chowa recorded 23% as within the WHO limit and 77% above the limit. As for Kanayama, 18% were within the WHO limit and 82% above the limit. However, Chelstone-Obama recorded 36 % as within the WHO limit and 64% above the limit. Further, Makululu recorded the highest lead level contamination of groundwater from boreholes followed by Kanyama, Chowa, and Chesltone-Obama in that order.

In summary, from the 34 groundwater samples that were collected in Kabwe sites, only 9% of the samples were within the WHO limit and about 91% were above the limit. Then Lusaka sites recorded 26% as within the WHO limit and 74% above the limit.

Table 4.2: Pb (mg/L) levels in groundwater with WHO limit (0.010 mg/L)

Sampling site	≤ WHO limit	> WHO limit	Total
Makululu	0	21	21
Chowa	3	10	13
Kabwe sites total	3	31	34
Chelstone -Obama	2	11	13
Kanyama	5	9	14
Lusaka sites total	7	20	27

≤ WHO limit signifies the groundwater samples that were within the WHO 2008 permissible limit for drinking water and > WHO limit represents the groundwater samples that were above the WHO permissible limit (WHO, 2008).

4.3 Levels for other measured physicochemical parameters in groundwater

The study showed that the physicochemical parameters like temperature, TDS, and pH from both areas were within the WHO permissible limits. In contrast, EC surpassed the WHO permissible limits in both areas and EC levels from non-mining areas in Lusaka (Median= 1100 µS/cm) was significantly higher ($p<0.05$) than mining areas in Kabwe (median = 585 µS/cm) as shown in Table 4.3 and Table 4.4.

Table 4.3: Concentrations for other physicochemical parameters in mining area (Kabwe)

Statistics		EC (µS/cm)	°C	TDS (ppm)	pH
Number of samples		34	34	34	34
Median		585*	24.75	303	6.955
Range		899	9.47	465	1.2
Minimum		270	20.4	141	6.33
Maximum		1169	29.87	606	7.53
Percentiles					
	25	479	24.0775	249.75	6.7025
	50	585	24.75	303	6.955
	75	847	25.425	437	7.14
MAC ^{a}		≤400	20-25	≤900	6.5-8.5

*Statistically significant at $p<0.05$, MAC ^{a} indicates the WHO maximum acceptable concentration for water quality physicochemical parameters (WHO, 2008).

Table 4.4: Concentrations for other physicochemical parameters in non-mining area (Lusaka)

Statistics		EC (µS/cm)	°C	TDS (ppm)	pH
Number of samples		27	27	27	27
Median		1100*	23.2	601	7.27
Range		825	5.8	613	1.68
Minimum		533	20	278	6.3
Maximum		1358	25.8	891	7.98
Percentiles					
	25	869	21.8	451	6.8
	50	1100	23.2	601	7.27
	75	1215	24.3	640	7.72
MAC [a]		≤400	20-25	≤900	6.5-8.5

*Statistically significant at $p<0.05$, MAC [a] indicates the WHO maximum acceptable concentration for water quality physicochemical parameters (WHO, 2008).

4.4 Correlations for Pb levels (mg/L) and other physicochemical parameters

The study results revealed correlations (r_s) between Pb levels and physicochemical parameters that were not statistically significant ($p> 0.05$). Among the measured parameters, only temperature showed a moderate positive correlation ($r_s = 0.188$, $P>0.05$) with Pb levels. The other parameters exhibited negative correlations with Pb levels, a negatively weak correlation ($r_s = -0.045$, $P>0.05$) was revealed between the Pb and EC levels. Similarly, a negative correlation ($r_s = -0.045$, $P>0.05$) between Pb levels and TDS was detected. Lastly, Pb levels correlated negatively ($r_s = -0.142$, $P>0.05$) with pH levels.

Table 4.5: Correlation matrix of lead and other physicochemical parameters

	Pb(mg/L)	EC(µS/cm)	°C	TDS(ppm)	pH
Pb(mg/L)	1				
EC(µS/cm)	-0.045	1			
°C	0.188	-0.111	1		
TDS(ppm)	-0.066	0.98	-0.114	1	
pH	-0.142	-0.037	-0.295*	0.006	1

*Statistically significant at $p<0.05$.

4.5 Human Health risk assessment

The determination of Pb levels in the groundwater from the mining areas in Kabwe and non-mining areas in Lusaka formed the basis for calculating the estimated daily intake. The EDIs were incorporated in non-carcinogenic and carcinogenic risk assessments from consuming groundwater contaminated with Pb in adults and children.

4.6 Estimated daily intakes of Pb through groundwater consumption

The EDIs through the consumption of groundwater contaminated with Pb varied significantly ($p<0.05$) between mining areas in Kabwe and non-mining areas in Lusaka. The high levels of EDIs were recorded in the order of children from mining areas in Kabwe, children from non-mining areas, adults from mining, and finally adults from non-mining areas correspondingly (Table 4.6).

Table 4.6: Pb levels and EDIs in adults and children

	Median Pb (mg/L) levels	**EDI (mg/kg/day)**	
		Adult	Children
Kabwe (mining area)	0.131*	0.004*	0.013*
Lusaka (non-mining area)	0.071*	0.002*	0.007*
MAC	0.010 [a] (WHO)	0.003[b](FAO/WHO)	

*Statistically significant at $p<0.05$.

MAC signifies the maximum acceptable concentration, [a] WHOs Pb (mg/L) MAC per day for drinking water, and [b] Maximum Pb (mg/L) concentration for drinking water as recognized by the Joint FAO/WHO Expert Committee on Food additives (FAO/WHO, 2013).

4.7 Carcinogenic and non-carcinogenic health risks

The results of the study showed that the THQs and TCR through the consumption of groundwater varied significantly ($p<0.05$) between adults and children from the mining areas in Kabwe and non-mining areas in Lusaka. The study revealed higher THQs in the direction of children from mining areas in Kabwe, children from non-mining areas, adults from mining, and adults from non-mining areas. Additionally, the THQs for children (THQ= 4.333) and adults (THQ= 1.333) from the mining areas and also children (THQ= 2.333) from the non-mining areas were all above 1. On the other hand, adults (THQ= 2.333) from non-mining areas revealed a THQ > 1 (Table 4.7).

