ASSESSMENT OF GROUNDWATER QUALITY IN RELATION TO BOREHOLE LOCATION IN CHIKHWAWA DISTRICT, MALAWI.

MSc (Environmental Science) Thesis

By

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DECLARATION

I, **Alic Stephen Joe Kafasalire**, declare that this is my own work and has not been presented or submitted elsewhere for any award. All additional sources of information have been acknowledged.

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CERTIFICATE OF APROVAL

We hereby declare that this thesis is the student's original work and where assistance has been sought, this has been acknowledged. It is therefore submitted with our approval.

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DEDICATION

This thesis is dedicated to my parents Stephen and late Elizabeth, my children (Elizabeth and Alic Junior) and my wife Charity. Your endurance was not in vain. God will surely honour it in due time

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My wife and our children. Words fail me to express my thanks for enduring with my absence and the hardship the leave of absence I took with my employer may have caused. I know it was not easy and you are good models on patience worthy emulating.

To my Father who is in heaven, I say thank you for your grace and mercy that were sufficient during my studies. I have seen your great hand.

ABSTRACT

The aim of this study was to assess the physical and chemical quality of groundwater in relation to borehole location and seasonality in Chikhwawa District, Southern Malawi. A multi-stage borehole sampling procedure was used to randomly collect water samples from 20 boreholes (one sample per borehole) in triplicates. From the three main topographical areas of Chikhwawa District, ten boreholes were randomly chosen from a flood plain area, five from marshy and swampy areas and the other five boreholes from upland or high altitude areas. The samples were analysed for pH, Total Dissolved Solids (TDS), chlorides, nitrates, phosphates, sodium, iron, potassium, manganese, magnesium and calcium (pH, TDS, Cl,NO_3^-, PO_3^{2-}, Na, Fe, K, Mn, Mg, Ca,). .

The results showed significantly higher values for pH, nitrates, phosphates, chlorides, sodium, potassium and magnesium in the dry season as compared to the wet season ($p < 0.05$). This could be attributed to the dilution factor. The levels of TDS in water samples for both seasons showed no statistically significant difference ($p < 0.05$). Only two boreholes recorded the presence of manganese while no borehole recorded the presence of iron in the water samples. But levels of pH, TDS, nitrates, phosphates, and chlorides (dry season only for chlorides) were above the recommended WHO and MS Maximum Contaminant Limits (MCL). For the cations, sodium is the most abundant with a decreasing trend of Na>Mg>Ca>K. Levels of nitrates, chlorides, sodium, calcium and magnesium showed spatial variation with boreholes in flood plain areas showed higher levels than boreholes in higher altitude/ basement complex aquifers.

The study suggests that groundwater quality in Chikhwawa varies with respect to topography, geology and climate (temperature and rainfall). It is recommended that further studies should be conducted on a wider scale with more parameters to establish the extent of groundwater pollution as this study was site specific. Secondly further studies should be carried out to establish any health related links with parameters like nitrates, sodium, chlorides and TDS whose levels were recorded above the WHO and MS MCL.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectrophotometer
DFID	Department for International Development
GIS	Geographical Information System
GPS	Global Positioning System
GOM	Government of Malawi
MASAF	Malawi Social Action Fund
MCL	Maximum Contaminant Level
MSB	Malawi Bureau of Standards
NRCM	National Research Council of Malawi
NEAP	National Environmental Action Plan
NGO	Non Governmental Organisation
SOER	State of Environment Report
SVADP	Shire Valley Agriculture Development Project
TDS	Total Dissolved Solids
UNEP	United Nations Environment Program
UNDP	United Nations Development Program
USGS	United States Geological Survey
WHO	World Health Organisation

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND

Groundwater resources constitute over two-thirds of the world's freshwater resources excluding polar ice caps; glaciers and permanent snow cover (Shiklomanov, 1993; Dutt, 1987). The socio-economic development of many countries particularly in rural areas relies on groundwater resources because they are a critical source of water supply for domestic, agricultural and industrial purposes.

Although groundwater, compared to surface water, is assumed to be free from bacteria and hence reduces the spread of water bone diseases like diarrhea (Falvey, 1999; Brownlow, 1979), the wholesome quality of groundwater cannot always be guaranteed. Chemical reactions within the aquifer through which the groundwater flows can lead to a build-up of both essential and non-essential substances (Falvey, 1999; Cairncross and Feachem, 1991). Some of the dissolved substances are essential but if present at higher concentrations, they render water unacceptable due to aesthetic problems while some are harmful. For example, excess nitrates in drinking water can cause blue baby disease (methaemoglobinaemia) in babies and cancer (Appendix 1) in adults (Harrison, 1995; USGS, 1978). Iron is a constituent of haemoglobin but if present in water in excess it may give water bad taste or odor while calcium is essential in borne formation but excess calcium and magnesium increase water hardness leading to excess scale formation in pipes and kettles and also wastage of soap (Msonda, 2003).

In addition to natural quality problems, anthropological activities can pollute groundwater resources. Urbanization, industries, and agriculture are major culprits in polluting groundwater (UNEP, 1996). For example some industrial pollutants are relatively insoluble and heavier than water. They therefore sink to the bottom of an aquifer where they are slowly dissolved and dispersed into deep circulating groundwater over a period of many years (UNEP, 1996). Once polluted, groundwater is extremely difficult to purify on account of its inaccessibility, huge volume and its slow flow rates (UNEP, 1996).

Malawi relies on groundwater resources for the socio-economic development of the country in rural areas. Over 80% of Malawi's estimated population of 12 million lives in rural areas where groundwater is the only safe source of water supply for domestic purposes. The Malawi Government has drilled hundreds of boreholes (Figure 1) in rural areas to enable many people access safe drinking water, using funds from the Malawi Social Action Fund (MASAF). However scaling up the development of groundwater resources for poverty reduction and economic growth is not straightforward and can present significant challenges. This is because many projects spend large amounts of money installing boreholes without trying to understand the hydro geological environment of the groundwater resources. This poses a risk of harvesting groundwater resources of poor quality because the emphasis is mainly on providing access to water to as many people as possible.

The aim of this study was to assess the quality of groundwater resources in Chikhwawa District in relation to the location of boreholes.

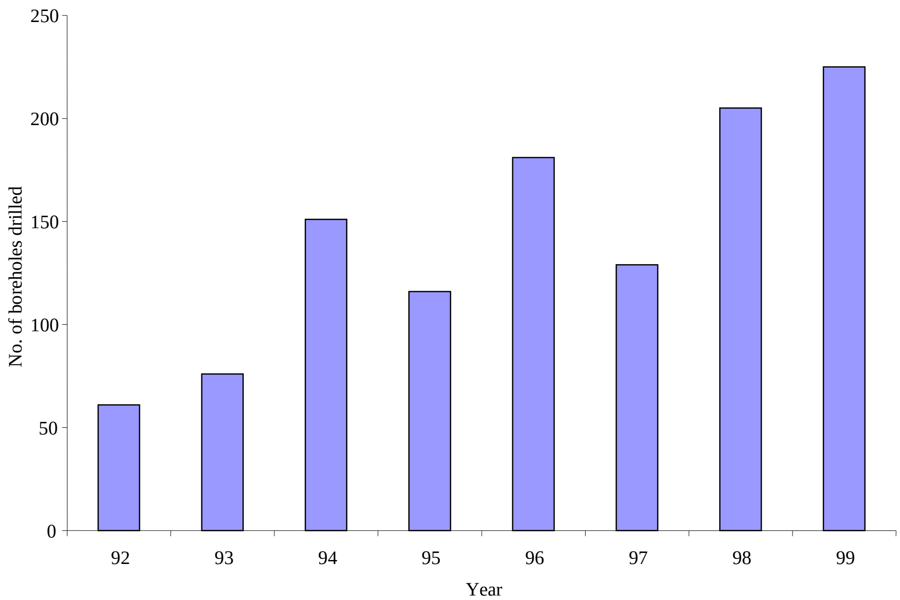

Figure 1: Number of boreholes drilled from 1992 to 1999 in Malawi
Source: Malawi State of Environment Report (SOER), 2002.

1.2 STUDY AREA

Chikhwawa District lies on the edge of Shire Highlands in the Lower Shire (Figure 4 in chapter 3) and experiences frequent floods that might be transporting industrial and agro-chemical pollutants of groundwater. The area comprises marshy and swampy areas along the Shire River that could be potential sources of pollution of groundwater resources on interaction with surface water. The Climate is semi-arid and its temperatures range from 20°C to 46°C (Collins, 1979). The temperatures encourage very high rates of evaporation that might be leading to a build-up of salts in the soil. The district is predominantly rural with 96% of the district's population of 356, 682 people living in rural areas (Chikhwawa District Socio-Economic Profile, 2003). People in rural areas rely on both groundwater and surface water harvested through gravity fed taps for safe drinking. However, only 25 % of the taps are working while 88 % of the boreholes are working (Chikhwawa District Socio-Economic Profile, 2003). Thus the majority of the 96 % of the people in rural areas rely on groundwater as the biggest supply of safe drinking water the district. Hence Chikhwawa makes a good case study for this work.

1.3 PROBLEM STATEMENT

Groundwater is a major source of drinking water for most of the rural communities in Malawi. This explains the increase in demand for groundwater resources over the years, forcing the Malawi Government and Non Governmental Organizations (NGOs) to drill more boreholes. However, in the context of the increase in demand of the groundwater resources, groundwater quality degradation continues to be a problem in Malawi despite the efforts of national environmental programs (NEAP, 1994).

The challenge has further been compounded by inadequate or lack of local capacity to undertake regular analyses of important parameters that could assist in effective and comprehensive groundwater monitoring country wide because emphasis is placed on supply and not quality as revealed by the state of the resources studies such as the UNDP/GOM (1986) and Chimphamba et al (in press). The inadequate research coupled with the lack of a comprehensive supporting monitoring mechanism on groundwater quality is a recipe for mismanaging the groundwater resources, making them vulnerable to pollution. The initial spot checks of groundwater quality that are conducted upon sinking boreholes in Chikhwawa District can only provide groundwater quality situation bench marks and there is a need for follow up analyses of groundwater for monitoring.

This study therefore recognizes this research and information gap requiring more detailed groundwater mapping, sampling and analysis of potential toxic compounds. It is expected that the results of this study will be disseminated to the general public and policy makers on the potential health risks from groundwater resources.

1.4 OBJECTIVES OF THE STUDY

1.4.1 Main Objective.

The main objective of this study was to assess the quality of ground water from boreholes in relation to borehole location in Chikhwawa District.

1.4.2 Specific objectives.

Specifically, the study aimed to:

1. Determine physical and chemical quality of groundwater resources in Chikhwawa District.

   a. To assess the physical and chemical characteristics of groundwater resources

2. Analyze spatial characteristics of groundwater resources of Chikhwawa District in terms of physical and chemical quality using Geographical Information System (GIS).

3. Relate borehole location to the quality of water.

   a. To examine the physical location of boreholes in relation to groundwater.

1.5 ORGANISATION OF THE REPORT

This report contains five chapters. Chapter one presents a background to the problem, objectives and problem statement. Chapter two is literature review that raises questions and gaps in which context this study fits. Chapter three is methods and materials that were used to generate data, analyze it and examine the problem while chapter four is results and discussion. Chapter five is conclusion and recommendations.

CHAPTER TWO: LITERATURE REVIEW

2.1 GROUNDWATER AVAILABILITY AND QUALITY.

Groundwater availability refers to the total amount of water that can be extracted from an aquifer (Noner, 1997). The ability of an aquifer to provide ample quantities of water depends on several factors such as sufficient storage for water to be available at all times, reliable annual recharge in the wetter years to provide a sustainable source of water. This includes rainfall variation from one year to the next (especially in drought vulnerability assessments) and sufficient groundwater mobility within the aquifer, as governed by the transmissivity of the aquifer (Carlow et al, 1999, Ngongondo, 2003).

Groundwater quality in this report refers to the maximum permissible levels of physical and chemical parameters as recommended by the World Health Organization (WHO) and the Malawi Bureau of Standards (MSB). The movement of groundwater and its interaction with surface water as linked components of a hydrologic continuum has important implications on the quality and the sustainability of the groundwater resources. Potentially, this affects groundwater quality due to the mixing of groundwater and surface water that can contaminate the water resources following on interaction in a variety of physiographic and climatic landscapes (Mather, 1993).

Aquifers in limestone (including chalk), sandstones and glacial sands and gravels are particularly at risk because they underlie large areas with a diversity of land uses, many of which are potentially polluting (Alloway and Ayres, 1997). In the United Kingdom (UK) limestone and sandstone are large aquifers, which are used for portable water supplies (Mather, 1993). Large industrial sites, leakages from petrol/diesel filling stations and farm waste disposal can cause significant pollution.

2.2 FACTORS AFFECTING GROUNDWATER QUALITY

The physical and chemical quality of groundwater resources depends on borehole depth, permeability of sediments and chemical make up of sediments through which groundwater moves, climatic variations and anthropogenic activities among other things (USGS, 1978; Harrison, 1996).

2.2.1 Borehole depth from the surface

The depth of groundwater has important implications on water quality particularly because water is an excellent solvent for many materials. The extremely high dielectric constant of water relative to other liquids has a profound effect on its solvent properties, in that most ionic materials are disassociated in water (Manahan, 1994). The longer groundwater takes to move through the sediments, the more mineralized it becomes. Water pumped from deeper aquifers typically has a much longer distance to travel to the surface and thus groundwater is in contact with mineral sediments and rocks for longer periods. Thus, shallow groundwater aquifers have a lower level of mineralization, or total dissolved solids (TDS), than deeper aquifers (Price, 1996)**.**

However, shallow wells have higher levels of calcium, magnesium and iron than deeper wells, making the water hard whilst deeper wells have higher levels of sodium and lower levels of hardness, making the water "soft." This is because deeper sediments and rock formations contain higher levels of sodium and as water moves downward through the sediments and different rock formations, a natural ion exchange process occurs (Appelo and Postma, 2005). Calcium, magnesium and iron in the groundwater are exchanged for sodium in the sediment and rock formations. The result is groundwater with higher levels of sodium with little or no hardness.

2.2.2 Permeability of sediments

The slow movement of groundwater through sediments with low permeability for example, clay allows more time for minerals to dissolve. In contrast, sediments with high permeability, like sand, allow groundwater to move more quickly.

The difference in the levels of dissolved solids is also reflected in groundwater in recharge zones and discharge areas. Precipitation infiltrates and percolates easily through permeable, sandy sediments in discharge zones that are mostly upland areas. Generally, water in recharge zones has low levels of TDS. But groundwater in discharge areas flow back eventually (or near) the ground surface (Price, 1996). Groundwater found in such areas can be extremely high in minerals such as sodium, sulfates and chlorides. Examples are saline seeps, sloughs and lakes.

2.2.3 Climatic variations

Annual rainfall and evaporation rates are some of the climatic variations that have an impact on groundwater quality. In semi-arid regions like Chikwawa District, discharging groundwater often evaporates as it approaches the surface. The minerals from the water are deposited in the soil, creating a salt buildup. Precipitation infiltrating through the soil can redissolve the salts, carrying them back into the groundwater. For example, in east central and southern Alberta where annual precipitation is from 25-40 cm (10-16 in.) and the evaporation rate is high, TDS are about 250 mg/L(USGS, 1980). In areas with higher precipitation and lower evaporation rates, precipitation that reaches groundwater is less mineralized.

