Human Health Risk Assessment of Exposure to Cadmium, Lead and Chromium through Consumption of Well and Bottled Water in Lusaka District, Zambia

BY

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A dissertation submitted to the University of Zambia in partial fulfillment for the requirement of the award of the degree of Master of Science in Food Safety and Risk Analysis (FSRA)

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DECLARATION

I, Mkuzi Banda, do hereby declare that the contents of the dissertation being submitted herein are my original work, and they have not been previously submitted to any University for the award of a degree or any other qualification.

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CERTIFICATE OF APPROVAL

This dissertation submitted by Mkuzi Banda is approved as fulfilling the requirements for the award of the degree of Masters of Science in Food Safety and Risk Analysis of the University of Zambia.

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ABSTRACT

Water is an essential product for human survival, which all age groups consume and access to safe drinking water is essential to health. Safe drinking water implies that the water does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages. Water is prone to contamination with heavy metals through natural and anthropogenic pollution, making it unsuitable for human consumption because of the negative health outcomes associated with it. This study assessed the non-carcinogenic and carcinogenic risk of human exposure to cadmium, lead and chromium through consumption of well and bottled water in Lusaka district of Zambia.

This study was a deterministic human health risk assessment that followed the Codex Alimentarius Commission's food safety risk assessment framework, comprising hazard identification, hazard characterisation, exposure assessment and risk characterisation. The objective was to assess the risk of exposure to cadmium, lead and chromium through water consumption. The study used results by Nambeye (2017) on well water quality analysis in George compound of Lusaka district and results by ZCSA (2021) on bottled water quality analysis in Lusaka district to estimate the non-carcinogenic and carcinogenic risk of exposure to cadmium, lead and chromium through consumption of well and bottled water. The high levels of cadmium, lead and chromium observed in these studies prompted the conduct of this exposure risk assessment study. The study adopted the World Health Organisation (WHO) and the United States Environmental Protection Agency (USEPA) default water consumption and exposure reference values to calculate the hazard quotient and cancer risk for the metals under study.

This study found that the hazard index for cadmium, lead and chromium in both well and bottled water was higher than 1, indicating an adverse effect on human health, over a lifetime of consumption. Similarly, the total cancer risk through exposure to cadmium and chromium in well and bottled water was 1.2×10^{-1} and 2.25×10^{-1}, respectively and higher than the safe threshold limit set by USEPA of 1×10^{-4}. This study has concluded that there is a possible non-carcinogenic risk of exposure to cadmium, lead and chromium through consumption of bottled water in Lusaka district. The study also concluded that there is a possible non-carcinogenic risk of exposure to cadmium, lead and chromium through consumption of well water in George compound of Lusaka district. This is attributed to the high concentration of heavy metals in both well and bottled water. Results also indicate that there is a possible carcinogenic risk of exposure to cadmium and chromium through consumption of both well and bottled water, with a chance of causing 1 case of cancer for every 10,000 people for those who consume well water and 2 cases of cancer for every 10,000 people for those who consume bottled water, over a lifetime of water consumption.

Owing to the proportion of samples that exceeded the Zambia Bureau of Standards threshold limit in both well and bottled water, cadmium poses the greatest concern and requires intervention to reduce exposure. Therefore, there is a need for relevant institutions to continue monitoring the levels of heavy metals in drinking water to protect the public from exposure to unacceptable levels of heavy metals.

DEDICATION

I dedicate this work to my family, friends and colleagues for their immeasurable support during my studies.

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LIST OF ABBREVIATIONS

CDI	Chronic Daily Intake
CR	Cancer Risk
FAO	Food and Agriculture Organisation
HGV	Health Guidance Value
HI	Hazard Index
HQ	Hazard Quotient
IARC	International Agency for Research on Cancer
JECFA	Joint FAO/WHO Expert Committee on Food Additives
LD	Lethal Dose
LOAEL	Low Observed Adverse Effect Level
NOAEL	No Observed Adverse Effect Level
PTWI	Provisional Tolerable Weekly Intake
USEPA	United States Environmental Protection Agency
WHO	World Health Organisation
ZABS	Zambia Bureau of Standards
ZCSA	Zambia Compulsory Standards Agency
ZEMA	Zambia Environmental Management Agency

CHAPTER ONE: INTRODUCTION

1.1 Background

Water is an essential product for human survival consumed by all age groups. Access to safe drinking water is essential to health, a basic human right and a component of effective policy for health protection. Safe drinking water implies that it does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages (WHO, 2004). Drinking water is prone to contamination by various hazards, with microbiological and chemical hazards being the most significant (WHO, 2004). Whilst the effects of microbiological hazards such as morbidity and mortality manifest almost immediately following exposure, chemical hazards, particularly heavy metals such as cadmium, arsenic, lead and chromium, can result in serious health consequences over time, including a variety of cancers and kidney damage and hence, require monitoring, regulation and risk management.

Heavy metals are released into the environment through natural processes or anthropogenic activities. Many heavy metals are the natural elements of the earth’s crust (Tchounwou et al, 2012). Weathering and decomposition of metal rock and ores can transfer heavy metals to groundwater (Mohammadi et al, 2019). Anthropogenic activities, especially mining, electroplating, metal smelting, chemical industries and manufacturing processes, are the main sources of anthropogenic heavy metals in water (Briffa et al, 2020). Poorly treated domestic, industrial and agricultural wastewater contains high concentrations of metals, which are often discharged into the environment. Some heavy metals, such as mercury and lead may also enter the atmosphere due to traffic pollution and industrial activities, which can be deposited in soils from which they can reach water reservoirs through surface runoff and underground drainage (Malik and Khan, 2016). Paolo et al (2019) also attribute the presence of heavy metals in the environment to rapid industrialisation, manufacture of fertilisers and the high production of industrial waste originating from metal plating, mining activities, smelting, battery manufacture, tanneries, petroleum refinery, paint manufacture, pesticides, pigment manufacture and printing or photographic industries.

One of the pathways in which populations are exposed to heavy metals is consuming contaminated water. When heavy metals enter and accumulate in body tissues faster than the body's detoxification pathways can dispose of, then a gradual build-up of these toxins occurs (Ezedom and Asagba, 2016). High concentration exposure is not a necessity to produce a state of toxicity in the body, as heavy metal accumulation occurs in body tissues gradually and, over time, can reach toxic concentration levels, much beyond the permissible limits (Suruchi and Khanna, 2011).

To date, several publications have reported various aspects of heavy metals in drinking water in Zambia (Mucheleng'anga, 2007: Nambeye, 2017: Kampeshi, 2003: Nick et al, 2010). These aspects include the types and quantities of metals in drinking water, their sources and factors affecting their concentrations at exposure points. The present study attempts to further explore the risk of human exposure to selected heavy metals through water consumption, which includes water from wells and bottled drinking water in Lusaka district, Zambia. According to WHO/FAO (2007), the risk assessment process is a means of providing an estimate of the probability and severity of illness attributable to a particular pathogen or hazard-commodity combination, involving hazard identification, hazard characterisation, exposure assessment and risk characterisation, leading to a decision whether any legal measures need to be taken to prevent harm by the food or ingredient concerned.

1.2 Statement of the Problem

Lusaka district is the most urbanised town and capital city of Zambia, with a population estimated at 2.6 million residents as of 2020 (ZSA, 2020). It is estimated that Lusaka generates about one million tons of solid waste annually, but only half of this is taken to the designated dump site (WOIMA, 2020). More than two-thirds of this waste is generated in peri-urban settlements, where 75% of the population lives (ECZ/NORAD, 2000). A survey conducted by the Zambia Statistical Agency (ZSA) in 2015 revealed that the most common method used for disposing of garbage in Zambia was using a pit, with about 68 percent of all households, while 25.3 percent of households disposed of their garbage by dumping, and only 6.2 percent had their refuse collected (ZSA 2015).

The disposal of liquid effluents from industrial processes and residential houses is also poor. Industrial effluents are discharged into open drains and sewerage systems with very little pre-treatment resulting in the pollution of both underground and surface water bodies. For instance, water-sampling results on a borehole located close to a Zamleather tannery factory in Lusaka had high levels of chromium, providing evidence of poor effluent management (Kampeshi, 2003). On the other hand, most effluents from residential houses are disposed of without treatment as only 25 percent of houses are serviced by the municipal sewerage system, while 20 percent use septic tanks, and the other 55 percent use pit latrines (Nkuwa, 2006).

In terms of air pollution, the presence of many industries that emit fumes, increased number of motor vehicles on the road and poor solid waste management practices such as open burning release large quantities of air pollutants, including heavy metals such as lead (Alexander, 2016: Iamat, 2022). Collectively, these poor disposal practices expose water reservoirs to contamination by heavy metals.

In addition, Lusaka is built over a karstic dolomite aquifer, which serves as a source for underground drinking water, accounting for about 61% of the total water supply within Lusaka district (Nachiyunde et al, 2013). Until recently, siting and drilling of water wells and boreholes were unregulated and remains inadequately regulated to a larger extent. The lack of regulation entails that some boreholes and wells could have been sited and drilled in areas with elevated levels of naturally occurring toxic heavy metals, which serve as a source of contamination of underground water. Since water from boreholes and wells is not usually subjected to treatment such as reverse osmosis, ion exchange and lime softening that can reduce the levels of heavy metals before consumption, there is an increased risk of exposure.

A study conducted by Nambeye (2017) to investigate heavy metal contamination of underground water in George compound of Lusaka district found high levels of selected heavy metals. The mean concentrations of cadmium (0.91 mg/l), lead (0.04 mg/l), chromium (0.14 mg/l) and iron (1.22 mg/l) were all above the Zambia Bureau of Standards (ZABS) threshold limits of 0.003 mg/l, 0.01 mg/l, 0.05 mg/l and 0.3 mg/l, respectively. Another study commissioned by the then Environmental Council of Zambia, now called Zambia Environmental Management Agency (ZEMA) to identify potential groundwater pollution sources found unsatisfactory results with respect to chromium at 2 mg/l (Kampeshi, 2003). Further, the boreholes with elevated levels of heavy metals were located near a tannery factory and a solid waste disposal site and thus were attributed as possible pollution sources (Kampeshi, 2003). A study by Nick et al (2010) also showed elevated levels of lead and cadmium in various sampled boreholes within Lusaka district.

Similarly, unpublished data from the Zambia Compulsory Standards Agency (ZCSA), a government agency mandated to monitor the quality of bottled drinking water in Zambia, shows that the mean concentrations of cadmium and lead in bottled water were higher than the national health guidance values, while that of chromium was within the limit. Water analysis results from 2015 to 2019 shows that the level of cadmium ranged from 0.001mg/l to 11 mg/l with a mean concentration of 0.27 mg/l. The level of lead ranged from 0.01mg/l to 7.5mg/l with a mean concentration of 0.09 mg/l, while that of chromium ranged from 0.003mg/l to 3.49mg/l with a mean concentration of 0.04mg/l (ZCSA, 2021).

From the statistics highlighted, there is evidence of heavy metal contamination of underground water sources in Lusaka district, hence a risk of exposure through consumption of well and bottled water. According to the United States Environmental Protection Agency (USEPA), intake of heavy metals such as chromium, lead, arsenic and cadmium through drinking water may increase the non-carcinogenic and carcinogenic risk on human health (USEPA, 2004 cited by Alidadi, 2019).

1.3 Rationale of the study

Water contamination with heavy metals has serious long-term health effects on consumers, including cancer and organ damage (Godt et al, 2006 and WHO, 2010a). The ability of heavy metals to bio-accumulate in body tissues is of concern because exposure to even small doses over an extended period can result in negative health outcomes (Jaishankar et al, 2014). The International Agency for Research on Cancer (IARC) has classified cadmium and chromium as group 1 carcinogens, and various reports have found that exposure to these compounds leads to disruptions in tumour suppressor gene expression and damage repair processes (Banfalvi, 2011). Exposure to lead impairs the development of the brain and nervous system in children, increases the risk of high blood pressure and kidney damage in adults, and causes miscarriages, stillbirths, premature births, and low birth weight children if pregnant women are exposed (WHO, 2019). A study by Hyuno and Young (2015) also found that heavy metals induce oxidative stress, DNA damage, and cell death processes, resulting in an increased risk of cancer and cancer-related diseases.

Several studies have been conducted in Zambia, which have shown contamination of underground water with toxic heavy metals which include cadmium, lead, chromium, arsenic, iron and copper (Nambeye, 2017: Nick et al, 2010: Mucheleng’anga, 2007: Kampeshi, 2003). However, a search through various databases has not found a record of a study conducted to assess the risk of human exposure to cadmium, chromium and lead through consumption of well and bottled water in Zambia. Owing to the high concentrations of cadmium, lead and chromium in well and bottled water reported in previous studies (Nambeye, 2017: ZCSA, 2021) and the adverse effects of exposure to these heavy metals, it was imperative to assess the risk posed to consumers and, if necessary, propose remedial measures.

1.4 Significance of the Study

This study may generate information on the risk of exposure to selected heavy metals namely; cadmium, lead and chromium, through consumption of well and bottled water, which could be useful to guide policy and regulation. In addition, the findings might add to the existing knowledge on chemical risk assessment and provide a platform to the academia for further research.

1.5 Research Questions

1.5.1 General Research Question

What is the risk of human exposure to cadmium, lead and chromium through the consumption of well and bottled water in Lusaka district?

1.5.2 Specific Research Questions

1. What is the non-carcinogenic risk of exposure to cadmium, lead and chromium through consumption of well and bottled water in Lusaka district?
2. What is the carcinogenic risk of exposure to cadmium, lead and chromium through the consumption of well and bottled water in Lusaka district?

1.6 Objectives

1.6.1 General Objective

To assess the risk of human exposure to cadmium, lead and chromium through consumption of well and bottled water in Lusaka district.

1.6.2 Specific Objectives

1. To estimate the non-carcinogenic risk of exposure to cadmium, lead and chromium through consumption of well and bottled water.
2. To estimate the carcinogenic risk of exposure to cadmium, lead and chromium through consumption of well and bottled water.

