UNIVERSITY OF ZIMBABWE

Assessment of the chemical quality of groundwater for drinking in Dedza District, Malawi

By

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DECLARATION

I, **James Fred Kushe,** do confirm that this is my own work and the use of all materials from other sources has been properly and fully acknowledged. No part of it has been submitted previously for a Degree at any other University.

I am responsible for the research and its articulation alone. In no way do any of the persons mentioned in the acknowledgement bear any direct responsibility for this work.

………………………………………………………………………………………………..

JULY 2009

DEDICATION

I dedicate this paper to my son Talandira and my late father.

ABSTRACT

A lot of emphasis has been placed on the safety of drinking water from biological contamination with little consideration on the chemical quality although there are well known health risks associated with the consumption of groundwater with high levels of chemical pollutants. An assessment of the chemical quality of groundwater was done in Kachindamoto Traditional Authority area, in Dedza district of Malawi. The area was chosen because of the reported occurrence of salty water in some places. The main purpose of the study was to determine the chemical quality of groundwater and to compare it to the Malawi Bureau of Standards (MBS) and the Ministry of Irrigation and Water Development (MoIWD) Standards and identify critical areas and possible interventions. Samples were collected from 48 groundwater points and analysed for selected water quality parameters. Field tests were carried out for pH, conductivity and temperature while TDS, carbonate, bicarbonate, chloride, sulphates, nitrate, fluoride, sodium, potassium, calcium, magnesium, iron, manganese, total hardness, total alkalinity and silica were analysed in a laboratory. It was found out that most parameters (75%) satisfied the MBS and MoIWD standards. Most communities reported that the groundwater quality was acceptable for drinking although there were more respondents who were of the view that the water was unacceptable for bathing and laundry. It was also established that the levels of most parameters increased with proximity to the lake. Indications of dental fluorosis were observed in adults in areas around 30% of the water points visited although the levels of fluoride found in the study were below the WHO guidelines, MBS and MoIWD limits. No observations or reports of other negative health implications of the other parameter studied were found. It was concluded that the water quality is generally of acceptable quality according to WHO guidelines, MBS and MoIWD standards. It is recommended that the depth of the water point, geological material and distance from the lake should be taken into consideration in future projects notwithstanding the optimum depth for minimum yield. Further studies on the long-term effect of exposure to certain parameters such as fluoride, nitrates and iron should be carried out.

Key words: *Chemical water quality, fluorosis, groundwater, health impacts, Kachindamoto, potable water*

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

The provision of adequate and safe water for drinking is important for the development of any country (Pritchard et al., 2007). Groundwater contributes only 0.59% of the total water resources of the earth (Jones, 1997); however, it is the major and most preferred source of drinking water in rural and peri-urban areas, as well as urban areas in developing countries because it does not require treatment (Sajidu et al., 2008). Groundwater is the main source of water for about 60% of both rural and urban residents throughout Southern Africa, (UNEP, 2002). There is increasing demand for water due to the increase in population in Malawi. The NSO (2008) report indicates that the population of Malawi has increased from 9.9 million in 1998 to 13.1 million in 2008 representing a percentage increase of 32%. About 80% of this population is based in rural areas (NSO, 2008), where the most convenient and reliable sources of water for domestic use is groundwater.

The government efforts in addressing water issues in rural areas in Malawi in the quest to achieve the Millennium Development Goal 7, Target 10 which aims at halving the proportion of people without sustainable access to safe drinking water and improved sanitation by 2015 have concentrated on provision of groundwater to the people (Van Koppen et al., 2006). Staines (2002) reported that in Malawi, about 37% of the population used water from boreholes while about 26% of the population used water from shallow wells.

Malawi is endowed with a variety of natural resources which include vast expanses of water systems (GoM, 2007). Kundell (2008) noted that Malawi is generally considered to be relatively rich in water resources, which are stored in the form of lakes, rivers, and aquifers. The country is divided into 17 Water Resources Areas, which are subdivided into 78 Water Resources Units (Kundell, 2008). These includes Lake Malawi (28750 km^2) Africa's third largest freshwater lake, Lake Malombe (303 km^2) an inflation of the Shire River which form part of the great East African Rift Valley, Lake Chilwa (683 km^2) an inland basin lake and a dense network of perennial rivers. These water systems cover over 21% of the country's territorial area. There are also widespread groundwater sources whose occurrences are associated with two major aquifers namely the basement complex aquifers which are extensive but low yielding ranging from 0.2 to 4 litres per second (and covering the plateau areas, Shire Highlands, the Upper Shire River Valley, Lilongwe to Kasungu Plain and the South Rukuru River catchment). The alluvial aquifers (which are localized to Lakeshore plains and the Shire Valley) are high yielding with recorded yields in excess of 10 litres per second (GoM, 2007). However, these resources are of variable quality and quantities, unevenly distributed in time and space, and are subjected to poor conservation and management (GoM, 2007).

Annual rainfall in Malawi ranges from 700 to 2,400 millimeters (mm) with mean annual rainfall being 1,180 mm and is the major source of recharge to the aquifers. Its distribution is mostly influenced by the topography and proximity to Lake Malawi. The highest rainfall is experienced in the high altitude and mountainous areas of Mulanje, Zomba, Dedza and the plateaus of Viphya and Nyika while the lowest rainfall is experienced in the low lying areas of the Lake Malawi shores and Lower Shire Valley and other rain shadow areas (Kundell, 2008).

The history of groundwater development in Malawi dates back as far as the early 1930s and by 1994, there were about 9,600 boreholes and 5,600 protected shallow wells, the majority of which were constructed by the government (Kundell, 2008). Since then the increase in boreholes drilled by the government, non-governmental organizations, and the private sector has been dramatic, and according to the Ministry of Water Development there were about 19,000 boreholes drilled by 2001 and this trend is continuing. Furthermore, due to the recent frequent occurrence of droughts, the number of hand-dug shallow wells has considerably decreased because they are highly vulnerable and prone to drying up, and therefore people have opted for boreholes instead of shallow wells (Kundell, 2008). Most rural water supply is provided by groundwater which is abstracted from hand-dug wells, springs and hand-pumped boreholes. In the urban areas, most public supply is derived from surface-water sources. In the alluvial areas, groundwater abstraction is found to be much less than recharge (UN, 1989).

Groundwater varies in quality due to variations in lithology, depth and climate (BGS, 2004). Water quality is determined by the solutes and gases dissolved in the water as well as the matter suspended in and floating on the water (Fetter, 1994). Groundwater is polluted in many ways such as deep percolation from intensively cultivated fields, disposal of hazardous wastes, liquid and solid wastes from industries, sewage disposal and surface impoundments (BGS, 2004). Groundwater chemistry changes as water moves along its paths, increasing the ion concentrations and Jones (1997) noted that the longer water remains underground and the further it travels, the more the molar ratio resembles sea water. The chemical constituents of the groundwater determine its usefulness for drinking and domestic use, industry and agriculture (Fetter, 1994). Chemical elements provide clues on the mode of origin of the water and the geochemical processes associated with its evolution. Potable water is one which is free from pathogens, toxic compounds, clear, not saline, free from compounds that cause colour, odour and taste (Pritchard et al., 2007).

The quality of the water resources in Malawi is dependent on three major factors: Chemical composition of the parent rocks existing in the area; Extent of agricultural activities (application of agrochemicals, farming practices, land husbandry); Disposal of industrial waste products as well as human sewage, particularly in urban areas (Kundell, 2008). Generally both surface water and groundwater are acceptable for human consumption. However, due to recently increased agricultural activities, there has been considerable degradation of water resources as a result of increased siltation in rivers and reservoirs. This is most severe in areas that are under immense population pressure, resulting in serious deforestation and cultivation of marginal and other fragile areas (GoM, 2007). Groundwater is more mineralized in alluvial aquifers than in the weathered basement aquifers and places such as the lower Shire Valley, eastern Bwanje valley (where the study area is located) and around Lake Chilwa have saline waters. As such the utilization of groundwater in such areas is limited due to high contents of iron, fluoride, sulphates, nitrates, and total dissolved solids (Kundell, 2008).

The Kachindamoto Traditional Authority area is found to the eastern part of Dedza district in the Central region, and on the shore of Lake Malawi. It borders Salima in the North and Ntcheu in the south. There are two reliable sources of water supply in the Kachindamoto traditional authority area, the Ngodzi gravity fed scheme and boreholes. However boreholes are the most used through out the area. The total population of Kachindamoto Traditional

Authority area is approximated at 93,808 (NSO, 2008). Generally the people of the area depend on farming for subsistence and to a lesser extent for commercial.

1.2 Problem Statement

The chemical quality of groundwater in the aquifers of Malawi has been little documented (BGS, 2004). From the limited information available, groundwater compositions appear to be spatially variable and highly dependent on aquifer lithology (BGS, 2004). A large proportion of the population of Malawi relies on groundwater for domestic use. However treated borehole water supplies for natural chemicals by accredited water utilities are not available (Pritchard et al., 2007). There are health problems associated with intake of water with high concentrations of chemical compounds from groundwater (EPA, 2008). Dental fluorosis is common in some parts of Malawi but studies on fluoride levels of drinking water sources have not been adequately done (Sajidu et al., 2007). In small doses (0.5-1.5 mg/l), fluoride helps prevent dental carries but in doses above 1.5mg/l fluoride causes teeth and bone fluorosis (WHO, 2008). EPA (2008) observes that the short-term problems associated with excessive levels of nitrate in drinking water are serious illness and sometimes death especially in infants. These problems range from an acute condition in which health deteriorates rapidly over a period of days. Long-term intake of nitrates and nitrites has the potential to cause diuresis, increased starchy deposits and hemorrhaging of the spleen (EPA, 2008).

1.3 Justification

The quality of water we ingest is a critical parameter in determining the quality of our lives (Fetter, 1994).There is a likelihood that a good population of Malawians are at health risk due to consumption of water with high concentrations of naturally occurring chemical elements in groundwater as EPA (2008) indicated that high chemical compounds in water poses a health risk. At Mtubwi Primary School in Machinga District, for example, mild to severe dental fluorosis cases in Standard 3 and 4 pupils had been determined to be 50 to 80% (Sajidu et al., 2007). In Nathenje area in Lilongwe the fluoride levels were high up to 17 mg/l (Msonda et al., 2007).

EPA (2008) indicated that the short-term problems associated with excessive levels of nitrate in drinking water cause serious illness and sometimes death especially in infants. This can be an acute condition in which health deteriorates rapidly over a period of days on the other hand the long-term intake of nitrates and nitrites has the potential to cause diuresis, increased starchy deposits and hemorrhaging of the spleen (EPA, 2008).

Since groundwater provision to rural areas in Malawi is the most reliable option available for domestic use, it is important that the chemical composition of all groundwater points must be determined. The feasible and cost effective methods of water treatment should be implemented and future groundwater development should consider locations and formations of safe groundwater for human consumption as suggested in this study.

1.4 Objectives

1.4.1 Main objective

The main objective of the study was to analyze and determine the chemical quality of groundwater for drinking in Kachindamoto Traditional Authority area in Dedza in relation to WHO guidelines, MBS and MoIWD standards and to identify areas with critical quality issues and suggest possible interventions.

1.5.2 Specific objectives

The specific objectives of the study were to;

- Determine the chemical quality of groundwater by measuring TDS, hardness, calcium, sodium, potassium, magnesium, chloride, sulphate, carbonate, bicarbonate, electrical conductivity, pH, nitrate, fluoride, iron and to compare with the WHO guidelines and MBS and MoIWD standards.
- Map the spatial variations of groundwater quality in the area.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

The quality of water that human beings ingest is critical in determining the quality of their lives (Fetter, 1994). The World Health Organisation has repeatedly insisted that the single major factor adversely influencing the general health and life expectancy of a population in many developing countries is the ready access to drinking water (Hoko, 2005). The usefulness of water for a particular purpose is determined by the water quality (Fetter, 1994). Groundwater is used by about 1.5 billion people worldwide (Jones, 1997).

2.2 Groundwater occurrence

Groundwater may be found almost anywhere in the world and in almost all types of geological formations however, its distribution in terms of quality and quantity varies from one place to another and from one geological formation to another (Fetter, 1994). Freeze and Cherry (1979) noted that there are at least three factors that influence groundwater occurrence: hydraulic properties of the geological formations, geological framework, and climate.

2.2.1 Hydraulic properties of geological formations

The hydraulic properties of geological formations are those properties that govern groundwater storage and transmission such as pores, vesicles, lava tubes (and tunnels), solution cavities, bedding planes, foliation, faults, shear zones, unconformities, and intrusive contacts (Fetter, 1994). Primary structures are those that were formed at the same time as the rock formation and those that were formed after the rock formation are referred to as secondary structures (Freeze and Cherry, 1979). The generic term for the relative volume of a geologic formation in which water can be stored is porosity regardless of whether that volume consists of pores or other types of openings. Geological formations with interconnected openings are said to be permeable where as the ability of a geological formation to transmit water and yield it in usable quantities to wells depends on its permeability (Jones, 1997).

Geological formations differ considerably in their ability to store and transmit water therefore knowledge of typical values of porosity and permeability of different geological formations is a prerequisite for successful groundwater exploration (Fetter, 1994). Virtually all groundwater originates as surface water (Freeze and Cherry, 1979) and in order to reach the saturated zone, water must not only be available at the surface; it must also be able to infiltrate to the saturated zone. The availability of water at the surface depends on climate, while the infiltration rate depends on the thickness and permeability of the unsaturated zone as well as topography (Fetter, 1994).

2.2.2 Geological framework

The occurrence, distribution, movement, and composition of subsurface waters are intricately linked to the structure and nature of the geological formations (Freeze and Cherry, 1979). One of the primary objectives of hydrogeological investigations is to identify geological formations and structures of importance for the occurrence of groundwater and understand the different types of geological formations, as well as the events that produce them and their fundamental properties (Fetter, 1994). There are three main groups of rocks: igneous, sedimentary and metamorphic and once formed, rocks are subject to weathering, alteration, deformation, and transformation (Bradshaw and Weaver, 1995).