However, the TCRs from the consumption of groundwater contaminated with Pb in children ($1.0\text{x}\ 10^{-4}$) from mining areas recorded the highest TCR. Then followed by children ($5.6\text{x}10^{-5}$) from the non-mining areas, adults (3.5E-5) from the mining area, and then the lowest were the adults ($1.6\text{x}10^{-5}$) from the non-mining area in Lusaka. All the TCR values in this study were below the typical range of ($1\text{x}10^{-6}$ to $1\text{x}10^{-4}$) which is known to be public health protective by the USEPA for risk management (Table 4.7). The results of the study indicate that ingesting the groundwater from boreholes significantly contributed to the THQ and TCR values among residents from the mining area in Kabwe and the non-mining area in Lusaka.

Table 4.7: Non-cancer risk (THQ) and cancer risk (TCR) from oral ingestion of groundwater

	THQ		**TCR**	
	Adult	Children	Adult	Children
Kabwe (mining area)	1.333*	4.333*	3.5E-5*	1.04E-4*
Lusaka (non-mining area)	0.667*	2.333*	1.6E-5*	5.6E-5*
MAC (USEPA)	<1.00(TH)		$1.0\text{x}10^{-6}$ - $1.0\text{x}10^{-4}$(TCR)	

*Statistically significant at $p<0.05$.

MAC represents the maximum acceptable concentration the United States Environmental Protection Agency (USEPA) recommends for THQ and TCR considered to be public health protective.

CHAPTER FIVE: DISCUSSION

The study broadly compared and assessed the Pb levels and human health risks associated with the consumption of groundwater contaminated with Pb between the mining areas in Kabwe and non-mining areas in Lusaka. The other physicochemical parameters measured in groundwater samples were total dissolved solids (TDS), temperature, electrical conductivity (EC), and pH. The water samples were drawn from groundwater to be specific boreholes that are used as a source of drinking water along with domestic household tasks in the Kabwe and Lusaka districts of Zambia. Kabwe is known to be contaminated with Pb due to the Zinc-lead mine and Lusaka is known to be a non-mining area because it has no mining history of Pb hence it was used for comparison purposes.

5.1 Pb levels in groundwater

The Pb levels that were recorded in groundwater of mining areas in Kabwe ranged from the lowest 0 mg/L to the highest 0.379 mg/L, with a median concentration of 0.131 mg/L, and from non-mining areas in Lusaka ranged from 0 mg/L to 0.197 mg/L, with a median concentration of 0.071 mg/L and the difference was significant ($p < 0.05$). Furthermore, about 91% of all the groundwater samples collected from mining areas and 74% of all groundwater samples collected from non-mining areas were above the maximum acceptable concentration of 0.010 mg/L of Pb in drinking water as recommended by WHO (WHO, 2008). The percentages of the groundwater samples exceeding the WHO maximum acceptable concentration from both areas are very alarming because even the non-mining areas in Lusaka recorded a huge percentage.

From the findings, the proximity of the former Zn-Pb mine from mining areas in Kabwe contributed to the high concentrations of Pb in groundwater. In comparison with a study in India on proximity, researchers also suggested that proximity near the open-cast chromium mine was playing a major role in the heavy metal contamination in the groundwater of Sukinda valley in Orissa due to the possibility of leaching contaminants from the ore material wastages and degraded material produced during the mining process (Dhakate and Singh, 2008).

Similarly, a recent study on the geochemical identification of particulate lead pollution in groundwater of mining areas in Kabwe detected high particulate Pb concentrations (0.002–0.1 mg/L) in shallow groundwater samples and some wells exceeded the WHO guideline of (0.010 mg/L) as safe limit (Toyoda et al., 2022). Another similar study on proximity in Nigeria exceeded the WHO guidelines of Pb in water resources of lead–zinc mining communities of Abakalik (Obasi and Akudinobi, 2020).

In contrast, the high percentages from non-mining areas in Lusaka might suggest the possibility that the contaminants are migrating to the aquifer system from seepage of bottom automobile exhaust during road traffic and waste from manufacturing industries (Masindi and Muedi, 2018).

Despite Lusaka being a non-mining area with no history of Pb mining, the area recorded a high proportion of 74 % of groundwater samples which were above the WHO safe limit of 0.01mg/L (WHO, 2008). Additionally, Kanyama is one of the non-mining areas in Lusaka which contributed to the high proportion because 84% of the groundwater samples from this site were above the WHO safe limit (0.01 mg/L). On the contrary, no study is pointing out the exact sources of groundwater Pb contamination in Lusaka.

Nevertheless, studies in Zambia and Ethiopia suggest that anthropogenic activities such as nearby manufacturing industries, and chemical and metallurgic activities can be attributed to heavy metal groundwater contamination due to groundwater flow direction (Nambeye, 2013; Tesfaye et al., 2017).

A previous study has shown high levels of Pb in children, over 95% of the children living in townships near the mining area in Kabwe recorded high blood lead levels greater than the WHO limit of 3µg/dL due to ingestion and inhalation of Pb dust (Yabe et al., 2020).

In contrast to Chowa, which is also close to the former Kabwe mining area, Makululu township typically relies on groundwater for drinking and other household tasks. Hence this current study suggests that consumption of groundwater contaminated with Pb from boreholes might contribute to high blood lead levels in children from the previous study.

Additionally, the groundwater samples from the non-mining areas in Lusaka recorded a wider variation of Pb levels with an interquartile range of 0.138 mg/L than the mining areas in Kabwe with an interquartile range of 0.067 mg/L. These variations in Pb levels could suggest geological differences, the study, therefore, agrees with the findings from an earlier study on the evaluation of the spatial distribution of heavy metals which showed that areas geographically distant from mining beds had only moderate or low heavy metal concentrations (Ikenaka et al., 2010). In the future, investigating the source of Pb in the groundwater of Lusaka is a preeminent research area.

