CHARACTERISATION AND TEMPORAL VARIABILITY ASSESSMENT OF GROUNDWATER QUALITY IN PETAUKE TOWN, EASTERN PROVINCE, ZAMBIA

By

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A thesis submitted to the University of Zambia in partial fulfilment of the Degree of Master of Science in Integrated Water Resources Management in the Department of Geology, School of Mines

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DECLARATION

This thesis was written and submitted in accordance with the rules and regulations governing the award of Master of Science in Integrated Water Resources Management of the University of Zambia. I further declare that the thesis has neither in part nor in whole been presented as substance for award of any degree, either to this or any other University. Where other people's work has been drawn upon, acknowledgement has been made.

Signature of author: ....

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APPROVAL

This thesis of Solomon Mbewe is approved as fulfilling the requirements of the Degree of Master of Science in Integrated Water Resources Management of the University of Zambia.

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ABSTRACT

The study was aimed at contributing to the provision of good quality groundwater supply in Petauke District. It comprised collection and analysis of 50 groundwater samples from boreholes in the dry and wet season in Petauke Town. Water exit points were sterilised before collection of samples. Physical properties were assessed on-site using potable pH and conductivity meters, whereas samples for chemical and microbiological analysis were collected in sterilised bottles and transported to the Environmental Engineering Laboratory at the University of Zambia for analysis. In the laboratory, the numbers of total and faecal coliforms were determined using the membrane filtration technique whereas for chemical analysis, samples were analysed for major ion chemistry using the standard methods after APHA (1998). The quality of analytical data was evaluated by computing the ionic balances for all the samples. Furthermore, data for the major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, Cl^{-}, $CaCO_3^{2-}$, HCO_3^{2-}) were plotted on the Piper diagram so as to understand the evolution of hydro-chemical parameters of groundwater in the town. Groundwater classification was done after WHO (2006) whereas temporal variability of water quality between the dry and wet season was assessed using the ANOVA. The suitability of water for drinking was assessed by comparing the data obtained in the field and laboratory analysis to the WHO (2008) and ZABS (2008) limits. Parameters with values above the limits were identified as groundwater contaminants in the town.

The study revealed that groundwater in the town was characterised by low pH (6.17), high iron (2.63 mg/l) and high bicarbonate content (609.6 mg/l), high total hardness (as 598 mg$CaCO_3$/l) and the abundance of major ions were in the order of Ca > Mg >Na> K = HCO_3 > Cl >SO_4. Hydrochemical facies identified were Ca-HCO_3 and Ca (Mg) HCO_3 type. Fifty eight percent of groundwater was hard, 26% was moderately hard, 14% was very hard and only 2% was soft. Observed values of most of the parameters fell within the ZABS and WHO guidelines for drinking water except for nitrate (10%), total colifoms (72%), faecal coliforms (56%), pH (28%), iron (24%) and total hardness (58%). The ANOVA showed that there was no significant seasonal variation in groundwater quality. Groundwater contaminants in the town were found to be total and faecal coliforms, nitrate, pH, iron and total hardness.

Groundwater in Petauke Town belongs to the $CaHCO_3$ and Ca (Mg) HCO_3 group and is hard. Most of the boreholes (75%) were microbiologically contaminated. There was no seasonal variability in groundwater quality and most of the parameters fell within the WHO/ZABS guidelines for drinking water except total and faecal coliforms, total hardness, turbidity, nitrates, nitrites pH and iron which were identified as contaminants. The over-abundance of carbonates, iron and calcium are naturally caused whereas microbiological pollution and excess nitrates are caused by anthropogenic activities. To prevent the effects of water pollution on human health, there is need for effective groundwater monitoring and chlorination of boreholes.

To my daughter

Lonjezo Mbewe

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
DEM	Digital Elevation Model
DNHW	Department of National Health and Welfare
D-WASHE	District Water, Sanitation and Hygiene Education
EWSC	Eastern Water and Sewerage Company
FAO	Food and Agriculture Organisation
FTC	Farmers Training Centre
GRZ	Government of the Republic of Zambia
IPCS	International Programme on Chemical Safety
JICA	Japan International Cooperation Agency
MDG	Millennium Development Goals
MEWD	Ministry of Energy and Water Development
MMT	Methylclopentadienyl Manganese Tricarbonyl
NWASCO	National Water and Sanitation Council
PDC	Petauke District Council
TDS	Total Dissolved Solids
TNTC	Too Numerous To Count
UN	United Nations
UNICEF	United Nations International Children's Emergency Fund
US-EPA	United States Environmental Protection Agency
US-NRC	United States National Research Council
V-WASHE	Village Water, Sanitation and Hygiene Education
WHO	World Health Organisation
ZABS	Zambia Bureau of Standards

CHAPTER 1

INTRODUCTION

1.1 Background

Monitoring of water quality is one of the important tools for sustainable water resources development and provides important information for its management. Groundwater quality is greatly influenced by the biological, physical and chemical soluble parameters due to weathering from source rocks and anthropogenic activities (Sadashivaiah et al., 2008). In general, the quality of groundwater depends on the composition of recharge water, the interaction between the water and the soil, the soil and the gas, the rock with which it comes into contact in the unsaturated zone and the residence time and reactions that take place within the aquifer (Freeze and Cherry, 1979; Hem, 1989; Fetter, 1990; Appelo and Postma, 2005). Thus, the principal processes that influence the quality of groundwater in an aquifer are physical, geochemical and biochemical (Sadashivaiah et al., 2008).

Changes in the concentrations of certain constituents due to natural or anthropogenic causes may alter the suitability of groundwater for certain uses. Characterising groundwater and assessing its quality and developing strategies to protect aquifers from contamination are necessary aspects for proper planning, designing and managing water resources (Sadashivaiah et al., 2008). The importance of water quality in human health has recently attracted a great deal of interest especially in developing countries where around 80% of all diseases are directly related to poor drinking water quality and unhygienic conditions (Olajire and Imeokparia, 2001; Prasad, 1984; World Health Organization (WHO), 2002). It is estimated that 1.2 billion people across the world do not have access to safe drinking water whereas about 1.6 million deaths per year are attributable to unsafe water and sanitation, including lack of hygiene (WHO, 2002; WHO, 2003a).

Access to safe water supplies in Zambia in 2005 was estimated at 84% of the population in urban areas and 37% of the population in rural areas (Government of the Republic of Zambia (GRZ), 2007). With regards to sanitation, GRZ (2007) notes that the estimated national coverage was 33% for urban areas and 4% for rural areas. In the high density areas where 50-70% of the urban population live, as the case is in Petauke Town's unplanned settlements, water supply and sanitation services are poor, inadequate and unreliable; at least 50% of the population do not have access to safe water supply and as much as 90% lack access to satisfactory sanitation facilities (GRZ, 2007).

Generally, Zambia is endowed with vast water resources in the form of surface and groundwater. The available water resources far exceed the total national consumptive demand (domestic, industrial, agriculture, and ecological) even in drought years (Japan International Cooperation Agency (JICA)/Ministry of Energy and Water Development (MEWD), 1995). However, water resources development and management has not succeeded to substantially improve access to water or prevent pollution of both surface and groundwater (GRZ, 2005). The challenges faced over the years in water resources development and management has resulted in inadequate supplies to meet various needs. These challenges have been inadequate information for decision making and efficient use of the resource, surface and groundwater pollution, inadequate financing and insufficient stakeholder awareness and participation among others. Surface water is very varied in terms of coverage and availability (Gauff-Ingenieure, 2001). As such groundwater has over the years proved to be the most reliable resource, especially for rural districts like Petauke of Eastern Province, Zambia.

In order to improve access to water and sanitation in rural and urban areas, the Government of the Republic of Zambia developed the Water Supply and Sanitation (WSS) programmes which have clear set of priorities and approaches that are intended to both speed up the achievement of the Millennium Development Goals (MDGs) and meet the government's vision for universal coverage (GRZ, 2005; GRZ, 2006; GRZ, 2007; United Nations (UN), 2008). The drilling of boreholes has been the major approach that has been implemented in a number of districts especially Eastern Province where surface water is not easily accessible for the residents (Gauff-Ingenieure, 2000). An example of these interventions is a project such as the Rural Water Supply for Eastern Province (RWSP-EP) (Gauff-Ingenieure, 2000). It is worth mentioning here that most of such interventions have however concentrated on improving access to water in terms of quantity with less emphasis on quality. It is in this regard that this study to characterize groundwater quality in Petauke Town, Eastern Province, was chosen so as to lay a basis for improved groundwater resource development and management.

1.2 Problem Statement

Comprehensive water quality studies are not a routine part of groundwater supply projects in Zambia's rural districts. Analyses which are rarely done are limited only to bacteriological criteria and physical properties. Unfortunately, this is the case obtaining in Petauke District where water resources development programmes such as borehole drilling have not been coupled with comprehensive water quality assessment programmes. The characterization of groundwater quality for the town and district as whole has never been done. Thus, communities, especially those in areas not served by township water supply, drink untreated water from boreholes and wells whose quality has not yet been ascertained.

This is despite 67% of the boreholes sampled in the district by the District Water Supply and Hygiene Education Committee (D-WASHE) in 2009 failing to meet the WHO (2008) and Zambia Bureau of Standards (ZABS) (2008) minimum requirement of nil total and faecal coliforms per 100ml of water meant for drinking (Petauke District Council (PDC), 2009). Additionally, the township water which is currently serving most of the planned residential areas has high levels of calcium carbonate that has over the years affected the water reticulation network by depositing in pipes, blocking them and even clogging up water meters, the tools for effective water utilization (Gauff-Ingenieure, 2001). Drinking water whose quality has not yet been ascertained poses a great danger to human health in Petauke Town as untreated water which might be contaminated is known to contribute to about 80% of all diseases in developing countries (WHO, 2008).

It is against this background that, there is a pressing need for reliable information on the certainty of groundwater quality in the district in order to provide a basis for planning of effective water treatment and management strategies. Central to this information requirement is the need to ensure that the water, people consume is of acceptable quality and satisfies the WHO (2008) and ZABS (2008) guidelines for drinking water.

1.3 Aim

The aim of the study was to contribute to the provision of good quality groundwater supply in Petauke District.

1.4 Objectives

Arising from the aim were the following specific objectives:

i. To describe the chemical, physical and microbiological characteristics of groundwater in Petauke Town.
ii. To assess the temporal variability of groundwater quality in Petauke Town.
iii. To assess whether the quality of groundwater being consumed in Petauke Town satisfied the ZABS (2008)/WHO (2008) standards for drinking water.
iv. To identify groundwater contaminants in Petauke Town.

1.5 Research Questions

i. What are the physical, chemical and microbiological characteristics of groundwater in Petauke Town?
ii. Is there any temporal variability in groundwater quality in Petauke Town?
iii. Does the water being provided to the residents in Petauke Town satisfy the ZABS (2008) and WHO (2008) standards for drinking water?
iv. What are the groundwater contaminants in Petauke Town?

1.6 Hypothesis

The hypothesis which was used to test objective (ii) quantitatively was that there is no significant difference in the quality of groundwater between the dry and wet season in Petauke Town.

1.7 Significance of the Study and Scientific Contribution

One of the objectives of the Government of the Republic of Zambia with regards to water and sanitation is to promote sustainable water resources development and management with a view to facilitating an equitable provision of adequate quantity and quality of water for all users at acceptable costs and ensuring security of supply under varying climatic conditions and local pressures (GRZ, 2005). This goal can only be achieved when the development of water resources such as borehole drilling is coupled with effective water quality monitoring and management programmes not only in major towns but also in smaller towns, peri-urban and rural areas.

A study into the characterisation and temporal variability assessment of groundwater quality in Petauke District, with special emphasis on the town will reveal the concentrations of different groundwater quality parameters which will provide a basis for optimized water resources management, quality monitoring activities and enhanced treatment rates. This is cardinal in ensuring public health and the wellbeing of households. Furthermore, the knowledge gained and skills acquired can be passed on and used in other needy areas that may have similar challenges. The study will also fill the knowledge gap on groundwater quality in Petauke Town and will provide reference to would be researchers in similar fields.

1.8 Scope of Work

The research project involved a desktop study, field and laboratory work:

i. In the desktop study, a literature review was carried out to document and understand previous studies/projects on characterisation of groundwater. A field campaign was then planned to implement the observations from literature. In the field, a study site was defined and study boreholes selected using information available at Petauke District Council and Department of Water Affairs offices.
ii. Groundwater sampling was conducted for the selected boreholes in the dry and wet season. Physical analysis was done on site while bacteriological and chemical analysis was conducted at the Environmental Engineering Laboratory, University of Zambia.

iii. The groundwater samples from the boreholes were analysed for physical, chemical and microbiological parameters in the laboratory. The data collected in the field was combined with the theoretical understanding of characterisation of groundwater quality to interpret it.

1.9 Thesis Organisation

The thesis consists of seven chapters, which are outlined below.

Chapter 1: Background to the research, research problem, objectives, questions, hypothesis and scope of work are included in this chapter.

Chapter 2: This chapter consists literature review on groundwater occurrence, geochemistry of groundwater, national groundwater quality overview for Zambia, national coverage of water and sanitation in Zambia, Millennium Development Goals on access to safe water, potable water, chemical, microbiological and physical pollution of groundwater, effects of groundwater pollution on human health, WHO and ZABS guidelines for drinking water quality, environmental occurrence and significance of water quality parameters and analysis of hydro-geochemical data.

Chapter 3: Description of the study area – location and extent of Petauke Town, population dynamics, socio-economic characteristics, climate, vegetation, relief and drainage, soils and geology are described in this chapter.

Chapter 4: This chapter describes data collection and analysis methods.

Chapter 5: The analyses of results appear in this chapter.

Chapter 6: This chapter contains the discussion and interpretation of results on the characterisation and temporal variability assessment of groundwater water quality.

Chapter 7: The summary, conclusions and recommendations appear in this chapter. Following this chapter are references and appendices.

CHAPTER 2

LITERATURE REVIEW

2.1 General Remarks

This chapter presents a review of literature regarding characterisation and temporal variability assessment of groundwater quality. The need is to have a deeper understanding of groundwater quality, sources of contamination and related effects on human health. Additionally, it is to understand the principles of methods currently in use to characterise and describe groundwater quality.

2.2 Environmental Occurrence of Groundwater

Freeze and Cherry (1979) defined groundwater as the subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated. The occurrence of groundwater is illustrated in Figure 1.

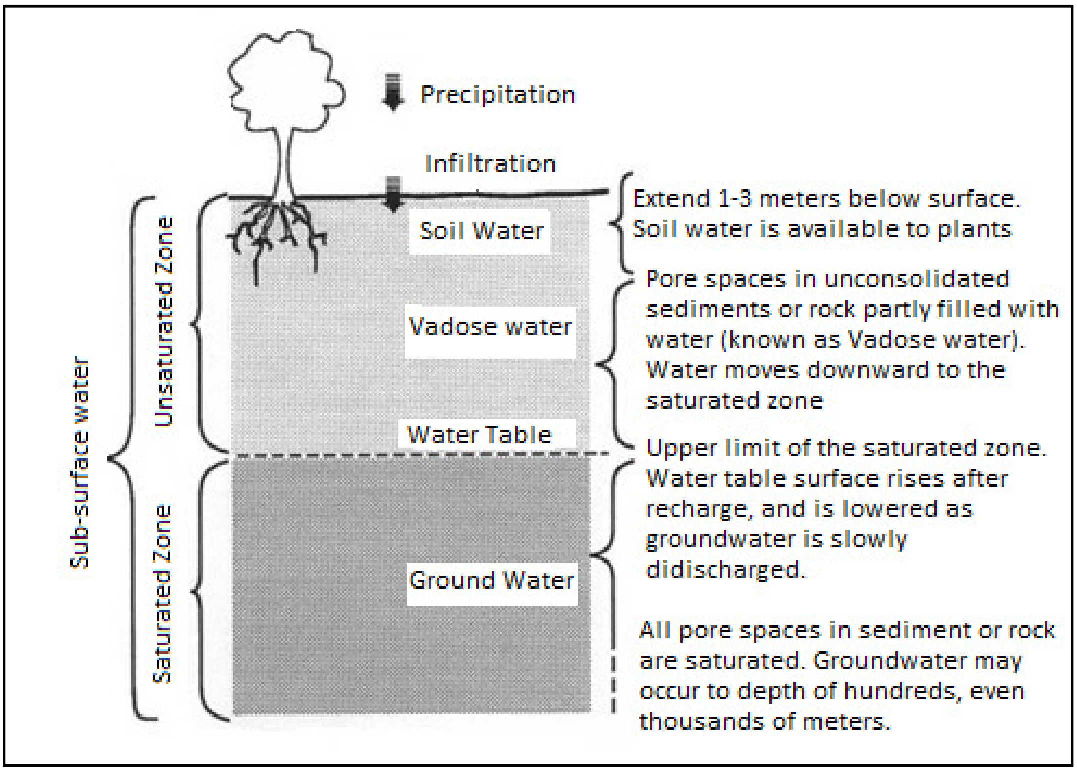


Figure 1: Environmental occurrence of groundwater (after American Groundwater Trust, 2000).

Similarly the American Groundwater Trust (2000) notes that below the water table, all the pore spaces and cracks in sediments and rocks are completely filled (saturated) with water. These saturated layers, known as the saturated zone (or the phreatic zone), are where ground water occurs. It is stored in and moves slowly through layers of soil, sand and rock formations usually referred to as aquifers (American Groundwater Trust, 2000). An aquifer is considered as a hydrostratigraphic unit that is saturated, permeable and capable of yielding economic water (Freeze and Cherry 1979). It is cardinal to stress here that only water found in the saturated zone is groundwater (American Groundwater Trust, 2000).

In hard rocks, groundwater occurs in secondary developed features such as weathered zones, joints, fractures, faults or solution features (JICA/MEWD, 1995). In Zambia, the weathered zones usually form shallow aquifers which are shallower than 20m in depth. Fracture zones have been developed under weathered zones and usually extend to around 30m-40m in depth and often extend to more than 90m in depth. The thickness and permeability of aquifers are closely related to the original rock type (JICA/MEWD, 1995).

2.3 The Geochemistry of Groundwater

Water is a very universal solvent capable of dissolving most solids to some degree. Inorganic and organic solids, organic liquids and gases found in subsurface dissolve in groundwater. Freeze and Cherry (1979) noted that the major factors controlling the geochemical evolution and quality of groundwater are chemical composition of rainwater, soil types and mineralogy of rock formations. The geochemical reactions in the soil zone and the underlying unsaturated and saturated zones, temperature, pressure, duration of contact of percolating water and surrounding media determine the chemical composition of groundwater (Freeze and Cherry, 1979). Thus, the composition of groundwater provides information about the environment through which water has circulated (Freeze and Cherry, 1979; Hem, 1989; Fetter, 1990; Appelo and Postma, 2005).

Changes in the concentrations of certain constituents due to natural or anthropogenic causes may alter the suitability of groundwater for certain uses (Sadashivaiah et al., 2008). For example the increase in iron due to corroding galvanised iron rising mains and connecting rods and high turbidity levels leading to the change in colour of water as the case was in West Africa, made borehole users to stop using the pumps (Langenegger, 1994).

Anthropogenic activities like explosion of population, industrial growth, inputs of fertilizer, pesticides and irrigation have been crucial factors for determining the quality of groundwater. Numerous publications have reported that urban development and agricultural activities directly or indirectly affect the groundwater quality (Jalali, 2005; Rivers *et al.,* 1996, Kim *et al.*, 2004, Srinivasamoorthy *et al.,* 2009, Goulding, 2000; Pacheco and Cabrera, 1997). For example Srinivasamoorthy et al., (2009) in their characterisation and assessment of groundwater quality in Thirumanimuttar sub basin in India, observed that whereas the piper plot indicated calcite dissolution and reverse ion exchange as some of the processes controlling the water chemistry in the study area, higher electrical conductivity values were confined along up stream, central and downstream indicating the dominance of domestic, industrial and agricultural activities. Fluoride was also higher during pre-monsoon indicating leaching from fluoride rich source rocks and easier accessibility of rain water to weathered rock, long term irrigation processes, semi arid climate and long residence time of groundwater. Furthermore, Srinivasamoorthy et al., (2009) noted that higher nitrate levels were observed during the post monsoon in areas where intensive irrigation practices are dominant, whereas higher total hardness was identified in locations confined to occurrence of dyeing and bleaching industries. Overall, the hydrogeochemical analytical study revealed that 36% of the samples were unsuitable for irrigation purposes and 69% were unsuitable for drinking purposes. The above confirms that the principal processes that influence the quality of water in an aquifer are physical, geochemical and biochemical. It is cardinal to note here that anthropogenic activities like inputs of fertilizer, pesticides and high population growth which promote the mushrooming of unplanned settlements with poor sanitation facilities are also occurring in Petauke Town, hence posing a danger to groundwater quality and raising need for its characterisation and analysis.

Deutsch (1997) notes that of the many solutes found in groundwater, only a relatively few are present at concentrations greater than 1 mg/l under natural conditions. Inorganic constituents are classified as major ion constituents with concentrations greater than 10 mg/l, minor constituents with concentrations ranging from 0.01 mg/l to 10 mg/l, and trace elements with concentrations less than 0.01 mg/l (Table 1).

Table 1: Dissolved constituents found in groundwater (after Davis and De Wiest (1966) as cited in Freeze and Cherry, 1979)

Major constituents (range of concentrations greater than 5 mg/l)	
Calcium	Bicarbonate
Sodium	Sulphate
Magnesium	Chloride
Silica	
Minor constituents (range of concentrations 0.01 to 10 mg/l)	
Iron	Carbonate
Potassium	Nitrate
Strontium	Fluoride
Boron	
Trace constituents (range of concentrations less than 0.01mg/l)	
Antimony, Bromide, Aluminium, Arsenic, Phosphate, Iodide, Barium, Cadmium, Chromium, Cobalt, Copper, Zinc, Germanium, Lead, Lithium, Manganese, Molybdenum, Nickel, Rubidium, Selenium, Titanium, Uranium, Vanadium Beryllium, Bismuth, Cerium, Caesium, Gold, Gallium, Indium, Lanthanum, Niobium, Platinum, Radium, Ruthenium, Scandium, Silver, Thorium, Tin, Tungsten, Ytterbium, Yttrium, Zirconium	

The ions commonly available in water are positively charged (cations) and negatively charged (anions). The major cations include calcium (Ca^{2+}), sodium (Na^{+}), potassium (K^{+}) and magnesium (Mg^{2+}), whereas major anions include chloride (Cl^{-}), sulphate (SO_4^{2-}), nitrate (NO_3^{-}), fluoride (F^{-}) and the bicarbonate (HCO_3^{-}) (Freeze and Cherry, 1979).

Alkalinity is a measure of the total acid-neutralizing capacity of the water, while acidity is the base-neutralizing capacity of the water (Freeze and Cherry, 1979). Alkalinity is expressed in terms of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^{-}) whereas acidity of water is generally expressed as concentrations of hydrogen (H^{+}) ion (Davis and De Wiest (1996) as cited in Freeze and Cherry, 1979).

2.4 National Groundwater Quality Overview for Zambia

Very few chemical data are available for groundwater in Zambia on which to base an assessment of the quality of available resources. It is argued that most investigations of water quality in the country appear to have been concentrated in the Kafue River Basin (Norrgren et al., 2000; Pettersson et al., 2000) perhaps because some 50% of the national population lives in the catchment and because mining, industrial and agricultural development have been particularly important in the basin. This implies that for other river basins in Zambia such as Luangwa where Petauke Town is located, data on groundwater quality is scantly and/or not available. Even in the Kafue River Basin, the investigations have however focused on the surface water quality with little or no investigation of groundwater (Norrgren et al., 2000).

From the limited data, Zambian groundwater has generally very low concentrations of dissolved constituents (total dissolved solids concentrations) typically less than 200 mg/l (MacDonald and Partners, 1990). Given the geology of Zambia, the principal groundwater quality problems are likely to be those associated with anthropogenic activities. In Petauke Town, Eastern Province where there are no major industries, anthropogenic activities that could be of great concern with regards to groundwater quality are the use of pit latrines and septic tanks in both low and high density areas and the use of fertilizers in areas near the Nyika Plain. However, there is a void or lack of baseline information on the dissolved groundwater chemical constituents in the town, a situation that greatly affects the effective planning and management of the resource. It is this void that this study attempts to fill.

2.5 National Coverage of Water and Sanitation in Zambia

Improvement of access to basic social services such as water and sanitation are some of the basic development challenges facing most developing countries across the world, Zambia inclusive (GRZ, 2007). Safe and clean water sustains a healthy population and contributes to the quality of life of households. It is reported that 80% of all illness especially in developing countries like Zambia are related to water and sanitation (Tebbutt, 1998). Potable water supports public health and ensures economic growth. Water of poor quality can cause social and economic damages through water-related epidemics such as cholera which in turn increases medical treatment costs (Nkhuwa, 2006). Over the years, Zambia has experienced water related epidemics such as cholera and dysentery due to contaminated water and those most affected have been high density areas such as Misisi, John Laing and Kanyama compounds in Lusaka (Sichingabula and Nkhuwa, 1998; Nkhuwa, 2006). A typical challenge in the affected areas which is similar to Petauke Town is the poor sanitation status and increased use of pit latrines which poses a danger to groundwater quality. For Petauke Town the problem is even more complex as the residents, especially in the high density areas, drink untreated water from boreholes whose quality has not yet been characterised and hence not known with certainty.

GRZ (2005) reported that based on constructed and rehabilitated water and sanitation facilities, access to safe water supplies in Zambia in 2005 was estimated at 84% of the population in urban areas and 37% of the population in rural areas. With regards to sanitation, the estimated national coverage was 33% for urban areas and only 4% for rural areas (GRZ, 2007). Real coverage is much lower and varies considerably from one place to another due to non functioning facilities and poor usage. In the high density areas where about 50-70% of the urban population live, as the case is in Petauke Town's unplanned residential areas, water supply and sanitation services are poor, inadequate and unreliable; at least 50% of the population do not have access to safe water supply and as much as 90% do not have access to satisfactory sanitation facilities (GRZ, 2007). Due to erratic water supply most residents in the low density areas in Petauke Town have also resorted to using pit latrines because the water borne toilets cannot function without water, a situation that complicates the sanitation problems even more (Gauff-Ingenieure, 2001).

2.6 Millennium Development Goals on Access to Safe Water

Safe drinking water and basic sanitation are fundamental to human life and access to these basic necessities becomes essential and critical for survival, health, growth and development (National Water Supply and Sanitation Council (NWASCO), 2011; UN, 2008). Zambia's goal with regards to water and sanitation is to promote sustainable water resources development and management with a view to facilitating an equitable provision of adequate quantity and quality of water for all users at acceptable costs and ensuring security of supply under varying conditions (GRZ, 2005). This is in line with the Millennium Development Goals (MDG's) and the

World Summit on Sustainable Development (WSSD) targets of 2002 to strive to halve the population of people without access to safe water and sanitation by 2015(GRZ, 2005; United Nations (UN), 2008). It is pertinent to note here that this is a big challenge for Zambia due to the country's social economic problems where over 79 % of the people live below the poverty line while 63% and 87% of those in rural areas such as Petauke District lack access to safe water and sanitation respectively (GRZ, 2005). However, efforts are being made to increase investments through the development and implementation of both National Rural and Urban Water Supply and Sanitation Programmes to speed up the achievement of MDGs and governments vision of universal coverage (NWASCO, 2011). But the basis of these investments should be accurate data on surface and groundwater quality, not only for selected big towns but also smaller ones such as Petauke. Such information is only made available through research, hence the necessity of carrying out this present study.

2.7 Potable Water

Potable water is water that is free from disease causing micro-organisms (pathogens), low in concentrations of compounds that are acutely toxic or that have serious long term effects on health (WHO, 2008). United Nations Children's Fund (UNICEF) (1998) and Zuzan and Kalulu (2010) stressed that potable water should also be clear, not saline, and free from compounds that can affect colour, taste and odour. The conventional way of extracting drinking water from the ground is by drilling boreholes and shallow wells (Zuzan and Kalulu, 2010). However, its potability is only ascertained by characterisation of its constituents and continuous monitoring of its quality.

2.8 Groundwater Pollution

Generally, groundwater is not easily prone to pollution as the case is with surface water (JICA/MEWD, 1995; Zuzan and Kalulu, 2010). However, it can get contaminated from industrial, domestic and agricultural chemicals from the surface (Sadashivaiah et al, 2008). In some cases as the water percolates through the soil, harmful physical, biological and chemical constituents (e.g. fine suspended matter, faecal coliform and fluoride) can come into contact with water and in the process make it unsuitable for human consumption (Zuzan and Kalulu 2010). Even though the ground is an excellent mechanism for filtering out particulate matter, such as leaves, soil, and bugs, dissolved chemicals and gases can still occur in large enough concentrations in groundwater to cause problems (Momba, et al., 2006). Groundwater pollution is better understood when considered under three major categories which are chemical, microbiological and physical.

2.9 Chemical Pollution

Chemical pollution of groundwater sources include nitrate, fluoride and trace metals, especially arsenic, sulphate or chloride, which could have detrimental effects on the health of users (Ansa-Asare et al., 2009). Whereas heavy metal contamination of water is rare in Zambia's non mining towns such as Petauke, most of the chemicals such as pesticides and herbicides that are used in agriculture are also utilised in the study area and the surrounding areas. Environmental occurrence and significance of the chemical water quality parameters is describe below.

2.9.1 Nitrate and Nitrite

Several publications (WHO, 2006; Gustafson, 1993; Kross, et al, 1993) have reported that nitrate (NO_3) is found naturally in the environment and is an important plant nutrient. It is present at varying concentrations in all plants and is part of the nitrogen cycle. Nitrite (NO_2) is not usually present in significant concentrations except in a reducing environment, since nitrate is the most stable oxidation state (WHO, 2003a). It can be formed by the microbial reduction of nitrate. Nitrite can also be formed chemically in distribution pipes by *Nitrosomonas* bacteria during stagnation of nitrate containing and oxygen poor drinking water in galvanized steel pipes or if chloramination is used to provide a residual disinfectant (WHO, 2007).

Nitrate can reach both surface and groundwater as a consequence of agricultural activity (including excess application of inorganic nitrogenous fertilizers and manures), from wastewater disposal and from oxidation of nitrogenous waste products in human and animal excreta, including septic tanks (Burkart and Kolpin, 1993). Surface water nitrate concentrations can change rapidly owing to surface runoff of fertilizer, uptake by phytoplankton and denitrification by bacteria, but groundwater concentrations generally show relatively slow changes (Jalali, 2005; Jalali, 2007). In some cases groundwater may also have nitrate contamination as a consequence of leaching from natural vegetation (Burkart and Kolpin, 1993).