Igneous rocks form mainly from silicate melts (molten rock) by a process called crystallization and the magmas from which igneous rocks form are produced by partial melting of pre-existing solid rock (de Blij and Muller, 2005). However, most igneous rocks are composed mainly of silicon, oxygen with lesser amounts of aluminum, iron, magnesium, calcium, sodium, and potassium (Zumberg et al., 1996). Sedimentary rocks are those rocks formed at or near the earth's surface at relatively low temperatures and pressures and clay minerals and quartz are the most abundant constituents of sedimentary rocks, followed by rock fragments (Zumberg et al., 1996). Sedimentary rocks may be classified on the basis of various criteria such as composition, grain size, grain shape, orientations of the grains and the packing of the grains (Table 2.1) and such characteristics are important features of an aquifer material.

Table 2.1:

Classification of Clastic Sedimentary Rocks (Source: Hamilton et al., 1982)

Sediment Name and Particle Size	**Rock Name**
Gravel (>2 mm)	Conglomerate Breccia
Sand (1/16 - 2 mm)	Sandstone
Silt and clay (<1/16 mm)	Siltstone Shale Mudstone

Metamorphic rocks form from other rocks by essentially solid-state changes in mineralogy and/or texture as a result of changes in temperature (T), pressure (P), and prevailing stress condition (Hamilton et al., 1982). Apart from possible losses or gains of minor amounts of volatile constituents (e.g. H_2O, CO_2, O_2, and S), most metamorphic rocks have chemical compositions close to their precursors. The response of a solid rock body to changing P, T, and X (chemical composition) conditions depends on; the nature of the original rock; the grade of metamorphism, that is, the relative temperature of metamorphism; and presence or absence of a fluid phase which consequently affect the chemical quality of water (Zumberg et al., 1996).

2.2.3 Climate and groundwater occurrence

Water on earth resides in the atmosphere, on the surface of the earth, and below the surface of the earth. However, water does not remain in anyone of these environments indefinitely but it is constantly moving among them. This unending circulation of the earth's water is called the hydrologic cycle (Freeze and Cherry, 1979). The cycle has no beginning or ending. Figure 2.1 shows a schematic diagram of the hydrologic cycle.

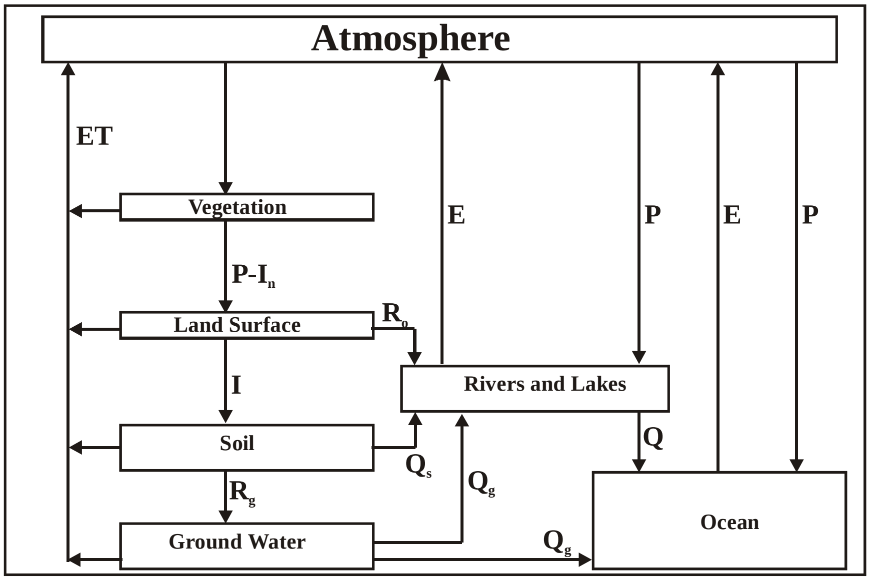

Fig 2.1 : Box model of the hydrologic cycle (Source: Freeze and Cherry, 1979)

(ET = evapotranspiration, I_n = interception, R_g = recharge, Q_s = interflow, P = precipitation, E = evaporation, R_o = overland flow, Q = Runoff, and Q_g = subsurface flow to streams and oceans)

Various estimates of the quantity of water in different components of the hydrologic cycle have been made and all of them show that groundwater constitutes an insignificant proportion of the earth's total water balance (Freeze and Cherry, 1979). Jones (1997) indicates that groundwater contributes only 0.59% of the total water resources of the earth. As far as the world's freshwater resources are concerned, however, groundwater accounts for almost 97% of the utilizable freshwater resources excluding that held in icecaps and glaciers (Freeze and Cherry, 1979).

Figure 2.2 shows near-surface hydrologic processes, some of which contribute to groundwater storage. It shows that precipitation that falls on land may be intercepted by vegetation, pond on the land surface, flow overland to streams and rivers and eventually end up in the oceans, infiltrate into the ground, flow through the unsaturated zone, and discharge into streams, percolate through the unsaturated zone to recharge groundwater, evaporate from the oceans and the land surface (Freeze and Cherry, 1979). Some of the infiltrated water is returned to the atmosphere by evapotranspiration.

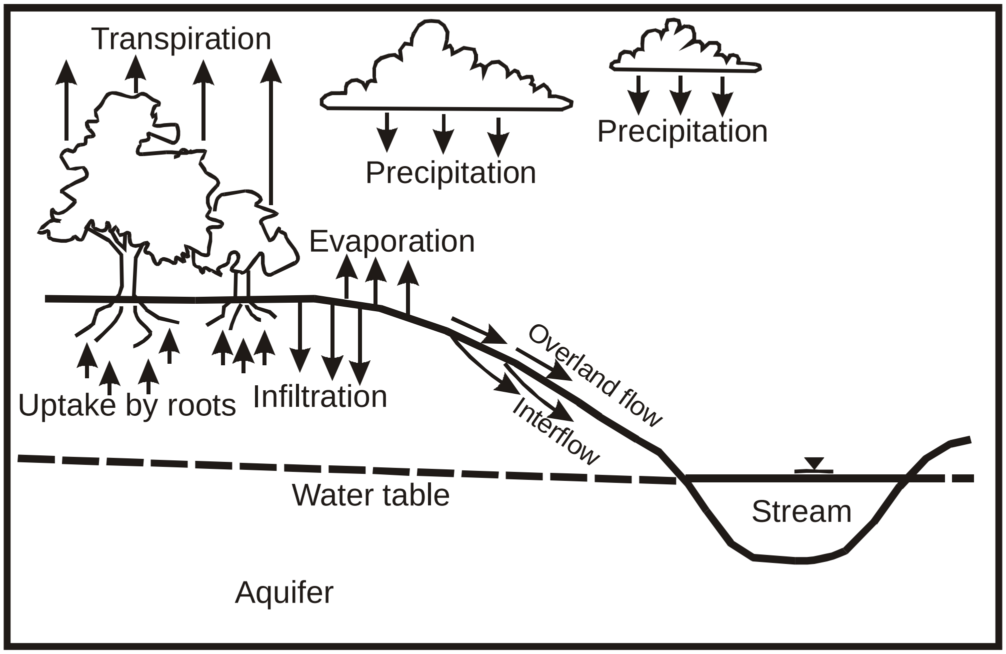

Fig 2.2: Near surface hydrologic processes (Source: Freeze and Cherry, 1979)

2.3 Groundwater uses

Over 1.5 billion people worldwide depend on groundwater for drinking water and of the world's water that is usable by humans, 98% is stored in aquifers (www.groundwater.org). The chemical constituents of the ground water determine its usefulness for drinking and domestic use, industry and agriculture (Fetter, 1994). Principally water is used at household level for drinking, hygiene and sanitation. Many studies on the multiple use of water have identified and quantified the livelihoods benefits from using water (Van Koppen et al., 2006). In the developed world groundwater has been used as a pivot for development. As groundwater is an integral component of the hydrological cycle, the health of the streams, lakes, wetlands, and associated ecosystems depends upon groundwater. Groundwater also sustains economic activities by providing significant water supplies for industries involved in manufacturing, mining and petroleum (Van Koppen et al., 2006). Although groundwater is a renewable resource, it is not limitless and requires wise management to protect its integrity, security and sustainability.

2.4 Groundwater quality

Water is formed by the union of two hydrogen atoms with one oxygen atom in an asymmetry bonding (Freeze and Cherry, 1979). This asymmetrical arrangement gives rise to an unbalanced electrical charge that imparts a polar characteristic to the molecule. This means that water in liquid state is composed of molecular groups with the HOH molecules in each group held together by hydrogen bonding. Groundwater chemistry changes as water moves along its paths, increasing the ion concentrations with distance and time. Water drawn from boreholes in rural areas is perceived to be of good quality as such no treatment for chemical constituents is done before use. Fetter (1994), argue that, natural waters are never pure and contain some amounts of dissolved gases, solids, and suspended materials.

Generally both surface water and groundwater are acceptable for human consumption (Kundell, 2008). However, due to recently increased agricultural activities, there has been considerable degradation of water resources as a result of increased siltation in rivers and reservoirs. This is most severe in areas that are under immense population pressure, resulting in serious deforestation and cultivation of marginal and other fragile areas (Aquastat, 2006). Groundwater is more mineralized in alluvial aquifers than in the weathered basement aquifers (Kundell, 2008). Areas such as the lower Shire Valley, eastern Bwanje valley and around Lake Chilwa have saline waters as such the utilization of groundwater in such areas is limited due to high contents of iron, fluoride, sulphates, nitrates and total dissolved solids (Aquastat, 2006).

2.4.1 Features of water quality

The principle features of water quality in all its occurrences, which engineers are concerned with are considered in three main groups – physical, chemical and biological (Shaw, 1994). These include solids derived from organic and inorganic sources and color, taste and odor are aesthetic properties of water that are judged subjectively and are caused by the dissolved impurities either from natural resources, like the peaty waters from upland moors, or from the discharge of noxious substances into the water by man (Shaw, 1994). Turbidity is the term used for the cloudiness of the water due to fine suspended colloidal particles of clay or silt, waste effluent or micro-organisms and is measured in turbidity units (NTU) based on the comparison of the scattering of light by the water sample with that of a standard suspension of formazin (Shaw, 1994). Electrical conductivity (EC) is a physical property of water that is dependent on the dissolved salts thus its measurement in microseimens per centimeter gives a good estimate of the dissolved solid contents of the water (Shaw, 1994). Temperature in a standard physical characteristic that is important in the consideration of the chemical properties of water. It is measured in degrees and is necessary for assessing effects of temperature changes on living organisms. Radioactivity in water bodies has increasing attention as its harm to life in all forms becomes more recognised (Shaw, 1994).

Water is the most common solvent and many chemical ions can be found in solution at the temperature of naturally occurring water bodies (Fetter, 1994). The power of hydrogen (pH) is a measure of the concentration of hydrogen ions (H^+) and indicates the degree of acidity or alkalinity of the water. The pH scale ranges from 0-14, and a pH of 7 is indicative of a neutral solution. The pH of less than 7 means that water is acidic and more than 7 means it is alkaline (Shaw, 1994). Dissolve oxygen (DO) plays a large part in the assessment of water quality since it is an essential ingredient for the sustenability of fish and other forms of aquatic life. It also affects the taste of water, and a high concentration of DO in domestic supplies is encouraged by aeration. Nitrogen may be present in water in several forms: in organic compounds as ammonia and ammonium salts, in nitrites or fully oxidized nitrates. Measures of nitrogen give indications of the state of pollution by organic waste with large quantities in the nitrate form being an indication of oxidation (Shaw, 1994). Chlorides, most often occurring in the NaCl (common salt) form, are found in brackish water bodies contaminated by sea water and groundwater aquifers with high salt content. The presence of chloride in water is an indication of sewage pollution from other chloride compounds (Shaw, 1994).

2.4.2 Chemical reactions in water

Considering that subsurface geochemical processes control the composition of groundwater to a very large extent, there is need to identify the chemical reactions important in the evolution of groundwater (Fetter, 1994). Chemical reactions in an aqueous solution are either reversible or irreversible. Groundwater contains a wide variety of dissolved chemical constituents mainly because of the chemical and biochemical interactions between groundwater and the geological material occurring in the soil and saturated zone. Generally these chemicals react until they reach an equilibrium point and the following are listed as some of the common reactions in water (Fetter, 1994).

- *Acid-base reactions*

It affects the pH which is the main variable controlling ion chemistry. For example, alkalinity and carbonate solubility result in cation exchange thereby accelerating the karstification process.

- *Dissolution*

Is the solution of gases, weathering inorganic products and organic solutes in water. It is the dominant process for large solute loading to groundwater.

- *Precipitation*

Is the settling down of solutes when the pH or temperature of the solution changes.

- *Complexation*

It is the process whereby an ion forms by combining simpler ions, usually the central ion is a metal. It is significant in saline groundwater as it affects the saturation state of groundwater with respect to ions. It facilitates and enhances transport of toxic metals which are mobile at a higher pH than a metal ion.

- *Sorption*

It is the reaction and exchange of ions between cations and solids. It changes cation chemistry and retard or immobilize some contaminants. Sorption varies with pH, grain size, surface area, temperature and mineralogy. When molecules in solution carry a charge and interact with a charged clay particle, electrostatic attraction may lead to the exchange of the particles for one of a lower valence. For example clay sorp Al^{3+} and release Na^{+}.

- *Oxidation-reduction*

These reactions are mediated by micro-organisms. They are relatively slow in relation to other reactions. Oxidation involves the removal of an electron from a cation. They can influence the mobility of metals and can transform organic compounds into simpler inorganic forms.

- *Hydrolysis*

It is the transformation reaction that operates on organic compounds in the presence of water. It attaches a hydroxyl group to the molecule making it more susceptible to biodegradation or solubility.

- *Isotopic Process*

It is a radioactive decay which occurs at the rate dependent on half life of individual isotopes. The groundwater residence time of several half lives decrease the hazard of radioactive contaminants.

2.4.3 Major constituents that determine groundwater quality

- *Total dissolved solids (TDS)*

The total concentration of dissolved solids in water is generally an indication of its suitability for particular use. The concentration of TDS is determined by weighing the solid residues obtained by evaporating a measured volume of filtered sample to dryness (Fetter, 1994). Table 2.2 presents a classification of water based on total dissolved solids.