5.2 Levels for other physicochemical parameters in groundwater of Kabwe and Lusaka

The current study indicated EC values that surpassed the WHO standards of ≤ 400 µS/cm from both mining areas in Kabwe and non-mining areas in Lusaka. However, similar values of EC ranging from (950-3120µS/cm), were reported in groundwater samples from areas surrounding a copper mine in India (Yadav et al., 2012). This entails that the high levels of EC are likely to be associated with the proximity of a mine. Another study from a non-mining area reported high EC

(1580-5200 μS/cm), values in groundwater samples of Agra city in India (Annapoorna and Janardhana, 2015).

Meanwhile, researchers in Poland also found higher EC values in groundwater due to leachate contamination from a landfill (Przydatek and Kanownik, 2021). This can be supported by a study from Zambia which indicated pit latrines to be a source of groundwater contamination and further discovered that microbial contamination was observed during the rainy season (Chandipo, 2015). The current study results indicate that groundwater in the study area was ionised with high levels of ions because of inorganic dissolved solids. Hence, the results of the study suggest that high levels of EC in non-mining areas and mining areas can be linked to rainwater runoff and mining activities.

5.3 Correlations for Pb levels (mg/L) and other physicochemical parameters

The study results exhibited Spearman correlation (r_s) between Pb levels and physicochemical parameters that were not statistically significant ($p > 0.05$). However, a weak and positive correlation ($r_s = 0.188$) between Pb levels and the temperature was noticed. Even so, positive and negative correlations can be attributed to other factors because the correlations were not statistically significant. The findings can therefore be supported by a study from Ethiopia that found negative correlations between other physicochemical parameters and lead levels in groundwater (Tesfaye et al., 2017).

5.4 Carcinogenic and non-carcinogenic health risks

The study showed significantly higher EDIs of Pb levels through the consumption of groundwater in adults (0.013 mg/kg/day) and children (0.004 mg/kg/day) from mining areas in Kabwe than EDIs (0.002 and 0.007 mg/kg/day) in adults (0.002 mg/kg/day) and children (0.007 mg/kg/day) from non-mining areas in Lusaka. The EDIs from mining areas in Kabwe were above the MAC for WHO (0.003 mg/kg/day) ingested Pb levels (FAO/WHO, 2013). In two townships (Bagjata and Banduhurang) in India near the proposed mining area, the EDIs arising from ingestion of groundwater contaminated with Pb were 0.026 and 0.028 mg/L (Giri and Singh, 2015). A study from America found similar results, the study showed higher EDIs Pb values ranging from 0.22 to 4.4mg/kg/day in groundwater for adults and children (Emmanuel et al., 2007). However, since 0.003 mg/kg/day is the recommended daily MAC then adults and children from mining areas as well as children from non-mining areas could be at risk of associated Pb health complications.

The non-carcinogenic risk was calculated through THQs, the THQ value ≤ 1 implies a safe limit, and the THQ value > 1 implies non-carcinogenic risk. Overall, the study recorded higher THQs (1.333 and 4.333) for adults and children from mining areas as well as children (2.333) from non-mining areas. Even though the THQ value for adults from the mining area was slightly higher than the safe limit, it does not change the fact that it is higher than the safe limit. The recorded values are disturbing because health complications that have been documented due to exposure to Pb may include; mental retardation and behavioural disorders in children, renal impairment, hypertension, immunotoxicity, and toxicity to the reproductive organs (Yabe et al., 2015; Assi et al., 2016; WHO, 2017).

An Iranian study, in the city of Kerman, also found children consuming water contaminated with Pb and other heavy metals to be at risk of non-carcinogenic adverse health effects (Aghasi, 2019). Nonetheless, if the high levels of Pb that the current study detected in groundwater from both mining and non-mining areas remain constant then it is inevitable to conclude that the mentioned health complications are obvious.

On the other hand, the TCRs that the current study determined were within the EPA acceptable level of (1.0 x10^{-6} to 1.0 x10^{-4}). The study echoes findings from an earlier study in Ethiopia, the study found the carcinogenic risk values between 1x10^{-7} and 9.9 x 10^{-5} (Tesfaye et al., 2017). Meanwhile, researchers in China assessed the concentration of heavy metals in groundwater near a coal mine and indicated Pb cancer risk values that were within the EPA-acceptable levels (Zhang et al., 2016). Therefore, the results of this study suggest no potential carcinogenic risk from ingesting groundwater from mining areas of Kabwe and non-mining areas of Lusaka.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Kabwe is known to be polluted by lead because of the former zinc-lead mine, the current study is the first study to compare lead levels and human health risks between known mining areas in Kabwe and non-mining areas in Lusaka. The findings can be summarised as follows;

1. The results of the study established that there was a significant difference in the Pb concentration of groundwater between mining areas in Kabwe (median = 0.131mg/L) and non-mining areas in Lusaka (median = 0.071mg/L).
2. The levels of other physicochemical parameters were within WHOs permissible limits except for EC which recorded 585 µS/cm and 1100 µS/cm for mining areas and non-mining areas respectively. The recommended WHOs permissible limit of ≤ 400 µS/cm was surpassed.
3. The levels of Pb in groundwater were not associated with alterations in the physicochemical parameters like TDS, temperature, pH, and EC of groundwater.
4. The EDIs surpassed WHO limit (0.003mg/l), THQs >1 and TCRs within USEPA limits from both Kabwe and Lusaka. This implies that health risk complications are likely to accumulate in the future if control measures are not laid in place to reduce the health complications.
5. However, ingesting groundwater from mining areas in Kabwe and non-mining areas in Lusaka is likely to be a significant source of exposure to Pb.

6.2 Recommendations

1. Local authorities to consider strengthening law enforcement by ensuring the monitoring of groundwater sources and the levels of heavy metals conforming with WHO guidelines
2. Health facilities to consider conducting community mobilization and sensitization activities on the mitigation measures for reducing exposure to Pb.
3. The local authorities like the ministry of health, Kabwe water, and the sewerage company to consider multisectoral collaboration to adequately fund the treatment of groundwater before being used by the community for drinking.
4. The need for authorities to advocate for changing the source of drinking water in the affected communities from groundwater to national service providers like water and sewerage companies, especially in areas that strictly rely on hand pump boreholes.