In general, the most important source of human exposure to nitrate and nitrite is through vegetables (nitrite and nitrate) and through meat in the diet (nitrite is used as a preservative in many cured meats) (WHO, 2008). In some circumstances, however, drinking water can make a significant contribution to nitrate and, occasionally, nitrite intake. In the case of bottle fed infants, drinking water can be the major external source of exposure to nitrate and nitrite (Lukens, 1987).

Lukens (1987) notes that high nitrite intake causes a condition called methaemoglobinaemia in humans which forms as a consequence of the reaction of nitrite with haemoglobin in the red blood cells to form methaemoglobin that binds oxygen tightly and does not release it, thereby blocking oxygen transport. Although most absorbed nitrite is oxidized to nitrate in the blood, residual nitrite can react with haemoglobin. High levels of methaemoglobin (greater than 10%) formation can give rise to cyanosis, referred to as blue-baby syndrome (Lukens, 1987). Although clinically significant methaemoglobinaemia can occur as a result of extremely high nitrate intake in adults and children, the most familiar situation is its occurrence in bottle fed infants (WHO, 2008). Considering the natural and anthropogenically induced occurrence of nitrate and nitrite in the environment and groundwater, its presence is inescapable for areas like Petauke Town where nitrogenous fertilisers are used in agriculture. It is therefore important that the nitrate and nitrite concentrations in groundwater in the study area are checked so as to prevent any occurrence of its negative consequences.

2.9.2 Fluoride

Fluorine is a common element that is widely distributed in the earth's crust and exists in the form of fluorides in a number of minerals, such as fluorspar, cryolite and fluorapatite (Bardsen et al., 1996; Handa, 1975; Pickering, 1985; Brunt et al., 2004). Traces of fluorides are present in many waters, with higher concentrations often associated with underground sources. In areas rich in fluoride containing minerals, groundwater may contain up to about 10 mg of fluoride per litre (Handa, 1975). High fluoride concentrations can be found in many parts of the world, particularly in parts of Central Africa, India, China and South America (Brunt et al., 2004; WHO, 2008). Virtually all foodstuffs contain at least traces of fluorine. All vegetation contains some fluoride, which is absorbed from soil and water. Tea in particular can contain high fluoride concentrations, and levels in dry tea are on average 100 mg/kg (Fung et al., 1999).

Fluoride is widely used in dental preparations to combat dental carriers, particularly in areas of high sugar intake. These can be in the form of tablets, mouthwashes, toothpaste, varnishes and gels for local application (Heller et al., 1997). In some countries, fluoride may also be added to table salt or drinking water in order to provide protection against dental carriers (WHO, 2003b). The amounts added to drinking water are such that final concentrations are between 0.5 and 1 mg/litre. The fluoride in final water is always present as fluoride ions, whether from natural sources or from artificial fluoridation (Beg, 2009). Total daily fluoride exposure can vary markedly from one region to another. This will depend on the concentration of fluoride in drinking water and the amount drunk, levels in foodstuffs and the use of fluoridated dental preparations (WHO, 2008). In addition, fluoride exposure in some areas is considerably higher as a consequence of a range of practices, including the consumption of brick tea and the cooking and drying of food with high fluoride coal (WHO, 2008).

Fluoride may be an essential element for humans; however, essentiality has not been demonstrated unequivocally. Meanwhile, there is evidence of fluoride being a beneficial element with regard to the prevention of dental carriers. To produce signs of acute fluoride intoxication, minimum oral doses of about 1 mg of fluoride per kilogram of body weight were required. Many epidemiological studies (Choubasia and Sompura, 1996; Rajgopal and Tobi, 1991; Ripa, 1993) of possible adverse effects of the long term ingestion of fluoride via drinking water have been carried out and clearly establish that high fluoride intakes primarily produce effects on skeletal tissues (bones and teeth). Low concentrations provide protection against dental caries, both in children and in adults (WHO, 2003b).

The protective effects of fluoride increase with concentration up to about 2 mg of fluoride per litre of drinking water; the minimum concentration of fluoride in drinking water required to produce it is approximately 0.5 mg/litre (Heller et al., 1997). However, fluoride can also have an adverse effect on tooth enamel and may give rise to mild dental fluorosis (prevalence: 12–33%) at drinking water concentrations between 0.9 and 1.2 mg/litre, depending on drinking water intake and exposure to fluoride from other sources. Mild dental fluorosis may not be detectable except by specialist examination (WHO, 2003b).

Elevated fluoride intakes can have more serious effects on skeletal tissues. Skeletal fluorosis (with adverse changes in bone structure) may be observed when drinking water contains 3–6 mg of fluoride per litre, particularly with high water consumption (Kumaran et al., 1971). Crippling skeletal fluorosis usually develops only where drinking-water contains over 10 mg of fluoride per litre. The International Programme on Chemical Safety (IPCS) (2002) concluded that there is clear evidence from India and China that skeletal fluorosis and an increased risk of bone fractures occur at a total intake of 14 mg of fluoride per day. This conclusion was supported by a review by the United States National Research Council in 2006 (US NRC, 2006). The relation between exposure and response for adverse effects in bone is frequently difficult to ascertain because of inadequacies in most of the epidemiological studies. IPCS (2002) concluded from estimates based on studies from China and India that for a total intake of 14 mg/day, there is a clear excess risk of skeletal adverse effects.

In Zambia, dental fluorosis is not very common and is generally not well documented (Shitumbanuma et al., 2006; WaterAid and British Geological Survey, 2000). However, from a study done in an area with hot springs in Choma District of the Southern Province of Zambia by Shitumbanuma et al., (2006), it was observed that there exists a high incidence of people with discoloured and mottled teeth due to drinking water with high fluoride content. Furthermore, WaterAid and British Geological Survey, (2000) reported that although there is no proper documentation on levels of fluoride in Zambian groundwater, concentrations are generally expected to be increased in some areas of the East African Rift (Zambezi and Luangwa Valleys in the south-east) especially that high fluoride concentrations (above 1.5

mg/l the WHO guideline value) have been found in groundwater from the Rift areas of neighbouring Tanzania and Malawi, areas of granitic geology. This necessitates the need for studying its occurrence in groundwater of Petauke Town, especially, that granite has been reported as one of the geological formations found in the area (Phillips, 1964).

2.9.3 Sulphate

Sulphates occur naturally in numerous minerals and are used commercially, principally in the chemical industry. They are discharged into water in industrial wastes and through atmospheric deposition; however, the highest levels usually occur in groundwater and are from natural sources (WHO, 2008). In general, the average daily intake of sulphate from drinking water, air and food is approximately 500mg, food being the major source (WHO, 2008). However, in areas with drinking water supplies containing high levels of sulphate, drinking water may constitute the principal source of intake. The existing data do not identify a level of sulphate in drinking water that is likely to cause adverse human health effects (WHO, 2008).

The data from a liquid diet piglet study and from tap water studies with human volunteers indicate a laxative effect at concentrations of 1000–1200 mg/litre of Sulphates but no increase in diarrhoea, dehydration or weight loss. No health-based guideline is proposed for sulphate. However, WHO (2008) strongly notes that because of the gastrointestinal effects resulting from ingestion of drinking water containing high sulphate levels, it is recommended that health authorities be notified of sources of drinking water that contain sulphate concentrations in excess of 500 mg/litre. The presence of sulphate in drinking water may also cause noticeable taste and may contribute to the corrosion of distribution systems (WHO, 2008).

2.9.4 Iron

Iron is the second most abundant metal in the earth's crust (Elinder et al, 1986). Elemental iron is rarely found in nature, as the iron ions Fe^{2+} and Fe^{2+} readily combine with oxygen and sulphur containing compounds to form oxides, hydroxides, carbonates, and sulphides, as such it is most commonly found in nature in the form of its oxides (Elinder et al, 1986). In well water, iron concentrations below 0.3 mg/litre are characterized as unnoticeable, whereas levels of 0.3-3 mg/litre are found acceptable (WHO, 2008).

In drinking water supplies, iron (II) salts are unstable and are precipitated as insoluble iron (III) hydroxide, which settles out as a rust-coloured silt (Department of National Health and Welfare (DNHW), 1990). The DNHW (1990) further reported that anaerobic groundwater may contain iron (II) at concentrations of up to several milligrams per litre without discoloration or turbidity in the water when directly pumped from a well, although turbidity and colour may develop in piped systems at iron levels above 0.05-0.1 mg/litre. Staining of laundry and plumbing may occur at concentrations above 0.3 mg/litre. Iron also promotes undesirable bacterial growth ("iron bacteria") within a waterworks and distribution system, resulting in the deposition of a slimy coating on the piping. Iron may also be present in drinking water as a result of the use of iron coagulants or the corrosion of steel and cast iron pipes during water distribution especially in areas with low water pH (WHO, 2008).

Kare and Anscombe (2007) reported high levels of iron in groundwater in the North Western Province of Zambia where reliable hand pumps with good yields contained high levels of iron that led to the boreholes being rejected for potable water supply. They stressed that this has led the local community returning to using unprotected sources of water because the high concentrations of iron in groundwater caused water discolouration and imparted an unpleasant taste to water as well as causing staining of food and laundry. Kare and Anscombe (2007) argue that while iron is not known to cause directly detrimental affects to human health, in many places it can cause health problems indirectly since people will return to unprotected sources due to the unpleasant taste and colour of the groundwater. It is in this regard that a careful analysis of iron content should be conducted in groundwater quality studies especially in areas with ferromagnesian rock types as the case is for Petauke Town (Phillips, 1964).

2.9.5 Manganese

Manganese is one of the most abundant metals in the earth's crust, usually occurring with iron (Leach and Harris, 1997). It is used principally in the manufacture of iron and steel alloys, as an oxidant for cleaning, bleaching and disinfection as potassium permanganate and as an ingredient in various products. Most recently, it has been used in an organic compound Methylcyclopentadienyl Manganese Tricarbonyl (MMT) as an octane enhancer in Petrol in North America (Wedler, 1994). Manganese greensands are used in some locations for potable water treatment (WHO, 2008). It is an essential element for humans and other animals and occurs naturally in many food sources (Wedler, 1994). The most important oxidative states for the environment and biology are Mn^{2+}, Mn^{4+} and Mn^{7+}. Manganese is naturally occurring in many surface water and groundwater sources, particularly in anaerobic or low oxidation conditions, and this is the most important source for drinking water (Leach and Harris, 1997). The greatest exposure to manganese is usually from food (WHO, 2008).

Manganese adverse effects can result from both deficiency and overexposure. Manganese is known to cause neurological effects following inhalation exposure, particularly in occupational settings, and there have been epidemiological studies that report adverse neurological effects following extended exposure to very high levels in drinking water (Wasserman and Liu, 2006). But there are a number of significant potential confounding factors in these studies, and a number of other studies have failed to observe adverse effects following exposure through drinking water. However, it is important to characterise it in groundwater so as to provide baseline information which is cardinal for manganese monitoring.

2.9.6 Sodium

Sodium salts (e.g., sodium chloride) are found in virtually all foods (the main source of daily exposure) and drinking water. Although concentrations of sodium in potable water are typically less than 20 mg/litre, they can greatly exceed this in some countries (WHO, 2008).

The 1958, 1963 and 1971, W.H.O. *International Standards for Drinking water* did not refer to sodium. In the first edition of the *Guidelines for Drinking Water Quality*, published in 1984, it was concluded that there was insufficient evidence to justify a guideline value for sodium in water based on health risk considerations, but it was noted that intake of sodium from drinking water may be of greater significance in persons who require a sodium-restricted diet and bottle-fed infants. A guideline value of 200 mg/litre was established for sodium based on taste considerations. No health based guideline value was proposed for sodium in the 1993 Guidelines, as no firm conclusions could be drawn concerning the possible association between sodium in drinking-water and the occurrence of hypertension. However, concentrations in excess of 200 mg/litre may give rise to unacceptable taste (WHO, 2008). Water rich in sodium chloride have a saline taste and are aesthetically not accepted for domestic use. Certain parts of Petauke District have reported cases of salty water, however no chemical analysis has yet been conducted to ascertain their composition (Petauke District Council, 2009).

2.9.7 Calcium and Magnesium

Calcium and magnesium are both essential elements to human health (Kozisek, 2004). Calcium is a substantial component of bones and teeth in addition to playing a role in neuromuscular excitability (i.e. decreases, the proper function of the conducting myocardial system, heart and muscle contractility, intracellular information transmission and the coagulability of blood) (Kozisek, 2004). Similarly, magnesium plays an important role as a cofactor and activator of more than 300 enzymatic reactions including glycolysis, transport of elements such as sodium, potassium, and calcium through membranes, synthesis of proteins and nucleic acids, neuromuscular excitability and muscle contraction (Kozisek, 2004).

Recent studies suggest that the intake of soft water, i.e. water low in calcium, may be associated with higher risk of fracture in children (Verd *et al.*, 1992), certain neurodegenerative diseases (Jacqmin *et al.,* 1994) and pre-term birth (Yang *et al.*, 2002). In addition to an increased risk of sudden death (Eisenberg, 1992; Bernardi *et al.*, 1995; Garzon and Eisenberg, 1998; Iwami *et al.*, 1994), reported that the intake of water low in magnesium seems to be associated with a higher risk of motor neuronal disease and pregnancy disorders (so-called preeclampsia) (Melles and Kiss, 1992). While the effects of most chemicals commonly found in drinking water manifest themselves after long exposure, the effects of calcium and magnesium, in particular, those of magnesium on the cardiovascular system are believed to reflect recent exposures. Illustrative of such short term exposures are cases in the Czech and Slovak populations who began using reverse osmosis-based systems for final treatment of drinking water at their home taps in 2000-2002 (Kozisek, 2004). Within several weeks or months various health complaints suggestive of acute magnesium (and possibly calcium) deficiency were reported and among those complaints were cardiovascular disorders, tiredness, weakness or muscular cramps (Kozisek, 2004).

The WHO in the 2nd edition of *Guidelines for Drinking water Quality* (WHO, 1996) evaluated calcium and magnesium in terms of water hardness but did not recommend either minimum levels or maximum limits for calcium, magnesium, or hardness (WHO, 2008). On the other hand, it does not prevent member states from implementing such a requirement into their national legislation. The Zambian government has set the action level for calcium at 200mg/l but has not given a guideline value for magnesium (ZABS, 2008). From the preceding paragraphs, it is clear that the effects of deficiency and overexposure to calcium and magnesium have several consequences. Therefore, the need to carefully measure it in groundwater as in this study cannot be overemphasised.

2.9.8 Hardness

Hardness in water is caused by dissolved calcium and, to a lesser extent, magnesium (WHO, 2008). It is usually expressed as the equivalent quantity of calcium carbonate and is indicated by precipitation of soap scum and the need for excess use of soap to achieve cleaning. Public acceptability of the degree of hardness of water may vary considerably from one community to another, depending on local conditions. In particular, consumers are likely to notice changes in hardness. The taste threshold for the calcium ion is in the range of 100–300 mg/litre, depending on the associated anion, and the taste threshold for magnesium is probably lower than that for calcium. In some instances, consumers tolerate water hardness in excess of 500 mg/litre (WHO, 2008).

Depending on the interaction of other factors, such as pH and alkalinity, water with hardness above approximately 200 mg/litre may cause scale deposition in the treatment works, distribution system and pipe-work and tanks within buildings. It will also result in excessive soap consumption and subsequent “scum” formation. On heating, hard waters form deposits of calcium carbonate scale. Soft water, with a hardness of less than 100 mg/litre, may, on the other hand, have a low buffering capacity and so be more corrosive for water pipes (WHO, 2008). A number of ecological and analytical epidemiological studies (Schroeder et al., 1966; Schroeder, 1960) have shown a statistically significant inverse relationship between hardness of drinking-water and cardiovascular disease and that there is some indication that very soft waters may have an adverse effect on mineral balance. However conclusions from detailed studies are not yet available for evaluation (WHO, 2008). It is worth noting here that whereas the effects of water hardness such as formation of scales in pipes have been observed in Petauke Town (Gauff-Ingenieure, 2001), the concentrations of ions, such as calcium, magnesium and bicarbonate have not been assessed and thus they are not kwon with certainty. This necessitates their characterisation in groundwater of the study area.

2.10 Microbiological Pollution

Microbiological pollution of groundwater is increasing due to faecal contamination and poor waste management. Groundwater quality is more at risk in large settlements such as high density areas because of the lack of proper sanitation facilities. In some cases facilities are available but of poor quality (Nyambe and Maseka, 2000 as quoted by Nyambe and Feilberg, 2009). In Petauke just like other towns in the country, the sewerage treatment plant has not been functioning for some years and therefore people depend on pit latrines and or septic tanks. Major causes of microbiological water pollution are bacteria, viruses and protozoa (Ashbolt et al., 2001).

The major health risk associated with groundwater is from the microbial pathogens derived from human and animal faeces (Lehloesa and Muyima, 2000). Pathogenic organisms found in groundwater with high counts of faecal coliforms include especially *Escherichia coli*, and/or other pathogenic microorganisms such as *Vibrio cholerae, Aeromonas hydrophila, Shigella dysenteria, Salmonella tyhimurium, Pseudomonas spp, Klebsiella spp* (Momba et al., 2006) and these organisms contribute to waterborne diseases occurring in a number developing countries world over. These organisms could also occur in Petauke Town, Eastern Zambia. Below is a description of the environmental occurrence and significance of biological parameters that affect groundwater quality.

2.10.1 Total Coliform Bacteria

The WHO (2008) notes that Total coliform bacteria include a wide range of aerobic and facultative anaerobic, Gram-negative, non-spore-forming bacilli capable of growing in the presence of relatively high concentrations of bile salts with the fermentation of lactose and production of acid or aldehyde within 24 hours at 35–37 °C. *Escherichia coli* and thermo tolerant coliforms are a subset of the total coliform group. Traditionally, coliform bacteria were regarded as belonging to the genera *Escherichia*, *Citrobacter*, *Klebsiella* and *Enterobacter*, but the group is more heterogeneous and includes a wider range of genera, such as *Serratia* and *Hafnia*. The total coliform group includes both faecal and environmental species (Lippy and Waltrip, 1984).

Total coliform bacteria (excluding *E. coli*) occur in both sewage and natural waters. Some of these bacteria are excreted in the faeces of humans and animals, but many coliforms are heterotrophic and able to multiply in water and soil environments. Total coliforms can also survive and grow in water distribution systems, particularly in the presence of biofilms (Ashbolt et al., 2001).

According to the WHO (2008) and ZABS (2008) guidelines, Total coliforms should be absent in drinking water. The presence of Total coliforms in drinking water may indicate inadequate treatment whereas their presence in distribution systems and stored water supplies can reveal re-growth and possible biofilm formation or contamination through ingress of foreign material, including soil or plants (Chorus and Bartram, 1999).

2.10.2 Faecal Coliform Bacteria

Faecal coliform are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Disease causing microbes (pathogens) in these wastes can cause diarrhoea, cramps, nausea, headaches or other symptoms (Ansa-Asare et al., 2009; Ashbolt et al., 2001). These pathogens may pose a special health risk for infants, young children and people with severely compromised immune systems (WHO, 2008).

2.11 Physical Pollution

Physical pollution of groundwater is determined by the changes in Total Dissolved Solids (TDS), Total Suspended Solids (TSS), taste, odour, temperature, and colour.

2.11.1 Total Dissolved Solids

TDS comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphates) and small amounts of organic matter that are dissolved in water (WHO, 2008). TDS in drinking water originate from natural sources, sewage, urban runoff and industrial wastewater (WHO, 2008). Salts used for road de-icing in some countries may also contribute to the TDS content of drinking water. Concentrations of TDS in water vary considerably in different geological regions owing to differences in the solubility of minerals (Sadashivaial et al., 2008).

The 1958 W.H.O. *International Standards for Drinking water* suggested that concentrations of total solids greater than 1500 mg/litre would markedly impair the potability of the water. The 1963 and 1971 International Standards retained this value as a maximum allowable or permissible concentration. In the first edition of the *Guidelines for Drinking water Quality*, published in 1984, a guideline value of 1000 mg/litre was established for TDS, based on taste considerations. No health based guideline value for TDS was proposed in the 1993 Guidelines, as reliable data on possible health effects associated with the ingestion of TDS in drinking water were not available. However, the presence of high levels of TDS in drinking water (greater than 1200 mg/litre) may be objectionable to consumers. Water with extremely low concentrations of TDS may also be unacceptable because of its flat, insipid taste and owing to excessive scaling in water pipes, heaters, boilers and household appliances (Sadashivaiah et al., 2008).

2.11.2 Turbidity

Turbidity in drinking water is caused by particulate matter that may be present from source water as a consequence of inadequate filtration or from re-suspension of sediment in the distribution system (WHO, 2008). It may also be due to the presence of inorganic particulate matter in some groundwaters or sloughing of biofilm within the distribution system (WHO, 2008). The appearance of water with a turbidity of less than 5 Nupherometric Turbidity Units (NTU) is usually acceptable to consumers, although this may vary with local circumstances. Particulates can protect microorganisms from the effects of disinfection and can stimulate bacterial growth. In all cases where water is disinfected, the turbidity must be low so that disinfection can be effective (U.S NRC, 2006).

Turbidity is also an important operational parameter in process control and can indicate problems with treatment processes, particularly coagulation/sedimentation and filtration (WHO, 2008). No health-based guideline value for turbidity has been proposed; ideally, however, median turbidity should be below 0.1 NTU for effective disinfection, and changes in turbidity are an important process control parameter (U.S NRC, 2006).

2.11.3 Temperature

Cool water is generally more palatable than warm water, and temperature will impact on the acceptability of a number of other inorganic constituents and chemical contaminants that may affect taste (EAWAG, 2007; Islam and Johnston, 2006). High water temperature enhances the growth of microorganisms and may increase taste, odour, colour and corrosion problems.

2.11.4 pH

The pH level of drinking water reflects how acidic or alkaline it is. The initials pH stands for "potential of hydrogen," referring to the amount of hydrogen found in a substance (in this case, water) (Nordberg et al., 1985). It is measured on a scale that ranges from 0 to 14. Seven is neutral, meaning there is a balance between acid and alkalinity. A measurement below 7 means acid is present and a measurement above 7 is basic (or alkaline) (U.S. Environmental Protection Agency (EPA), 2007).

With regards toxicological review of pH, the U.S. EPA (2007) notes that although the pH level in drinking water is regulated in most countries, it is important to classify it as a secondary drinking water contaminant whose impact is considered aesthetic. It is thus strongly recommended that public water systems maintain pH levels of between 6.5 and 8.5, a good guide for drinking water providers (WHO, 2008; ZABS, 2008).

Water with a low pH can be acidic, naturally soft and corrosive. Acidic water can leach metals from pipes and fixtures, such as copper, lead and zinc. It can also damage metal pipes and cause aesthetic problems, such as a metallic or sour taste, laundry staining or blue green stains in sinks and drains (U.S. EPA, 2007). Water with a low pH may contain other metals in addition to copper, lead and zinc. Drinking water with a pH level above 8.5 indicates that high levels of alkalinity minerals are present (Rose, 1986). High alkalinity does not pose a health risk, but can cause aesthetic problems, such as an alkali taste to the water that makes coffee taste bitter; scale build-up in plumbing; and lowered efficiency of electric water heaters (U.S. EPA, 2007). Petauke Town has reported cases of pipe corrosion which could be linked to low pH levels in most boreholes (Gauff-Ingenieure, 2000).

2.12 Effects of Groundwater Contamination on Human Health

The transmission of diseases by polluted water has a long history and remains a worldwide problem to this day. Diarrhoea is a symptom of these waterborne diseases, although not all cases of diarrhoea are related to water (Gundry et al., 2004; Jensen et al., 2004). It is reported that diarrhoeal diseases due to contaminated drinking water result in 2.5 million childhood deaths yearly (Kosek et al., 2003). Sporadic outbreaks of waterborne diseases such as cholera, typhoid fever and dysentery have been recorded in Lusaka due to polluted groundwater, with serious public health implications and risks for users (Nkhuwa, 2006). It is thus possible that such outbreaks can also results from water contamination in other towns in Zambia such as Petauke.

2.13 Guidelines for Drinking Water Quality

Since water quality in any source of water and at the point of use, can change with time and other factors, continuous monitoring of water quality is essential (Zuzan and Kaluu, 2010). It is one of the most important tools for sustainable development and management of water resources (Zuzan and Kalulu, 2010; Sadashivaiah et al., 2008). Characterising and 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 sources of water for rural and some urban and peri-urban communities are boreholes, protected and unprotected shallow wells. In the Eastern Province and Petauke in particular surface water is not easily accessed by most communities (Gauff-Ingenieure, 2000), as such boreholes provide the much needed resource. To ensure that the water users are protected from consuming polluted water, many countries and WHO came up with water quality guidelines that specify the maximum permissible amount water constituents. National drinking water standards/guidelines often stipulate the maximum permissible concentration of contaminants in the drinking water that should be adhered to (Zuzan and Kalulu, 2010). In cases where such national standards are not available, the guidelines for drinking water quality published by the WHO should be followed and used as a basis to control consumable water quality. Each 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 that the consumer enjoys safe potable water and not to shut down deficient water supplies. Water quality assessment therefore provides the baseline information on water safety (Zuzan and Kalulu, 2010; WHO, 2008).

It is cardinal to note here that there is a very close similarity between the WHO and ZABS guidelines in that most of the guidelines for parameters are the same. The guideline values are established taking into account of available techniques for controlling, removing or reducing the concentration of the contaminant to the desired level (WHO, 2008). It is also important to mention that not all of the chemicals with WHO guideline values will be present in all water supplies or, indeed, all countries. If they do exist, they may not be found at levels of concern. Conversely, some chemicals without guideline values or not addressed in the WHO guidelines may nevertheless be of legitimate local concern under special circumstances (WHO, 2008). Only a few chemicals have been shown to cause widespread health effects in humans as a consequence of exposure through drinking water when they are present in excessive quantities. These include fluoride, arsenic and nitrate. The WHO (2008) and ZABS (2008) guidelines for drinking water are shown in Table 2.

Table 2: Guidelines for Drinking Water Quality by WHO (2008) and Zambian Bureau of Standards (2008)

Parameter	Action Level	
	WHO	ZABS
Arsenic	0.01mg/l	0.01mg/l
Cadmium	0.003mg/l	0.003mg/l
Chromium	0.05mg/l	0.05mg/l
Cyanide	0.07mg/l	0.01mg/l
Fluoride	1.5mg/l	1.5mg/l
Lead	0.05mg/l	0.01mg/l
Mercury	0.006mg/l	0.001mg/l
Nitrate	10mg/l	10mg/l
Nitrite, Nitrogen	0.1mg/l	0.1mg/l
Selenium	0.01mg/l	0.01mg/l
Chloride	250mg/l	250mg/l
Sulphate	400mg/l	-
Hardness as $CaCO_3$	500mg/l	500mg/l
Total Dissolved Solids	1000mg/l	1000mg/l
Aluminium	0.2mg/l	0.2mg/l
Copper	2.0mg/l	1.0mg/l
Calcium	-	200mg/l
Iron	0.3mg/l	0.3mg/l
Manganese	0.4mg/l	0.1mg/l
Sodium	200mg/l	200mg/l
Zinc	5.0mg/l	3mg/l
Chlorophenols	0.01mg/l	-
Chloroform	30µg/l	-
DDT	1.0µg/l	1.0µg/l
Heptochlon	30µg/l	-
Lindane	3.0µg/l	3.0µg/l
Turbidity	5NTU (Nephelometric Turbidity Units)	5NTU
Taste	Not objectionable to 90% Consumers	Unobjectionable to most consumers
pH	6.5 - 8.5	6.5-8.0
Coliforms	absent in 100ml	absent in 100ml

Human health effects have also been demonstrated in some areas associated with lead (from domestic plumbing), and there is concern because of the potential extent of exposure to selenium and uranium in some areas at concentrations of human health significance. Iron and manganese are of widespread significance because of their effects on acceptability (WHO, 2008). Since water quality in any source of water and at the point of use, can change with time and other factors, continuous monitoring of water is very essential in order to protect the users (Zuzan and Kalulu, 2010). It is for this reason that the selected chemicals have been described in somewhat detail above.

2.14 Analysis of Hydro-geochemical Data

Basic statistics on mean, median and mode give an idea of the centre of distribution; whereas, variance and standard deviation are generally used to describe the variability within the data. Most of the statistical analyses are based on the assumption that data follow a normal (symmetric) distribution. However as observed by Beg (2009), geochemical data usually exhibit asymmetric distribution. It is in this regard that certain transformations are applied so that data follow a more or less symmetric distribution.

Freeze and Cherry (1979) note that an important task in groundwater investigations is the compilation and presentation of chemical data in a convenient manner for visual inspection. Groundwater quality data have major cations and anions which represent the quality of groundwater. Results of chemical quality of groundwater may be very difficult to interpret, particularly when more than a few analyses are involved (Freeze and Cherry, 1979). To overcome this, graphic representations are useful for display purposes, for comparing analysis and also for emphasizing similarities and differences (Todd, 1980). A graph can also aid in detecting the mixing of water of different compositions and in identifying chemical processes occurring as groundwater moves (Todd, 1980). It is cardinal to stress here that water quality data may be interpreted on the basis of both individual analysis and set of analysis from one sampling location or different locations in an area (Beg, 2009).

There are several commonly used graphical methods available for presenting water quality data. The simplest of these are the bar graph and circular chart/graphs (Freeze and Cherry, 1979). Examples are shown in Figure 2 and 3. For a single sample, these two graphs represent the major ion composition in equivalents per litre and in percentages of total equivalents.

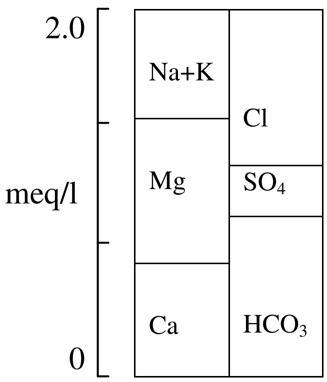


Figure 2: Chemical analyses of groundwater represented by a bar graph in milliequivalent per litre (after Devis and De Wiest (1966) as cited in Freeze and Cherry, 1979).

