AN ASSESSMENT OF HEAVY METAL CONTAMINATION OF GROUNDWATER IN GEORGE COMPOUND OF LUSAKA

By

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A dissertation submitted to the University of Zambia in partial fulfilment of the requirement for the award of degree of Master of Science in Environmental and Natural Resources Management

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DECLARATION

I, Alice Nambeye, declare that this dissertation has been done by me, that the source of all material referred to have been specifically acknowledged, and that the dissertation has not been accepted in any previous application for academic awards.

Signature:………………………………

Date:…………………………………...

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CERTIFICATE OF APPROVAL

This dissertation of Alice Nambeye has been approved as partial fulfilment of the requirement for the award of degree of Master of Science in Environmental and Natural Resources Management of the University of Zambia.

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ABSTRACT

This study investigated groundwater contamination in a suburban area of George Compound located on the outskirts of the city of Lusaka in Zambia. The aim was to assess heavy metal contamination of groundwater and the local people's awareness about the contamination in the study area. The objectives were fivefold; to (i) ascertain the usage of groundwater from wells among residents of George Compound; (ii) determine the concentration of heavy metals (cadmium, chromium, copper, iron and lead) in groundwater of the sampled wells in George Compound; (iii) examine the extent to which industries in close proximity to George Compound contributed to heavy metal contamination; (iv) find out local people's level of awareness and knowledge about heavy metal contamination of the groundwater; and (v) find out whether or not past sensitisation campaigns have had an impact on the local people's level of awareness of groundwater contamination in George Compound. A case study design was employed to ensure a detailed understanding of the situation. The data were collected through interviews, questionnaire, field observations and water quality measurements. Purposive and snowball sampling procedures were used in the selection of a sample of 38 respondents. Water sampling in wet and dry seasons was conducted on 14 purposively sampled wells. Respondents included 14 households with wells and 24 households without. Additionally, four (4) key informants were interviewed. Analysis of data revealed that, in the dry season, there were high levels of chromium (Cr) (0.14 mg/l), cadmium (Cd) (0.91 mg/l), and iron (Fe) (1.22 mg/l) as maximum concentrations above the Zambia Bureau of Standards (ZABS) for drinking water. Conversely, lead (Pb) and copper (Cu) concentration were found to be below the ZABS's permissible limits. For the wet season, parameters found to have concentrations above the ZABS limits were chromium (0.64 mg/l), cadmium (0.32 mg/l), iron (3.11 mg/l), and lead (0.07 mg/l), while copper (Cu) (0.04 mg/l) was below the limit. The sources of these heavy metals were attributed to the manufacturing industries and illegal waste sites. A total of 45 percent of the sampled residents in George Compound were unaware of the groundwater contamination. It is concluded that groundwater in shallow wells in George Compound is contaminated with heavy metals (cadmium, chromium, iron and lead). This calls for regular groundwater quality monitoring by Water Resources Management Authority (WARMA) and Zambia Environmental Management Agency (ZEMA) for evidence to support strict enforcement of compliance by industries on discharge of effluents that meet ZABS standards in order to reduce health risks among residents.

DEDICATION

This work is dedicated to my late father, Mr. Ackson Simbeye and my mother Loveness Namfukwe Simbeye for their wisdom of parenting, encouragement and unconditional support.

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ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectrophotometer
APHA	American Public Health Association
ATSDR	Agency for Toxic Substances and Disease Registry
CBD	Central Business District
CSO	Central Statistical Office
Cd	Cadmium
Cr	Chromium
Cu	Copper
DO	Dissolved Oxygen
DWA	Department of water affairs
EC	Electrical Conductivity
ECZ	Environmental Council of Zambia
Fe	Iron
GIS	Geographical Information System
GPS	Global Positioning System
GRZ	Government of the Republic of Zambia
IWRM	Integrated Water Resources Management
Km	Kilometre
LWSC	Lusaka Water and Sewerage Company
MCL	Maximum Contaminant Level
MDG	Millennium Development Goal

MEWD	Ministry of Energy and Water Development
MoH	Ministry of Health
Mg	Milligram
Mg/l	Milligram per litre
Mv	Millivolt
NGO	Non-Governmental Organization
NIOSH	National Institute for Occupational Safety and Health
NWASCO	National Water and Sanitation Council
Pb	Lead
pH	Hydrogen Potential
RDC	Resident Development Committee
REDOX	Reduction-Oxidation Reaction
SPSS	Statistical Package for the Social Sciences
SW	Shallow Well
TDS	Total Dissolved Solids
UNDP	United Nation Development Program
UNICEF	United Nations Children's Fund
μS/cm	Micro Siemens per Centimetre
WARMA	Water Resources Management Authority
WHO	World Health Organisation
ZABS	Zambia Bureau of Standards

ZAMCOM	Zambezi Watercourse Commission
ZEMA	Zambia Environmental Management Agency
ZRA	Zambezi River Authority
Zn	Zinc
ZMD	Zambia Meteorological Department

CHAPTER 1: INTRODUCTION

1.1 Background

Water is the most basic and important natural resource for life. Plant and animal life depend on water for survival. Human life is centred on water. In view of that, access to abundant and safe freshwater is paramount to the ability to prosper and fulfil the potential in life (Pan Africa Chemistry Network, 2010). Every individual thus, must have access to quality water to live a better life. It has been noted that of the more than 6 billion people globally, over 1 billion lack access to safe and quality drinking water while 2.5 billion people do not have access to adequate sanitation services (Pan-Africa Chemistry Network, 2010). Consequently, millions of people every year, especially children, reportedly die due to waterborne diseases.

Water is a polar molecule, and due to its polarity and hydrogen ions, it has special chemical properties (Momodu and Anyakora, 2010). It is able to dissolve, absorb, adsorb and suspend various kinds of compounds. As such, water is not pure in nature owing to its magnetic capacity to attract and acquire contaminants from surroundings as well as those arising from anthropogenic and other biological activities. This suggests that the quality of groundwater is the sum of natural and anthropogenic influences (Chilton, 1996).

There are two principal natural sources of water, surface and groundwater (Momodu and Anyakora, 2010). Surface water includes water from rivers, lakes and dams, among others, while groundwater is accessed through boreholes, wells and springs from the subsurface. Both surface and groundwater are exploited for industrial, domestic and agricultural purposes (Chilton, 1996). Groundwater is held underground in soil or permeable rock often feeding springs and wells. Groundwater accounts for approximately 30 percent of global freshwater reserves, constituting by far the largest reservoir of freshwater (Perry and Vanderklein, 1996). In Africa, 75 percent of drinking water emanates from groundwater. In Zambia, groundwater supply provides for more than 28 percent of the domestic water supply (British Geological Survey, 2001). The use of groundwater among Zambians is not uncommon in rural and unplanned peri-urban settlements.

Heavy metals find themselves in groundwater through domestic effluent, geologic weathering, ore mining and processing (Perry and Vanderklein, 1996). Other sources include use of metal and metal components, leaching of metals from garbage, solid waste dumps and animal and human excretions, mobilisation through acidification of water and excessive irrigation (Perry and Vanderklein, 1996).

Cumulative evidence in environmental studies suggests that groundwater pollution is on an upswing globally (Perry and Vanderklein, 1996). The underlying causes for this scenario could be due to the increasing complexity of socio-economic activities such as mining, agriculture and other industrial activities. This has made groundwater contamination to become one of the most important environmental topics attracting serious debates in academia. It should be noted that groundwater is polluted by different contaminants, one type of which are heavy metals (Mucheleng'anga, 2007; Oyeku and Eludoyin, 2010). Heavy metals have been singled out due to their toxic concentrations (Momodu and Anyakora, 2010). Heavy metals refer to any naturally occurring metal often toxic to organisms, that has a relative density of $4g/cm^3$ or higher such as lead, mercury, arsenic, cadmium and copper (Mebrahtu and Zerabruk, 2011), to mention a few.

Studies have reported that in Zambia about 86 percent of urban and, to some extent, peri-urban human populations are served with treated water from which heavy metals are removed by water supply treatment plants (De waele and Follesa 2003). However, a large number of people within these peri-urban areas still used other sources of water, mainly groundwater (GRZ, 1997; Potter *et al*., 2008). Accessing water in this way, without proper treatment, put many households at risk of consuming contaminated water because of dependence on groundwater from hand-dug shallow wells and boreholes by people in peri-urban areas for their domestic purposes. For instance, De waele and Follesa (2003) reported that there were more than 3000 private boreholes in Lusaka, used to extract large quantities of groundwater.

During the period 2000-2002, a study on Adaptive Capacity, Water Demand Management and Natural Resource Reconstruction was done. It involved three countries in the SADC region namely Botswana, South Africa and Zambia. One of the findings of this study in Zambia was that, as a way of copping up with the problems of access to cleaner water supply, communities in one of the peri-urban areas of Zambia called George Compound in Lusaka, also depended on shallow wells for their water supply despite having an ultra-modern water supply system (Turton *et al.*, 2002). It was also revealed that almost all the residents of this area had shallow wells as an alternative form of water supply. The shallow wells provided a ready supply of water when the clean piped water supply was inaccessible due to limited time of supply from 04:00 to 08:00 hours in the morning and 15:00 to 17:00 hours in the afternoon with a limited quantity of 100 litres per household, among other things. The study also revealed that at least one percent of a sample of three hundred fifty (350) respondents interviewed in the study area solely depended on shallow wells for their every day supply of domestic water (Turton *et al.,* 2002). Apparently, the modern water supply infrastructure in this area was built to reduce the incidence of cholera outbreaks and other contaminants in George Compound.

The study area was one of the most affected in the then nearly-endemic cholera outbreaks in Lusaka (Nkhuwa, 2000). Since the study by Nkhuwa concentrated on socio-economic issues as influenced by bacteriological contamination, a look on the quality of the water in terms of heavy metals of this area seemed an appropriate thing to do. To assess the quality of the water during and after the rainy season was therefore important. This was further supported by the fact that despite some form of monitoring of the quality of water being done in the past, it has been limited in scope and not covered George Compound. For example, Nkhuwa (2000) made observations on monitoring the water quality of some shallow wells in some peri-urban areas of Lusaka between 2003 and 2005 but excluded George Compound. The issue of monitoring the quality of water regularly was also raised by the Japan International Cooperation Agency (JICA) in the National Water Resources Master Plan (MEWD, 1995). However, for a long time, George Compound had not had any water quality monitoring studies especially on heavy metal contamination despite having ad-hoc water monitoring activities during the outbreaks of Cholera.

1.2 Problem Statement

Located between 15°18' - 15°30' south and of 28°18' - 28°30' east; the average altitude of George Compound is 1250 metres above sea level, but its eastern and southern parts harbours Lusaka’s heavy industrial area lying at a higher altitude than the compound itself. The proximity of the compound to the heavy industrial area, coupled with the indiscriminate disposal of industrial and city waste had the potential to contaminate groundwater in hand-dug shallow wells with heavy metals (Mulenga and Mcgrahanan, 2011). Among the industries are Zamleather, Goodtime Steel, gas stations, Zambian Breweries and many more. Industries like Zamleather which is basically tannery industry, use chromium in their processes. Steel production industry too involves heavy metals. In addition, spillages from gas stations may contain other heavy metals such as lead. The result is the flow of all these heavy metals through industrial wastewater towards George Compound which is not only lying on the lower altitude but also on top of Lusaka's karst aquifer with a high water table susceptible to leaching. The flow could be both on the surface especially in wet season through runoff and underground infiltration in the soil.

Ikenaka *et al*. (2010) on heavy metal contamination in Zambia revealed that Lusaka had higher concentrations of copper near industrial areas, zinc and lead in soils near roads due to automobile oil spillages and an increase in the oil industries. However, the study did not look at George Compound in particular despite it being within a kilometre to the heavy industrial area with an increased number of oil, agrochemical, leather and steel industries whose effluents contained heavy metals. According to World Health Organisation (1993), heavy metal presence in water above permissible limits poses a danger to the health of consumers and can even lead to death. The heavy metals, lead (Pb), cadmium (Cd), and chromium (Cr), are considered to be very toxic (ATSDR, 2012). The heavy metals are known to cause damaging health effects even at very low concentrations, and are among top 20 Hazardous Substances according to Agency for Toxic Substances and Disease Registry (ATSDR) listing.

Ingestion of these heavy metals in people's bodies may lead to different health complications such as cancer, kidney problems, nausea, high blood pressure, and in general, a series of health problems as they are carcinogenic even in small concentrations (Wongsasuluk *et al.,* 2013). Additionally, Mucheleng'anga (2007) assessed the physical and chemical quality of groundwater in shallow wells of George Compound, which revealed that the bacteriological contamination of groundwater was high due to human waste. Apart from that, the study also revealed that the heavy metals cadmium and lead were present in higher concentrations; however, the study did not go further to find out on the local people's level of awareness on heavy metal contamination of groundwater.

There is evidence from literature showing that George Compound residents were still dependent on groundwater from shallow wells for their domestic purposes mainly drinking, washing and bathing due to the inadequate service from Lusaka Water and Sewerage Company.

Based on this background, this study focused on the assessment of the quality of water in shallow wells of George Compound with respect to the presence of heavy metal contaminants and local people's knowledge and levels of awareness on groundwater contamination. This was necessary because the extent to which heavy metals contaminated the groundwater in George Compound was not well understood. This information was required because water contamination by heavy metals beyond the recommended permissible limits posed great risks to the health of consumers according to Zambia Bureau of Standards.

1.3 Aim

The study was aimed at assessing heavy metals contamination of groundwater and the local people's awareness of heavy metal contamination of groundwater in wells in George Compound.

1.4 Objectives

The objectives of the study were to:

(i) Determine the concentration of heavy metals (cadmium, chromium, copper, iron and lead) in groundwater in selected wells in George Compound.

(ii) Examine the extent to which industries in close proximity to George Compound contribute to heavy metal contamination.

(iii) Ascertain the usage of groundwater from wells among residents of George Compound.

(iv) Find out local people's levels of awareness and knowledge about heavy metal contamination of groundwater.

(v) Find out whether past sensitisation campaigns have had an impact on the local people's level of awareness of groundwater contamination in George Compound.

1.5 Research Questions

In relation to the specific objectives, the research questions were as follows:

(i) What is the quality of groundwater in selected shallow wells of George Compound with respect to the presence and levels of heavy metals (cadmium, chromium, copper, iron and lead)?

(ii) To what extent does the proximity of industries to George Compound contribute to heavy metal contamination of groundwater in the area?

(iii) How prevalent is the use of groundwater from shallow wells among residents of George Compound?

(iv) What do local people know about heavy metal contamination of groundwater in shallow wells of George Compound?

(v) How have past sensitisation campaigns in George Compound impacted on the local people's awareness of groundwater contamination in the area?

1.6 Significance of the Study

This study investigated the heavy metal contamination of groundwater in George Compound and suggested possible solutions to the problem. Furthermore, the study will contribute to the existing body of knowledge by providing a baseline on the concentration of heavy metals in the study area. Such baseline data will be useful for planning and implementing groundwater pollution prevention and remediation interventions, and for evaluating the effectiveness of such interventions in Lusaka by environmental, health, water and sanitation sectoers.