6.3 Limitations

1. The current study only used the ingestion of groundwater from boreholes to estimate the carcinogenic and non-carcinogenic risks. It is therefore possible for the estimated values for carcinogenic and non-carcinogenic risks to change if factors like dust inhalation and consumption of various foods were to be considered.
2. A few boreholes were not functioning during groundwater sample collection in both mining areas in Kabwe and non-mining areas in Lusaka.

6.4 Funding

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APPENDICES

Appendix A: Information Sheet

1.0 INFORMATION SHEET

1.1 Introduction

I am a student at the University of Zambia studying Master of Science in Ecological Public Health. I am carrying out a study on the **comparative determination of lead levels in groundwater in selected known high risk (Kabwe) and low risk (Lusaka) areas in Zambia**. Your borehole is among the collection points that have been selected in the research. Your voluntary involvement is requested so we may learn more about the status of waterbourne Lead against the standard and quantify the degree of exposure and the associated health risks from the consumption of Lead contaminated groundwater. Please understand you do not have to decide to agree to participate today, you may take your time to discuss the research with anyone you feel comfortable with before deciding. If at any point there are words or concepts you do not understand please stop me and I will clarify to the best of my ability. If questions should arise at a later time you may contact me or another one of the researchers to answer or clarify your questions or concerns.

1.2 Procedures

The study will involve collecting water samples from your borehole. No questions will be asked, it is only your permission that the study will request.

1.3 Risk Factors and Discomfort

The study will not generate any concrete risk to our knowledge. However, there is a loss of work time during the collection of water samples and when guiding us where to collect from.

1.4 Confidentiality Anonymous

Your name will not be recorded on the consent form instead; you will be given an identification number for identification purposes only. The information revealed will be used purely for academic purposes and treated with the strictest confidentiality possible.

1.5 Benefits

The information generated will be used to advise you and other relevant authorities on lead levels in groundwater in selected known high risk (Kabwe) and low risk (Lusaka) areas in Zambia.

1.6 Voluntary Participation

Your participation is voluntary and you may choose not to allow us to collect water samples from your borehole. If you are not comfortable with it even after signing the consent form. You are also allowed to withdraw from the study at any time if you wish.

APPROVED
04 MAY 2022
ERES CONVERGE
P/BAG 125, LUSAKA.

1.7 Results or New Findings

The results of the study and all the findings will be made available after the study by the principle investigator, in case you would like to refer to them. In addition, the school library and laboratory will be asked to keep samples in case you wish to check or confirm the results with what will be reported by the principle investigator.

1.8 Contact Information

Excellence in Research Ethics and Science Converge Institutional Review Board, Plot No. 272 | Corner Olive Tree Mean wood Road Mean Wood Ibex | Lusaka - Zambia. Office : +260 955 155633 | +260 955 155634 : E-mail : eresconverge@yahoo.co.uk