Table 2.2

Classification of Water based on TDS (Source: Fetter, 1994)

Class	**TDS (mg/l)**
Fresh	0-1000
Brackish	1000-10000
Saline	10000-1000000
Brine	>1000000

- *Electrical Conductivity*

In most groundwater almost all major and minor dissolved chemical elements occur in ionic form, with positively (cations) and negatively (anion) charged ions. Therefore groundwater can be looked at as an electrolyte solution. The TDS ionic constituents can be can be determined by measuring the electrical conductivity (EC) of the groundwater expressed in microseimens (Fetter, 1994).

- *Inorganic Constituents in Groundwater*

Fetter (1994) indicates that water naturally contains a number of different dissolved inorganic constituents; the major cations are calcium, magnesium and sodium; the major anions are chloride, sulfate, carbonate and bicarbonate. Silica, although not an ion, is a major element. These constitute the bulk of mineral matter contributing to TDS. In addition there are minor elements such as potassium, iron, manganese, fluoride, nitrate, strontium and boron. Trace elements such as arsenic, lead, cadmium and chromium in amounts, very small per liter of water, but they are very important from a water quality point of view. Table 2.3 shows some of the major, minor and traces elements of groundwater quality importance.

Dissolved gases are also present in both surface and groundwater. The major gases of concern are oxygen (O_2) and carbon dioxide (CO_2). Minor gases of concern include hydrogen sulfide and methane. Hydrogen sulfide is toxic and is responsible for the bad odor of water, but it is not present when water contains O_2 (Fetter, 1994).

2.5 Groundwater availability in Malawi

The GoM (2007) reported that Malawi is endowed with a variety of natural resources which include vast expanses of water systems. Kundell (2008) noted that Malawi is generally considered to be relatively rich in water resources, which are stored in the form of lakes, rivers, and aquifers. The country is divided into 17 Water Resources Areas (WRAs), which are subdivided into 78 Water Resources Units (WRUs) (Kundell, 2008). There are widespread groundwater sources whose occurrences are associated with two major aquifers namely the basement complex aquifers which are extensive but low yielding ranging from 0.2 to 4 liters per second (and covering the plateau areas, Shire Highlands, the Upper Shire River Valley, Lilongwe to Kasungu Plain and the South Rukuru River catchment). The alluvial aquifers (which are localized to Lakeshore plains and the Shire Valley) are high yielding with recorded yields in excess of 10 liters per second (GoM, 2007). However, these resources are of variable quality and quantities, unevenly distributed in time and space, and are subjected to poor conservation and management (GoM, 2007).

Table 2.3

Classification of dissolved inorganic constituents in groundwater (Source: Chilton, 1996)

Major constituents (1.0 to 1000mg/l	**Minor constituents (0.01 to 10.0 mg/l)**	**Trace constituents (less than 0.1mg/l)**		
Sodium (Na)	Iron (Fe)	Aluminum	Gold	Scandium
Calcium (Ca)	Strontium	Antimony	Indium	Selenium
Magnesium (Mg)	Potassium (K)	Arsenic	Iodine	Silver
Bicarbonate (C_2O_3)	Carbonate (CO_3)	Barium	Lanthanum	Thallium
Sulphate (S)	Nitrate (N2)	Beryllium	Lead	Thorium
Chloride (Cl)	Fluoride (F)	Bismuth	Lithium	Tin
Silica (Si)	Boron	Bromide	Manganese	Titanium
		Cardinium	Molybdenum	Tungsten
		Cerium	Nickel	Uranium
		Cesium	Niobium	Vanadium
		Chromium	Phosphate	Ytterbium
		Cobalt	Platinum	Yttrium
		Copper	Radium	Zinc
		Gallium	Rubidium	Zirconium
		Germanium	Ruthenium	

The productivity of the crystalline basement rocks of aquifers varies widely according to the degree of alteration and distribution of overlying colluvial deposits in Malawi (BGS, 2004). Depths of weathering of the basement rocks on the plateau are typically around 10–30 m but can be thicker in fault zones and thinner close to outcropping inselbergs (Chilton and Smith-Carington, 1984). This weathered layer forms a laterally extensive minor aquifer of considerable value for small-scale rural water supplies. The degree of weathering of the overburden is generally greatest close to the surface and higher permeability is typical in coarse-grained rock types such as granites and gneisses (UN, 1989). The frequency of faults and joints also has a major control on rock permeability.

Groundwater levels in the basement aquifers are in most cases less than 15 m below surface and the seasonal fluctuations are typically 1–5 m (BGS, 2004). Yields of 0.25–0.5 l/s can usually be obtained from the basement rocks provided the saturated thickness of the weathered layer is more than 10 m. Such yields are usually adequate for hand-pumped supplies (BGS, 2004). Mesozoic alkaline intrusions in the south-east uplands are largely fresh and poorly-permeable as such, they have little aquifer potential. Since the Karoo sediments are usually well cemented, they have low porosity (UN, 1989) and therefore their aquifer potential is restricted. In the lower Shire valley, groundwater levels in this aquifer are typically 20–30 m below surface (BGS, 2004). The less well-indurated Cretaceous sediments have greater potential as an aquifer. The Quaternary alluvial deposits can be important areas for groundwater storage and generally form a good resource for water supply.

Watercourses draining into Lake Malawi lose a large part of their flow to infiltration in the alluvial areas upstream of the lake (BGS, 2004). Sediments below Lake Chilwa are more clayey and hence less permeable. Water levels are generally less than 10 m below surface, with annual fluctuations of around 1–3 m (BGS, 2004). In areas irrigated by the Shire River, groundwater levels have risen by several metres since the start of irrigation. Most rural water supply is provided by groundwater which is abstracted from hand-dug wells, springs and hand-pumped boreholes. In the alluvial areas, groundwater abstraction is found to be much less than recharge (BGS, 2004).

2.6 Groundwater quality in Malawi

The quality of the water resources in Malawi is dependent on three major factors: Chemical composition of the parent rocks existing in the area; Extent of agricultural activities (application of agrochemicals, farming practices, land husbandry); Disposal of industrial waste products as well as human sewage, particularly in urban areas (Kundell, 2008). Generally both surface water and groundwater are acceptable for human consumption. However, due to recently increased agricultural activities, there has been considerable degradation of water resources as a result of increased siltation in rivers and reservoirs. This is most severe in areas that are under immense population pressure, resulting in serious deforestation and cultivation of marginal and other fragile areas. Groundwater is more mineralized in alluvial aquifers than in the weathered basement aquifers and places such as the lower Shire Valley, eastern Bwanje valley (where the study area is located) and around Lake Chilwa have saline waters. As such the utilization of groundwater in such areas is limited due to high contents of iron, fluoride, sulphates, nitrates, and total dissolved solids (TDS) (Kundell, 2008). Generally for groundwater deeper than 50 to 75 feet, seasonal temperature changes are less than one degree and temperature variations do not play a significant role in groundwater composition. For shallow groundwater, larger seasonal variations, related to warming or cooling at the surface are common (Nelson, 2002).

BGS (2004) indicated that the chemical quality of groundwater in the aquifers of Malawi has been little documented and from the limited information available, groundwater compositions appear to be spatially variable and highly dependent on aquifer lithology. Most documented groundwater compositions appear to be of near-neutral pH. Chilton and Smith- Carington (1984) reported the pH values of 6.3–6.8 for groundwater from basement aquifers. MacFarlane and Bowden (1992) reported a range of pH of 6.4–7.0 for springs issuing from dambos, also in basement aquifers and Palamuleni (2002) reported a pH range of 6.4–7.1 for groundwater from basement aquifers in Blantyre. One of the main problems affecting the groundwater in Malawi appears to be high salinity. This is particularly the case in groundwater from the alluvial deposits of the lower Shire valley. High sulphate concentrations have also been reported in some areas of weathered basement. Fluoride problems appear not to be widespread but high concentrations have been found in some parts of the alluvial aquifers (UN, 1989) as well as sporadically in the basement. Deterioration of water courses through pollution from agricultural runoff, sewage and industrial wastes are concerns for surface-water quality but there is currently little information available to assess their impact on groundwater resources (Kundell, 2008).

Most available analyses of nitrate in groundwater have yielded low concentrations. Data summarized by Bath (1980) showed that concentrations at the time of the study were usually much less than the WHO guideline value for nitrate (N) in drinking water of 50 mg/l. Sporadic high concentrations were apparent in the groundwater from the lower Shire valley though even here, NO_3-N concentrations were mostly less than 5 mg/l; many were below the detection limits (<0.7 mg/l). UN (1989) also quoted values for nitrate (as N) of less than 1 mg/l in groundwater from both the basement and the alluvial aquifers in Malawi. Such low values imply minimal pollution inputs. The significance of denitrification (bacterially-mediated removal of nitrate from groundwater under anaerobic conditions) has also not been quantified. Denitrification may be an important process in some of the Quaternary alluvial aquifers but probably has less significance in the basement aquifers where conditions are likely to be more commonly aerobic (BGS, 2004).

High salinity appears to be a feature of some Malawian groundwater and is as a result of either evaporative concentration or dissolution of evaporates minerals in sedimentary rocks (BGS, 2004). Evaporative concentration is greatest where the water table is close to the ground surface and where evaporation greatly exceeds recharge such that high concentrations of sodium and chloride have been reported for groundwater from the lower Shire valley (Bath, 1980), both as a result of evaporation and dissolution of evaporate minerals. Most boreholes close to the river and with shallow water tables have saline groundwater compositions. Chloride concentrations up to 4000 mg/l and sodium up to 3600 mg/l have been reported in Shire Valley (Bath, 1980). Affected boreholes are frequently abandoned in favour of water holes in dry river beds or surface water.

Further away from the river, saline groundwater result from the dissolution of evaporite minerals such as halite (NaCl) and gypsum ($CaSO_4.2H_2O$). In groundwater from alluvial deposits close to the edge of the Karoo sediments, chloride concentrations up to 2100 mg/l and sulphate up to 2400 mg/l were recorded (BGS, 2004). High salinity is more problematic in these areas as alternative water sources are not readily available. Bath (1980) reported generally low salinity values for groundwater from weathered basement in the Bua catchment of western Malawi. Total dissolved solids were quoted in the range 200–740 mg/l. Chilton and Smith-Carington (1984) also found mostly low-conductivity groundwater in basement aquifers from the Livulezi (central) and Dowa West (south-central) areas. Electrical conductances were usually <750 µS/cm but extremes up to 4000 µS/cm (total dissolved solids up to around 2500 mg/l) were found. The saline waters often had high concentrations of sulphate, some in excess of 2000 mg/l, presumably as a result of dissolution of evaporite salts. The salinity and high sulphate concentrations were highly variable spatially. In the Nkhotakota area on the western shores of Lake Malawi in central Malawi, Bath (1980) reported electrical conductivity values of 180–4600 µS/cm (total dissolved solids up to 2900 mg/l) in weathered basement and colluvium. The groundwater from this region is mainly of calcium-(magnesium)-bicarbonate type with typically low concentrations of chloride, usually below 60 mg/l (BGS, 2004).

In colluvium and weathered basement aquifers of the South Rukuru catchment of north-west Malawi, groundwater with high salinity have been noted especially around the town of Emcisweni Mzimba District of Malawi (Bath, 1980). The catchment as a whole has groundwater with very variable salinity, with electrical conductivity values in the range 70–7700 µS/cm and chloride concentrations of 4–2000 mg/l. The saline groundwater appears to be of calcium chloride or mixed-ion type with concentrations of sodium up to 500 mg/l, magnesium up to 280 mg/l and sulphate up to 1800 mg/l. The origin of the salinity in this region is unclear (Bath, 1980).

The East African Rift Valley is well recognised as a high-fluoride province and many countries in the region have significant groundwater fluoride problems (BGS, 2004). As such, Malawian groundwater in the Rift zone (eastern alluvial plains), are likely to be most affected. Some groundwater in the weathered basement in the west may also have high concentrations (greater than 1.5 mg/l, the WHO guideline value for fluoride in drinking water) though climatic factors, i.e. high rainfall compared to high-fluoride basement aquifers elsewhere, suggest that the concentrations in this region should be mostly low. UN (1989) reported fluoride concentrations of less than 1 mg/l in areas of altered basement rocks in Malawi but much higher concentrations, in the range 2–10 mg/l, in groundwater from the alluvial areas. Bath (1980) reported concentrations of fluoride in the range <0.1–7.6 mg/l in basement aquifers of the Nkhotakota area of central Malawi though only one sample exceeded the WHO guideline value and most were below 1 mg/l.

Concentrations in the basement aquifer of South Rukuru were in the range <0.1–3.3 mg/l, though most of them were below 0.6 mg/l (Bath, 1980). Similarly, concentrations of around 0.9 mg/l were reported in groundwater from 8 sites in South Lunzu Township, Blantyre (Palamuleni et al., 2002). In the lower Shire valley, much higher fluoride concentrations, up to 15 mg/l in some samples, were reported by Bath (1980), and the hydrothermal sources of fluoride were likely in this active Rift zone.

The widespread occurrence of high iron concentrations in Malawian groundwater has been reported by a number of authors (e.g. Bath, 1980; UN, 1989). UN (1989) gave ranges for total iron in groundwater from both weathered basement rocks and alluvial sediments as 1–5 mg/l. Concentrations of iron up to 84 mg/l have been reported by Bath (1980), in the Lower Shire Valley and up to 82 mg/l in the weathered basement aquifers of Nkhotakota area.

However, the ranges quoted reflect compositions of unfiltered water samples and therefore represent total iron (including particulate iron) rather than dissolved iron. As such, the concentrations will vary considerably according to the turbidity of the water and the degree of flushing (pumping) of the well before collection (Chilton and Smith-Carington, 1984). Nonetheless, the total concentrations reported may be indicative of the concentrations in water used for domestic purposes. High concentrations of dissolved iron can occur under acidic or reducing conditions (BGS, 2004). There is no evidence for the occurrence of strongly acidic groundwater in Malawi and it is unlikely that groundwater acidity could be responsible for producing the very high iron concentrations observed in some of the groundwater (BGS, 2004).