CHAPTER TWO: LITERATURE REVIEW

The literature review followed the steps of conducting a risk assessment under the Codex Alimentarius Commission Food Safety Risk Assessment Methodology. Therefore, the literature review digresses from the traditional way of presenting a literature review. The four steps of conducting a food safety risk assessment are hazard identification, hazard characterisation, consumer exposure assessment and risk characterisation.

2.1 Hazard Identification

Heavy metals are naturally occurring elements with a high atomic weight and a density at least 5 times greater than water. However, being a heavy metal has little to do with density but concerns chemical properties that affect humans, animals and the environment (Duruibe et al, 2007). Their multiple industrial, domestic, agricultural, medical, and technological applications have led to their wide distribution, raising concerns over their potential effects on human health and the environment (Tchounwou et al, 2012). Reported sources of heavy metals in the environment include industrial waste originating from metal plating, mining activities, smelting, battery manufacture, tanneries, petroleum refinery, paint manufacture, pesticides, pigment manufacture, printing or photographic industries and fertiliser production (Paolo et al, 2010). Although heavy metals are naturally occurring elements that are found throughout the earth's crust, most environmental contamination and human exposure result from anthropogenic activities (He et al, 2005).

The main pathways for human exposure include ingestion through food and water, inhalation and direct skin contact (Tchounwou et al, 2012: Duruibe et al, 2007). Once ingested, they can bio-accumulate in the body for a long period until they reach toxic levels. For instance, cadmium has a long half-life of 25 to 50 years in the kidneys, lead can persist up to 30 years in the bones, and chromium has a half-life of up to 10 years in epidermal tissues such as hair, bones, liver, kidney, spleen and lungs (Kabata-Pendias et al, 2015: Petersen et al, 2000). All age groups can be affected but children are more vulnerable partly because their defence mechanisms may not be fully developed and their high absorption rate for some heavy metals (Westrell et al, 2006). In a study conducted by Kabata-Pendias et al (2015), they observed that cadmium absorption appeared to be higher in new-borns and infants, in contrast to adults, independent of iron status. The concentration chromium was also relatively higher in new born children than in adults. Although water consumption is lower among children compared to adults, they have higher ingestion in relation to their body weight, which makes them more sensitive to contaminants (Westrell et al, 2006).

2.2 Hazard Characterisation

The toxicity of heavy metals depends on several factors, including the dose, route of exposure, chemical species, age and gender of exposed individuals (Godt et al., 2006). Cadmium, chromium and lead rank among the priority heavy metals that are of public health significance because of their high degree of toxicity (Tchounwou et al, 2012). These metallic elements are considered systemic toxicants that are known to induce multiple organ damage, even at lower levels of exposure (WHO, 2019). They are also classified as human carcinogens (known or probable) according to USEPA and the International Agency for Research on Cancer (Tchounwou et al, 2012). Research has documented the characteristics and adverse effects of exposure to heavy metals as follows:

Cadmium

The None Observable Adverse Effects Level (NOAEL) for cadmium is 0.001 mg, Low Observable Adverse Effects Level (LOAEL) is 100 mg, and the lethal dose (LD 50) is 350 to 3500 mg (Krajnc, 1987). According to Godt et al (2006), exposure to cadmium causes short term effects that include nausea, vomiting, diarrhoea, muscle cramps, salivation, sensory disturbances, liver injury, convulsions, shock and renal failure. Long term effects include kidney damage, testicular necrosis and prostate cancer, pneumonitis and the destruction of the mucous membrane in the reproductive and respiratory systems (Water Quality Association, 2013).

Lead

There is no known 'safe' blood lead concentration as even blood lead concentrations as low as 5 µg/dl may be associated with decreased intelligence in children, behavioural difficulties and learning problems (WHO, 2010b), even though blood lead levels of 10 µg/dl in children and 25 µg/dl in adults are what are considered as toxic (Bellinger et al, 1991: Roscoe et al, 2002). This lack of an indication of a threshold level for key effects of lead, based on the dose-response analysis, led the Joint FAO/WHO Expert Committee on Food Additives (JECFA) to conclude that a new Provisional Tolerable Weekly Intake (PTWI) considered as health-protective could not be established (WHO, 2019). The World Health Organisation (2019) also found that exposure to lead impairs the development of the brain and nervous system in children, increases the risk of high blood pressure and kidney damage in adults and causes miscarriages, stillbirths, premature births and having low birth weight children if pregnant women are exposed. Other adverse effects include; joint and muscle pain, headache, trouble concentrating, memory problems and mood changes (CDC, 2022).

Chromium

Although several studies have been conducted on animal subjects to assess the severity of chromium exposure, the NOAEL, LOAEL and LD50 for chromium have not been established. However, in a study conducted by Zhang and Lee (1987) that found exposure levels of 0.57 mg /kg/day, associations were found between drinking the contaminated water and oral ulcer, diarrhoea, abdominal pain, indigestion, and vomiting. Another study in China reported an increase of stomach cancer mortality in the residents of small villages in the Liaoning province, where the drinking water was heavily contaminated with chromium (VI) (Sun et al, 2015). Other effects of exposure to chromium include increased incidence of liver and lung cancers and increased incidence of gastrointestinal and dermatological complaints (Linos et al, 2011: Sharma et al, 2012).

Based on experimental data and dose-response relationships, Health Guidance Values (HGV) for heavy metals in drinking water have been set, which vary from country to country. For example, in the United States, the maximum allowable amount of a contaminant in drinking water (MCL) is 0.005 mg/l for cadmium, 0.015 mg/l for lead and 0.1 mg/l for chromium (USEPA, 2021). Zambia has adopted the WHO threshold limit values of 0.003 mg/l for cadmium, 0.01 mg/l for lead and 0.05 mg/l for chromium (ZABS, 2010).

2.3 Exposure Assessment

Exposure Assessment is defined as “the qualitative and/or quantitative evaluation of the likely intake of biological, chemical and physical agents via food as well as exposure from other sources if relevant” (CAC, 2006). It measures the extent of human exposure to the toxic element (actual or anticipated) and takes into consideration the prevalence and concentrations of toxic elements in the diet, the consumption patterns of the foods containing the toxic elements and the likelihood of consuming the contaminated food (Prabhat et al, 2019).

2.3.1 Prevalence of Heavy Metals in Water

The concentration of heavy metal contaminants in drinking water is one of the significant factors to consider when determining the risk of human exposure. The concentration and distributions of heavy metals in water is influenced by various factors among them; the level of contaminants in the earth’s crust, human activities such as mining, manufacturing and agriculture as well as the existing waste management systems, which all contribute to the contamination of water. For instance, Friberg et al (1986) reported that the concentrations of cadmium in unpolluted natural waters are usually below 1 µg/l. The WHO/ UNEP (1989) conducted a survey at 110 stations around the world and also found median concentrations of dissolved cadmium to be less than 1 µg/l, with the maximum value recorded being 100 µg/l in the Rio Rimao in Peru. However, these results are in stark contrast to those found in polluted environments, which recorded high concentrations of heavy metals in water. For instance, Ahmed and Moktar (2020) found high concentration of cadmium near ex-mining sites in Langat river basin of 0.35 mg/l and attributed to possible anthropogenic pollution from runoffs. Similarly, Maigari et al (2016) found high concentrations of cadmium (0.5mg/l) and lead (0.19 mg/l) in Nigeria, indicating that human activities have a bearing on the concentration of heavy metals in water.

Other significant factors that influence the concentration of heavy metals in underground water are pH and temperature. In a study conducted by Haiyan et al (2013), heavy metals release rates were higher in low pH (4–7) condition than in high pH (8–10) conditions. At higher temperature (30–35°C) the release rates of metals also increased more rapidly than at low temperature.

In Zambia, a study conducted by Nambeye (2017) to investigate heavy metal contamination of underground water in George compound of Lusaka district found high levels of selected heavy metals. The levels of chromium (0.14 mg/l), cadmium (0.91 mg/l), lead (0.07 mg/l) and iron (1.22 mg/l) were all above the national health guidance values. Another study commissioned by the Zambia Environmental Management Agency (ZEMA) to identify potential groundwater pollution sources in Lusaka district found unsatisfactory results with respect to chromium at 2 mg/l (Kampeshi, 2003). Interestingly, boreholes with elevated heavy metal levels were located near a tannery factory and a solid waste disposal site, which were attributed as possible pollution sources. To the contrary, Nachiyunde et al (2013) found that the concentration of heavy metals in water, that included cadmium, lead and chromium, was insignificant.

Most studies have focused on the concentration of heavy metals in untreated underground water with little focus on processed bottled drinking water (Mucheleng'anga, 2007: Nambeye, 2017: Kampeshi, 2003: Nick et al, 2010: Mohammadi et al, 2019). However, this study will focus on both untreated and treated water in order to also document the concentration of heavy metals in bottled water, by analysing water analysis results collected by the regulator of bottled water sold in Lusaka district of Zambia. Unpublished data from the Zambia Compulsory Standards Agency (ZCSA), a government agency mandated to monitor the quality of bottled water in Zambia, shows that the mean concentration of cadmium and lead in packaged water was higher than the national health guidance values, while that of chromium was within the limit. From the water analysis conducted from 2015 to 2019, the level of cadmium ranged from 0.001 mg/l to 11.09 mg/l with a mean concentration of 0.27 mg/l. The level of lead ranged from 0.01 mg/l to 7.5 mg/l with a mean concentration of 0.09 mg/l, while that of chromium ranged from 0.003 mg/l to 3.49 mg/l with a mean concentration of 0.04 mg/l (ZCSA, 2021).

2.3.2 Water Consumption Patterns

Measurement of water consumption patterns in individuals is fairly new in focus. As a result, the state of the science is poorly developed, data are most likely fairly incomplete, and adequate validation of the measurement techniques used are not available (Popkin et al, 2010). Water consumption patterns vary among different age groups, seasons and countries. One study in the United States attempted to examine all the sources of water in a regular human. The study used data on National Food Consumption Survey for food and fluid intake from 1977–78, which found average water consumption for children aged 2 to 18 years to be 1.9 l/day and for adults above 19 years to be 2.4 l/day (Popkin et al, 2010). In another National Health and Nutritional Education Survey (NHANES) conducted between 1994–1996 in the United States, total water consumption for adults aged 40 to 69 years was 3.7 l/day for men and 2.7 l/day for women, and there was a 20% difference in water consumption between the winter and summer months (Heller et al, 1999). These results are similar to those of Popkin and Jebb (2010) who found average water consumption in adults to be 2.8 l/day in the United States and 1.8 l/day in the United Kingdom in the 2001-2002 period. In Germany, Manz and Wentz (2005) found average water consumption for children aged 4 to 10 years to be 1.5 l/day and 1.3 l/day for boys and girls, respectively.

From these results, it is clear that water consumption patterns differ between different age groups, sexes and seasons of the year. Lavallee et al (2021) found that gender was significantly associated with well water consumption, with higher consumption rates found among female respondents compared to males in Sweden. However, these results are in contrast to those of FWR (1996) in a study conducted in England and Wales, which found that men consumed a higher total quantity of liquids than women. Gofti-Laroche et al (2001) present clear seasonal differences in water intake in their study conducted in France. While the total water intake was 1.87 l/day in winter for adults, the intake during late spring was 2.23 l/day and they attributed this difference to the need for more liquids during warmer periods of the year. The other factors that could influence water consumption patterns could be the source and availability of drinking water and social-economic characteristics. Westrell et al (2006) found that people receiving municipal water consumed slightly more water than those with excavated private wells and generally were of the opinion that it was of very high quality, suggesting that the source of water and perceived quality attributes could influence how much water a person consumed. Further, FWR (1996) revealed that bottled water consumption increases with increased income, bringing to the fore the aspect of social class.

In the case of Zambia, water consumption patterns and the factors that could influence consumption patterns, have not yet been determined. However, Kleiner (1999) suggests that, based on US National Research Council guidelines in relation to hydration needs resulting from average energy expenditure and environmental exposure in the USA, the average male should consume a minimum of 2.9 l/day and the average female 2.2 l/day. Approximately one-third of this fluid was considered likely to be derived from food, and based on this rationale, the World Health Organisation (WHO) recommends direct water consumption of 2 l/day for adult males, 1.4 l/day for adult females and 1 l/day for children below 10 years (Howard and Bartram, 2003: WHO, 2003).

Water consumption patterns have a significant role in health risk assessment for exposure to toxic elements. The amount of water consumed is one of the parameters used in determining the Chronic Daily Intake (CDI) which in turn, is used in risk estimation. Therefore, absence of water consumption values for different individuals and seasons of the year specific to Zambia, is a challenge that warrants future research.

2.4 Risk Characterisation

Risk Characterisation is defined as "the qualitative and/or quantitative estimation, including attendant uncertainties, of the probability of occurrence and severity of known or potential adverse health effects in a given population based on hazard identification, hazard characterization and exposure assessment" (CAC, 2006). It is the final step in the risk assessment process in which the information from the intake/exposure assessment and the hazard characterization are integrated into advice suitable for decision-making in risk management and provides estimates of the potential risk to human health under different exposure scenarios (WHO, 2008). Several studies have been undertaken to estimate the non-carcinogenic and carcinogenic risk of exposure to heavy metals through consumption of water. In Iran, Alidadi et al (2019) conducted a study to assess the probable health risk (non-carcinogenic and carcinogenic risk) for adults and children exposed to arsenic and other toxic heavy metals, namely lead, chromium, nickel, and mercury, through ingestion and dermal contact with drinking water. Chemical analysis and testing were conducted on 140 water samples taken from treated drinking water in Mashhad and health risk assessments were evaluated using hazard quotient, hazard index and lifetime cancer risk. They found that the cancer risk through exposure to drinking water for children and adults was borderline or higher than the safety level of United States Environmental Protection Agency (USEPA), suggesting the probability of carcinogenic risk for the children and adults to the carcinogenic elements via ingestion and dermal routes. These results are similar to those of Majid et al (2017), who also investigated the excess health risk of heavy metals (chromium, lead, and cadmium) intake through drinking water in Iran. The hazard quotient and Excess Lifetime Cancer Risk (ELCR) were determined to show the carcinogenic and non-carcinogenic effects among children and adults. The comparisons indicate no possibility of non-carcinogenic effects to the local population, but the ELCR index was found above acceptable risk levels for chromium and cadmium in both children and adult groups.