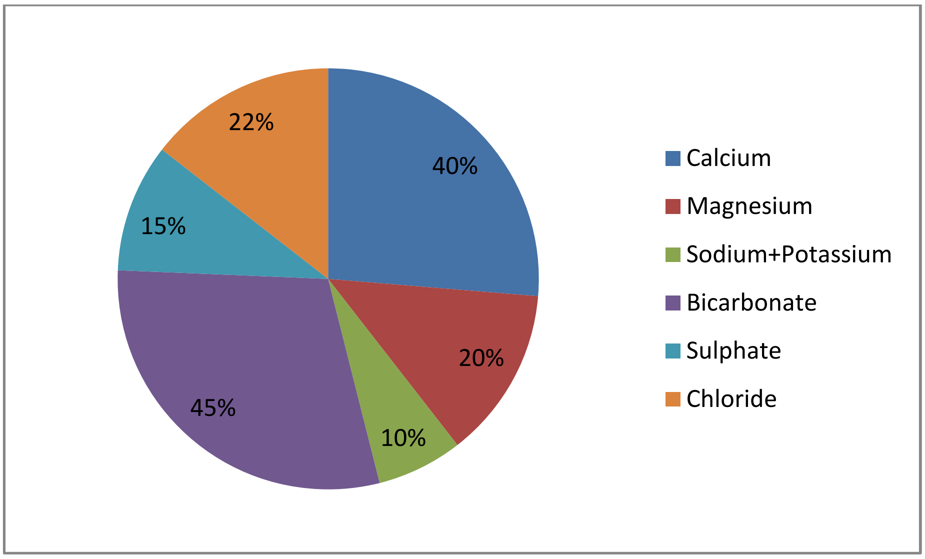


Figure 3: Chemical analysis of groundwater represented by a circular diagram. The division is proportional to the milliequivalents (after Davis and De Wiest (1966) as cited in Freeze and Cherry, 1979).

Another method is one that is in a manner that facilitates rapid comparison as a result of distinctive graphical shapes. This is known as a stiff diagram, named after the hydrogeologist who first used it. Stiff diagrams plot major ion chemistry in terms of meq/l on two axes. One exists for cations and other for anions. The axes increase outwards from a common zero point (Figure 4).

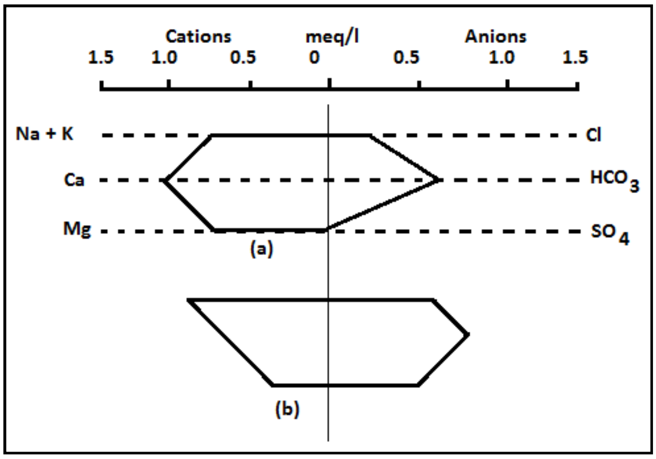


Figure 4: Two chemical analyses represented in the manner originated by Stiff, showing two different samples (a) and (b) with different chemical compositions (after Devis and De Wiest (1966) as cited in Freeze and Cherry, 1979).

One of the most useful graphs for representing water quality analysis is the Piper diagram by Piper (Piper, 1994) (Figure 5).

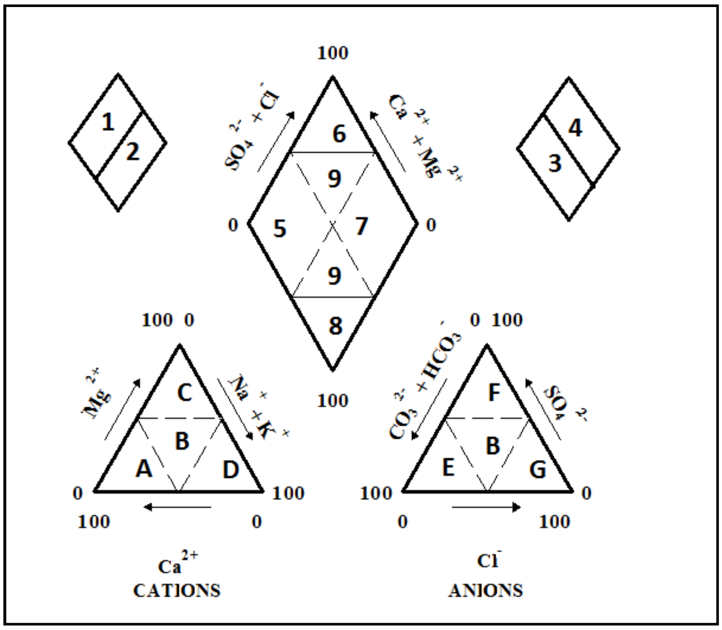


Figure 5: Graphical representation of water quality using Piper diagram (after Back and Hanshaw (1965) as cited by Sadashivaih et al., 2008). The letters in the above diagram signify; A- calcium type, B – no dominant type, C – magnesium type, D – sodium and potassium type, E – bicarbonate type, G – chloride type.

In a Piper plot, major ions are plotted as cations and anion percentage of milli-equivalent in two base triangles. The total cations in meq/l, and the total anions in meq/l, are set equal to 100%. The data points in the two triangles are then projected onto the central diamond shaped grid parallel to the upper edge of the central area. The projection indicates certain useful properties such as similarities and differences among groundwater samples. Those with similar quality will tend to plot together as groups and simple mixture of two water sources can also be identified (Todd, 1980). The bar, circular and Stiff diagrams are all easy to construct and provide quick visual comparison of individual chemical analyses. They are not, however, convenient for graphic presentation of large number of analysis (Freeze and Cherry, 1979). It is for this reason that the Piper diagram was chosen for this study as it allows analysis for a large number of samples. The subdivisions in the Piper diagram denoted by the numbers 1 to 9 are explained in Table 3.

Table 3: Explanation of the subdivisions in a Piper diagram

Subdivision of Diamond	Characteristics of Corresponding Diamond Shape
1	Alkaline earth (Ca + Mg) exceed alkalies (Na + K)
2	Alkalies exceeds alkaline earth
3	Weak acids (CO_3 + HCO_3) exceeds strong acids (SO_4 + Cl)
4	Strong acids exceeds weak acids
5	Magnesium/Calcium bicarbonate type
6	Calcium Chloride type
7	Sodium - Chloride type
8	Sodium - bicarbonate type
9	Mixed type (no cation/anion exceeds 50%)

In terms of groundwater quality the characterisations in the above table mean the following:

i. Alkaline earth (Ca + Mg) exceed alkalies (Na + K): Such waters have higher calcium and magnesium content than sodium and potassium. The metal cations react with soaps, causing unsightly precipitation. More seriously, calcium and magnesium react with carbonates to form calcium carbonate and magnesium carbonate (subdivision of diamond 5) which tend to precipitate out as adherent solids on the surface of pipes and especially on the hot surfaces (Sadashivaiah et al, 2008). The resulting build up can impede water flow. The water types have a soapy texture (WHO, 2008).

ii. Alkalies exceed alkaline earth: Such waters are generally soft as they contain less calcium and magnesium ions. Additionally, they have low alkaline levels which make them to be more corrosive to water pipes (WHO, 2008).

iii. Weak acids (CO_3 + HCO_3) exceed strong acids (SO_4 + Cl): Typical of these waters is the occurrence of carbonic acid which gives them pH less than 7.

iv. Strong acids exceed weak acids: Water types under this category are generally corrosive and unsuitable for domestic uses because of the bitter taste which is aesthetically rejected by users (WHO, 2008).

v. Magnesium bicarbonate type: Such water turn to be hard as the magnesium reacts with the bicarbonate to form magnesium bicarbonate ($MgHCO_3$) water as already alluded to under point (i) above.

vi. Calcium Chloride type: These water are generally saline and hard (Sadashivaiah et al., 2008)

vii. Sodium chloride type: These form from the dissolution of very small quantities of plagioclase and biotite with precipitation of illite and kaolinite and have very high conductivity (Pereira and Almeida, 2000). Sodium chloride water types are saline and generally not good for drinking (Sadashivaiah et al, 2008; WHO, 2008).

viii. Sodium bicarbonate type: Pereira and Almeida (2000) notes that such waters have very high conductivity and are associated with the oxidation of sulphide minerals in schist were some carbonate minerals are present.

ix. Mixed type (no cation/anion exceeds 50%): such waters have no single cation and anion that shows dominance. As such they do not have any specific feature that is salient to them.

CHAPTER 3

DESCRIPTION OF THE STUDY AREA

3.1 General Remarks

This chapter describes the physical and socio-economic characteristics of the study area. It describes the location of the Petauke District in Eastern Province of Zambia and the location of the study area in Petauke District. It also highlights the major characteristics of the study area in terms of the physical characteristics such as climate, soils, drainage and vegetation, and the socio-economic characteristics.

3.2 Location of Petauke Town

Petauke Town is located in Petauke, one of the nine districts in the Eastern Province of Zambia (Figure 6).

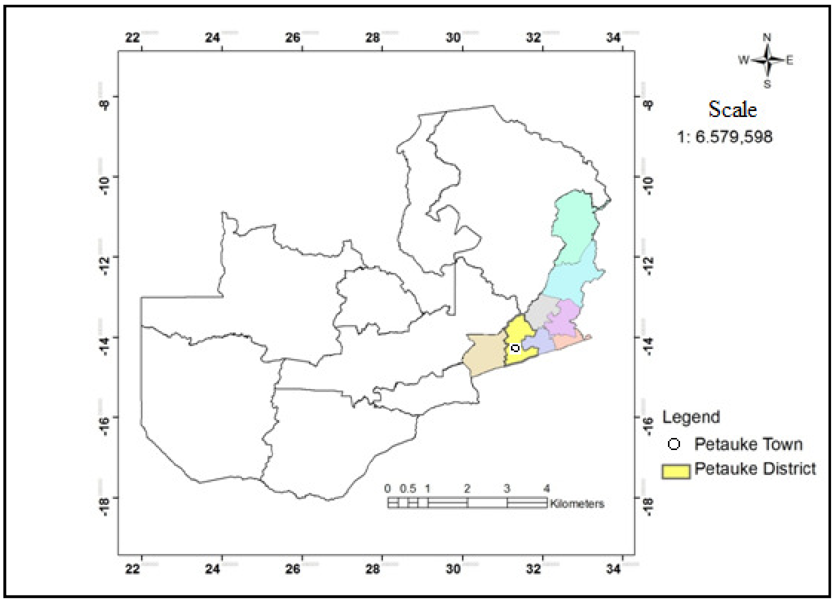


Figure 6: Location of Petauke District in Eastern Province of Zambia.

It is situated 420 km east of the capital city Lusaka, and 180 km west of Chipata, the provincial headquarter. The district is located in the southern part of Eastern Province, and lies between Latitudes 13^{o} and 14^{o} south, and Longitudes 31^{o} and 32^{o} east. The district shares an international boundary with Mozambique in the south and district boundaries with Sinda and Mambwe in the north east, Nyimba in the west, and Serenje in the north west (PDC2005). Figure 7 shows the map of Petauke Town.

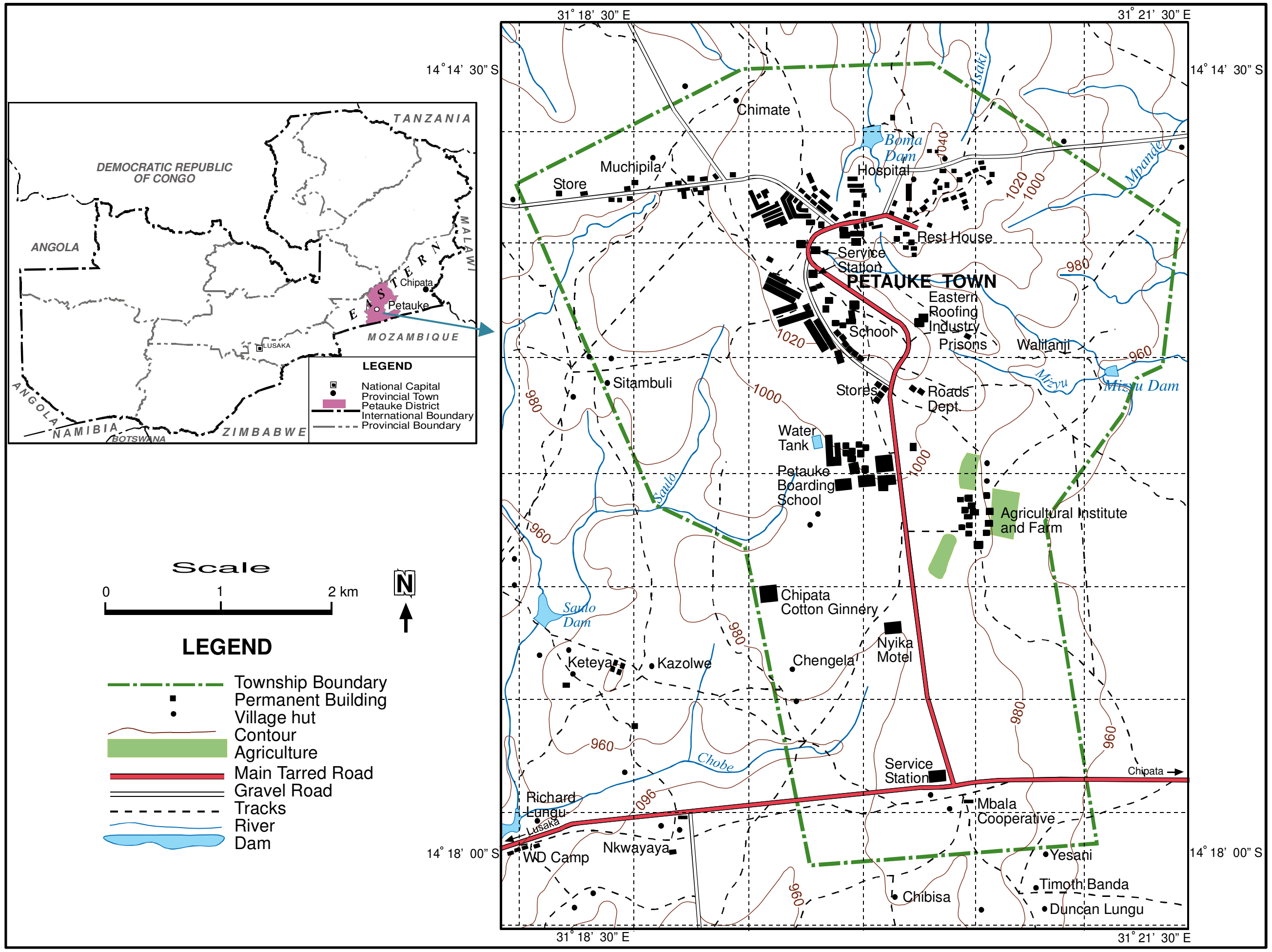


Figure 7: Location of Petauke Town in Petauke District, Eastern Province, Zambia (after Land Survey Department, 1970).

The study area, Petauke Town with a total area of 20.6 Km^2 lies between Latitudes 14.14° and 14.20° south and Longitudes 31.18° and 31.21° east.

3.3 Social Economic Characteristics

PDC (2005) reported that Petauke is one of the districts in Eastern Province that have been experiencing rapid population growth as well as other related social economic activities. Given hereunder are the social economic characteristics for Petauke Town.

3.3.1 Population

The Central Statistics Office (CSO), (2010) notes that Petauke District has a total population of 337,779 people comprising 165,463 males and 172,316 females while Nyika Ward where Petauke Town is located has a population of 36,143 people. The population in the district grew at an average annual growth rate of 3.7 percent in the period 2000 - 2010. Most of the people (58%) in Nyika Ward live in the town area. The high concentration of people in the town has resulted in a number of unplanned compounds such as Tasala 1 to 11 and Showgrounds. About 90% of these compound lack piped water supply as the current water reticulation system and pumping capacity of Eastern Water Supply and Sewerage Company (EWSC) water works is only able to supply the low density areas and just a small part of the high density areas. The only sources of water therefore are boreholes that are managed by the Village Water Supply and Hygiene Education (V-WASHE) (Gauff-Ingenieure, 2001). Sanitation levels in most of the low density areas in Petauke Town are poor as people depend on pit latrines, which are at times near water points (PDC, 2009). This poses a challenge to groundwater contamination and calls for effective water resources management plans in order to safeguard the water sources.

3.3.2 Social Services and Economic Activities

Petauke is generally an agricultural district where farmers practice both arable and pastoral farming. Agricultural production is oriented towards local needs and a lot of amounts of farmers' products are sold on the markets. Some farmers and other residents within Petauke Town are involved in mixed farming, vegetable gardening and trading. Agricultural activities with high uses of fertilizers and pesticides like weed killers are also being done at the Farmers Training centre (FTC). The major crops grown are maize, groundnuts and sun flower. Cotton is being grown as a cash crop and its market is readily available through Cargill and Dunavant Cotton Limited.

The district also has Dunavant Cotton and Chipata Cotton Ginneries and Eastern Roofing Industries that have provided employment to some people in the township. The introduction of these industries in the town poses a challenge as regards groundwater resource management. It increases the demand of water for use which in return increases waste water production, which at times, if poorly managed, can affect groundwater quality. The District Development and Coordinating Committee (DDCC) (2008) reported that the hospitality industry has also grown in the past years. This is evidenced by a number of Lodges and Guest Houses that have been developed in the township. The informal sector is also on the increase in Petauke Town. The town has three service stations namely; Puma, IMY and Oryx.

3.4 Physical Characteristics

The Physical characteristics of Petauke Town were considered under three categories namely climate, vegetation and relief and drainage.

3.4.1 Climate

The district experiences subtropical climate, with hot wet summers from November to April and a cool dry season from May to November. The mean annual temperature ranges from 22 - 35^{o}C (Archer, 1971). Potential evaporation exceeds rainfall by about 100mm for the year (JICA/MEWD, 1995). In December, January and February rainfall exceeds potential evaporation and the surplus being 202mm. The rain season extends from October/November to March/April. Rainfall in the district ranges from 900mm to 1000mm. The mean temperature for the year is 21°C ranging from 10.6°C in July to 31.5°C in October. The average sunshine hours per year are 8.1 hours (JICA/MEWD, 1995).

3.4.2 Vegetation

The vegetation type in different parts of the district is largely related to the amount of available water and the soil type. Characteristically, the vegetation includes mixed forests, thickets, woodlands, and grass especially in dambos. Miombo woodlands with its characteristic vegetation form the dominant vegetation in Petauke and so does grassy dambos. The Miombo vegetation in the district consists of the following tree species: *Julbernadia globiflora, Brachystergia boemehmii,* and *Sterculia Africana* trees; and *Hyperrhaenia newtonii, Hyperrhaenia rufa, Hyperrhaenia filipendula, Dactyloctenium sp*. among other grasses (Trapnell, 1953). The people especially on the plateau have, however, created extensive deforestation by clearing vegetation for charcoal, settlements and agricultural activities (PDC, 2005). It is cardinal to note here that most of the indigenous vegetation in the town has been cleared to pave way for human settlements and other related developments.

3.4.3 Relief and Drainage

Petauke district is divided into two distinct areas namely the valley and the plateau. The southern and central parts of the district, where Petauke Town is located, are mostly plateau with an altitude ranging from 750 to 1200m above sea level and cover three quarters of the district. A quarter of the northern part of the district is the valley. The Luangwa River which lies on the western boundary is the largest water body in the district and flows from the north to southwest into the Zambezi River. It has five tributaries, namely; Mvuvye, Lusangazi, Msanzala, Nyimba and Msumbazi (PDC, 2005). However, none of the major rivers flows through Petauke Town. The district also has a number of dams and non perennial streams.

Within the town, the altitude rises from approximately 944 m in the Nyika Plain to about 1042 m above sea level on the Mupya Hill near the town centre. The Nyika Plain is the largest wet area that is found in Petauke Town. Following the topography of the area, it is deduced here that surface and groundwater in Petauke Town flows out of the town into the peripheral. The relief of Petauke Town is visualised in Figure 8 using a Digital Elevation Model (DEM).

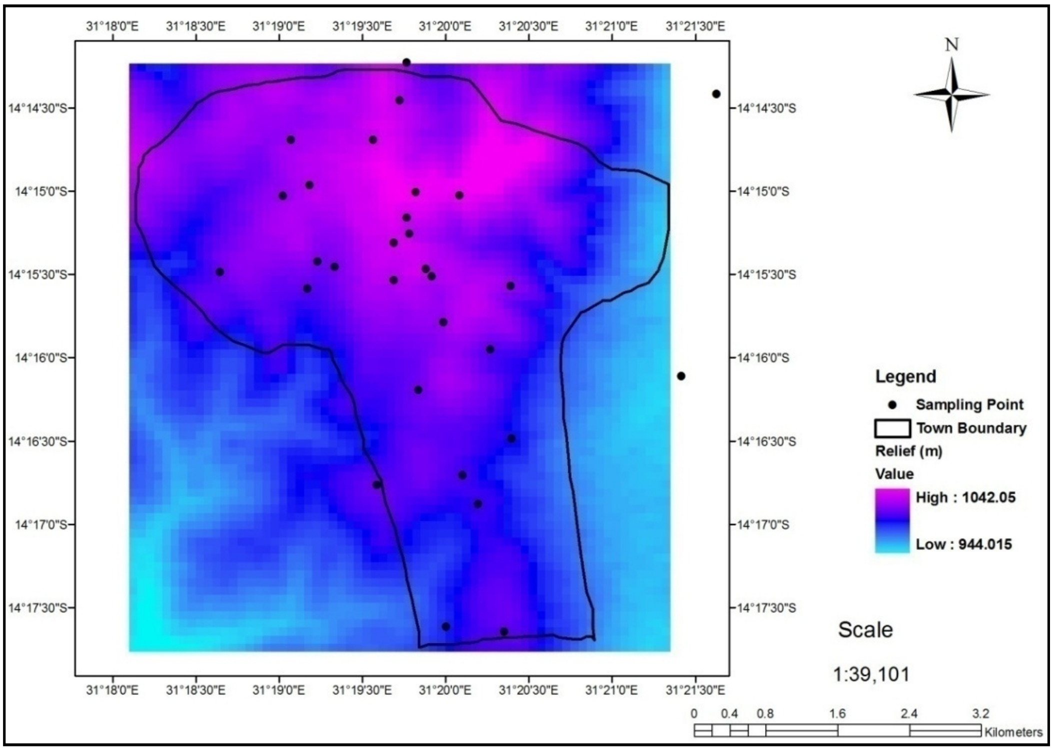


Figure 8: Relief Map of Petauke Town, Eastern Province, Zambia.

3.4.4 Soils and Geology

Trapnell (1953) observed that the soils in Petauke are generally brownish to yellowish red. In highlands they range from coarse sandy clay loams to sands. Further down the slope there is however a gradual transition from sandy clay loams soils to much more pallid and sandier, whereas around the dambos soils are usually dark in colour and sticky. The brownish yellow to reddish yellow soils are classified as *haplic acrisols* whereas the dark sticky soils which occur around most drainage and flooded areas are called *vertisols* (Trapnell, 1953). These soils are poorly drained and have a high available water capacity which ranges between 80mm and 200mm (Trapnell, 1953).

According to Reeve (1963), the geology of the district is affected by two distinct and different periods namely, the Precambrian and Karoo. Rocks of the Precambrian have undergone intense faulting, metamorphism as well as later igneous intrusions (Reeve, 1963). The Precambrian is characterized by gneisses, schists and granites.

The Karoo on the other hand, which is geologically much younger, is characterized by sedimentary rocks such as sandstone, grit and mudstone (Reeve, 1963). A lava flow is also present and the Karoo rocks in the valley are for the most part bordered by the Precambrian rocks such as pyroxene, garnet-silimanite, biotite, quartzo-feldspathic and calc silicate gneisses, granulites, quartzites, quartz schists, muscovite schists which are situated around depressions (Dodds and Patton, 1968).

Furthermore, Phillips (1964) gave a detailed description of the geology in Petauke Town and noted that the area under which the town is located is characterised by alluvium, semipelitic gneiss which falls under the Minga Magnetite Formation and quartzo-feldspathic paragneiss which falls under the Boma Gneiss Formation.

The Minga Magnetite and Boma Gneiss belong to the Mvuvye and Sinda Groups respectively. The Boma Gneiss Formation is marginal to the batholiths and grades into small bodies of pink pegmatitic granite. The major constituents are quartz and feldspar usually parthitic microcline ($KAlSi_3O_8$) and oligoclase ($(NaCa)\ AlSi_3O_8$); biotite is ubiquitous, accompanied in places by minor hornblende. Typical Sinda Granite underlying some parts of the town is adamellitic and the accessory minerals include magnetite, hematite, sericite, amphibole, allanite, zircon and chlorite. Assimilation of lime has occurred where the Sinda Granite has intruded calc-silicate material associated with Minga Magnetite Formation. Varieties of contaminated granite contain significant amounts of carbonate and marble ($CaCO_3$) (Phillips, 1964).

Furthermore, Drysdall (1960) in his detailed investigation of localities for graphite deposits in Petauke notes that the term paragneiss as contained in the Mvuvye Paragneiss genera includes all the paragneisses and calc-silicate rocks. Figure 9 shows a geology map for Petauke Town and sites for petroleum service stations as well as a site for the old dump site.

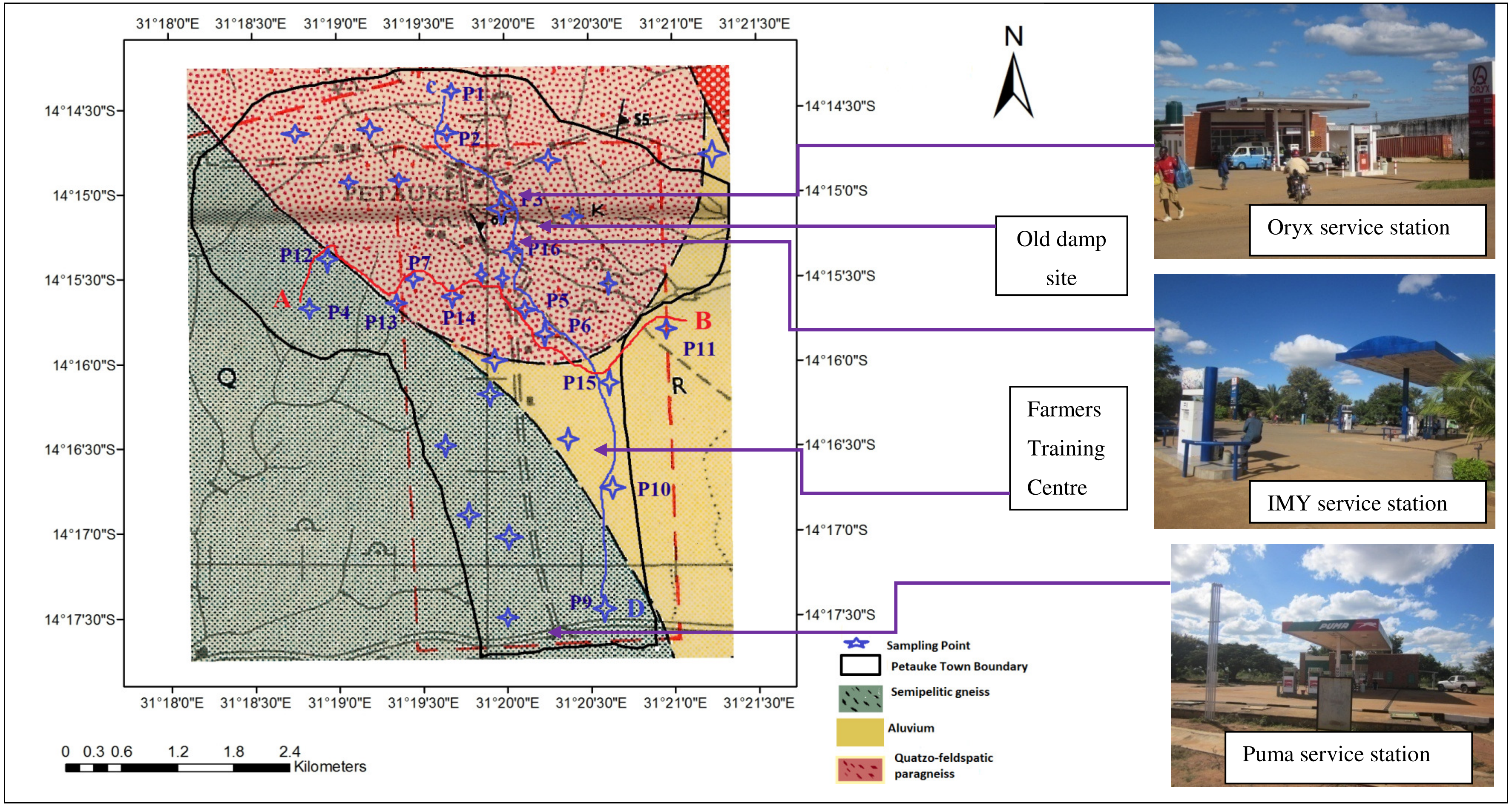


Figure 9: Geology Map of Petauke Town, Eastern Province, Zambia and Sites of Petroleum Service Stations, Old Dump Site and Farmers Training Centre (Geology modified from Phillips, 1964).

3.4.5 Hydrogeology

Petauke Town lies on an un-confined aquifer, and just like other parts of the district is located in an area with an aquifer that is low yielding with limited potential. This category includes part of the argillaceous formations, Karoo basalts and older Basement Complex (JICA/MEWD, 1995).

CHAPTER 4

METHODOLOGY

4.1 General Remarks

This chapter presents the methods used in data collection, highlights the primary and secondary sources and types of data and outlines the data analysis that was conducted. It also outlines the limitations of the study. The research basically comprised collection and analysis of groundwater samples. The schematic representation of the research methodology is shown in Figure 10.