However, anaerobic conditions could exist in some aquifers, particularly the alluvial deposits of the lower Shire valley and locally within parts of the basement where overlain by thick deposits of poorly-permeable lateritic soils. High concentrations of dissolved iron (i.e. from filtered groundwater samples) have been found in groundwater of neutral pH from basement rocks in Lilongwe (Bath, 1980). One 60 m deep borehole had a concentration of 7 mg/l iron. It is likely that the groundwater from this borehole was anaerobic, although Bath (1980) speculated that the iron could have been complexed with organic acids in solution. High iron concentrations are one of the main causes of well abandonment in Malawi (BGS, 2004).

Concentrations of manganese have not been reported in Malawian groundwater. Like iron, manganese is mobilized in groundwater under acidic or anaerobic conditions and therefore often accompanies iron (when in dissolved form). Iron cannot be used as an indicator of likely manganese concentration because correlations between the two elements are rarely sufficiently good. Correlations between iron and manganese are even less likely if metallic pumps and pipes are responsible for iron contamination of groundwater (BGS, 2004).

2.7 Human perception on groundwater quality

Hoko (2005) noted that the taste and soap consumption perception may be affected by the different composition of the total dissolved solids especially the metallic ions and their individual concentrations. It was then concluded that the direct relationship between conductivity and soap consumption does not exist. Little is known on the direct relationship between human perceptions of the groundwater quality especially in relation to chemical constituents however, water for domestic use can be rejected if the color, odor and taste are affected unlike with the measured chemical constituents (BGS, 2004). But there is a direct relationship between taste and chemical composition of water.

2.8 Groundwater contamination

The sources of groundwater contamination are many and the contaminants numerous (Fetter 1994). While industrial effluent may find its way into the groundwater, suburban areas have its groundwater with high levels of nitrate due to use of lawn fertilizers and septic tank discharge while agricultural areas, have high levels of fertilizers found in groundwater and also specialized synthetic organic and inorganic chemicals as well (Fetter, 1994). Landfills in urban and rural areas are known sources of groundwater contamination. While most of the elements are actually necessary to support healthy ecosystems such as, nitrates, and phosphorous associated with groundwater, it is not the simple presence of these items that is problematic, but the excess amounts that pollutes groundwater resources for both human use and natural ecosystems (TWDB, 2002).

CHAPTER THREE

3.0 STUDY AREA

3.1 Location

Malawi is a landlocked country in southern Africa, bordered by Zambia, Mozambique and Tanzania, and is located between latitudes 9°22'S and 17°03'S and longitudes 33°40'E and 35°55'E. The country has a total land area of around 118,500 square kilometres (Aquastat, 2006). Lake Malawi, some 580 km long, is the largest lake in Southern Africa and third largest in Africa. It forms a significant part of the eastern national border covering almost 20% of the total area of the country (Aquastat, 2006). The study was conducted in Kachindamoto Traditional Authority area in Dedza District. The area is approximately 540 sq kilometers stretching about 30 kilometers in length from Golomoti/Mua hills in the west to Lake Malawi in the east and 17 kilometers in width along Lake shore road north to south. Figure 3.1 shows the Kachindamoto Traditional Authority area in relation to Lake Malawi.

3.2 Demography

The population of Malawi was approximately 13,066,320 (NSO, 2008). The majority of this population stays in rural areas where groundwater is the most reliable sources of water for domestic use. The total population for Dedza District was approximately 623,789 with Kachindamoto Traditional Authority approximately 93,808 (NSO, 2008). The population density for the district was 172, while the growth rate was 2.5 and the average size of a household was 4.5 (NSO, 2008).

3.3 Social economic activities

Generally the people of the area depend on farming for subsistence and to a lesser extent commercial faming is practiced. Major crops grown in the area include maize, millet, ground-nuts, rice, tobacco and cotton (Aquastat, 2006). People in the study area are also involved in fishing but to a very small scale both in the lake swamps and streams that are emptying their water into the lake (Aquastat, 2006).

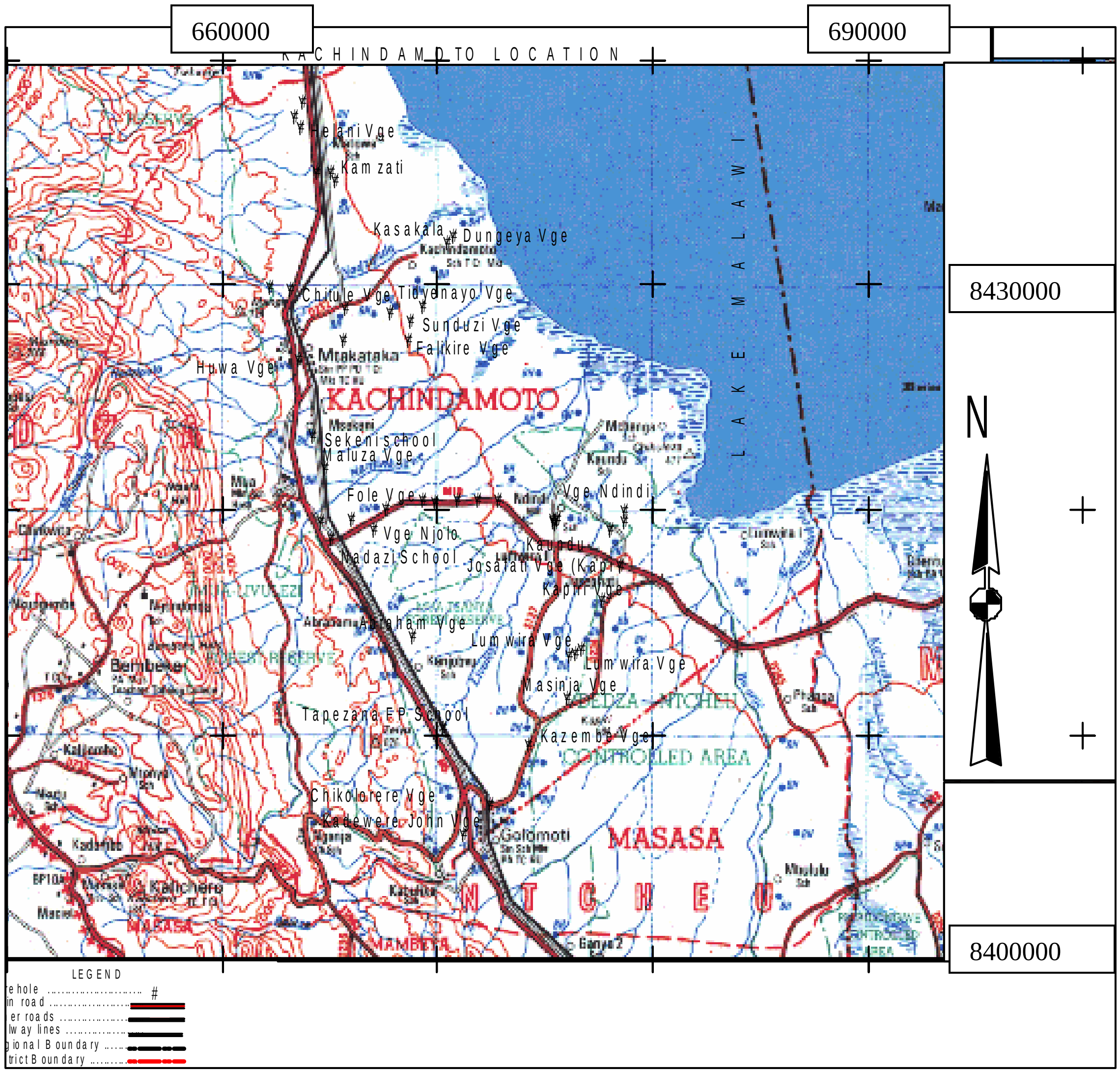

Figure 3.1 Map of Kachindamoto Traditional Authority (Source; Department of Geography, Mzuzu University)

3.4 Geology

Most of the land area of Malawi consists of Precambrian or Lower Palaeozoic crystalline basement rocks, including gneiss and granulite with some granite (Figure 3.2). Younger Karoo (Jurassic) alkaline granitic and syenitic intrusions of the Chilwa complex also occur in the south-east of the country (BGS, 2004). These intrusions are harder and more resistant to weathering than the basement rocks and so form the uplands with highest elevations. Mesozoic volcanic rocks occupy a small area in the extreme south of the country. Sediments of Karoo (mainly Permo-Triassic) age, in places over 3500 m thick, occupy smaller areas in the north and the extreme south (UN, 1989). These deposits are mainly sandstones, marls and conglomerates with some coal seams. They are usually well-indurated with calcite cements. Younger sediments of Cretaceous to Pleistocene age also occur in small areas of the north and south of the country. These include poorly indurated sandstones, marls, clays and conglomerates with some evaporites. Quaternary alluvium, colluvium and lacustrine deposits occupy the plains around Lakes Malawi and Chilwa. Much of the alluvium arises from erosion of rock material from the Rift Valley escarpment slopes. The sediments are partly faulted as tectonism along the Rift Valley is still active (BGS, 2004).

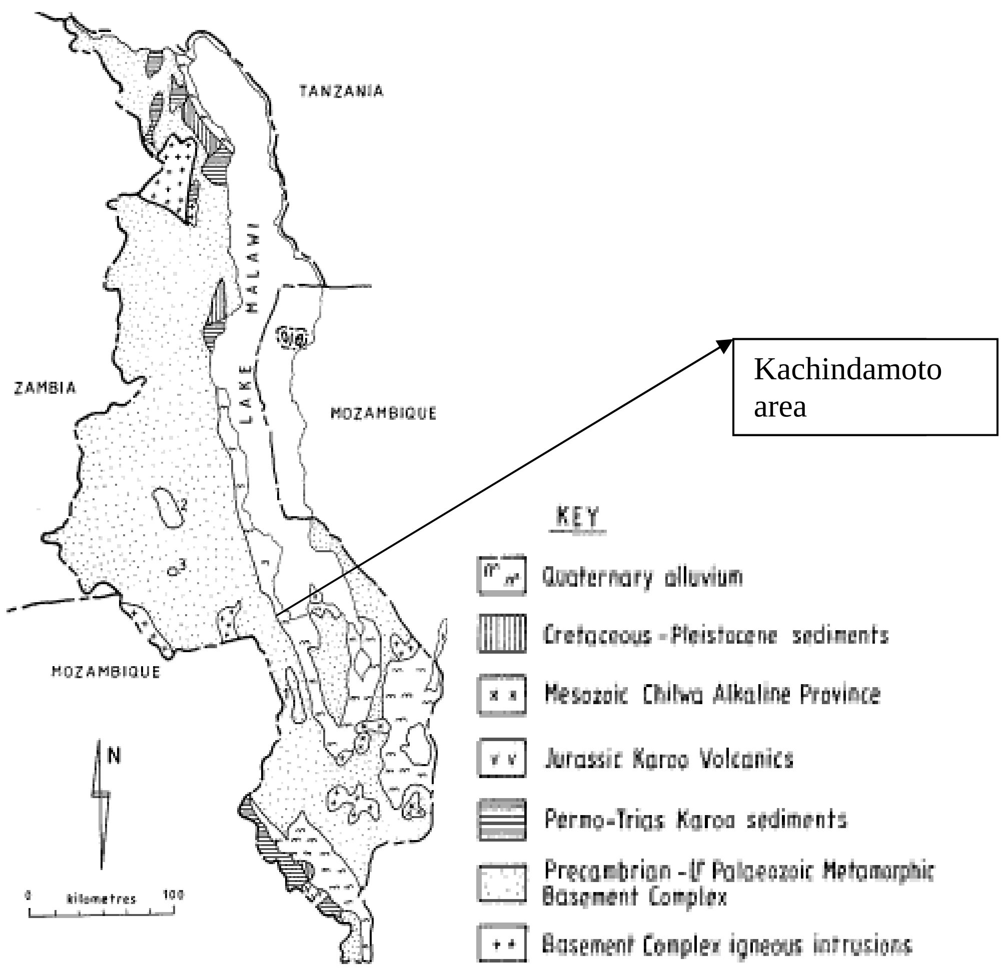

Figure 3.2. The geology of Malawi (Source: Chilton and Smith-Carington, 1984)

The Quaternary deposits consist of unconsolidated mixed clays, silts, sands and gravels. Along the shore of Lake Malawi, these reach up to 60 m thick but are up to 150 m thick in the lower Shire valley (BGS, 2004). The two major types of aquifers have been identified, the extensive but low yielding (1-2 liters, per second) weathered basement aquifer of the plateau area, and the high yielding (up to 15 liters per second) aquifer of the lakeshore plains and the lower Shire River (GoM, 1994). Kachindamoto Traditional Authority is underlain by quaternary type of geological formations which is dominated by deposits of sandy silt and partly clayey materials (BGS, 2004). It falls within the alluvial formation of the Great Rift Valley and abstract the groundwater resources from the high yielding (up to 15 liters per second) aquifer of the lakeshore plains and the lower Shire River (GoM, 1994).

3.5 Climate

The climate of Malawi is tropical continental and largely influenced by the huge water mass of Lake Malawi, which defines almost two-thirds of Malawi's eastern border. There are two distinct seasons: the rainy season from November to April during which the aquifers are recharged and the dry season from May to October. The dry season may be divided into the cool dry period from May to July and the hot dry period from August to October. Annual rainfall in Malawi ranges from 700 to 2 400 mm with mean of 1 180 mm. Its distribution is mostly influenced by the topography and proximity to Lake Malawi. The highest rainfall is experienced in the high altitude and mountainous areas of Mulanje, Zomba, Dedza and the plateaus of Viphya and Nyika while the lowest rainfall is experienced in the low lying areas of the Lower Shire Valley and other rain shadow areas (Aquasta, 2006). Temperatures are greatly influenced by the topography and decreases with increasing altitude. The mean minimum and maximum temperatures are 10 °C and 28 °C respectively in the plateau areas, 14 °C and 32 °C respectively in the rift valley plains. The highest temperatures occur in October/November while the lowest temperatures are experienced in June/July. The Kachindamoto Traditional Authority area has a typical rift valley type of climate (Aquasta, 2006). The place is generally hot with maximum temperature reaching greater than 32 °C during hot months and dropping to 14 °C during cold months. The area receives an average annual rainfall of 800 mm to 1200 mm of which most of it is received in 4 to 5 month and experiences a dry season of 7 to 8 month in a year (Kundell, 2008). Just like in most valley areas, the soils of Kachindamoto Traditional Authority area are generally deep and tend to range from colluvial sands to makande clays (vertisols), and its climatic supports *Acacia* vegetation type with *Faidherbia albida* (the White or Camel Thorn, msangu), *Adansonia digitata* (baobab, mlambe), *Sterculia quinqueloba* (msetanyani), and *Bauhinia petersiana* (mponda) dominating on the valley floor (GoM, 2001)

3.6 Water supply

The history of groundwater development in Malawi dates back as far as the early 1930s. By 1994, there were about 9,600 boreholes and 5,600 protected shallow wells, the majority of which were constructed by the government (Kundell, 2008). Since then the increase in boreholes drilled by the government, non-governmental organizations, and the private sector has been dramatic, and according to the Ministry of Water Development there were about 19,000 boreholes drilled by 2001 and this trend is continuing. Furthermore, due to the recent frequent occurrence of droughts, the number of hand-dug shallow wells has considerably decreased because they are highly vulnerable and prone to drying up, and therefore people have opted for boreholes instead of shallow wells (Kundell, 2008). Most rural water supply is provided by groundwater which is abstracted from hand-dug wells, springs and hand-pumped boreholes. In the urban areas, most public supply is derived from surface-water sources. In the alluvial areas, groundwater abstraction is found to be much less than recharge (UN, 1989).