In India, Vetrimurugan et al (2016) applied the Heavy Metal Pollution Index (HPI) and human exposure hazard index to study the groundwater quality based on heavy metals' concentration in their study in an intensively irrigated part of the Cauvery river basin, Tamil Nadu. Sixteen heavy metals were analysed that included chromium, cadmium and lead. Chromium was within permissible limits of the Bureau of Indian Standards for drinking water quality, while lead was above limits in all the groundwater samples and less than 50 % of the groundwater samples, cadmium exceeded permissible limits. The heavy metal pollution index indicated that groundwater quality of this area is poor-to-unsuitable, and the study concluded that the non-carcinogenic risk for humans due to ingestion of groundwater through drinking water pathway was very high for infants, children and adults.

In Nigeria, Onyinyechi et al (2018) also conducted a human health risk assessment in some rural springs and analysed four heavy metals namely; lead, iron, cadmium and chromium. The health risk assessment for all the sites indicated that there is no particularly dangerous single heavy metal, but their cumulative effect, indicated by the hazard index (HI) calls for concern for both children and adults as they highly exceeded threshold value of 1.

The studies cited, evaluated the risk of exposure to heavy metals through untreated underground water. This study, however, will evaluate both untreated underground water from wells and treated bottled water to evaluate the risk posed by each product. The study will focus on cadmium, lead and chromium because available data suggests that the concentration of the 3 heavy metals in both untreated underground water and treated bottled water was higher than the recommended levels by the Zambia Bureau of Standards (Nambeye, 2017: ZCSA, 2021).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study Design

This was a deterministic human health risk assessment study through review of secondary data followed by risk characterisation. It followed the Codex Alimentarius Commission’s food safety risk assessment framework, comprising hazard identification, hazard characterisation, exposure assessment and risk characterisation (FAO/WHO, 2009). Risk estimation was conducted using the hazard quotient and cancer risk models suggested by USEPA (2016).

3.2 Data Source

The study used secondary data by Nambeye (2017) on well water quality analysis in George compound of Lusaka district and data by ZCSA (2021) on bottled water quality analysis in Lusaka district, to conduct risk characterisation. Additional data on reference values for the metals under study was collected from ZABS, USEPA and WHO.

3.3 Study Site

The study was conducted in Lusaka district, which is the capital city and most populated town in Zambia, with an estimated population of 2.6 million people (ZSA, 2020). Its geographical position is between 15°18' - 15°30' south and of 28°18' - 28°30' east; and lies on a plateau above 1200 m above mean sea level. The district has a surface area of 360 square kilometres and shares district boundaries with Chongwe in the east, Mumbwa in the west, Chisamba in the north and Chilanga district in the south (Nambeye, 2017). It was purposively selected because underground water serve as the main source of water supply accounting for about 61% of the total water supply in the district (Nachiyunde et al, 2013). The city also generates large quantities of industrial and municipal waste which are implicated in the contamination of underground water sources due to poor waste disposal practices (Kampeshi, 2003). In addition, bottled water is widely consumed throughout the district and water analysis results of some bottled water produced and distributed on the market were found to contain elevated levels of heavy metals.

The study used results by Nambeye (2017) from a study conducted in George compound to conduct the health risk assessment through exposure to heavy metals in well water and results from ZCSA (2021) in Lusaka district to conduct the health risk assessment through exposure to heavy metals in bottled water. George Compound is located in north-west of Lusaka central business district (CBD) lying between 1200 m and 1300 m above sea level (Baumle and Museteka, 2008). It is a legalised but unplanned settlement, which is located in an area of highly vulnerable and poor quality groundwater (Waterwitness, 2022). Like other unplanned peri-urban residential areas in Lusaka district, it has inadequate piped water supply facilities and many residents fetch their water at public kiosks, serviced by the local utility company (NWASCO, 2014), while water wells also serve as an important alternative source of drinking water due to inadequate water supply (Waterwitness, 2022). George compound has an estimated population of about 200,000 people (Waterwitness, 2022) and due to its proximity to the industrial area, many people are engaged in temporary employment but the majority of the population are small scale traders who earn their living by selling of assorted commodities in the markets and on the streets (Nambeye, 2017). The area was purposively selected based on its proximity to industries such as tannery, paint manufacturing plants, steel manufacturing plants and plastic manufacturing plants, whose waste products include cadmium, lead and chromium which serve as pollution sources for underground water.

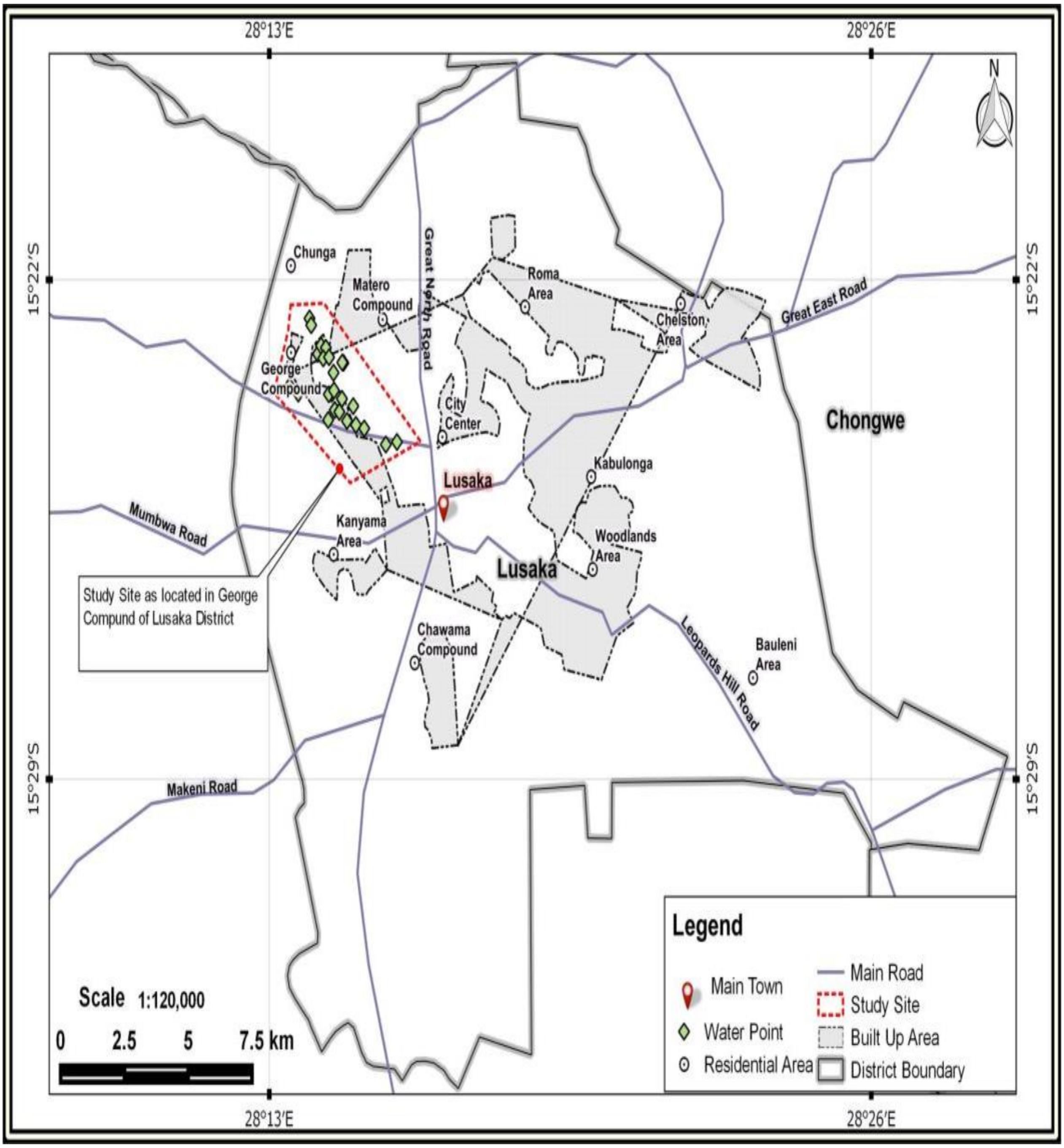


Figure 1: Location of Study Area

Source: Nambeye (2017)

3.4 Sampling Size and Frame

This study collected data from two secondary sources. Data on well water analysis was reported in a scientific publication by Nambeye (2017) while data on bottled water analysis was collected from the database of the regulator of bottled water in Zambia, the Zambia Compulsory Standards Agency. The data sources were purposively selected.

3.5 Data Collection

This study collected results from a report by Nambeye (2017) which estimated the mean concentrations of heavy metals in well water in George compound, Lusaka. In the second part, the study collected results from a report by ZCSA (2021) on bottled water analysis conducted between January 2018 and June 2020, which estimated the mean concentrations of heavy metals in bottled water. Laboratory analysis for both well and bottled water were conducted according to the American Public Health Association (APHA), Association of Official Agricultural Chemists (AOAC) and the International Standards Organisation (ISO) test procedures and results interpreted according to the Zambian standards for drinking water (Nambeye, 2017: ZCSA, 2021).

3.6 Data Analysis

This study adopted the results of Nambeye (2017) which determined the mean concentrations of heavy metals in well water in George compound and results by ZCSA (2021) which determined the mean concentrations of heavy metals in bottled water. Risk estimation for the non-carcinogenic and carcinogenic risk exposure to heavy metals was done by calculating the hazard quotient and cancer risk, respectively.

3.6.1 Chronic Daily Intake

The chronic Daily Intake (CDI) is the exposure expressed as mass of a substance ingested per unit body weight per unit time, averaged over a long period of time (Pawełczyk, 2013). This study adopted the USEPA formula for calculating the CDI as follows (USEPA, 2016):

$$CDI = (C \times IR \times EF) / BW \tag{1}$$

Where: CDI is chronic daily intake (mg/kg/day)

C is concentration of contaminant (mg/l)

IR is intake rate of contaminant (l/day)

EF is exposure factor (unitless)

BW is body weight (kg)

3.6.2 Non-Carcinogenic Risk Exposure Estimation

The non-carcinogenic risk refers to the potential for adverse systemic or toxic effects caused by exposure to non-carcinogenic elements of concern (Mohammadi et al, 2019). It is estimated using the hazard quotient, which compares the chronic daily intake of a heavy metal with the Reference Dose (RfD). The reference dose represents a daily oral intake rate that is estimated to pose no appreciable risk of adverse health effects, even to sensitive populations, over a 70-year lifetime (USEPA, 2005). A hazard quotient value below 1 implies that there is no adverse effect on human health, while the value above 1 implies adverse effect on human health (USEPA, 2016). The non-carcinogenic risk of exposure to cadmium, lead and chromium was calculated using the proposed formulae for both Hazard Quotient (HQ) and Hazard Index (HI) as follows (USEPA, 2005):

$$HQ = CDI / RfD \qquad (2)$$

$$HI = \sum HQ$$

Where; HQ is hazard quotient

HI is hazard index, representing the sum of HQs for cadmium, lead and chromium

CDI is chronic daily intake (mg/kg/day)

RfD is oral reference dose (mg/kg/day)

3.6.3 Carcinogenic Risk Exposure Estimation

Carcinogenic or cancer risks (CR) is defined as “the incremental probability of an individual to develop cancer, over a lifetime, as a result of exposure to a potential carcinogen” (USEPA, 2016). It is a product of the chronic dietary exposure to a toxic element and the Cancer Slope factor (CS), defined as a measure of cancer risk from a lifetime exposure to an agent (USEPA, 1991). The safe threshold limit for cancer risk is 1×10^{-4} to 1×10^{-6} (USEPA, 2012). A risk higher than 1×10^{-4} is interpreted to mean a chance of 1 in 10,000 people developing cancer during their lifetime from the exposure being evaluated and is considered unacceptable, requiring some sort of intervention and remediation. (USEPA, 2005). The carcinogenic risk was calculated only in respect of cadmium and chromium because there is no validated cancer slope factor set for lead. The carcinogenic risk exposure to cadmium and chromium was estimated using the formulae proposed by USEPA (2005) as follows:

$$CR = CDI \times CS \qquad (3)$$

$$TCR = \sum CR$$

Where; CR is a cancer risk,

TCR is total cancer risk, representing the sum of CRs for cadmium and chromium

CDI is chronic daily intake (mg/kg/day)

CS is the oral cancer slope factor $(mg/kg/day)^{-1}$

3.7 Ethics Consideration

Authority to conduct research was obtained from the School of Veterinary Medicine at the University of Zambia, the University of Zambia Biomedical Research Ethics Committee (Ref No. 2169-2021) and the National Health Research Authority (Ref No. NHRA000023/28/12/2021). In addition, written permission was obtained from ZCSA (Ref No. ZCSA/ED/10/04/21) to use water analysis data. Further, the names of bottled water brands and the identities of their manufacturers have not been disclosed to ensure confidentiality.