1.7 Organisation of the dissertation

The dissertation consists of seven (7) chapters, which are outlined below.

Chapter 1 provides a brief background to the research, research problem and outlines the aim, objectives, research questions and the significance of the study. Chapter 2 reveals relevant literature on socio-economic development, groundwater quality studies in Zambia, water sanitation and supply in Zambia, sources of water and pollution in Zambia and heavy metal contamination of groundwater and health implications. Chapter 3 describes the location of study area, physical characteristics in terms of climate, geology, topography, hydrogeology, hydrology including the socio- economic characteristics of the study area. Chapter 4 describes the methods used in data collection and the types of data collected. Chapter 5 presents the results obtained from laboratory testing as well as the data collected from the field by observation and from field instruments. Chapter 6 discusses and interprets all the results obtained from the study analyses. Chapter 7 concludes the study with some recommendations. The last chapter is followed by references and appendix.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of literature regarding heavy metal contamination of groundwater resources. The chapter first looks at the role that water plays in socio-economic development, followed by studies on groundwater quality. Additionally, it reviews water supply and sanitation in Lusaka, surface water and groundwater pollution sources, the associated health implications and guidelines on the quality of drinking water.

2.2 Role of Water in Socio-Economic Development: An Overview

Water is an essential commodity and human beings depend on it for survival. As a chemical freak, water is an absolute necessity, a frightening phenomenon and a benevolent friend (Todd, 1980). Human beings require quality water in right quantities to survive. Water is vital for industrial and socio-economic development of any nation as it cuts across all sectors of the economy. For instance, freshwater is a necessary input for industry and mining, hydropower generation, tourism, subsistence and commercial agriculture, fisheries and livestock production to mention but a few. Unfortunately, many people especially in rural and peri-urban areas lack access to quality potable water (Mulenga and McGrahanan, 2011). The UNDP (2009) reports that, globally close to 1 billion people lack clean drinking water, 2.5 billion people have no access to hygienic sanitation facilities. The report further indicated that an average of 5000 children die each year due to preventable water and sanitation related diseases.

It should be noted that access to safe and adequate clean water was part of requirement of achieving the 2015 MDG number (7) seven: achieving environmental sustainability in developing countries. Striving hard towards achieving this goal could help the poor who are disproportionally affected to move out of the water and sanitation crisis. In Sub-Saharan Africa, governments, NGOs and other donor agencies have been working hard to ensure that the disadvantaged in rural and urban areas, had access to safe drinking water (Groanwall *et al*., 2010). Indeed, providing accessible but affordable water and sanitation services to rural and peri-urban settlements was important if Sub-Saharan countries such as Zambia were to achieve the Millennium Development Goals (MDGs) by 2015. Therefore, the provision of good quality and affordable water becomes very critical in achieving particular MDGs such as number seven (7) "achieve environmental sustainability" (Chiwele and Syampungani, 2011).

2.3 Groundwater Quality Studies in Zambia

The literature reviewed clearly showed that although many studies had been conducted on water quality and sanitation in Zambia, very few specifically focused on the contamination of groundwater in shallow wells by heavy metals (Ikenaka *et al*. 2010). Many studies focused on heavy metal contamination in wastewater, crops and soil. For instance, Ikenaka *et al*. (2010) found that heavy metal pollution of groundwater was currently increasing and was caused by anthropogenic activities. The study revealed that Lusaka had higher concentrations of copper near industrial areas, zinc and lead in soils near roads. Lastly, the study found that while the Copperbelt region was polluted with copper and cobalt, Kabwe was highly polluted with lead, arsenic, cadmium and zinc to name a few. In another study conducted in Kafue and Mufulira towns of Zambia, Kapungwe (2013) found that the wastewater used to grow crops was contaminated. The wastewater, soils and the crops grown were all found to be contaminated with heavy metals (lead, cadmium, arsenic and others) beyond the permissible limits for human consumption. From these studies, one can arguably deduce that if heavy metals are present above recommended levels in soil and surface waters, then they could be present in groundwater as well.

In another study, Mucheleng'anga (2007) assessed the physical and chemical quality of groundwater in shallow wells of George Compound and revealed that the bacteriological contamination of groundwater was high due to human waste. The same study revealed that heavy metals cadmium and lead were present in higher levels. His study however, did not go further to find out if the local people were aware of heavy metal contamination of groundwater sources, which the current study took into consideration.

Another study which focused on groundwater chemistry of springs and water supply wells in Lusaka, found that the heavy metals such as iron throughout the research were low (Baumle and Museteka, 2008). According to these researchers, the low concentration was due to the solubility of iron and the heavy metals such as cadmium, zinc and lead at the prevailing high pH and the abundance of bicarbonate ions. Despite this conclusion, (Baumle and Museteka, 2008) recommended for more studies to confirm these findings by additional sampling and geochemical modelling.

Although limited data suggested that the quality of groundwater in Zambia had generally low levels of total dissolved solid concentration less than 200mg/l (MacDonald and Partners, 1990), this may have changed due to the passage of time. The trend is likely to change due to urbanisation, higher population concentration and an upsurge in various anthropogenic activities such as mining and Industry.

2.4 Water Supply and Sanitation in Lusaka

The provision of treated municipal water has continued to be a major challenge to those entrusted with the responsibility to do so in many parts of Zambia. In Lusaka, the utility company, the Lusaka Water Sewerage Company (LWSC) under the Lusaka City Council and policy direction from National Water and Sanitation Council (NWASCO) is mandated to provide treated piped water to the urban dwellers (NWASCO, 2009). UN-Habitat (2007) reported that the quantities of water supplied by the LWSC is between 200, 000m³ and 220, 000m³ per day and an estimated 80, 000m³ is sourced from private boreholes. The quantity of water supplied by LWSC is short of the current daily-expected demand of more than 280, 000m³ of water to cater for the more than 2 million residents of Lusaka because of the increasingly growing population due to natural growth and in-migration(NWASCO, 2009). This scenario had left residents in many peri-urban settlements to depend on a variety of water sources such as water kiosks by the LWSC, shallow wells and deep wells to meet the demand (Mulenga and McGrahanan, 2011).

Mulenga and McGrahanan (2011) further noted that the alternative sources of water for the peri-urban settlements such as water kiosks that were put in place and run by LWSC, the Resident Development Committees (RDCs) and other NGOs were not sufficient and reliable. Water kiosks were characterised by intermittent water supply, which were opened for a few hours in a day to the residents at a fee. As a result, many households in George Compound had resorted to using shallow wells as a source of water for domestic and other uses. One study also found that many residents in Chawama and John Laing used hand-dug shallow wells as a source of drinking water as they had no access to city water and sanitation services (Munch and Mayumbelo, 2007). Similarly, in Ng'ombe Compound, 50 percent of the households depended on shallow wells for their domestic water needs (Munch and Mayumbelo, 2007).

This was in contrast with the objective of the National Water Policy, which aimed at universal access to safe, adequate and reliable water supply and sanitation (GRZ, 1994; 1997). In Zambia, though the supply of surface and groundwater was good, those in rural and unplanned settlements did not have an equal share to this important commodity (Nyambe and Feilberg, 2009). This clearly agreed with the United Nations report on Zambia's progress towards achieving the MDG number seven (7). For instance, though the country worked hard to reduce the proportion of the population without sustainable access to improved water sources from 51 percent in 1996 to 40 percent in 2006, many still had no access to safe water and sanitation (Nyambe and Feilberg, 2009). Currently, it had been estimated that 86 percent and 37 percent of the urban and rural population respectively, had access to safe drinking water. For the residents in peri-urban settlements however, the situation is not so conducive (Mitlin and Satterthwaite, 2004; NWASCO, 2009) indicated that 26.4 percent of the population in these areas had no access to safe water.

Though many households in peri-urban areas resort to using on-plot self-supply dug wells, research evidence showed that groundwater was often susceptible to bacteriological contamination thereby posing a health risk to the masses of the urban poor (Mucheleng'anga, 2007). Mulenga and McGrahanan (2011) also observed that many stakeholders in the water sector were of the view that wells dug in peri-urban settlements did not provide safe water and as a result, policy makers did not support their use. The use of groundwater was pre-conceived to be an illegal practice, which was to be eliminated by discouraging the use of shallow wells, while expanding piped water systems at the same time. Despite that, the majority of the poor in urban slums still considered hand-dug wells useful to their domestic water needs (Hoffman, 2011). This could even be the reason why the UNDP (2009) in its country sector assessment survey recommended for the need to pay special attention to the informal settlements that had developed around the cities, with particular focus on the drilling secure boreholes and small water supply and sanitation systems.

It was difficult to tell when the majority of the peri-urban settlements would be connected to quality and sustainable water supplies and stopped depending on localised groundwater resources (MEWD, 1995). This had been worsened by the fact that the LWSC had no capacity to provide piped water to every household. Furthermore, though the MEWD seemed to be concerned with groundwater quality in the country, the current water policy did not clearly mention the institutions specifically responsible for enforcing water quality in Zambia (Phiri, 2000).

The above reviewed literature showed that, use of hand-dug shallow wells in unplanned settlements and domestic water use in general lacked support from the authorities in the water sector. In addition, the Integrated Water Resources Management (IWRM) programmes and projects only seemed to prioritise large-scale water projects and rarely engaged NGOs and utility company managers working to provide water to deprived peri-urban areas (Uhlendahi *et al*., 2011; Mulenga and McGrahanan, 2011).

2.5 Surface Water Sources in Zambia

Zambia, with a total population of 13, 092, 666 (GRZ, 2012), was one of the African countries blessed with plenty of water of generally good quality (both surface and groundwater). The main water bodies are within the watersheds of Zambezi and

Congo rivers with their tributaries of Kafue, Luangwa, Luapula and Chambeshi; and Lakes Tanganyika, Bangweulu, Mweru and Mweru Wa-ntipa including the man-made lakes of Kariba and Itezhi-Tezhi (British Geological Survey, 2001). As the main water bodies are shared with neighbouring countries, Zambia is a major stakeholder in the international agreements on trans-boundary waters and has been a partner on the Zambezi River through the Zambezi River Authority (ZRA) between Zambia and Zimbabwe, and currently has been participating actively on the establishment of Zambezi Watercourse Commission (ZAMCOM).

There has been an increase in the demand for water resources in Zambia and the use of groundwater is increasing steadily. This could be attributed to the very fact that when populations concentrate in cities and towns, the amount of water needed for drinking, individual uses, waste disposal, energy generation, and other purposes multiply exponentially. This brings with it a plethora of concerns cutting across human and environmental health such as water pollution.

2.6 Water Pollution

Apart from its shortage, drinking water may be polluted by different contaminants, which have an impact on both the health and economic status of consumers. Studies showed that an estimated half of the world's population suffers from water-related diseases, contracted by drinking and bathing polluted waters (Perry and Vanderklein, 1996). Over the years, Zambia had experienced water related epidemics such as cholera, dysentery, and those most affected have been from high population density areas such as Misisi, John Laing, and Kanyama compounds in Lusaka (Sichingabula and Nkhuwa, 1998). Therefore, the argument that water from self-supply hand-dug wells may not be safe for human consumption might hold true due to the higher probability of these sources being polluted. Pollution of water varies from place to place depending on the source of water (ground or surface). The Water Resources Management Act (No.21 of 2011, p.27) takes pollution in relation to water to mean…

> *"Any direct or indirect contamination or alteration of the biological, chemical or physical properties of water, including changes in colour, odour, taste, temperature and turbidity… as will or is likely to create a nuisance or render the water detrimental, harmful or injurious to, or potentially harmful or injurious to, the health, safety or welfare of any human being, bird, fish, or other aquatic ecosystem, livestock, wildlife on the environment."*

The above comprehensive legal definition of pollution in relation to water referred to the contamination of water regardless of its source, thereby rendering it unsuitable and harmful for human consumption. The quality of water therefore, is compromised when water is polluted. Water quality is a term used to describe the chemical, physical and biological characteristics of water generally in terms of its suitability for particular use (Pan-Africa Chemistry Network, 2010). The quality of water is therefore impacted upon by the natural processes, such as seasonal trends, underlying geology and hydrology, weather and climate, and by human activities, such as domestic, agriculture, industry and environmental engineering (Pan-Africa Chemistry Network, 2010). Though both ground and surface water sources get contaminated, this study focused on groundwater pollution in peri-urban settlements.

2.7 Groundwater Sources

Groundwater as a renewable and finite natural resource is vital for man's life, social and economic development and a valuable component of the ecosystem (Singh *et al.*, 2013). According to Chilton (1996), groundwater constituted about two thirds of the freshwater resources of the hydrological cycle on earth. If the polar ice caps and glaciers were excluded, groundwater accounted for nearly all-usable freshwater. Groundwater bodies therefore, made up for 95 percent of the total freshwater. Lakes, swamps and rivers account for 3.5 percent and soil moisture for only 1.5 percent (Chilton, 1996). This signified the fact that the use and protection of groundwater sources was of fundamental importance to human survival and economic activity.

Groundwater comes from precipitation that filters through soil and reaches the water table, the point at which all spaces between soils particles are filled with water. Areas that fall within this saturated zone are called aquifers (Perry and Vanderklein, 1996). In Zambia for instance, the best aquifers and recharge zones occurred within the limestone and dolomite horizons of the Katanga system (British Geological Survey, 2001).

Zambia is estimated to have a total potential groundwater abstraction of 157 million m^3/ day and the total groundwater storage estimated at 1, 740, 380 mcm/year (GRZ, 2008). The geological formation and rainfall was a major determinant of groundwater availability. In Zambia groundwater occurred in fractured, weathered rocks, and coarse and fine grained soils (WHO, 2008). Groundwater supply in Zambia provided 28 percent of domestic water supply. In Lusaka alone, there were at least 40 production boreholes and 4000 private boreholes, which extracted large quantities of water (De Waele and Follesa, 2003). Though groundwater sources were said to be the safest and single most important reservoirs of freshwater, they were equally vulnerable to contamination just like surface water (De Waele and Follesa, 2003).

2.8 The Karst Aquifer

An aquifer is an underground zone or layer that is of relatively good source of water (Ojo *et al*., 2012). It may be an underground zone of gravel or sand, a layer of sandstone, a zone of highly shattered or cracked rock or layer of cavernous limestone (Leopold, 1974). The karstic aquifers in Lusaka were usually subjected to Karstification. This resulted into the expansion of fissures and crevices preventing the filtration in aquifers (Ojo *et al*., 2012). This turns the fissures into streams of running water. This is what allows contaminants to be carried along as the process of purification is disrupted. This could be the reason why De Waele and Follesa (2003) noted that once groundwater was polluted; restoring it to drinking water standards could be very expensive if not impossible.