The Kachindamoto area has estimated number of boreholes over 367 (MoIWD, 2004). The western part is partly supplied by a gravity fed water scheme. The groundwater supply in the Kachindamoto Traditional Authority area dates back to 1954 when the first borehole was sunk (MoIWD, 2004). Since then, boreholes, tube holes and wells have been sunk to supply water to the people. Most of the boreholes were provided by the government, however there are others which were provide by non-governmental organisations, faith based organisations and most of the shallow wells were hand dug by the communities and only pumps were provided by government or non-governmental organisations (MoIWD, 2004).

Each borehole has a water point committee which is answerable to the village headman and ensures that the borehole is functioning. Minor maintenance is done at village level while major ones are reported to the District Water Works Office based at the District Office. The village water point committee is trained to dismantle the pump and reassemble it. The replacement of all consumables is the responsibility of the committee. They raise funds from the community using the water point so that they should be able to any small parts of the pump that easily wears out.

The majority (48) of the water points studied were Afridev pumps except one which a tap is fed by a motorized pump. The depths of the boreholes range from 18 m to 55 m. Most of the boreholes were estimated within the distance of 15 m to about 200m from the houses. This being a rural area households use pit latrines which might contaminate the groundwater. The area is basically flat especially the eastern part where it drops into Lake Malawi and the western part is hilly with steep slopes.

CHAPTER FOUR

4.0 MATERIALS AND METHODS

4.1 Study Design

4.1.1 Location/Selection of Water points

The study was conducted in Kachindamoto Traditional Authority (T/A) in Dedza District in Malawi. The area was selected because of its position in relation to groundwater morphometry. It falls in the quaternary alluvial formations of Lake Malawi which are known to have high saline groundwater (Kundell, 2008). There were 48 water points which were sampled. The Kachindamoto Traditional Authority area is underlain by the generally uniform quaternary alluvial formation of the rift valley (BGS, 2004) therefore the choice of these points was random. The locations of the GPS points of the groundwater points (Appendix 6) were plotted on a map (Figure 4.1).

4.1.2 Sampling methods and frequency

For each water source, two samples in 1 liter bottles were collected at each sampling time and each point was sampled in February and March to validate the data collected (appendices 2 and 3) and test if there is a change in concentration with time. Out of the two samples one was raw while the other was acidified as provided in APHA (1998). From each borehole, three times of the estimated volume were expelled first to minimize contamination from pipes as recommended by APHA (1998).

4.2 Sample tests

Acidified samples were used for titration, colorimetric and coloriphotometric methods for unstable parameters mostly ions. The pH and conductivity parameters were measured on site using electrode Kent which combines EIL 7065 digital pH meter (Figure 4.2) and WPA-CM 35 digital conductivity meter and a thermometer. The rest of the parameters were measured at the Central Water Laboratory using protocols provided by APHA (1998). A survey using a semi-structured interview (appendices 1 and 4) was conducted to collect information on human perception on the quality of water at each water point. A total of 144 subjects were interviewed on the uses of the water and their perception on color, odor, and taste and soap consumption. The summary of the results are presented in appendix 7.

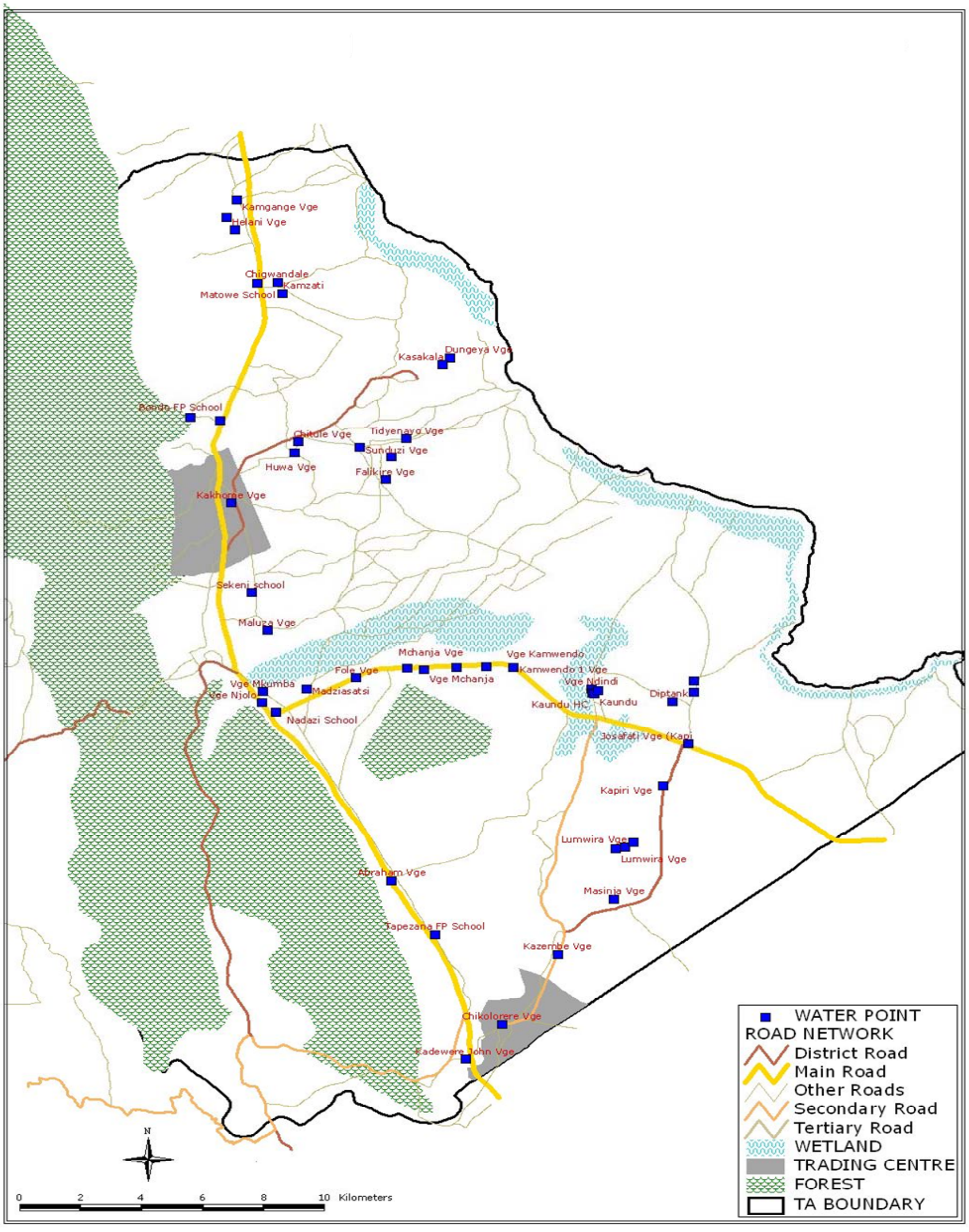

Figure 4.1 Map of Kachindamoto Traditional Authority area

The Figure 4.2 shows one of the sample points where conductivity and pH were being measured.

Figure 4.2 Water point at Sunduzeni

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION

5.1 Introduction

The summary of the results of the water quality analysis for Kachindamoto Traditional Authority area and the comparison of the results with the guidelines for WHO and standards for MBS and MoIWD is presented in Table 5.1

5.1.1 The pH

The pH values were in the ranges of 6.4 - 7.7 with a mean of 7.3 (Table 5.1). Sajidu et al. (2007) reported the pH values ranging from 6.7 to 9.26 for the dry season and 6.91 to 9.37 for the wet season in a study conducted in Machinga district in the Shire valley. Nelson (2002) defined a pH less than 7 as acidic and a pH greater than 7 as alkaline. Of the water points sampled in Kachindamoto traditional authority area, 19% had acidic water, 4% neutral water and 77% had alkaline water. The results found in Kachindamoto area were within the minimum pH limit of 6.0 and the maximum limit of 9.5 (Figure 5.1) as recommended by the MoIWD, however 4% was below the minimum acceptable limit of 6.5 by WHO guidelines.

Highly acidic water may result in corrosion parts of borehole pump, causing the possible release of iron, lead, or copper into the water while a low pH may discolor the water and give it a bitter taste (ODNR, 1997). Exposure to extreme pH values (less than 4 and greater than 11) may result in irritation of the ayes, skin and mucus membranes (Hoko, 2008). The range of the pH found in the study (6.4-7.7) may therefore be said to be in the range of acceptable limits. There were no health implications associated with low or high pH which were found in the study. Hoko (2005) indicated that a low pH tends to make the water corrosive while a high pH results in taste complaints. However there was no unsatisfactory color perception and the taste perception of the water with the lowest and highest pH values was satisfactory, but the soap consumption was perceived as high for the water points at Chagunda, Lumwila and Masinja where the pH of 7.4 to 7.7 was found. Most water points with pH less than 7.4 reported soap consumption which was perceived normal. It was therefore concluded that the pH values of the groundwater in the study area were within the acceptable limits and that they did not cause color and taste perception problems since the points with low and high pH were reported to have satisfactory color and taste perceptions.

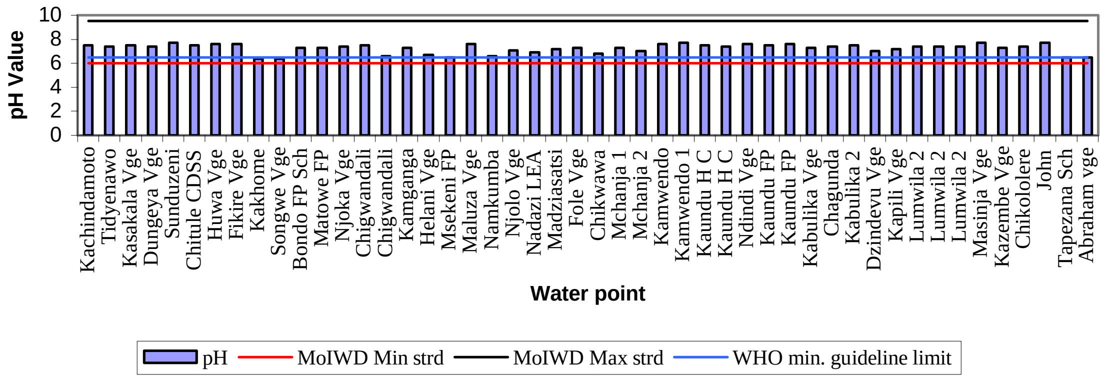

Fig 5.1. The pH values of the groundwater in Kachindamoto Traditional Authority area (March 2009)

5.1.2 Conductivity

The conductivity results ranged from 195 to 4156 µS/cm with a mean of 1242 µS/cm (Table 5.1). The values were higher above 1400 µS/cm as recommended by the MoIWD, in 29% of the water points sampled. The extreme cases of conductivity were recorded at Lumwila village (4078 µS/cm) and Chagunda village (4156 µS/cm) as shown in Figure 5.2. In the Nkhotakota area on the western shores of Lake Malawi in central Malawi, Bath (1980) reported slightly higher electrical conductivity values of 180–4600 µS/cm in weathered basements and colluvium aquifers. The range of values found in the study area were consistent with what was found in a study by Pritchard et al. (2008) in Chikwawa district (586-3750 µS/cm). Chilton and Smith-Carington (1984) found that there was a high correlation (0.725) between conductivity and total dissolved solids for groundwater in basement aquifers from the Livulezi and Dowa West areas in Malawi. Groundwater points which reported high conductivity had also high total dissolved solids and this was consistent with what Chilton and Smith-Carington (1984) reported for Livulezi and Dowa West. The high conductivity values at Lumwila and Chagunda can be attributed to high concentrations of dissolved solids.