CHAPTER FOUR: RESULTS

4.1 The concentration of Heavy Metals in Drinking Water

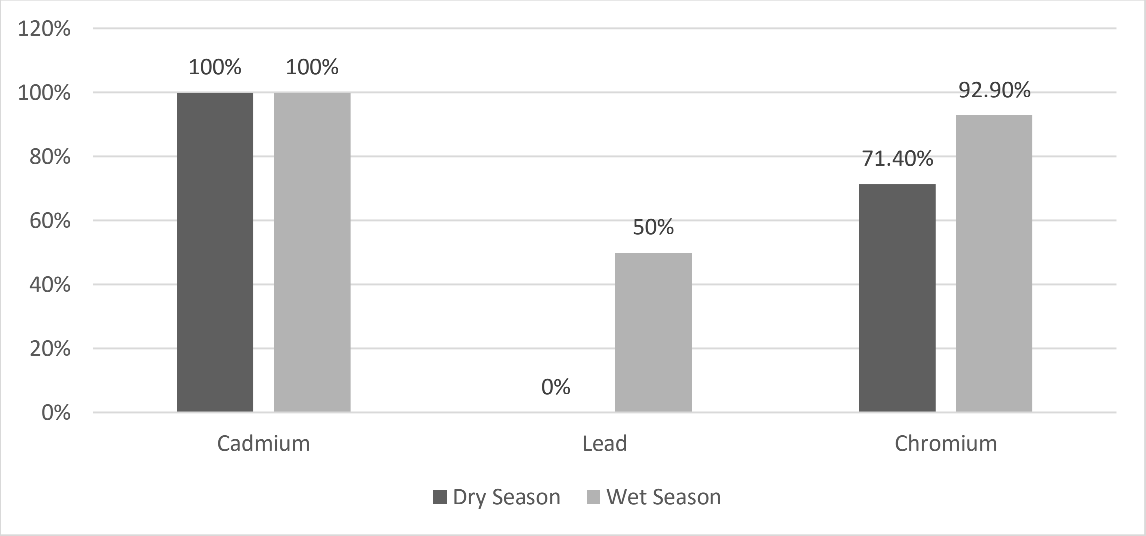
4.1.1 The concentration of Heavy Metals in Well Water

The concentration of cadmium ranged from 0.02 mg/l to 0.91 mg/l with mean concentration of 0.62 mg/l, the concentration of lead ranged from 0.01 mg/l to 0.07 mg/l with the mean concentration of 0.04 mg/l while the concentration of chromium ranged from 0.01 mg/l to 0.64 mg/l with mean concentration of 0.39 for both seasons. Further, the proportion of samples that exceeded the ZABS threshold limit in the wet season was 100 % for cadmium, 50 % for lead and 92 % for chromium. In the dry season, the proportion of samples that exceeded the threshold limit for cadmium and chromium was 100 % and 71 % respectively but none of the samples exceeded the threshold limit for lead (Nambeye, 2017).

Table 1. Concentration of Heavy Metals in Well Water

Metal	**Concentration (mg/l) Wet Season**		**Concentration (mg/l) Dry Season**		**Concentration (mg/l) All Seasons**	**Maximum Limit (Zambian Standard)**
	Range	**Mean**	**Range**	**Mean**	**Mean**	
Cadmium	0.05 - 0.30	0.32	0.02 - 0.91	0.91	**0.62**	0.003*
Lead	0.01 - 0.07	0.07	0.01 - 0.01	0.01	**0.04**	0.01*
Chromium	0.04 - 0.64	0.64	0.01 - 0.14	0.14	**0.39**	0.05*

Source: Nambeye (2017): ZABS (2010)*



Source: Nambeye (2017)

Figure 2. The proportion of Samples with Concentration above Threshold Limit

4.1.2 Concentration of Heavy Metals in Bottled Water

The mean concentration of cadmium was found to be 1.2 mg/l, lead was 1.16 mg/l, and chromium was 1.03 mg/l, all above the ZABS thresholds of 0.003 mg/l, 0.01 mg/l and 0.05 mg/l for cadmium, lead, and chromium respectively. Cadmium had the highest proportion of samples that exceeded the ZABS threshold limit with 82 % of all samples analysed, while 14 % of samples exceeded the threshold limit for lead. Chromium had the lowest proportion of samples that exceeded the threshold limit with only 11 % of samples exceeding the threshold limit (ZCSA, 2021).

Table 2. Concentration of Heavy Metals in Bottled Water

Metal	Number of Samples	Samples above Threshold limit	Proportion above Threshold limit (%)	Mean Concentration (mg/l)	Maximum Limit (Zambian Standard)
Cadmium	254	209	82	**1.2±0.136**	0.003*
Lead	254	36	14	**1.16±0.944**	0.01*
Chromium	254	28	11	**1.03±0.132**	0.05*

Source: ZCSA (2021): ZABS (2000) *.

4.2 Water Consumption Pattern

This study adopted the default water consumption values proposed by the International Programme on Chemical Safety (IPCS) and adopted by the WHO for different categories of consumers as follows (WHO, 2003: ATSDR, 2005):

Table 3. Water Consumption Patterns

Category	Weight (kg)	Consumption (l/day)
Adult Males	70	2
Adult Females	70	2
Children below 10 years	16*	1*

Source: WHO (2003): ATSDR (2005) *

4.3 Human Health Risk Assessment

4.3.1 Chronic Daily Intake

The Chronic Daily Intake (CDI) for cadmium was 0.018 mg/kg/day and 0.034 mg/kg/day for well and bottled water respectively, while that of lead was 0.001mg/kg/l and 0.033 mg/kg/l for well and bottled water respectively. For chromium, the CDI was 0.011 mg/kg/day and 0.029 mg/kg/day for well and bottled water respectively. All the metals analysed had CDIs above the reference dose in both well and bottled water.

Table 4. Chronic Daily Intake for Heavy Metals

Metal	Well Water (mg/kg/day)	Bottled Water (mg/kg/day)	Reference Dose (mg/kg/day)
Cadmium	0.018	0.034	0.0005**
Lead	0.001	0.033	0.0004*
Chromium	0.011	0.029	0.003**

Source: ATSDR (2005) *: USEPA (1991)**.

4.3.2 Non-carcinogenic Risk

Table 5 shows the calculated Hazard Quotient (HQ) and Hazard Index (HI) for selected metals in drinking water. The HQ for cadmium, lead and chromium in well water was 36.00, 2.50 and 3.67 respectively, while the HQ of the same heavy metals in bottled water was 68.00, 82.50 and 9.67, respectively. The HI for cadmium, lead and chromium in well water was 42.17, while that of bottled water was 160.17.

Table 5. Hazard Index of Heavy Metals

Parameter	**Well Water**			**Bottled Water**		
	Cadmium	**Lead**	**Chromium**	**Cadmium**	**Lead**	**Chromium**
HQ	36.00	2.50	3.67	68.00	82.50	9.67
HI	**42.17**			**160.17**		

4.3.3 Carcinogenic Risk

The calculated Cancer Risk (CR) for cadmium and chromium in well water was 1.1×10^{-1} and 6.0×10^{-3}, respectively. For bottled water, the calculated cancer risk was 2.1×10^{-1} and 1.5×10^{-2}, respectively. The Total Cancer Risk (TCR) for cadmium and chromium in well water was 1.2×10^{-1} while that of bottled water was 2.25×10^{-1}. Table 6 shows the calculated CR for each individual metal and the TCR for the two metals in both well and bottled water.

Table 6. Carcinogenic Risk

Parameter	**Well Water**		**Bottled Water**	
	Cadmium	**Chromium**	**Cadmium**	**Chromium**
CDI (mg/kg/day)	0.018	0.011	0.034	0.029
CS $(\text{mg/kg/day})^{-1}$	6.1**	0.5*	6.1**	0.5*
CR	1.1×10^{-1}	6.0×10^{-3}	2.1×10^{-1}	1.5×10^{-2}
TCR	$\mathbf{1.2 \times 10^{-1}}$		$\mathbf{2.25 \times 10^{-1}}$	

Source: Stern (2010) *: USEPA (1991)**.

CHAPTER FIVE: DISCUSSION

5.1 Concentration of Heavy Metals in Well Water

According to the findings of Nambeye (2017), concentrations of heavy metals in most wells sampled was higher than the threshold limit set by ZABS. The mean concentration of cadmium, lead and chromium was 0.62 mg/l, 0.04 mg/l and 0.39 mg/l for both seasons against the threshold limit of 0.003 mg/l, 0.01 mg/l and 0.05mg/l respectively. Further, the proportion of samples with concentrations of cadmium that exceeded the ZABS threshold limit was 100 % in both wet and dry seasons. For lead, 50 % of the samples exceeded the threshold limit in the wet season, while none of the samples exceeded the threshold limit in the dry season. In the case of chromium, the proportion of samples that exceeded the threshold limit of 0.05mg/l was 93 % and 71 % in the wet and dry season, respectively. The wells that had high concentrations of heavy metals in the wet season also had high concentrations in the dry season, with the exception of lead, an indication of a common pollution source. The presence of heavy metals was attributed to anthropogenic water pollution due to the proximity of George compound to industries such as tannery, steel, paint and plastic manufacturing plants. Further, water samples had low pH ranging between 5 and 8, a situation which could have led to the rapid release of naturally occurring heavy metals from rocks to underground water as suggested by Haiyan et al (2013). These results are consistent with those of Mucheleng'anga (2007), who also conducted a chemical water analysis of 10 wells and boreholes in the same locality and found high concentrations of heavy metals. In his study, he found that the mean concentrations of cadmium and chromium were 0.021 mg/l and 2.54 mg/l, respectively, all above the ZABS threshold limit.

5.2 Concentration of Heavy Metals in Bottled Water

According to findings by ZCSA (2021), concentrations of cadmium, lead and chromium were higher than the ZABS threshold limit for bottled water. Cadmium had a mean concentration of 1.20 mg/l, well above the threshold of 0.003 mg/l, and most significantly, 82% of all tested samples had exceeded the threshold limit. This indicates widespread underground water contamination with cadmium which could be attributed to anthropogenic and to a lesser extent, natural water pollution. The majority of producers of bottled water are located in the industrial area, from where they extract underground water while other producers are located in areas such as Lusaka west and Makeni, which were previously used for agricultural activities. Therefore, there is a possibility of underground water contamination from toxic wastes emitted from other industries as well as residuals from fertilisers used in the farms. The mean concentrations of lead and chromium were 1.16 mg/l and 1.03 mg/l and all above the set threshold limits of 0.01 mg/l and 0.05 mg/l, respectively. However, only 14% of the analysed samples exceeded the threshold limit for lead, and 11% exceeded the threshold limit for chromium. Further, 5 water samples had extremely higher concentrations of lead ranging between 6.57 mg/l and 7.51 mg/l, which contributed to the higher mean concentration and was indicative of possible anthropogenic water pollution of specific water sources. ZCSA (2021) did not state the reasons why they were high levels of heavy metals in bottled water but a possible explanation could be that it is an indication of inadequate water treatment techniques during production, since bottled water usually undergoes some form of treatment before packaging. For this reason, there is need to conduct investigations to determine the exact sources of heavy metals and also evaluate the effectiveness of existing water treatment techniques being used by manufacturers, in order to take remedial measures. Although the concentration of lead and chromium in the majority of bottled water sold on the market was below the thresholds set by ZABS, the concentration of cadmium was above the threshold limit and therefore, compromise the safety of bottled water. These results are in agreement with those of Salihu et al (2019) who also found high concentrations of cadmium and lead in table water in Nigeria.

5.3 Water Consumption Patterns

Water consumption patterns differ between different sexes, age groups, seasons of the year and countries. In Sweden, Lavallee et al (2021) found that gender had an influence on the amount of water consumed and suggested that females had higher water consumption rates compared to males. To the contrary, FWR (1996) found that men had higher water consumption than women England and Wales. In terms of seasonal variations in water consumption, Gofti-Laroche et al (2001) observed an increase in the quantity of water consumed in the spring season compared to the winter season and attributed it to need for more fluids during the warmer periods of the year. Other notable factors that have been found to influence water consumption patterns include source of drinking water (Westrell et al, 2006), availability of drinking water (FWR, 1996) and the nature of physical activities a person is involved in (San et al, 2019). In Zambia, the amount of water consumed by different categories of consumers and factors that affect water consumption have not been determined. In the absence of a comprehensive national water consumption survey to determine water consumption patterns, this study adopted the WHO (2003) default water consumption values which were derived from studies undertaken in other countries (Popkin and Jebb, 2010: Manz and Wentz, 2005: Howard and Bartram, 2003). Thus, it was assumed that adults and children below the age of 10 years consumed 2 l/day and 1 l/day of water, respectively.

5.4 Health Risk Assessment

5.4.1 Chronic Daily Intake

The Chronic Daily Intake (CDI) for all metals evaluated exceeded the respective Reference Doses (RfD) in both well and bottled water. The CDI for cadmium, lead and chromium through well water was 0.018 mg/kg/day, 0.001 mg/kg/day and 0.011 mg/kg/day, respectively, against the recommended reference doses of 0.0005 mg/kg/day, 0.0004 mg/kg/day and 0.003 mg/kg/day for cadmium, lead and chromium, respectively. Similarly, the CDI for cadmium, lead and chromium in bottled water of 0.034 mg/kg/day, 0.033 mg/kg/day and 0.029 mg/kg/day, respectively, were higher than the oral reference doses. This implies that consumers of both well and bottled water are exposed to higher concentrations of heavy metals beyond the recommended tolerable levels. The high CDI is as a result of the high concentration of cadmium, lead and chromium found in both well and bottled water which by implication, results in high hazard quotients. In addition, results show that the CDI for the reviewed heavy metals were higher in bottled water compared to well water implying a higher exposure to heavy metals through consumption of bottled water compared to well water. These finding are similar to those in studies conducted in Ghana and Pakistan that found high CDIs in underground drinking water (Bempah and Ewusi, 2016: Khan et al, 2014).

5.4.2 Non- carcinogenic Risk

Results show that cadmium had the highest Hazard Quotient (HQ) in well water at 36, followed by chromium at 3.6 and lead at 2.5. In bottled water, lead had the highest HQ at 82.5 followed by cadmium at 68 and chromium at 9.6. The combined HQ for cadmium in both well and bottled water was higher than that of lead and chromium combined, indicating that cadmium posed the greatest risk among the 3 metals analysed. Cadmium, lead and chromium all had HQs above 1, implying that water consumers are exposed to heavy metals in concentrations higher than the reference dose and thus, likely to experience negative health outcomes associated with exposure to these metals over a lifetime of water consumption (USEPA, 2016). Further, the Hazard Index (HI) in bottled water was 160.17 and much higher than the HI in well water of 42.17, indicating that those who consumed bottled water were at a higher risk of exposure to cadmium, lead and chromium compared to those who consumed well water. These results are consistent with other studies that found high HI in underground water in Nigeria (Onyinyechi et al, 2018) and Pakistan (Khan et al, 2014).