2.9 Sources of Groundwater Pollution

There are different sources of pollutants. A variety of activities can result in groundwater contamination. Such may include unsewered domestic sanitation, industrial effluents, municipal or city waste in urban areas, cultivation with agrochemicals, acid deposition, accidents and leaks and septic tank overflow or leakages (Nkhuwa, 2000; Munch and Mayumbelo, 2007).

2.9.1 Unsewered Sanitation

Groundwater pollution by unsewered sanitation is mostly likely to occur where soils are thin and absent, where fissures allow for swift movement and the water table is shallow. This is likely to happen so especially in areas where pit latrines are built near the water wells. In Zambia, research findings revealed that 75 percent of people use on-site sanitation which is a threat to groundwater (Nkhuwa, 2006). This practice was likely to be disastrous to the health of those in peri-urban settlements in Lusaka as it leads to the deterioration of the quality of groundwater especially in the rain season. This was because pollution and recharge occurred due to pit latrines and the presence of preferential fast flow mechanisms in the karst rock formations (Nkhuwa, 2000; Munch and Mayumbelo, 2007).

These pit latrines were often poorly sited, constructed and maintained. The resultant effect of lack of adequate sanitation in these communities had been the widespread outbreaks of water related diseases carried in human waste such as cholera and dysentery year in year out. Approximately 80 percent of preventable diseases in Zambia were related and induced by poor sanitation (MoH, 2005).

2.9.2 Undesignated Landfills

Apart from the lack of access to adequate sanitation systems, indiscriminate disposal of liquid and solid industrial and municipal waste in self-created dumpsites within the unplanned settlements was increasingly becoming a major contributing factor to groundwater pollution. Disposal of solid industrial and municipal waste in landfills was a common practice in urban areas. A landfill is a given space utilized for the deposit of mainly solid waste. Landfills constituted a significant potential crisis of groundwater pollution (Everett, 1980). This could be so in that most of the landfills were located in unplanned settlements and therefore illegally sited thereby posing a great danger to the surroundings and groundwater quality due to leachate. The quality of water was likely to be compromised by toxic substances such as chemicals, suspended matter, high concentration of dissolved salts, inorganic matter derived from faecal and municipal waste, acid and alkaline substances with varying pH (Oyeku and Eludoyin, 2010). The contaminants find themselves in landfills and eventually leach down into groundwater through the soil. Some of these contaminants often find themselves in shallow wells used by the local households. It is therefore, worth noting that while groundwater is said to be bacteriologically pure, the aquifers can become bacteriologically polluted from sources of contamination such as latrines, garbage dumps, and cemeteries, and through poorly constructed wells (WHO, 2008). Among these groundwater contaminants are heavy metals, the prime focus of this study.

2.9.3 Heavy Metals

Heavy metals as earlier noted, are a group of metals and metalloids with an atomic density greater than 4g/cm^3. Some of these heavy metals include among others lead, arsenic, cadmium, mercury, cobalt, nickel and copper. Though some of these heavy metals are said to occur naturally in nature, they are not harmful to the environment, as they are present only in very small amounts (Mebrahtu and Zerabruk, 2011). Even so, if the levels of these metals are higher than the recommended standard limits, Maximum Contaminant Levels (MCL), (cadmium, 0.003 mg/l and lead, 0.01 mg/l), their effects can be negative in human lives (WHO, 1993). Ingesting water with higher levels of heavy metals can bring about a number of health implications. While human beings could be exposed to heavy metals in a number of ways, drinking water was the primary source of contamination.

Heavy metals find themselves in groundwater through various sources. Some sources of heavy metal contamination include domestic effluents (the largest source), geologic weathering, ore and mineral mining and processing (Perry and Vanderklein, 1996). Oyeku and Eludoyin (2010) also found that heavy metals found themselves down in groundwater through the presence of depressions into which solid wastes were often dumped, and in abandoned quarry excavation sites. This was common in some selected portions of residential and commercial areas in urban settlements where the capacities to collect, process, dispose of or reuse solid waste in a cost efficient and safe manner was limited, as this was the case with most of the peri-urban areas in Lusaka. In Zambia, heavy metals are very common in industrial and mining areas such as the Copperbelt. In view of the foregoing, it should be noted that sources of heavy metal contamination were so intricate that it is practically difficult to identify specific point sources of groundwater contamination.

2.10 Heavy Metal Contamination of Groundwater and Health Implications

Having considered the main sources of groundwater contamination, it was vital that a microscopic view was taken to look at how heavy metal contamination of groundwater affected human health. The study reviewed the health implications of groundwater contamination by five (5) heavy metals. These were chromium, lead, cadmium, iron and Copper. The justification for this was that these metals were associated with higher potential negative effects when ingested in large quantities (Kapungwe, 2013). Assessment of heavy metal contamination of groundwater in self-supply wells of peri-urban settlements in Lusaka merits every responsible citizen's attention as excessive exposure to them could result into serious and even irreversible intoxication (Momodu and Anyakora, 2010). Heavy metals can have serious health effects on an individual depending on the nature and quantity of the metal ingested.

2.10.1 Chromium

Chromium is an important industrial metal used in diverse products and processes. At many locations, chromium is released to the environment via leakages and improper disposal practices (Palmer, 1990). The unique anticorrosive and tanning properties of chromium favoured its application as undercoat in chrome plating industries, leather tanneries, and many more. However, not many industries follow norms of treating toxic waste before it is released into the environment. This has resulted into increased ecological toxic burdens leading to groundwater contamination (NIOSH, 1987). Chromium in groundwater was associated with gastrointestinal and dermatological complaints and haematological functions as reviewed from the study, which was done in India (Sharma, 2012).

2.10.2 Lead

Lead is a common heavy metal, which has affected many people for decades. Due to its higher toxicity levels, lead may cause diseases such as haematological, gastrointestinal and neurological dysfunctions and neuropathy. Actually, children are more susceptible to lead contamination than adults are. In Zambia, many studies have confirmed the presence of lead concentrations in the blood of Kabwe residents beyond the recommended MCL. These are the after effects of lead mining activities, which once rocked the town (Ng'uni, 2013).

2.10.3 Cadmium

As a metal, cadmium is used for making rechargeable second power sources such as batteries; however, it is a very toxic metal. Apart from its many uses, application of fertilizers, pesticides and bio-solids, disposal of industrial waste and the deposition of the atmospheric contaminants, increases the total contamination of cadmium in soil and groundwater in turn. This is because it is bio-persistent, once ingested or absorbed by an organism, cadmium can remain resident for many years. In the human body, cadmium can affect many enzymes. It also causes renal failure due to re-absorption of proteins in kidney tubules if ingested above 0.003 mg/l of MCL (Sharma, 2012).

2.10.4 Iron

Iron is most commonly found in drinking water from wells and aquifers. Water contaminated by ferrous iron is clear; however, if it sits for a period, the ferrous iron precipitates out of the solution due to the oxygen presence. Ferric iron is insoluble in water and is noticeably a red brown precipitate when exposed to the atmosphere. Humans can have negative effects from ingesting too little or too much iron. If drinking water contains a concentration of 3mg/l or more, it will exhibit rust colour, an odour and leave residue stains on clothes and food, however, this concentration is not harmful to health (NIOSH, 1987). When humans lack enough iron, they become anaemic. Anaemia can cause tiredness, headaches and loss of concentration. When too much is ingested, it is stored in the pancreas, liver, spleen and heart (Sharma, 2012).

2.10.5 Copper

Very small amounts of copper are natural in the human body. People who drink water containing copper in excess of the action level may, with short time exposure, experience gastrointestinal distress, and with long term exposure may experience liver or kidney damage (Sharma, 2012).

2.11 Drinking Water Guidelines

Water quality can change with time and other factors such as anthropogenic activities, therefore monitoring of water quality is essential (Zuzan and Kaluu, 2010). Assessing groundwater quality and developing strategies to protect aquifers from contamination are necessary aspects for proper planning and designing water resources programmes (Sadashivaiah *et al.,* 2008). The main source of water for urban, rural and peri-urban communities are boreholes, protected and unprotected shallow wells. In George Compound, communities access water from kiosks and un protected shallow wells. To ensure that the water users are protected from consuming polluted water, many countries and WHO come up with water quality guidelines that specify the maximum permissible amount of constituents in water. A value given in the guidelines represents the concentration of a constituent that does not result in any significant health risk to the consumer over a lifetime of consumption (WHO, 2008). The aim of national drinking water laws and standards are meant to ensure the consumer enjoys safe portable water and not to shut down deficient water supplies (Table 1). Water quality assessment therefore provides the baseline information on water safety (Zuzan and Kaluu, 2010). In cases where national standards are not available, the guidelines for water quality published by WHO should be followed and used as a basis to control water quality. It is important to note here that there is close similarity between the WHO and ZABS guidelines in that most of the guidelines for parameters are the same (Table 1).

Given the fact that George Compound lies in the discharge zone downstream of industrial, trade and domestic activities, groundwater was likely to be contaminated. It is important then to obtain insights into the possible presence of heavy metals in the groundwater and to ascertain if their levels were below the recommended permissible limit for drinking water (WHO, 2008). By knowing the possible sources and concentrations of heavy metals in the groundwater sources, it would be possible to evaluate the associated risks and recommend appropriate measures. Metals are cardinal for human growth, but if consumed in excess, may cause serious physiological disorders.

Table 1: Guidelines for drinking water quality by WHO and ZABS.

PARAMETER	PERMISSIBLE LIMIT	
	World Health Organisation	Zambia Bureau of Standards
Cadmium	0.003 mg/l	0.003 mg/l
Chromium	0.05 mg/l	0.05 mg/l
Lead	0.01 mg/l	0.05 mg/l
Copper	2 mg/l	2 mg/l
Iron	0.3 mg/l	0.1 mg/l
Total Dissolved Solids	1000 mg/l	1000 mg/l
pH	6.5-8.5	6.8-8.0
Electrical Conductivity	1500 µS/cm	3000 µS/cm

Source: WHO (2008) and ZABS (2008)

In George Compound, the risk of consuming contaminated groundwater was increased by poor municipal waste disposal (both solid and liquid) and location of household owned water points (commonly shallow wells) close to the pit latrines and other waste disposal facilities (Mulenga and McGrahanan, 2011). To date, bacteriological contamination is the most addressed and to a lesser extent chemical contamination. While health interventions for safe water access such as treatment with household chlorine have helped to reduce incidences of waterborne diseases, heavy metal contamination of shallow wells has not received much intervention.

More so, it was not clear whether the local people using self-supply wells in George Compound were aware of heavy metal contamination of groundwater sources. The next chapter provides detailed description of the study area.

CHAPTER 3: DESCRIPTION OF THE STUDY AREA

This chapter describes the physical and socio-economic characteristics of the study area. In terms of physical characteristics, the chapter highlights climate, hydrogeology, hydrology, topography and geology of the study area.

3.1 Location

Lusaka is the Capital City of Zambia whose 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 (Figure 1). 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).

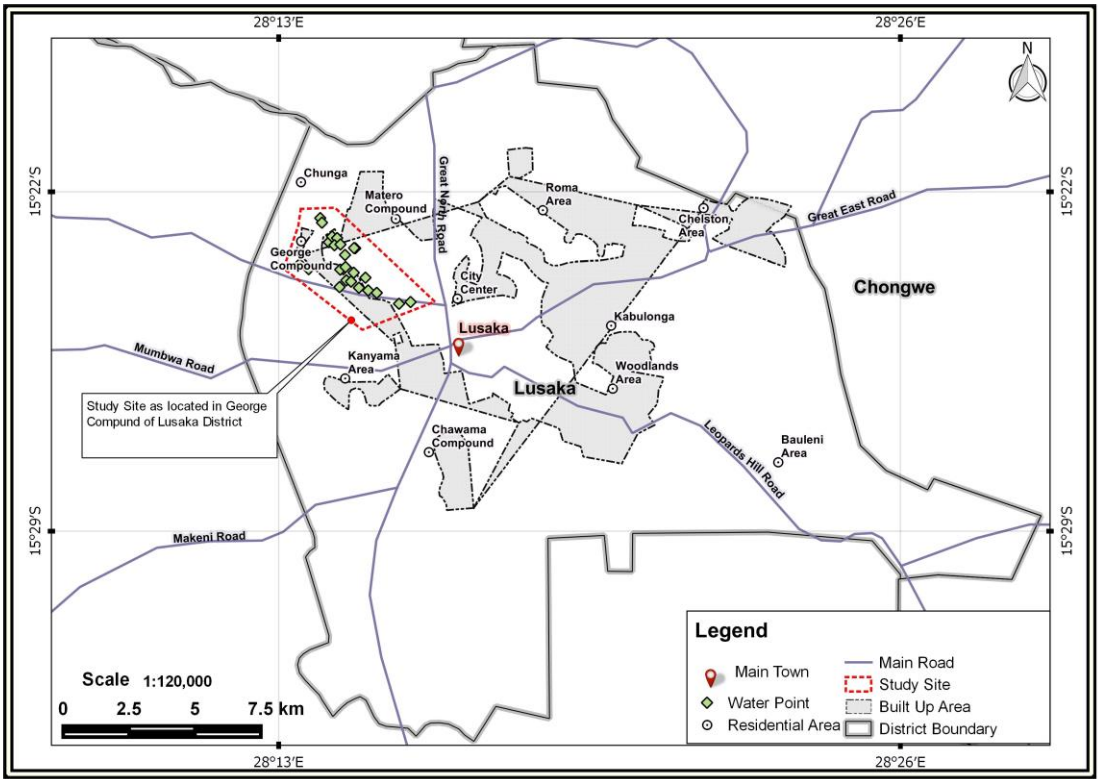

Figure 1: Location of the study sites in George Compound of Lusaka District.

George Compound is one of the unregulated and unplanned peri-urban settlement located 3.15 km north-western of Lusaka CBD. The study area using Google Earth imagery is bounded by Matero Township to the east of George Compound, Commonwealth Road to the north, Zingalume road to the west, and Mungwi Road to the south (Figure 2). The eastern and southern part of the George Compound comprises part of Lusaka's heavy industrial area.

The delineated perimeter ABCD in Figure 2 defines the study area within the coordinates shown in Table 2.