Table 5.1
Summary of groundwater quality results for Kachindamoto Traditional Authority area for Feb and March 2008

	pH	Cond	TDSmg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	K^{+} mg/l	CO_3mg/l	HCO_3mg/l	Cl mg/l	SO_4mg/l	$CaCO_3$Hmg/l	$CaCO_3$Amg/l	NO_3mg/l	F mg/l	Fe^{2+} mg/l	Mn^{+} mg/l	SiO_2mg/l	Turbidity NTU	TSSmg/l
Mean	7.3	1242.1	629.6	117.1	21.8	81.1	2.4	14.6	377.8	58.9	132.1	376.6	329.8	0.5	0.8	0.2	0.0	24.6	3.1	2.8
Strd Error	0.1	121.3	61.7	10.0	1.4	9.4	0.5	1.7	19.3	8.0	27.9	30.0	17.7	0.2	0.0	0.0	0.0	1.0	0.2	0.4
Median	7.4	1040.2	535.9	98.3	20.4	61.4	1.2	16.0	371.8	40.5	70.4	330.5	332.0	0.1	0.9	0.1	0.0	22.8	3.0	2.0
Strd Deviation	0.4	840.6	427.5	69.0	9.5	65.3	3.5	12.1	133.8	55.5	193.1	208.0	122.3	1.2	0.2	0.2	0.0	6.9	1.5	2.9
Kurtosis	-0.1	4.5	4.8	4.0	1.2	5.0	20.8	0.5	-0.1	3.5	7.8	2.9	0.1	4.7	2.6	8.9	-2.1	0.6	31.1	27.9
Skewness	-1.0	2.0	2.0	1.8	1.1	2.1	4.1	0.6	0.4	2.0	2.8	1.6	0.5	2.4	-1.2	2.8	-1.0	0.7	5.1	4.7
Minimum	6.4	195.3	99.0	15.8	7.7	11.5	0.3	0.0	96.0	8.5	5.1	70.5	78.0	0.0	0.2	0.0	0.0	12.5	1.5	0.0
Maximum	7.7	4156.0	2120.0	350.9	50.1	313.5	21.9	49.0	728.0	248.0	886.5	1035.5	672.0	4.7	1.1	1.1	0.0	45.5	12.5	20.0
WHO	6.5-8.5	1400	1000	200	150	200	***	***	***	600	400	500	500	50	1.5	1.0	0.4	***	5	***
MBS	6.5-8.5	1400	1000	200	150	200	***	***	***	600	400	500	500	100	2.0	1.0	2.0	***	5	***
MoWD	6-9.5	1400	2000	250	200	500	***	***	***	750	400	800	800	100	3.0	3.0	1.5	***	25	***
% above MoIWD strd	0	29.2	4.2	6.3	0	0	***	***	***	0	4.2	6.3	0	0	0	0	0	***	0	***

*** no standard was specified

The taste perception was unsatisfactory in areas with high conductivity. Hoko (2005) noted that objectionable taste perceptions were high in areas with the highest conductivity values in Gokwe in Zimbabwe. The soap consumption perception on the water for these two villages was unsatisfactory. The unsatisfactory taste and high soap consumption of water in these two villages show that the conductivity is directly related to the total dissolved solids. It was therefore concluded that the conductivity values found in the study area resulted from the dissolved ions and that the values measured were dependent on the concentration of the dissolved ions and that high conductivity values indicated unsatisfactory taste for drinking water and high consumption of soap for washing.

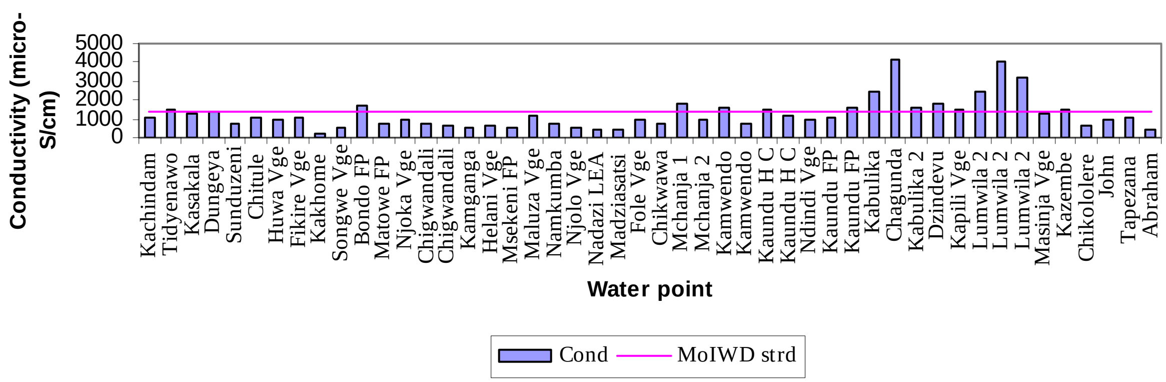

Fig 5.2. Conductivity of groundwater of Kachindamoto T.A (March 2009)

5.1.3 Total Dissolved Solids

The total dissolved solids ranged from 99 mg/l to 2120 mg/l with a mean of 629.6 mg/l and the majority of the water points had the TDS within the recommended limit (Table 5.1) for MoIWD. Only 4.2% of the total number of points sampled had water above the recommended limit of 2000 mg/l by MoIWD (Figure 5.3). The values reported in the study were higher than those which were reported by Sajidu et al. (2007) for Machinga which ranged from 50 mg/l to 1556 mg/l for the dry season and 43 mg/l to 1772 mg/l for the wet season. Pritchard et al. (2008) reported values ranging from 713- 2250 mg/l for dry season and 312-2210 mg/l for wet season for Chikwawa. Pritchard et al. (2007) in a similar study conducted in the Southern region of Malawi attributed lower values of TDS to dilution effect of the recharge during the rainy season. This is expected to be the case in the area under study since all the samples were collected during the rainy season (February and March).

The TDS was derived from the interaction of water with the sediments originating from different parent materials in the saturated zone, unsaturated zone and on the surface during run off. Generally, high TDS which is greater than WHO recommendations of 1000 mg/l is commonly objectionable or offensive to taste and the TDS levels over 2000 mg/l are generally considered undrinkable due to strongly offensive taste (WHO, 1996; ODNR, 1997). There were two water points at Lumwila and Chagunda where TDS values were higher than 2000 mg/l and the taste perceptions and soap consumption perceptions were unsatisfactory. A higher concentration of TDS usually poses no health threat to humans until the values exceed 10,000 mg/l where it causes a gastrointestinal irritation in the consumers (Subba Rao, 2006). It was concluded that the quality of water in Kachindamoto area was acceptable in most water points except at Chagunda and Lumwila villages where water is of brackish nature.

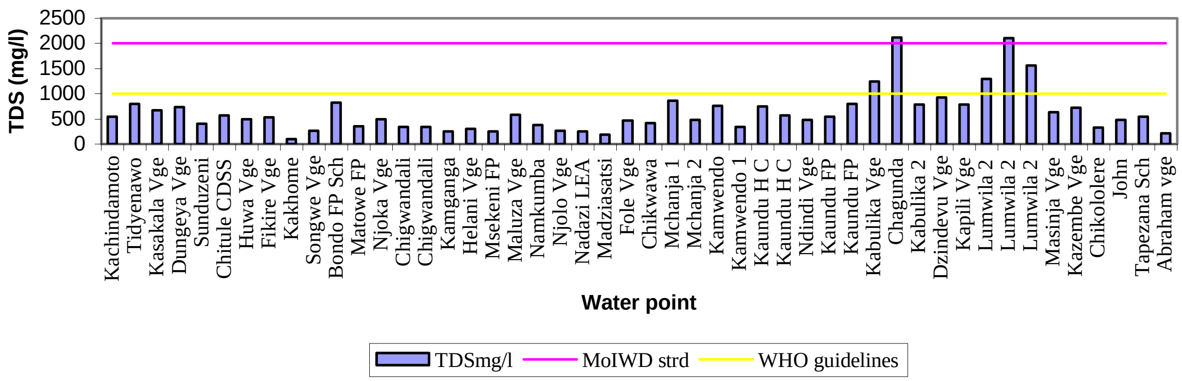

Fig 5.3. Total Dissolved Solids in groundwater of Kachindamoto Traditional Authority (March 2009)

5.1.4 Hardness

Hardness values ranged from 71 mg/l to 1036 mg/l with a mean of 376.6 mg/l (Table 5.1). Of the total number of water points which were sampled 6.3% were found to have hardness above the recommended limit of 800 mg/l set for the MoIWD (Figure 5.4). Pritchard et al. (2008) reported hardness values ranging from 38-850 mg/l for dry season and 6-1370 mg/l for wet season for Chikwawa; 3-185 mg/l for dry season and 6-220 mg/l for wet season. These results were consistent with those which were found for shallow wells in Blantyre, 47-170 mg/l for dry season and 118- 220 mg/l for wet season (Mkandawire, 2008). Hardness is defined as water that is rich in calcium (Ca^{2+}) and/or magnesium (Mg^{2+}) (ODNR, 1997). The consistently high values obtained during the rainy season were attributed to the dissolution of calcium and magnesium by rain water. The values reported are likely to have derived from the dissolution of calcium and partly magnesium from the calcite, dolomite and clay material which form part of the aquifer material of the study area.

The taste perception was satisfactory in most water points of the study area. Sawyer et al. (1994) suggests that the upper limit for soft water is 150 mg/l. Although hard water may be satisfactory for drinking, there adverse effects on soap consumption may be unsatisfactory (Sawyer et al. 1994). Hoko (2008) found that the satisfaction for taste (drinking) 95% was higher than soap consumption (laundry and bathing) which was 72% for Bindura district. The satisfactory taste perception was reported in 94% and the soap consumption satisfaction was 85% of the respondents in the study area. Unsatisfactory taste perception and soap consumption perception was high for Lumwira and Chagunda where the hardness was high. The soap lather was reported to be not normal when washing which forced the people to use a lot of soap.

Hard water leads to incidence of urolithiosis, anencephaly, some types of cancer and cardio-vascular disorders (Subba Rao, 2006). There was no health problems associated with hardness which were reported from the study area. It was concluded that the quality of water in Kachindamoto traditional authority area was acceptable in terms of hardness in 94% percent of the water points sampled. However there were few water points which reported water which was very hard and unacceptable for both drinking and washing. The results are consistent with the assertion by Sawyer et al. (1994) and Hoko (2005) which suggested that there is a higher satisfaction for taste as compared to soap consumption associated with hard water. They are also consistent with the findings for Bindura where satisfactory taste at 95% was higher than the soap consumption at 72% (Hoko, 2008).

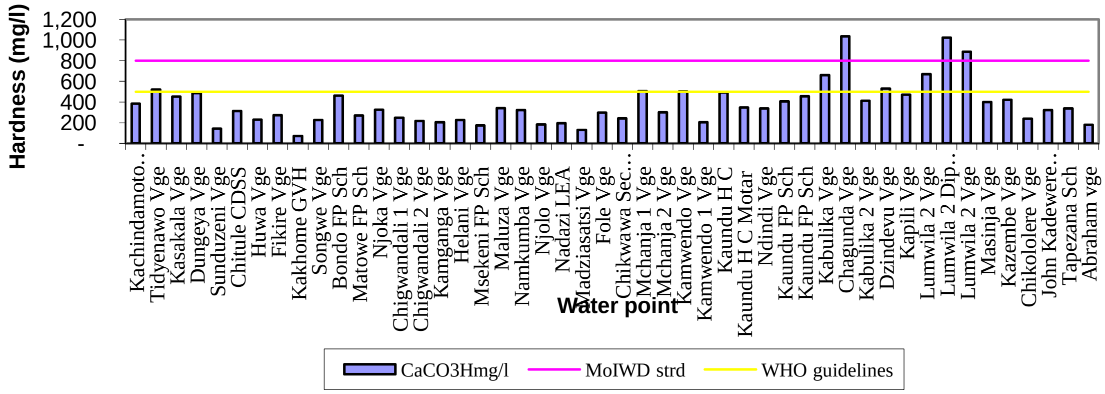

Fig 5.4 Hardness in groundwater of Kachindamoto Traditional Authority (March 2009)

5.1.5 Alkalinity

The alkalinity measurements ranged from 78 mg/l to 672 mg/l with a mean of 329.8 mg/l. (Table 5.1). As already indicated in section 5.1.1 a pH less than 7 is defined as acidic and a pH greater than 7 as alkaline (Nelson, 2002). About 77% of the water was near neutral to alkaline. However the highest values of 672 did not exceed the standards limit acceptable by the MoIWD of 800 mg/l of $CaCO_3$ (Figure 5.5). Alkalinity relates to concentration of calcium and carbonate and high alkalinity has a bearing on the hardness of the water. It was concluded that alkalinity of the water in the area was acceptable in most water points.

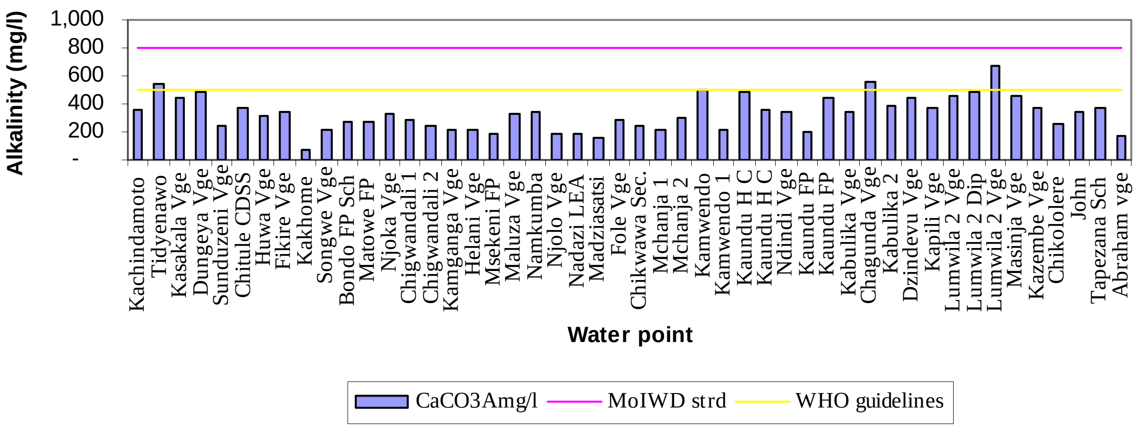

Fig 5.5. Alkalinity in groundwater of Kachindamoto Traditional Authority (March 2009)

5.1.6 Calcium

Calcium concentration ranged from 15.8 mg/l to 350.9 mg/l with a mean of 117.1 mg/l (Table 5.1). The majority of the water points had calcium concentration within the acceptable limits set by the MoIWD of 250 mg/l. Only 6.3% of the total water points sampled had the calcium concentration above the permissible limits of MoIWD (Figure 5.6). Ahmed et al. (2000) reported calcium concentration in groundwater of Khartoum State, Sudan in the range of 10.4-93 mg/l. Hoko (2008) found levels of calcium in the range of 6-71.6 mg/l in the groundwater of Bindura in Zimabwe. Calcium is the principal parameter in hardness of the water (WHO, 1996). Calcium is a dietary mineral that is present in the human body in amounts of about 1.2 kg and no other element is more abundant in the body (ODNR, 1997). It comes from a variety of different dietary sources such that a concentration above 180 mg/l from drinking water alone is considered very high (EPA, 2008). When one takes up large amounts of calcium this may negatively influence human health. Metallic calcium corrodes the skin when it comes in contact with skin, eyes and mucous membranes (NIHCC, 2009). Excessively high intakes of calcium in drinking water have adverse effects such as hypercalcemia (elevated levels of calcium in the blood), impaired kidney function and decreased absorption of other minerals such as iron, zinc, magnesium, and phosphorus (NIHCC, 2009). The unsatisfactory taste perception was reported in two villages of Lumwila and Chagunda where the water was hard. Calcium can be concluded to have contributed a lot to the hardness of the water in these two villages. The soap consumption was high such that most people in these villages resort to alternative sources such as shallow open wells for washing. There were no health problems which were reported in relation to calcium concentration at Chagunda and Lumwila. It was concluded that calcium was the most prominent cation in all groundwater points sampled and contributed to the hardness of the water in some villages in Kachindamoto area.