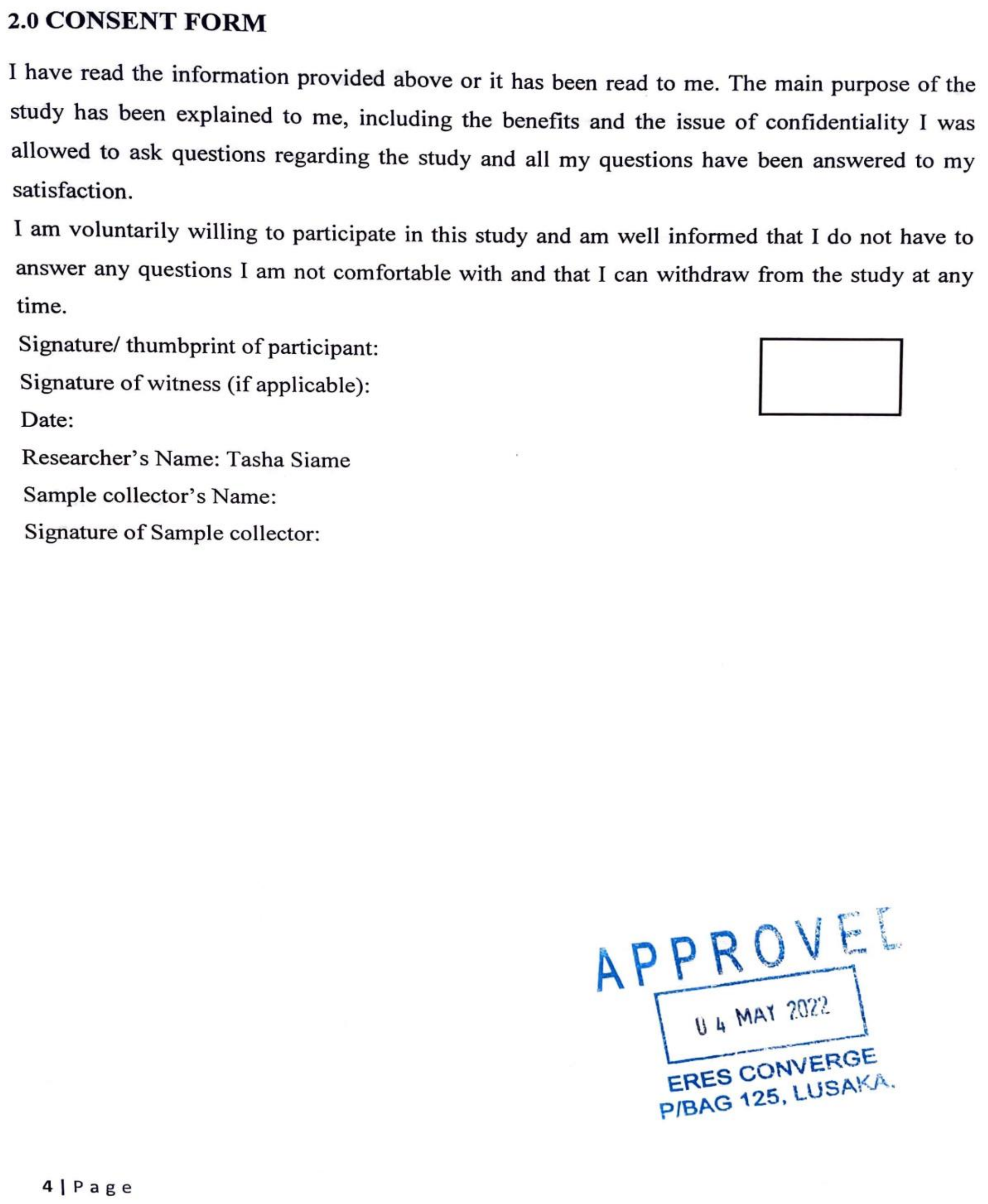
Yours faithfully,

Tasha Siame

Address of researcher: Tasha Siame. C/O University of Zambia, Postgraduate School of Veterinary Medicine, Department of Biomedical Sciences, P.O. Box 32379 Main Campus. Cell number: +260 971190850. E-mail: tashamsiame@gmail.com

APPROVED
04 MAY 2022
ERES CONVERGE
P/BAG 125, LUSAKA.

Appendix B: Consent Form



2.0 CONSENT FORM

I have read the information provided above or it has been read to me. The main purpose of the study has been explained to me, including the benefits and the issue of confidentiality I was allowed to ask questions regarding the study and all my questions have been answered to my satisfaction.

I am voluntarily willing to participate in this study and am well informed that I do not have to answer any questions I am not comfortable with and that I can withdraw from the study at any time.

Signature/ thumbprint of participant:
Signature of witness (if applicable):
Date:
Researcher's Name: Tasha Siame
Sample collector's Name:
Signature of Sample collector:

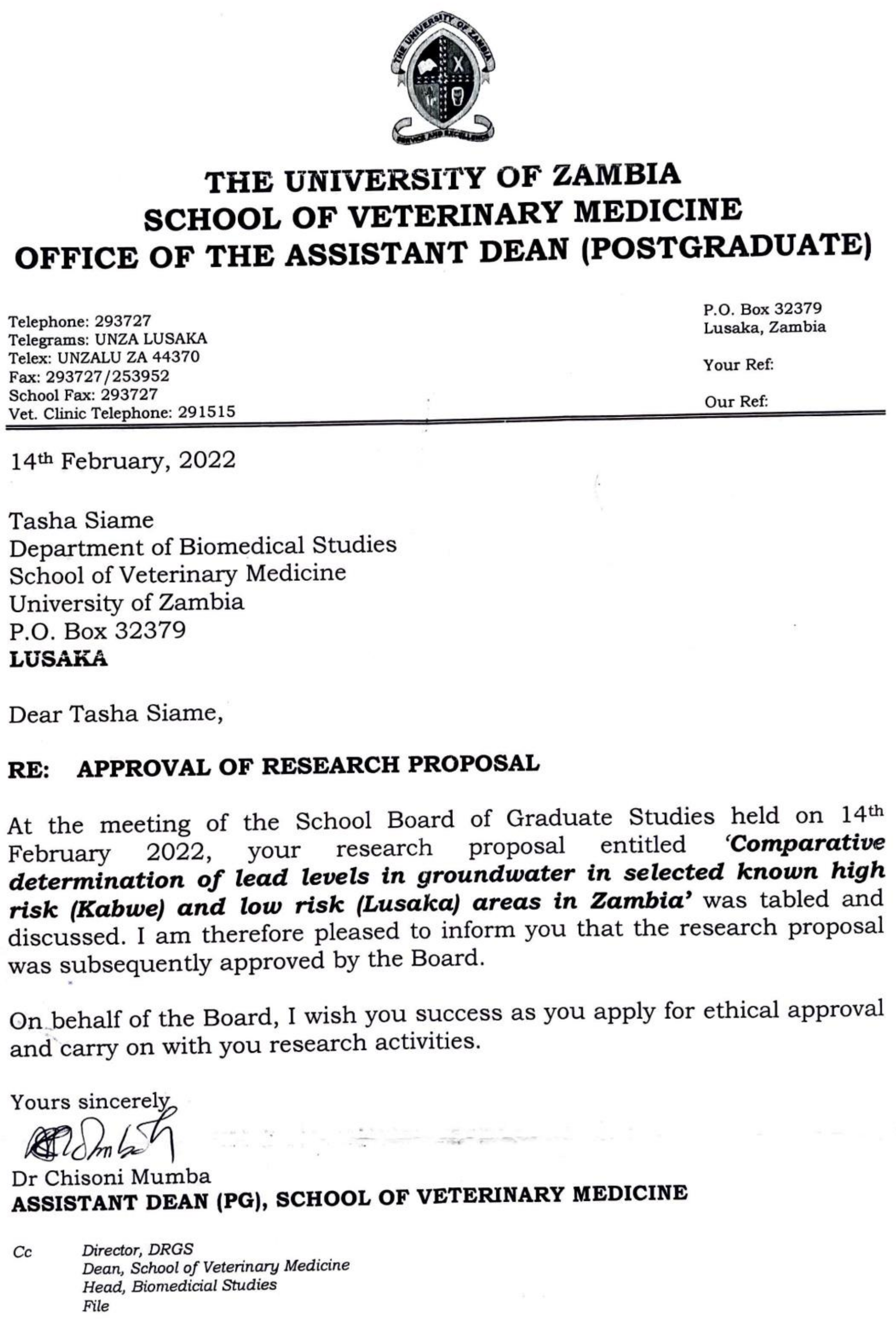
APPROVED
04 MAY 2022
ERES CONVERGE
P/BAG 125, LUSAKA.