2.3 THE IMPACT OF GEOLOGY ON LEVELS OF CHEMICAL PARAMETERS IN GROUNDWATER

Comparatively, ground water contains more minerals than surface water. This is attributed to the slow movement of groundwater through soil and the unsaturated zone to underground aquifers. This slow movement of groundwater results in some filtration of particulate matter and adsorption of some chemical compounds onto clay minerals. Soil quality thus becomes another critical factor that determines groundwater quality. Soil contaminated with chemical pollutants will be dissolved as water moves from the land surface, infiltrate and percolate into the ground. The interaction between surface water and groundwater therefore will carry with it chemical contaminants that can pollute groundwater.

The chemical make up of minerals and their solubility in the rocks has a bearing on groundwater quality. Chemicals that are more soluble than others are easily dissolved in water so that groundwater that is in contact with sediments containing large concentrations of sodium, sulfate and chloride will become more mineralized at a faster rate than if other chemicals were present (USGS, 1999. Thus the chemical composition of rocks available in an area determines the groundwater quality. For this reason groundwater quality in alluvial aquifers found in sedimentary rocks is different from basement complex aquifers with igneous and metamorphic rocks. This is because the dominance of alkaline earths in the cations group and carbonates in the anionic group in basement complex aquifers characterize groundwater quality. Most of the groundwater in the basement complex aquifers shows low total mineralization indicating that most of the water is derived from recent recharge (Chimphamba et al, in press).

But excess levels of mineral elements in groundwater have different effects in human health (Price 1990) (Appendix 1) as follows:

Sodium

Sodium is normally present in drinking water at concentrations below 50mg/l. High sodium levels have an effect on bottle fed infants (Harrison,1995). Sodium can make the water taste bad and can be a health risk for people with heart problems (Appendix 1). Clinical studies have shown that although sodium chloride is used as a condiment, high sodium content influences blood pressure. People who are on low sodium diets should not drink water with sodium contents in excess of 20 mg/L (Harper et al, 1979).

Chloride

Chlorine alone as Cl_2 is highly toxic, and it is often used as a disinfectant. Some common chlorides include sodium chloride (NaCl) and magnesium chloride ($MgCl_2$). In combination with a metal such as sodium it becomes essential for life. Small amounts of chlorides are required for normal cell functions in plant and animal life.

Chlorides are not usually harmful to people; however, the sodium part of table salt has been linked to heart and kidney diseases. Sodium chloride may impart a salty taste at 250 mg/l; however, calcium or magnesium chlorides are not usually detected by taste until levels of 1000 mg/l are reached. Public drinking water standards require chloride levels not to exceed 250 mg/l.

Chlorides may get into surface water from several sources including, rocks containing chlorides, agricultural runoff, and wastewater from industries, oil well wastes, and effluent wastewater from wastewater treatment plants.

Chlorides can corrode metals (Figure 2) and affect the taste of food products. Therefore, water that is used in industry or processed for any use has a recommended maximum chloride level. Chlorides can contaminate freshwater streams and lakes. Fish and aquatic communities cannot survive in high levels of chlorides

Nitrates

Presence of nitrates in groundwater is also attributed to natural sources as a product of the microbial mineralisation of dead plant and animal tissues in the soil (Hem, 1985; Robertson, 1991; Gellenbeck, 1994; Alloway and Ayres, 1997 and Coes, (1999). Dissolution of evaporite deposits, decay of buried organic matter, precipitation, weathering of rocks and soils and fixation by microorganisms is some of the possible sources of naturally occurring nitrate in groundwater (U. S Geological Survey, 1995-98). However there has been marked increase in the nitrate content of both surface water and groundwater as a result of the increased use of the nitrogen fertilizers and the degradation of a greater mass of litter (Alloway and Ayres, 1997). For example in the United Kingdom, increased use of nitrogenous fertilizers, the conversion of more pasture into arable land and increased recycling of sewage effluent in lowland waters was responsible for the increase in nitrate levels in groundwater.

Excessive nitrates in groundwater are a health concern for children and adults. High nitrate concentrations in children result in methaemoglobinaemia or blue-baby syndrome in which oxygen levels in the blood of infants are low, sometimes fatally so (National Governors Association, 1991;Harrison, 1995; Price, 1996:197; Alloy and Ayres, 1997). Birth defects as well have been attributed to high nitrate concentrations (National Governors Association, 1991). In adults, high nitrate concentrations have been associated with cancer (National Academy of Sciences, 1977).

Iron (Fe) and manganese

A high concentration of iron causes reddish-brown stains on fixtures and laundry. It can cause a bad taste and odor in water when associated with growth of iron bacteria. It can be dissolved in ground water and not be evident until oxidized to its insoluble form by exposure to air or an oxidant or disinfectant such as chlorine (Price,1996). Iron precipitates and deposits reddish-brown stains on pipes and sinks, and also causes discoloration of food and laundry (Appendix 1).

Manganese is important to the health of humans because deficiency in manganese causes a decrease in serum cholesterol, depressed growth of hair and nails, scaly dermatitis, weight loss, reddening of his black hair and beard and impaired blood clotting. However manganese gives water undesirable taste and has staining problems. A high concentration of manganese can cause brownish to black stains in laundry (Price, 1996). Like iron, it may not be apparent until the water has been exposed to oxygen or a disinfectant.

Calcium and magnesium

Calcium is an essential element as it builds and maintains bones and teeth. It also regulates the rhythm of the heart, eases insomnia, helps regulate the passage of nutrients in and out of cellular membranes, and assists in blood clotting (Price,1996). Calcium is also very valuable in maintaining proper nerve and muscle function, as well as normal kidney function. Magnesium plays a crucial role in regulating the neuromuscular activity of the heart, maintaining normal heart rhythm, and converting blood sugar into energy.

2.4 GEOLOGICAL AND LITHOLOGICAL COMPONENTS OF CHIKHWAWA

The nature of geology or lithology in a particular area has important implication on groundwater quality. Geologically Chikwawa District has limestone with widespread presence of calcium that causes water hardness (Table 1). Over large areas on the floor of the Shire Valley colluvium and alluvium obscure the basement complex rocks (Figure 6). Holt (1953) also described the rocks in Chikhwawa as probably isoclinically folded and step faulted so that strong jointing is developed in them. The mineral composition of the rocks is mostly composed of amphibolite facies that show evidence of the presence of potash metasomatism over a wide area. The dominant mineral in this part is pleochronic green hornblende that is associated with biotite to form mosaic with quartz. Magnitite occurs in cubes at Saopa in Chikhwawa and the vesicles are lined with chlorite and zeolite and infilled later with calcite (Habgood, 1963).

The area between Mwanza and Nkombezi wa Fodya Rivers on the sides of Mwanza anticline consists of sandstones. The sandstones give rise to broad highlands standing two to three hundred feet above sea level and extend to the North West, parallel to the strike of the country rock. The central part of this area has softer weathering sandstones and shells that form a slight depression.

Geologically, faults and dykes affect groundwater movement and hence the spread of pollutants in a particular area. In Chikhwawa District a number of dykes are observed in the district cutting different geological formations. For example a dyke cuts the Coal Shells at the confluence of Phwadzi and Nkombezi wa Fodya rivers. A typical dyke intrudes into the carbonates shells in Phwadzi with interstitial ferro-magnesiun minerals entirely replaced with chlorite and abundant secondary iron. The dyke associated with Nlombezi Fault is very much fractured and contains calcareous-siliceous fault rock occupying joints. An associated smaller dyke observed cutting grits in Kambwete River is more broken and invaded with vein calcite that occurs in coarse crystals (Holt, 1953).

This dyke contains dolerite of thin feldspar laths averaging 0.7 mm in black iron stained groundmass containing secondary calcite. Another larger dyke associated with the Nkombezi dyke is composed with fresh dolerite having a hypocrystalline-por-phyritic texture. The dolerite consists of labrodorite laths averaging 0.5mm long with sub-ophitic pyroxene and approximately 30 per cent of black, glassy of groundmass containing secondary calcite (Habgood, 1963).

Table 1: Lithological units of the geology in Chikhwawa and its mineral content

No	Lithological Unit	Mineral content
1	Terrece alluvium and colluvium	Magnesium, Chlorite, Sodium, Nitrates
2	Synite	Silica
3	Calcareous sandstones	Calcium and magnesium, silica, dolerite
4	Basement complex	Calcium
5	Basalt lava	Magnetite,quartz, silica, basaltic horneblende
6	River alluvium	Sodium and nitrates
7	Karroo system sediments	Calcium

Source: Habgood (1963).

Figure 2: Borehole metal corrosion that could be due to chloride concentration in groundwater

2.5 ANTHROPOGENIC SOURCES OF GROUNDWATER POLLUTION

On a widespread basis, groundwater sources are at risk from pollution due to insufficient control of land use and effluent discharge in aquifer recharge areas (DFID, Knowledge and Research, 2005). Consequently, most land uses or activities, whether industrial, urban or agricultural, have an impact on groundwater quality (Harrison, 1995). Contaminated land arising from many different industrial and waste disposal practices in the past has the potential to impact on groundwater moving beneath it. In turn the groundwater can provide the pathway for movement of contaminants from beneath the land to adjacent waterways.

For example a study in the city of Jaipur in Asia revealed that groundwater was polluted on interaction with surface water because streams were used to damp garbage. Whilst it is clearly impractical to prohibit all such activities, it is important to protect groundwater from degradation as a result of industrial activities that pollute the water resources. For this reason, controls are necessary to ensure that the environmental impact of land uses are taken into account both for new developments and those already in existence (Harrison, 1995).

Land use controls reduce the risk of pollution from priority activities such as the storage of large amounts of hazardous substances. Regulating the way in which the activity is carried out vis-à-vis requiring certain storage measures, or controlling fertilizer use (Harrison, 1995) can control the risk of pollution on groundwater resources. For example, groundwater is more likely to be contaminated with nutrients and man-made chemicals associated with urban and agricultural land uses.

The deeper the aquifer is the less vulnerable it is to pollution. This is according to the United States Geological Survey (USGS, 1999). By contrast shallow aquifers are potentially exposed to pollution and countries like the US hydrology and land use control the contamination of major aquifers. In the US shallow groundwater was polluted with man made chemicals associated with urban and agricultural land use. Irrigation water that seeps down is a principal source of groundwater recharge in irrigated areas (USGS; 1999) and this has a potential pollution effect on groundwater quality.

In Africa, Uganda has areas of very high iron content from natural pollution or geological formation while in Mali groundwater quality studies found iron and manganese concentration ranging between <0.01-3.5 mg/l and manganese between <0.002–3.8 mg/l (Price,1996). This is above World Health Organization (WHO) acceptable standards of 1.0 mg/l for iron and 0.5mg/l for manganese (Appendix 2). In the Southern Africa Development Community (SADC), groundwater resources face significant problems of pollution. For example groundwater in Mozambique experiences salinity problems particularly in some parts of the tertiary aquifers as a result of seawater intrusion. In South Africa, use of chemicals and generation of wastes have contaminated aquifers in urban areas and this has presented a threat to the sustainability of the quality of the water resources. In Madagascar groundwater quality varies considerably across the island and with depth, especially in the distinct sediment formations of the coastal basins. Groundwater is generally soft (low Ca, Mg concentrations) in the silicate rock types (sands, silts and crystalline basement) and is aggressive with relatively low pH values (<7, typically 6;Besairie, 1959). Where carbonate rock types occur, groundwater is generally harder with near-neutral pH values (7 or more).

Other causes of groundwater quality degradation may include return flow from surface water irrigation, leakage from urban sewers, infiltration ponds for waste water, septic tanks, urban waste landfills, abandoned wells, mine tailings, and many other activities not related to groundwater development (Barraque, 1997; Forster, et al, 1998). Thus land use (Figure 3) has implication on groundwater quality.

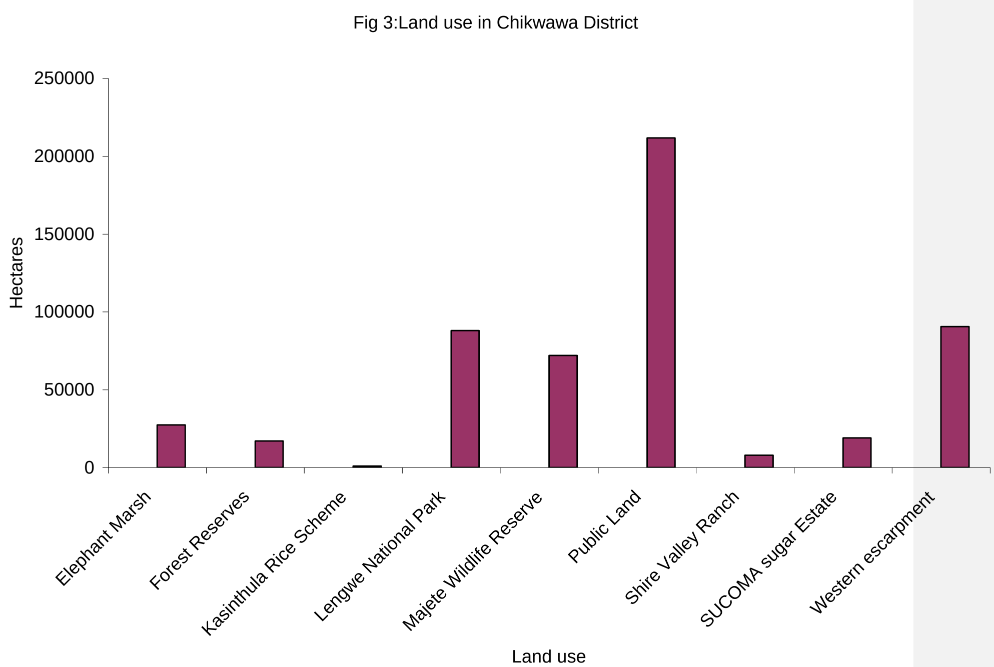

Figure 3: Land use in Chikhwawa District
Source: Chikhwawa Socio-Economic profile, 2003

2.7 GROUNDWATER SITUATION ANALYSIS IN MALAWI

Both surface and groundwater resources in Malawi are depleted and degraded (The National Environmental Action Plan-NEAP, 1994, 1998, 2002). Some parts of Malawi including Lower Shire that falls in the rift valley have groundwater with high fluoride content (Msonda, 2003). The areas with high fluoride content situated along Lake Malawi extend from Karonga to Lower Shire Valley. High fluoride contents in groundwater have been reported in Nkhotakota, Karonga, Chikhwawa, Machinga, and Nsanje. In the case of Machinga a few boreholes were sampled for fluoride determination where fluoride content in water sources was as high as 8.6mg/L (Sibale et, al, 1998). In Nkhotakota district, water from hot springs has a fluoride content of up to about 17mg/L and Chikwidzi spring is about 8 mg/L(Chapusa and Harrison, 1975). Flouride also occurs in fluorite (CaF_2) around carbonatite centers at Lake Chilwa, Nsengwa and kangankunde (Carter and Bennet, 1973).