5.4.3 Carcinogenic Risk

The Cancer Risk (CR) due to exposure to cadmium and chromium in well water was 1.1×10^{-1} and 6.0×10^{-3}, respectively, while the CR in bottled water was 2.1×10^{-1} and 1.5×10^{-2}. The Total Cancer Risk (TCR) through exposure to both cadmium and chromium was 1.2×10^{-1} and 2.25×10^{-1} in well and bottled water respectively. These results show that the TCR for cadmium and chromium in both well and bottled water was higher than the threshold of 1×10^{-4}, thus implying a chance of causing 1 case of cancer for every 10,000 people for those who consume well water and 2 cases of cancer for every 10,000 people for those who consumed bottled water, over a lifetime of water consumption. The results also show that cadmium was the biggest contributor to the TCR in both well and bottled water at 1.1×10^{-1} and 2.1×10^{-1}, respectively. Therefore, interventions to address the high content of heavy metals in drinking water, particularly cadmium, need to be implemented to ensure that drinking water meets regulatory standards. These measures could include use of improved water treatment techniques that lower the levels of heavy metals in drinking water such as reverse osmosis, ion exchange and lime softening. The findings of this study are in agreement with other studies conducted in Nigeria (Salihu et al, 2019) and Iran (Majid et al, 2017), (Alidadi et al, 2019) and Mohammadi et al (2019) that found high cancer risks in drinking water. Ahmed and Mokhtar (2020), also suggested the application of additional water treatment techniques as a means to reduce the levels of heavy metals in drinking water, where consumers are at risk of exposure.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study evaluated the non-carcinogenic risk of exposure to cadmium, lead and chromium through consumption of well and bottled water. Results indicate that there is a possible non-carcinogenic risk of exposure to cadmium, lead and chromium through consumption of bottled in Lusaka district. Further, results indicate that there is a possible non-carcinogenic risk of exposure to cadmium, lead and chromium through consumption of well water in George compound of Lusaka district. This is because the calculated hazard quotients in both well and bottled water were above the threshold limit of 1. This is attributed to the high concentration of heavy metals in both well and bottled water.

The study also evaluated the carcinogenic risk of exposure to cadmium and chromium, which are known or probable carcinogens, through the consumption of well and bottled water in Lusaka district. Results indicate that there is a possible carcinogenic risk of exposure to cadmium and chromium through consumption of both well and bottled water with an estimated risk of 1.1×10^{-1} and 2.1×10^{-1} respectively, implying a chance of causing 1 case of cancer for every 10,000 people for those who consume well water and 2 cases of cancer for every 10,000 people for those who consumed bottled water, over a lifetime of water consumption. Owing to the proportion of samples that exceeded the threshold limit set by the Zambia Bureau of Standards for the 3 evaluated heavy metals, cadmium poses the greatest concern and requires intervention to reduce exposure.

6.2 Recommendations

1. The Ministry of Water and Sanitation through the Lusaka Water and Sewerage Company should expand the water reticulation system in George compound to ensure access to safe drinking water for all households.
2. Manufacturers of bottled water should consider investing in purification methods that can reduce the level of heavy metals in bottled water to acceptable levels, in the absence of effective pollution control methods.
3. The Zambia Compulsory Standards Agency should strengthen inspection and monitoring of bottled water production to ensure that companies have adequate facilities for purification of water and prevention contamination during the production process.

4 The Water Resources Management Authority and Zambia Environmental Management Agency should strengthen monitoring to ensure boreholes are sited in non-polluted aquifers.

5 The National Food and Nutrition Commission should conduct a national water consumption survey to generate data on water consumption patterns for Zambia.

6 Ministry of Health should conduct sensitisation to residents on the adverse effects of exposure to heavy metals.

6.3 Uncertainty of Risk/ Limitations

There is the possibility of uncertainties that may not be taken into account and could be considered as a limitation for the validity of this risk estimation.

1. The body weights and water consumption patterns for different categories of consumers and seasons of the year were not estimated for the people who live in Lusaka district. The use of WHO default values may result in over or underestimation of the risk.
2. The study used the mean concentrations of heavy metals in water to calculate the CDI irrespective of the proportion of samples that exceeded the threshold limits for the metals under study. For this reason, the few samples with elevated lead and chromium levels in bottled water could have contributed to high mean concentrations and hence, overestimating the risk.
3. The carcinogenic risk for exposure to lead could not be calculated because there is no validated CSF set for the metal.
4. The health risk was only assessed using the 3 heavy metals under study but drinking water also contains other chemicals that may have an adverse effect on health. Therefore, the level of risk from drinking water may be higher than the estimated risk in this study.

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CHAPTER EIGHT: APPENDICES

Appendix 1: Bottled Water Analysis Results, 2018 -2020.

S/N	SAMPLE CODE	STATION	DATE SAMPLED	Lead	Cadmium	Chromium
				0.01 MAX	0.003 MAX	0.05 MAX
SN 1	00-03-04-0001	Lusaka	22-Jan-18	0.01	**0.3**	0.01
SN 2	00-03-04-0016	Lusaka	5-Feb-18	0.01	**0.3**	0.01
SN 3	00-03-04-0003	Lusaka	14-Feb-18	0.01	**0.3**	0.01
SN 4	00-03-04-002	Lusaka	14-Feb-18	0.01	**0.3**	0.01
SN 5	00-03-04-0013	Lusaka	7-Feb-18	0.01	**0.3**	0.01
SN 7	00-03-04-2625	Lusaka	3-Jan-18	0.005	**0.1**	**0.1**
SN 8	00-03-04-0051	Lusaka	14-Feb-18	0.01	**0.3**	**1.18**
SN 9	00-03-04-0037	Lusaka	12-Feb-18	**0.2**	**0.3**	**0.5**
SN 10	08-03-04-1223	Lusaka	14-Feb-18	**0.04**	**0.3**	**1.38**
SN 11	08-03-04-1220	Lusaka	14-Feb-18	**0.03**	**0.3**	**0.84**
SN 12	00-03-04-0082	Lusaka	21-Feb-18	0.01	**0.3**	0.01
SN 13	00-03-04-0057	Lusaka	21-Feb-18	**0.16**	**0.3**	0.01
SN 14	00-03-04-0100	Lusaka	21-Feb-18	**0.18**	**0.3**	0.01
SN 15	00-03-04-0097	Lusaka	21-Feb-18	**0.17**	**0.3**	0.01
SN 16	00-03-04-0113	Lusaka	23-Feb-18	0.01	**0.3**	0.01
SN 17	00-03-04-0116	Lusaka	23-Feb-18	0.01	**0.3**	0.01
SN 18	00-03-04-1243	Lusaka	23-Mar-18	0.01	**0.3**	0.01
SN 19	00-03-04-0118	Lusaka	23-Mar-18	0.01	**0.3**	0.01
SN 20	00-03-04-0053	Lusaka	13-Feb-18	0.01	**0.3**	0.01
SN 21	00-03-04-0084	Lusaka	21-Feb-18	**0.11**	**0.3**	0.02
SN 23	00-03-04-0159	Lusaka	20-Mar-18	**0.12**	**0.3**	**0.06**
SN 24	00-03-04-0150	Lusaka	19-Mar-18	0.01	**0.3**	0.02
SN 25	00-03-04-0248	Lusaka	12-Apr-18	0.01	**0.01**	0.01
SN 27	00-03-04-0214	Lusaka	26-Mar-18	**1.53**	**0.3**	0.01
SN 28	00-03-04-0266	Lusaka	12-Apr-18	0.01	**0.3**	0.01
SN 30	00-03-04-0274	Lusaka	30-May-18	**0.09**	**0.09**	0.03

SN 32	00-03-04-0117	Lusaka	26-Mar-18	0.01	**0.3**	0.01
SN 34	00-03-04-2641	Lusaka	3-Jan-18	0.01	**0.1**	**0.1**
SN 35	00-03-04-0184	Lusaka	21-Mar-18	**6.3**	**0.3**	**0.37**
SN 36	00-03-04-0279	Lusaka	14-May-18	**6.7**	**0.3**	**0.1**
SN 37	00-03-04-0190	Lusaka	21-Mar-18	0.01	**0.3**	**0.13**
SN 38	00-03-05-0190	Lusaka	21-Mar-18	0.01	**0.3**	**0.13**
SN 41	00-03-04-0276	Lusaka	14-May-18	**0.1**	**0.3**	**0.1**
SN 42	00-03-04-0200	Lusaka	21-Mar-18	0.01	**0.3**	**0.08**
SN 43	00-03-04-0318	Lusaka	23-May-18	0.01	**0.01**	0.01
SN 44	00-03-04-0287	Lusaka	23-May-18	0.01	**0.3**	0.01
SN 45	00-03-04-0322	Lusaka	23-May-18	0.01	**0.3**	0.01
SN 46	00-03-04-0288	Lusaka	23-May-18	0.01	**0.3**	0.01
SN 47	00-03-04-286	Lusaka	23-May-18	0.01	**0.01**	0.01
SN 48	00-03-04-285	Lusaka	23-May-18	0.01	**0.3**	0.01
SN 49	00-03-04-0224	Lusaka	12-Apr-18	0.01	**0.3**	0.01
SN 53	00-03-04-0143	Lusaka	19-Mar-18	0.01	**0.03**	0.03
SN 54	00-03-04-0143	Lusaka	19-Mar-18	0.01	**0.3**	0.03
SN 55	00-03-04-0220	Lusaka	9-Apr-18	**7.51**	**0.3**	0.01
SN 56	00-03-04-0330	Lusaka	9-Jul-18	0.01	**0.3**	0.01
SN 57	00-03-04-0331	Lusaka	9-Jul-18	0.01	**0.3**	0.01
SN 58	00-03-04-0332	Lusaka	9-Jul-18	0.01	**0.01**	0.01
SN 59	00-03-04-0414	Lusaka	5-Jul-18	0.01	**0.3**	0.01
SN 60	00-03-04-0417	Lusaka	5-Jul-18	0.01	**0.3**	0.01
SN 61	00-03-04-0507	Lusaka	1-Aug-18	0.01	**0.3**	0.01
SN 62	00-03-04-0428	Lusaka	5-Jul-18	0.01	**0.3**	0.01
SN 63	00-03-04-0411	Lusaka	5-Jul-18	0.01	**0.3**	0.01
SN 64	00-03-04-0339	Lusaka	5-Jul-18	0.01	**0.3**	0.01
SN 65	00-03-04-0365	Lusaka	19-Jul-18	0.01	**0.3**	0.01
SN 66	00-03-04-0368	Lusaka	5-Jul-18	0.01	**0.3**	0.01
SN 67	00-03-04-0355	Lusaka	5-Jul-18	0.01	**0.3**	0.01
SN 68	00-03-04-0343	Lusaka	5-Jul-18	0.01	**0.3**	0.01
SN 69	00-03-04-0347	Lusaka	5-Jul-18	0.01	**0.3**	0.01
SN 70	00-03-04-0518	Lusaka	1-Aug-18	0.01	**0.3**	0.01

SN 71	00-03-04-0428	Lusaka	1-Aug-18	0.01	**0.3**	0.01
SN 72	00-03-04-0456	Lusaka	1-Aug-18	0.01	**0.01**	0.001
SN 73	00-03-04-0442	Lusaka	1-Aug-18	0.01	**0.3**	0.01
SN 74	00-03-04-0461	Lusaka	1-Aug-18	0.01	**0.3**	0.01
SN 75	00-03-04-0452	Lusaka	1-Aug-18	**1**	**0.3**	0.01
SN 76	00-03-04-0586	Lusaka	8-Sep-18	0.01	**0.3**	0.01
SN 77	00-03-04-0579	Lusaka	30-Sep-18	0.01	**0.3**	0.01
SN 78	00-03-04-0684	Lusaka	8-Nov-18	0.01	**0.3**	0.01
SN 79	00-03-04-0682	Lusaka	8-Nov-18	0.01	**0.3**	0.01
SN 80	00-03-04-1514	Lusaka	19-Nov-18	**6.57**	**0.3**	0.01
SN 81	00-03-04-0717	Lusaka	30-Oct-18	0.01	**0.3**	0.01
SN 82	00-03-04-0704	Lusaka	7-Nov-18	0.01	**0.3**	0.01
SN 83	00-03-04-0706	Lusaka	7-Nov-18	0.01	**0.3**	0.01
SN 84	00-03-04-0742	Lusaka	19-Nov-18	**0.1**	**0.3**	0.04
SN 86	00-03-04-0552	Lusaka	24-Sep-18	0.01	**0.3**	**0.1**
SN 87	00-03-04-0584	Lusaka	31-Jul-18	0.01	**0.3**	0.01
SN 88	00-03-04-0601	Lusaka	4-Sep-18	0.01	**0.3**	0.01
SN 89	00-03-04-1434	Lusaka	24-Sep-18	0.01	**0.3**	**0.07**
SN 90	00-03-04-0792B	Lusaka	17-Dec-18	0.01	**0.3**	0.01
SN 91	00-03-04-0802	Lusaka	18-Dec-18	0.01	**0.3**	**0.09**
SN 92	00-03-04-0827	Lusaka	16-Jan-18	0.01	**0.01**	0.04
SN 93	00-03-04-0748	Lusaka	19-Nov-18	0.01	**0.3**	**0.06**
SN 94	00-03-04-0688	Lusaka	7-Nov-18	0.01	**0.3**	0.01
SN 95	00-03-04-0627	Lusaka	4-Oct-18	0.01	**0.3**	0.01
SN 97	00-03-04-0780	Lusaka	26-Dec-18	**0.1**	**0.3**	0.01
SN 98	00-03-04-0670	Lusaka	4-Oct-18	0.01	**0.3**	0.01
SN 99	00-03-04-0657	Lusaka	28-Oct-18	**0.02**	**0.3**	0.04
SN 100	00-03-04-0654	Lusaka	29-Oct-18	0.01	**0.3**	0.01
SN 101	00-03-04-0663	Lusaka	12-Oct-18	0.01	**0.3**	0.04
SN 102	00-03-04-0816	Lusaka	4-Jan-19	0.01	**0.01**	0.01
SN 103	00-03-04-0825	Lusaka	15-Jan-19	0.01	**0.01**	0.03
SN 104	00-03-04-0826	Lusaka	15-Jan-19	0.01	**0.01**	0.05
SN 105	00-03-04-0801	Lusaka	18-Dec-18	0.01	**0.3**	**0.09**