Appendix C: Study Approvals

i. Approval of Research proposal by School of Veterinary Medicine, UNZA

ii. Ethical Approval by ERES CONVERGE

iii. Approval to conduct Research by the Local Authority from Kabwe and Lusaka



THE UNIVERSITY OF ZAMBIA
SCHOOL OF VETERINARY MEDICINE
OFFICE OF THE ASSISTANT DEAN (POSTGRADUATE)

Telephone: 293727
Telegrams: UNZA LUSAKA
Telex: UNZALU ZA 44370
Fax: 293727/253952
School Fax: 293727
Vet. Clinic Telephone: 291515

P.O. Box 32379
Lusaka, Zambia

Your Ref:

Our Ref:

14th February, 2022

Tasha Siame
Department of Biomedical Studies
School of Veterinary Medicine
University of Zambia
P.O. Box 32379
LUSAKA

Dear Tasha Siame,

RE: APPROVAL OF RESEARCH PROPOSAL

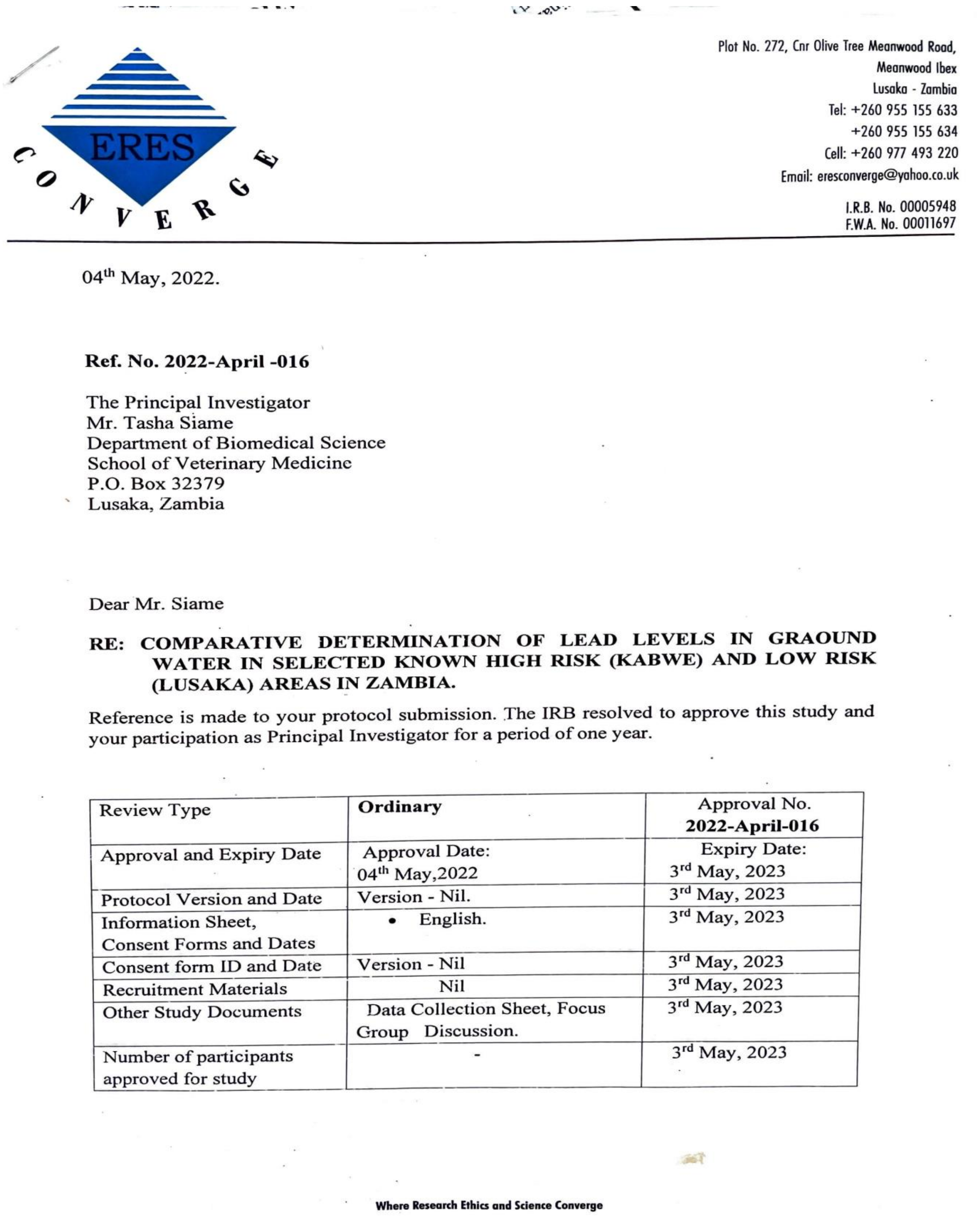
At the meeting of the School Board of Graduate Studies held on 14th February 2022, your research proposal entitled ***'Comparative determination of lead levels in groundwater in selected known high risk (Kabwe) and low risk (Lusaka) areas in Zambia'*** was tabled and discussed. I am therefore pleased to inform you that the research proposal was subsequently approved by the Board.

On behalf of the Board, I wish you success as you apply for ethical approval and carry on with you research activities.

Yours sincerely,

Dr Chisoni Mumba
ASSISTANT DEAN (PG), SCHOOL OF VETERINARY MEDICINE

Cc *Director, DRGS*
Dean, School of Veterinary Medicine
Head, Biomedicial Studies
File



ERES CONVERGE

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Lusaka - Zambia
Tel: +260 955 155 633
+260 955 155 634
Cell: +260 977 493 220
Email: eresconverge@yahoo.co.uk

I.R.B. No. 00005948
F.W.A. No. 00011697

04th May, 2022.

Ref. No. 2022-April -016

The Principal Investigator
Mr. Tasha Siame
Department of Biomedical Science
School of Veterinary Medicine
P.O. Box 32379
Lusaka, Zambia

Dear Mr. Siame

RE: COMPARATIVE DETERMINATION OF LEAD LEVELS IN GRAOUND WATER IN SELECTED KNOWN HIGH RISK (KABWE) AND LOW RISK (LUSAKA) AREAS IN ZAMBIA.

Reference is made to your protocol submission. The IRB resolved to approve this study and your participation as Principal Investigator for a period of one year.