In Malawi certain areas have phosphate bearing fluoride deposits such as Tundulu in Mulanje District and the fluoride content in Tundulu phosphate is reported to be about 2 percent (Appleton, 1990). The dissolution of this phosphate could lead to high fluoride concentrations in groundwater supplies.

2.8 SITE GEOLOGY, HYDROLOGY AND TOPOGRAPHY

Site geology, hydrology and topography plays an important role in the investigation of contaminant movement towards sensitive receptors of pollution such as water courses and water bearing strata which in turn may be in hydro geological continuity with water bearing aquifers (Mennick, 1998). Failure to investigate the site geology and hydrology of the area can disregard some disastrous consequences, like release of contaminants from excavations into groundwater. Site history and the potential for contamination sources at specific locations determine the preferred location of exploratory boreholes and trial pits.

2.8.1 Alluvial aquifers

Alluvial aquifers are mostly found in the rift valley floor areas along Lake Malawi Shore, including the Western side of the Shire River Valley, the Upper Shire Valley, the Lake Chilwa basin on the outer slopes of Zomba plateau and the Lower Shire Valley (GOM-UNDP, 1986; Stanley International, 1983). The main lithological component of alluvial aquifers is clay with significant occurrences of poorly sorted sands in some localities. Most of the alluvium aquifers are unconfined although some thick clay sequences are semi-confined (GOM-UNDP, 1986).

Alluvial aquifers contain fluvial and lucustrine sediment variations in both vertical and lateral extent. The alluvial aquifers have high TDS, sodium, chloride and nitrate content because they are found in relatively low lying areas and discharge water which is exposed to evaporation. The alluvial aquifers are mostly found in arable land which is good for economic activities like agriculture and industrial development which are a source of effluents that can pollute groundwater. Human activities such as the use of synthetic fertilizers, industrial effluents like sewage systems can pollute groundwater. The area under study (Chikhwawa District) mainly comprises the alluvial aquifers particularly in the floodplain areas with colluvium and alluvium geological formations (Figure 5).

2.8.2 Basement complex aquifers

Basement complex aquifers are associated with igneous and metamorphic rocks. The less porous nature of igneous and metamorphic rocks does not allow a lot of water to pass through the rocks and this explains for their low yielding capacity. But in spite of their low yielding capacity of about 0.15mls^{-1} , basement complex aquifers are sources of water supply for about 60 % of the rural population in Malawi. This is because most of the boreholes and wells are in basement complex aquifers, which cover approximately 70 % of the land surface in Malawi (Chimphamba *et al*, in press).

Fractures, weathered zones and intrusions control the occurrence of basement rocks leading to heterogeneity of basement aquifers in terms of hydraulic characteristics and lithology (Chimphamba et al, in press). The basement aquifers Most of Malawi apart from the low-lying valley areas is composed of these basement complex aquifers including some parts of Chikhwawa District particularly in high altitude areas where this study is conducted.

The basement complex aquifers are mostly found in upland areas and because of their nature of recharging water groundwater movement is high. This lessens the susceptibility of groundwater in basement complex aquifers to pollution. However, natural pollution is another factor that can pollute groundwater. Thus the nature of rocks in the basement complex aquifers has important implications on the quality of groundwater in basement complex aquifers.

The groundwater levels and variations on site also influence the depth of exploratory excavations because groundwater levels influence the mobility of contaminants. Water-soluble contaminants from past spillages can be dispersed very rapidly if the groundwater table is close to the ground surface. Therefore, if contaminants are soluble or physically mobile in groundwater, the resulting rapid dispersion of contaminants may present difficulties in locating the actual source by site investigation.

2.8.3 Borehole locations

A number of factors should be taken into account when choosing a site for sinking a borehole. The preferred location of boreholes should be determined largely by the site history and the potential for contamination sources at specific locations, but the decision on where to locate a borehole and its depth should be made on the basis of site geology. Knowledge of geological strata beneath the site is therefore a prerequisite to site investigation as the permeability of various strata determines the likely location of contaminants and the degree to which they are retained temporally and spatially beneath the site. Social issues for example location of settlements particularly pit latrines and septic tanks should be considered as well. This is because pit latrines and septic tanks have a potential to pollute groundwater whenever there is a leakage into the groundwater system.

2.9 SUSTAINABLE MANAGEMENT OF GROUNDWATER QUALITY

Owing to the potential problems that groundwater quality may suffer, it is critical to sustainably manage groundwater resources. Many nations especially in the developing world like Malawi need to appreciate their dependency on groundwater and invest in strengthening institutional provisions and building institutional capacity for improved groundwater management (DFID Research and Knowledge, 2005). But there is no simple blueprint for action due to inherent variability of groundwater systems and related socio-economic situations but practical advances are urgently needed and it is always feasible to make incremental improvements.

CHAPTER THREE: METHODS AND MARTERIALS

3.1 DESCRIPTION OF STUDY AREA

3.1.1 Location of Chikhwawa District

Chikhwawa District is located in the Southern Region of the Republic of Malawi. It is bordered with four districts, Mwanza to the North, Blantyre to the North East, Thyolo to the East, and Nsanje to the South (Chikhwawa District Socio-Economic profile, 2003). This study took place in Chikhwawa District in Traditional Authorities Katunga, Ngabu and Kasisi in the West Bank of the Shire River and in Traditional Authority Mlilima in the East Bank of the Shire River. The district is between latitudes 15° 45' and 16° 30'South of the Equator and longitudes 34 ° 15' and 35° 15' East of the Green Witch Meridian (Collins Atlas for Malawi and Figure 4 below).

3.2.1 Climate of Chikhwawa district

Two well-defined seasons characterize the climate of Chikhwawa District: a dry season from May to October and a rainy season from November to April (SVADP, 1975). The climate is conditioned with interplay between the subtropical ridges of high pressure and the Equatorial low belt (Inter Tropical Convergence Zone). From October to April the weather over Malawi and Chikhwawa in particular is controlled with the Equatorial Trough, which brings in unstable air that causes convectional rainfall (SVADP, 1975).

The temperatures of Chikhwawa, which is in Lower Shire, are the highest in Malawi. As they fall to their lowest in June with mean minimum and maximum ranging from 13.4 °C to 27.4 °C and rise rapidly through September to a mean maximum of 40.9 °C and sometimes the district experiences extra climatic events, ranging from highest temperatures, rainfall, drought and floods (Chikhwawa District Socio-Economic profile, 2003). Average annual rainfall range from 762-1,016 mm per annum that has resulted in a comparatively low rate of weathering and the accumulation of salts in low lying-areas (SVADP, 1975).

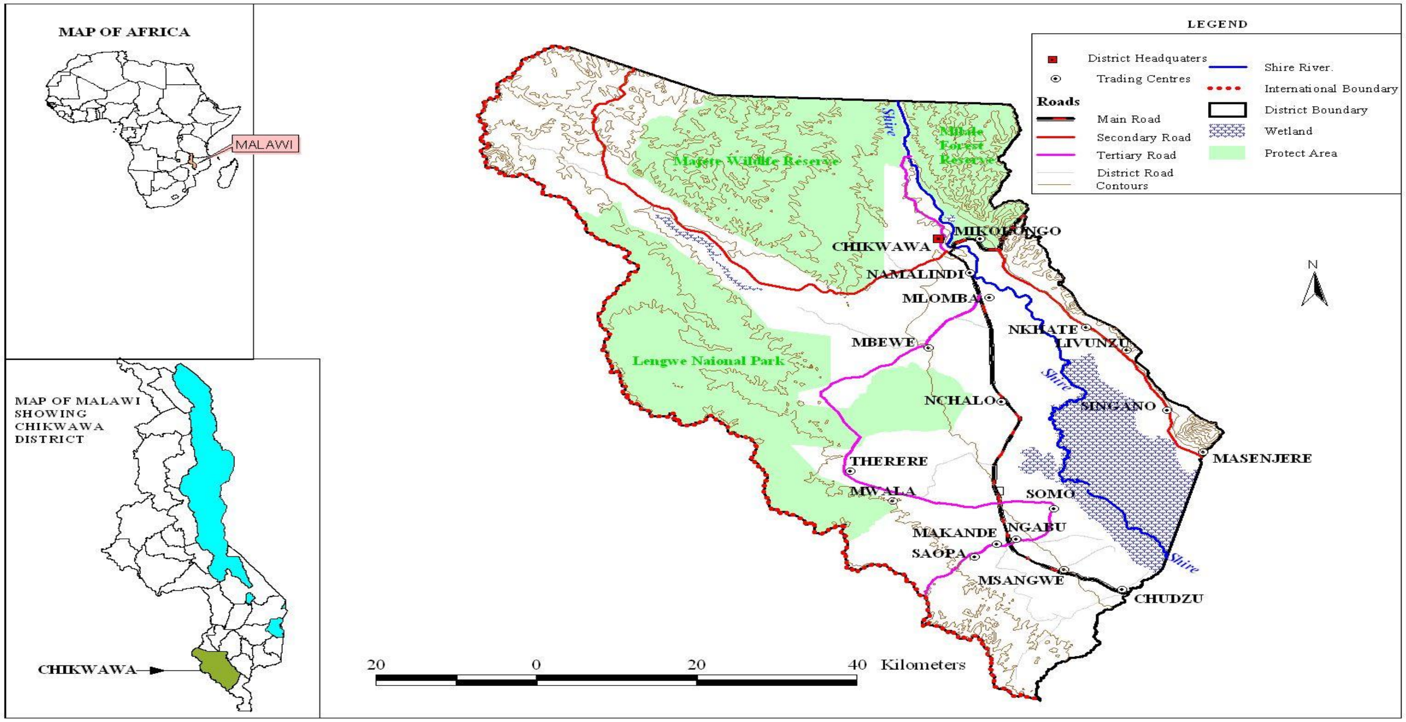

Figure 4: Map of Malawi and location of Chikhwawa District

In figure 5 the spacing of the contour lines suggests that high altitude areas comprise Karroo system sediments and basement complex lithological components. This suggests that groundwater in the study area flows from these areas following the hydraulic gradient (Alloway and Ayres, 1997) towards calcareous sandstones, terrece alluvium and colluvium, basalt lava and river alluvium. This may affect the quality of groundwater in the study area should polluted floodwater interact with groundwater.

3.2.3 Soil type

The soils of Chikhwawa District can be placed into floodplain and swamps of the Shire River, the floodplains, alluvial terraces and drift deposits flanking the Shire floodplain and the upland soils of the valley walls and the Middle Shire (SVADP, 1975). Alluvial carcimorphic grey brown earths are the principle soil groups in the district particularly in the northern part, along the east bank (Figure 7, chapter 4). The Ngabu area is dominated with Makande soils- the vertisols while lithosols, including shallow soils over basaltic tongues form the western escarpment (FRIM, 1978).

3.2.4 Land use in Chikhwawa District

The hydrology of Chikhwawa District comprises physical characteristics of landscape and geology. The Shire Highlands, floodplains and the Elephant Marsh form part of the landscape of the district. To a greater extent, these geographical and physical characteristics determine different types of land uses in the district.

In agricultural terms the total land area of Chikhwawa is 471, 957 hectares of which almost half of this land is protected or conserved area in a form of a forest reserve and or national park/ wildlife reserve (Chikhwawa District Socio Economic Profile 2003). About 20,118 hectares is dry arable land and 29, 962 ha is wet arable land while Estates cover 19, 000 hectares while public land covers 211, 788 hectares (Figure 3 in chapter 2).

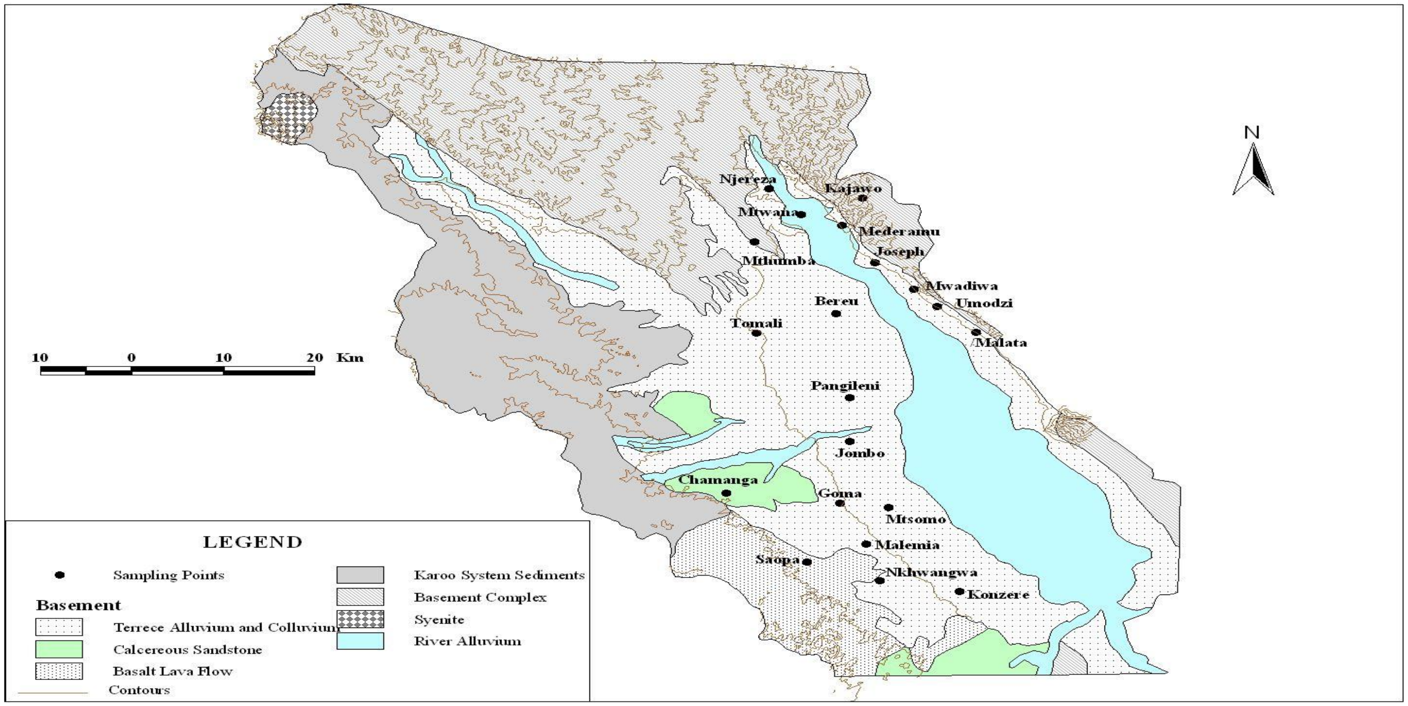

Figure 5: Location of sampling points in relation to geology in the study area.
Note the spacing of contours that indicate high and low altitude areas suggesting that groundwater flows towards the river alluvium.