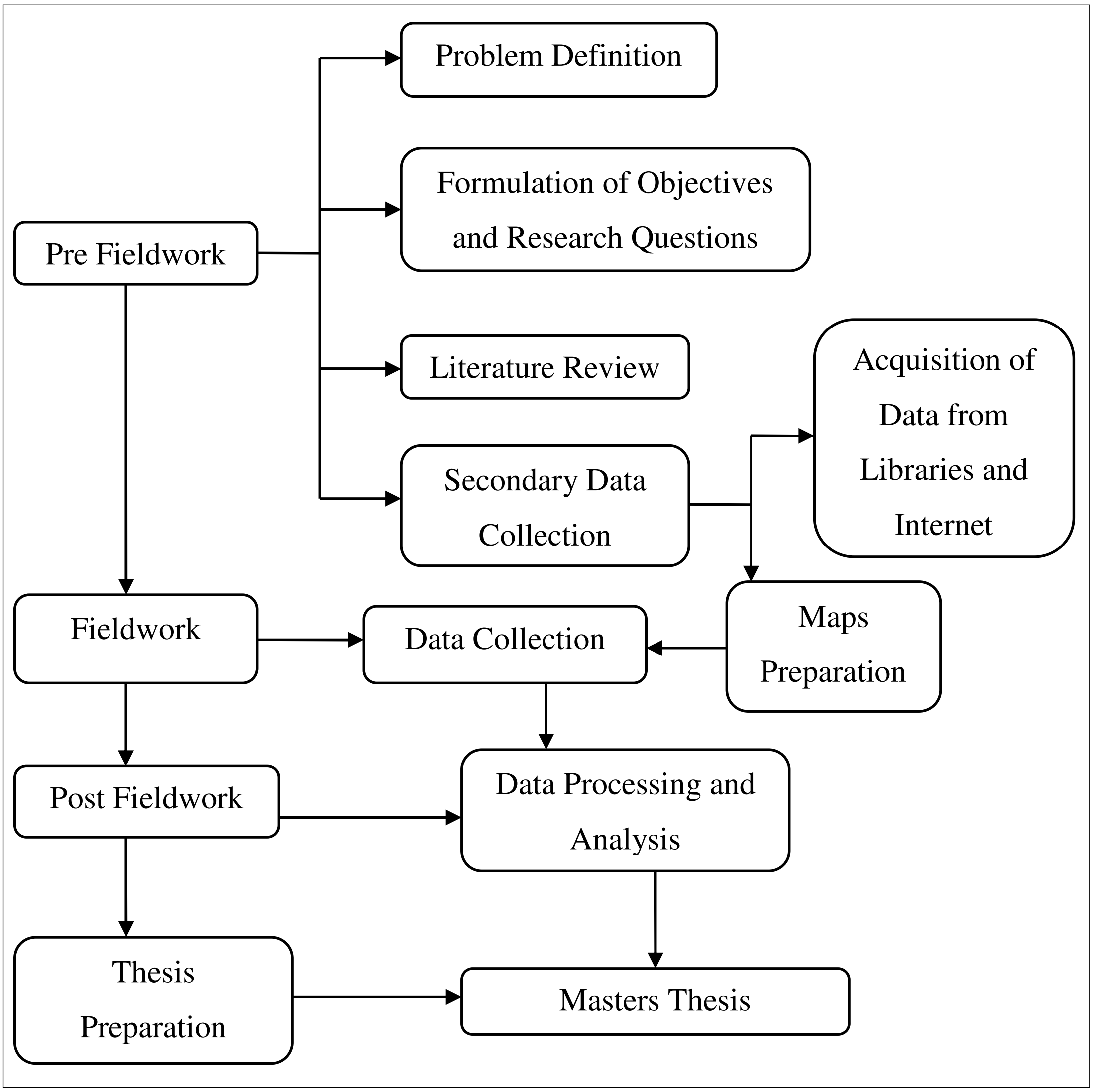


Figure 10: Schematic Representation of the Study Methodology.

As illustrated in Figure 10, the study was carried out in three major stages:

(i) Pre-Fieldwork: This involved problem definition, literature review on groundwater quality, physical, microbiological and chemical parameters of water, WHO and ZABS standards for drinking water, searching and collection of literature on water quality from libraries and the internet.

(ii) Fieldwork: This stage comprised collection of groundwater samples and measuring of the physical, microbiological and chemical parameters.

(iii) Post-Fieldwork: This stage involved data processing, results analysis and presentation and thesis writing.

4.2 Data Collection

The study used both primary and secondary data. These were collected differently. Primary data collection was done both in the wet and dry season whereas secondary data was collected from literature regarding the study from various sources.

4.2.1 Primary Data

Fifty groundwater samples were collected for the study from June 2011 to January 2012. The sampling of groundwater was carried out both in the dry season (June and August, 2011) and wet season (January, 2012) so as to allow for temporal variability assessment of the groundwater quality. During each monthly sampling, groundwater samples were collected comprising boreholes located in the high and low density areas and Nyika Plain where Eastern Water and Sewerage Company (EWSC) pumps water for township water supply.

The coordinates of each borehole were taken using a hand held Global Positioning System (GPS). Sterile conditions for water sampling bottles were obtained prior to sampling by using an autoclave steamer and during sampling by using flaming techniques around water exit points. Furthermore, sampling bottles were rinsed with distilled water to minimize the risk of external contamination.

The hand pumps were flushed for approximately 1-3 minutes so as to pump out water that had settled in the pipes before collecting samples using the sterile glass and polythene bottles. All the bottles were properly sealed and labled for easy identification of the samples. Name of each water point, general water point surrounding and time of sampling was also entered in a hard cover field note book. Potable pH and conductivity meters were used for the on-site physical analysis of groundwater. The testing kits enable water to be tested in accordance with the WHO (2008), American Public Health Association (APHA) (1998) and ZABS (2008) regulations and procedures. The samples for chemical and microbiological analysis were then put in a cool box containing ice packs and transported to the Environmental Engineering Laboratory at the University of Zambia for further analysis. It is important to note here that the samples reached the Environmental Engineering laboratory at the University of Zambia within five hours of being collected as such, no sample expired with regards to bacteriological and/or chemical parameter.

4.2.1.1 Sampling and Measurement

Groundwater sampling locations were established in such a way that different physiographic regions and geological formations were represented and the boreholes are more uniformly distributed in the study area. The endeavour here was to ensure that the entire study area was covered for groundwater sampling so as to arrive at more meaningful and more realistic analysis with reference to characterisation of groundwater quality and its temporal variation. It was therefore planned that a sampling borehole be selected every 500 meters of distance.

4.2.1.1.1 Microbiological Parameters

The numbers of total and faecal coliforms were determined using the membrane filtration technique. A measured volume of water was filtered through a membrane. Bacteria, if present was retained on the membrane and incubated for 24 hours, at $37^{o}C$ and $44^{o}C$ for total coliforms and faecal coliforms respectively. To ensure sterile conditions, petri dishes, medium and forceps were all autoclaved. After each sample preparation, the filtration unit was also flame sterilized using 70% methanol. It is important to note here that grate care was taken in handling the samples in the field, during transportation and also in the laboratory so that there was no external contamination of the groundwater samples.

4.2.1.1.2 Physical and Chemical Parameters

The groundwater physical properties such as pH, Electrical Conductivity (EC) and temperature were measured on site. The pH was measured using a pH meter (pH Model 3310) while the electrical conductivity and temperature of the groundwater samples were determined using a conductivity meter (Cond 3310 set1).

Groundwater samples for microbiological analysis were collected in 1 litre sterilised glass bottles whereas those for chemical analyses to determine total water hardness, alkalinity, acidity and the concentrations of nitrates, fluoride, sulphate, chloride, magnesium, sodium, calcium, potassium and related ions in water were collected in 1 litre polythene bottles and taken to the Environmental Engineering Laboratory at University of Zambia for analysis as already alluded to. The samples were transported in a cool box containing ice parks and reached the laboratory for analysis within 5 hours after their collection.

4.2.2 Secondary Data

The study also utilised secondary data regarding groundwater quality characterisation and related studies.

4.2.2.1 Sources and Types of Data

Secondary data was collected from various books, magazines, journals, manuals, topography and geological maps, articles, and reports related to the study. These materials were accessed by making use of a number of institutions such as the Geological Survey Department, Petauke District Council, Central Statistics Office, and by making use of various libraries such as the University of Zambia library. Furthermore, other relevant data was obtained by use of the internet. Stipulated standards on consumable water were collected from the ZABS and WHO literature. It is cardinal to note here that the literature relating to the subject was reviewed in order to get a comprehensive understanding of the problem at hand. The literature review also sought to understand the geology of the study area and the various methods that are being utilized to characterize groundwater quality in the different parts of the world.

4.3 Data Analysis

Data analysis involved a wide variety of techniques so as to arrive at more meaningful and realistic research finding and conclusions. The hinge was to follow the research objectives systematically.

4.3.1 Laboratory Analysis

It is cardinal to note here that in the laboratory, groundwater samples were analysed for major ion chemistry employing the standard methods (American Public Health Association (APHA), 1998). Total hardness was measured by the titrimetric method using the standard (0.1M) Ethylene Diamine Tetra acetic Acid (EDTA) solution. Sodium (Na^+) and potassium (K) were analysed by systronics flame photometry. Calcium (Ca^{2+}) and magnesium (Mg) were determined titrimetrically using standard EDTA. Manganese (Mn^{2+}) was analysed by the persulphate method and sulphate (SO_4^{2-}) was measured using the turbidimetric method. Ammonia (NH_4) was determined using the phenate method whereas for nitrite (NO_2^-) the calorimetric method was used. Fluoride (F^-) was analysed using the electrometric method, while chloride (Cl^-) was analysed by systronics spectrophotometer. Phosphate (PO_4) was analysed using the vanadomolydophoric acid method and nitrate was determined using the chromotropic method. Total Suspended Solids and Total Dissolved Solids (TDS) were measured using the gravimetric method at 105^{o}C.

The bicarbonate which was expressed in terms of alkalinity (mg $CaCO_3$/l) was converted into HCO_3^{-1}. This was done by using the formula proposed by Hem (1985) as quoted by Sanders (1998):

$$\text{mg/l } HCO_3^{-1} = \frac{\text{mg/l alkalinity as } CaCO_3}{0.8202} \ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots\ldots..\text{Equation 1}$$

The concentrations of ions which were in mg/l were transformed into meq/l by multiplying the concentration in milligrams per litre (mg/l) by the valence of the ion, and dividing the result by the formula weight of the ion (Sanders, 1998). That is:

$$\text{Concentration in} \frac{\text{meq}}{\text{l}} = \frac{\text{concentration in mg/l} \times \text{valence}}{\text{formular weight}} \ldots\ldots\ldots\ldots\ldots \text{Equation 2}$$

4.3.2 Desk Analysis

A number of desk analyses were done so as to critically consider and analyse the data obtained from the field and laboratory.

4.3.2.1 Description of the Chemical, Physical and Microbiological Characteristics of Groundwater in Petauke Town

In order to successfully describe the chemical, physical and microbiological characteristics of the groundwater in the study area, statistical packages such as Excel, Genstat and the Statistical Package for Social Sciences (SPSS) programmes were used to determine the statistical summaries; mean, minimum and maximum values, standard deviation and the range of each parameter considered for all the data sets. This was done for both the dry and wet season samples. Additionally, classification of the groundwater found in Petauke Town was done on the basis of Total Dissolved Solids, total/calcium hardness and electrical conductivity after the WHO (2006) classification as cited by Srinivasamoorthy (2009).

The quality of analytical data (concentration of cation and anion) was evaluated by computing the ionic balance for all the samples. The ionic balances of the solutions were calculated by comparing the equivalents of cations with the sum of the equivalents of the anions after (Hounslow, 1995) using the following formula:

$$\text{Balance} = \frac{(\sum \text{cations} - \sum \text{anions})}{(\sum \text{cations} + \sum \text{anions})} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \text{Equation 3}$$

It is important to mention here that a positive balance/number means that either there are excess or insufficient anions in the analysis, whereas a negative balance/number corresponds to excess anions or insufficient cations. For fresh water, a balance is assumed to be good if it falls within ± 10% (Celesceri et al., 1998).

Furthermore, data for the major ions; Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, Cl^{-} and HCO_3^{2-} were plotted on the Piper diagram so as to understand the evolution of hydro-chemical parameters of groundwater in Petauke Town, Eastern Province, Zambia. The Piper plot helps in recognizing various hydro-geochemical types/groups in a groundwater environment (Sanders, 1998).

4.3.2.2 Assessment of the Temporal Variability of Groundwater Quality in Petauke Town

Temporal variability of water quality for the study area was done by comparing the data sets for the dry season with that of the wet season. This was done by comparing the means of the laboratory and field results for the two seasons. It is cardinal to note here that data for comparison purposes was gotten from the same boreholes. In order to check whether the variation in groundwater quality between seasons as depicted graphically was statistically significant, the Analysis of Variance (ANOVA) parametric test was utilised. Thus the second objective which was dealing with the assessment of the temporal variability in water quality in Petauke Town was analyzed and tested using a parametric test. The hypothesis of significant differences in the means of seasonal water qualities was tested at the significance level of 0.5. The formula that was used for the analysis is:

$$F = \frac{\text{Variation between the groups}}{\text{Variation within the groups}}$$ .... Equation 6

Where, the variation between the groups is the mean difference between the three monthly samples namely, June, August and January. The variation within the groups is the difference in water quality measurements within each of the monthly samples.

Variation between the three classes was calculated using the formula by Taylor (1977) and Bless and Kethuria (1993):

$$S^2b = \frac{\sum n(xm-Gm)^2}{k-1}$$ .... Equation 4

Where S^2b = variance between the three classes, n = number of water quality parameter measurement in each period,

k = Number of sample classes,

Xm = mean for each sample period,

xGm = Grand mean of all the water quality values.

Variation within the four classes was calculated after Taylor (1977); and Bless and Kethura (1993) as given:

$$S^2w = \frac{\sum\sum n(x - xm)^2}{N - k} \qquad \text{Equation 5}$$

Where S²w = variance within the sample periods,

N = total number of all water quality measurements in all the 3 months,

k = number of sample periods,

Xm = mean for each sample period,

x = water quality parameter measurement.

The F test value was then calculated using the formula by Bluman (2007);

$$F_{cal} = \frac{S^2}{S^2w} \qquad \text{Equation 7}$$

The basis for interpretation was to reject the formulated research hypothesis if the calculated $F_{calculated}$ is greater than the $F_{critical}$ (F-value got from the critical tables) at 0.5 level of significance. From this, it was possible to determine whether the differences in the average means of groundwater quality during the dry and wet seasons was significant which could entail an appreciable diversion from the mean. This diversion could mean that groundwater quality varies from season to season.

Furthermore groundwater quality variation was assessed by comparing the quality of groundwater for different boreholes along transects that were drawn across the town from the N to S and from the W to the E. It is worth noting here that transects were passing through the different geologic formations found in the town (Figure 9). This was done so as to account for any variation in groundwater quality and its source.

4.3.2.3 Comparison of Groundwater Quality in Petauke Town with the ZABS (2008) and WHO (2008) Guidelines for Drinking Water

Objective number three which was trying to establish whether the groundwater being supplied to the residents in Petauke Town satisfied the ZABS and WHO requirements for drinking water was addressed by comparing the data obtained in the field and laboratory analyses in the dry season, 2011 and wet season 2012 to the WHO (2008) and ZABS (2008) guidelines for drinking water.

4.3.2.4 Identification of Groundwater Contaminants in Petauke Town

Finally, identification of water quality parameters with measurements/values above the ZABS (2008)/WHO (2008) recommended guidelines/permissible limits in the dry and wet season was done and itemised as the groundwater contaminants in the study area. In addition, possible sources of contaminants were described.

4.4 Limitations of the study

The study encountered some challenges during data collection. The spatial location of boreholes in the study area was not evenly distributed. As such some parts of the area, especially north eastern and north western parts, did not have boreholes where groundwater sampling could be done (Figure 9). The boreholes in Petauke Town are more concentrated in the central part than in the peripheral. Furthermore, two of the boreholes sampled in the dry season could not be sampled in the wet season as they were not functioning due to leaking raising main pipes in the hand pumps.

CHAPTER 5

DATA ANALYSIS AND RESULTS

5.1 General Remarks

This chapter presents data analysis and results obtained in line with the study objectives.

5.2 Physical, Microbiological and Chemical Description of Groundwater in Petauke Town

Groundwater quality and characterisation is better described under three major categories, physical, microbiological and chemical. Below is a detailed description of the groundwater characteristics for Petauke Town in the dry and wet season.

5.2.1 Hydrochemistry of Groundwater in Petauke Town

The physical-chemical properties of analyzed groundwater samples for Petauke Town showed considerable variation in the water quality with respect to their chemical and physical composition. The logarithm of the reciprocal of the hydrogen ion concentration (pH) in the dry season samples varied from 5.83 to 7.22 with mean value of 6.13. The EC values were found to be in the range of 211 - 982µS/cm with a mean value of 574.2µS/cm. The concentration of TDS ranged from 47 to 479 mg/l with a mean of 262.7mg/l while turbidity ranged from 0.15 NTU to 81.9 NTU. The total hardness (measured as $mgCaCo_3/l$) ranged from 72 to 598 mg/l in the water samples. Calcium hardness ranged from 52 to 300 mg/l and had a mean value of 176mg/l. Alkalinity on the other hand had a range of 68 to 500mg/l. The calcium (Ca^{2+}) ion concentrations in the dry season showed a wide variation from a minimum of 20.8 mg/l to as high as 120mg/l. The magnesium (Mg^{2+}) concentration varied from 0.96 mg/l to 125.28 mg/l. Sodium (Na^{+}) recorded values varying from 6.12 mg/l to 29.84 mg/l. The bicarbonate (HCO_3) concentration in the dry season ranged from 82.9-609.6 mg/l. Table 4, appendix 1 and appendix 2 shows the hydrochemistry of groundwater in Petauke Town in the dry and wet season.

Table 4: Hydrochemistry of groundwater in Petauke Town, Eastern Province, Zambia in the dry and wet season

Parameter	Dry Season			Wet Season			Permissible limits	
	Sample Size	Range	Mean	Sample Size	Range	Mean	WHO	ZABS
Temperature (^{o}C)	20	22-25.9	24.59	30	22.4-25.8	25.3	-	-
pH	20	5.83-7.22	6.13	30	5.89-7.15	6.21	6.5-8.5	6.5-8.5
EC(µS/cm)	20	211-982	574	30	0.28-48.4	6.56	1500	1500
Turbidity (NTU)	20	0.1581.9	8.43	30	309-851	548.6	5NTU	5NTU
Total Dissolved Solids (mg/l)	20	47-479	262.7	30	154-428	274.27	1000	1000
Total Suspended Solids (mg/l)	20	0-32	3.46	30	0.9-12.5	1.68	-	-
Total hardness (as mg $CaCO_3$/l)	20	72-598	291.1	30	90-306	168.8	500	500
Calcium hardness (as mg $CaCO_3$/l)	20	52-300	176	30	48-212	124.27	-	-
Alkalinity (as mg $CaCO_3$/l)	20	68-500	278.2	30	75-300	160.33	-	-
Bicarbonate (as mg HCO_3/l)	20	82.9-609.6	360.8	30	91.4-365.5	195.8		
Iron (mg/l)	20	0-2.62	0.49	30	0-3.53	0.29	0.3	0.3
Ammonia (as NH_4-Nmg/l)	20	0-0.18	0.02	30	0-1.09	0.11	1.5	-
Sulphates (mg/l)	20	2.25-201.8	61.1	30	0-93.4	26.23	400	-
Chlorides (mg/l)	20	Sep-44	22.95	30	10-136	30.37	250	250
Nitrites (as NO_2 –N mg/l)	20	0-0.27	0.04	30	0-0.45	0.03	0.1	0.1
Nitrates (as NO_3 –N mg/l)	20	0-23.2	5.06	30	0.06-12.2	3.46	10	10
Acidity (as mg $CaCO_3$/l)	20	0-48	15.2	30	0-12	1.83	-	-
Total phosphates (mg/l)	20	0-1.81	0.54	30	0	0	5	-
Magnesium (mg/l)	20	0.96-125.3	26.17	30	0.48-39.92	14.42	-	-
Calcium (mg/l)	20	20.8-120	70.6	30	19.2-84.8	49.71	-	200
Fluorides (mg/l)	20	0.07-022	0.16	30	0.09-0.38	0.16	1.5	1.5
Potassium (mg/l)	20	1.89-9.58	5.08	30	28.72-194.53	6.48		
Sodium (mg/l)	20	6.12-29.84	16	30	6.6-89.76	20.26	200	200
Manganese (mg/l)	20	0-0.03	0.005	30	0	0	0.4	0.1

The potassium (K^+) ion varied from 1.89 mg/l to 9.58mg/l. Iron (Fe^{2+}) was ranging from negligible amounts to 2.62 mg/l. It was higher than 0.3mg/l in boreholes that are located on the quartzo-feldspathic paragneiss under the Minga Magnetite Formation. These are Tasala 2 (31.3197, -14.2494) and Tasala 9 (-14.2578, 31.3135). The chloride (Cl^-) concentration on the other hand ranged from 9mg/l to 44mg/l, whereas sulphate (SO_4), nitrates, (NO_3^-), fluoride (F^-) and total phosphates, recorded ranges of 2.25-201.8 mg/l, 0-23.2 mg/l, 0.07-0.22 mg/l and 0-1.8 mg/l respectively. Nitrite (NO_2^-) ranged from negligible amounts to 0.27 mg/l.

During the wet season pH and temperature varied from 5.89 to 7.15 and 22.4 ^oC - 25.8 ^oC with mean values of 6.21 and 25.8 ^oC respectively, whereas the electrical conductivity values were between 309 µS/cm to 851 µS/cm indicating potable nature of the groundwater (Table 4; Appendix 3).

The concentrations of TDS ranged from 154-428mg/l with a mean value of 274.27mg/l. The total hardness which denotes the concentration of calcium and magnesium and is an important criterion for determining the usability of water for domestic supplies, ranged from 90 to 306mg/l with a mean value of 168.8mg/l. Calcium and magnesium were ranging from 19.2 to 84.8mg/l and 0.48 to 37.92mg/l respectively. The bicarbonate (HCO_3) concentration in the wet season was ranging from 91.4-365.5mg/l. The concentrations of sodium and potassium in groundwater were found in the range of 6.6 to 89.76mg/l and 28.72 to 194.53mg/l respectively. The alkalinity (measured as mg $CaCO_3$/l) was ranging from 75-300 mg/l with an average of 160.33mg/l whereas the acidity (expressed as mg $CaCO_3$/l) had an average value of 1.83 mg/l and was ranging from undetectable levels to 12 mg/l.

5.2.3 Microbiological Status of Groundwater in Petauke Town

Microbiological contamination of water is one of the major challenges facing management of groundwater especially in rural districts and unplanned settlements. In the June sampling, 70% of the boreholes showed presence of total and faecal coliforms whereas in August another 70% had total and faecal coliforms. Overall, for the dry season, this translated to 70% of the boreholes in the study area showing microbiological contamination of groundwater as they contained total and/faecal coliforms per 100ml of groundwater sampled having faecal coliforms per 100ml volume of water mean for drinking (Table 5).

Table 5: Microbiological status of groundwater in Petauke Town, Eastern Province, Zambia in the dry season (June and August, 2011) and wet season (January, 2012)

Dry Season (June, 2011)										
Sample ID	**Pt1**	**Pt2**	**Pt3**	**Pt4**	**Pt5**	**Pt6**	**Pt7**	**Pt8**	**Pt9**	**Pt10**
TC (#/100ml)	9	11	9	0	0	0	2	14	11	4
FC (#/100ml)	0	3	0	0	0	0	0	3	0	0
Dry Season (August, 2011)										
Sample ID	**Pt1**	**Pt2**	**Pt3**	**Pt4**	**Pt5**	**Pt6**	**Pt7**	**Pt8**	**Pt9**	**Pt10**
TC (#/100ml)	2	0	0	0	9	11	9	4	14	11
FC (#/100ml)	0	0	0	0	0	3	0	3	0	0
Wet Season (January, 2012)										
Sample ID	**SM 1**	**SM 2**	**SM 3**	**SM 4**	**SM 5**	**SM 6**	**SM 7**	**SM 8**	**SM 9**	**SM 10**
TC (#/100ml)	0	6	TNTC	0	0	7	TNTC	32	0	6
FC (#/100ml)	0	2	100	0	0	0	83	6	0	5
Wet Season (January, 2012)										
Sample ID	**SM 11**	**SM 12**	**SM 13**	**SM14**	**SM 15**	**SM 16**	**SM 17**	**SM 18**	**SM 19**	**SM 20**
TC (#/100ml)	12	29	10	105	TNTC	8	TNTC	TNTC	40	0
FC (#/100ml)	10	10	3	26	TNTC	3	TNTC	70	10	0
Wet Season (January, 2012)										
Sample ID	**SM 21**	**SM 22**	**SM23**	**SM 24**	**SM 25**	**SM 26**	**SM 27**	**SM 28**	**SM 29**	**SM 30**
TC (#/100ml)	TNTC	15	19	TNTC	TNTC	13	TNTC	4	0	2
FC (#/100ml)	TNTC	12	12	TNTC	TNTC	12	TNTC	0	0	0

TC = total coliform, FC = feacal coliform, TNTC = Too Numerous to Count

In the wet season microbiological characteristics of groundwater quality showed a varied range of total coliform and faecal coliform presence. It ranged from nil/100ml of water to Too Numerous to Count (TNTC). In the wet season the percentage of boreholes that could not meet the WHO (2008)/ZABS (2008) minimum requirement of nil coliform per 100ml volume of water meant for drinking was observed to have increased from 70% as measured in the dry season to 80%.

5.3 Classification of Groundwater in Petauke Town Based on Total Dissolved Solids, Total Hardness and Electrical Conductivity

All the samples collected in the dry season had TDS less than 1000 mg/l suggesting that the groundwater in Petauke Town is fresh. With regards to total hardness only one sample had a value of 72mg/l of $CaCO_3$ which was very close to the upper threshold of 75mg/l of $CaCO_3$ for soft water (Table 6).

Table 6: Classification of groundwater in Petauke Town, Eastern Province of Zambia on the basis of Total Dissolved Solids, total hardness (as mg CaCO3/l) and electrical conductivity in the dry and wet season (after WHO (2006) as cited by Srinivasamoorthy, 2009)

Parameter	Water Classification	This Study			
		Dry Season		Wet Season	
Total Dissolved Solids	**Water Classification**	**n = 20**	**%**	**n = 30**	**%**
<1000	Freshwater	20	100	30	100
1000 - 10,000	Brackish water	Nil	0	Nil	0
10,000 - 100,000	Saline water	Nil	0	Nil	0
>100,000	Brine water	Nil	0	Nil	0
Total hardness (as mg $CaCO_3$/l)	**Water Classification**	**n = 20**		**n=30**	
<75	Soft	1	5	0	0
75 – 150	Moderately Hard	4	20	9	30
150 – 300	Hard	9	45	20	67
>300	Very Hard	6	30	1	3
Electrical Conductivity	**Water Classification**	**n =20**		**n=30**	
<250	Excellent	2	10	0	0
<250 – 750	Good	16	80	28	93
750 – 1500	Permissible	2	10	2	7

n=sample size

This translated to only 5% of groundwater being soft in the study area in the dry season. Twenty percent of the samples fell under the moderately hard water category whereas 45% fell under hard water. Thirty percent of the groundwater in Petauke Town in the dry was classified as being very hard as its total hardness (CaCOmg/l) concentration was above 300mg/l.

Based on the groundwater samples collected in the dry season, generally the water in the study area ranged from soft, through moderately hard to hard water. However, the bulky of the water was found to be hard and very hard. In teams of electrical conductivity, the study revealed that 80% of the groundwater in Petauke Town in the dry season was good while 10% is under the permissible category and another 10% is excellent water.

In the wet season, 67% percent of the water in Petauke Town was classified as hard water whereas 30% and 3% fell under moderately hard and very hard water classes respectively. Generally following the classification of water by the WHO, (2006) as cited by Srinivasamoorthy, 2009, groundwater in Petauke Town was observed to be ranging from moderately hard to hard. With regards electrical conductivity values in the wet season, 93% of groundwater in the boreholes in the study area fell under good water while 7% was under the permissible category for human consumption.

5.3.1 Ionic Balance of Groundwater in Petauke Town

The ionic balance of the solution gives a comparison between the equivalents of cations with the sum of the equivalents of the anions (Hounslow, 1995). The ionic balances for groundwater in the study area were calculated for both the dry and wet seasons so as to ascertain the abundance of ions controlling the water chemistry. Figures 11 and 12 show the results for the dry and wet seasons, respectively.

The histogram of ionic balance for the dry season show that (16 samples) or 80% of the samples fell within the acceptable limit of ±10 % (Celesceri et al., 1998) for drinking water whereas only 4 samples or 20% are more than the acceptable limit because they contained more anions (Figure 11).

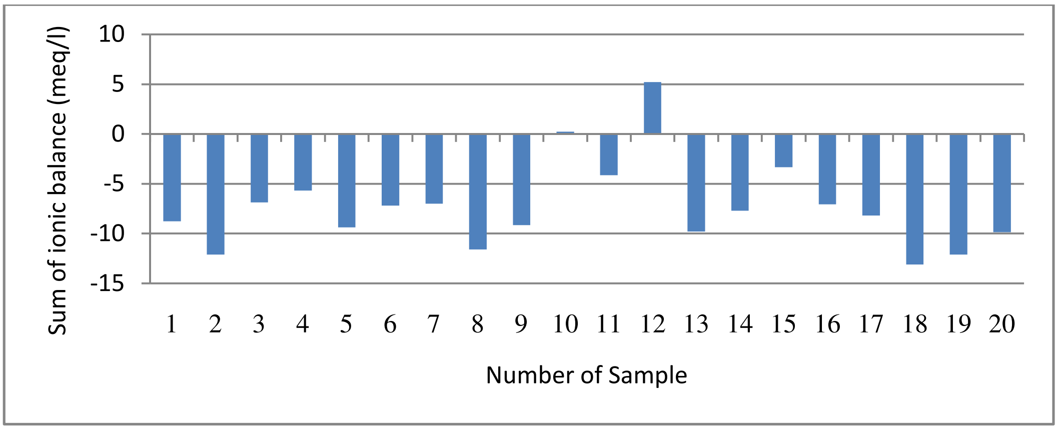


Figure 11: Histogram of cation (Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}) and anion (HCO_3^{-}, SO_4^{-2}, Cl^{-}) balance for groundwater in Petauke Town, Eastern Province, Zambia in the dry season.

The histogram of ionic balance for the wet season was not very different from that one of the dry season. It indicated that 23 samples or 76.6% of the wet season groundwater samples existed within the acceptable limit of ±10 % for drinking water (Celesceri et al., 1998) while 7 samples (23.3%) fell beyond the acceptable limit because of excess cations and/ or anions. Figure 12 shows the histogram of ionic balances for January 2012 (wet season).