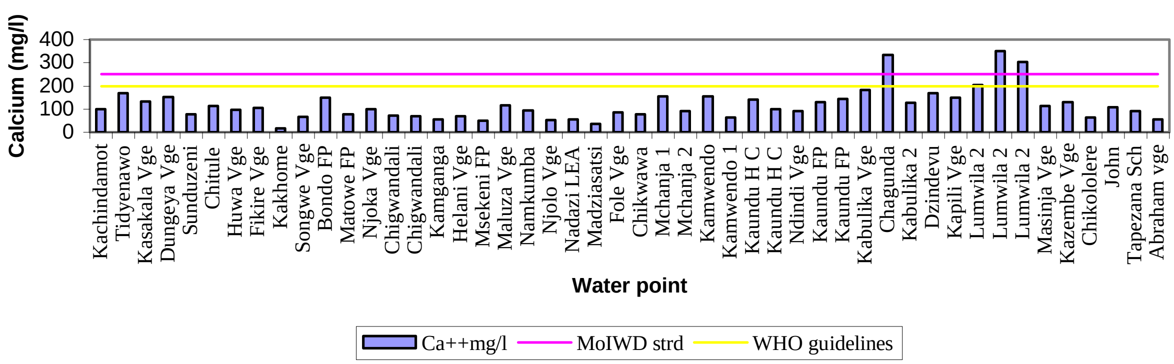

Fig 5.6. Calcium concentration in groundwater of Kachindamoto Traditional Authority (March 2009)

5.1.7 Magnesium

Magnesium concentration ranged from 7.7 mg/l to 50.1 mg/l with a mean of 21.8 mg/l (Table 5.1). It may have derived from the sediments originating from dolomite, pyrexenes, magnesite and clay materials. These concentrations were within the acceptable limits by the MoIWD of 200 mg/l and the limits by WHO guidelines of 150mg/l (Figure 5.7). The results found in the Kachindamoto area are consistent with those which Hoko (2008) reported for Bindura in Zimbabwe which was in the range of 1.2-49.6 mg/l. Ahmed et al. (2000) reported magnesium values in the range of 16.4-53 mg/l for Khartoum State, Sudan. Magnesium is one of the principal components responsible for the hardness of the water. Magnesium deficiency may increase the risk for cardiac arrhythmia and the contractility of blood vessels, as shown in animal experiments. A lack of magnesium leads to a decrease in the concentration of intracellular potassium and an increase in calcium levels in human body (NIHCC, 2009). Magnesium is an activator for several enzyme systems and is essential for cell membrane permeability and neuromuscular excitability (NIHCC, 2009). There were no health problems which are caused by magnesium which were reported. Magnesium was found in less quantity such that the hardness of the water in some water points was related to calcium than magnesium. It was concluded that magnesium was not the cause of hardness in groundwater in the study area and that it did not cause the chemical and perception problems. The results are consistent with the assertion that calcium hardness dominates the groundwater compared to magnesium hardness (WHO, 1996)

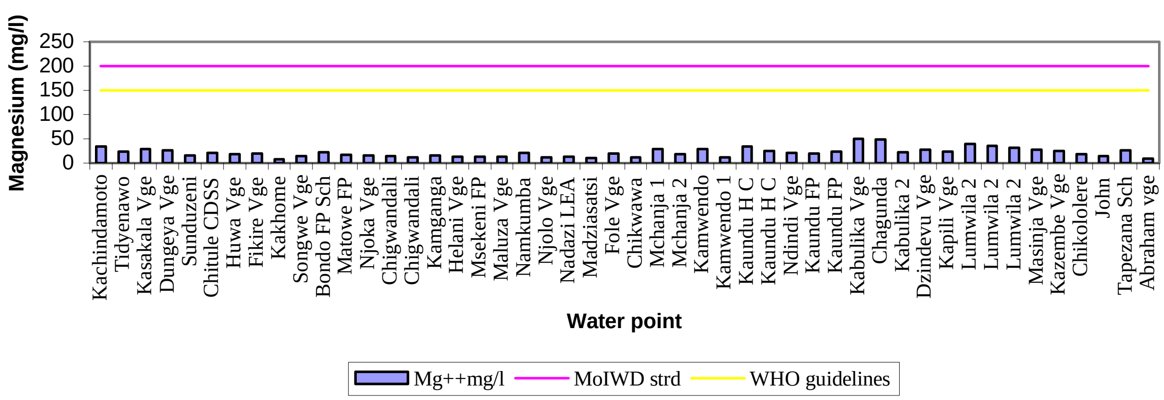

Fig 5.7 Magnesium concentration in groundwater of Kachindamoto Traditional Authority (March 2009)

5.1.8 Sodium

Sodium concentration ranged from 11.5 mg/l to 313.5 mg/l wit a mean of 81.1 mg/l (Table 5.1). These concentrations are lower than what Bath (1980) reported of the Lower Shire up to 3600 mg/l. Ahmed et al. (2000) reported sodium values for Khartoum State, Sudan in the range of 16-232 mg/l. Sodium is an evaporite and is common where the water table is high and the climatic conditions are hot (BGS, 2004). It is the common cause of well abandonment due to salty taste of the water especially when the concentration is above 500 mg/l. The values reported in Kachindamoto traditional authority were within the acceptable limits of 500 mg/l in drinking water by MoIWD. However with WHO guidelines 6.3% of the total number of water points sampled indicates concentration higher than the permissible limits of 200 mg/l (Figure 5.8). It can be concluded then that sodium contributed to salty taste of the water at Lumwila, Chagunda and Masinja villages where the perception on taste was unsatisfactory. In Kachindamoto area the levels of sodium above 200 mg/l in the three villages coincided with the hardness levels. The levels reported in the three villages may be critical to patients on sodium-restricted diet such as those suffering from hypertension or congenial heart diseases and also from kidney problems (Subba Rao, 2006). It was concluded that the quality of water of Kachindamoto area was acceptable for drinking in most water points except in the three villages where the taste was unsatisfactory.

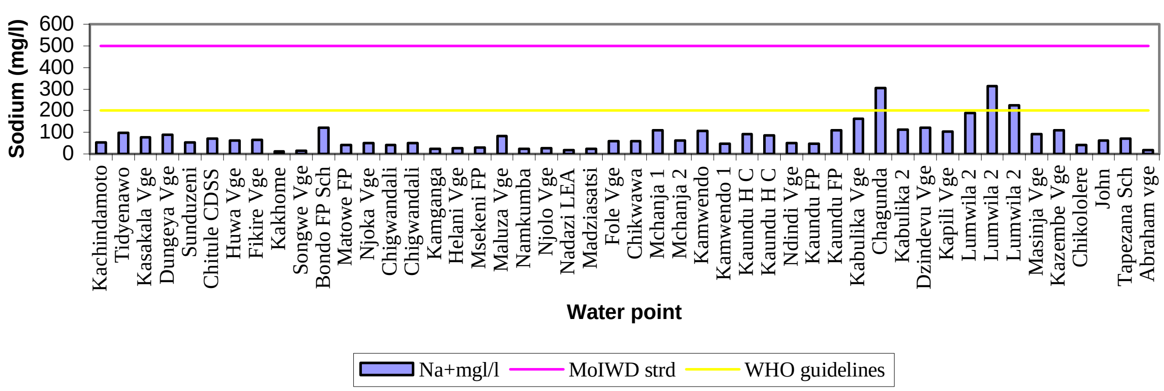

Fig 5.8 Sodium concentration in groundwater of Kachindamoto Traditional Authority (March 2009)

5.1.9 Potassium

Potassium concentration ranged from 0.3 mg/l to 21.9 mg/l with a mean of 2.4 mg/l (Table 5.1). The results obtained in the study are slightly high than those reported for Khartoum State, Sudan which ranged from 0-7.8 mg/l (Ahmed et al., 2000). Banks et al. (2002) reported potassium levels of up to 83 mg/l for Khakassia, Siberia and 24 mg/l for Mitrovice region, Kosova in places where people use pit latrines. Potassium mostly is derived from surface agricultural land which uses K-containing fertilizers and manure (including human waste from pit latrines) through infiltration of water to the groundwater Griffioen (2001). Additionally, weathering of biotite, muscovite and feldspar from the subsurface may be the internal sources of potassium. Potassium does not have limits in drinking water however high concentration would give the water a salty taste as it relates to sodium. The trace concentrations which were reported in Kachindamoto area may have derived from manure from animal waste, fertilizers and the pit latrines when the water table was recharged. It was concluded that the concentrations of potassium was not significant to cause chemical and perceptual problems on the quality of the groundwater in the study area.

5.1.10 Carbonate

Carbonate measurements ranged from 0.0 mg/l to 49 mg/l with a mean of 14.6 mg/l (Table 5.1). The carbonate may have derived from the sediments of calcite and dolomite in the study area (Chilton, 1996). Carbonate is important to the hardness of the water especially due to its relationship with calcium and magnesium. The hardness of the water of the Kachindamoto area was associated with calcium carbonate. The perception on taste was unsatisfactory in 6.3% of the area sampled. The soap consumption was high in these villages with hard water. Although there are no specific limit standards for WHO and MoIWD, higher carbonate concentrations result in hardness of the water which can be rejected. It was concluded that the presence of carbonate was related mostly to the calcium carbonate (hardness) in the groundwater of the study area.

5.1.11 Bicarbonate

Bicarbonate concentration ranged from 96 mg/l to 728 mg/l with a mean of 377.3 mg/l (Table 5.1). Ahmed et al. (2000) reported bicarbonate levels ranging from 97.0-414.8 mg/l for

Khartoum State, Sudan. The bicarbonate concentration in the study area may have derived from the dissolution of calcite and dolomite sediments during precipitation of acidic rain (Chilton,1996). There is no specification on the maximum acceptable limits of bicarbonate by WHO or MoIWD standards however higher concentrations with calcium and magnesium result in hard water. Hardness was found to be higher than the recommended limits in 6.3% (Figure 5.9) of the area sampled. The unsatisfactory perception on taste and soap consumption was high in these three villages. It was therefore concluded that the concentration of bicarbonate contributed the hardness of the groundwater especially in the villages where the perception of taste and soap consumption was unsatisfactory.

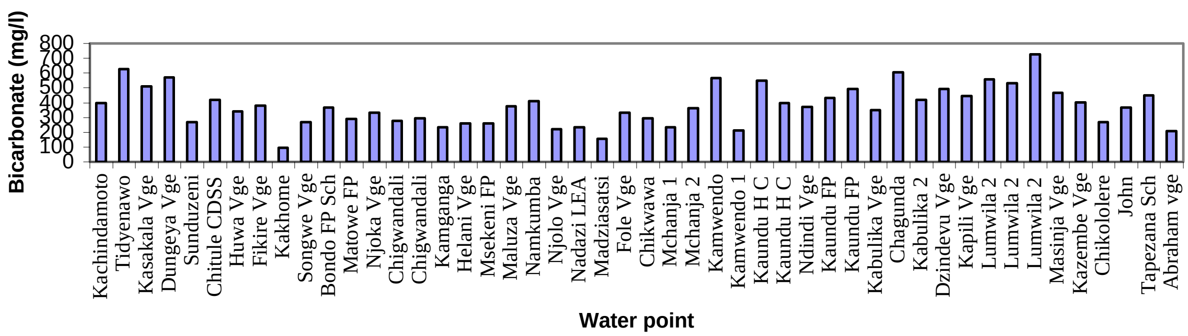

Fig 5.9 Bicarbonate concentration in groundwater of Kachindamoto Traditional Authority (March 2009)

5.1.12 Chloride

Chloride ranged from 8.5mg/l to 248mg/l with a mean of 58.9 mg/l (Table 5.1). Higher values were reported for Khartoum State, Sudan ranging from 5.3-798 mg/l (Ahmed et al., 2000).
Banks et al. (2002) reported levels up to 56 325 mg/l for Khakassia, Siberia and 190 mg/l for Mitrivice region, Kosova in places where people mostly use pit latrines. The values found in Kachindamoto area show that all the water points were within the maximum recommended limit of 500mg/l for WHO guidelines and 750mg/l for the MoIWD recommended limits (Figure 5.10). Chloride in the study area may have derived from the sediments originating from igneous rocks, evaporites, pit latrines and animal waste. Excess concentration of Cl^- in drinking water gives a salty taste and has a laxative effect in people not accustomed to it (Subba Rao, 2006). Unsatisfactory taste perception was found at Lumwila, Chagunda and Masinja. However it may not necessarily be attributed to chloride since the values were low. There were no health problems which were reported from the area. It was concluded that the concentration

of chloride was not responsible for that taste of the water in the villages where the perception was unsatisfactory.