Review Type	**Ordinary**	Approval No. **2022-April-016**
Approval and Expiry Date	Approval Date: 04th May,2022	Expiry Date: 3rd May, 2023
Protocol Version and Date	Version - Nil.	3rd May, 2023
Information Sheet, Consent Forms and Dates	• English.	3rd May, 2023
Consent form ID and Date	Version - Nil	3rd May, 2023
Recruitment Materials	Nil	3rd May, 2023
Other Study Documents	Data Collection Sheet, Focus Group Discussion.	3rd May, 2023
Number of participants approved for study	-	3rd May, 2023

Where Research Ethics and Science Converge

Specific conditions will apply to this approval. As Principal Investigator it is your responsibility to ensure that the contents of this letter are adhered to. If these are not adhered to, the approval may be suspended. Should the study be suspended, study sponsors and other regulatory authorities will be informed.

Conditions of Approval

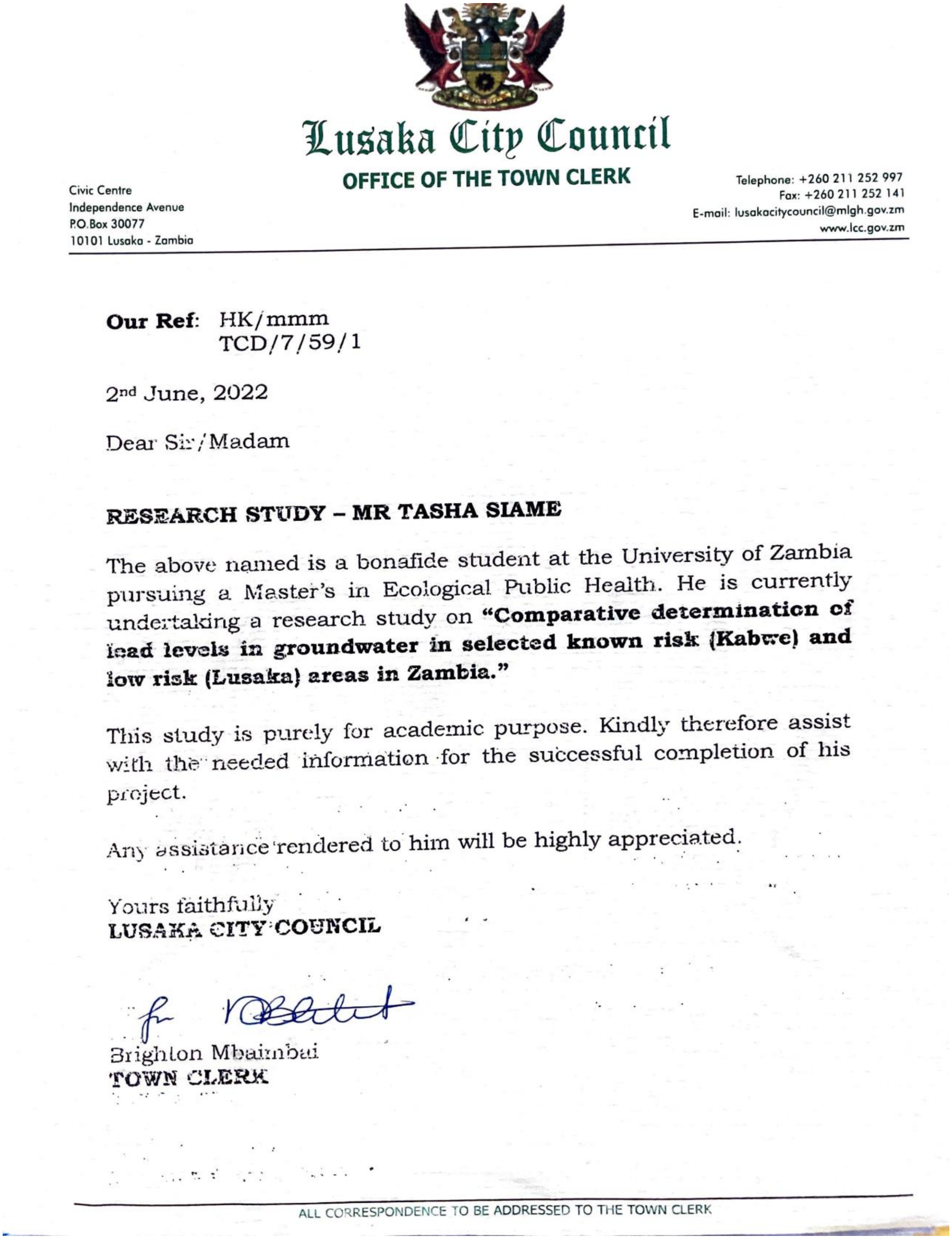
- No participant may be involved in any study procedure prior to the study approval or after the expiration date.
- All unanticipated or Serious Adverse Events (SAEs) must be reported to the IRB within 5 days.
- All protocol modifications must be IRB approved prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address.
- All protocol deviations must be reported to the IRB within 5 working days.
- All recruitment materials must be approved by the IRB prior to being used.
- Principal investigators are responsible for initiating Continuing Review proceedings. Documents must be received by the IRB at least 30 days before the expiry date. This is for the purpose of facilitating the review process. Any documents received less than 30 days before expiry will be labelled "late submissions" and will incur a penalty.
- Every 6 (six) months a progress report form supplied by ERES IRB must be filled in and submitted to us.
- A reprint of this letter shall be done at a fee.

Should you have any questions regarding anything indicated in this letter, please do not hesitate to get in touch with us at the above indicated address.

On behalf of ERES Converge IRB, we would like to wish you all the success as you carry out your study.