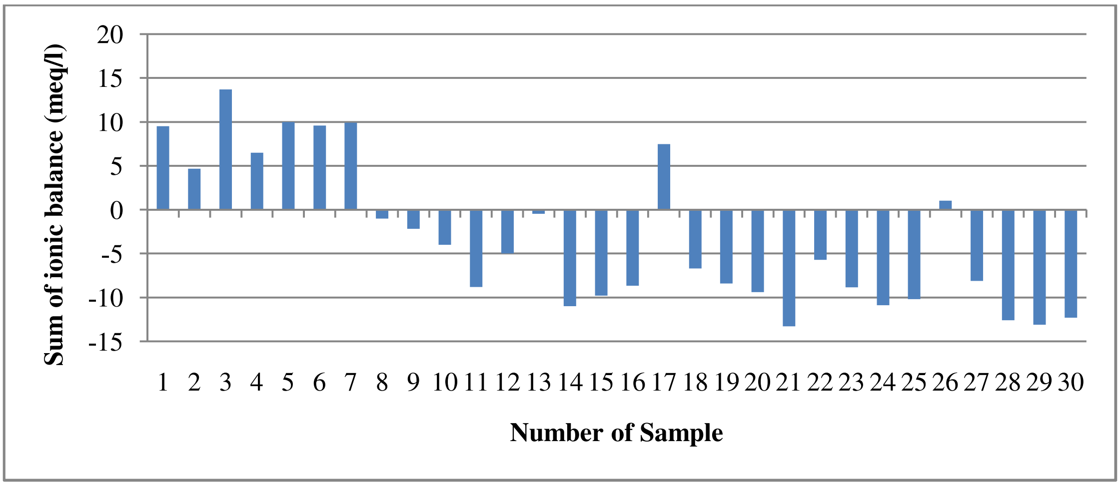


Figure 12: Histogram of cation (Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}) and anion (HCO_3^{-}, SO_4^{-2}, Cl^{-}) balance for groundwater in Petauke Town, Eastern Zambia in the wet season.

5.4 Groundwater Types in Petauke Town

The ionic concentrations of major cations (Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}) and anions (HCO_3^-, Cl^-, SO_4^{-2}) found in groundwater of the study area as revealed by the analysis of the samples obtained in the dry and wet seasons were plotted on the Piper diagram so as to identify the type of groundwater in the boreholes as well as its evolution. A Piper plot was done for the dry and wet samples.

5.4.1 Groundwater Types in Petauke Town in the Dry Season

The analysis of the Piper diagram for samples collected in the dry season suggests that the following major water types exist in the study area.

- $CaHCO_3$ type of water; and
- Ca (Mg) HCO_3 type of water.

Majority of the groundwater samples were observed to belong to the $CaHCO_3$ type. Seventy percent of the dry season samples belonged to this group ($CaHCO_3$) with carbonate ranging from 30 – 80% and calcium contents ranging from 80-90%. The plot suggest that among the cation species, Ca^{2+} and Mg^{2+} dominated in the aquifers which tend to shift towards Ca^{2+}. This denotes that the alkaline earth (Ca + Mg) exceed alkalies (Na + K). On the other hand, the HCO_3^- is the major anion showing dominance over the other anions. The Piper plot for the analysis of groundwater in Petauke Town in the dry season is shown in Figure 13.

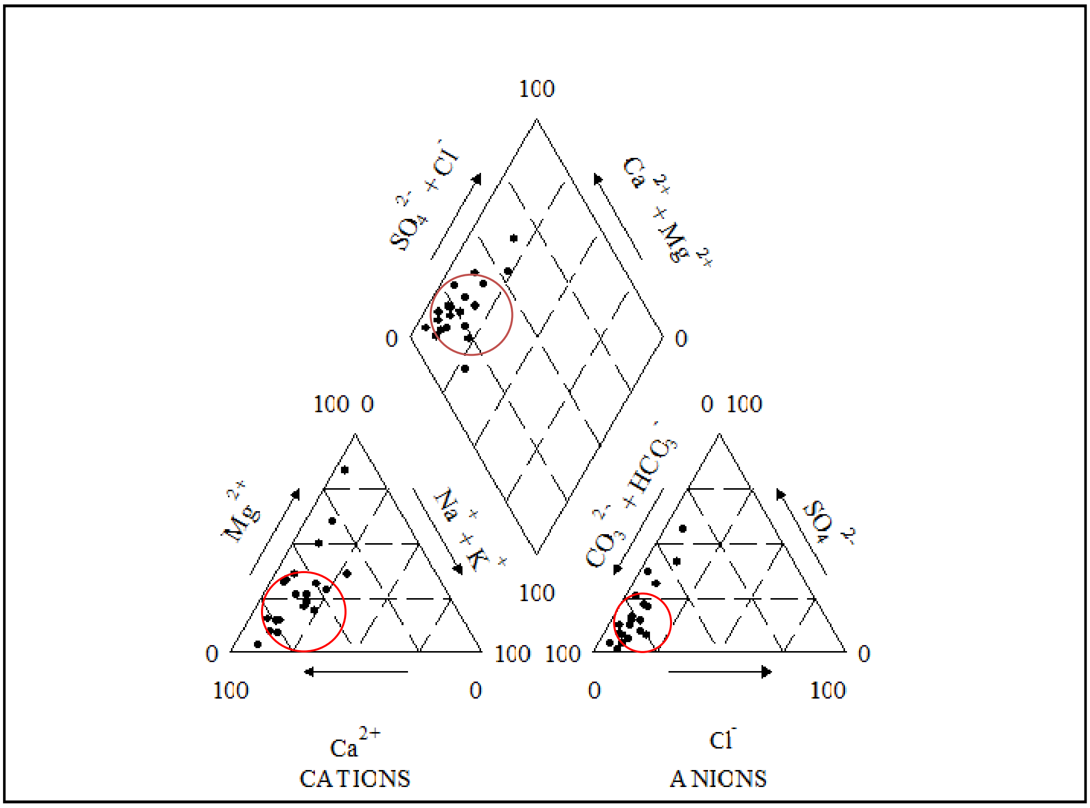


Figure 13: Piper diagram of the chemical analysis results from the boreholes sampled in the dry season showing calcium bicarbonate Ca $(HCO_3)_2$ and calcium magnesium bicarbonate (Ca (Mg) HCO_3) groundwater type in Petauke Town, Eastern Province, Zambia.

5.4.2 Groundwater Types in Petauke Town in the Wet Season

Similarly, the Piper plot for groundwater samples collected in the wet season suggests that the major groundwater types that existed in the study area were $CaHCO_3$ and Ca (Mg) HCO_3. Seventy one percent of the samples for the wet season were found to belong to the $CaHCO_3$ group with bicarbonate content ranging from 60-90% and calcium content ranging from 80-90%. Only 16% of the samples had Ca (Mg) HCO_3 type of water. Few traces of CaCl (6%) and Ca (Na) HCO_3 (4%) groundwater types were found to also exist in Petauke Town (Figure 14).

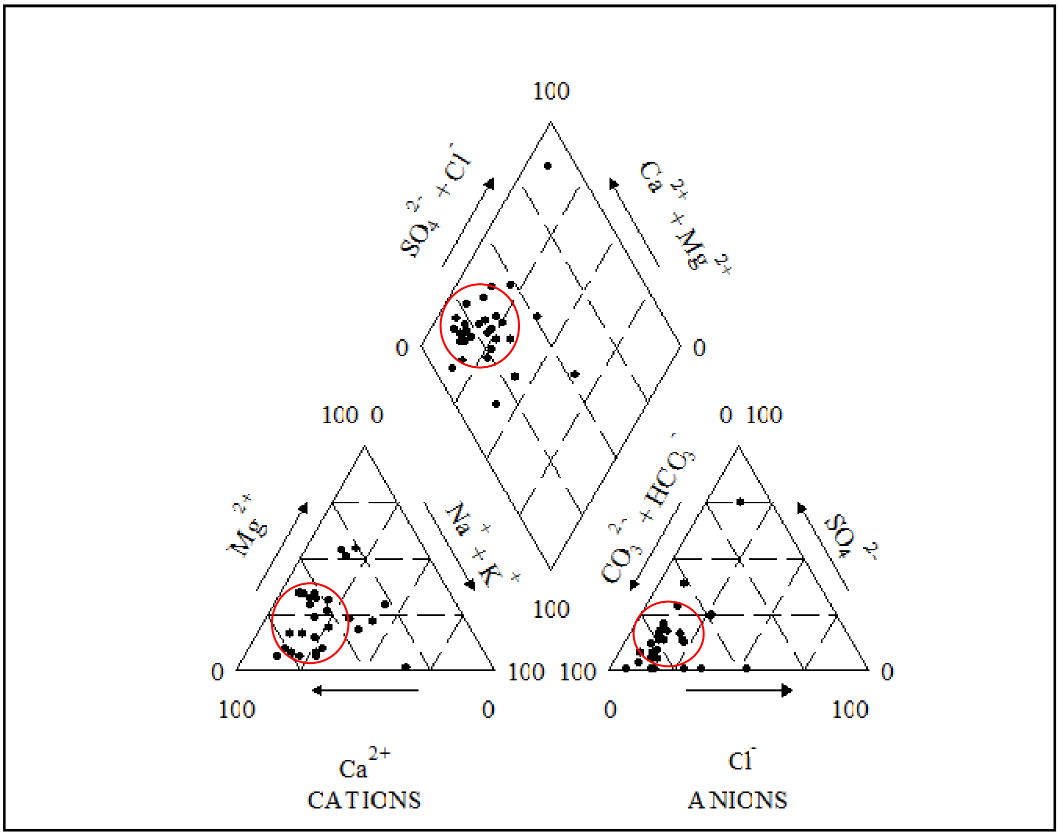


Figure 14: Piper diagram of the chemical analysis results from the boreholes sampled in the wet season showing calcium bicarbonate ($CaHCO_3$) and calcium magnesium bicarbonate (Ca (Mg) HOC_3) groundwater types in Petauke Town, Eastern Province, Zambia.

5.5 Assessment of Temporal Variability of Groundwater Quality in Petauke Town

Temporal variation assessment of groundwater quality in Petauke Town was done so as to ascertain whether groundwater quality varied from season to season by analysing the concentration behaviour of the major cations (Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}) and major anions (HCO_3^-, Cl^-, SO_4^-). The concentration of calcium in the groundwater was observed to showed some distinctive variations, for example, in sample borehole number P9, the concentration of Ca was noted high in August whereas for boreholes number P16 and P6, it was highest in June (2011) and January (2012) respectively (Figure 15).

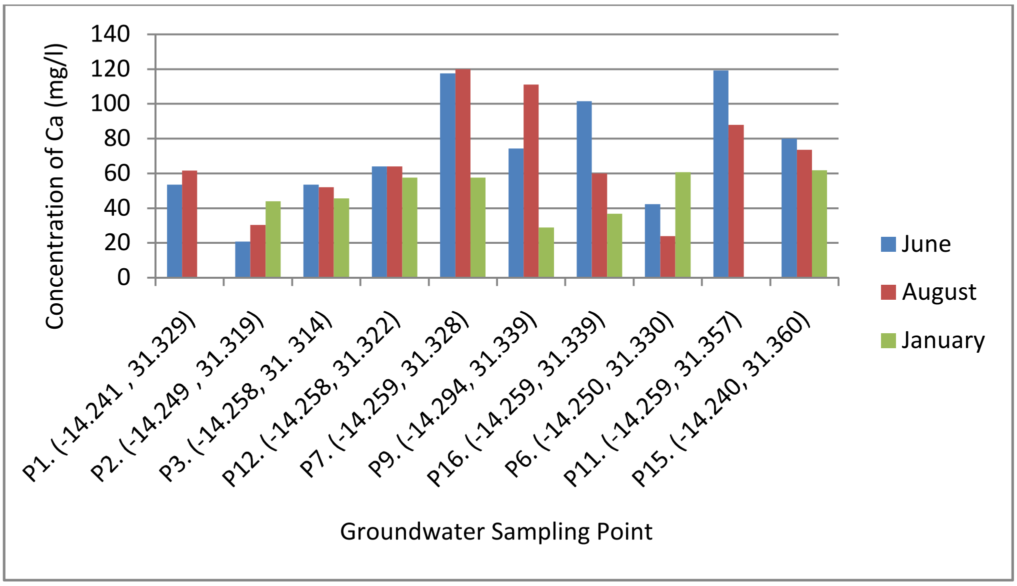


Figure 15: Histogram showing the temporal variation of calcium in the groundwater of Petauke Town, Eastern Province, Zambia.

Unlike calcium, magnesium was observed to have considerable variation across the three months of sampling. It was found to be generally low in the dry season (June and August, 2011) compared to the wet season (January, 2012) (Figure 16).

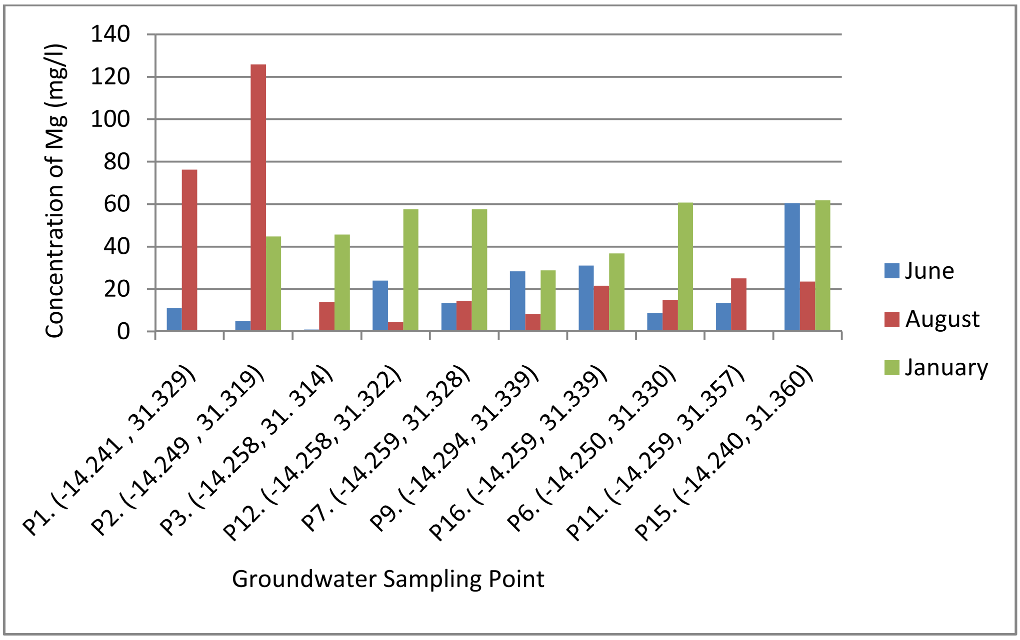


Figure 16: Histogram showing the temporal variability of magnesium concentration in the groundwater of Petauke Town, Eastern Province, Zambia.

Sodium concentration was however different from that of Magnesium. It was highest in the dry season particularly in the August samples and low in the wet season (Figure 17).

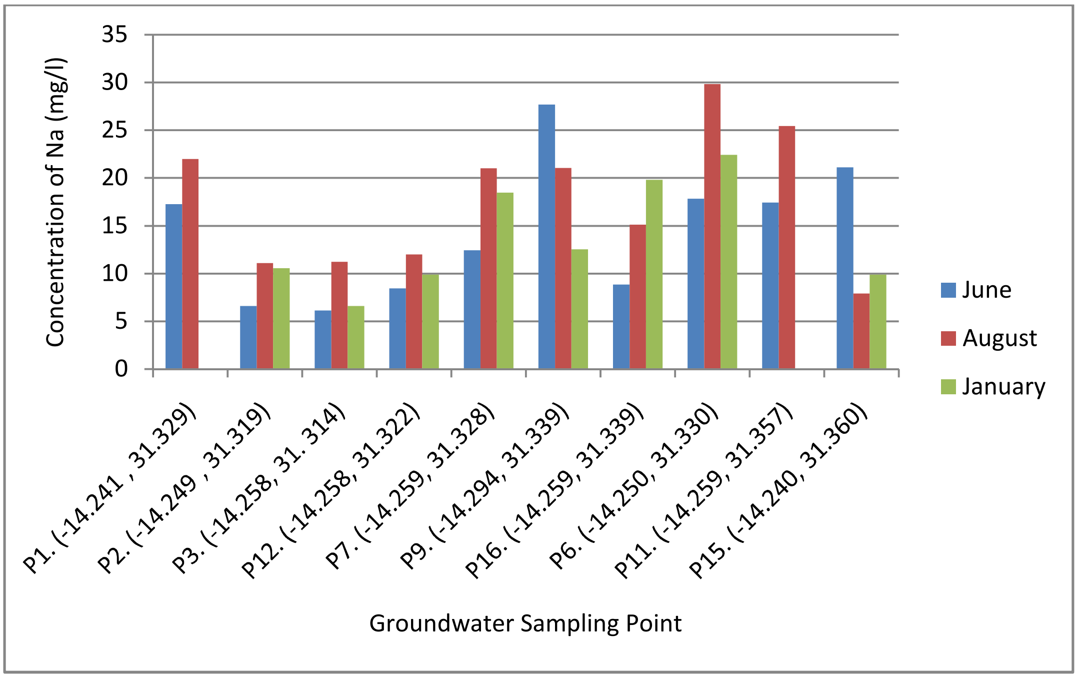
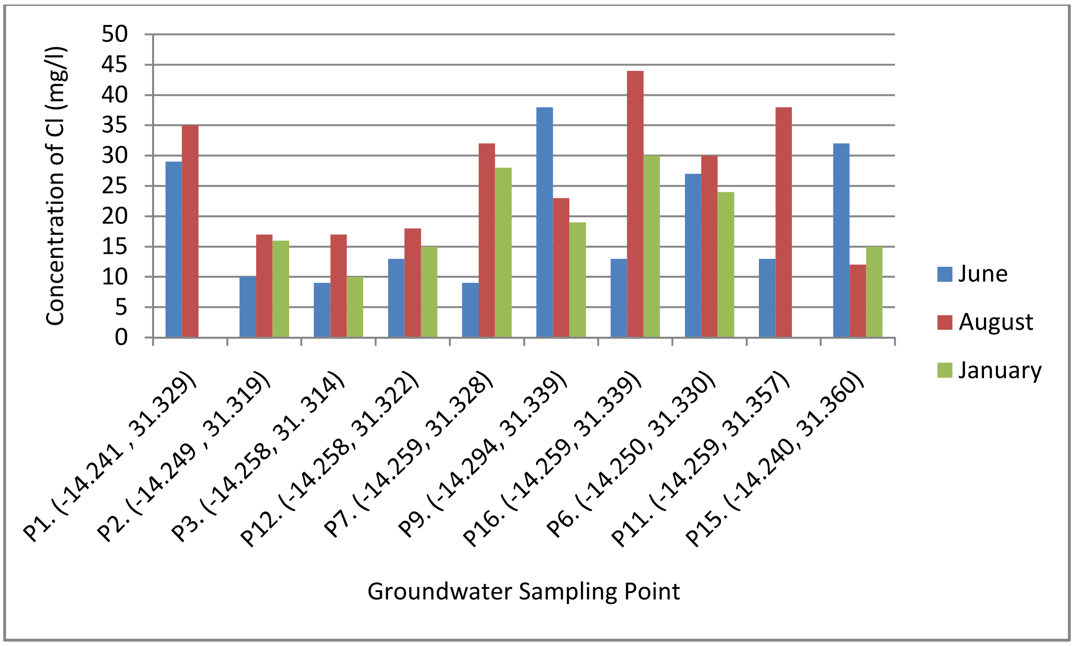
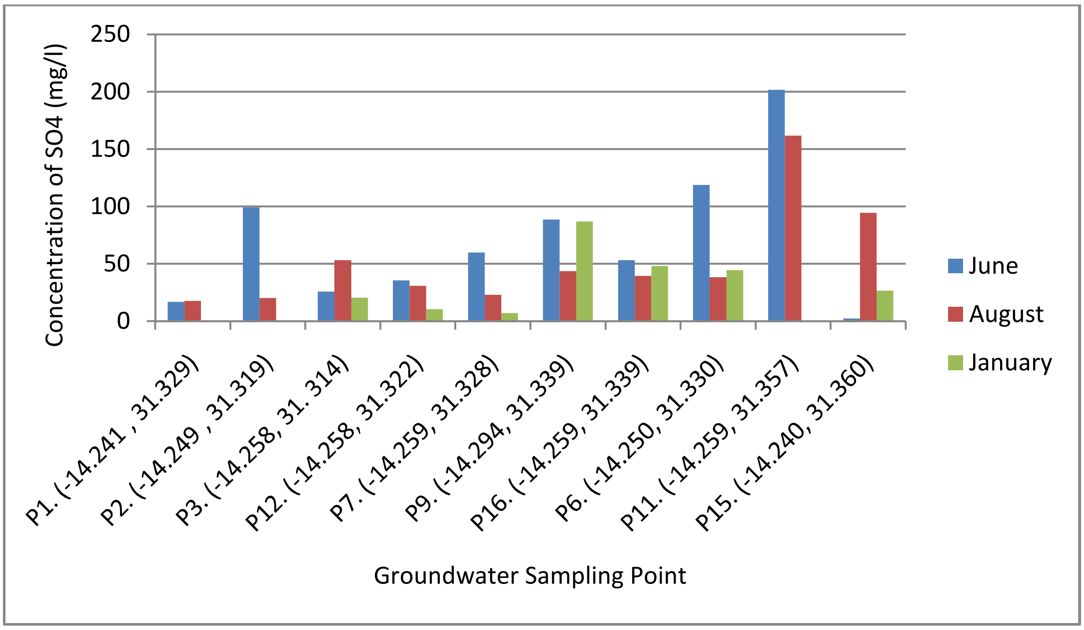


Figure 17: Histogram showing the temporal variability of sodium concentration in the groundwater of Petauke Town, Eastern Province, Zambia.

The concentration of the other anions Cl and SO_3 (Figure 18) and HCO_3 (Figure 19) was not very different from those of the cations. They were all observed to show some temporal variation.



(a)



(b)

Figure 18: Histogram showing the temporal variability of (a) chloride and (b) sulphate concentration in the groundwater of Petauke Town, Eastern Province, Zambia.

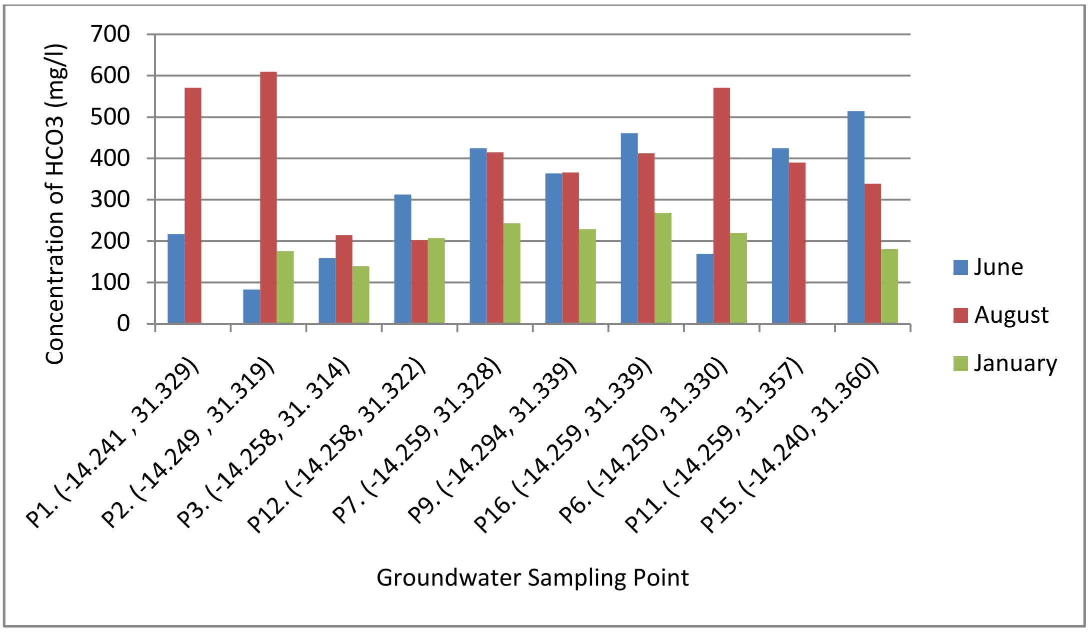


Figure 19: Histogram showing the temporal variability of bicarbonate concentration in the groundwater of Petauke Town, Eastern Province, Zambia.

One important aspect to note about the observed variations in ionic concentrations in groundwater in Petauke Town is that all the major anions HCO_3, Cl, SO_4 and cations Ca, Na, K except for Mg had high concentrations in the dry season than in the wet season. This was because in the wet season an increase in groundwater level (Appendix 7) caused dilution of ionic concentrations in groundwater. However, the increase/decrease in concentration of ions was not uniform for all the ions and did not show any trend across the sampling period with respect to number of sampling points. The concentration of the bicarbonate was higher in the dry season (June and August, 2011) and less in the wet season (January, 2012) (Figure 19).

When the observed variation in the groundwater quality was subjected the parametric test to check for its significance, the Analysis of Variance (ANOVA) in groundwater quality between the dry and wet season revealed that for all the parameters of groundwater quality in Petauke Town, $F_{critical}$ was greater than the P-Value at 0.05 or 95% level of significance (Table 7).

Table 7: Results of the Analysis of Variance in groundwater quality between monthly samples done in the dry and wet seasons in Petauke Town, Eastern Province, Zambia

Parameter	No. Groups	Sum of Squares	df	Mean of Squares	F	P Value	F Critical
pH	3	0.96	2	0.48	4.09	0.03	3.39
Turbidity (NTU)	3	596.07	2	298.03	1.17	0.33	3.39
EC (µS/cm)	3	278.80	2	139.40	0.00	1.00	3.39
TDS (mg/l)	3	43,666.03	2	21,833.01	3.73	0.04	3.39
TSS (mg/l)	3	76.70	2	38.35	0.92	0.41	3.39
Total hardness	3	85,533.13	2	42,766.56	3.21	0.06	3.39
Ca hardness	3	13,626.51	2	6,813.26	1.43	0.26	3.39
Alkalinity	3	75,594.58	2	37,797.29	3.34	0.05	3.39
HCO_3 (mg/l)	3	112,428.14	2	56,214.07	3.34	0.05	3.39
Fe (mg/l)	3	1.09	2	0.55	1.06	0.36	3.39
NH_4 (mg/l)	3	0.03	2	0.01	1.22	0.31	3.39
SO_4 (mg/l)	3	7,003.77	2	3,501.89	1.58	0.23	3.39
Cl (mg/l)	3	329.63	2	164.81	1.68	0.21	3.39
NO_2 (mg/l)	3	0.00	2	0.00	0.58	0.57	3.39
NO_3 (mg/l)	3	10.82	2	5.41	0.11	0.90	3.39
Acidity	3	3,657.36	2	1,828.68	13.93	0.00	3.39
Total PO_4 (mg/l)	3	4.97	2	2.48	16.88	0.00	3.39
Mg (mg/l)	3	1,428.60	2	714.30	1.07	0.36	3.39
Ca (mg/l)	3	2,700.37	2	1,350.19	1.75	0.19	3.39
F (mg/l)	3	0.01	2	0.00	0.94	0.41	3.39
K (mg/l)	3	12.68	2	6.34	1.43	0.26	3.39
Na (mg/l)	3	77.65	2	38.82	0.85	0.44	3.39
Mn (mg/l)	3	0.00	2	0.00	1.60	0.22	3.39
Total coliforms (#/100ml)	3	20,151.76	2	10,075.88	1.80	0.19	3.39
Feacal coliforms (#/100ml)	3	19,675.23	2	9,837.62	1.42	0.26	3.39

It is important to note here that based on the ANOVA results, there was no significant difference in groundwater quality between samples collected in the dry season (June and August, 2011) and wet season (January, 2012) in Petauke Town.

The results of the comparison of groundwater quality for boreholes along the transects C-D and A-B drawn on the geology map from North to South and West to East respectively (Figure 8) showed some variation in the concentration of ions.

Along transect C-D, It was observed that the major ions Ca, Mg, Na, K, HCO_3, SO_4 and Cl increased in concentration from the quatzo-feldspatic paragneiss formation (Boreholes nos. P1, P2, P3, P16, P5 and P6) (Figure 20) in the northern part of the town to the centre where the geology differentiates into three major formations in the town which are semipelitic gneiss, alluvium and quatzo-feldspatic. Magnesium, Na and SO_4 tend to increase in the alluvium which is comprised of clay, mudstone and sandstone (Borehole nos. P10, P11 and P15) (Figure 21).

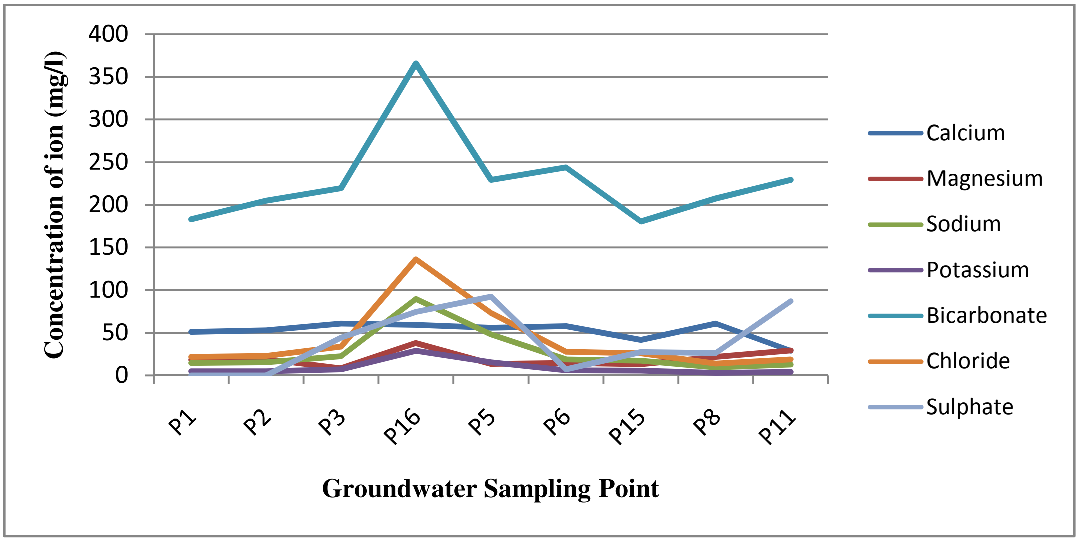


Figure 20: Spatial variation of Ca, Mg, Na, K, HCO_3, Cl, and SO_4 in Petauke Town, Eastern Province, Zambia from north to south passing through quatzo-feldspatic paragneiss (borehole nos. P1, P2, P3, P16, P5 and P6), alluvium (borehole nos. P15 and P10), and semipelitic gneiss(borehole no. P9).