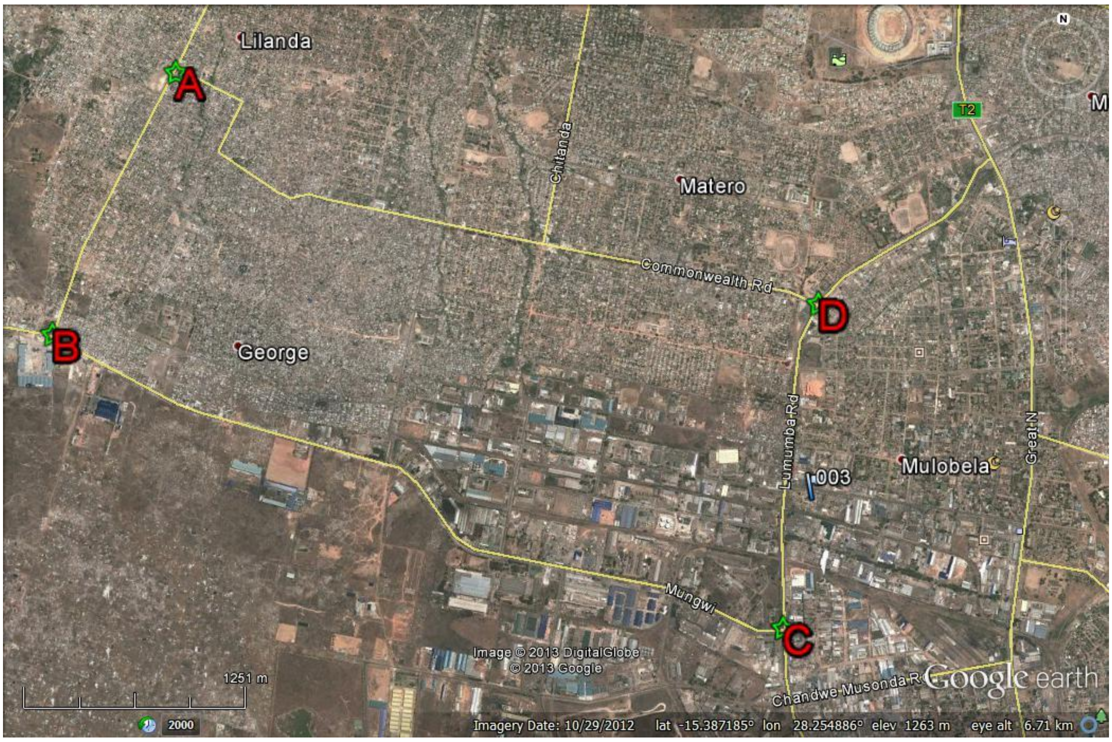

Figure 2: Google image showing George Compound delineated by ABCD.

Table 2: Boundary Coordinates of George Compound in Lusaka.

Boundary Letters	Latitude	Longitude
A	15º 22’ 18’’S	28º 14’ 05’’E
B	15º 23’ 08’’S	28º 13’ 42’’E
C	15º 24’ 02’’S	28º 16’ 01’’E
D	15º 23’ 02’’S	28º 16’ 07’’E

3.2 Selection of the Study Area

George Compound was selected as the study area for heavy metal contamination in wells because it was one of the unplanned settlements in Lusaka. Furthermore, many households had no access to piped water from LWSC, instead used shallow wells. It was also one of the densely populated areas in Lusaka located near the heavy industrial area and was known to have a shallow water table; hence there was a high possibility of groundwater contamination from anthropogenic activities which required investigation.

3.3 Physical Characteristics

This section describes the physical characteristics of the study area such as climate, hydrogeology, hydrology, topography and geology.

3.3.1 Climate

Lusaka experiences a savannah type of climate and lies in the Agro-Ecological region II with less than 900 mm of mean annual rainfall. According to Zambia Metrological Department, the average rainfall of Lusaka is 837 mm per annum received between November and March with the mean annual temperature being between 20˚ C in September and 25˚ C in October. The maximum temperature reaches 30˚C in January and the lowest is about 10℃ in June and July (Baumle and Museteka 2008).

3.3.2 Geology and Topography

The study area is situated on the Lusaka dolomite formation. Shallow wells in George Compound are usually channels filled with water in the limestone excavations resulting from weathering by solutions. These channels are most probably fed from the groundwater supply lines bringing the resource from the surrounding highly channelized aquifer. The major rock type that contributes to the geology of the area is mainly dolomite. Where this is not exposed, sand or lateritic concretions cover the area. The groundwater flow direction is mainly controlled by the topography of the plateau. The study area lies on the lower side of Lusaka that influences the flows towards western side (Baumle and Museteka, 2008).

3.3.3 Hydrogeology and Hydrology

Literature revealed that groundwater in Lusaka Karstic aquifer has been characterised by quality and quantity depletion due to over pumping, compromised environmental situation and other anthropogenic activities (Nyambe and Maseka, 2000; DWA, 2008). The boundary of Lusaka aquifer is shown in Figure 3. The groundwater table is often shallow with depths between 0 and 6 meters in many parts of the area. The area is highly vulnerable to contamination from natural and anthropogenic activities. The Lusaka aquifer groundwater systems comprise several subordinate and minor or local aquifers as well as one main aquifer with high groundwater potential hosted by marble of the Lusaka dolomite formation (Nick *et al*., 2014).

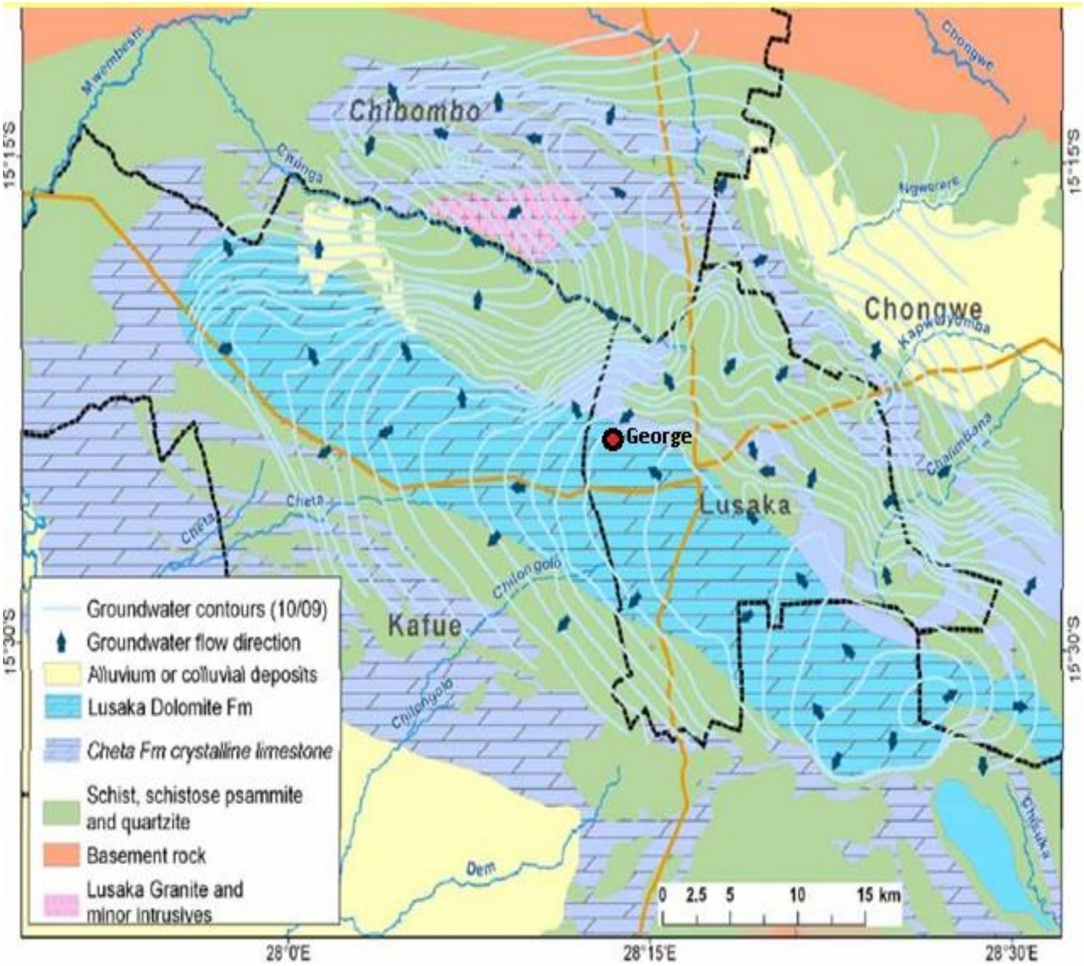

Figure 3: Aquifer System in Lusaka.

Source: Baumle and Museteka. (2008)

On the lowest part of the area, springs and surface water channels exist as discharge zones of the aquifer thereby contributing to the shallow water table in the area. The channel that form and drains outside the study area eventually ends up in Chunga stream (Mucheleng'anga, 2007).

3.4 Socio-Economic Characteristics

This section describes the socio-economic activities of the study area such as people's livelihoods and population.

3.4.1 Population

George Compound has a population of at least 152,346 people (CSO, 2012). The compound is heavily populated with the majority of the people lacking proper sanitation (Mulenga and McGrahanan, 2011).

3.4.2 People's Livelihoods

Located in the proximity of the industrial area, some residents of George Compound are engaged in temporary employment. The unemployed do casual work (which is not guaranteed on a daily basis) as a way of making ends meet. Majority of the population are small scale traders who earn their living by selling of assorted commodities in the markets and on the streets of the George Compound. In addition, because most residents in George Compound live on less than a dollar per day, others therefore, engage in excavation of rocks, which they crush into stone aggregates and sell to building contractors (Figure 4).

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Figure 4: Photographs showing Stone aggregate for sale along Mungwi road in George Compound.

Source: Field data, 2014 – 2015.

CHAPTER 4: METHODOLOGY

This chapter presents the methods used in sampling, data collection and analysis of both primary and secondary. It also outlines the methods of data analysis that were conducted.

4.1 Sampling Procedures

The study purposively sampled 38 respondents who were stratified as 14 households with wells and 24 households without wells. Additionally, a total of four (4) key informants were purposively sampled and interviewed. Purposive sampling was also used to choose members of the study sample by selecting one family member from each of the 14 households with water wells. The other 24 households without wells were selected through snowball sampling procedure. This was done by interviewing a responded and requested for another person they shared the same characteristics in terms of water usage. Purposive sampling was further used to select 4 key informants namely, a representative from Village Water, Resident Development Committee, LWSC and George Clinic Environmental Health Staff, on the premise that they were directly involved in dealing with water issues and had more knowledge on water supply and sanitation in George Compound.

Purposive sampling was further used to select 14 wells for water quality analysis because water levels had gone down in the dry season (October) and as a result, some wells had dried up. In addition, willingness of well owners to give information led to the use of purposive sampling. The help of the Environmental Health Officer at George Clinic and volunteers who normally conducted door-to-door campaigns on health issues helped to identify wells, which did not dry up. They also explained the scope of the study to the participating families. After being allowed access, a field reconnaissance was undertaken in order to familiarize with the area. Global

Positioning System (GPS) coordinates of the wells were taken in order to map the study area using Geographical Information System (GIS) software.

4.2 Primary Data

Semi-structured, interviews were administered to the target respondents. Water samples in dry and wet seasons were collected using clean containers, labelled and transported immediately to the Zambia Bureau of Standards (ZABS) laboratory in a container of ice for heavy metal analysis. The obtained analytical results from the laboratory were compiled. Table 7 gives the descriptions, locations and well identity numbers of the sampled wells.

4.2.1 Questionnaire

Questionnaire was used to collect data from respondents (Appendix 1). The questionnaire was conducted in order to assess among other things the usage of groundwater from wells among residents of George Compound and the local people's levels of awareness and knowledge on heavy metal contamination of the groundwater.

4.2.2 Semi – structured interview

In order to supplement the information by respondents, interviews were conducted on four (4) key informants who dealt in water and sanitation related issues in George Compound by administering interview schedules (Appendix 2). The key informants clarified issues raised by respondents and also gave an assessment of whether or not past sensitisation campaigns have had a positive impact on local people's level of awareness on groundwater contamination in George Compound.

4.2.3 Field Measurements

The in-situ water quality measurements of pH, conductivity, TDS, redox and temperature (Appendix 6) were recorded in the data sheet for both wet and dry seasons. On-site parameters were tested in the field because they are unstable. A Wagtech Multi meter was used to measure in-situ parameters. Water levels were also collected using a depth recorder and recorded on the field data sheet. The location coordinates of sampling points were taken using a hand held Global Positioning System (GPS) Garmin 62 stc.

4.2.4 Water Sampling

A total of 28 water samples from shallow wells were collected for analysis, 14 in dry and another 14 in the wet season. The sampling of groundwater from the wells was carried out in both dry season (October and November, 2014) and wet season (February, 2015) so as to allow for temporal variability assessment of groundwater quality. Preservation of water samples with nitric acid for heavy metal analysis was done and later taken to the Zambia Bureau of Standards laboratory for further analysis using APHA procedures (APHA, 1992).

4.3 Secondary Data

Secondary data was sourced from existing literature, past groundwater studies, books and reports containing relevant information to the topic of study. Stipulated standards on consumable water were collected from the ZABS and WHO literature. The literature also helped to understand the geology of the study area and the various methods used for analysing heavy metals.

4.4 Data Analysis

Collected data was coded and then analysed using descriptive statistics such as percentage, frequency and mean. The Statistical Package for Social Science (SPSS) computer programme was used to analyse the data collected from the respondents using questionnaire and interview schedule. Data collected from key informants were summarised in the narratives based on themes. Incorporating different application software such as Surfer, Quantum GIS and Google Earth were used to generate maps and graphs.

4.5 Limitations of Study

The limitations of the study were threefold, that is finances, drying wells and resident's willingness. Finances limited the study to the use of only one laboratory for the analysis of the water samples as the use of any additional laboratory for purposes of inter-comparison was not possible. In dry season, some of the wells had dried up because the water table had gone down which limited the number of wells sampled. Some residents owning wells did not allow access to their wells for the study. Despite these limitations, adequate data was collected for data for analysis.

CHAPTER 5: RESULTS

This chapter presents results of the study in line with the objectives under different subheadings.

5.1 Heavy Metals Concentration in Shallow Wells of George Compound.

As required, background information on water quality, parameters measured included pH, electrical conductivity, redox, TDS and temperature (Appendix 2). The figures for parameters above the allowable limits are presented in Appendix 2 in bold and where there was no standard, they were left blank. Physical parameters were tested in order to determine the physical characteristics of the groundwater in George Compound.

5.1.1 pH

Two wells had values below the ZABS lower limit (6.5). Well 14 had pH of 5.51 in dry season and Well 13 had pH of 6.13 in wet season as shown in Figure 5. The highest pH was recorded on Well 7 with the value of 7.43 during the dry season.

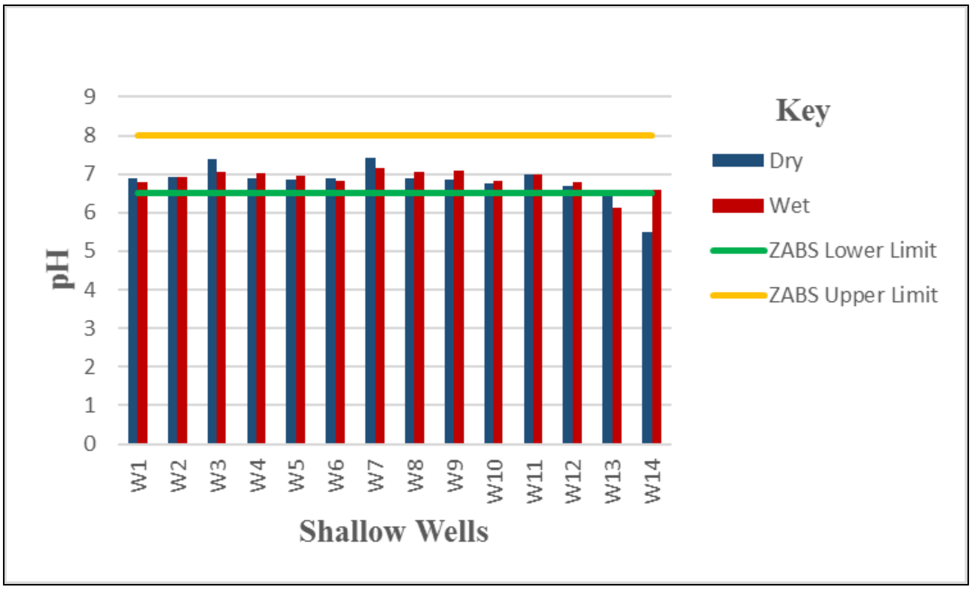

Figure 5: Levels of pH from sampled wells in dry and wet seasons, 2014-2015.