SN 106	00-03-04-0807	Lusaka	12-Dec-18	0.01	**0.3**	0.01
SN 107	00-03-04-0806	Lusaka	18-Dec-18	0.01	**0.3**	**0.09**
SN 108	00-0-04-0551	Lusaka	21-Oct-18	0.01	**0.01**	0.01
SN 109	00-03-04-0721	Lusaka	31-Oct-18	0.01	**0.3**	0.04
SN 110	00-03-04-0553	Lusaka	21-Oct-18	0.01	**0.3**	0.01
SN 111	00-03-04-0550	Lusaka	21-Oct-18	0.01	**0.3**	**0.1**
SN 112	00-03-04-0567	Lusaka	27-Sep-18	**0.1**	**0.3**	0.01
SN 113	00-03-04-0636	Lusaka	4-Oct-18	0.01	**0.3**	0.01
SN 115	00-03-04-0638	Lusaka	4-Oct-18	0.01	**0.3**	0.01
SN 116	00-03-04-0603	Lusaka	6-Sep-18	0.01	**0.03**	0.01
SN 117	00-03-04-0598	Lusaka	17-Sep-18	0.01	**0.3**	0.01
SN 118	00-03-04-0606	Lusaka	10-Sep-18	0.01	**0.3**	0.01
SN 119	00-03-04-0604	Lusaka	10-Oct-18	**0.02**	**0.3**	0.01
SN 120	00-03-04-0604	Lusaka	10-Sep-18	0.01	**0.3**	0.01
SN 121	00-03-04-0568	Lusaka	27-Sep-18	**0.1**	**0.3**	0.01
SN 122	00-03-04-0574	Lusaka	27-Sep-18	**0.1**	**0.3**	0.01
SN 123	00-03-04-0727	Lusaka	15-Nov-18	0.01	**0.3**	0.01
SN 124	00-03-04-0575	Lusaka	27-Sep-18	**0.1**	**0.3**	0.01
SN 125	00-03-04-0877	Lusaka	7-Mar-19	0.01	**0.3**	**0.06**
SN 126	00-03-04-0881	Lusaka	7-Mar-19	0.01	**0.3**	**0.08**
SN 127	00-03-04-0885	Lusaka	7-Mar-19	0.01	**0.3**	**0.08**
SN 128	00-03-04-0869	Lusaka	7-Mar-19	0.01	**0.3**	**0.07**
SN 129	00-03-04-0939	Lusaka	22-Mar-19	0.01	**0.3**	0.01
SN 130	00-03-04-0926	Lusaka	22-Mar-19	0.01	**0.3**	0.01
SN 131	00-03-04-0908	Lusaka	22-Mar-19	0.01	**0.3**	0.01
SN 133	00-03-04-0876	Lusaka	15-Mar-19	0.01	**0.3**	0.01
SN 134	00-03-04-0849	Lusaka	27-Mar-19	0.01	**0.3**	0.04
SN 135	00-03-04-0080	Lusaka	27-Mar-19	0.01	**0.3**	0.05
SN 137	00-03-04-0832	Lusaka	18-Feb-19	0.01	**0.3**	0.03
SN 138	00-03-04-0858	Lusaka	27-Mar-19	0.01	**0.3**	**0.06**
SN 139	00-03-04-0833	Lusaka	22-Mar-19	0.01	**0.3**	0.01
SN 140	00-03-04-0902	Lusaka	22-Mar-19	**0.02**	**0.3**	0.01
SN 141	00-03-04-0862	Lusaka	19-Mar-19	**0.03**	**0.03**	0.01

SN 142	00-03-04-0895	Lusaka	18-Mar-19	0.01	**0.3**	0.01
SN 143	00-03-04-0862	Lusaka	19-Mar-19	**0.03**	**0.3**	0.01
SN 144	08-03-04-1635	Lusaka	1-Apr-19	0.01	**0.3**	0.01
SN 145	08-03-04-1638	Lusaka	1-Apr-19	0.01	**0.3**	0.01
SN 146	08-03-04-1636	Lusaka	1-Apr-19	0.01	**0.3**	0.01
SN 147	00-03-04-0978	Lusaka	18-Apr-19	0.01	**0.3**	0.01
SN 148	08-03-04-1648	Lusaka	17-Apr-19	0.01	**0.3**	0.01
SN 149	13-03-04-0187	Lusaka	15-Apr-19	0.01	**0.3**	0.01
SN 150	00-03-04-0957	Lusaka	11-Apr-19	0.01	**0.3**	0.01
SN 151	09-03-04-0462	Lusaka	16-Apr-19	0.01	**0.3**	0.01
SN 152	00-03-04-0962	Lusaka	11-Dec-19	0.01	**0.3**	0.01
SN 153	00-03-04-0874	Lusaka	20-Mar-19	**0.04**	**0.3**	0.01
SN 154	00-03-04-0992	Lusaka	20-May-19	0.01	**0.3**	0.01
SN 155	08-03-04-1652	Lusaka	6-May-19	0.01	**0.3**	0.01
SN 157	00-03-04-0876	Lusaka	15-Mar-19	0.01	**0.3**	0.01
SN 158	08-03-04-1654	Lusaka	20-May-19	0.01	**0.3**	0.01
SN 159	08-03-04-1665	Lusaka	20-May-19	0.01	**0.3**	0.01
SN 161	00-03-04-1012	Lusaka	30-Jun-19	0.01	**0.3**	0.01
SN 162	08-03-04-1665	Lusaka	30-May-19	0.01	**0.3**	0.01
SN 164	00-03-04-0994	Lusaka	30-May-19	0.01	**0.3**	0.01
SN 165	08-03-04-1666	Lusaka	30-May-19	0.01	**0.3**	0.01
SN 166	00-03-04-0988	Lusaka	20-May-19	0.01	**0.3**	0.01
SN 168	08-03-04-1656	Lusaka	20-May-19	0.01	**0.3**	0.01
SN 169	15-03-04-0221	Lusaka	20-May-19	0.01	**0.3**	0.01
SN 170	08-03-04-1663	Lusaka	30-May-19	0.01	**0.3**	0.01
SN 171	00-03-04-0998	Lusaka	30-May-19	0.01	**0.3**	0.01
SN 172	08-03-04-1664	Lusaka	30-May-19	0.01	**0.3**	0.01
SN 173	00-03-04-1007	Lusaka	31-May-19	**6.65**	**0.3**	0.01
SN 174	08-03-04-1667	Lusaka	30-May-19	0.01	**0.3**	**0.3**
SN 175	09-03-04-0437	Lusaka	29-Dec-18	**0.02**	**0.3**	0.01
SN 177	00-03-04-1073	Lusaka	10-Jun-19	0.01	**0.3**	0.05
SN 178	00-03-04-1046	Lusaka	3-Jun-19	0.01	**0.3**	0.01
SN 179	00-03-04-0765	Lusaka	29-Dec-18	0.01	**0.3**	0.01

SN 180	00-03-04-0774	Lusaka	29-Dec-18	0.01	**0.3**	0.01
SN 181	00-03-04-0764	Lusaka	29-Dec-18	**0.02**	**0.3**	0.01
SN 183	00-03-04-1074	Lusaka	12-Jun-19	0.01	**0.3**	0.05
SN 184	00-03-04-1091	Lusaka	12-Jun-19	0.01	**0.3**	0.05
SN 185	00-03-04-1094	Lusaka	12-Jun-19	0.01	**0.3**	**0.06**
SN 186	00-03-04-1061	Lusaka	10-Jun-19	0.01	**0.3**	0.04
SN 187	00-03-04-1068	Lusaka	10-Jun-19	0.01	**0.3**	0.04
SN 188	00-03-04-1104	Lusaka	18-Jun-19	0.01	**0.3**	0.01
SN 189	00-03-04-1111	Lusaka	18-Jun-19	0.01	**0.3**	0.03
SN 190	00-03-04-1123	Lusaka	18-Jun-19	0.01	**0.3**	0.02
SN 191	00-03-04-1110	Lusaka	18-Jun-19	0.01	**0.3**	0.02
SN 192	00-03-04-1122	Lusaka	18-Jun-19	0.01	**0.3**	0.01
SN 193	00-03-04-1152	Lusaka	3-Jul-19	0.01	**0.3**	0.01
SN 194	00-03-04-1149	Lusaka	8-Jul-19	0.01	**0.3**	0.01
SN 195	00-03-04-1148	Lusaka	8-Jul-19	0.01	**0.3**	0.01
SN 196	00-03-04-1189	Lusaka	23-Jul-19	0.01	**0.3**	0.01
SN 197	00-03-04-1188	Lusaka	16-Jul-19	0.01	**0.3**	0.01
SN 198	00-03-04-1153	Lusaka	8-Jul-19	0.01	**0.3**	0.01
SN 199	00-03-04-1158	Lusaka	8-Aug-19	0.01	**0.3**	0.01
SN 200	00-03-04-1156	Lusaka	8-Jul-19	0.01	**0.3**	0.01
SN 201	00-03-04-1192	Lusaka	7-Aug-19	0.01	**0.3**	0.01
SN 203	00-03-04-1199	Lusaka	6-Aug-19	0.01	**0.3**	0.01
SN 204	00-03-04-1227	Lusaka	8-Sep-19	**0.07**	**0.3**	**0.1**
SN 205	00-03-04-1228	Lusaka	8-Sep-19	0.01	**0.3**	0.01
SN 206	00-03-04-1215	Lusaka	8-Sep-19	**0.04**	**0.3**	0.01
SN 207	00-03-04-1220	Lusaka	8-Sep-19	**0.03**	**0.3**	0.01
SN 208	00-03-04-1205	Lusaka	8-Sep-19	0.01	**0.3**	0.01
SN 209	00-03-04-1209	Lusaka	8-Sep-19	0.01	**0.3**	0.01
SN 210	00-03-04-1211	Lusaka	8-Sep-19	0.01	**0.3**	0.01
SN 211	00-03-04-1257	Lusaka	13-Sep-19	0.01	**0.01**	0.01
SN 212	00-03-04-1318	Lusaka	24-Sep-19	0.01	**0.01**	0.01
SN 213	00-03-04-1268	Lusaka	13-Sep-19	0.01	**0.01**	0.01
SN 214	00-03-04-1262	Lusaka	13-Sep-19	0.01	**0.01**	0.01

SN 215	00-03-04-1256	Lusaka	13-Sep-19	0.01	**0.01**	0.01
SN 216	00-03-04-1240	Lusaka	13-Sep-19	0.01	**0.01**	0.01
SN 217	00-03-04-1237	Lusaka	28-Sep-19	**0.04**	**0.01**	0.01
SN 218	00-03-04-1198	Lusaka	28-Aug-19	0.01	**0.3**	0.01
SN 219	00-03-04-1200	Lusaka	28-Aug-19	0.01	**0.3**	0.01
SN 222	00-03-04-1193	Lusaka	6-Aug-19	0.01	**0.3**	0.01
SN 224	00-03-04-1358	Lusaka	30-Oct-19	0.01	0.001	0.01
SN 225	00-03-04-1352	Lusaka	30-Oct-19	0.01	0.003	0.01
SN 226	00-03-04-1345	Lusaka	30-Oct-19	0.01	**0.004**	0.01
SN 228	00-03-04-1524	Lusaka	25-May-19	0.01	**0.01**	0.01
SN 229	00-03-04-1506	Lusaka	17-Nov-19	0.01	0.003	0.01
SN 230	00-03-04-1483	Lusaka	17-Nov-19	0.01	0.003	0.01
SN 231	00-03-04-1479	Lusaka	17-Nov-19	0.01	0.002	0.01
SN 232	00-03-04-1486	Lusaka	20-Nov-19	0.01	0.001	0.01
SN 233	00-03-04-1475	Lusaka	30-Oct-19	0.01	**0.004**	0.01
SN 235	00-03-04-1454	Lusaka	16-Oct-19	0.01	0.001	0.01
SN 236	00-03-04-1448	Lusaka	8-Oct-19	0.01	0.001	0.01
SN 237	00-03-04-1400	Lusaka	10-Oct-19	0.01	0.001	0.01
SN 238	00-03-04-1412	Lusaka	10-Oct-19	**0.03**	0.001	0.01
SN 239	00-03-04-1421	Lusaka	10-Oct-19	0.01	0.001	0.01
SN 240	00-03-04-1422	Lusaka	10-Oct-19	0.01	0.001	0.01
SN 241	00-03-04-1434	Lusaka	10-Oct-19	0.01	0.001	0.01
SN 242	00-03-04-1426	Lusaka	10-Oct-19	0.01	0.001	0.01
SN 243	00-03-04-1584A	Lusaka	19-Jan-20	0.01	0.001	0.01
SN 244	00-03-04-1584b	Lusaka	19-Jan-20	0.01	0.001	0.01
SN 245	00-03-04-1588	Lusaka	2-Jan-20	0.01	**0.01**	0.01
SN 246	00-03-04-1575	Lusaka	2-Jan-20	0.01	**0.01**	0.01
SN 247	00-03-04-1587	Lusaka	2-Jan-20	0.01	**0.01**	0.01
SN 248	00-03-04-1609	Lusaka	3-Mar-20	0.01	**0.01**	0.01
SN 249	00-03-04-1613	Lusaka	2-Mar-20	0.01	**0.01**	0.01
SN 250	00-03-04-1606	Lusaka	21-Feb-20	0.01	**0.01**	0.01
SN 251	00-03-04-1599	Lusaka	4-Feb-20	0.01	**0.01**	0.001
SN 252	00-03-04-1600	Lusaka	4-Feb-20	0.01	0.001	0.01