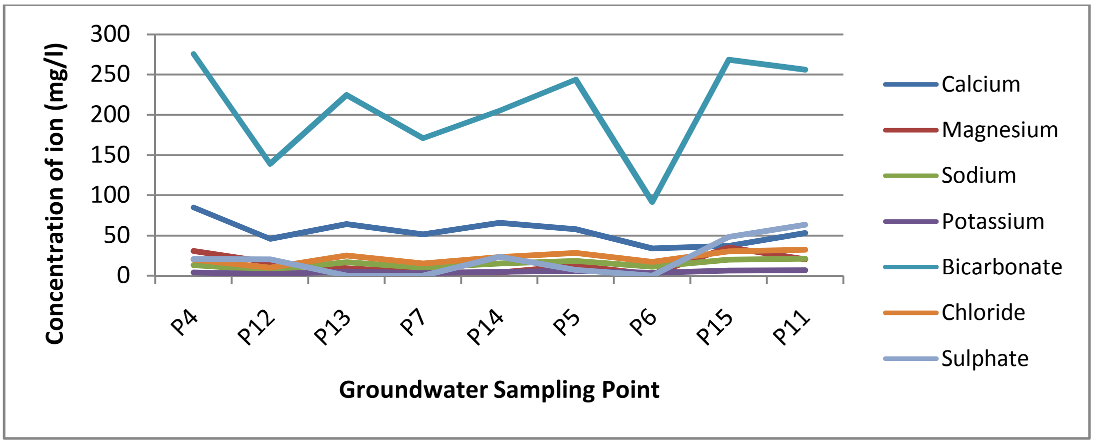


Figure 21: Spatial variation of Ca, Mg, Na, K, HCO_3, Cl and SO_4 in Petauke Town, Eastern Province, Zambia from west to east passing through semipelitic gneiss (borehole nos. P4 and P12), quartzo-feldspatic paragneiss (borehole nos P7, P14, P5 and P6), and Alluvium (borehole nos. P15 and P11

The most striking concentration of groundwater parameters was that of NO_3 for both transects C-D and A-B (Figure 22; Figure 23).

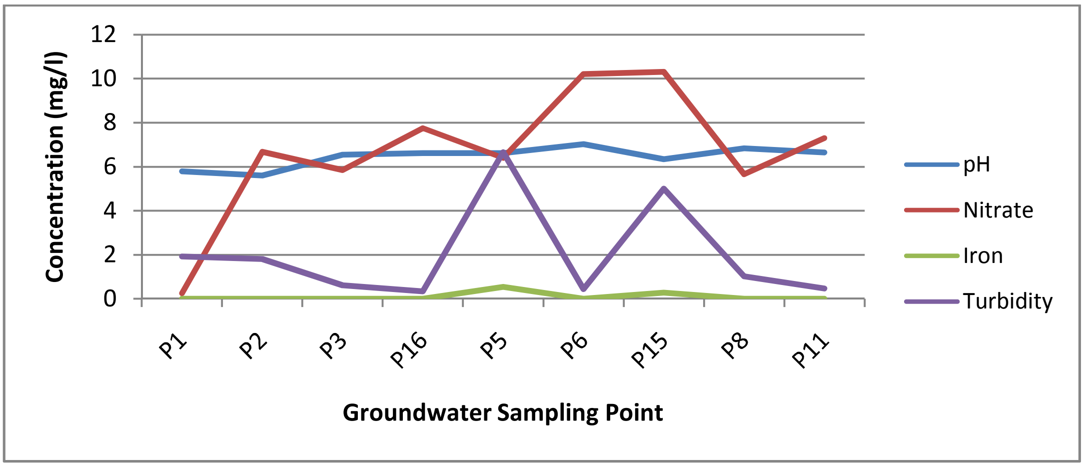


Figure 22: Spatial variation of pH, NO_3, Fe and turbidity in Petauke Town, Eastern Province, Zambia from north to south passing through quatzo-feldspatic paragneiss (borehole nos. P1, P2, P3, P16, P5 and P6), alluvium (borehole nos. P15 and P10), and semipelitic gness (borehole no. P9). Except for pH and turbidity the concentration of all the attributes are in mg/l

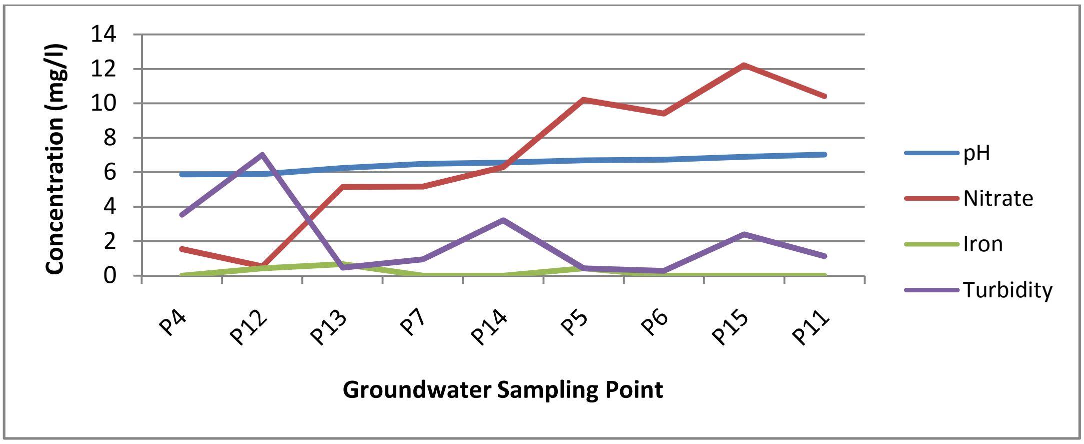


Figure 23: Spatial variation of pH, NO3, Fe and turbidity in Petauke Town, Eastern Province, Zambia from west to east passing through semipelitic gneiss (borehole nos. P4 and P12), quartzo-feldspatic paragneiss (borehole nos P7, P14, P5 and P6), and Alluvium (borehole no. P15 and P11). Except for pH and turbidity the concentration of all the attributes are in mg/l.

In the northern and western parts of the town which lies on a higher altitude the concentration of NO_3 was observed to be lower. However, it increased towards the centre where the old dump site was (Boreholes nos. P3, P6 and P16) and near where two petroleum service stations are situated (Figure 9). The increase was also observed towards the eastern part of the town where agriculture activities take place around and near the Farmers Training Institute (boreholes nos. P11 and P15). Similarly, the pH increased from west to east. It was high where the HCO_3 is highest.

5.6 Comparison of the Petauke Town Groundwater Quality with the WHO (2008) and ZABS (2008) Drinking Water Quality Standards

Twenty five percent of the samples collected in the dry season were below the recommended lower pH limit of 6.5 for drinking water whereas 25% of the water in the boreholes in Petauke Town was turbid for most parts of the dry season (Table 8). The total hardness (measured as mg$CaCO_3$/l) had one sample with a value of 598 mg/l of $CaCO_3$ which is above the ZABS and WHO permissible limit of 500mg/l total hardness for drinking water.

Table 8: Comparison of the groundwater quality for Petauke Town with the WHO (2008) and ZABS (2008) drinking water guidelines

Parameter	Maximum permissible limit for drinking water		Dry Season			Wet Season		
	WHO	ZABS	Petauke Town Range of results	No. Samples with values below/above ZABS/WHO limits	% Samples with values below/above ZABS/WHO limits	Petauke Town Range of results	No. Samples with values below/above ZABS/WHO limits	% Samples with values below/above ZABS/WHO limits
pH	6.5 - 8.5	6.5 - 8.5	5.83 - 7.22	5	25	5.32 - 7.22	9	30
Turbidity (NTU)	5	5	0.15 - 81.9	5	25	0.15 -81.9	6	20
EC (µS/cm)	1500	1500	211 - 982	-	-	233 - 982		-
TDS (mg/l)	1000	1000	47 - 344	-	-	47 - 344	-	-
TSS (mg/l)	-	-	0 - 32	-	-	0.9 – 12.5	-	-
Total hardness	500	500	52 - 598	1	5	52 - 298	-	-
Fe (mg/l)	0.3	0.3	0 - 2.62	4	20	0.01 - 2.11	8	26.7
NH_4 (Nmg/l)	1.5	-	0 - 0.09	-	-	0 – 1.09	-	-
SO_4 (mg/l)	400	-	2.25 - 201.8	-	-	0 – 93.4	-	-
Cl (mg/l)	250	250	0.9-38	-	-	9 - 38	-	-
NO_2 (Nmg/l)	0.1	0.1	0 - 0.271	1	5	0 – 0.44	1	5
NO_3 (Nmg/l)	10	10	0 - 23.2	3	15	0.8 - 23.2	2	4
Total PO_4 (mg/l)	5		0 - 1.81	-	-	0	-	-
Mg (mg/l)	-	-	0.96 – 125.2	-	-	0.96 – 60.44	-	-
Ca (mg/l)	-	200	20.8 - 119.2	-	-	20.8 – 119.2	-	-
F (mg/l)	1.5	1.5	0.13 - 0.22	-	-	0.7 – 0.22	-	-
Na (mg/l)	200	200	6.12 – 29.84	-	-	6.12 – 27.7	-	-
Mn (mg/l)	0.4	0.1	0 - 0.3	-	-	0 – 0.2	-	-
Total coliforms (#/100ml)	0	0	0 – 74	12	60	0 - 74	24	80
Faecal coliforms (#/100ml)	0	0	0 – 40	7	35	0 - 40	21	70

It is also important to mention here that during the dry season sampling iron was found to be above the permissible limit in 20% of the groundwater samples. Fifteen and Five percent of the groundwater samples had nitrate and nitrite values above the permissible limits. Sixty and thirty five percent of the samples did not meet the bacteriological requirement of nil TC/100ml and nil FC/100ml of drinking water respectively as set by WHO (2008) and ZABS (2008) (Table 8). The most affected areas were the high density ones.

Similarly, in the wet season, some samples had pH and turbidity levels above the permissible limits. Thirty percent of sample had pH values below 6.5 whereas 30% had above normal turbidity (Table 9). Twenty Seven and four percent of samples had iron and nitrate values above the ZABS and WHO guidelines for drinking water respectively. Five percent had nitrite above the permissible limits. Eighty and seventy percent samples could not meet the minimum requirement of zero/nil total and faecal coliforms per 100ml of drinking water respectively.

Combining results for the whole study, 28% of the samples had pH values below the permissible limits whereas turbidity, total hardness and iron were above the guideline values in 22%, 0.02% and 24% of the groundwater samples respectively. Seventy percent of the samples contained total coliforms whereas 56% showed presence of faecal colifoms per 100ml volume of water meant for drinking.

5.7 Groundwater Contaminants in Petauke Town

The parameters with values above or below the stipulated WHO (2008) and ZABS (2008) permissible limits in Table 10 were considered to be groundwater contaminants in Peatauke Town. These are pH, turbidity, iron, nitrate, total and faecal coliforms. The pH with the lowest value of 5.32, had 28% samples recording values below the permissible limits for drinking water. Twenty two percent of samples were above the limits for turbidity. The highest value for turbidity was 81.9 NTU. Iron with the highest measurement of 2.62 mg/l was noted above the permissible limit in 24% of the samples. Nitrate (with a highest value of 23.2 mg/l) was above the limits in 10% of groundwater samples. Total coliforms and faecal coliforms with measurements ranging from 1 to Too Numerous To Count were above the permissible limits in 72% and 56% of the samples respectively.

CHAPTER 6

DISCUSSION AND INTERPRETATION OF RESULTS

6.1 General Remarks

This chapter presents the discussion and interpretation of the results. This discussion and interpretation of the results follows the order of the study objectives.

6.2 Description of Microbiological, Chemical and Physical Characteristics of Groundwater in Petauke Town

It is worth to appreciate here that groundwater quality and characterisation is better considered and discussed under three major categories, physical, microbiological and chemical.

6.2.1 Hydrochemistry of Groundwater in Petauke Town

The study revealed that groundwater in the study area was characterised by low pH (5.83-7.22), high HCO_3 (81.2-609.6 mg/l) and high $CaCO_3$ (90-306 mg/l). Further analysis regarding the abundance of the major ions showed that for most of the boreholes, they were in the order of Ca > Mg >Na> K = HCO_3 > Cl >SO_4. Appendices 4, 5 and 6 show the details on the abundance of ions for all the boreholes that were sampled for this study in the dry season (June and August, 2011) and wet season (January, 2012). The dominance of these ions showed that the geology of the area is composed of calci-silicate minerals. This was in line with the findings of Dodds and Patton (1968) and Phillips (1964) who reported that the Precambrian Basement showed amphibolites facies and contains pyroxene, biotite, quartzo-feldspathic and calcsilicate gneisses, quartzites, quartz schists, and varieties of granite contaminated with significant amounts of carbonate and marble. The hydrochemistry of groundwater therefore showed influence of the weathering of these rock types.

The high iron content in the groundwater of the study area was observed to be emanating from the weathering of magnetite and other formations like quartzite which occurs in the study area in various shades of pink and red due to the varying amounts of iron oxide (Fe_2O_3) (Phillips, 1964). Similarly, the high bicarbonate content was also noted to be emanating from geology as a result of natural processes that occurs when water reacts with the geological units. Several publications (Freeze and Cherry, 1979; Appello and Postma, 2005; Wanda et al, 2010) reported that water infiltrating into the soil zone may contain dissolved carbon dioxide which reacts with the hydroxyl (OH^-) to form carbonic acid, which when in contact with a terrain containing calcite, causes the mineral to dissolve forming calcium carbonate and the bicarbonate. It is important to point out here that this explained the occurrence of the higher amounts of calcium carbonate and the bicarbonate that were observed in the groundwater in Petauke Town and also confirmed publications that reported that groundwater quality depends on among other things, the interaction between the water and the soil, the soil and the gas, the rock with which it comes into contact and reactions that take place within the aquifer (Hem, 1989; Fetter, 1990; Appello and Postma, 2005; Freeze and Cherry, 1979; Sadashivaiah et al, 2008).

6.2.2 Microbiological Status of Groundwater in Petauke Town

The use of indicator organisms such as faecal coliforms and *E. coli* for the assessment of faecal contamination is a widely accepted procedure for the determination of water quality deterioration (WHO, 2006; UNICEF, 1998; Byamukama et al., 2000; Byamukama et al., 2005; ZABS, 2008). According to the WHO (2008) and ZABS (2008) guidelines for drinking water quality (Table 2), *E. coli* or thermo tolerant coliforms should not be detectable in any water intended for drinking. However, the findings of this study revealed that groundwater sources (boreholes) in Petauke Town are microbiologically contaminated, mostly by total and faecal coliforms. In particular, 70-80% of boreholes in the dry and wet season respectively could not meet the ZABS (2008) and WHO (2008) requirements for water intended for drinking because they contained total and faecal coliforms per 100ml volume of groundwater analysed. These results support the earlier findings of PDC (2009) where 69% of boreholes sampled for bacteriological analysis in the district were found to be microbiologically contamination. Additionally, although PDC (2009) and this study obtained similar results regarding microbiological contamination of groundwater in Petauke Town, it is worth to note here that whereas PDC (2009) used the H_2S method which could only indicate a pass or fail result for microbiological contamination of water, this study utilised the membrane filtration technique which does not only give the pass/fail result but also gives the total count of total and faecal colifoms per water sample. The total count analysis also shows the degree and extent of the contamination.

According to Kimani and Ngindu (2007), Lehloesa and Muyima (2000) and Lippy and Waltrip (1984) the presence of indicator organisms such as total and faecal coliforms in water shows recent contamination of the water source with faecal matter. Faecal pollution of the water sources is most likely from the faecal matter in the environment due to lack of effective waste treatment plants which lead to high use of septic tanks and latrines (Kimani and Ngindu, 2007; Nyambe and Maseka, 2000). The findings of the present study showed to be in agreement with Kimani and Ngindu (2007) and Nyambe and Maseka (2000) in that the largest number of boreholes that showed microbiological contamination of groundwater were those located in the high density areas which have poor sanitary facilities. Furthermore, the wet season sampling which was characterised by rains recorded the highest levels of contamination compared to the dry season. These findings are comparable to the observations made by Erume and Ocaido (2010) in Nakawa, Amuria and Kiboga in Uganda where they noted that Amuria which had heavy rains during the time of groundwater sampling had the highest levels of contamination compared to Kiboga and Nakawa which were dry. It is also in conformity with the observations made by Nyambe and Maseka (2000) in Kanyama Township, Lusaka where they noted that microbiological contamination was increasing due to faecal contamination and poor waste management. Consequently they pointed out that groundwater quality is more at risk in large settlements such as high density areas because of lack of proper sanitation facilities. Furthermore Nyambe and Maseka (2000) highlighted that in some cases facilities are available but of poor quality, as such they cannot stop groundwater contamination. The sewer ponds in Petauke Town were observed not to be receiving any sewer as they were not connected to any functioning sewerage line.

Whereas during the dry season, the levels of coliforms were low in Petauke Town due to the reduced groundwater levels that came into contact with sanitary facilities, it was higher in the wet season as the numbers of total and faecal coliforms per 100ml of water even increased to Too Numerous To Count (TNTC). It is most probable that in the wet season, the rains washed off indiscriminately disposed excreta into the water sources leading to the contamination. The seepage of wastewater from septic tanks and latrines also came into contact with the rising groundwater table (Appendix 7) in the wet season in the unconfined aquifers which are naturally open to seepage. Other studies have also linked the rain or wet season to the contamination of water sources (Egwari and Aboaba, 2002; Howard *et al.,* 2003; Erume and Ocaido, 2010). Furthermore, the water points in the study area, especially those situated in the low income/high density areas faced other risks of contamination in addition to the aforementioned, such as having very poorly maintained fences or lack of them, lack of soak away pits and a general lack of hygiene. Most of the boreholes (60%) were observed to have poorly maintained soak away pits and fences which could contribute to bacteriological contamination of groundwater as domestic animals such as goats, pigs and dogs could easily have access to the water point surrounding. Figure 24 shows a borehole with an unhygienic surrounding and lacking a fence and soak away.

Figure 24: A water point with unhygienic surrounding, without a fence and soak away pit in Tasala 1, a high density area in Petauke Town.

6.3 Classification of Groundwater in Petauke Town Based on Total Dissolved Solids, Total Hardness and Electrical Conductivity

Water hardness has been reported to be caused primarily by the presence of cations such as calcium and magnesium and anions such as carbonate, bicarbonate, chloride and sulphate in water (Sadashivaiah et al., 2008; WHO, 2008; Schroeder et al., 1966). WHO (2008) reported that water hardness has no known adverse effects on human health but, Schroeder (1960) and Schroeder et al., (1966) notes that although the effects of hard water on human health have not yet been conclusively done around the world, some evidence indicate its role in heart disease. However, it is cardinal to note here that hard water is unsuitable for domestic use as it reacts with soaps and causes scale formation in addition to increasing the boiling point of water (WHO, 2008). The carbonates and bicarbonate also play a major role in determining water hardness. WHO (2008) and ZABS (2008) did not set a guideline value for bicarbonate in drinking water. However, studies in India, one of the countries with a guideline value for bicarbonate, have revealed that water with HCO_3 above 300mg/l result in precipitation of CO_3 which forms as scales in pipelines and affects pumps causing loses to farmers/users (Sadashivaiah et al., 2008). A very similar observation was made in Petauke Town where galvanised iron water reticulation pipes have shown reduced diameters due to scale formations (cf. Gauff-Ingenieure, 2001). The formation of scales and blocking of water passage in certain pipes especially on points of pipe size reductions, connections and in water meters was therefore as a result of the high $CaCO_3$ and HCO_3 in the groundwater which was observed in this study (cf. Gauff-Ingenieure, 2001).

6.3.1 Ionic Balance of Groundwater in Petauke Town

The ionic balances of the groundwater in Petauke Town in the dry and wet season indicated that for most of the samples, anions were higher in concentration compared to cations. Appelo and Postma (2005) and Freeze and Cherry (1979) noted that this occurs like this because in most carbonate, metamorphic and sedimentary aquifers, the increase in cation concentration is accompanied by the dissociation of bicarbonate acid resulting in an increase in bicarbonate concentration in groundwater. It is therefore this increased level of HCO_3^- that influences the ionic balance to shift towards the negative balance. Several publications (Domenico and Schwartz, 1990; Rao, 2005; Hounslow, 1995; Garizi et al., 2011) reported that the most important aspect of the ionic balance is that it shows the quality of the laboratory that analysed the data used in water quality characterisations/studies. Freeze and Cherry (1979) reported that water fulfils the principle of electro-neutrality and is therefore always uncharged, however, they pointed out that in most studies, a charge balance of zero is very difficult to attain. An ionic balance of up to ±5 % is tolerable, while every water sample with a calculated balance beyond ±10% in typical laboratory applications should be re-measured (Hounslow, 1995). Celesceri et al., (1998) however notes that for drinking water purposes, an ionic balance of ±10% is acceptable.

It is important therefore at this point to appreciate that conditions of disequilibrium in ionic balances are not uncommon in carbonate aquifers. Freeze and Cherry (1979) notes that one of the most enigmatic of disequilibrium conditions in hydrogeochemical systems is the existence of undersaturation with respect to calcite and dolomite in situations where these minerals occur in abundance. According to laboratory results obtained by Howard and Howard (1967) and Rauch and White (1977) as cited by Freeze and Cherry (1979), rates of calcite dissolution indicated that equilibrium should be achieved in a matter of hours or days, yet in some studies in the Pennsylvanian and Floridan carbonate-rock aquifers by Back and Hanshaw, (1970) and Jacobson and Longmir (1971) respectively, much older water in contact with calcite and dolomite was observed to persist in a state of under saturation (Freeze and Cherry, 1979). Furthermore, to understand the complexity of the in-balance between cations and anions in groundwater, Jacobson and Langmuir (1970) conducted tracer tests in Parts of the Pennsylvanian aquifer and the results indicated groundwater residence times of 2-6 days overflow distances of about 7000 m. They concluded that the residence times of many of the spring was generally somewhat longer than 2-6 days and that the waters sampled from the wells were much older than 2-6 days. Their investigation suggested that in field situations, weeks or even months of residence time can be necessary for dissolution to proceed to equilibrium with respect to carbonate rocks. It is deduced here therefore that in Petauke Town, the larger percentage (80%) of the boreholes samples that are within ±10 % of ionic balance showed that the water possibly had sufficient time to equilibrate with the calcite in the aquifers. While the remaining percentage needed a much longer period to equilibrate or reach electro-neutrality. This study however, did not measure the residence time of water in the aquifer which could have given a basis of explaining the in-balance between cations and anions. Based on the foregoing observation, in groundwater characterisation programmes, it is pertinent to consider residence time of water in a particular aquifer and the solubility of major formations that are present.

Additionally, it is worth noting here that the excess ions (cations or anions) contributes to water hardness and can be removed from water by a process called ion exchange, which is an exchange of ions between two electrolytes or between an electrolyte solution and a complex (Kangjoo and Seong-Taek, 2005). Typical ion exchangers are ion exchange resins (functionalized porous or gel polymer), zeolites, montmorillonite, clay and soil humus. Ion exchangers are either cation exchangers that exchange positively charged ions (cations) or anion exchangers that exchange negatively charged ions (anions) (Wagenet et al., 1995). Therefore, in situations where there are more anions than cations in water as it was observed in the ionic balances of some samples in Petauke Town, anion exchangers should be added to soften the water.

6.3.2 Groundwater Types in Petauke Town

The dominance of the $CaHCO_3$ and Ca (Mg) HOC_3 water types in the study area was observed to be in conformity with the geology of the area which has carbonate minerals in metamorphic terrain (Phillips, 1964). As such the weathering of calcium bearing minerals such as oligoclase and calcite is responsible for the dominance of calcium in groundwater of the study area. Carbonate metamorphic rocks are reported to contribute high concentrations of elements such as Ca^{2+}, Mg^{+2} Na^{+}, K^{+} and Cl^{-} to the groundwater (cf. Zuurdeeg and Van der Weiden, 1985 as quoted in Appelo and Postma, 2005). Wanda et al (2010) obtained similar results in the weathered basement aquifers in Northern Malawi and concluded that the weathering of minerals such as calci silicates, marble, quartzo-feldspathic, biotite, and pyroxene contribute the concentrations of Mg^{+2} Na^{+}, K^{+} and Ca^{+2} to groundwater. Furthermore, Wanda et al, (2010) noted that Ca-HCO_3 type of water also results from the influence of carbonic acid on the weathering of silicate and ferromagnesian minerals by percolating water reach in CO_2. The major cation (Ca, Mg, Na, K) and anion (HCO_3, SO_4, Cl) composition of groundwater in the study area is typical for continental groundwater of primarily meteoric origin, shown by the accumulation of data in the left quarter (Ca/Mg-HCO) of the rhombus in the Piper diagram (Figure 13; Figure 14) and further shows that most groundwater is hard (cf. Baumle et al., 2007).

6.4 Temporal Variability of Groundwater Quality in Petauke Town

While the graphical plots of the major cations and anions (Figures 15; Figure 16; Figure 17; Figure 18; Figure 19) show that there is some temporal variations/differences in the concentrations of the cations and anions, the ANOVA results (Table 8) clearly indicate that there exists no significant difference in groundwater quality in Petauke Town between the groundwater samples collected in the dry and wet season. The graphical variations observed in Figures 15 to 19, though visually evident were found not to be statistically significant at 0.5 level of confidence. The seasonal change therefore does not affect groundwater quality in Petauke Town with regards chemical and physical characteristics. Going by the observation made by (Freeze and Cherry, 1979), temporal variation of groundwater chemical quality may be easy to visualize, but its detailed chemical composition as emanating from the natural dissolution of the geological units in which the particular aquifer occurs is complex and involves a number of considerations such as the rate of solubility of the rock type, residence time of water in a particular aquifer, aquifer type and groundwater level fluctuations. They argued that whereas the carbonate terrain can change rapidly due to percolating water, sedimentary aquifers rich in sandstone, siltstone and granites generally show low chemical changes over short periods of time. However, it is important to point out here that the concentration of chemical constituents in groundwater can change rapidly due to anthropogenic causes such as increased use of agricultural fertilizers, pesticides and industrial spillages (Karim et al., 2010). It is possible here that the temporal variation in groundwater quality in Petauke Town could be significant if the number of sampling boreholes was increased and the period and frequency of sampling was also increased.

There was, however variation in groundwater quality between the different boreholes (Figures 15, 16, 17, 18 and 19). This was observed to be as result of the spatial variation of borehole locations, as each borehole was drilled in a formation with different chemical combination as emanating from geology (Appendix 9). The results obtained in the analysis of groundwater quality along transects on the geology map (Figure 9), showed that the concentration of ions varied considerably with spatial variation (Figure 20; Figure 21; Figure 22; Figure 23). In particular, the concentration of the major ions HCO_3, Cl, SO_4, Ca, Mg, Na and K increased from the quatzo-feldspatic paragneiss formation in the northern part of the town to the centre where the geology differentiates into the semipelitic gneiss, alluvium and quatzo-feldspatic paragneiss. Magnesium, Na and SO_4 tend to increase in the alluvium which is comprised of clay, mudstone and sandstone. This observation was also similar along the transect from west to east across the town suggesting that the quality of groundwater was influenced by the ion exchange in the clay soils and the weathering from lithological units. Appendix 9 shows the lithology of some of the sampling boreholes and their respective spatial location. Phillips (1964) reported that geochemical processes within Petauke Town included the incongruent weathering of the intermixed silicates such as quartz, feldspar (plagioclase, albite, biotite) and locally, the dissolution of interbedded impure/contaminated limestone. Freeze and Cherry (1979) pointed out that since silicate weathering is a slow process, the total dissolved load of minerals in groundwater in carbonate metamorphic and sedimentary aquifers, is usually lower (<500 mg/l). This was as observed in this study. The effect of silicate weathering on the water chemistry is the additions of dissolved silica as well as cations such as sodium from the weathering of albite (Na-feldspar) or magnesium and iron from the weathering of ferromagnetic magnetite (cf. Freeze and Cherry, 1979). Appelo & Postma (2005), Wanda et al (2010) and Freeze and Cherry (1979) noted that the increase in cation concentration is always accompanied by the dissociation of bicarbonate acid resulting in an increase in bicarbonate. Similar observations were made in this study (Figure 20; Figure 21).

The observed high levels of nitrate concentration around the unused dump site, petroleum service stations and farmland area is attributable to the use of pesticides and fertilisers for agriculture purposes and also due to waste products of petroleum products and leachate from the service stations and old dump site respectively (cf. Karim et al., 2010). This is comparable to observations made by Burkart and Kolpin (1993) who reported that nitrate can reach both surface and groundwater as a consequence of agricultural activity (including excess application of inorganic nitrogenous fertilizers and manures), from wastewater disposal and from oxidation of nitrogenous waste products in human and animal excreta, including septic tanks and dump sites). Mpamba et al (2008) in studying the evidence and implication of groundwater mining in the Lusaka urban aquifers made similar observations and concluded that elevated chloride and nitrate in some boreholes were attributed to anthropogenic pollution arising from on-site sanitation.

Similarly, the ANOVA revealed that there was no significant statistical difference in bacteriological contamination of groundwater between the dry and wet season. This was because the same high percentages of water points (70-80%) were found not to meet the ZABS (2008) and WHO (2008) standards of nil total and faecal coliforms per 100ml of water meant for drinking in both seasons. However, it is cardinal to appreciate here that with regards microbiological contamination, it was observed that the difference existed in the amount/count of coliforms between the dry and wet season. It was found out that as the season changed from dry to the wet one, the number of total and faecal coliforms per 100ml of groundwater sample tended to increase. In some samples, the total count of coliforms even increased and became Too Numerous To Count (Table 6; Appendices 1 and 2). These findings were similar to the findings of Egwari and Aboaba (2002), Erume and Ocaido (2010), Baumle et al., (2007) and Howard et al., (2003) who linked the rainy season to increasing levels of microbiological contamination of water especially in areas with poor sanitation. Considering the effects of drinking contaminated water on the human health and how that microbiological contamination accounts for a larger percentage of all water borne diseases such as diarrhoea, dysentery and cholera especially in developing countries (WHO, 2008; UNICEF, 1998; UN, 2008), there is need for concerted effort in water quality monitoring, treatment and other water resources management aspects that ensure public health and well being of all households.

6.5 Comparison of the Groundwater Quality for Petauke Town with the WHO (2008) and ZABS (2008) Drinking Water Quality Standards

Whilst it was observed that measurements of most of the samples collected in the dry and wet seasons fell within the ZABS (2008) and WHO (2008) guidelines for drinking water except pH, turbidity, iron, nitrate, total and faecal coliforms, it is cardinal to note that the physical, chemical and microbiological properties of the analysed groundwater samples for the two seasons showed considerable variation. For example, the percentages of total and faecal coliform in the wet season were slightly above those observed during the dry season. This indicated that microbiological contamination of groundwater increased in the wet season compared to the dry one. This increase also occurred with respect to pH, turbidity, iron and nitrate. However, the percentages of samples with total hardness and nitrite values above the permissible limits dropped to zero and 4% in the wet season from 5 and 15% in the dry season respectively. This could be due to the increased groundwater level in the boreholes which is expected to rise in the rainy season, thus the concentration of calcium, nitrite and other ions per litre of water decreased due to dilution.