Source: Field data, 2014 - 2015.

5.1.2 Electrical Conductivity

Electrical conductivity (EC) for the sampled wells ranged from 630 µS/cm (Well 3) to 4640 µS/cm (Well 2) (Figure 6). The highest values of electrical conductivity of 4640 µS /cm in the wet season and 2170 µS/cm in the dry season were both recorded at Well 2. The lowest values of EC where recorded at Well 3 with a value of 630 µS/cm in the wet season and 740 µS/cm at Well 7 during the dry season.

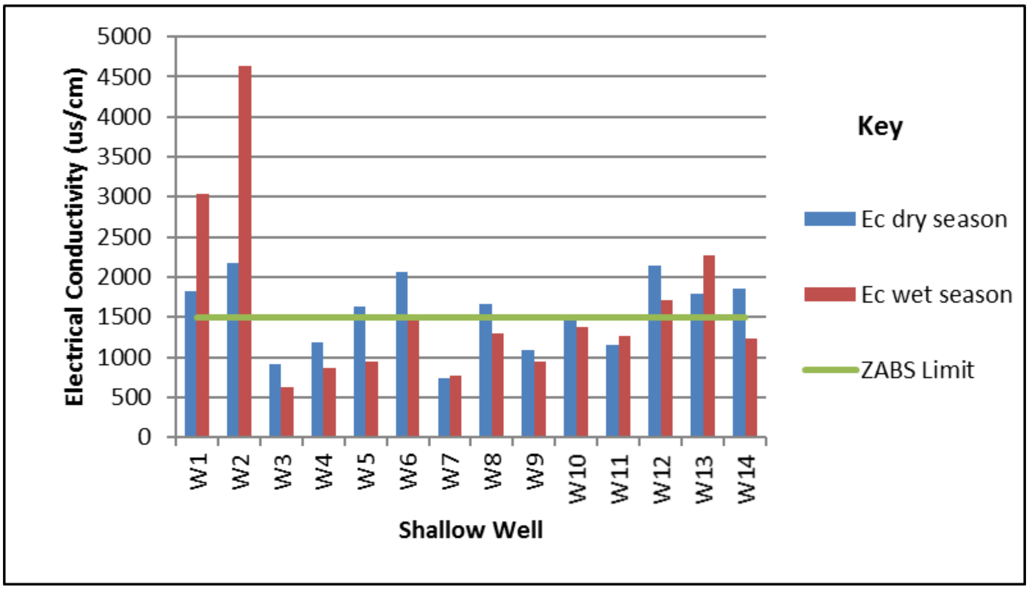

Figure 6: Levels of EC from study wells in dry and wet seasons, 2014-2015.

Source: Field data, 2014 - 2016.

5.1.3 Total Dissolved Solids

Total Dissolved Solids (TDS) was found to vary from of 2460 mg/l (Well 14) to 316mg/l (Well 3) during wet season. In dry season, the values ranged from 457 mg/l to 1100 mg/l at Well 7 and 2, respectively (Figure 7).

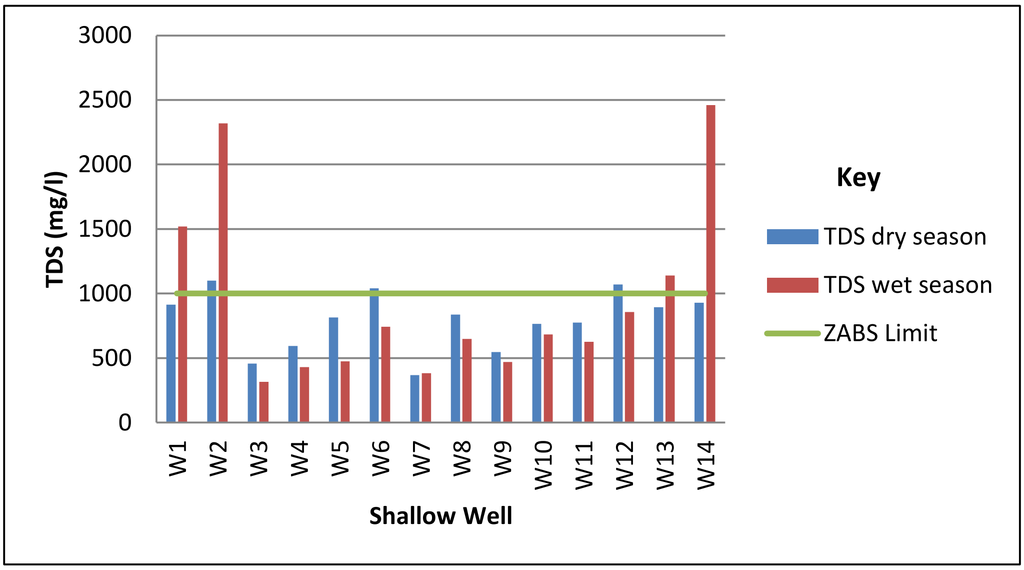

Figure 7: Levels of TDS from studied wells in dry and wet seasons, 2014-2015.

Source: Field data, 2014 – 2015.

The results of copper, chromium, cadmium, iron and lead concentration levels for selected shallow wells in George Compound are presented in Appendix 3 where the figures for parameters above the allowable limits are in bold.

5.2.1 Copper

The concentration of copper in both dry and wet season varied from less than 0.01 mg/l (Wells 5, 10 and 11) to 0.08 mg/l (Well 4). All the concentrations were below ZABS limit of 2 mg/l (Figure 8).

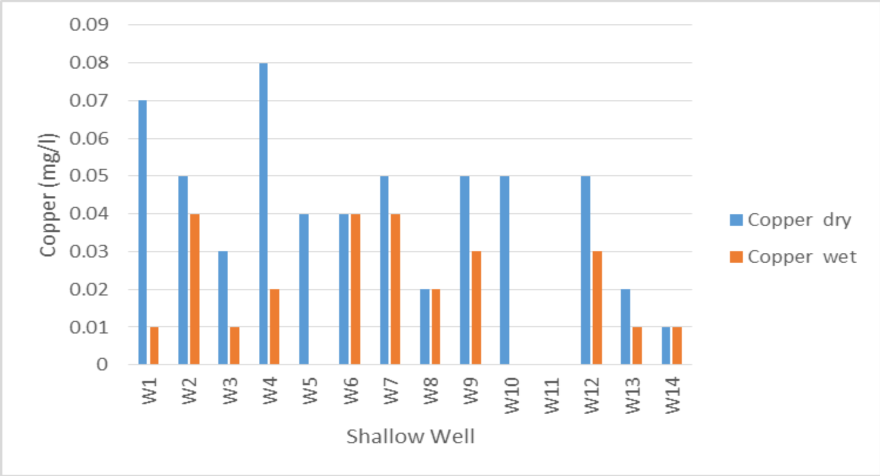

Figure 8: Levels of Copper concentration from studied wells in dry and wet seasons, 2014-2015.

Source: Field data, 2014 – 2015

5.2.2 Chromium

Chromium concentrations ranged from 0.01-0.14 mg/l (Well 14-Well 12) in dry season and 0.04-0.64 mg/l (Well 2-Well 13) in wet season (Appendix 3). In dry season, ten (10) wells recorded high concentrations of Chromium above the ZABS permissible limit of 0.05 mg/l (Figure 9). Wells with higher concentrations in the wet season also generally recorded higher concentrations in the dry season and vice versa.

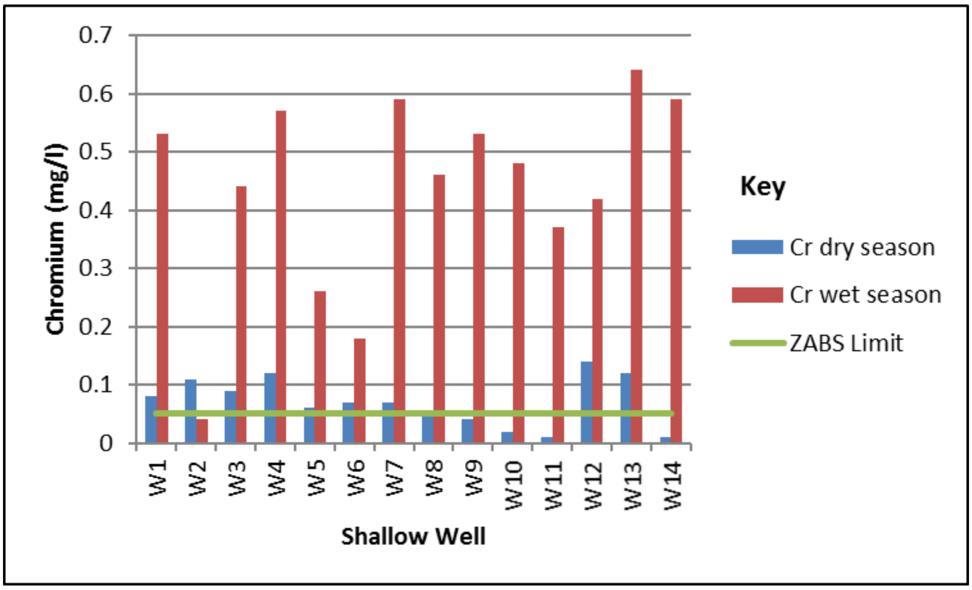

Figure 9: Level of chromium concentration from studied wells in dry and wet seasons, 2014-2015.

Source: Field data, 2014 -2015.

5.2.3 Cadmium

In both wet and dry seasons, all the 14 wells sampled recorded cadmium concentrations above 0.003 mg/l a ZABS permissible limit. The maximum value recorded was in dry season at Well 8 which had 0.91 mg/l and lowest was recorded at Well 2 with the concentration of 0.022 mg/l in the same season. All the recorded concentrations were above the ZABS limit of 0.003 mg/l (Figure 10).

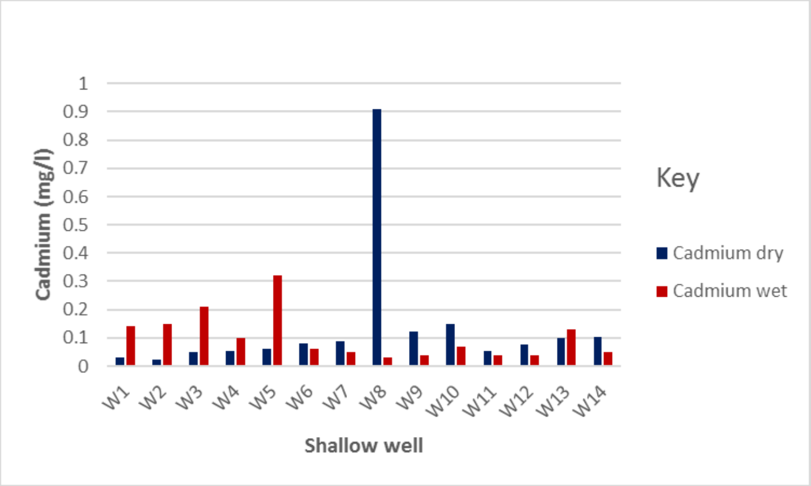

Figure 10: Levels of Cadmium concentration from studied wells in dry and wet season, 2014-2015.

Source: Field data, 2014 – 2015.

5.2.4 Iron

In dry season only two wells with values of 0.41 mg/l (Well 7) and 1.22 mg/l (Well 10) recorded concentrations of Iron above the ZABS limit of 0.3 mg/l. In the wet season, ten wells recorded values above the limit (Figure 11). Well five (5) recorded the highest concentration of iron with a value of 3.11mg/l in wet season while Well 10 recorded the highest value of 1.22 mg/l in dry season.

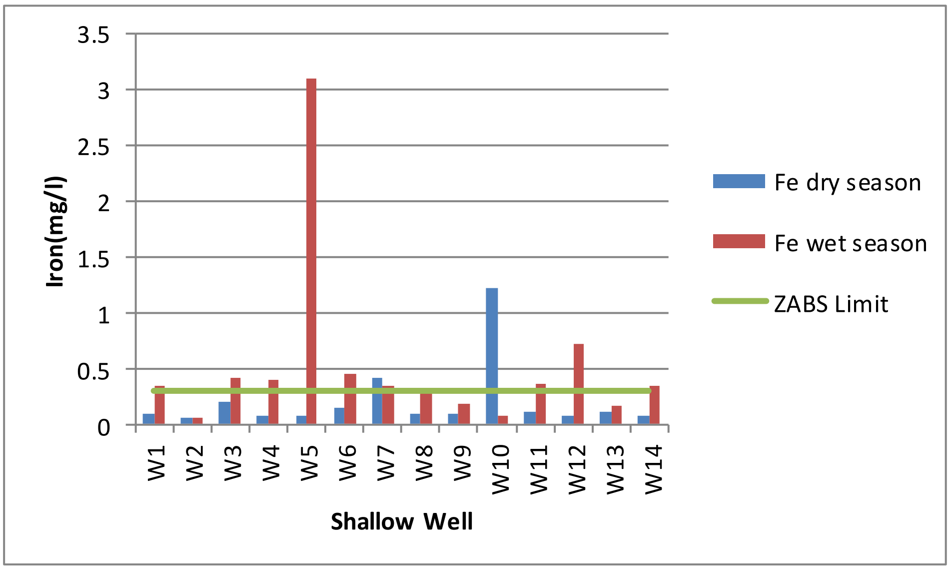

Figure 11: Levels of Iron concentration from studied wells in dry and wet season, 2014-2015.

5.2.5 Lead

A look at Figure 12 shows that in the wet season, seven studied wells recorded presence of lead with maximum concentration of 0.07 mg/l (Well 13) and minimum of 0.01 mg/l (Wells 3, 4, 5, 6, 7 and 11) while the other seven had less than 0.01 mg/l. However, all the 14 studied wells in the dry season recorded concentration of less than 0.01 mg/l.