SN 253	00-03-04-1592	Lusaka	22-Jan-20	0.01	0.001	0.01
SN 254	08-03-04-1841	Lusaka	20-Jan-20	0.01	0.001	0.01
SN 255	00-03-04-1534	Lusaka	6-Dec-19	0.01	0.001	0.01
SN 256	00-03-04-1621	Lusaka	3-Mar-20	0.01	0.001	0.01
SN 257	00-03-04-1615	Lusaka	2-Mar-20	0.01	0.001	0.01
SN 258	00-03-04- 1614	Lusaka	6-Mar-20	0.01	0.001	0.01
SN 259	00-03-04-1714	Lusaka	19-Mar-20	0.01	0.001	0.01
SN 260	00-03-04-1700	Lusaka	19-Mar-20	0.01	**0.01**	0.01
SN 261	00-03-04-1318	Lusaka	24-Sep-19	0.01	**0.01**	0.01
SN 262	00-03-04-1584A	Lusaka	17-Jan-20	0.01	0.001	0.01
SN 263	00-03-04-1584B	Lusaka	17-Jan-20	0.01	0.001	0.01
SN 264	00-03-04-1866	Lusaka	11-Mar-20	0.01	0.001	0.01
SN 265	00-03-04-1695	Lusaka	11-Mar-20	0.01	0.001	0.01
SN 266	00-03-04-1546	Lusaka	6-Dec-19	0.01	0.001	0.01
SN 267	00-03-04-1547	Lusaka	6-Dec-19	0.01	0.001	0.01
SN 269	00-03-04-1550	Lusaka	6-Dec-19	0.01	0.001	0.01
SN 270	00-03-04-1549	Lusaka	6-Dec-19	0.01	0	0.01
SN 271	00-03-04-1601	Lusaka	13-Feb-20	0.01	0.003	0.01
SN 272	00-03-04-1602	Lusaka	14-Feb-20	0.01	0.001	0.01
SN 273	00-01-04-1732	Lusaka	20-May-20	0.01	0.001	0.01
SN 274	00-01-04-1735	Lusaka	8-May-20	0.01	0.001	0.01
SN 275	00-01-04-1736	Lusaka	26-Mar-20	0.01	0.001	0.01
SN 276	00-03-04-1749	Lusaka	3-Jun-20	0.01	0.001	0.01
SN 277	00-03-04-1750	Lusaka	3-Jun-20	0.01	0.001	0.01
SN 278	00-03-04-1751	Lusaka	3-Jun-20	0.01	0.001	0.01
SN 280	00-03-04-1776	Lusaka	19-Jun-20	0.01	0.001	0.01
SN 281	13-03-04-0245	Lusaka	22-Jun-20	0.01	0.001	0.01
SN 282	00-03-04-1775	Lusaka	19-Jun-20	0.01	0.001	0.01
SN 283	00-03-04-1780	Lusaka	19-Jun-20	0.01	0.001	0.01
SN 284	00-03-04-1788	Lusaka	22-Jun-20	0.01	0.001	0.02
N	**254**	**254**	**254**	**254**	**254**	**254**
TR (%)				**100.00**	**100.00**	**100.00**

MEAN				1.16	1.20	1.03
F				**36**	**209**	**28**
FR (%)				**14.17**	**82.28**	**11.02**
RG				**L**	**H**	**L**
KEY (ZS388 BOTTLED WATER)						
N= Total Number of samples						
TR=Test rate						
F=Failure						
FR=Failure rate						
RG=Risk grading						
🟩	Low (Under 20%)					
🟨	Medium (20%-50%)					
🟥	High (over 50%)					

Source: ZCSA (2021)

Appendix 2: Well Water Analysis Results, 2014-2015.

	Lead		**Cadmium**		**Chromium**	
Well	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**
W1	<0.01	<0.01	**0.032**	**0.14**	**0.08**	**0.53**
W2	<0.01	<0.01	**0.022**	**0.15**	**0.11**	0.04
W3	<0.01	**0.01**	**0.05**	**0.21**	**0.09**	**0.44**
W4	<0.01	**0.01**	**0.055**	**0.1**	**0.12**	**0.57**
W5	<0.01	**0.01**	**0.06**	**0.32**	**0.06**	**0.26**
W6	<0.01	**0.01**	**0.08**	**0.06**	**0.07**	**0.18**
W7	<0.01	**0.01**	**0.086**	**0.05**	**0.07**	**0.59**
W8	<0.01	<0.01	**0.91**	**0.03**	**0.05**	**0.46**
W9	<0.01	<0.01	**0.123**	**0.04**	0.04	**0.53**
W10	<0.01	<0.01	**0.147**	**0.07**	0.02	**0.48**
W11	<0.01	**0.01**	**0.055**	**0.04**	0.01	**0.37**
W12	<0.01	<0.01	**0.78**	**0.04**	**0.14**	**0.42**
W13	<0.01	**0.07**	**0.099**	**0.13**	**0.12**	**0.64**
W14	<0.01	<0.01	**0.103**	**0.05**	0.01	**0.59**
ZABS	**0.01**		**0.003mg/l**		**0.05mg/l**	

Source: Nambeye A. (2017).

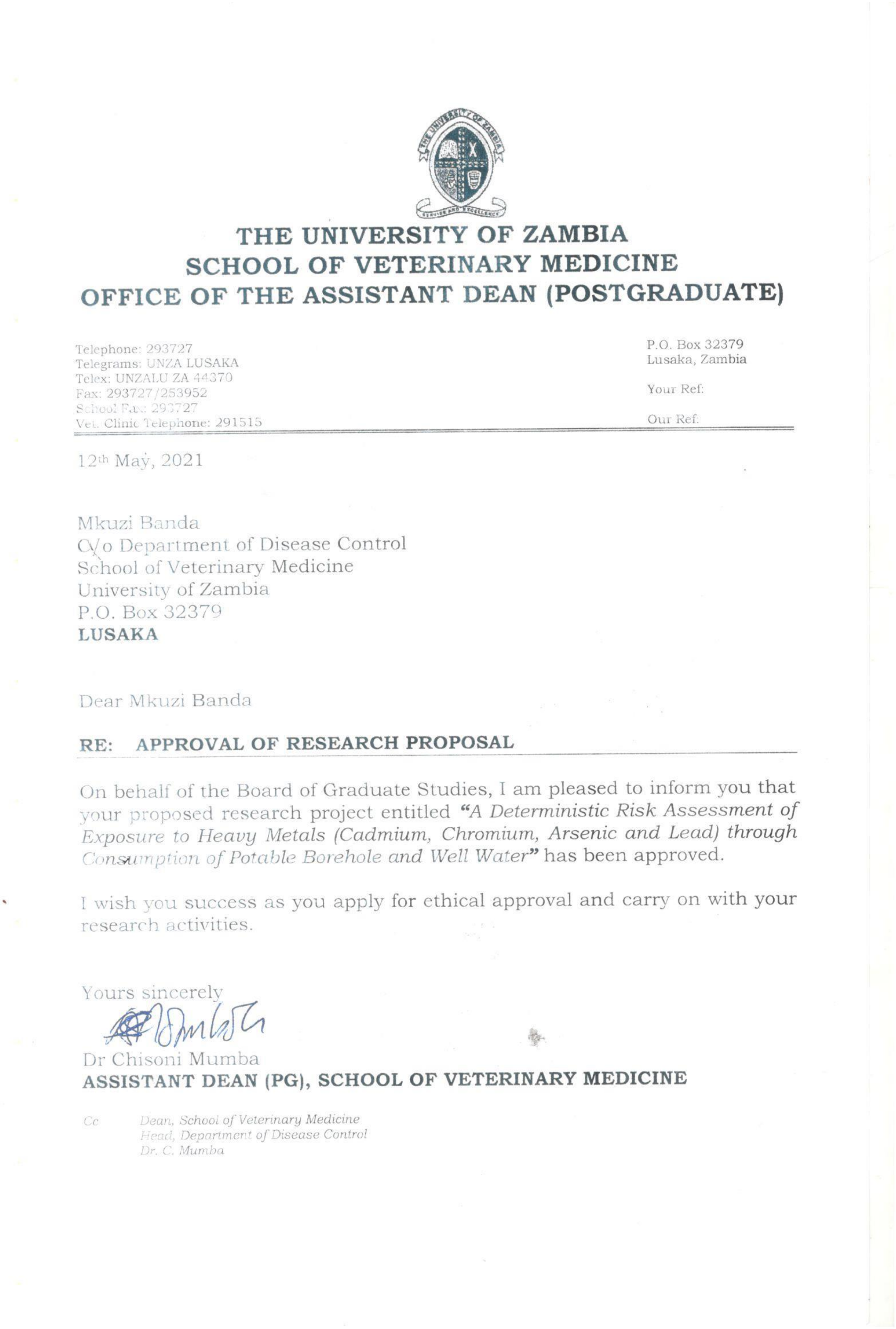
Appendix 3: Drinking Water Quality Specification

Toxic Chemical Substances in Drinking Water

Substance	**Maximum permissible limit (mg/litre)**	**Method of test**
Aluminium (Al)	0.2	ZS ISO 10566
Arsenic (As)	0.01	ZS ISO 11969
Cadmium	0.003	ZS ISO 5961
Barium	0.7	ZS ISO 11885
Chromium (Cr)	0.05	ZS ISO 9174
Cobalt(Co) (mg/litre)	0.5	ZS ISO 8288
Cyanide (CN-)	0.01	ZS ISO 6703-1
Fluoride (F-)	1.5	ZS ISO 10359 Part 1
Lead (Pb)	0.01	ZS ISO 8288
Mercury (Hg)	0.001	ZS ISO 5666
Manganese (Mn)	0.1	ZS ISO 6333
Nitrates (NO-3 -N)	10	ZS ISO 7890 Part 3
Nitrite (NO-2 N)	1.0	ZS 312: Part 13
Selenium (Se)	0.01	ZS ISO 9965
Silver (Ag)	0.05	ZS ISO 11885

Source: ZABS (2010).

Appendix 4: Permission Letters



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:

12th May, 2021

Mkuzi Banda
C/o Department of Disease Control
School of Veterinary Medicine
University of Zambia
P.O. Box 32379
LUSAKA

Dear Mkuzi Banda

RE: APPROVAL OF RESEARCH PROPOSAL

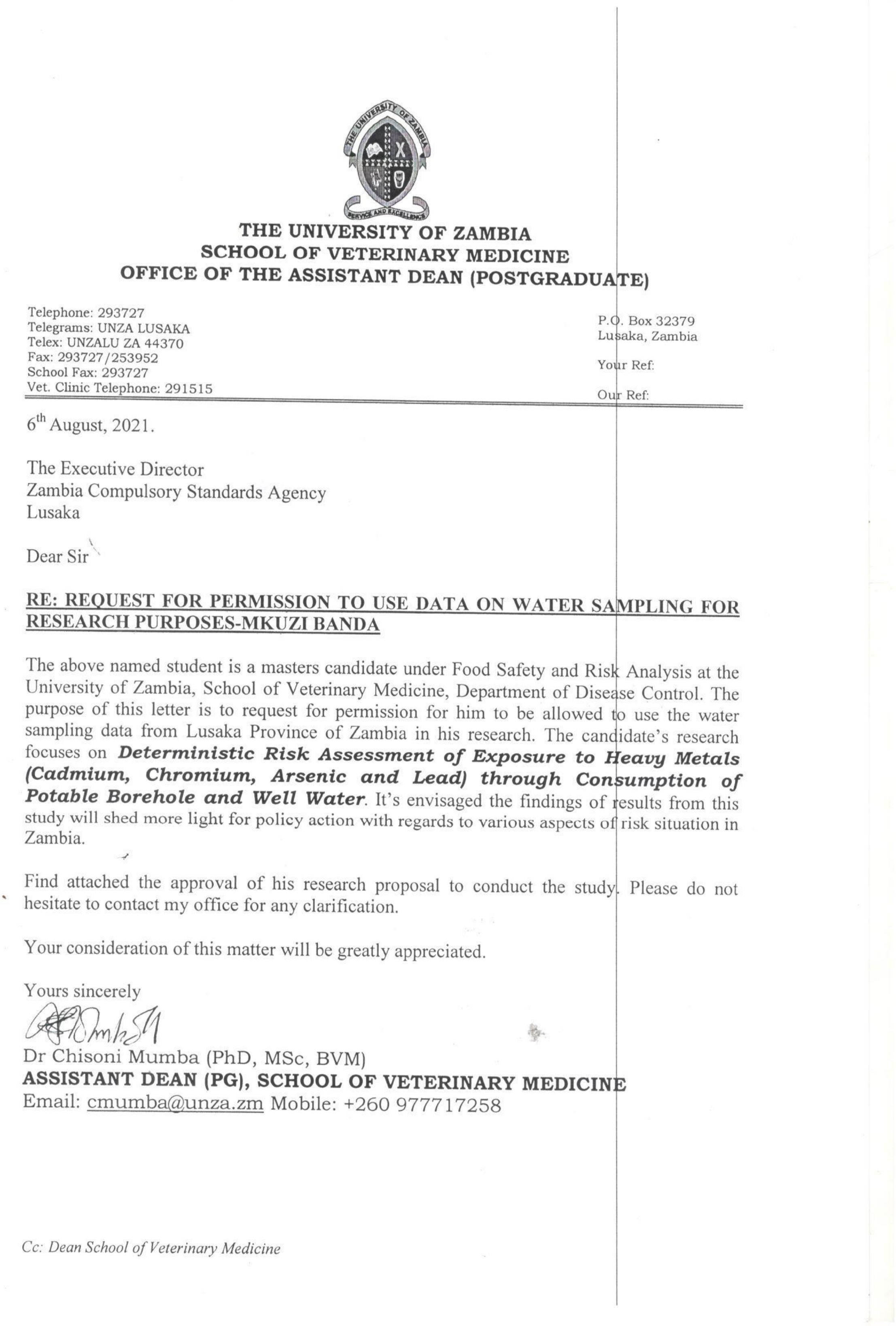
On behalf of the Board of Graduate Studies, I am pleased to inform you that your proposed research project entitled ***"A Deterministic Risk Assessment of Exposure to Heavy Metals (Cadmium, Chromium, Arsenic and Lead) through Consumption of Potable Borehole and Well Water"*** has been approved.

I wish you success as you apply for ethical approval and carry on with your research activities.

Yours sincerely

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

Cc *Dean, School of Veterinary Medicine*
Head, Department of Disease Control
Dr. C. Mumba



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

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Fax: 293727/253952
School Fax: 293727
Vet. Clinic Telephone: 291515

P.O. Box 32379
Lusaka, Zambia

Your Ref:

Our Ref:

6th August, 2021.