The World Health Organisation (2003) notes that the pH of drinking water is not a health concern, however, acidic water (with low pH) can leach metals from plumbing systems, which can cause health problems (Rose, 1986). Water with a pH value less than 7 indicates acidity and tends to be corrosive. Symptoms of low pH are bluish green stains on fixtures with copper plumbing, reddish stains with galvanized iron plumbing and water system corrosion problems and plumbing leaks (U.S. Environmental Protection Agency (EPA) 2007). In the study area the effects of low pH especially in the high density areas where it was observed has been corrosion of galvanised iron pipes which has been a major challenge on the Village Water, Sanitation and Hygiene Education (V-WASHE) committees as they have to replace the pipes more often, a situation that increases the cost of borehole maintenance (Gauff-Ingenieure, 2001). This was actually one of the reasons why two of the boreholes could not be sampled in the wet season as they were found not be working at the time of sampling due to leaking galvanised iron pipes.

Whilst it is probable that the high iron content in the groundwater of the study area is as a result of the weathering of the ferromagnesian minerals such as magnetite encountered in the geology of the area (Phillips, 1964), part of it is being added to the water as a result of the corrosion of the galvanised iron pipes and connecting rods in the India Mark II hand pumps due to low pH. The corrosion also results in water being turbid. These observations compare well with those made by Langenegger (1994) who conducted a geochemical survey in West Africa to identify the cause of red water problems encountered by many hand pump users when natural groundwater quality had generally iron levels typically below 1 mg/l. The results showed that approximately half of the water samples had a pH below 6.5 and water delivered from hand pumps equipped with galvanise iron hand pumps contained excessive levels of iron (over 20 mg/l in many cases) and most consumers were unwilling to drink water containing 5 mg/l iron or more. Based on these findings Langenegger (1994) concluded that aggressive water, especially with a pH less than 6.5, as was observed in this study in Petauke Town, was corroding hand pump rods and rising mains. Additionally, Langenegger (1994) noted that about two-thirds of hand pump failures in the West Africa were directly or indirectly caused by corrosion, which even damaged galvanized rising mains and pump rods. As newly installed hand pumps corroded, they produced red water that was unacceptable to users.

The Petauke Town situation regarding low pH has not reached a point where users reject to use a particular water point however collective measures similar to those encouraged by (Langenegger, 1994) where water quality was improved in low pH groundwater in West Africa by using corrosion resistant pipes (e.g. stainless steel and pvc) rising mains should be adopted.

CHAPTER 7

CONCLUSION AND RECOMMENDATION

7.1 General Remarks

This chapter concludes the findings of the study on the characterisation and temporal variability assessment of groundwater quality in Petauke Town. A summary on the study and recommendations are also outlined.

7.2 Summary

The chemical, physical and microbiological characteristics of groundwater in Petauke Town were studied and they showed considerable variation. The groundwater was found to be generally hard due to high calcium and magnesium content, the ions that contribute to the total hardness of water. In particular, 58% of the water was found to be hard, 26% was moderately hard, 14% was very hard and only 2% was soft. While water hardness has no known health effect on humans, it causes scale deposition in the treatment works, distribution system and water heating utensils, effects that were observed in the Petauke Town. The study revealed that the abundance of the major ions in the groundwater in the study area were in the order $Ca>Mg>Na>K=HCO_3>Cl>SO_4$. The major water types in the town were observed to be $CaHCO_3$ (71%) and Ca (Mg) HCO_3 (19%). However there also exists small occurrences of CaCl (6%) and Ca (Na) HCO_3 (4%) groundwater types. Nitrate in groundwater in the study area was noted higher around the town centre where there are petroleum service stations and also where the old dump site was situated and near the Farmers Training Centre where agriculture activities with high uses of fertilizers and pesticides take place. Physical properties did not show a lot of variations except for turbidity and total suspended solids.

Most of the sampled boreholes in the study area were microbiologically contaminated due to high levels of total and faecal coliform presence. This contamination of water was observed to be as a result of the lack of hygiene for most of the boreholes and poor sanitation practices in the town, especially in the high density areas where people use pit latrines. Microbiological contamination of water turns to increase in the rain season as the rains washed off the indiscriminately disposed excreta into the water sources and came into contact with the rising groundwater level. The increase in microbiological contamination was showed by increased numbers of boreholes recording the presence of total and faecal coliform. It increased from 70% in the dry season to 80% in the wet season. The increase in contamination was also showed by the increased count of the total and faecal coliforms in the samples. Whereas in the dry season the counts ranged from 1-80 in the groundwater samples, in the wet season they even became too numerous to count. The presence of total and faecal colifoms in water meant for human consumption posses a great threat to human health as these pathogens are known to contribute to waterborne diseases such as diarrheal. It is in this regard that there is need to safeguard the water sources through water quality monitoring and chlorination.

With regards temporal variability in groundwater quality in the study area, the study revealed that some variation existed between the dry and wet season. The concentrations of the major ions (Ca, Mg, Ca, HCO_3, Cl and SO_4) were observed to be high in the dry season than in the wet season. This was as a result of the increased groundwater level in the rain season which resulted in dilution of the ions hence less concentrated. The number of boreholes showing presence of total and faecal coliforms and the total count of these pathogens was observed to increase in the wet season compared to the dry one. However, when the variation was subjected to a statistical test to check for its significance, the ANOVA revealed that the variation was not statistically significant since for all the parameters of groundwater quality considered in Petauke Town, $F_{critical}$ was greater than the P-Value at 0.05 or 95% level of significance. Consequently, it was noted that there was no seasonal variation in groundwater quality in Petauke Town.

When compared to the ZABS (2008) and WHO (2008) guidelines, it was observed that most of the parameters of the groundwater in Petauke Town fell within the permissible limits for drinking water quality except for pH, turbidity, nitrates, iron, total and faecal coliforms. Twenty eight percent of the samples showed to have pH lower than the permissible limits whereas 22% and 24% had turbidity and iron values above the standards respectively. The pH recorded values that were as low as 5.83 against the permissible limit of 6.5 whereas iron was found to have readings as high as 2.62 mg/l above the permissible limit of 0.3mg/l in water meant for human consumption. Nitrate was observed to be higher than the limits in 10% of the samples whereas 72% and 56% showed presence of total and faecal colifoms in 100ml of water meant for drinking respectively. Any parameter above/below the ZABS/WHO limits was considered as a groundwater contaminant. Therefore, in the study area the groundwater contaminants were observed to be pH, turbidity, nitrates, iron, total and faecal coliforms. The sources of the groundwater contamination in the study area are therefore both natural and anthropogenic. Water hardness and pH is caused naturally by the geology of the area and related reactions whereas the increase in nitrate and the presence of total and faecal coliforms in water meant for drinking was caused by anthropogenic activities. It is worth to note here that with effective monitoring of water sources in the town, anthropogenic pollution of groundwater can be kept in check and controlled.

7.3 Conclusion

Groundwater in Petauke Town is characterised by low pH (6.21), high HCO_3 (609.6 mg/l), high $CaCO_3$ (598 mg/l) and the abundance of major ions is in the order of Ca > Mg >Na> K = HCO_3 > Cl >SO_4. The high amounts of Ca^{2+} are the likely cause of scale deposition in the water reticulation system. Groundwater varies from soft to very hard water. In particular, 58% of the groundwater in the town is hard, 26% is moderately hard, 14% is very hard and only 2% is soft. The major groundwater types in Petauke Town are $CaHCO_3$ and Ca (Mg) HCO_3.

The study revealed that there was no significant temporal variation in the groundwater quality in Petauke Town between the dry and wet season and observed values of most of the groundwater parameters fell within the ZABS (2008)/WHO (2008) permissible limits for drinking water except for total colifoms (TNTC), faecal coliforms (TNTC), pH (5.83), total hardness (598 mg$CaCO_3$/l), nitrate (23.2 mg/l), iron (2.62 mg/l) and turbidity (81.9 NTU). It is important to note here that the low pH level in groundwater which is slightly acidic is the main cause of galvanised iron pipes corrosion leading to leakages and pump failure. Total and faecal coliforms, pH, total hardness, turbidity, nitrate and iron are the major groundwater contaminants in the study area.

7.4 Recommendations

The recommendations are as follows;

i. The local authority, Department of Water Affairs, Ministry of Health and Eastern Water Supply and Sewerage Company should enhance and ensure that water quality monitoring activities are routinely done in Petauke Town and district as a whole. This will enable early detection and control of parameters that may pose a danger to human health such as the presence of total and faecal coliform in drinking water.

ii. The local authority, Ministry of Health and Eastern Water Supply and Sewerage Company should ensure that chlorination of boreholes in the township and Petauke district as a whole is enhanced so as to curb microbiological pollution of groundwater and ensure provision of safe and clean water to the residents.

iii. The Government of the Republic of Zambia should set up water quality analysis laboratories in the provincial centres to reduce the cost of water analysis and enable more assessments to be done.

iv. The Government of the Republic of Zambia, working together with cooperating partners in the water sector should start using hand pumps with pvc and stainless steel pipes to impede corrosion of galvanised iron pipes.

v. There is need for more research on the geospatial analysis of groundwater quality in Petauke District whose scope should also include analysis of the residence time of groundwater in the aquifer and measuring the dissolution rates of the major rock formations.

vi. In cases where boreholes are not chlorinated regularly, each household in the community should chlorinate their drinking water to curb microbiological contamination. The community should also enhance their role with regards borehole maintenance by constructing proper soak away pits and fences in addition to ensuring high levels of hygiene around water points.

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APPENDICES

Appendix 1: Physical, chemical and microbiological parameters of groundwater in the dry season (June, 2011) in Petauke Town, Eastern Province, Zambia.

Parameter	Sample Identification Number and Location of Borehole					Permissible Limits	
	Pt1	Pt2	Pt3	Pt4	Pt5	WHO	ZABS
	S: -14.241°	S: -14.249°	S: -14.258°	S: -14.258°	S: -14.259°		
	E: 31.339°	E: 31.319°	E: 31.314°	E: 31.322°	E: 31.328°		
Temp (C°)	25.8	25.9	25.6	25.1	22.2	-	-
pH	7.28	6.61	6.55	6.76	6.99	6.5-8.5	6.5-8.5
Turbidity (NTU)	6.65	29.4	81.9	0.35	0.15	5	5
EC (µS/cm))	369	95	397	390	515	1500	1500
TDS (mg/l)	185	47	198	195	258	1000	1000
TSS (mg/l)	2.6	12	32	<1.0	<1.0	-	-
Total hardness (as mg $CaCO_3$/l)	180	72	138	260	350	500	500
Ca hardness (as mg $CaCO_3$/l)	134	52	134	160	294	500	500
Alkalinity (as mg $CaCO_3$/l)	178	68	130	256	348	500	500
Iron (mg/l)	0.36	1.33	2.11	0.31	0.33	0.3	0.3
NH_4 (as NH_4-Nmg/l)	0.02	0.09	0.04	<0.01	<0.01	1.5	1.5
SO_4 (mg/l)	16.65	99.2	25.7	35.55	59.8	400	-
Cl (mg/l)	29	10	9	13	27	250	250
NO_2 (as NO_2-Nmg/l)	0.038	0.271	0.016	0.031	<0.001	0.1	0.1
NO_3 (as NO_3-Nmg/l)	1.29	3.54	0.94	2.24	16.8	10	10
Acidity (as mg $CaCO_3$/l)	Nil	22	28	Nil	Nil	500	500
Total PO_4 (mg/l)	0.53	1.55	1.81	0.31	0.33	5	5
Mg (mg/l)	11.04	4.8	0.96	24	13.44	-	-
Ca (mg/l)	53.6	20.8	53.6	64	117.6	200	200
F (mg/l)	0.14	0.07	0.12	0.13	0.22	1.5	1.5
K (mg/l)	5.35	2.18	1.89	2.79	3.77	-	-
Na (mg/l)	17.28	6.6	6.12	8.45	12.58	200	200
Mn (mg/l)	<0.01	<0.01	0.02	<0.04	<0.01	0.5	0.5
Total coliforms (#/100ml)	0	0	0	0	64	0	0
Faecal coliforms (#/100ml)	0	0	0	0	30	0	0

Appendix 1 cont.........................

Parameter	Sample Identification Number and Location of Borehole					Permissible Limits	
	Pt6	Pt7	Pt8	Pt9	Pt10	WHO	ZABS
	S: -14294^o	S: -14.259^o	S: -14.250^o	S: -14.259^o	S: -14.240^o		
	E: 31.339^o	E: 31.339^o	E: 31.330^o	E: 31.357^o	E: 31.360^o		
Temp (C^o)	24.8	25.8	23.5	22	25	-	-
pH	6.93	6.92	6.58	6.84	6.88	6.5-8.5	6.5-8.5
Turbidity (NTU)	8.6	0.17	0.47	0.2	0.36	5	5
EC (µS/cm))	482	532	259	547	686	1500	1500
TDS (mg/l)	241	265	179	272	344	1000	1000
TSS (mg/l)	2	<1.0	<1.0	<1.0	<1.0	-	-
Total hardness (as mg $CaCO_3$/l)	308	386	142	354	456	500	500
Ca hardness (as mg $CaCO_3$/l)	186	244	106	298	200	500	500
Alkalinity (as mg $CaCO_3$/l)	298	378	139	348	422	500	500
Iron (mg/l)	<0.01	0.11	0.09	<0.01	0.13	0.3	0.3
NH_4 (as NH_4-Nmg/l)	<0.04	<0.01	<0.01	<0.01	<0.01	1.5	1.5
SO_4 (mg/l)	88.6	53.2	118.7	201.8	2.25	400	-
Cl (mg/l)	38	13	27	13	32	250	250
NO_2 (as NO_2 -Nmg/l)	0.034	<0.001	<0.001	<0.001	<0.001	0.1	0.1
NO_3 (as NO_3 -Nmg/l)	23.2	1.15	5.37	1.2	0.8	10	10
Acidity (as mg $CaCO_3$/l)	Nil	Nil	14	Nil	Nil	500	500
Total PO_4 (mg/l)	1.64	0.88	1.33	0.83	0.28	5	5
Mg (mg/l)	28.32	31.01	8.64	13.44	60.44	-	-
Ca (mg/l)	74.4	101.6	42.4	119.2	80	200	200
F (mg/l)	0.19	0.19	0.14	0.18	0.21	1.5	1.5
K (mg/l)	8.15	2.9	4.98	4.77	6.96	-	-
Na (mg/l)	27.7	8.84	17.82	17.42	21.12	200	200
Mn (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	0.5	0.5
Total coliforms (#/100ml)	74	22	18	0	0	0	0
Faecal coliforms (#/100ml)	40	12	6	0	0	0	0

Appendix 2: Physical, chemical and microbiological parameters of groundwater in the dry season (August, 2011) in Petauke Town, Eastern Province, Zambia.

Parameter	Sample Identification Number and Location of Borehole					Permissible Limits	
	SM 1	SM 2	SM 3	SM 4	SM 5	WHO	ZABS
	S: -14.2371°	S: -14.2419°	S: -14.2448°	S: -14.249°	S: -14.250°		
	E: 31.3294°	E: 31.3260°	E: 31.3177°	E: 31.319°	E: 31.317°		
Temp (C°)	24.4	25	24.6	24.9	25.5	-	-
pH	6.5	6.92	6.86	6.76	6.68	6.5-8.5	6.5-8.5
Turbidity (NTU)	1.91	2.7	1.8	4.47	0.7	5	5
EC (µS/cm))	510	523	530	409	354	1500	1500
TDS (mg/l)	256	262	265	204	177	1000	1000
TSS (mg/l)	<1.0	<1.0	<1.0	<1.0	<1.0	-	-
Total hardness (as mg $CaCO_3$/l)	156	180	178	152	120	500	500
Ca hardness (as mg $CaCO_3$/l)	128	132	156	112	110	500	500
Alkalinity (as mg $CaCO_3$/l)	150	174	168	144	110	500	500
Iron (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	0.3	0.3
NH_4 (as NH_4-Nmg/l)	0.01	<0.01	<0.01	<0.01	<0.01	1.5	1.5
SO_4 (mg/l)	<0.01	<0.01	9.9	<0.01	6	400	-
Cl (mg/l)	22	23	13	16	16	250	250
NO_2 (as NO_2-Nmg/l)	0.003	0.002	0.042	0.018	0.018	0.1	0.1
NO_3 (as NO_3-Nmg/l)	0.25	0.06	6.67	2.54	2.61	10	10
Acidity (as mg $CaCO_3$/l)	Nil	Nil	Nil	Nil	8	500	500
Total PO_4 (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	5	5
Mg (mg/l)	18.43	19.01	22.46	16.13	15.84	-	-
Ca (mg/l)	51.2	52.8	62.4	44.8	44	200	200
F (mg/l)	0.15	0.18	0.11	0.18	0.2	1.5	1.5
K (mg/l)	4.65	4.86	2.75	3.38	3.38	-	-
Na (mg/l)	14.52	15.18	8.58	10.56	10.56	200	200
Mn (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	0.5	0.5
Total coliforms (#/100ml)	0	6	TNTC	0	0	0	0
Faecal coliforms (#/100ml)	0	2	100	0	0	0	0

TNTC - Too Numerous To Count

Appendix 2 cont............

Parameter	Sample Identification Number and Location of Borehole					Permissible Limits	
	SM 6	SM 7	SM 8	SM 9	SM 10	WHO	ZABS
	S: -14.256°	S: -14.258°	S: -14.259°	S: -14.257°	S: -14.258°		
	E: 31.314°	E: 31.312°	E: 31.319°	E: 31.321°	E: 31.322°		
Temp (C°)	25.3	24.6	24	24.2	25.5	-	-
pH	6.3	6.28	6.62	6.79	6.78	6.5-8.5	6.5-8.5
Turbidity (NTU)	7	3.52	0.47	0.95	3.18	5	5
EC (µS/cm))	513	826	620	461	511	1500	1500
TDS (mg/l)	256	414	310	230	255	1000	1000
TSS (mg/l)	<1.0	<1.0	<1.0	<1.0	<1.0	-	-
Total hardness (as mg $CaCO_3$/l)	120	238	198	144	176	500	500
Ca hardness (as mg $CaCO_3$/l)	114	212	160	128	144	500	500
Alkalinity (as mg $CaCO_3$/l)	114	226	184	140	170	500	500
Iron (mg/l)	0.43	<0.01	0.67	<0.01	<0.01	0.3	0.3
NH_4 (as NH_4-Nmg/l)	0.54	0.01	<0.01	<0.01	<0.01	1.5	1.5
SO_4 (mg/l)	20.4	20.8	<0.01	<0.01	10.4	400	-
Cl (mg/l)	10	20	25	15	15	250	250
NO_2 (as NO_2-Nmg/l)	0.032	0.024	0.057	0.026	0.017	0.1	0.1
NO_3 (as NO_3-Nmg/l)	0.54	1.55	5.15	5.17	1.34	10	10
Acidity (as mg $CaCO_3$/l)	10	12	Nil	Nil	Nil	500	500
Total PO_4 (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	5	5
Mg (mg/l)	16.42	30.53	9.12	3.84	7.68	-	-
Ca (mg/l)	45.6	84.8	64	51.2	57.6	200	200
F (mg/l)	0.38	0.15	0.11	0.12	0.19	1.5	1.5
K (mg/l)	2.11	4.22	5.28	3.17	3.17	-	-
Na (mg/l)	6.6	13.2	16.5	9.9	9.9	200	200
Mn (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	0.5	0.5
Total coliforms (#/100ml)	7	TNTC	32	0	6	0	0
Faecal coliforms (#/100ml)	0	83	6	0	5	0	0

TNTC - Too Numerous To Count

Appendix 3: Physical, chemical and microbiological parameters of groundwater in the wet season (January, 2012) in Petauke Town, Eastern Province, Zambia.

Parameter	Sample Identification Number and Location of Borehole					Permissible Limits	
	SM 11	SM 12	SM 13	SM 14	SM 15	WHO	ZABS
	S: -14.255°	S: -14.259°	S: -14.263°	S: -14.294°	S: -14.294°		
	E: 31.321°	E: 31.328°	E: 31.333°	E: 31.339°	E: 31.333°		
Temp (C°)	24.4	22.5	25.5	24.8	24.3	-	-
pH	6.67	7.02	6.71	6.64	6.63	6.5-8.5	6.5-8.5
Turbidity (NTU)	0.55	0.43	10.4	0.46	1.37	5	5
EC (µS/cm))	489	672	309	618	484	1500	1500
TDS (mg/l)	245	336	154	308	241	1000	1000
TSS (mg/l)	<1.0	<1.0	1.3	<1.0	<1.0	-	-
Total hardness (as mg $CaCO_3$/l)	144	204	96	194	138	500	500
Ca hardness (as mg $CaCO_3$/l)	142	144	64	72	84	500	500
Alkalinity (as mg $CaCO_3$/l)	138	200	91	188	128	500	500
Iron (mg/l)	0.43	<0.01	0.67	<0.01	<0.01	0.3	0.3
NH_4 (as NH_4-Nmg/l)	<0.01	0.22	0.74	<0.01	<0.01	1.5	1.5
SO_4 (mg/l)	40.6	7	<0.01	86.8	93.4	400	-
Cl (mg/l)	36	28	18	19	22	250	250
NO_2 (as NO_2-Nmg/l)	0.002	0.002	0.088	0.001	0.002	0.1	0.1
NO_3 (as NO_3-Nmg/l)	7.25	10.2	5.75	0.73	0.42	10	10
Acidity (as mg $CaCO_3$/l)	Nil	Nil	Nil	Nil	Nil	500	500
Total PO_4 (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	5	5
Mg (mg/l)	0.48	14.4	7.68	29.28	12.96	-	-
Ca (mg/l)	56.8	57.6	25.6	28.8	33.6	200	200
F (mg/l)	0.18	0.1	0.09	0.14	0.1	1.5	1.5
K (mg/l)	7.6	5.91	5.91	4.01	4.65	-	-
Na (mg/l)	23.76	18.48	18.48	12.54	14.52	200	200
Mn (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	0.5	0.5
Total coliforms (#/100ml)	12	29	10	105	TNTC	0	0
Faecal coliforms (#/100ml)	10	10	3	26	TNTC	0	0

TNTC - Too Numerous To Count

Appendix 3 cont............

Parameter	Sample Identification Number and Location of Borehole					Permissible limits	
	SM 16	SM 17	SM 18	SM 19	SM 20	WHO	ZABS
	S: -14.281^o	S: -14.275^o	S: -14.269^o	S: -14.265^o	S: -14.259^o		
	E: 31.337^o	E: 31.339^o	E: 31.331^o	E: 31.338^o	E: 31.339^o		
Temp (C^o)	23.8	24.2	22.4	22.6	25.8	-	-
pH	6.49	6.83	6.71	6.73	6.75	6.5-8.5	6.5-8.5
Turbidity (NTU)	41.5	1.01	3.22	0.7	2.39	5	5
EC (µS/cm))	545	582	630	392	668	1500	1500
TDS (mg/l)	271	290	316	195	333	1000	1000
TSS (mg/l)	9.3	<1.0	<1.0	<1.0	<1.0	-	-
Total hardness (as mg $CaCO_3$/l)	164	174	180	106	238	500	500
Ca hardness (as mg $CaCO_3$/l)	152	152	164	92	92	500	500
Alkalinity (as mg $CaCO_3$/l)	158	170	168	100	220	500	500
Iron (mg/l)	1.38	<0.01	<0.01	<0.01	<0.01	0.3	0.3
NH_4 (as NH_4-Nmg/l)	<0.01	<0.01	<0.01	<0.01	0.01	1.5	1.5
SO_4 (mg/l)	27.5	26.4	23.4	10.6	48	400	-
Cl (mg/l)	16	14	23	25	30	250	250
NO_2 (as NO_2-Nmg/l)	0.011	<0.001	0.04	0.006	0.029	0.1	0.1
NO_3 (as NO_3-Nmg/l)	0.91	5.65	6.3	0.48	12.2	10	10
Acidity (as mg $CaCO_3$/l)	8	Nil	Nil	Nil	Nil	500	500
PO_4 (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	5	5
Mg (mg/l)	2.88	21.76	3.84	3.36	35.04	-	-
Ca (mg/l)	60.8	60.8	65.6	36.8	36.8	200	200
F (mg/l)	0.1	0.11	0.2	0.21	0.19	1.5	1.5
K (mg/l)	3.38	2.96	4.86	5.28	6.34	-	-
Na (mg/l)	10.56	9.24	15.18	16.5	19.8	200	200
Mn (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	0.5	0.5
Total coliforms (#/100ml)	8	TNTC	TNTC	40	0	0	0
Faecal coliforms (#/100ml)	3	TNTC	70	10	0	0	0

TNTC - Too Numerous To Count

Appendix 3 cont............

Parameter	Sample Identification Number and Location of Borehole					Permissible Limits	
	SM 21	SM 22	SM 23	SM 24	SM 25	WHO	ZABS
	S: -14.250^o	S: -14.240^o	S: -14.258^o	S: -14.250^o	S: -14.253^o		
	E: 31.330^o	E: 31.360^o	E: 31.351^o	E: 31.335^o	E: 31.329^o		
Temp (C^o)	24.9	25	25.1	25	25	-	-
pH	6.54	6.9	6.44	7.61	6.61	6.5-8.5	6.5-8.5
Turbidity (NTU)	0.61	0.45	1.13	1.31	0.33	5	5
EC (µS/cm))	556	7.7	617	484	851	1500	1500
TDS (mg/l)	279	353	308	241	428	1000	1000
TSS (mg/l)	<1.0	<1.0	<1.0	<1.0	<1.0	-	-
Total hardness (as mg $CaCO_3$/l)	186	164	216	146	306	500	500
Ca hardness (as mg $CaCO_3$/l)	152	154	132	48	148	500	500
Alkalinity (as mg $CaCO_3$/l)	180	148	210	132	300	500	500
Iron (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	0.3	0.3
NH_4 (as NH_4-Nmg/l)	<0.01	<0.01	<0.01	0.18	0.01	1.5	1.5
SO_4 (mg/l)	44.4	26.6	19.6	36.9	74.1	400	-
Cl (mg/l)	34	15	32	21	136	250	250
NO_2 (as NO_2-Nmg/l)	0.003	<0.001	0.001	0.019	0.005	0.1	0.1
NO_3 (as NO_3-Nmg/l)	5.84	0.55	0.71	0.2	7.75	10	10
Acidity (as mg $CaCO_3$/l)	Nil	Nil	Nil	Nil	Nil	500	500
PO_4 (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	5	5
Mg (mg/l)	8.16	2.4	20.16	23.52	37.92	-	-
Ca (mg/l)	60.8	61.6	52.8	19.2	59.2	200	200
F (mg/l)	0.13	0.18	0.22	0.21	0.2	1.5	1.5
K (mg/l)	7.18	3.17	6.76	4.44	28.72	-	-
Na (mg/l)	22.44	9.9	21.12	13.86	89.76	200	200
Mn (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	0.5	0.5
Total coliforms (#/100ml)	TNTC	15	19	TNTC	TNTC	0	0
Faecal coliforms (#/100ml)	TNTC	12	12	TNTC	TNTC	0	0

TNTC - Too Numerous To Count

Appendix 3 cont............

Parameter	Sample Identification Number and Location of Borehole					Permissible Limits	
	SM 26	SM 27	SM 28	SM 29	SM 30	WHO	ZABS
	S: -14.259°	S: -14.279°	S: -14.267°	S: -14.279°	S: -14.254°		
	E: 31.332°	E: 31.326°	E: 31.334°	E: 31.334°	E: 31.329°		
Temp (C°)	23.6	22.4	23.9	24	25	-	-
pH	6.76	6.56	6.34	6.18	6.61	6.5-8.5	6.5-8.5
Turbidity (NTU)	0.28	44	5	48.4	6.66	5	5
EC (µS/cm))	396	524	475	601	608	1500	1500
TDS (mg/l)	196	261	237	303	304	1000	1000
TSS (mg/l)	<1.0	3.8	<1.0	12.5	<1.0	-	-
Total hardness (as mg $CaCO_3$/l)	90	156	158	146	196	500	500
Ca hardness (as mg $CaCO_3$/l)	84	104	104	108	140	500	500
Alkalinity (as mg $CaCO_3$/l)	75	149	148	139	188	500	500
Iron (mg/l)	<0.01	0.81	0.33	3.53	0.54	0.3	0.3
NH_4 (as NH_4-Nmg/l)	<0.01	<0.01	<0.01	1.09	0.43	1.5	1.5
SO_4 (mg/l)	<0.01	<0.01	27.2	34.6	92.2	400	-
Cl (mg/l)	17	120	26	31	73	250	250
NO_2 (as NO_2-Nmg/l)	0.002	0.004	0.004	0.447	0.016	0.1	0.1
NO_3 (as NO_3-Nmg/l)	4.3	0.61	3.95	2.8	1.46	10	10
Acidity (as mg $CaCO_3$/l)	Nil	Nil	7	10	Nil	500	500
Total PO_4 (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	5	5
Mg (mg/l)	1.44	12.48	12.96	9.12	13.44	-	-
Ca (mg/l)	33.6	41.6	41.6	43.2	56	200	200
F (mg/l)	0.19	0.1	0.22	0.13	0.13	1.5	1.5
K (mg/l)	3.59	25.34	5.49	6.55	15.42	-	-
Na (mg/l)	11.22	79.2	17.16	20.46	48.18	200	200
Mn (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	0.5	0.5
Total coliforms (#/100ml)	13	TNTC	4	0	2	0	0
Faecal coliforms (#/100ml)	12	TNTC	0	0	0	0	0

TNTC - Too Numerous To Count

Appendix 4: Abundance of the major ions in the groundwater of Petauke Town, Eastern Province, Zambia in the dry season (June, 2011).