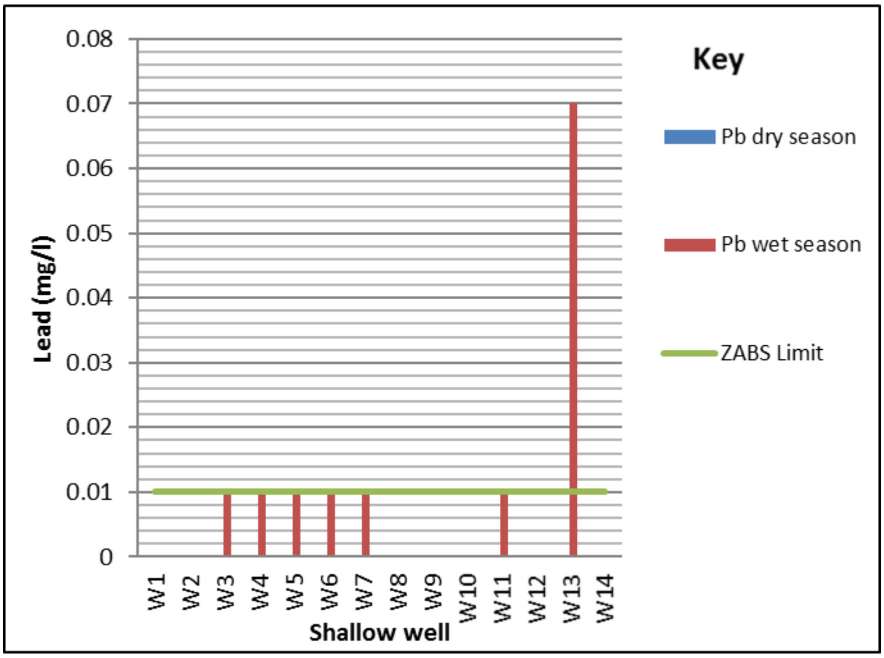

Figure 12: Level of Lead concentration from studied shallow wells in dry and wet season, 2014-2015.

Source: Field data, 2014 – 2015.

5.3 The Extent to which Industries in Close Proximity to George Compound Contribute to Heavy Metal Contamination

The industries in close proximity to the study area were Zamleather, Zambia Breweries, Goodtime Steel, Pembe Milling Company, Jubilee Breweries, Varun Beverages Limited, Parmalat Plc., Shonga Steel, and Puma Filling Station. The industries in close proximity to George Compound and the groundwater flow direction are shown in Figure 13. The flow direction shows that groundwater in George Compound flows from the industrial area towards the compound. This implies that the contaminations are largely due to industrial waste.

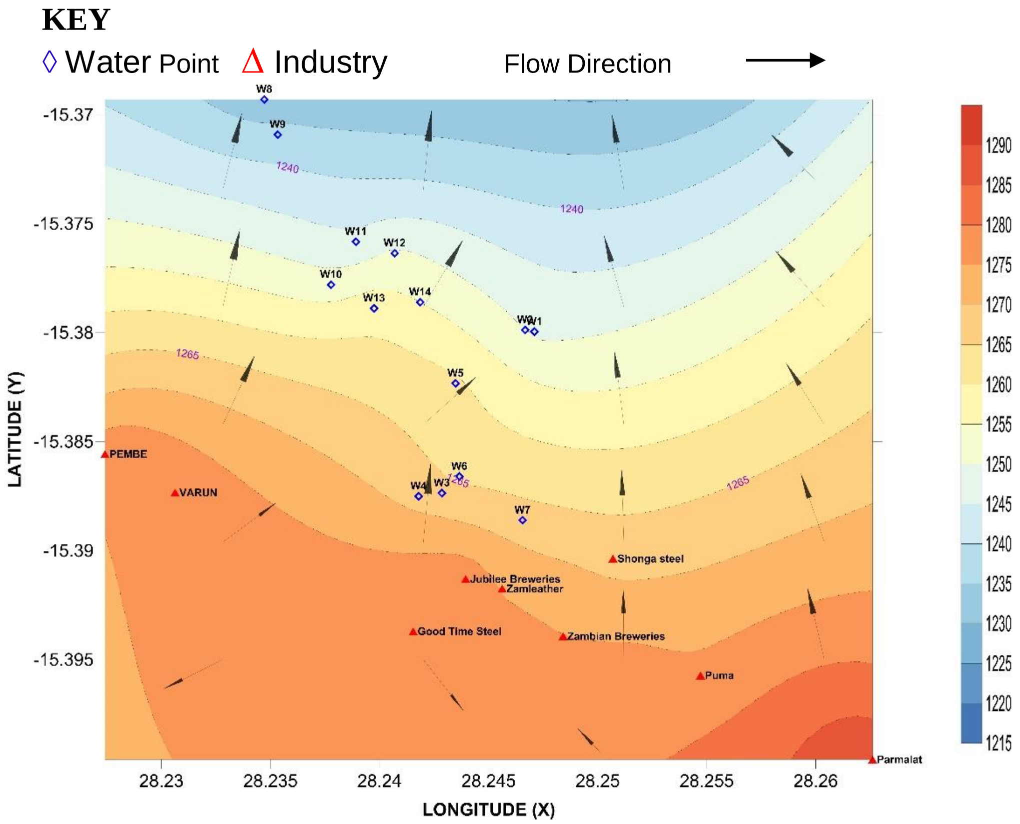

Figure 13: Groundwater flow direction around studied wells north-west of Lusaka's CBD.

Source: Field data, 2014 -2015.

The studied shallow wells in George Compound were within 3 kilometres from the industrial area. The nearest well was Well 7, which was 0.4 km away, and the furthest was Well 8, which was 2.6 km away from the industrial area (Table 3).

Table 3: **Proximity of studied shallow wells to industries in George Compound**

Water well Point	Vicinity	Distance between well and Industrial area [Km]
W1	Zambian Breweries	1.311
W2	Shonga Steel	1.332
W3	Varun	0.476
W4	Zamleather	0.491
W5	Zamleather	1.019
W6	Zamleather	0.525
W7	Jubilee Breweries	0.428
W8	Zamleather	2.649
W9	Zamleather	2.447
W10	Zamleather	1.656
W11	Zamleather	1.812
W12	Zamleather	1.704
W13	Zamleather	1.487
W14	Zamleather	1.445

Source: Field data, 2014 – 2015.

5.4 Characteristics of Respondents

For views on the extent of groundwater use and awareness of heavy metal contamination. As required background information on respondents, the characteristics considered included age structure, employment status and education background.

5.4.1 Age Structure of the Respondents in George Compound

The majority (24) of the respondents (63.1%) were above or equal to 30 years, followed by 23.7 percent in the age group of 25-29 years, 7.9 percent in the age group 20-24 years, and 5.3 percent in the age group of 15-19 years (Table 4).

Table 4: Age and percentage representation of respondents of George Compound in Lusaka.

Respondent's Age Range (Years)	Number	Percentage (%)
15 – 19	2	5.3
20 – 24	3	7.9
25 – 29	9	23.7
≥30	24	63.1
Total	**38**	**100.0**

Source: Field data, 2014 - 2015.

5.4.2 Education Background of the Respondents in George Compound

The results revealed that 55.3 percent (21) of respondents attained secondary education, compared to 28.9 percent (11) with primary education, while 15.8 percent (6) attained tertiary education (Table 5).

Table 5: Level of Education of the Respondents in George Compound.

Level of Education	Number	Percentage (%)
Primary	11	28.9.0
Secondary	21	55.3
Tertiary	6	15.8
Total	**38**	**100.0**

Source: Field data, 2014 - 2015.

5.4.3 Employment status of the respondent in George Compound

The majority of the respondents 50 percent (19) were in non-formal employment, followed by 31.6 percent (12) who were neither in formal nor non-formal employment with only 10.5 percent (4) being in formal employment and lastly 7.9 percent (3) who never gave a response on the same (Table 6).

Table 6: Employment status of the respondents in George Compound.

Type of Employment	Number	Percentage (%)
Formal	4	10.5
Non-formal	19	50
None	12	31.6
No response	3	7.9
Total	**38**	**100.0**

Source: Field data, 2014 - 2015.

Table 7: Location and description of sampled wells in George Compound.

Well Number	Location		Description of Sampled Well
	Longitude (East)	Latitude (South)	
Well 1	28.247100	-15.379960	Located near a pit latrine which was within a radius of three metres. Water from this well was used for drinking, bathing, and washing
Well 2	28.246680	-15.379880	Newly dug well. Water only used for drinking, bathing and washing purposes.
Well 3	28.242860	-15.387360	Water from the well was used for drinking, bathing, and washing.
Well 4	28.241790	-15.387510	Water used for drinking, bathing, and washing
Well 5	28.243490	-15.382330	A rubbish pit located within three metres from the well. Water from this well is used for drinking, bathing, and washing
Well 6	28.243660	-15.386600	Water used for bathing and washing only.
Well 7	28.246560	-15.388610	Water used for bathing and washing only.
Well 8	28.234722	-15.369306	Pit latrine less than five metres from the well, water used for domestic purposes including drinking, bathing, and washing
Well 9	28.235333	-15.370917	About six metres away from this well was a rubbish pit. Water used for drinking, bathing, and washing
Well 10	28.237778	-15.377806	Well surrounded by a slab with latrine six metres away. Well water used for drinking, bathing, and washing

Well Number	Location		Description of Sampled Well
	Longitude (East)	Latitude (South)	
Well 11	28.238917	-15.375833	One metre away from the well was a rubbish pit and about three metres away a pit latrine. Water used for drinking, bathing, and washing
Well 12	28.240694	-15.376361	The well was hidden. Owner hides the well under a table where different dry foods and fresh vegetables are displayed for sell. Water used for drinking, bathing, and washing
Well 13	28.239750	-15.378889	The well was hidden under a big basin with plates on top. Water used for drinking, bathing, and washing
Well 14	28.241861	-15.378611	This well was three metres away from a pit latrine and a rubbish pit. Water used for drinking, bathing, and washing

Source: Field data, 2014 - 2015.

5.5 Key Informants

The four key informants (Appendix 1) in this study were Resident Development Committee (RDC), Village Water, Lusaka Water and Sewerage Company and George Clinic Environmental Staff. All key informants submitted that the major sources of water supply for George Compound residents included kiosks, taps and wells. Key informants indicated that some of the residents use water from shallow wells because of the intermittent supply of the commodity by LWSC; it is cheap and easily accessed. The Key informants were aware that, the water from shallow wells was contaminated by faecal matter and chemicals because of pit latrines and nearby industries respectively.

The key informants admitted that most of the residents were not aware about heavy metal contamination of groundwater. The sensitisation campaigns in the area had been effective in terms of bacteriological contamination of water but not on heavy metal contamination. They all emphasised that there was need to manage waste effectively by treating it accordingly before discharge.

5. 6 Usage of Groundwater from Shallow Wells among Residents of George Compound

There are various sources as well as usage of water for residents of George Compound. Figure 14 presents the percentage usage of water from groundwater shallow wells among residents of George Compound. The Pie chart shows that 69 percent of people used groundwater from shallow wells for their domestic use, 12 percent used piped water from kiosks, while 19 percent did not give any response on whether they depended on groundwater from shallow wells or piped water.

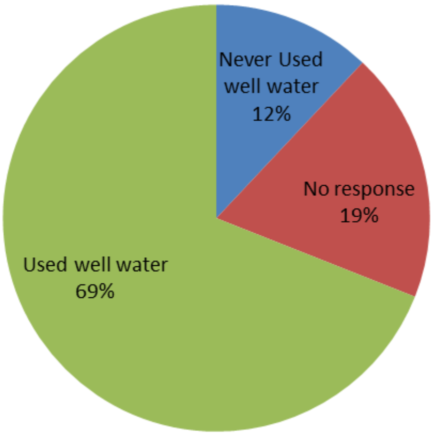

Figure 14: Percentage usage of water from shallow wells by respondents in George Compound

Source: Field data, 2014 - 2016.

5.7 Local People's Levels of Awareness and Knowledge about Heavy Metal Contamination of Groundwater in the Study Area.

The structured questionnaire results reviewed that, some people in the study were aware of the contamination of groundwater with heavy metals. It was found that 55 percent of the respondents had the knowledge and knew about the sources of heavy metal contamination in groundwater in George Compound. The main sources of heavy metal pollution in the groundwater cited by respondents in the study area were the industries whose distances away from the studied shallow wells were in the range of 0.4 km to 2.6 km.   On the other hand, 45 percent of the respondents were not aware of heavy metal groundwater contamination in George Compound.

5.8 Impact of Past Sensitization Campaigns on Local Peoples' Awareness of Groundwater Contamination in George Compound.

The four key informants namely, the RDC, Village Water, LWSC, and George Clinic Environmental Staff, affirmed that past sensitization campaigns had not yielded the intended purpose in George Compound. Many households still depended on shallow wells as a cheap source of both domestic and drinking water especially during large gatherings such as funerals.

Sensitisation campaigns were only done adhoc mainly when there were outbreaks of waterborne diseases, thus downplaying the effects of heavy metal contamination on the groundwater resource, resulting in 45 percent of the respondents being unaware of and lacking knowledge of heavy metal groundwater contamination in the area.

CHAPTER 6: DISCUSSION

This chapter presents the discussion and interpretation of the results with respect to the study objectives.

6.1 Groundwater Physical Characteristics and Heavy Metal Concentrations

Physical characteristics discussed in this section are pH, EC, and TDS as an important component of water quality while heavy metals included chromium, iron, cadmium, lead, and copper.

6.1.1 Physical Characteristics

The pH, EC and TDS of groundwater were analysed in this study because of the vital roles they play in contaminant characteristics and behaviour. The parameter pH is a measure of the acidity or alkalinity of a substance. Similarly, EC is a measure of electrical conductance in water, while TDS is a measure of the solids such as metals, which are dissolved in the water.

One site (Well 14) during dry season had the lowest pH of 5.5 which was uncharacteristic of karst aquifer pH values, the rest of the pH values fell within the permissible limits. The WHO (2008) notes that the pH of drinking water was not a health concern between 6.5 to 8.5. Acidic water with low pH could leach metals from plumbing systems, which can cause health problems (Rose, 1989). The TDS and EC in dry season appeared to be low, which was as a result of lower recharge rates due to reduced flows, and vice versa in the wet season.

6.1.2 Heavy Metals

The concentration of heavy metals (Cadmium, Chromium, Copper, Lead and Iron) in groundwater samples are discussed below.

Chromium (Cr) is not found naturally as a free metal, its most common ore is chromite ($FeCr_2O_4$), which is found in various countries including United States of America, South Africa and elsewhere. Chromium metal is produced by the reduction of the ore and it is used to harden steel, to manufacture stainless steel, to form alloys, and for leather processing in the tannery industries. It is also used to give glass an emerald green colour and in the textile and aeronautic industries (Sharma, 2012). Chromium compounds are regarded as highly toxic. The toxicity of chromium compounds depends on the oxidation state of the metal. Exposure to chromium (VI) compounds has been associated with lung cancer while chromium (III) is an essential element, which can be toxic at high doses (ATSDR, 2012). Chromium plays a role in how insulin helps the body regulate blood sugar levels but its deficiency in the human body has also been associated with diabetes, infertility and cardiovascular disease (ATSDR, 2012).