3.3 SAMPLING AND SAMPLE PREPERATION

Twenty water samples were collected in triplicates from 20 boreholes from 29th February to 1st March (wet season) and from 1st to 2nd July 2007 (dry season). A multi-stage sampling was used to randomly select boreholes for sampling. The method was chosen because it helped provide a representative sample out of the 800 working boreholes in Chikhwawa District as the district was divided into three areas in terms of its topography: the flood plain area which dominates the district, marshy and swampy areas or areas that are near marshes and swamps or the Shire River and thirdly the upland or high altitude areas. Ten boreholes were randomly chosen from a flood plain area, five from marshy and swampy areas and the other five boreholes from upland or high altitude areas (Figures 5 and 6). First a geological map of Chikhwawa (of scale 1:500000) was used to randomly sample 20 boreholes. Secondly, two field visit were made (one in the wet season and another in the dry season) using the map as a guide while tracking and identifying the boreholes to collect the water samples.

The water samples were collected in one liter plastic bottles and in two sets. The first set was for non-metal determination and another set was for metal analyses. The water samples for metal analysis were preserved by acidifying them with 1ml of concentrated nitric acid per liter sample (AOAC, 1990) while the water samples for non-metals were kept 4 °C of temperature in cooler boxes with ice blocks soon after collection and later put in a refrigerator at Chancellor College Chemistry Department Laboratory.

Secondary information was also used in collecting data for this study. Thus a description of the surrounding land use, slope and nature of geology (Table 5) for each sampled borehole was made. Borehole pictures were taken and a description of its geology using secondary information (e. g. geological maps of Chikhwawa). Photographs of boreholes with their surrounding environment were also taken. A GPS point of each of the 20 boreholes was recorded with a GPS receiver.

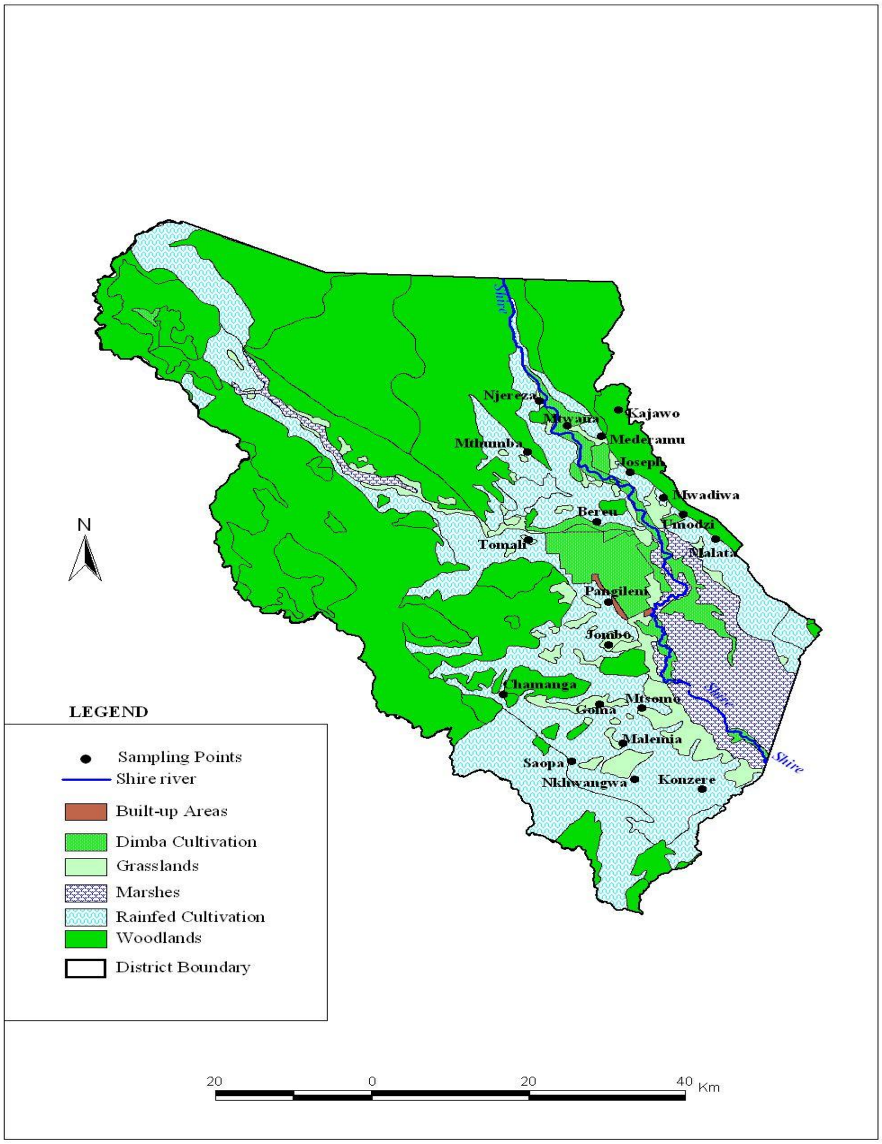

Figure 6: Location of sampling points in relation to land use in the study area.

3.4 WATER SAMPLE ANALYSIS

The samples was analyzed for pH, nitrates, phosphates, Total Dissolved Solids (TDS), Chlorides, and selected metals like Magnesium, Manganese, Iron, Sodium, Potassium, and Calcium.

3.5 DETERMINATION OF PH AND TDS, NITRATES, PHOSPHATES AND CHLORIDES.

The pH of water samples was determined in the field using a glass electrode Kent EIL 7020 pH meter as described in (APHA; 1990) while Total Dissolved Solids (TDS) was determined by evaporation (APHA; 1990). Nitrates were determined using an Automated Cadmium Method (APHA;1990), phosphates were determined using an Ascorbic Acid Reduction Method (APHA 1989) while chlorides were determined using Chlorides were determined by using an Argentrometric Method (APHA, 1990).

3.6 DETERMINATION OF METALS: IRON, MAGNESIUM, MANGANESE, POTASSIUM AND SODIUM AND CALCIUM

Sample preparation, handling and determination of iron, magnesium, manganese, potassium, sodium and calcium was done according to the described standard procedures for the Perkin Elmer Aanalyst 100 Atomic Absorption Spectrometer operating procedure (AOAC, 1990).

3.7 DATA ANALYSIS

i. The means and standard deviations for each analyte were calculated. The means for groundwater samples were compared with maximum limits set by Malawi

Bureau of Standards and World Health Organisation guidelines on drinking water standards.

ii. The Statistical Package for Social Sciences, (SPSS) windows program (version 12.0) was used to analyse the data. A paired t-Test was applied to determine significant differences in the physical chemical levels of groundwater samples between sites. Multi-variate correlations were applied to perform a cluster analysis of the physical and chemical levels of parameters of the sample means.

iii. Geographical Information System (GIS) was used to analyse digital information of the sampled boreholes using Arc View software. A map of geology of Chikhwawa District of scale 1:500 000 was scanned and digitised on which borehole GPS points were superimposed to produce maps of sampling points and spatial distribution of groundwater quality.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 PHYSICAL AND CHEMICAL GROUNDWATER QUALITY

4.1.1: pH and TDS

Results show that groundwater in the area ranges from neutral to slightly alkaline (Figure 7 and table 4), with significantly higher pH values ($p < 0.05$; appendix 2) in the dry season (7.37-8.59) than in the rainy season (7.12-8.45), which could be attributed to simple dilution factor because of precipitation in the wet season. The pH values of all sampled boreholes fall within the guidelines from the MBS and WHO (Table 4) and as expected of groundwater influenced by carbonates (vanLoon and Duffy, 2006; Price, 1996).

TDS values in the dry season ranged from 281mg/L (Ntwana borehole) to 3592 mg/L (Chamanga borehole) while in the wet season the values ranged from 221mg/L (Malata borehole) to 2801 mg/L (Goma borehole) (Figure 7; Table **4**). However, there is no statistically significant difference between the two seasons for TDS ($p > 0.05$, Appendix 2).

The water samples from the studied boreholes belong to the "Fresh water" category (TDS < 1000). This is explained by Gorrel (1958) very simple classification based on the total dissolved solids.

It should be noted, however, that no standards have been established for TDS based on health effects (WHO, 1993) and no data is available on the possible health effects of the TDS content (van der Aa, 2003). However, TDS may strongly influence the taste of drinking water. Water with a TDS lower than 1,000 mg/l is usually acceptable for consumers, although this may strongly depend on local conditions. A higher TDS may lead to extreme scale deposits in borehole pumps, pipelines and home appliances. Water with a low TDS tastes flat and is often considered to be tasteless. There are indications that extremely soft water adversely affects the mineral balance (Van der Aa, 2003).

A 1975 study conducted by the Shire Valley Agriculture Development Project (SVADP, 1975) indicated that some areas along the west bank of the Shire River have groundwater with high TDS content. The high TDS level (>1, 000 mg/L) in these boreholes was reported to be principally due to sodium chloride and was mainly attributed to low permeability, low recharge and the presence of highly soluble minerals. Further, the observed high TDS content of groundwater in the area (Tables 2, 3 and 4) may also be attributable to the comparatively hot dry climate with rainfall of 762-1016 mm per annum, resulting in a comparatively low rate of weathering and then accumulation of salts in low lying areas (SVADP, 1975). Similarly, in this study the boreholes that showed higher levels of TDS also showed higher levels of chloride and sodium (Table 2) in the dry season.

4.1.2 Levels of nitrates, phosphates and chlorides

Groundwater samples had nitrate values in the range 0.57 – 28.81 mg/L and 0.10 – 23.05 mg/L for the dry and wet seasons, respectively. Six boreholes namely Jombo, Goma, Chamanga, Mtsomo Bereu and Njereza have higher nitrates levels above MBS and WHO guidelines (10 mg/L) (Table 4; Figure 11). In the wet season, the levels of nitrates for ten of the twenty boreholes sampled (Konzere, Tomali, Bereu, Nthumba, Njereza, Ntwana, Joseph, Diwa, Mederamu and Kajawo), were less than the WHO and MBS MCL (Tables 2 and 4). All boreholes (except one, Malemiya in the wet season) show higher phosphate values above the MBS and WHO guidelines (0.01 mg/L) for both seasons (Tables 1 and 3). The source of these nitrates and phosphates could be leaching from pit latrines, waste dumps, fertilizer and manure from agricultural activities because the sampled boreholes are located close to Nchalo Sugar Estate and Kasinthula Irrigation Rice Scheme (Figures 6 and 8) and natural sources (local geology) (Price, 1996).

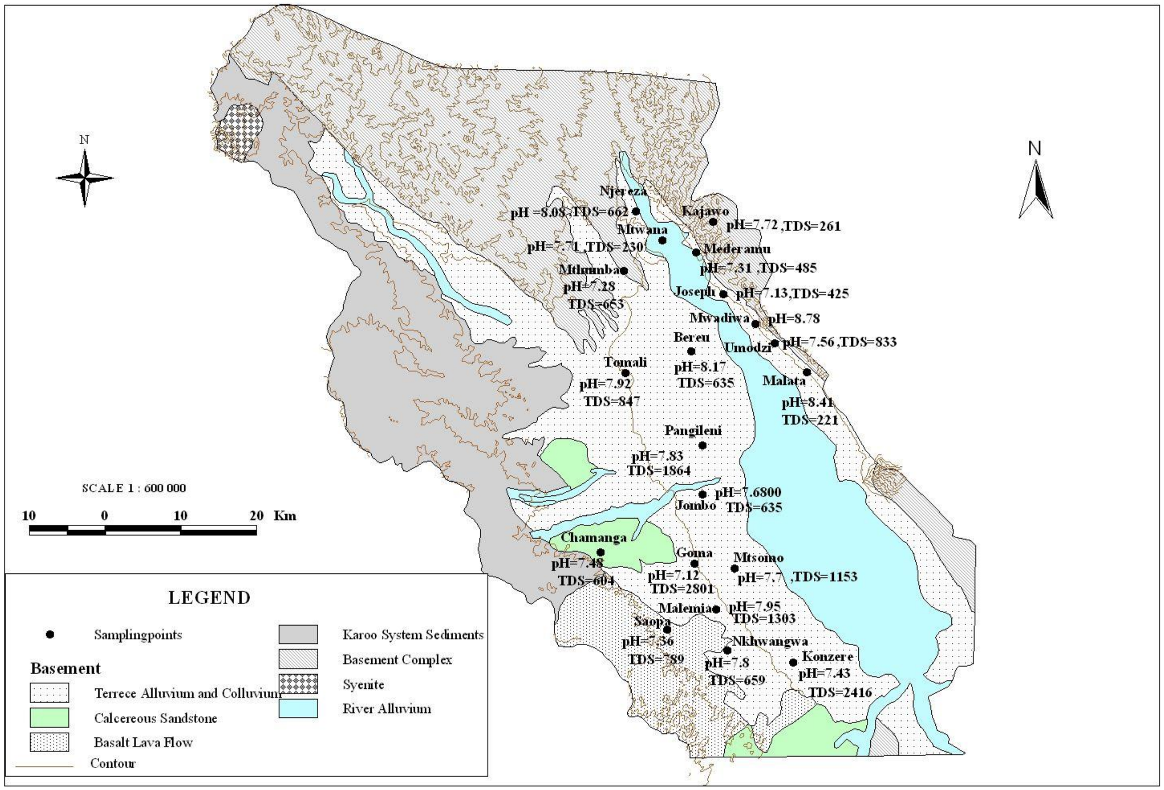

Figure 7: Distribution of pH and TDS (wet season samples) in relation to geology

The chloride levels range from 5.52 mg/L (Malata borehole) to 614.49 mg/L (Pangileni borehole) for the dry season (Table 2) and from below detection limit (Saopa, Nkhwangwa, Bereu, Nthumba, Ntwana, Joseph, Malata, Diwa Mederamu and Kajawo boreholes) to 0.62 mg/L (Pangileni borehole) in the wet season (Figure 9). The chloride levels for the wet season fell below the WHO guideline of 250 mg/L (Tables 2 and 4). However, in the dry season, Goma (597.91 mg/L), Konzere (578.74 mg/L) and Pangileni (614.49 mg/L) showed chloride values above the WHO guideline

The dry season recorded significantly higher levels of nitrates, phosphates and chlorides than the wet season ($p < 0.05$; Appendix 2;Tables 2 and 4; Figure 9), a variation which may again be attributed to simple dilution leading to washout during flooding episodes and concentration due to high evaporation rates in the dry season (SVADP, 1975).