Yours faithfully,
ERES CONVERGE IRB

Dr. Jason Mwanza
Dip. Clin. Med. Sc., BA., M.Sc., PhD
CHAIRPERSON



Lusaka City Council

OFFICE OF THE TOWN CLERK

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E-mail: lusakacitycouncil@mlgh.gov.zm
www.lcc.gov.zm

Our Ref: HK/mmm
TCD/7/59/1

2nd June, 2022

Dear Sir/Madam

RESEARCH STUDY – MR TASHA SIAME

The above named is a bonafide student at the University of Zambia pursuing a Master's in Ecological Public Health. He is currently undertaking a research study on **"Comparative determination of lead levels in groundwater in selected known risk (Kabwe) and low risk (Lusaka) areas in Zambia."**

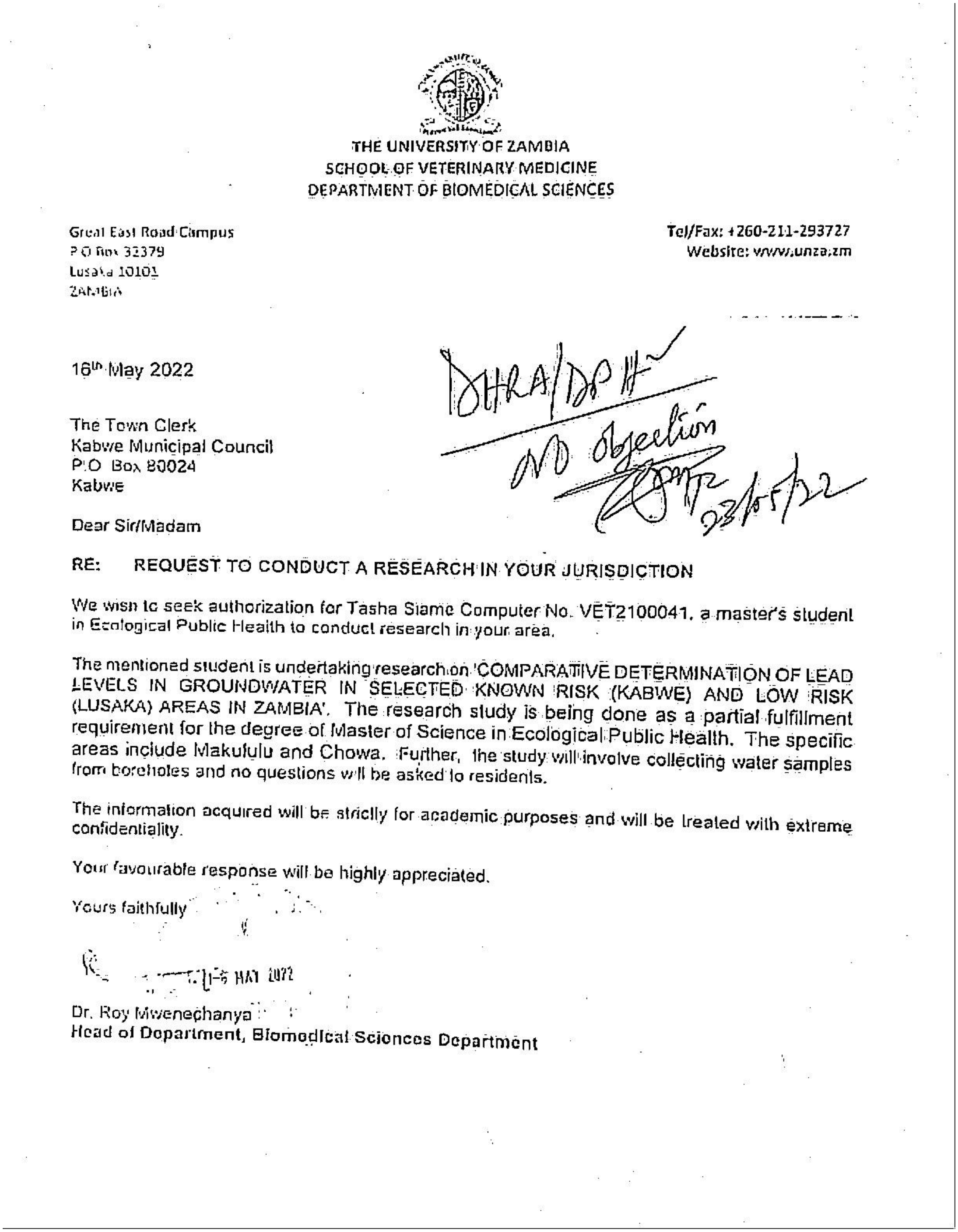
This study is purely for academic purpose. Kindly therefore assist with the needed information for the successful completion of his project.

Any assistance rendered to him will be highly appreciated.

Yours faithfully
LUSAKA CITY COUNCIL

Brighton Mbaimbai
TOWN CLERK

ALL CORRESPONDENCE TO BE ADDRESSED TO THE TOWN CLERK



THE UNIVERSITY OF ZAMBIA
SCHOOL OF VETERINARY MEDICINE
DEPARTMENT OF BIOMEDICAL SCIENCES

Great East Road Campus
P.O Box 32379
Lusaka 10101
ZAMBIA

Tel/Fax: +260-211-293727
Website: www.unza.zm

16th May 2022

DHRA/DPH
No objection
23/05/22

The Town Clerk
Kabwe Municipal Council
P.O Box 80024
Kabwe

Dear Sir/Madam

RE: REQUEST TO CONDUCT A RESEARCH IN YOUR JURISDICTION

We wish to seek authorization for Tasha Siame Computer No. VET2100041, a master's student in Ecological Public Health to conduct research in your area.

The mentioned student is undertaking research on 'COMPARATIVE DETERMINATION OF LEAD LEVELS IN GROUNDWATER IN SELECTED KNOWN RISK (KABWE) AND LOW RISK (LUSAKA) AREAS IN ZAMBIA'. The research study is being done as a partial fulfillment requirement for the degree of Master of Science in Ecological Public Health. The specific areas include Makululu and Chowa. Further, the study will involve collecting water samples from boreholes and no questions will be asked to residents.

The information acquired will be strictly for academic purposes and will be treated with extreme confidentiality.

Your favourable response will be highly appreciated.

Yours faithfully

16 MAY 2022

Dr. Roy Mwenechanya
Head of Department, Biomedical Sciences Department