This study found that Chromium concentrations in the wells were above the limit of the WHO guidelines and the ZABs limits except for Well 2 (0.04 mg/l) during the wet season. The high concentrations of chromium were recorded in the wet season, which could be attributed to surface runoff from the industries towards George Compound. These industries (Goodtime steel, Shonga steel and Zamleather) are the main users of chromium in their manufacturing and processing chains (Sharma, 2012; ZEMA, 2014; Nick *et al* 2014) hence, the likely sources of high concentrations of chromium recorded in the sampled wells in George Compound. However, the concentrations of chromium recorded in dry season was considerably lower compared to that in wet season. This could be due to the fact that there was no runoff.

Iron (Fe) is the fourth most abundant element in the earth's crust and its common natural source is hematite Fe_2O_3 and magnetite (Fe_3O_4); the ore from which iron metal is extracted. Iron has many applications in industries and plays important roles in biology. Areas near wastefills and industrial areas like George Compound are more prone to water percolation and contaminant leaching during precipitation owing to the exposure of the landfill wastes. However, the average Fe concentration of 0.9 mg/l does not pose potential health risk since the recommended dietary allowance for iron is between 7mg and 18mg per day, depending on age and gender and as such, several litres of water would need to be consumed per day before toxicity could occur (Lenntech, 2013). In this study, only wells seven (7) (0.41 mg/l) and 10 (1.22 mg/l) recorded iron concentrations above ZABS standards in dry season. On the other hand, in wet season, over 70 percent of the wells recorded high concentrations above ZABS standards with the highest being Well 5 which recorded 3.11 mg/l.

Cadmium (Cd) and its compound are extremely toxic. Exposure to cadmium is known to cause cancer and targets the body's cardiovascular, renal, gastrointestinal, neurological, reproductive, and respiratory systems (NIOSH, 1987). Cadmium is soluble in acids but not in alkali. Cadmium industrial waste streams including those emanating from landfill leachates mainly end up in soils. Sources of cadmium into waste streams could include zinc production, battery production, phosphate ore extraction and industrial manure (Lenntech, 2013).

In this study, cadmium concentrations were found to be high and above ZABS permissible limits for both dry and wet seasons. However, Well 8 recorded the highest concentration of cadmium (0.91 mg/l) in the dry season and lowest in wet season (0.03mg/l). The lower concentration in the wet season was attributed to dilution effect of surface runoff. Cadmium may also enter the air through waste combustion and burning of fossil fuels. Human exposure to cadmium is mainly through food. People who smoke and those who live close to hazardous landfills have higher exposure to cadmium.

Lead (Pb) is regarded as a heavy metal, which can be poisonous to animals including humans at very small concentrations. Lead is usually found in ore together with other metals including silver, copper, zinc and gold. The main lead mineral is galena (PbS), which accounts for 86.6 percent lead by weight. Much of human exposure to lead comes from anthropogenic activities including mining, use of fossil fuels, leaded gasoline and paint, and landfills. In George Compound, seven boreholes recorded presence of lead in the wet season with maximum concentration of 0.07 mg/l (Well 13) and minimum of 0.01 mg/l (Wells 3, 4, 5, 6, 7and 11) which is also ZABS permissible limit. However, the other seven had concentrations less than 0.01 mg/l. The possible source of this lead contamination into the shallow wells was attributed to leachate from landfills in the rainy season, a phenomenon absent in the dry season.

Copper (Cu) is a good conductor of heat and electricity. The electrical industry uses 60 percent of the world copper production, while the construction industry, industrial machinery, and alloys account for 20 percent, 15 percent and 5 percent respectively (Lenntech, 2013). Copper has beneficial biological effects in humans. The human body system can handle large concentrations of copper, but the ingestion of more than 15 mg/l of copper has been reported to be toxic to humans (Sharma, 2012). The concentrations of Copper in the shallow wells were below the ZABS's limit of 2mg/l as it ranged from 0.01 mg/l to 0.08 mg/l. This could be attributed to the absence of any copper processing or additive industry in the study area. Hence, the concentration of copper in the study area were within tolerable levels and could be due to natural causes.

Overall, this study has revealed that chromium, cadmium, iron, copper and lead were present in most of the wells sampled. In dry season cadmium, chromium and iron were above the ZABS standards in some of the sampled wells, whereas all the metals mentioned above except copper were above the permissible ZABS limit in the wet season. These findings support Mucheleng'anga's (2007) findings and observations showing that heavy metals, especially cadmium and lead were present in shallow wells in George Compound. However, it should be pointed out that once groundwater systems become polluted with toxic substances, it is extremely difficult to clean the contamination, as many pollutants remain hazardous and persistent even at lower concentrations (Yongxin and Brent, 2006). Consequently, the people consuming water from these shallow wells in long term were likely to have carcinogenic and physiological health effects resulting from heavy metal contamination especially the young and the aged whose immune systems are weak.

This study revealed that chromium, cadmium, iron, copper and lead were present in the shallow wells of George Compound, with the high-level concentrations recorded for chromium and cadmium. Therefore, objective (ii) was achieved.

6.2 Extent to which Industries in Close Proximity to George Compound Contribute to Heavy Metal Contamination

Apart from effluents, during the rainy season, industrial wastes (solid wastes and solid sludge from the effluent treatment plants) also end up in the groundwater as non-point source pollution, on account that they are openly dumped within the premises of the industries (ZEMA, 2014). This was also true for George Compound, which is in close proximity to some of the industries such Zamleather, Goodtime Steel, gas stations, Zambian Breweries and many more. Discharges from these industries include chromium, cadmium, lead, and iron. As a result, the groundwater in the studied shallow wells was polluted with these heavy metals in both dry and wet seasons.

High contents of heavy metals were found with significant spatial variations as a result of the influence of anthropogenic activities. Well 13 had 0.07 mg/l of lead above the ZABS limit of 0.01 mg/l. However, it was located further away from the industrial activities compared to Wells 3, 4, 5 and 7 (Table 3). Therefore, the concentration of lead in Well 13 was attributed to poor waste on-site sanitation and possibly its low altitude location as compared to the other wells. Nick *et al.* (2014) reports that George Compound was situated along the Mungwi road with dense settling of domestic households including pit latrines and illegal waste dumps north of Mungwi road. This illegal waste dump was a source of lead contamination from used car batteries.

About 75 percent of the selected wells were moderately to strongly contaminated with Cd and Cr, moderately contaminated with Fe, and relatively uncontaminated with Pb and Cu. The major source of contamination was mainly from anthropogenic while Fe was most likely of natural sources. The groundwater flow direction was determined by the collection of depth-to-water table levels from the wells (Appendix 2). The depth-to-water table water levels were converted to groundwater potential also known as hydraulic head, which was the main core determinant of the groundwater flow regime. Just like flow nets, the groundwater potential (groundwater contours) were being cut at 90º to represent the flow direction. Variations in the flow direction were therefore noticed as being from south-east to north-west. Figure 13 confirmed the flow according to the distance from the industrial proximate to the wells as being from south-east to north-west. These findings agree with Akoteyon *et al*. (2011) who investigated the heavy metal contamination of groundwater around a landfill site in Alimosho area of Lagos State, Nigeria; they concluded that the leachates from the landfill had impacted on the groundwater resources of the sampled wells in the study area based on the direction of groundwater flow. This shows that the shallow wells in George Compound were most likely to be contaminated by heavy metals and other effluents from the industries which include Zamleather, Goodtime steel, gas stations, Zambian breweries and many more as the compound lies in the groundwater flow direction.

Additionally, it was observed that there was an increase in the number of storage facilities for agricultural chemicals and fertilisers located east of the compound which might be insufficiently covered or leaking with a possibility of these substances causing pollution to the groundwater. There was also a high frequency of trucks and other heavy-duty vehicles, which pass, stop, and get serviced in the area. These trucks and heavy-duty vehicles were usually being washed and serviced along the Mungwi road. The implication of this is that areas to the west of the study area have greater likelihood of possible pollution through fuels and motor engine oils and other chemicals transported along Mungwi road, as these infiltrate through soil into the groundwater during the rainy season unlike areas to the east of the study area.

The different number of industries and illegal dumping of waste might have different impacts on the groundwater quality of George Compound. Consequentially, there was a high risk that the various usage of chemicals and fuels especially by Zamleather and gas stations in the light industrial area, which were in very close proximity to the study area polluted the groundwater resource in all the sampled wells in George Compound. The study revealed that the industries in close proximity to the study area were the major contributors to the heavy metal contamination in George Compound, followed by illegal disposal of solid waste. Therefore, objective (ii) of the study, which related to the extent to which industries in close proximity to George Compound contribute to heavy metal contamination, was achieved.

6.3 Usage of Groundwater from Shallow Wells among Residents of George Compound

The study revealed that, majority of the residents of George Compound still used water from shallow wells for their domestic purposes especially drinking. The majority of the respondents were aged thirty and above, and they attained secondary education giving the researcher a high percentage of reliability of the information provided (Tables 4 and 5). Out of the 38 respondents, a total of 69 percent indicated that the residents drink water from the wells. However, 12 percent of the respondents said they never use well water whilst the rest where none responsive. The study also revealed that the minority about 10 percent of the residents were in the formal sector, leaving the majority without a stable income to afford paying for water at the kiosks owned by LWSC. This was also confirmed by the LWSC staff who revealed that the payments by residents were erratic and not up-to-date. The fee for drawing water from the kiosks was 20 Kwacha (ZMW20.00) per month at the time of the study, a figure that was high for most residents, given their status of employment. Furthermore, some residents indicated that even if they paid, they did not get the commodity all the time because the water levels had gone down, a situation, which led to low supply by LWSC. Additionally, there was a cry from some residents that even if they paid the water fees, some kiosks did not even function because they were never maintained by LWSC.

Some residents of George Compound still use water from shallow wells because of the ease with which groundwater was accessed by the locals as well as the restrictive supply of the good quality water from the kiosks by LWSC, thus influencing the communities into increased use of the resource. Also, some of the residents had been using water from shallow wells for a long time as early as 1970s and assumed that the quality was not compromised. During public gatherings like funerals, people use water from shallow wells for domestic purposes, which include drinking, as they could not wait for the intermittent supply of the commodity from kiosks. The LWSC had challenges of supplying water to the compound because of the low groundwater levels due to poor rains during the 2014/2015 rainy season.

This study, found that the usage of groundwater from shallow wells in George Compound was widespread and considered the cheapest and most readily available source of water for domestic purposes especially drinking cooking, bathing and washing kitchen utensils (Table 7). Similarly, Mucheleng'anga (2007) found out that water from shallow wells in George Compound was used for drinking, cooking, washing and bathing. However, consuming untreated water from the shallow wells put people's health at risk from possible heavy metal groundwater contamination.

Groanwall *et al.* (2010) revealed that in Africa, Asia and Latin America, an estimated 269 million urban dwellers depended on nearby wells as their principal source of drinking water thus, represented about 30 percent of the urban population. Given that urban groundwater was rarely even considered in discussions relating to water access, it was striking that hundreds of millions of urban dwellers surveyed in Asia and Sub-Saharan Africa depended mainly on nearby wells to supply them with drinking water. George Compound being a peri-urban residential area, the possibility of groundwater usage as revealed by the study above was inevitable.

Therefore, objective (iii) of the study related to the usage of groundwater from wells among residents of George Compound was achieved.

6.4 Local People's Levels of Awareness and Knowledge about Heavy Metal Contamination of Groundwater

The close proximity of George Compound to the manufacturing industries makes the shallow wells more vulnerable to heavy metal contamination. Some respondents indicated that they had been using water from these shallow wells since the 1970s, and they have not suffered from sicknesses due to heavy metal contamination. The current situation showed that there were more manufacturing industries in the industrial area near George Compound than it used to be in the past, hence a very high likelihood of contaminating the groundwater (ZEMA, 2014). Although, more than half of the respondents (55 %) were aware of the heavy metal groundwater contamination in George Compound, 45 percent were not aware. This indicated that almost half of the population did not realize the dangers posed by heavy metal contamination in the shallow wells, and thus felt safe to continue using water from these wells. In a related study (Wongsasuluk *et al.,* 2013), residents commonly consumed shallow groundwater from wells drilled in the unconfined aquifer on their farms, but were unaware of the risk of heavy metal contamination in the shallow groundwater and the associated adverse health effects. As such, many residents still regarded groundwater to be safe for use domestically, a trend which the key informants also alluded to.

This implies that there was need to create more awareness regarding the adverse effects of heavy metal contamination in groundwater among different stakeholders (industrialists, concerned government departments, the local people and NGOs). Collective efforts towards heavy metal pollution management have not effectively taken place in George Compound. Information obtained from the key informants indicated that local health centres have been raising the issue in various fora, but have not been able to find a solution to the problems faced by the local people. The results of this study showed that the levels of awareness particularly on adverse health risks from consuming heavy metal contaminated groundwater were low amongst people who generally drunk shallow groundwater, a result agreeable with Wongsasuluk *et al.* (2013). With the information stated above, the fourth (iv) objective of assessing the level of awareness and knowledge of the local people about heavy metal contamination in groundwater was achieved.

6.5 Impact of Past Sensitisation Campaigns on Local Peoples' Awareness of Groundwater Contamination in George Compound

Based on the fourth objective, a considerable number of residents in George Compound were unaware of groundwater contamination signifying the ineffectiveness of some past sensitisation campaigns. Of the residents who were aware, it was due to the past sensitization campaigns by the Ward Development Committees, and the Ministry of Health. On the other hand, the realization of the possible contamination of the groundwater in George Compound was enhanced by the occurrence of waterborne diseases such as Cholera and other diarrheal diseases (Nkhuwa, 2000). However, the sensitisation has been more on microbial contamination than that of heavy metal groundwater contamination.

Despite this awareness, most households in peri-urban areas preferred to have their own dug shallow wells. This was because they were forced to fend for themselves, or while waiting for intermittent water supply from municipal or city water supply to be offered to them or continued to use groundwater from shallow wells despite being connected to the piped-water network to save money (Hadipuro and Indriyanti, 2009). Owning a well provides freedom and great saving on time, energy, and also money. Hand-dug shallow wells were often simple structures that anyone could construct and maintain themselves, meaning that they were sustainable and could also be maintained in a good state in the long run (Carter and Bevan 2008). Because of the above benefits and sustainability of using water from shallow wells, most people downplay the negative effects of consuming groundwater at risk of heavy metal contamination.

Therefore, objective (v) was achieved, and much more still needed to be done to sensitise the locals on the effects of heavy metals in groundwater contamination.

CHAPTER 7: CONCLUSION AND RECOMMENDATIONS

This chapter concludes the findings of the study, an assessment of heavy metal contamination in George Compound. Recommendations are also outlined.

7.1 Conclusion

The study area was found to be characterised by a high concentration of different types of industries and illegal dumping sites, and high population density. This type of land use poses a great threat to the quality of the groundwater resource. Consequentially, there was a high risk that the various usage of chemicals, and fuels in the light Industrial area, which was in very close proximity to the study area most likely, polluted the groundwater resource in George Compound.