Figure 8: A photograph of a proximity sampled borehole at Umodzi Village in Chikhwawa District showing its relative to a pit latrine and a rain-fed maize garden

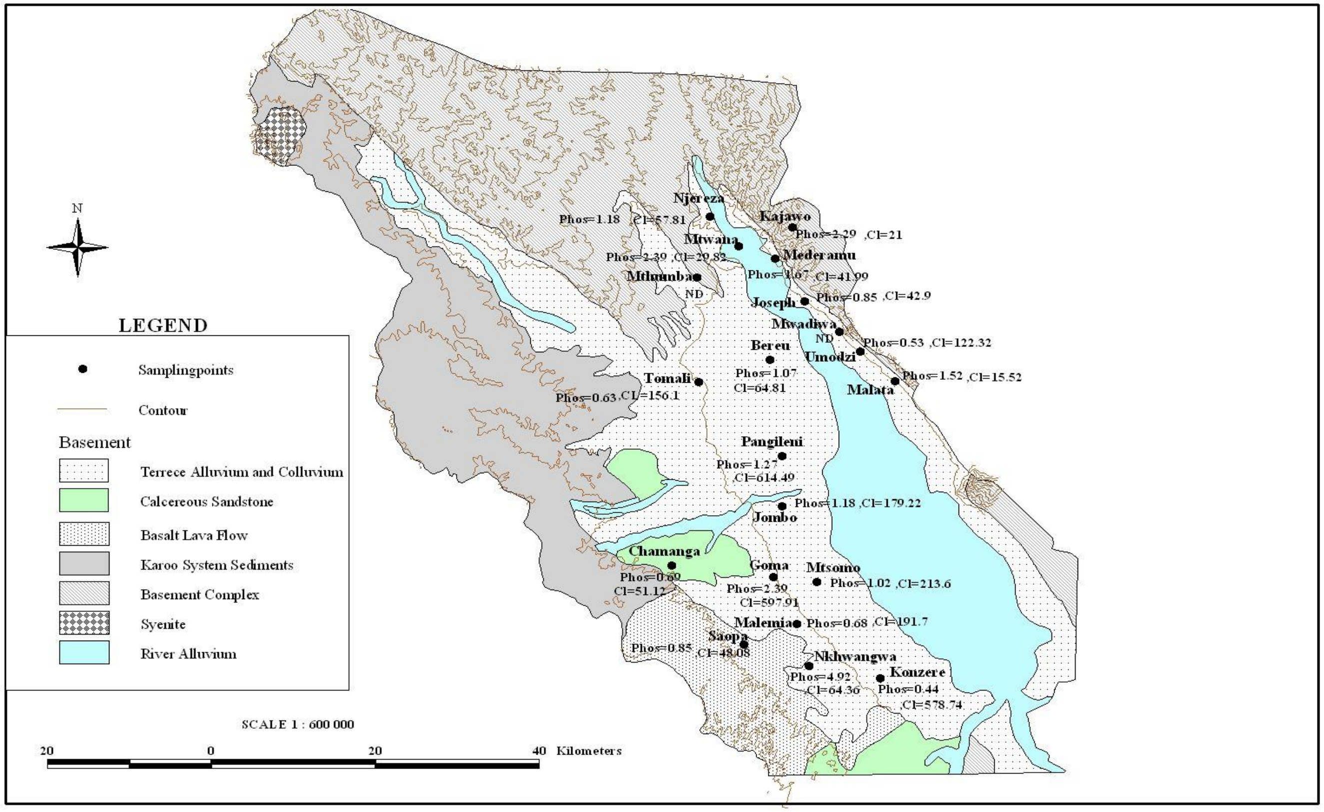

Figure 9: Distribution of phosphate and chloride (wet season samples) in relation to geology

4.1.3 Levels of sodium, potassium, calcium, magnesium, iron, and manganese

Values of sodium ranged from 32.86 mg/L (Nkhwangwa) to 55.78 mg/L (Umodzi borehole) and 16.65 mg/L (Nthumba) to 41.69 mg/L (Njereza) in the dry and wet seasons, respectively (Table **4** ; Figure 11). The concentration of potassium ranged from below detection limit (Joseph and Malata boreholes) to 7.19 mg/L (Nkhwangwa) during the dry season. One borehole at Konzere recorded the lowest value of potasium (0.44 mg/L) while another borehole at Nkhwangwa recorded the highest value (4.92 mg/L) during the wet season (Table 4; Figure 9). Calcium levels ranged from 0.25mg/L (Jombo borehole) to 19.95 mg/L (Malata borehole) in the dry season and from below detection limit (Goma borehole) to 14.17 mg/L (Nthumba borehole) in the wet season (Table **4**; Figure 10). Magnesium values ranged from 13.23 mg/L (Ntwana borehole) to 36.20 mg/L (Saopa borehole) in the dry season whilst in the wet season the values ranged from 1.51mg/L (Nthumba borehole) to 31.3 mg/L (Saopa borehole) (Table **4**). The manganese results ranged from below detection limit to 0.25 mg/L in the dry season and from below detection limit to 0.08 mg/L in the wet season (Table 4).

The dry season recorded significantly higher levels of sodium, potassium and magnesium than the wet season ($p < 0.05$; Appendix 2: Tables 11, 12 and 14) a variation, which may again be attributed to dilution. There was no statistically significant difference between the concentrations of calcium for the two seasons ($p > 0.05$; Appendix 2). Iron was not detected in all the samples (Tables 2 and 3). Manganese was only detected at Tomali (0.25±0.05 and Ntwana (17±0mg/L) in the dry season and at Diwa (0.08±0.26 mg/L in the wet season only (Table 3).

Table 2: Results of analysis of ground water samples for pH, EC, TDS, nitrates, phosphates and chlorides
Note: (mean ± standard deviation)- (N.D = Not determined)

	PARAMETER	**pH**		**TDS (mg/L)**		**Nitrates (mg/L)**		**Phosphates (mg/L)**		**Chlorides (mg/L)**	
NO	**BOREHOLE**	**Dry season**	**Wet season**	**Dry season**	**Wet season**	**Dry season**	**Wet season**	**Dry season**	**Wet season**	**Dry season**	**Wet season**
1	JOMBO	8.41±0.05	7.68±0.40	899±68	635±4	28.81±5.63	20.39±5.75	0.26±0.28	0.03±0.00	179.22±13.21	0.03
2	GOMA	8.24±0.05	7.12±0.03	3096±14	2801±44	19.01±2.63	13.92	0.14±0.08	0.07±0.00	597.91±30.98	0.08
3	CHAMANGA	8.38±0.03	7.48±0.20	759±75	604±34	28.62±5.61	23.05±9.11	0.11±0.03	0.14±0.01	51.12	0.01
4	MTSOMO	8.54±0.06	7.78±0.15	1489±59	1153±15	25.07±0.27	16	0.10±0.02	0.03±0.00	213.60±4.83	0.02
5	SAOPA	8.35±0.08	7.36±0.02	866±93	789±31	25.30±0.28	17	0.19±0.14	0.09±0.07	48.08±3.80	0
6	MALEMIYA	8.59±0.05	7.95±0.17	1794±166	1303±6	25.41±0.48	20.75±4.2	0.41±0.34	0.01±0.00	191.70±5.16	0.17
7	KONZERE	8.19±0.08	7.43±0.12	3203±40	2416±7	10.31±2.77	2.92±0.94	0.18±0.04	0.02±0.02	578.74±7.75	0.07
8	NKHWANGWA	7.76±0.06	7.8±0.40	751±25	659±1	24.93±0.10	13	0.34±0.16	0.02±0.00	64.36±8.39	0
9	PANGILENI	8.19±0.08	7.83±0.10	3592±34	1864±11	26.11±2.95	13.62±5.42	1.83±0.63	0.02±0.00	614.49±15.28	0.62±0.02
10	TOMALI	7.37±0.65	7.92±0.05	892±87	847±8	0.57±0	0.09±2.20	2.95±1.41	0.02±0.00	156.10±3.87	0.18
11	BEREU	8.47±0.15	8.17±0.40	736	635±4	0.76±0.58	0.10	2.01±0.51	0.09±0.00	64.81±3.87	0
12	NTHUMBA	N.D-	7.28±0.13	N.D-	653±3	N.D-	7.0±0.01	N.D-	0.02±0.00	N.D-	0
13	NJEREZA	8.38±0.52	8.08±0.05	865±22	662±20	24.29±0.52	7.80±0.0	2.04±0.48	0.02±0.01	57.81±2.11	0.1
14	NTWANA	8.30±0.39	7.71±0.06	281±16	230±6	10.34±0.06	4.68±1.46	3.59±1.12	0.02±0.00	29.82±13.70	0
15	JOSEPH	8.01±0.49	7.13±0.57	594±45	425±5	14.02±8.87	2.61±0.49	0.27±0.13	0.03±0.00	42.90±3.87	0
16	UMODZI	7.56±0.42	7.56±0.50	835±66	833±3	24.42±1.32	14.71±4.92	0.17±0.03	0.03±0.00	122.32±3.16	0.01
17	MALATA	8.03±0.34	8.41±0.90	337±53	221±2	22.11±0.11	14.01	0.57±0.01	0.10±0.15	15.52±1.29	0
18	DIWA	N.D	8.45±0.67	N.D	322±2	N.D	1.61±0.04	N.D	0.03±0.00	N.D	0
19	MEDELAMU	7.86±0.47	7.31±0.67	466±10	485±13	7.36±0.36	6.84±1.93	0.33±0.08	0.11±0.00	41.99	0
20	KAJAWO	7.50±023	7.72±0.73	313±15	261±3	11.84±2.77	4.0 ±0.9	0.28±0.02	0.13	21±1.29	0

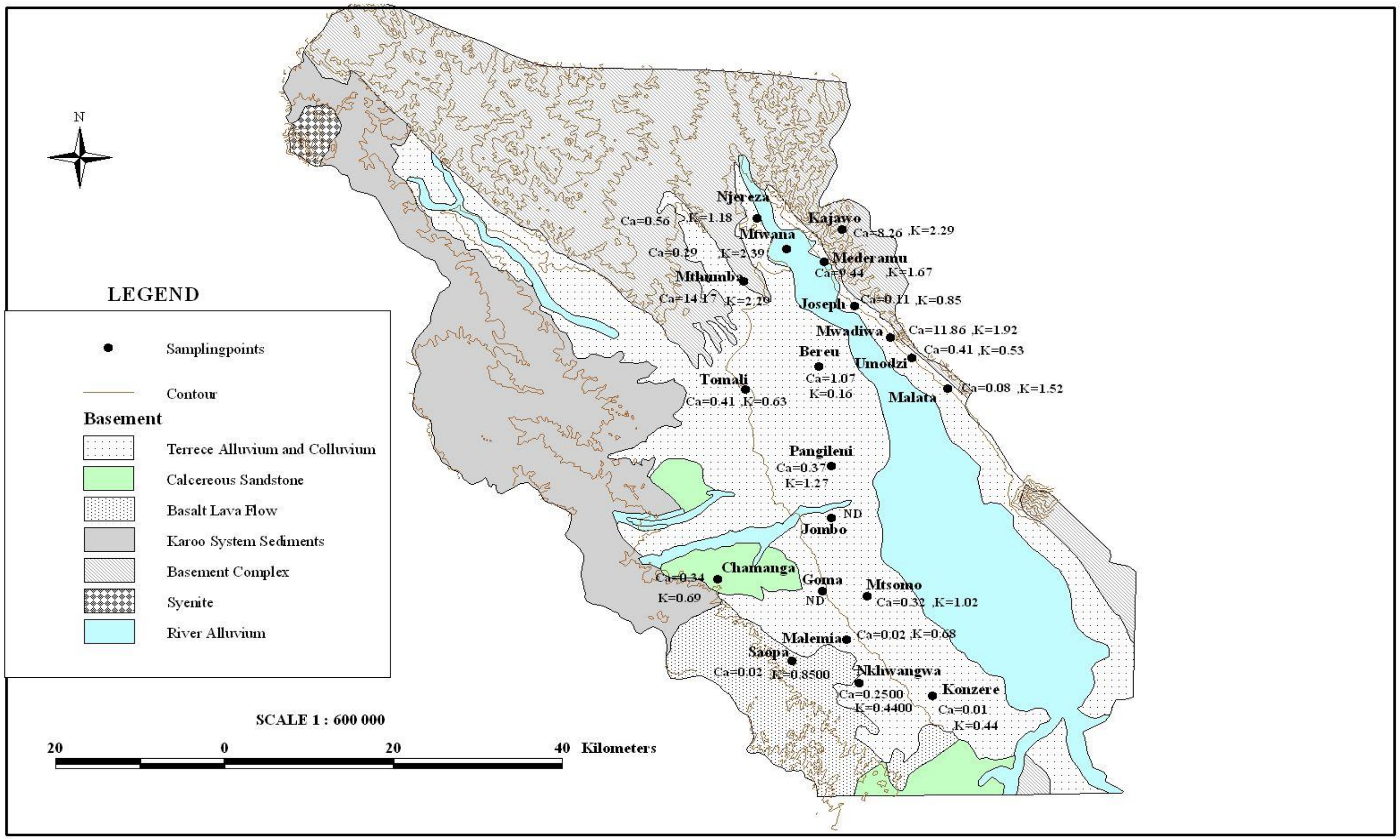

Figure 10: Distribution of calcium and potassium (dry season samples) in relation to geology. Note: N. D = Not Determined

Table 3: Results of chemical analysis for Na, K, Ca, Fe, Mg and Mn

Note: (mean ± standard deviation) N.D=Not Determined

	PARAMETER	**Sodium (mg/L)**		Potassium (mg/L)		**Calcium (mg/L)**		**Iron (mg/L)**		**Mg (mg/L)**		**Mn (mg/L)**	
NO	**NAME**	**Dry Season**	**Wet Season**	**Dry Season**	**Wet Season**	**Dry Season**	**Wet Season**	**Dry Season**	**Wet Season**	**Dry Season**	**Wet Season**	**Dry Season**	**Wet Season**
1	JOMBO	46.88±3.87	29.69±0.92	4.03	1.18±0.02	0.25±0.01	0.23±0.10	<0.03	<0.03	27.60±0.16	24.42±0.49	<0.01	<0.01
2	GOMA	53.85±1.41	36.16±0.05	6.09	2.39±0.04	0.73±0.06	0	<0.03	<0.03	33.28±0.74	27.64±0.21	<0.01	<0.01
3	CHAMANGA	55.87	30.71±0.10	1.01	0.69±0.01	0.35±0.04	0.34±0.19	<0.03	<0.03	28.71±0.55	25.83±0.24	<0.01	<0.01
4	MTSOMO	52.53±2.92	32.83±0.01	3.02	1.02±0.01	0.40±0.03	0.32±0.02	<0.03	<0.03	32.56±1.6	28.10±0.62	<0.01	<0.01
5	SAOPA	54.90±1.36	31.51±0.17	0.9	0.85±0.03	0.50±0.02	0.02±2.32	<0.03	<0.03	36.20±0.4	31.38±0.10	<0.01	<0.01
6	MALEMIYA	52.88±0.6	33.27±0.07	1.1	0.68±0.04	0.44±0.03	0.02±0.93	<0.03	<0.03	29.31±0.23	20.53±0.44	<0.01	<0.01
7	KONZERE	54.19±0.19	33.24±0.05	2.26±0.29	0.44	0.32±0.02	0.01±0.28	<0.03	<0.03	35.63±0.24	29.25±0.4	<0.01	<0.01
8	NKHWANGWA	32.86±5.54	28.2	7.19±0.37	4.92±0.06	0.33±0.08	0.25	<0.03	<0.03	28.39±0.43	22.17±0.29	<0.01	<0.01
9	PANGILENI	54.50±0.22	29.1	3.14±0.01	1.27±0.01	0.88±0.03	0.37±1.39	<0.03	<0.03	33.28±0.83	16.13±0.27	<0.01	<0.01
10	TOMALI	50±0.50	28.90±0.09	2.01	0.63	0.67±0.28	0.41±0.75	<0.03	<0.03	21.63±1.5	11.23±0	0.25±0.05	0.02
11	BEREU	50.60±0.94	31.02±0.13	2.2	1.07±0.02	0.61±0.55	0.16±0.10	<0.03	<0.03	13.23±1.22	8.66±0.02	<0.01	<0.01
12	NTHUMBA	N.D	16.65±0.76	N.D-	.29±0.96	N.D	14.17±0.18	N.D-	<0.03	N.D	1.51±0.03	N.D-	<0.01
13	NJEREZA	51.88±1.41	41.69±0.92	3.1	1.18±0.02	0.77±0.19	0.56±0.22	<0.03	<0.03	22.35±0.78	16.42±0.49	<0.01	<0.01
14	NTWANA	54.34±2.19	36.16±0.05	2.0	2.39±0.04	0.40±0.24	0.29±0.47	<0.03	<0.03	13.88±2.43	9.64±0.21	0.17±0	<0.01
15	JOSEPH	55.64±0.01	31.51±0.17	0	0.85±0.03	0.67	0.11±0.05	<0.03	<0.03	26.66±1.54	18.38±0.10	<0.01	<0.01
16	UMODZI	55.78±0.05	31.99±0.13	1.05	0.53±0.03	0.82±0.07	0.41±1.87	<0.03	<0.03	31.46±0.23	24.42±0.32	<0.01	<0.01
17	MALATA	55.61±0.01	32.79±0.10	0	1.52±0.04	19.95±0.84	10.08±0.22	<0.03	<0.03	24.23±0.46	10.86±0.08	<0.01	<0.01
18	DIWA	N.D	28	N.D-	1.92±0.07	N.D -	11.86±0.13	N.D-	<0.03	N.D-	15.16±0.09	N.D-	.08±0.26
19	MEDELAMU	55.76±0.01	27.76±0.37	3.02	1.67±0.04	14.14±0.02	9.44±0.15	<0.03	<0.03	28.33±0.63	15.27±0.02	<0.01	<0.01
20	KAJAWO	55.37±0.01	39.65±0.76	4.31	2.29±0.96	9.14	8.26±0.10	<0.03	<0.03	25.91±0.13	16.51±0.03	<0.01	<0.01