Sample ID: Pt1 **Location of Borehole** S: -14.2409°. E: 031. 3387°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	% mg/l	%meq/l
Ca	53.6	2.67	61.42	67.75
Mg	11.04	0.91	12.65	23.01
Na+K	22.63	0.36	25.93	9.23
Cl	29	0.82	11.04	17.38
SO_4	16.65	0.34	6.34	7.14
HCO_3	217	3.55	82.62	75.48

Abundance of major ions (%meq/l): Ca>Mg>Na+K=HCO_3>Cl>SO_4

Sample ID: Pt2 **Location of Borehole** S: -14.2494° E: 031.3197°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	20.80	1.04	60.50	65.93
Mg	4.80	0.39	13.96	25.09
Na+K	8.78	0.14	25.54	8.98
Cl	10.00	0.28	5.21	7.74
SO_4	99.20	2.00	51.64	54.99
HCO_3	82.90	1.36	43.15	37.27

Abundance of major ions (%meq/l): Ca>Mg>Na+K= SO_4>HCO_3>Cl

Sample ID: Pt3 **Location of Borehole** S: -14.2578° E: 031.3135°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	53.60	2.67	81.46	91.14
Mg	0.96	0.08	1.46	2.69
Na+K	11.24	0.18	17.08	6.17
Cl	9.00	0.25	4.66	7.54
SO_4	25.70	0.52	13.30	15.41
HCO_3	158.50	2.60	82.04	77.06

Abundance of major ions (%meq/l): Ca> Na+K> Mg = HCO_3>SO_4 >Cl

Sample ID: Pt4 **Location of Borehole** S:-14.2576° E: 031.3222°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	64.00	3.19	64.49	59.70
Mg	24.00	1.97	24.18	36.92
Na+K	11.24	0.18	11.33	3.38
Cl	13.00	0.37	3.71	6.12
SO_4	25.55	0.52	7.29	8.61
HCO_3	312.10	5.11	89.01	85.27

Abundance of major ions (%meq/l): Ca > Mg> Na+K = HCO_3> SO_4 >Cl

Sample ID: Pt5 **Location of Borehole** S:-14.2589° E: 031.3281°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	117.60	5.87	79.79	81.08
Mg	13.44	1.11	9.12	15.28
Na+K	16.35	0.26	11.09	3.64
Cl	27.00	0.76	5.28	8.54
SO_4	59.80	1.21	11.70	13.54
HCO_3	424.30	6.95	83.02	77.92

Abundance of major ions (%meq/l): Ca > Mg> Na+K = HCO_3> SO_4 >Cl

Sample ID: Pt6 **Location of Borehole** S:-14.2941° E: 031.3392°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	74.40	3.71	53.69	56.08
Mg	28.32	2.33	20.44	35.20
Na+K	35.85	0.58	25.87	8.72
Cl	38.00	1.07	7.76	12.17
SO_4	88.60	1.79	18.09	20.31
HCO_3	363.30	5.95	74.16	67.53

Abundance of major ions (%meq/l): Ca > Mg> Na+K = HCO_3> SO_4 >Cl

Sample ID: Pt7 **Location of Borehole** S:-14.2595° E: 031.3398°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	101.60	5.07	70.38	64.91
Mg	31.01	2.55	21.48	32.67
Na+K	11.74	0.19	8.13	2.42
Cl	13.00	0.37	2.47	4.08
SO_4	53.20	1.07	10.09	11.95
HCO_3	460.90	7.55	87.44	83.97

Abundance of major ions (%meq/l): Ca > Mg> Na+K = HCO_3> SO_4 >Cl

Sample ID: Pt8 **Location of Borehole** S:-14.2501° E: 031.3303°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	42.60	2.13	57.54	66.35
Mg	8.64	0.71	11.67	22.19
Na+K	22.80	0.37	30.79	11.46
Cl	27.00	0.76	8.57	12.83
SO_4	118.70	2.40	37.66	40.39
HCO_3	169.50	2.78	53.78	46.78

Abundance of major ions (%meq/l): Ca > Mg> Na+K = HCO_3> SO_4 >Cl

Sample ID: Pt9 **Location of Borehole** S:-14.2585° E: 031.3569°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	119.20	5.95	76.99	80.26
Mg	13.44	1.11	8.68	14.92
Na+K	22.19	0.36	14.33	4.82
Cl	13.00	0.37	2.03	3.22
SO_4	201.80	4.07	31.58	35.78
HCO_3	424.30	6.95	66.39	61.00

Abundance of major ions (%meq/l): Ca > Mg> Na+K = HCO_3> SO_4 >Cl

Sample ID: Pt10 **Location of Borehole** S:-14.2403° E: 031.3604°.

Parameter	**Concentration (mg/l)**	**Concentration (meq/l)**	**%mg/l**	**%meq/l**
Ca	80.00	3.99	47.47	42.39
Mg	60.44	4.97	35.87	52.81
Na+K	28.08	0.45	16.66	4.80
Cl	32.00	0.90	5.83	9.63
SO_4	2.25	0.05	0.41	0.48
HCO_3	514.50	8.42	93.76	89.89

Abundance of major ions (%meq/l): Mg > Ca> Na+K = HCO_3>Cl > SO_4

Appendix 5: Abundance of the major ions in the groundwater of Petauke Town, Eastern Province, Zambia in the dry season (August, 2011).

Sample ID: Pt1 **Location of Borehole** S: -14.2409°. E: 031. 3387°.

Parameter	**Concentration (mg/l)**	**Concentration (meq/l)**	**% mg/l**	**%meq/l**
Ca	61.60	3.07	36.75	31.26
Mg	76.32	6.28	45.53	63.87
Na+K	29.72	0.48	17.73	4.87
Cl	35.00	0.99	5.62	9.24
SO_4	17.50	0.35	2.81	3.31
HCO_3	570.59	9.34	91.57	87.45

Abundance of major ions (%meq/l): Mg > Ca> Na+K = HCO_3>Cl > SO_4

Sample ID: Pt2 **Location of Borehole** S: -14.2494° E: 031.3197°.

Parameter	**Concentration (mg/l)**	**Concentration (meq/l)**	**%mg/l**	**%meq/l**
Ca	30.40	1.52	17.83	12.57
Mg	125.28	10.31	73.49	85.45
Na+K	14.79	0.24	8.68	1.97
Cl	17.00	0.48	2.63	4.41
SO_4	20.15	0.41	3.12	3.74
HCO_3	609.61	9.98	94.26	91.84

Abundance of major ions (%meq/l): Mg > Ca> Na+K = HCO_3>Cl > SO_4

Sample ID: Pt3 **Location of Borehole** S: -14.2578° E: 031.3135°.

Parameter	**Concentration (mg/l)**	**Concentration (meq/l)**	**%mg/l**	**%meq/l**
Ca	52.00	2.59	64.32	65.19
Mg	13.92	1.15	17.22	28.78
Na+K	14.92	0.24	18.46	6.04
Cl	17.00	0.48	5.97	9.47
SO_4	52.95	1.07	18.61	21.12
HCO_3	214.58	3.51	75.42	69.41

Abundance of major ions (%meq/l): Ca > Mg > Na+K = HCO_3> SO_4 >Cl

Sample ID: Pt4 **Location of Borehole** S:-14.2576° E: 031.3222°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	64.00	3.19	75.96	83.92
Mg	4.32	0.36	5.13	9.34
Na+K	15.93	0.26	18.91	6.74
Cl	18.00	0.51	7.17	11.43
SO_4	30.75	0.62	12.24	13.98
HCO_3	202.39	3.31	80.59	74.60

Abundance of major ions (%meq/l): Ca > Mg > Na+K = HCO_3> SO_4 >Cl

Sample ID: Pt5 **Location of Borehole** S:-14.2589° E: 031.3281°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	120.00	5.99	73.89	78.54
Mg	14.40	1.18	8.87	15.54
Na+K	28.01	0.45	17.25	5.92
Cl	32.00	0.90	6.82	11.08
SO_4	22.80	0.46	4.86	5.65
HCO_3	414.36	6.78	88.32	83.27

Abundance of major ions (%meq/l): Ca > Mg > Na+K = HCO_3>Cl > SO_4

Sample ID: Pt6 **Location of Borehole** S:-14.2941° E: 031.3392°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	111.20	5.55	79.72	84.79
Mg	8.16	0.67	5.85	10.26
Na+K	20.12	0.32	14.43	4.95
Cl	23.00	0.65	5.31	8.61
SO_4	44.60	0.90	10.29	11.95
HCO_3	365.76	5.99	84.40	79.45

Abundance of major ions (%meq/l): Ca > Mg > Na+K = HCO_3> SO_4 >Cl

Sample ID: Pt7 **Location of Borehole** S:-14.2595° E: 031.3398°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	60.00	2.99	49.58	55.38
Mg	21.60	1.78	17.85	32.88
Na+K	39.42	0.63	32.57	11.74
Cl	44.00	1.24	8.88	14.14
SO_4	39.15	0.79	7.91	9.00
HCO_3	412.09	6.75	83.21	76.86

Abundance of major ions (%meq/l): Ca > Mg > Na+K = HCO_3>Cl > SO_4

Sample ID: Pt8 **Location of Borehole** S:-14.2501° E: 031.3303°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	24.00	1.20	36.80	42.08
Mg	14.88	1.22	22.82	43.02
Na+K	26.33	0.42	40.38	14.90
Cl	30.00	0.85	4.70	7.72
SO_4	38.35	0.77	6.00	7.06
HCO_3	570.59	9.34	89.30	85.22

Abundance of major ions (%meq/l): Mg > Ca> Na+K = HCO_3>Cl > SO_4

Sample ID: Pt9 **Location of Borehole** S:-14.2585° E: 031.3569°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	88.00	4.39	60.02	62.88
Mg	24.90	2.05	16.98	29.34
Na+K	33.72	0.54	23.00	7.78
Cl	38.00	1.07	6.44	10.00
SO_4	161.60	3.26	27.40	30.43
HCO_3	390.15	6.39	66.16	59.58

Abundance of major ions (%meq/l): Ca> Mg > Na+K = HCO_3> SO_4 >Cl

Sample ID: Pt10 **Location of Borehole** S:-14.2403° E: 031.3604°.

Parameter	**Concentration (mg/l)**	**Concentration (meq/l)**	**%mg/l**	**%meq/l**
Ca	73.60	3.67	68.37	63.57
Mg	23.52	1.94	21.85	33.50
Na+K	10.53	0.17	9.78	2.94
Cl	12.00	0.34	2.69	4.34
SO_4	94.50	1.91	21.21	24.47
HCO_3	338.94	5.55	76.09	71.19

Abundance of major ions (%meq/l): Ca> Mg > Na+K = HCO_3> SO_4 >Cl

Appendix 6: Abundance of the major ions in the groundwater of Petauke Town, Eastern Province, Zambia in the wet season (January, 2012).

Sample ID: SM1 **Location of Borehole** S: -14.23714^{o}. E: 031.32940^{o}.

Parameter	Concentration (mg/l)	Concentration (meq/l)	% mg/l	%meq/l
Ca	51.2	2.55	57.66	58.33
Mg	18.43	1.52	20.75	34.62
Na+K	19.17	0.31	21.59	7.05
Cl	22	0.62	10.74	17.16
SO_4	0.004	0.00	0.00	0.00
HCO_3	182.9	2.99	89.26	82.83

Abundance of major ions (%meq/l): Ca>Mg>Na+K=HCO_3>Cl>SO_4

Sample ID: SM2 **Location of Borehole** S: -14.24195^{o}. E: 031.32603^{o}.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	52.80	2.63	57.49	58.27
Mg	19.01	1.56	20.70	34.59
Na+K	20.04	0.32	21.82	7.14
Cl	23.00	0.65	9.78	15.74
SO_4	0.00	0.00	0.00	0.00
HCO_3	212.10	3.47	90.22	84.26

Abundance of major ions (%meq/l): Ca>Mg>Na+K=HCO_3>Cl>SO_4

Sample ID: SM3 **Location of Borehole** S: -14.24487^{o}. E: 031.317850^{o}.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	62.80	3.13	65.02	60.68
Mg	22.46	1.85	23.25	35.79
Na+K	11.33	0.18	11.73	3.53
Cl	13.00	0.37	5.71	9.35
SO_4	9.90	0.20	4.35	5.10
HCO_3	204.80	3.35	89.94	85.55

Abundance of major ions (%meq/l): Ca>Mg>Na+K=HCO_3>Cl>SO_4

Sample ID: SM4 **Location of Borehole** S: -14.2494°. E: 031.3197°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	44.80	2.24	59.84	59.03
Mg	16.13	1.33	21.54	35.05
Na+K	13.94	0.22	18.62	5.93
Cl	16.00	0.45	8.35	13.57
SO_4	0.00	0.00	0.00	0.00
HCO_3	175.60	2.88	91.65	86.43

Abundance of major ions (%meq/l): Ca>Mg>Na+K=HCO_3>Cl>SO_4

Sample ID: SM5 **Location of Borehole** S: -14.25047°. E: 031.31705°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	44.00	2.20	59.64	58.97
Mg	15.84	1.30	21.47	35.01
Na+K	13.94	0.22	18.89	6.03
Cl	16.00	0.45	10.25	16.30
SO_4	6.00	0.12	3.84	4.38
HCO_3	134.10	2.20	85.91	79.32

Abundance of major ions (%meq/l): Ca>Mg>Na+K=HCO_3>Cl>SO_4

Sample ID: SM6 **Location of Borehole** S: -14.2578°. E: 031.3135°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	45.60	2.28	64.47	60.41
Mg	16.42	1.35	23.22	35.87
Na+K	8.71	0.14	12.31	3.72
Cl	10.00	0.28	5.90	9.50
SO_4	20.40	0.41	12.04	13.87
HCO_3	139.00	2.28	82.05	76.63

Abundance of major ions (%meq/l): Ca>Mg>Na+K=HCO_3>Cl>SO_4

Sample ID: SM7 **Location of Borehole** S: -14.25809°. E: 031.31070°.

Parameter	**Concentration (mg/l)**	**Concentration (meq/l)**	**%mg/l**	**%meq/l**
Ca	84.80	4.23	63.88	60.24
Mg	30.53	2.51	23.00	35.76
Na+K	17.42	0.28	13.12	3.99
Cl	20.00	0.56	6.32	10.27
SO_4	20.80	0.42	6.58	7.64
HCO_3	275.50	4.51	87.10	82.09

Abundance of major ions (%meq/l): Ca>Mg>Na+K=HCO_3>Cl>SO

Sample ID: SM8 **Location of Borehole** S: -14.25974°. E: 031.31949°.

Parameter	**Concentration (mg/l)**	**Concentration (meq/l)**	**%mg/l**	**%meq/l**
Ca	64.00	3.19	67.44	74.36
Mg	9.12	0.75	9.61	17.47
Na+K	21.78	0.35	22.95	8.17
Cl	25.00	0.71	10.02	16.09
SO_4	0.00	0.00	0.00	0.00
HCO_3	224.50	3.68	89.98	83.90

Abundance of major ions (%meq/l): Ca>Mg>Na+K=HCO_3>Cl>SO_4

Sample ID: SM9 **Location of Borehole** S: -14.25703°. E: 031.32051°.

Parameter	**Concentration (mg/l)**	**Concentration (meq/l)**	**%mg/l**	**%meq/l**
Ca	51.20	2.55	75.17	82.91
Mg	3.84	0.32	5.64	10.25
Na+K	13.07	0.21	19.19	6.83
Cl	15.00	0.42	8.08	13.15
SO_4	0.00	0.00	0.00	0.00
HCO_3	170.70	2.80	91.92	86.85

Abundance of major ions (%meq/l): Ca>Mg>Na+K=HCO_3>Cl>SO_4

Sample ID: SM10 **Location of Borehole** S: -14.2576°. E: 031.3222°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	57.60	2.87	73.52	77.33
Mg	7.68	0.63	9.80	17.00
Na+K	13.07	0.21	16.68	5.66
Cl	15.00	0.42	6.45	10.51
SO_4	10.40	0.21	4.47	5.21
HCO_3	207.30	3.39	89.08	84.28

Abundance of major ions (%meq/l): Ca>Mg>Na+K=HCO_3>Cl>SO_4

Sample ID: SM11 **Location of Borehole** S: -14.25516°. E: 031.32812°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	% mg/l	%meq/l
Ca	56.80	2.83	64.08	83.88
Mg	0.48	0.04	0.54	1.17
Na+K	31.36	0.51	35.38	14.95
Cl	36.00	1.02	14.70	22.12
SO_4	40.60	0.82	16.58	17.86
HCO_3	168.30	2.76	68.72	60.03

Abundance of major ions (%meq/l): Ca>Mg>Na+K=HCO_3>Cl>SO_4

Sample ID: SM12 **Location of Borehole** S: -14.2589°. E: 031.3281°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	57.60	2.87	59.76	64.56
Mg	14.40	1.18	14.94	26.62
Na+K	24.39	0.39	25.30	8.82
Cl	28.00	0.79	10.04	16.04
SO_4	7.00	0.14	2.51	2.87
HCO_3	243.80	3.99	87.45	81.09

Abundance of major ions (%meq/l): Ca>Mg>Na+K=HCO_3>Cl>SO_4

Sample ID: SM13 **Location of Borehole** S: -14.26315^{o}. E: 031.33310^{o}.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	25.60	1.28	44.39	55.49
Mg	7.68	0.63	13.32	27.45
Na+K	24.39	0.39	42.29	17.06
Cl	18.00	0.51	13.96	21.85
SO_4	0.00	0.00	0.00	0.00
HCO_3	110.90	1.82	86.03	78.15

Abundance of major ions (%meq/l): Ca>Mg>Na+K=HCO_3>Cl>SO_4

Sample ID: SM14 **Location of Borehole** S: -14.2941^{o}. E: 031.3392^{o}.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	28.80	1.44	38.59	34.93
Mg	29.29	2.41	39.24	58.59
Na+K	16.55	0.27	22.17	6.48
Cl	19.00	0.54	5.67	8.87
SO_4	86.80	1.75	25.91	29.01
HCO_3	229.20	3.75	68.42	62.12

Abundance of major ions (%meq/l): Ca>Mg>Na+K=HCO_3>SO_4>Cl

Sample ID: SM15 **Location of Borehole** S: -14.29362^{o}. E: 031.33337^{o}.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	33.60	1.68	51.12	54.94
Mg	12.96	1.07	19.72	34.94
Na+K	19.17	0.31	29.16	10.12
Cl	22.00	0.62	8.10	12.26
SO_4	93.40	1.89	34.40	37.25
HCO_3	156.10	2.56	57.50	50.49

Abundance of major ions (%meq/l): Ca>Mg>Na+K=HCO_3>SO_4>Cl

Sample ID: SM16 **Location of Borehole** S: -14.28133°. E: 031.33657°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	60.80	3.03	78.33	86.80
Mg	2.88	0.24	3.71	6.78
Na+K	13.94	0.22	17.96	6.42
Cl	16.00	0.45	6.78	10.85
SO_4	27.50	0.56	11.65	13.35
HCO_3	192.60	3.15	81.58	75.81

Abundance of major ions (%meq/l): Ca>Mg>Na+K=HCO_3>SO_4>Cl

Sample ID: SM17 **Location of Borehole** S: -14.27474°. E: 031.33990°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	60.80	3.03	64.16	60.42
Mg	21.76	1.79	22.96	35.66
Na+K	12.20	0.20	12.87	3.91
Cl	14.00	0.39	5.65	9.14
SO_4	26.40	0.53	10.66	12.33
HCO_3	207.30	3.39	83.69	78.53

Abundance of major ions (%meq/l): Ca>Mg>Na+K=HCO_3>SO_4>Cl

Sample ID: SM18 **Location of Borehole** S: -14.26993°. E: 031.33059°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	65.60	3.27	73.31	83.67
Mg	3.84	0.32	4.29	8.08
Na+K	20.04	0.32	22.40	8.25
Cl	23.00	0.65	9.16	14.50
SO_4	23.40	0.47	9.32	10.56
HCO_3	204.80	3.35	81.53	74.94

Abundance of major ions (%meq/l): Ca>Na+K> Mg =HCO_3 >Cl>SO_4

Sample ID: SM19 **Location of Borehole** S: -14.26584°. E: 031.33780°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	36.80	1.84	59.41	74.54
Mg	3.36	0.28	5.42	11.22
Na+K	21.78	0.35	35.16	14.24
Cl	25.00	0.71	15.87	24.19
SO_4	10.60	0.21	6.73	7.34
HCO_3	121.90	2.00	77.40	68.47

Abundance of major ions (%meq/l): Ca>Na+K> Mg =HCO_3 >Cl>SO_4

Sample ID: SM20 **Location of Borehole** S: -14.2595°. E: 031.3398°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	36.80	1.84	37.56	35.72
Mg	35.04	2.88	35.76	56.09
Na+K	26.14	0.42	26.68	8.19
Cl	30.00	0.85	8.67	13.63
SO_4	48.00	0.97	13.86	15.61
HCO_3	268.20	4.39	77.47	70.75

Abundance of major ions (%meq/l): Ca>Mg >Na+K =HCO_3 > SO_4> Cl

Sample ID: SM21 **Location of Borehole** S: -14.2501°. E: 031.3303°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	% mg/l	%meq/l
Ca	60.80	3.03	61.68	72.54
Mg	8.16	0.67	8.28	16.05
Na+K	29.62	0.48	30.05	11.41
Cl	24.00	0.68	8.34	13.10
SO_4	44.40	0.90	15.42	17.35
HCO_3	219.50	3.59	76.24	69.55

Abundance of major ions (%meq/l): Ca>Mg >Na+K =HCO_3 > SO_4> Cl

Sample ID: SM22 **Location of Borehole** S: -14.2403°. E: 031.3604°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	61.80	3.08	79.98	88.32
Mg	2.40	0.20	3.11	5.66
Na+K	13.07	0.21	16.91	6.03
Cl	15.00	0.42	6.76	10.81
SO_4	26.60	0.54	11.98	13.72
HCO_3	180.40	2.95	81.26	75.47

Abundance of major ions (%meq/l): Ca> Na+K >Mg =HCO_3 > SO_4> Cl

Sample ID: SM23 **Location of Borehole** S: -14.25798°. E: 031.35054°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	52.80	2.63	57.49	57.30
Mg	20.16	1.66	21.95	36.08
Na+K	18.88	0.30	20.56	6.61
Cl	32.00	0.90	10.40	16.44
SO_4	19.60	0.40	6.37	7.21
HCO_3	256.00	4.19	83.22	76.35

Abundance of major ions (%meq/l): Ca> Mg > Na+K =HCO_3> Cl > SO_4

Sample ID: SM24 **Location of Borehole** S: -14.25042°. E: 031.33468°.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	19.20	0.96	31.47	30.05
Mg	23.52	1.94	38.55	60.71
Na+K	18.29	0.29	29.98	9.24
Cl	21.00	0.59	9.60	14.91
SO_4	36.90	0.75	16.86	18.76
HCO_3	160.90	2.63	73.54	66.33

Abundance of major ions (%meq/l): Mg> Ca > Na+K =HCO_3> SO_4> Cl

Sample ID: SM25 **Location of Borehole** S: -14.25265^{o}. E: 031.32942^{o}.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	59.20	2.95	27.46	37.01
Mg	37.92	3.12	17.59	39.09
Na+K	118.48	1.91	54.95	23.90
Cl	136.00	3.84	23.62	33.88
SO_4	74.10	1.50	12.87	13.21
HCO_3	365.80	5.99	63.52	52.90

Abundance of major ions (%meq/l): Mg> Ca > Na+K =HCO_3> Cl > SO_4

Sample ID: SM26 **Location of Borehole** S: -14.25855^{o}. E: 031.33190^{o}.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	33.60	1.68	68.78	83.10
Mg	1.44	0.12	2.95	5.87
Na+K	13.81	0.22	28.27	11.02
Cl	17.00	0.48	15.68	24.26
SO_4	0.00	0.00	0.00	0.00
HCO_3	91.40	1.50	84.31	75.73

Abundance of major ions (%meq/l): Ca > Na+K > Mg =HCO_3> Cl > SO_4

Sample ID: SM27 **Location of Borehole** S: -14.27938^{o}. E: 031.32641^{o}.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	41.60	2.08	26.23	43.37
Mg	12.48	1.03	7.87	21.45
Na+K	104.54	1.68	65.91	35.18
Cl	120.00	3.38	39.77	53.22
SO_4	0.00	0.00	0.00	0.00
HCO_3	181.70	2.98	60.22	46.78

Abundance of major ions (%meq/l): Ca > Na+K > Mg = Cl >HCO_3 > SO_4

Sample ID: SM28 **Location of Borehole** S: -14.26662^{o}. E: 031.33404^{o}.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	41.60	2.08	53.88	59.19
Mg	12.96	1.07	16.79	30.41
Na+K	22.65	0.36	29.34	10.40
Cl	36.00	1.02	14.78	22.47
SO_4	27.20	0.55	11.17	12.15
HCO_3	180.40	2.95	74.06	65.37

Abundance of major ions (%meq/l): Ca> Mg >Na+K =HCO_3 >Cl>SO_4

Sample ID: SM29 **Location of Borehole** S: -14.27847^{o}. E: E: 31.33499^{o}.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	43.20	2.16	54.46	64.52
Mg	9.12	0.75	11.50	22.46
Na+K	27.01	0.44	34.05	13.02
Cl	31.00	0.87	13.19	20.11
SO_4	34.60	0.70	14.72	16.07
HCO_3	169.50	2.78	72.10	63.83

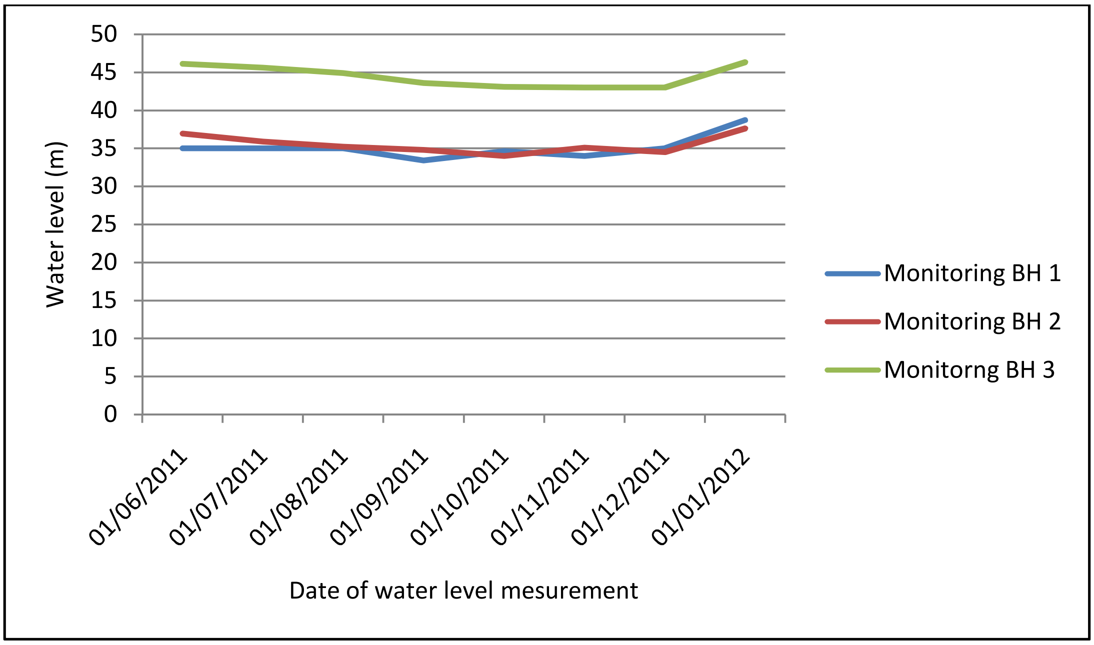
Abundance of major ions (%meq/l): Ca> Mg >Na+K =HCO_3 >Cl>SO_4

Sample ID: SM30 **Location of Borehole** S: -14.25429^{o}. E: E: 31.32968^{o}.

Parameter	Concentration (mg/l)	Concentration (meq/l)	%mg/l	%meq/l
Ca	56.00	2.79	42.09	56.74
Mg	13.44	1.11	10.10	22.46
Na+K	63.60	1.02	47.81	20.80
Cl	73.00	2.06	18.51	26.83
SO_4	92.20	1.86	23.38	24.26
HCO_3	229.20	3.75	58.11	48.91

Abundance of major ions (%meq/l): Ca> Mg >Na+K =HCO_3 >Cl>SO_4

Appendix 7: Variation of groundwater level from June 2011 to January 2012 in PetaukeTown, Eastern Province, Zambia.



Appendix 8: Borehole lithology.

Sampling Point: Showground West (-14.2371, 31.3294).

Lithological Description	Depth Range (m)		Thickness (m)
	From	To	
Top soil	0.00	1.00	1.00
Clay + Sandstone	1.00	4.50	3.50
Sandstone	3.50	9.00	5.50
Schist	9.00	11.00	2.00
Sandstone	11.00	15.00	4.00
Sandstone + Granite	15.00	22.00	7.00
Quartz	22.00	30.00	8.00
Granite	33.00	33.80	0.80

Sampling Point: Tasala 2 (-14.2494, 31.3197).

Lithological Description	Depth Range (m)		Thickness (m)
	From	To	
Top soil	0.00	1.00	1.00
Sandstone	1.00	24.00	23.00
Quartz	24.00	31.00	7.00
Quartz	31.00	37.80	6.80

Sampling Point: Tasala 9 (-14.2578, 31.3135).

Lithological Description	Depth Range (m)		Thickness (m)
	From	To	
Top soil	0.00	1.00	1.00
Laterite	1.00	7.00	3.50
Sandstone	7.00	15.00	8.00
Schist	15.00	17.00	2.00
Sandstone	17.00	24.00	7.00
Quartz	24.00	33.50	9.50

Sampling Point: Titukuke Community School (-14.2576, 31.3222).

Lithological Description	Depth Range (m)		Thickness (m)
	From	To	
Top soil	0.00	1.00	1.00
Sandstone	1.00	6.00	3.50
Schist	6.00	15.00	9.00
Sandstone/Quarzt	15.00	33.00	18.00

Sampling Point: Chimwemwe Lodge (-14.2941, 31.3392).

Lithological Description	Depth Range (m)		Thickness (m)
	From	To	
Top soil	0.00	1.00	1.00
Laterite	1.00	4.00	3.50
Red Schist	4.00	6.00	2.00
Sandstone	6.00	15.00	9.00
Schist	15.00	18.00	3.00
Clay	18.00	22.00	4.00
Sandstone	22.00	27.00	5.00
Quartz	27.00	37.50	10.50

Sampling Point: Petauke Prison (-14.2595, 31.3398).

Lithological Description	Depth Range (m)		Thickness (m)
	From	To	
Top soil	0.00	1.00	1.00
Sandstone	1.00	13.50	3.50
Schist	13.50	18.00	4.50
Sandstone	18.00	18.50	0.50
Schist	18.50	33.00	14.50
Sandstone + Granite	33.00	49.50	16.50
Quarzt + Granite	49.50	60.00	10.50

Sampling Point: Civic Centre (-14.2501, 31.3303).

Lithological Description	Depth Range (m)		Thickness (m)
	From	To	
Top soil	0.00	1.00	1.00
Clay	1.00	4.00	3.00
Schist	4.00	6.00	2.00
Sandstone	6.00	15.00	9.00
Schist	15.00	18.00	3.00
Sandstone	18.00	22.00	4.00
Quarzt	22.00	27.00	5.00
Granite	27.00	37.50	10.50

Sampling Point: Eastern Water and Sewerage Company (EWSC) BH 6 (-14.2585, 31.3287).

Lithological Description	Depth Range (m)		Thickness (m)
	From	To	
Top soil	0.00	1.00	1.00
Compact Clay	1.00	13.50	12.50
Clay + Sandstone + Quatzt	13.50	23.00	9.50
Schist	23.00	27.00	4.00
Quarzt + Sandstone	27.00	41.50	14.50