Based on the findings of the dry and wet seasons, chromium, cadmium, iron, copper and lead were present in most of the sampled wells. In dry season, cadmium, chromium and iron were above the ZABS standards in some of the sampled wells, whereas all the metals mentioned above except copper were above the permissible ZABS limit in the wet season. The results for the dry season indicated that the highest concentrations for chromium 0.14 mg/l (Well 12), cadmium 0.91mg/l (Well 8) and iron 1.22 mg/l (Well 10) were all above ZABS limits of 0.05mg/l, 0.003mg/l and 0.3mg/l respectively. However, lead and copper were found below ZABS detected limit. In the wet season, the results indicated that the highest concentrations for chromium 0.64mg/l (Well 13), cadmium 0.32 mg/l (Well 5), Iron 3.11 mg/l (Well 5) and lead 0.07 mg/l (Well 13) were all above ZABS limits of 0.05mg/l, 0.003mg/l, 0.3mg/l and 0.01mg/l respectively. Copper concentrations were found to be below ZABS detectable limit.

Additionally, the study established that the usage of water from shallow wells for domestic purposes was still prevalent among the majority of the residents of George Compound, although a number of programmes and sensitization campaigns were in place to educate the masses on the dangers of consuming untreated water from wells. The major driving force to this was the ease with which groundwater was accessed by the locals as well as the restrictive supply of the good quality water from the kiosks by LWSC. This challenge influenced the communities to increased use of water from shallow wells whether safe or not. Sensitisation campaigns on the dangers of consuming water from shallow wells have been conducted in the study area in the past by the Ministry of Health through the Ward Development Committees. Despite this effort, almost half of the respondents were not aware of the groundwater pollution in wells.

It is concluded that, groundwater in shallow wells of George Compound is contaminated with heavy metals (chromium, cadmium, and lead) because of its close proximity to the industrial area and some anthropogenic activities taking place within the compound. This calls for regular monitoring of groundwater so that the situation does not worsen.

7.2 Recommendations

Based on aforementioned study findings, the following recommendations were made:

(i) It is highly probable that the elevated concentration of cadmium and chromium observed in George Compound were derived from nearby industrial area. Therefore, ZEMA should seriously monitor groundwater quality and enforce applicable regulations if the sustainability of groundwater resources is to be achieved in George Compound.

(ii) Enforcement of regulation by the local authority on the disposal of liquid and solid waste is required with a view to protecting the environment and groundwater resources.

(iii) The LWSC should increase access to municipal water (piped water) for the residents of George Compound and maintain the existing water kiosks.

(iv) Continuous sensitization of the public on sources and dangers of heavy metal contamination by the local authority and Ministry of Health should be scaled up so that people are made fully aware of the dangers of consuming contaminated water.

(v) WARMA should come up with a long-term water quality monitoring network of groundwater in industrial area and George Compound to avert future catastrophes arising from groundwater contamination.

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APPENDIX

Appendix 1: Data Collected From Four Key Informants.

Question	RDC	LWSC	CLINIC STAFF	VILLAGE WATER
What are the major sources of water supply for George Compound Residents?	"Kiosks/ Taps Wells"	"Kiosks/ Taps Wells"	"Kiosks/ Taps Wells"	"Kiosks/ Taps Wells"
How prevalent is groundwater usage from wells in George Compound?	"A lot of people use it"	"Some people use it"	"Few use it"	"Most people use it"
Why do you think many households in George Compound have resorted to the use of groundwater from wells?	"Easily accessible Cheap"	"Intermittent supply due to low water table Non-payment of water services by residents"	"Intermittent supply by LWSC"	"No money to pay to LWSC because most residents are in informal employment"

Question	RDC	LWSC	CLINIC STAFF	VILLAGE WATER
Is drinking water from wells safe?	“It is not safe because it is not treated”	“Drinking untreated water is not safe”	“It is not safe though some people add chlorine they get from the clinic”	“It is not safe and as such Village Water supplied water testing kits to the clinic”
Are residents of George Compound aware about heavy metal contamination of groundwater in shallow wells?	“Those who work in the nearby industries are aware”	“They are not aware”	“Not all of them but are much aware of bacteriological dangers”	“Some are aware”
Do you think there is a likelihood of heavy metal presence in the wells in George Compound?	“Heavy metals are present in water”	“It is possible because of the runoff from the industries”	“Yes because of the presence of industries nearby”	“Looking at the location of industries it is possible”
Do you think industrial activities contribute to heavy metal contamination of groundwater in George Compounds?	“Yes, they contribute”	“Somehow especially in rainy season because of the runoff from the industries towards George Compound”	“To some extent because George Compound is near industries”	“Yes, because George Compound is in the discharge zone. Both runoff and groundwater flows from industrial area to George Compound”

Question	RDC	LWSC	CLINIC STAFF	VILLAGE WATER
Have there been any sensitization campaigns to educate the local people about groundwater contamination in wells in the area?	"Yes, by people from the clinic"	"Health personnel do sensitise residents"	"The clinic under public health do sensitise residents and distribute Chlorine. They also advise residents to boil drinking water and washing hands after using toilets."	"There are sensitisation campaigns especially on the dangers of drinking un treated water."
Who provide these sensitization campaigns?	"Ministry of Health NGOs Church "	"Ministry of Health"	"Ministry of Health NGOs"	"Ministry of Health NGOs"
Do you think these campaigns have been effective?	"Not much"	"To some extent"	"In terms of bacteriological campaigns have been effective but in terms of heavy metals nothing has been done"	"Yes, though some residents still drink from wells"

Question	RDC	LWSC	CLINIC STAFF	VILLAGE WATER
What measures do you think can be put in place to reduce on groundwater contamination in George Compound?	"Connect households to tap water Manage solid waste"	"Effluent from industries should be treated"	"Take care of solid"	"Connect households to tap water Manage solid waste"

Appendix 2: Physiochemical Results for Selected Parameters and Water Level in Studied Wells in Wet Dry Seasons 2014-2015.

Well No.	**pH**		**Temp (°C)**		**TDS (mg/l)**		**EC (μS/cm)**		**Water Level (m)**	
	Dry	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**
W1	6.89	6.79	22.2	23.7	913	**1520**	**1821**	**3030**	1.9	0.5
W2	6.91	6.92	21.5	24.0	**1100**	**2320**	**2170**	**4640**	2	0.5
W3	7.38	7.07	23.5	24.5	457	316	914	630	4.6	2.3
W4	6.88	7.01	24.4	24.4	594	431	1188	864	6.1	3.6
W5	6.85	6.95	24.3	23.7	815	475	**1628**	952	4.8	3.1
W6	6.9	6.82	23.6	24.4	**1040**	743	**2070**	1489	5.2	2.3
W7	7.43	7.15	23.3	24.6	368	382	740	767	2.9	1.7
W8	6.9	7.04	27.4	23.1	836	649	**1669**	1298	5.4	2
W9	6.84	7.1	24.7	24.6	548	470	1096	942	2.6	2.4
W10	6.76	6.81	24.1	23.5	766	684	**1533**	1368	3.2	2
W11	6.19	6.98	24.4	23.6	776	626	1151	1256	2.9	2.2
W12	6.7	6.8	25.0	23.2	**1070**	858	**2150**	**1716**	6.4	3.2
W13	6.5	**6.13**	24.2	24.2	895	**1140**	**1788**	**2270**	6.3	2.27
W14	**5.51**	6.6	24.6	24.3	930	**2460**	**1858**	1230	4.7	4
ZABS	6.5-8.0		-		1000		1500			

Source: Field data, 2014 - 2015**.**

Appendix 3: Heavy Metal Concentration Results for Studied Wells in Dry And Wet Seasons, 2014-2015.

	Lead (mg/l)		**Iron (mg/l)**		**Copper(mg/l)**		**Cadmium(mg/l)**		**Chromium(mg/l)**	
Well	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**
W1	<0.01	<0.01	0.09	**0.35**	0.07	0.01	**0.032**	**0.14**	**0.08**	**0.53**
W2	<0.01	<0.01	0.06	0.06	0.05	0.04	**0.022**	**0.15**	**0.11**	0.04
W3	<0.01	**0.01**	0.21	**0.41**	0.03	0.01	**0.05**	**0.21**	**0.09**	**0.44**
W4	<0.01	**0.01**	0.07	**0.4**	0.08	0.02	**0.055**	**0.1**	**0.12**	**0.57**
W5	<0.01	**0.01**	0.08	**3.11**	0.04	<0.01	**0.06**	**0.32**	**0.06**	**0.26**
W6	<0.01	**0.01**	0.14	**0.46**	0.04	0.04	**0.08**	**0.06**	**0.07**	**0.18**
W7	<0.01	**0.01**	**0.41**	**0.35**	0.05	0.04	**0.086**	**0.05**	**0.07**	**0.59**
W8	<0.01	<0.01	0.09	**0.31**	0.02	0.02	**0.91**	**0.03**	**0.05**	**0.46**
W9	<0.01	<0.01	0.09	0.19	0.05	0.03	**0.123**	**0.04**	0.04	**0.53**
W10	<0.01	<0.01	**1.22**	0.07	0.05	<0.01	**0.147**	**0.07**	0.02	**0.48**
W11	<0.01	**0.01**	0.12	**0.37**	0.05	<0.01	**0.055**	**0.04**	0.01	**0.37**

	Lead (mg/l)		**Iron (mg/l)**		**Copper(mg/l)**		**Cadmium(mg/l)**		**Chromium(mg/l)**	
Well	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**
W12	<0.01	<0.01	0.07	**0.72**	<0.01	0.03	**0.78**	**0.04**	**0.14**	**0.42**
W13	<0.01	**0.07**	0.11	0.16	0.02	0.01	**0.099**	**0.13**	**0.12**	**0.64**
W14	<0.01	<0.01	0.08	**0.34**	0.01	0.01	**0.103**	**0.05**	0.01	**0.59**
ZABS	0.01		0.3mg/l		2mg/l		0.003mg/l		0.05mg/l	

Source: Field data, 2014 – 2015.

Appendix 4: Questionnaire

THE UNIVERSITY OF ZAMBIA

SCHOOL OF NATURAL SCIENCES

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

Dear Respondent,

I am a post-graduate student at UNZA. I am conducting a study on heavy metal contamination of groundwater in George Compound. The purpose of the study is to assess groundwater contamination by heavy metals and the local people's awareness of heavy metal contamination of groundwater in self-supply wells in George Compound. You have been purposively selected to participate in the study by means of this questionnaire. The information provided will be considered confidential and used purely for academic purposes. Please answer the questions as appropriate and honesty as required.

Instructions

There are three (3) sections in this questionnaire: **A, B and C.** Please tick [√] or indicate your appropriate response (s) in the spaces […] provided.

Section A: Personal Information
1. Sex: Male [ ] Female [ ]
2. Age: 15-19 [ ] 20-24 [ ] 25-29 [ ] 30 and Above [ ]
3. Marital Status of Respondents Married [ ] Divorced [ ] Single [ ] Widowed [ ] Other [ ] (Specify)………………………
4. What is your household size? [ ]
5. Level of education of respondents Primary [ ] Secondary [ ] Tertiary [ ] None [ ]
6. Occupation: Formal [ ] Non Formal [ ] None [ ]
Section B: Usage of Groundwater from shallow Wells

7. For how long have you lived in George Compound? Less than 6 months [ ] 6 months to 1 year [ ] Above 1 year [ ]
8. What are your sources of water for household use? Tick the one (s) which apply to you Well [ ] Kiosks/ Tap [ ] Others [ ]
9. If the well is one of the sources of water, what do you use it for? Drinking [ ] Cooking [ ] Washing [ ] Bathing [ ] Others (Specify) ……………………………………………………………….
10. How often do you use water from the well in a day? Once a day [ ] Twice a day [ ] Three times in a day [ ] More than four times a day [ ]
Section C: Knowledge about Heavy Metal Contamination of Groundwater
11. Do you think it is safe to use groundwater from shallow wells for drinking? Yes [ ] No [ ]
12. Give reason (s) for your answer in question 11 above. …………………………………………………………………………..………. ……………………………………………………………………..……………. ……………………………………………………………………………... …………………………………………………..
13. State any four (4) things that you think can pollute groundwater in your area. i…………………………………………………………………………………… ii…………………………………………………………………………………… iii…………………………………………………………………………………... iv……………………………………………..
14. Are you aware about heavy metal contamination of groundwater in wells? Yes [ ] No [ ]
15. Do you know what heavy metals are? Yes [ ] No [ ]
16. Are there cases of waterborne disease outbreaks in George Compound? Yes [ ] No [ ]
17. How do you dispose of solid waste? Through a local waste management utility [ ] Through the use of a rubbish pit [ ] Any other (specify) …………………………………………………………………..

Thank you so much for your time!

Appendix 5: Interview Guide for Key Informants in George Compound

THE UNIVERSITY OF ZAMBIA

SCHOOL OF NATURAL SCIENCES

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

Dear Interviewee,

I am a post-graduate student at UNZA. I am conducting a study on heavy metal contamination of groundwater in George Compound. The purpose of the study is to assess groundwater contamination by heavy metals and the local people’s awareness of heavy metal contamination of groundwater in self-supply wells in George Compound. You have been purposively selected to participate in the study by means of an interview. The information provided will be considered confidential and used purely for academic purposes.

Section A: Particulars of the Interviewee

Name: …………………………………………………………………

Occupation: …………………………………….……………………..

Organisation: ……………………………….…………………………

Gender: ………………………………..……………………………….

Section B: Unstructured Questions

1. What are the major sources of water supply for George Compound Residents?
2. How prevalent is groundwater usage from wells in George Compound?
3. Why do you think many households in George Compound have resorted to the use of groundwater from wells?
4. How safe is groundwater from wells for drinking?
5. Are residents of George Compound aware about heavy metal contamination of groundwater in shallow wells?
6. Do you think there is a likelihood of heavy metal presence in the wells in George Compound?

7. Do you think industrial activities contribute to heavy metal contamination of groundwater in George Compounds?
8. Have there been any sensitization campaigns to educate the local people about groundwater contamination in wells in the area? If so who provide these sensitization campaigns? Do you think these campaigns have been effective? Give reasons for your answer.
9. What measures do you think can be put in place to reduce on groundwater contamination in George Compound?

Thank you so much for your time!

Appendix 6: Field Data Sheet for Heavy Metal Contamination of Groundwater in George Compound Lusaka

WELL NAME: ……………………………………………………………...…..........

WELL NUMBER: …………………………………………………………………...

GPS COORDINATES: …………………………………………………………………

DATE OF SAMPLING:…………………..TIME OF SAMPLING……………..…

SAMPLED BY:………………………………………………………………………

pH	**Ec(μS/cm)**	**Temp (˚C)**	**Eh (Mv)**	**TDS**	**WATERTABLE DEPTH**

ONSITE OBSERVATIONS:
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