Table 4: Univariate statistical overview of the data set (groundwater samples).
Note: All values in mg/l unless otherwise indicated.

Parameter	Groundwater samples *n* = 20								Standard Guidelines	
	Wet season				Dry season					
	Average	Minimum	Maximum	Std dev	Average	Minimum	Maximum	Std. dev	WHO	MBS
pH	7.73	7.12	8.78	0.3	8.12	7.37	8.59	0.3	6.5 to 8.5	6.5 to 9.5
TDS	889.9	221	2808	23	1209	281	3592	25	500	1000
Nitrates	10.53	0.1	23.05	4.56	18.29	0.157	28.81	2.87	10	10
Phosphate	0.05	0.01	0.14	0.1	0.88	0.1	3.59	0.56	0.01	0.01
Chlorides	0.06	0.00	0.62	0.01	171.75	15.52	614.49	8.26	200	200
Sodium	31.54	16.65	41.69	0.84	52.41	32.86	55	2.77	200	200
Potassium	1.49	0.44	4.92	0.03	2.58	<0.03	7.19	0.18	50	50
Calcium	2.87	<0.03	14.17	0.09	2.98	0.25	19.95	0.43	200	200
Iron	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.3	1
Magnesium	18.68	1.51	31.38	0.06	27.37	13.88	36.20	1.41	50	50
Manganese	0.01	<0.01	0.08	0.13	0.01	<0.01	0.25	0.01	0.5	2

4.3.1 Seasonal variations of groundwater quality

Seasonal variations in groundwater chemistry in any area are principally due to variations in groundwater recharge, pumping, well lithology and geochemical reactions (Scheytt, 1997). In the study area, most of the parameters show decreasing trends in the wet season, meaning that the concentration of ions in groundwater decreases with rise in water level. This is due to dilution of groundwater by recharge of rainwater. The recharge process reduces the ionic concentration in the groundwater through the mixing of fresh infiltrated water with groundwater. During the dry season, the lowering of water levels is accompanied by increasing ionic concentration due to evaporation (Rajmohan and Elango, 2006).

Socio-economic implications of groundwater quality

The neutral to slightly alkaline nature of groundwater (the pH levels) in the sampled areas suggest that no dissolution of toxic compounds can occur (Price, 1996), thus making the water suitable for domestic and commercial purposes. However, the seasonal groundwater quality variations and the relatively high TDS, sodium and chloride levels (Tables 2, 3 and 4; Figures 7, 8, and 11) above WHO and MBS MCL in all the sampled sites could make the water sour and vulnerable to pollution (SVADP, 1975). The high nitrate levels could be a source of blue baby disease in children and cancer in adults (Harrison 1996, USGS 1978) because they are above the WHO and MBS MCL of 10mg/l. High calcium (at Nthumba) and magnesium levels (Table 3) in the sampled areas suggest that borehole water is hard (Habgood 1963) and the water could require the usage of more soap in household/domestic chores like washing.

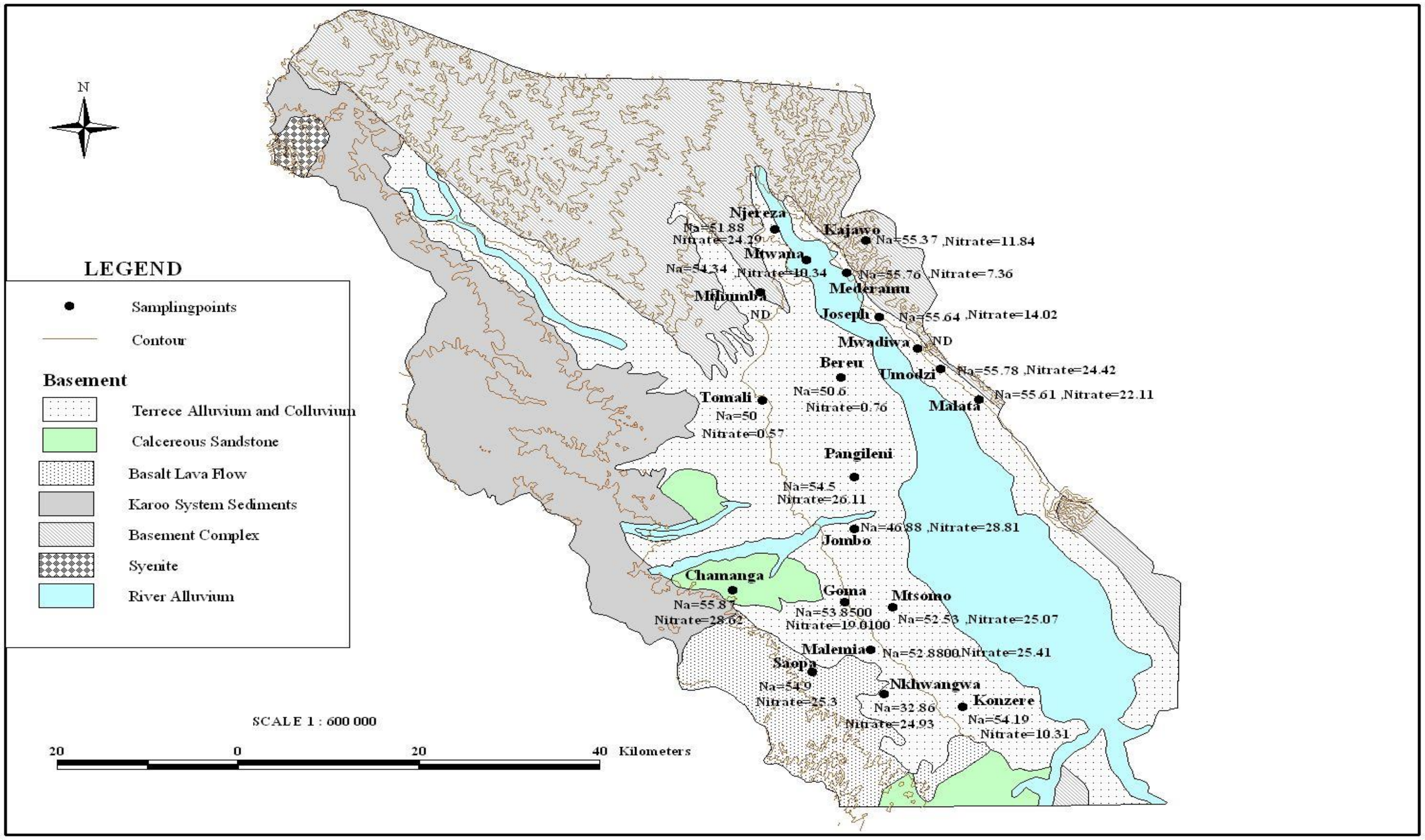

Figure 11: Distribution of sodium and nitrates (wet season samples) in relation to geology.

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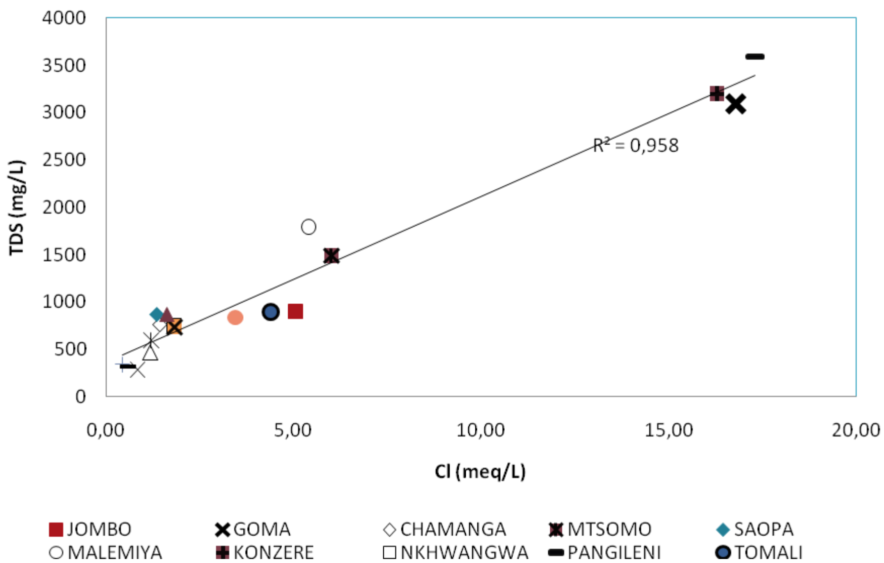

Figure 12: Variation of TDS with chlorides for the sampled boreholes (data for dry season)

Secondly most boreholes in the low altitudes and drilled on flat ground (Table.5; Figure 13) have higher TDS values (and hence chlorides) than in the high altitudes (Table 3; Figure 13: and 14) and for boreholes in the similar geological formation, high TDS values were recorded for most shallow boreholes.

Table 5: Depth, formations penetrated, altitude of sampled boreholes and description of their surroundings

NO	NAME	Depth (m)	Altitude (m	Formations penetrated	Surroundings description
1	JOMBO	20	84	Alluvium and drift and gravel	Found at a primary school and drilled on flat land, sandy loam soils and alluvium and colluvium sediments (fig.3).
2	GOMA	36	100	Sandy clay and gravel	Flat land, surrounded with houses.
3	CHAMANGA	46	134	Sandy clay and gravel	Gentle slopping land
4	MTSOMO	38	98	Alluvium and drift	Drilled on a flat land with alluvial carcimorphic soils
5	SAOPA	48	170	Alluvium, Drift with gravel	Drilled on gravel land, surrounded with houses with a toilet some meters away.
6	MALEMIYA	28	128	Colluvium and drift	Flat land with toilets about 30 m away
7	KONZERE	28	90	Colluvium and drift	Sloppy land with cattle kraal and pit latrines about 50 meters away.
8	NKHWANGWA	42	72	Sandy drift	Flat land with alluvial carcimorphic soils
9	PANGILENI	10	75	Sandy drift	Flat land. Surrounded with houses with pit latrines
10	TOMALI	42	105	Sandy clay and gravel	Flat land, drilled in alluvial and colluvial soils with houses and a cattle kraal about 30 meters away.
11	BEREU	22	83	Sandy drift	Found at a primary school with toilets about 50 meters away and drilled on a flat land in alluvial and colluvium soils/alluvial aquifer
12	NTHUMBA	40	130	Gravel and basement complex gneiss	Found on a sloppy and undulating land in a basement complex aquifer
13	NJEREZA	24	90±24	Sandy clay and drift	Drilled on gentle slopping land, on alluvium and colluvium soils about 100 meters from the main channel of the Shire River
14	NTWANA	20	96	Clay and sandy drift	Drilled on flat land on colluvium and alluvium soils, alluvial aquifers (see map 3), about 100 meters away from a marshy area (toilets 20 to 50 m away)
15	JOSEPH	32	100±25	Drift with gravel	Drilled on the foot of Thyolo escarpments, gravel land
16	UMODZI	44	120	Gravel and basement complex gneiss	Drilled on a steep slope in a basement complex aquifer with toilets around (fig. 4).
17	MALATA	38	100±30	Gravel and basement complex gneiss	Drilled on a gentle slopping land
18	DIWA	42	90	Gravel, basement complex gneiss and sandy drift	Drilled on a gravel soil, probably in a basement complex aquifer
19	MEDELAMU	40	91	Gravel and sandy drift	Drilled on the foot of Shire highland/escarpments,
20	KAJAWO	24	513	Very steep slope, basement complex gneiss (map 3 and fig. 5)	Very high altitude (Table 1.5). Drilled on a hill, very steep slope in basement complex aquifers with school toilets uphill (fig. 5)

The high TDS values recorded could be attributed to evaporation of groundwater discharge areas near the surface creating a salt build up because of high temperatures. The trend in Figure 12: is not apparent for data from the wet season, as there is a very low concentration of chlorides as already mentioned.