The Executive Director
Zambia Compulsory Standards Agency
Lusaka

Dear Sir

RE: REQUEST FOR PERMISSION TO USE DATA ON WATER SAMPLING FOR RESEARCH PURPOSES-MKUZI BANDA

The above named student is a masters candidate under Food Safety and Risk Analysis at the University of Zambia, School of Veterinary Medicine, Department of Disease Control. The purpose of this letter is to request for permission for him to be allowed to use the water sampling data from Lusaka Province of Zambia in his research. The candidate's research focuses on ***Deterministic Risk Assessment of Exposure to Heavy Metals (Cadmium, Chromium, Arsenic and Lead) through Consumption of Potable Borehole and Well Water***. It's envisaged the findings of results from this study will shed more light for policy action with regards to various aspects of risk situation in Zambia.

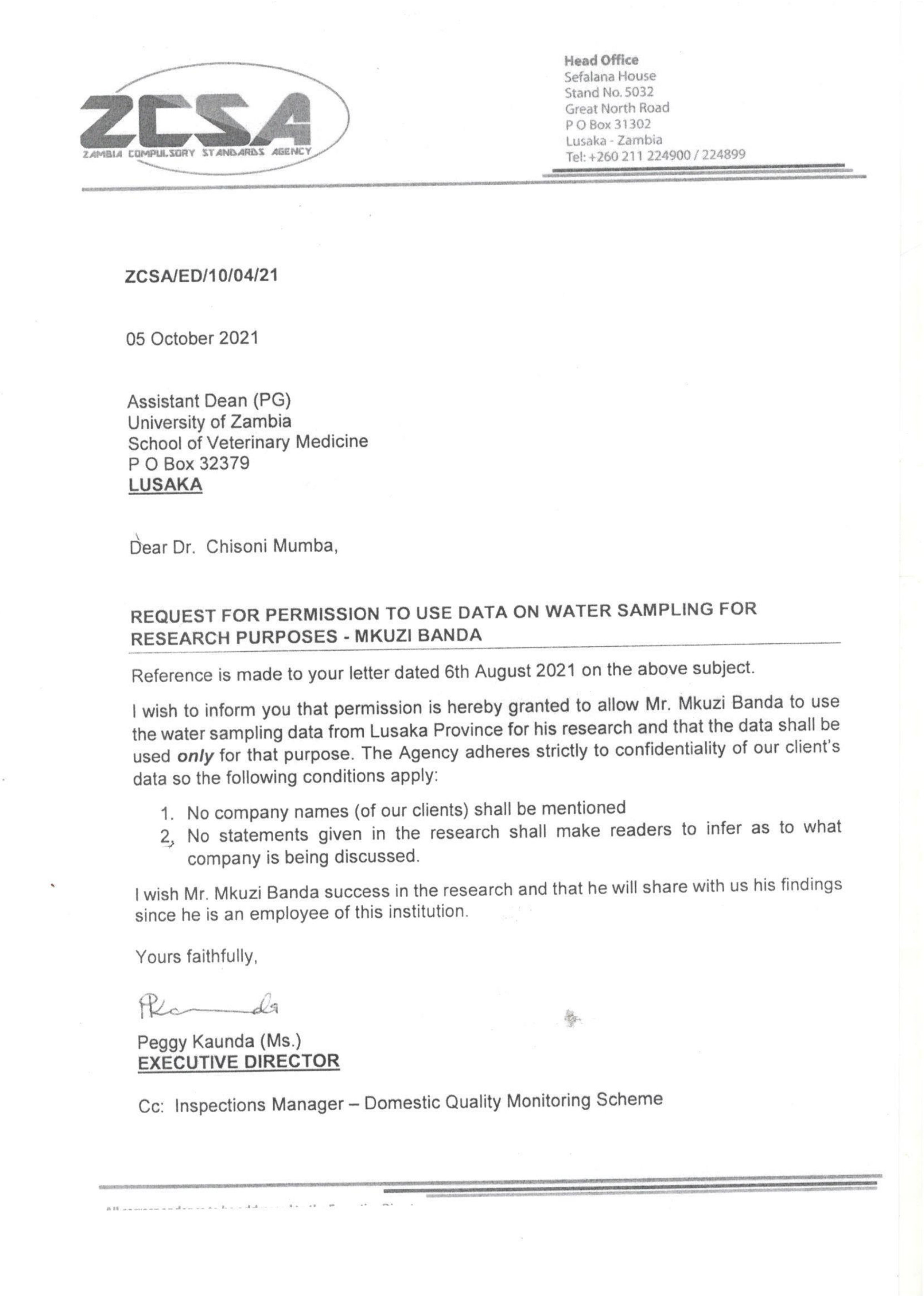
Find attached the approval of his research proposal to conduct the study. Please do not hesitate to contact my office for any clarification.

Your consideration of this matter will be greatly appreciated.

Yours sincerely

Dr Chisoni Mumba (PhD, MSc, BVM)
ASSISTANT DEAN (PG), SCHOOL OF VETERINARY MEDICINE
Email: cmumba@unza.zm Mobile: +260 977717258

Cc: Dean School of Veterinary Medicine



ZCSA
ZAMBIA COMPULSORY STANDARDS AGENCY

Head Office
Sefalana House
Stand No. 5032
Great North Road
P O Box 31302
Lusaka - Zambia
Tel: +260 211 224900 / 224899

ZCSA/ED/10/04/21

05 October 2021

Assistant Dean (PG)
University of Zambia
School of Veterinary Medicine
P O Box 32379
LUSAKA

Dear Dr. Chisoni Mumba,

REQUEST FOR PERMISSION TO USE DATA ON WATER SAMPLING FOR RESEARCH PURPOSES - MKUZI BANDA

Reference is made to your letter dated 6th August 2021 on the above subject.

I wish to inform you that permission is hereby granted to allow Mr. Mkuzi Banda to use the water sampling data from Lusaka Province for his research and that the data shall be used ***only*** for that purpose. The Agency adheres strictly to confidentiality of our client's data so the following conditions apply:

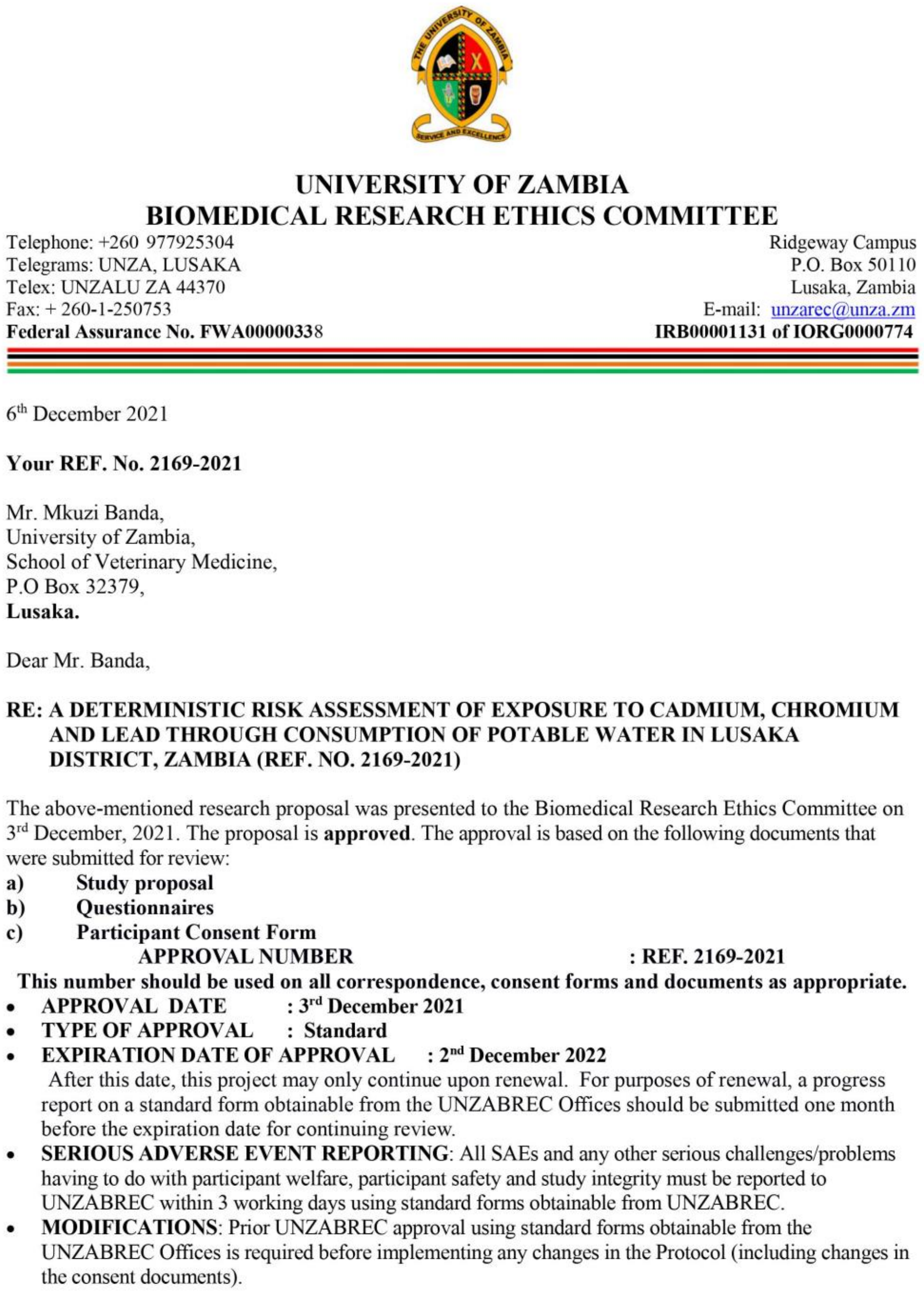
1. No company names (of our clients) shall be mentioned
2. No statements given in the research shall make readers to infer as to what company is being discussed.

I wish Mr. Mkuzi Banda success in the research and that he will share with us his findings since he is an employee of this institution.

Yours faithfully,

Peggy Kaunda (Ms.)
EXECUTIVE DIRECTOR

Cc: Inspections Manager – Domestic Quality Monitoring Scheme



UNIVERSITY OF ZAMBIA
BIOMEDICAL RESEARCH ETHICS COMMITTEE

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Federal Assurance No. FWA00000338

Ridgeway Campus
P.O. Box 50110
Lusaka, Zambia
E-mail: unzarec@unza.zm
IRB00001131 of IORG0000774

6th December 2021

Your REF. No. 2169-2021

Mr. Mkuzi Banda,
University of Zambia,
School of Veterinary Medicine,
P.O Box 32379,
Lusaka.

Dear Mr. Banda,

RE: A DETERMINISTIC RISK ASSESSMENT OF EXPOSURE TO CADMIUM, CHROMIUM AND LEAD THROUGH CONSUMPTION OF POTABLE WATER IN LUSAKA DISTRICT, ZAMBIA (REF. NO. 2169-2021)

The above-mentioned research proposal was presented to the Biomedical Research Ethics Committee on 3rd December, 2021. The proposal is **approved**. The approval is based on the following documents that were submitted for review:

a) Study proposal
b) Questionnaires
c) Participant Consent Form

APPROVAL NUMBER : REF. 2169-2021

This number should be used on all correspondence, consent forms and documents as appropriate.

- **APPROVAL DATE : 3rd December 2021**
- **TYPE OF APPROVAL : Standard**
- **EXPIRATION DATE OF APPROVAL : 2nd December 2022**
  After this date, this project may only continue upon renewal. For purposes of renewal, a progress report on a standard form obtainable from the UNZABREC Offices should be submitted one month before the expiration date for continuing review.
- **SERIOUS ADVERSE EVENT REPORTING**: All SAEs and any other serious challenges/problems having to do with participant welfare, participant safety and study integrity must be reported to UNZABREC within 3 working days using standard forms obtainable from UNZABREC.
- **MODIFICATIONS**: Prior UNZABREC approval using standard forms obtainable from the UNZABREC Offices is required before implementing any changes in the Protocol (including changes in the consent documents).

- **TERMINATION OF STUDY**: On termination of a study, a report has to be submitted to the UNZABREC using standard forms obtainable from the UNZABREC Offices.
- **NHRA:** You are advised to obtain final study clearance and approval to conduct research in Zambia from the National Health Research Authority (NHRA) before commencing the research project.
- **QUESTIONS**: Please contact the UNZABREC on Telephone No. +260977925304 or by e-mail on unzarec@unza.zm.
- **OTHER**: Please be reminded to send in copies of your research findings/results for our records. You are also required to submit electronic copies of your publications in peer-reviewed journals that may emanate from this study. Use the online portal: unza.rhinno.net for further submissions.

Yours sincerely,

Munsaka.

Sody Mweetwa Munsaka, BSc., MSc., PhD
CHAIRPERSON
Tel: +260977925304
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NATIONAL HEALTH RESEARCH AUTHORITY
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Tell: +260211 250309 | Email: znhrasec@nhra.org.zm | www.nhra.org.zm

Ref No: NHRA000023/28/12/2021 **Date: 28th Decemeber, 2021**

The Principal Investigator,
Mkuzi Banda,
University of Zambia,
Lusaka, Zambia.

Dear Mkuzi Banda,

Re: Request for Authority to Conduct Research

The National Health Research Authority is in receipt of your request for authority to conduct research titled **"A Deterministic Risk Assessment of Exposure to Cadmium, Chromium and Lead through Consumption of Potable Water in Lusaka District, Zambia.."**

I wish to inform you that following submission of your request to the Authority, our review of the same and in view of the ethical clearance, this study has been **approved** on condition that:

1. The relevant Provincial and District Medical Officers where the study is being conducted are fully appraised;
2. Progress updates are provided to NHRA quarterly from the date of commencement of the study;
3. The final study report is cleared by the NHRA before any publication or dissemination within or outside the country;
4. After clearance for publication or dissemination by the NHRA, the final study report is shared with all relevant Provincial and District Directors of Health where the study was being conducted, University leadership, and all key respondents.

Yours sincerely,

Prof. Victor Chalwe
For||Director/CEO
National Health Research Authority