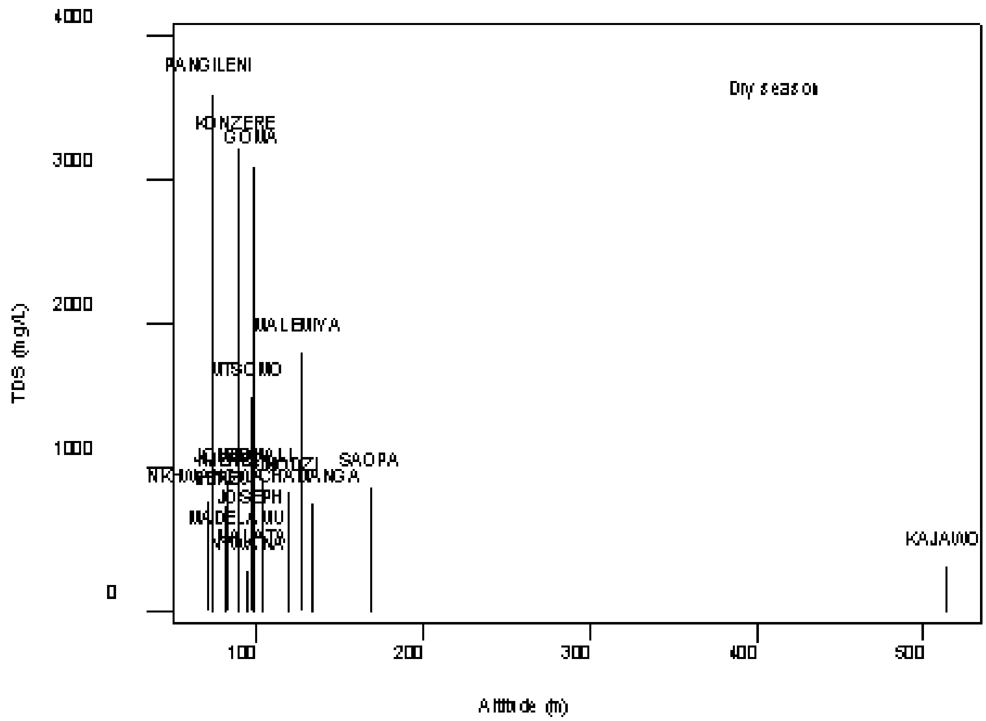

Figure 13: Variation of TDS with elevation for the sampled boreholes (data for dry season)

Six boreholes namely, Jombo, Goma, Chamanga, Mtsomo Bereu and Njereza boreholes yielded higher nitrates levels and were located in alluvial calcimorphic soils and topovertisols and lithomorphic vertisols that might be the source of this nitrate (Tables 2 and 3). Boreholes that yielded high sodium values such as Jombo, Goma, Chamanga, Malemiya and Konzere are located in discharge areas and their depth penetrated sandy clay (Table 5), vertisols and the medium textured soils that are often compact with significant amount of exchangeable sodium that contribute to poor internal drainage conditions (SVADP, 1975). Saline and sodic patches occur in the vertisols, particularly close to the edge of the Elephant Marsh, in areas where saline groundwater rises to the surface (SVADP, 1975).Tomali, Nkhwangwa, Nthumba, Pangileni Bereu and Nthumba boreholes detected relatively higher levels of potassium (Table 3, Figure 10). This could result from their location in alluvial calcimorphic soils because potassium levels in these soils were high (Malawi Government FRIM Report, 1978). Further, the mineral composition of the rocks in Chikhwawa District is mostly composed of amphibolite facies that show evidence of the presence of potash metasomatism over a wide area (Habgood, 1963).

The boreholes located in higher altitude (200m above sea level) and in basement complex gneiss (Nthumba, Malata, Medelamu Diwa, and (Figures 7, 8 and 15, and 19) yielded higher values of calcium whilst those located in lower altitude areas, below 200m above sea level (Jombo, Goma, Nkhwangwa, Bereu and Njereza) recorded lower calcium values (Figures 5; 6 and 12; Tables 3, and 4). This is because boreholes in higher altitude areas were geologically located in basement complex aquifers that contain limestone with widespread presence of calcium (Habgood, 1963) and it also indicates the presence of carbonate rocks (Figures 6 and 9) as the main reservoir rocks (Gemici, et, al, 2004;). On the other hand boreholes for example Jombo, Goma, Konzere and Nkhwangwa showed lower calcium levels (Table.3; Figure 10) and are located in alluvial aquifers with terrace alluvium and colluvium (Figure 10 and Table 5) because the alluviums are physically weathered Quartz which is very strong. The presence of Mg could be attributed to the basaltic lava that the boreholes penetrated at Saopa.

Figure 14**:** A photograph of Jombo borehole drilled in a flood plain/flat area and detected higher TDS, Mg and K^+ levels.


Figure 15: A sampled borehole at Kajawo drilled in basement complex aquifers that recorded high calcium values

Major cation Chemistry

Among the major cations, Na is the most abundant followed by Mg and in general the major cations decrease in the order: Na > Mg > Ca > K (Table 4). This is clearly evident in the ternary cation plot (Figure 16:) in which most of the samples cluster midway along the Mg-Na+K axis.

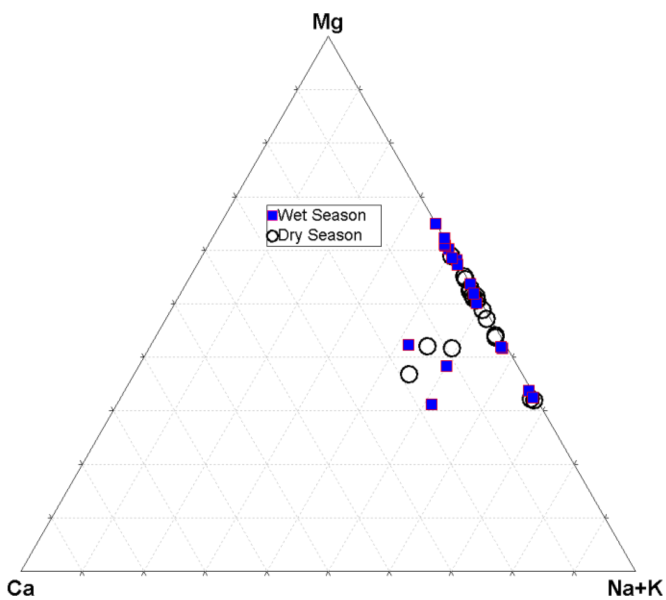

Figure 16**:** A ternary plot for cations in groundwater from sampled boreholes in Chikhwawa.
Most of the samples cluster mid way along the Mg-Na+K axis (see text for discussion)

There are three major natural processes controlling water chemistry: (1) atmospheric precipitation; (2) rock weathering; and (3) evaporation and fractional crystallization. Gibbs (1970) suggested that a simple plot of TDS versus the cation ratio, $\frac{Na^{+}+K^{+}}{Na^{+}+K^{+}+Ca^{2+}}$ or anion ratio, $\frac{Cl^{-}}{Cl^{-}+HCO_3^{-}}$ (where all ion concentrations are expressed in meq/l) would provide information on the relative importance of the three major natural processes controlling water chemistry. Gibbs cation ratio for the sampled boreholes has been plotted against their respective TDS values (Figure 17:). It is observed from the diagram that the groundwater in Chikhwawa District fall into the rock-water interaction area, indicating the interaction between rock and water in the subsurface and hence dependence of groundwater quality on aquifer lithology.

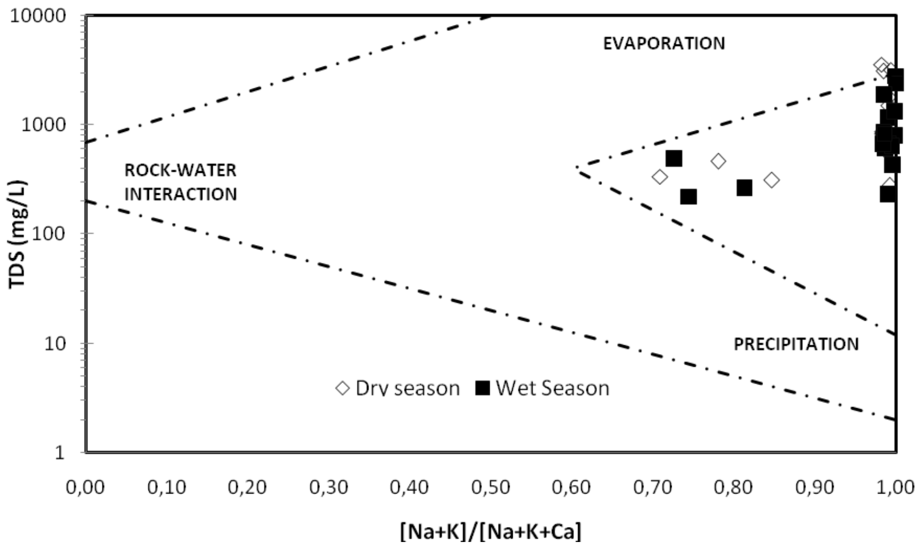

Figure 17**:** Gibbs diagram showing processes controlling the quality of groundwater (after Gibbs, 1970).

The rock dominance of Chikhwawa groundwater major element chemistry point towards ion exchange and weathering reactions as processes controlling the water chemistry. Weathering of different parent rocks (e.g. carbonates, silicates, and evaporites) yields different combinations of dissolved cations and anions to solution. For example, Ca and Mg are supplied by the weathering of carbonates, silicates and evaporites, Na and K by the weathering of evaporites and silicates, HCO_3^- by carbonates and silicates, SO_4^{2-} and

Cl^- by evaporites. Silica, on the other hand, is derived exclusively from the weathering of silicates. The dominance of Na^+, an index of weathering, suggests that the ions result from silicate weathering and/or dissolution of salts (evaporites).

If halite dissolution (weathering of evaporites) is responsible for high sodium content, the Na/Cl molar ratio should be approximately equal to one, whereas a ratio greater than one is typically interpreted as Na released from a silicate weathering reaction (Mayback 1987). In the present study, the molar ratio of Na/Cl for groundwater samples of the study area, in the dry season, generally ranges from 0.14 (Pangileni and Konzere boreholes, located in sandy collovium drifts, respectively) to 5.53 (Malata borehole, located in basement complex gneisses(Figure 7). Samples having a Na/Cl ratio greater than one indicate excess sodium, which might have come from silicate weathering. However, samples with a Na/Cl ratio around and less than one indicate the possibility of some other chemical processes, such as ion exchange (Rajmohan and Elango, 2006).

To determine the dominant sources (carbonate or silicate rocks) of major ions Ca+Mg is plotted against Na+K (Figure 18:). The data set is distributed above and below the equiline, indicating a possible contribution from both carbonate and silicate lithology as the dominant source of major ions. The cation ternary plot (Figure 16:), suggests Mg containing carbonates and silicates, as data points do not plot in a cluster near the Ca apex.

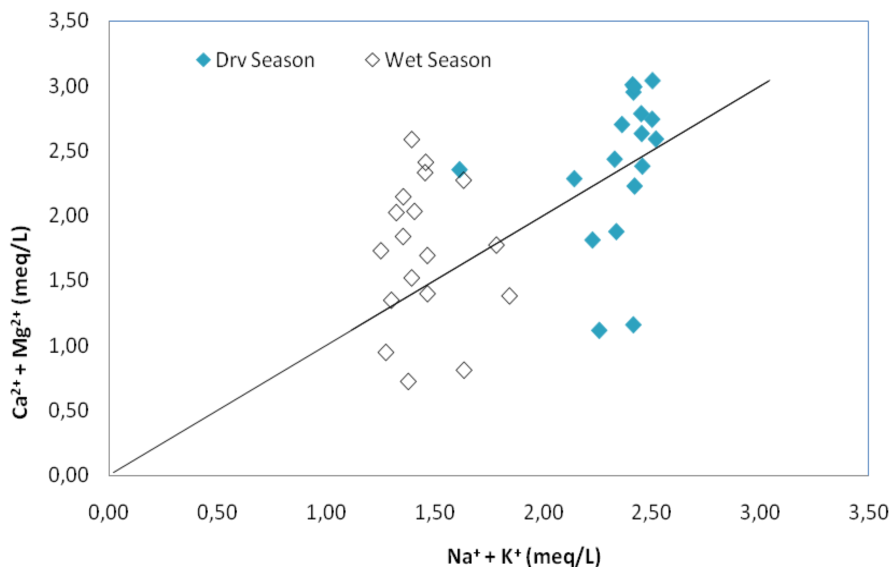

Figure 18**:** A plot of Ca+Mg (meq/L) vs Na+K (meq/L)

In the study area weathering is attributable to alternate wet and dry conditions (physical weathering) that prevail in the semi-arid climate. Chemical weathering may also result in the dissolution of silicate minerals, orthoclase, plagioclase, hornblende, diopside, hypersthene, olivine and biotitite, of country rocks in the area by carbonic acid in the district. This can be explained by a general reaction for the weathering of silicate rocks with carbonic acid is as follows:

$$\text{(cations)silicates} + H_2CO_3 \longrightarrow H_2SiO_4 + HCO_3^- + \text{cations} + \text{solid products (mailny clays)} \quad (1)$$

The carbonic acid in water results from the solubility of CO_2 in water given by the equilibria:

$$CO_2\,(g) \xrightleftharpoons{(a)} CO_2\,(aq) \xrightleftharpoons{(b)} H_2CO_3\,(aq) \xrightleftharpoons{(c)} HCO_3^-\,(aq) \xrightleftharpoons{(d)} CO_3^{2-}(aq)$$

(2)

Where step (a) describes the equillibrium between atmospheric CO_2 and dissolved CO_2 described by Henry's law; step (b) is the equilibrium between dissolved CO_2 and its equated from, H_2CO_3; step (c) describes the loss of the first proton of H_2CO_3 and step (d) is for the loss of the second proton of carbonic acid (vanLoon and Duffy, 2006).

The hydrogeochemical reaction (1) infers that the groundwater should acquire cations (besides SiO_2) and HCO_3^- as the most abundant anion. The pH range of the groundwater samples in the study area is reminiscent of groundwater in equilibrium with a source of bicarbonates (vanLoon and Duffy, 2006; Price, 1996). Ca^{2+}+Mg^{2+} vs TC (total cations) as this is explained by the fact that data analyzed lie below the equiline (1:1, Figure 19:), thereby depicting an increasing contribution of alkalines to the major ions. Groundwater in the study area (Chikhwawa District) has a higher ratio (0.5) of (Na^++K^+) vs TC (Figure 20:). This depicts the contribution of cations via silicate weathering and/or soils, to some extent (Sarin et al, 1989). Molar Na^+: Ca^{2+} ratios of the groundwater samples in Chikwawa District are more than unity (mean 78.94) indicating a deficiency of Ca^{2+}. This may be caused by precipitation of $CaCO_3$ and/or ion exchange process.

In the study area, the concentration of Mg^{2+} is more than that of Ca^{2+} in the groundwater (Tables 3 and 4; Figure 18). The low Ca/Mg ratio in water may result from the supply of Ca and Mg via dissolution of dolomites (Singh et al., 1998) and/or preferential removal of Ca from the water by precipitation (as calcite) (Sarin et al., 1989), since the solubility of $CaCO_3$ is much lower than (less than that of $MgCO_3$), resulting in a decline of Ca^{2+} values. The evaporation also results in the precipitation of $CaCO_3$ as described by the Hardie-Eugster model for evaporation of natural waters (Drever, 1988). The observed excess of Na^+ over K^+ is attributable to greater resistance of K^+ to weathering and its fixation in the formation of clay minerals (Rajmohan and Elango, 2004)

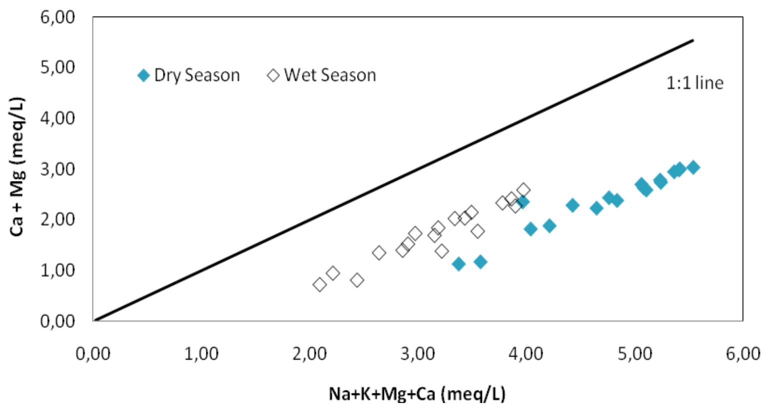

Figure 19: A plot of Ca+Mg against cations (in meq/L) for the samped boreholes

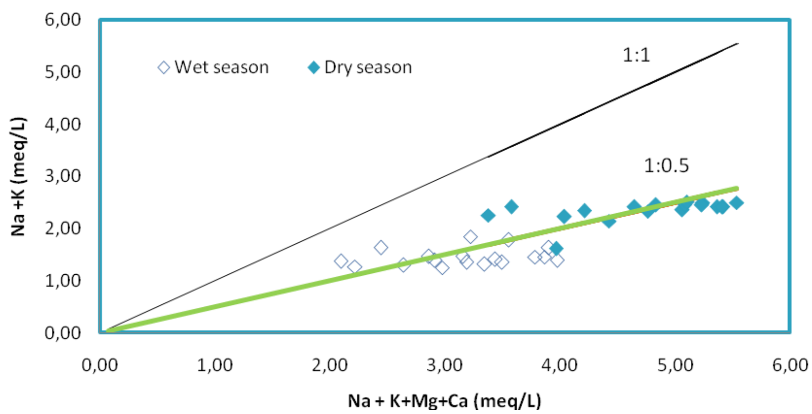

Figure 20: A plot of Na+K vs total cations for the groundwaters from the sampled boreholes depicting contribution via silicate weathering.

Hence in general the quality of groundwater is affected mainly by the lithology with rock-water interaction processes of carbonate and silicate weathering, ion exchange together with evaporation, to an extent, being important. Loss of groundwater as a result of the evaporation/evapotranspiration process results in the transfer of salts from the groundwater to the soils (Drever 1988). The study area has a gentle slope (Figure 5; Table 5) and lacks a good drainage system, being in a semi-arid climate, which leads to a high rate of evapotranspiration, especially during summer. It forms alkaline/saline soils, which serve as a source of dissolved ions. This may be attributable to increase in Cl in the low lying areas (Table 2 and Figure 20).

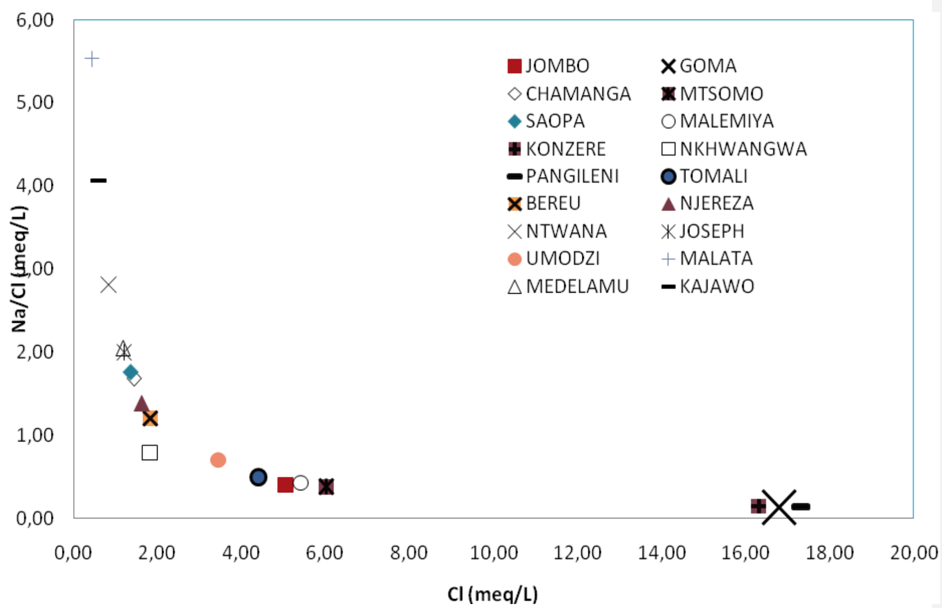

Figure 21: Variation of Na:Cl ratio with Cl for the sampled boreholes.
The concentration of Na is invariant; hence the reduction of the Na/Cl ratio is due to increase in Cl concentrations. See Table 5 for comments on the area surrounding the boreholes.

4.3 GROUNDWATER QUALITY VARIATION WITH BOREHOLE LOCATION.

Generally boreholes located in sandy clay (Goma) and colluvium (Konzere), sandy drift (Pangileni) and in discharge areas/low lying/floodplain areas with alluvial aquifers recorded high TDS levels whilst boreholes in recharge/high altitude areas which are principally basement complex aquifers recorded low TDS values (Figures 7, 8; Table 3). Three boreholes namely Ntwana, Joseph and Bereu yielded lower levels of TDS which is predominantly calcium bicarbonate because they are in the sidelines of the rift valley (SVADP, 1975). The TDS is strongly correlated with chlorides, indicating strong contrition of chlorides to ion content of the water (Figure 12:). But the levels of nitrates, chlorides, sodium, calcium, and magnesium vary with location of the boreholes (Tables 2, 3 and 4; Figures 9, 10, 13, and 16) in that floodplain areas have generally recorded lower levels of these parameters than high altitude areas. This suggests that apart from the seasonal variation in groundwater quality, there is spatial variation in groundwater quality in the district that is dependent on geology, soil type and topography.

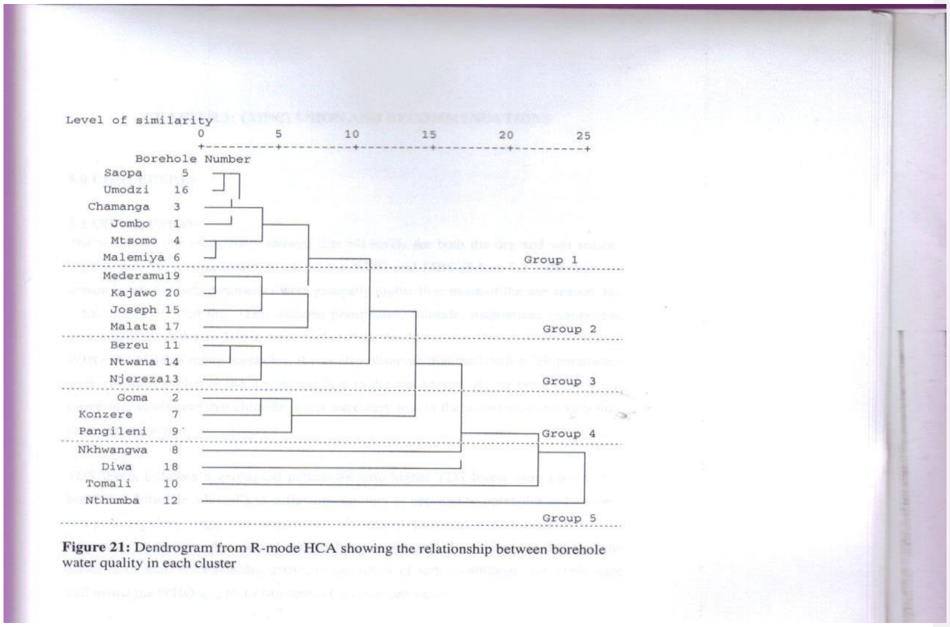

Figure 22: Dendrogram from R-mode HCA mode showing the relationship between borehole water quality in each cluster

Based on Figure 22 boreholes located in the same topographic and geological setting do not necessarily have the same water quality characteristics perhaps due to differences in depths and geological formations penetrated (Table 5). Thus the twenty boreholes were classified into five clusters based on their physical and chemical characteristics: (Group 1: 5 (Saopa), 16 (Umodzi), 3 (Chamanga), 1 (Jombo), 4 (Mtsomo), and 6 (Malemiya), Group 2: 19 (Medelamu), 20 (Kajawo), 15 (Joseph), and 17 (Malata). Group 3: 11 (Bereu), 14 (Ntwana), 13 (Njereza), Group 4: 2 (Goma), 7 (Konzere), and 9 (Pangileni), Group 5: 8 (Nkhwangwa), 18 (Diwa), 10 (Tomali) and 12 (Nthumba). Boreholes in groups 1, 3 and 4 were classified in their respective groups perhaps because of their differences in depths that may have penetrated the same geological formations (Table 5). Boreholes in groups 2 were drilled in high altitude and recharge areas with gravel whilst boreholes in group 5 were all located in the floodplain areas (Table 5).

The grouping of boreholes from different location into different clusters (Figure 22) suggests that classification of the water quality is dependent on a number of factors including climate (temperature, rainfall), nature of geology, topography and soil type.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Out of all the parameters (pH, TDS, Cl, $N0_{-3}$, Mn, Mg, Na, Ca, K, Fe) examined in this study, only the levels of pH, Na and Fe in the groundwater were safe for human consumption by WHO and MBS standards although the levels of these parameters were higher in the dry season compared to the wet seasons. But the levels of TDS, Cl, $N0_{-3}$, Phosphates, Mn, Mg, K, and Ca, were not safe for human consumption in some boreholes because their levels exceeded the WHO and MBS MCL.

TDS, Cl, $N0_{-3}$, and Na levels followed a geological pattern because higher TDS levels were observed in boreholes drilled in alluvial and colluvium aquifers as opposed to boreholes in basement complex aquifers. This suggests that boreholes drilled in basement complex aquifers which principally are high altitude areas have less TDS, Cl, and Na levels and hence good groundwater quality fit for human consumption than boreholes drilled in floodplain/low altitude areas.

In this study variation in groundwater quality suggests that water quality is affected with a number of factors including topography, climate (temperature and rainfall), and geology and soil type. But in general the quality of groundwater is affected mainly by the lithology with rock-water interaction processes of carbonate and silicate weathering, ion exchange together with evaporation, to an extent, being important. Loss of groundwater as a result of the evaporation/evapotranspiration process results in the transfer of salts from the groundwater to the soils. The study area has a gentle slope and lacks a good drainage system, being in a semi-arid climate, which leads to a high rate of evapotranspiration, especially during summer. It was observed that boreholes located in higher altitude areas and in basement complex aquifers generally had lower levels of pH, TDS, nitrates, phosphates, and chloride than boreholes in the flood plain areas. Apart from this boreholes located near the Shire River for example Njereza and Ntwana detected relatively lower levels of magnesium than boreholes located in similar geological structures probably because of dilution factor. It was also observed that a number of boreholes were located close to pit latrines.

The fact that the levels of some parameters were above the WHO and MBS MCL suggests that if groundwater is used as a means of providing safe drinking water to rural communities without treatment, it may not help government achieve poverty reduction, economic growth and the Millennium Development Goals. For this reason the following recommendations are made:

5.2 RECOMMENDATIONS

- Groundwater should be treated chemically particularly on parameters whose levels are above the recommended guidelines of WHO and MBS.
- Frequent groundwater quality tests should be done in order to monitor groundwater quality.
- Although the effect of land use (eg pit latrines, sewage systems and industrial effluents and chemical fertilisers) on groundwater quality is not examined in this study, a groundwater management plan need to be produced in order to manage land use practices that may be recharged into groundwater and pollute it consequently.
- A strategy for creating public awareness of problems facing groundwater resources is required to help manage groundwater quality problems. Dissemination of information generated on groundwater quality problems can help raise public awareness of the problems affecting groundwater resources.
- This study was site specific (Chikhwawa) and another extensive study should be done to include more parameters and some areas of different geological formations to determine the quality of groundwater.

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APPENDICES

Appendix 1: Health effects of excess levels of parameters in drinking water

No.	Parameter	Undesirable health effect
1	TDS	• Causes affects color and smell of water (UNDP, 1992)
2	Nitrates	• Causes blue baby or methaemoglobinaemia in babies that impairs binding of oxygen molecules on haemoglobin (O'Neill, 1999) • Causes birth defects (National Governors Association, 1991) • Associated with cancer in adults (National Academy of Sciences, 1977).
3	Sulphates	• Give water a bitter taste to water • Cause a gastro intestinal irritation (Cairncross and Feachem, 1991).
4	Phosphates	• Causes cancer
5	Chlorides	• May give water a salty taste at concentration >250 mg/L (NREPC, 2003)
6	Manganese	• Reduces metabolism of iron to form haemoglobin (WHO, 1993) • Causes mental and emotional disturbance (*manganism*) that can permanently injure part of the brain that helps in motor control (ATSDR, 2002).
7	Iron	• Causes bad taste and odor in water • Precipitates and deposits reddish-brown stains (rusty) on pipes and sinks, • Causes discoloration of food and laundry and has a metallic taste to water (http://www.hc-sc.gc.ca/ewh-semt/water-).

8	Calcium and magnesium	• Causes water hardness (Cairncross and Feachem, 1999)
9	Sodium	• Leads to hypertension (Twort et., 2000)

Appendix 2: Results of Paired Samples t-Test

Table 4: Paired Samples Test for pH

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	pH for dry season - pH for wet season	.3717	.5307	.1251	.1078	.6356	2.971	17	.009

Table 5: Paired Samples Test for Electrical Conductivity

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	EC for dry season - EC for wet season	9.2222	25.2809	5.9588	-3.3497	21.7941	1.548	17	.140

Table 6: Paired Samples Test for TDS

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std.	Std. Error	95%				

			Deviation	Mean	Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	TDS for dry season - TDS for wet season	274.7222	412.8160	97.3017	69.4337	480.0108	2.823	17	.012

Table 7: Paired Samples Test for nitrates

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Nitrates for dry season - Nitrates for wet season	7.4328	4.3090	1.0156	5.2900	9.5756	7.318	17	.000

Table 8: Paired Samples Test for Phosphates

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Phosphates dry season - Phosphates wet season	.8217	1.1101	.2617	.2696	1.3737	3.140	17	.006

Table 9: Paired Samples Test for Chlorides

		Paired					t	df	Sig. (2-

		Differences							tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Chloride for dry season - Chloride for wet season	171.6778	204.9432	48.3056	69.7619	273.5936	3.554	17	.002

Table 10: Paired Samples Test for Sodium

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Sodium for dry season - Sodium for wet season	19.8478	5.6317	1.3274	17.0472	22.6484	14.952	17	.000

Table 11: Paired Samples Test for Potassium

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Potassium for dry season - Potassium for wet season	1.1589	1.3308	.3137	.4971	1.8207	3.695	17	.002

Table 12: Paired Samples Test for Calcium

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std.	Std. Error	95%				

			Deviation	Mean	Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Calcium for dry season - Calcium for wet season	1.1161	2.4251	.5716	-8.9844E-02	2.3221	1.953	17	.068

Table 13: Paired Samples Test for Magnesium

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Magnesium for dry season - Magnesium fro wet season	7.5444	3.8911	.9172	5.6094	9.4795	8.226	17	.000

Table13:Paired Samples Test for Manganese

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Manganese for dry season - Manganese for wet season	2.222E-02	6.549E-02	1.544E-02	-1.0345E-02	5.479E-02	1.440	17	.168