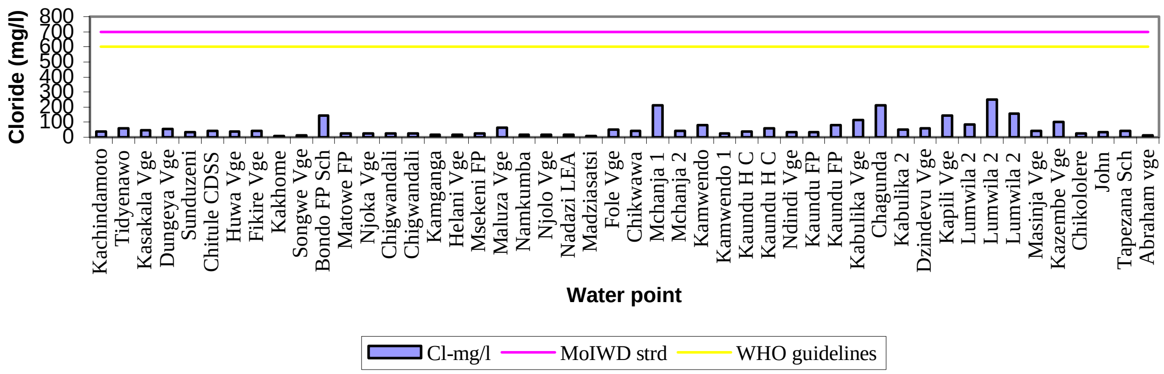

Fig 5.10 Chloride concentration in groundwater of Kachindamoto Traditional Authority (March 2009)

5.1.13 Sulphate

Sulphate ranged from 5.1 mg/l to 886 mg/l with a mean of 132.1 mg/l (Table 5.1) and was found to be within the recommended limits of the MoIWD standards of 800mg/l in the majority of the water points which were sampled. Only 4.2% of the total number of points sampled had the water with higher levels of sulphate than recommended by the MoIWD, however 13% was above the WHO guidelines of 250 mg/l (Figure 5.11). Bath (1980) reported values up to 2400 mg/l of sulphate in the weathered basements and colluvium of Lake Malawi. Mkandawire (2008) reported much lower values in the range of 0-79 mg/l for both dry and wet season in some boreholes in Blantyre. Pritchard et al. (2008) reported values ranging from 18-520 mg/l for Chikwawa for the dry and wet season. Sulphate in the Kachindamoto area may have derived from the dissolution of minerals such as gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$). Secondary sources of sulphate are from the weathering of pyrite and the dissolving of ammonium sulphate fertilizers.

The highest values of sulphate were recorded at Chagunda and Lumwila which coincided with the hardness of the water in these villages. It can therefore be concluded that sulphate contributed to the hardness of the water in these villages. The taste perception of water in these two villages was unsatisfactory. There was unsatisfactory odor perception at Chagunda.

Sulphates, at high levels than the WHO guidelines of 250 mg/l, taint the taste of water and may create a laxative effect (ODNR, 1997).

EPA (2006) noted that health concerns regarding sulphate in drinking water were raised because of reports that diarrhea may be associated with the ingestion of water containing high levels of sulphate especially in the population that react to abrupt change from drinking water with low sulphate concentrations to drinking water with high sulphate concentrations. It was reported that the laxative effect is common to those who use the water for first time and with long time of use the users get accustomed to the water at Chagunda and Lumwila villages. Subba Rao (2006) noted that higher concentration of SO_4^2 in drinking water is associated with respiratory problems and in combination with Na^+ and Mg^{2+}, SO_4^2 also exerts a cathartic effect on digestive tracts however such health problems were not reported. It was concluded that the majority of water points in Kahindamoto traditional authority area had water of good quality however sulphate contributed the unsatisfactory taste and odour of water at Chagunda.

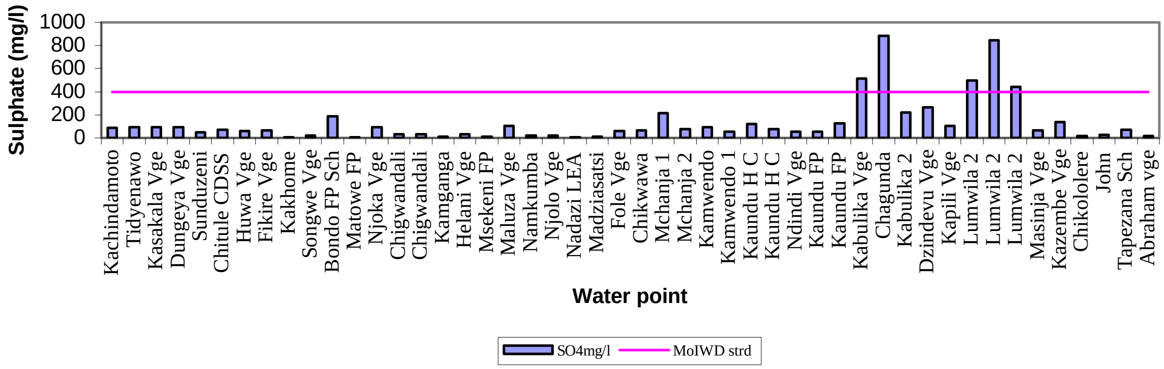

Fig. 5.11 Sulphate concentration in groundwater of Kachindamoto Traditional Authority (March 2009)

5.1.14 Fluoride

Fluoride ranged from 0.5 mg/l to 1.05 mg/l with a mean of 0.8 mg/l (Table 5.1). These measurements were within the acceptable limits of WHO and MoIWD of 1.5 mg/l and 3.0 mg/l respectively (Figure 5.12). These low concentrations can be attributed to dilution effect of rain water since all the samples were collected during the rainy season although there is a possibility that they may have result from high pH which prevents dissolution of fluoride

(Subba Rao, 2006). BGS (2004), noted that Malawian groundwater in the Rift zone (eastern alluvial plains) were likely to be affected with high fluoride by virtue if its position in the rift valley zone, though climatic factors, i.e. high rainfall compared to high-fluoride basement aquifers elsewhere, suggest that the concentrations in this region should be mostly low. UN (1989) reported fluoride concentrations of less than 1 mg/l in areas of altered basement rocks in Malawi but much higher concentrations, in the range 2–10 mg/l, in groundwater from the alluvial areas.

Msonda et al. (2007) found that fluoride concentration varied from <0.5 to 6.8 mg/l for the rainy season and <0.5 to 7.02 mg/l for the dry season in Nathenje area. Pritchard et al. (2008) found far much higher values for fluoride in the range of 0.3- 11 mg/l for dry season and 0.9-14 mg/l for the wet season for Chikwawa. These high values for the wet season in Balaka and Chikwawa were found in open and protected shallow wells. Msonda et al. (2007) reported that high fluoride zones are associated with areas of discharge, especially places where shallow groundwater less than 4m occurs. On the contrary Sajidu et al. (2007) reported higher values 0.46-10.3 mg/l for the dry season and lower values 0.35-8.23 mg/l for the wet season and the variation was attributed to the dilution effect of rain water during recharge to deep groundwater. The low fluoride concentrations therefore in the study area can be associated with deeper groundwater which was sampled and also the dilution effect from the rain water. Fluoride concentration in natural waters is usually limited by saturation with respect to fluorite (CaF_2) and owing to this constraint the waters containing high concentration of Ca^{2+} are characterized by low F^- content (Devadas et al., 2007). The dominance of calcium in the groundwater of Kachindamoto area is likely to be another importance factor that may have resulted in low fluoride levels. Fluoride in the study area may have derived from sediments which originated from fluorspar (fuorite), apatite, topaz and cryolite which forms part of the aquifer material.

Although the measured concentrations were within the recommended consumptive limits of WHO of 1.5 mg/l, cases of teeth fluorosis were evident in most villagers above the age of fifteen. Subba Rao (2006) noted that fluoride in excess of over 1.2 mg/l causes fluorosis. It can be suggested that high fluoride levels are common in the study area in most alternative sources of water such as shallow wells (protected and unprotected) which the people resort to when need arise. At concentrations from 0.5 to 1 mg/l, it reduces dental caries (WHO, 2008) whereas amounts substantially in excess of 1.0 to 3.0 mg/l causes mottling of teeth and excessive amounts are toxic (Twort et al., 1974; WHO, 2008). Meenakshi (2006) noted that concentrations of 3.0-4.0 result in stiffened and brittle bones and joints and above 4 mg/l results in deformities in knee and hip bones and finally paralysis, making the person unable to walk or stand in straight posture. Fluoride concentrations high than what was found are expected in the Kachindamoto area during the time when there is no dilution effect. Using a ratio of 1.2 that was calculated from the dry season to rainy season values (appendix 5) that were reported at Liwonde by Sajidu et al. (2007), fluoride levels at Kchindamoto can be projected at higher values of 1.4 mg/l during the dry season. It is concluded that the fluorosis in the area is caused by fluoride and may result from higher values during dry season and the cumulative effect of consumption especially during childhood before the age of 7.

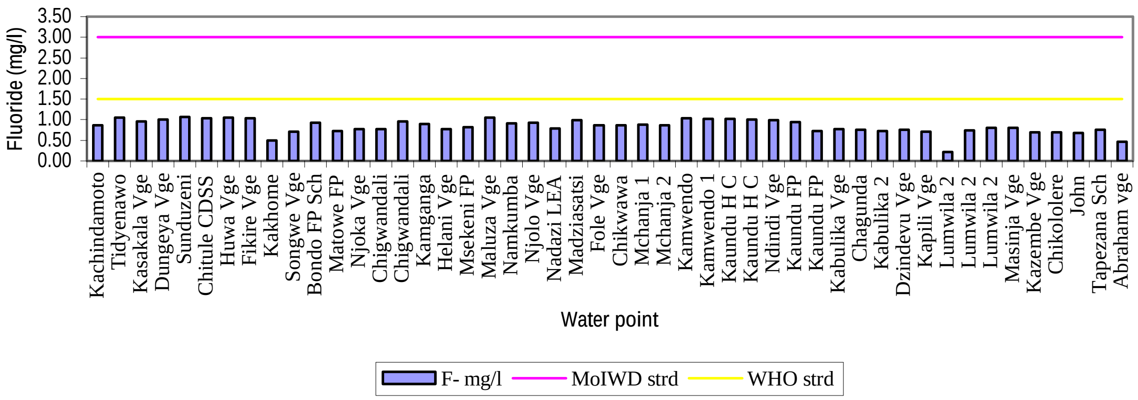

Fig. 5.12 Fluoride concentration in groundwater of Kachindamoto Traditional Authority (March 2009)

5.1.15 Nitrate

Nitrate (NO_3^-) ranged from 0.0 mg/l to 4.7 mg/l with a mean of 0.5 mg/l (Table 5.1). These values were within the acceptable limits for both WHO guidelines and the MoIWD standards of 40-50 mg/l and100 mg/l respectively (Figure 5.13). The results are also consistent with what was obtained for Chikwawa which ranged from 0 to 2 mg/l for both the dry and wet season (Pritchards et al., 2008). The nitrogen compounds that were found in the groundwater of the study area might have derived from the atmosphere through specific plants fixation of nitrogen from the atmosphere onto their roots (BGS, 2004). The other major source in the study area might be the agricultural fields which uses fertilizers. Nitrogen not used by the plant was released into the soil where free reactions with water, minerals, and bacteria took place. The secondary sources of nitrogen compounds which were detected may include, manure and urine from animal kraals, pit latrines, and landfills. ODNR (1997) noted that nitrates are especially toxic to children less than six months of age. Children who ingest nitrate may not have developed an immune system that can ward off the compound and a condition known as "blue-baby syndrome" may occur. Excessive NO_3 in drinking water can cause a number of health disorders, such as methaemoglobinemia, gastric cancer, goitre, birth malformations and hypertension (Majumdar and Gupta, 2000; BGS, 2004; Subba Rao, 2006). However no condition of such illness was reported in the area. It was concluded that the water in the study area did not have nitrate concemtration that could lead to health problems. Finally, it is suggested that if the origin is known, elimination of the source of nitrogen contamination may be the best corrective measure.

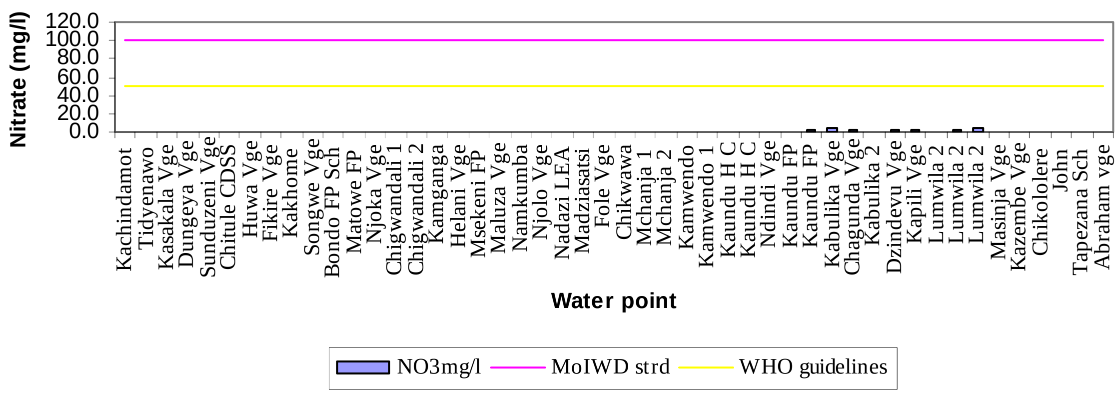

Fig. 5.13 Nitrate concentration in groundwater of Kachindamoto Traditional Authority (March 2009)

5.1.16 Iron

The Iron concentration ranged from 0.008 mg/l to 1.125 mg/l with a mean of 0.2 mg/l (Table 5.1) and this was within the recommended limit of the MoIWD of 3.0 mg/l. However 4% of the points sampled had iron above the WHO guidelines of 1 mg/l. Bath (1980) reported iron values of up 82 mg/l for Nkhotakota and Lower Shire valley. Higher values were reported for boreholes in Bindura district in the range of 0.08 to 9.6 mg/l (Hoko, 2008). Iron (Fe^{+2}) in groundwater provides the typical well water "rust" taste. Not only is the taste unpleasant, iron can also stain plumbing fixtures, clothes, and dishes. It was observed that most groundwater samples had at least trace amounts of iron which shows it is naturally present in the study area. The WHO (1996) guidelines recommends that domestic water should not exceed 0.3 mg/l. Iron concentrations exceeding this level may cause the characteristic reddish staining ODNR (1997). In the Kachindamoto traditional Authority area concentration above 0.3 mg/l were found in 14.6% of the water points sampled. Relatively higher concentrations of above 1 mg/l were reported at Bondo Primary School and Changwandali village. UN (1989) gave ranges for total iron in groundwater in Malawi from both weathered basement rocks and alluvial sediments as 1–5 mg/l. High iron concentration is one of the common causes of well abandonment in Malawi (Bath, 1980). The water in these points had acceptable taste however there was likelihood that there could be staining of clothes although it was not reported. It was concluded that iron did not cause chemical quality and perception problems in the water of the study area.

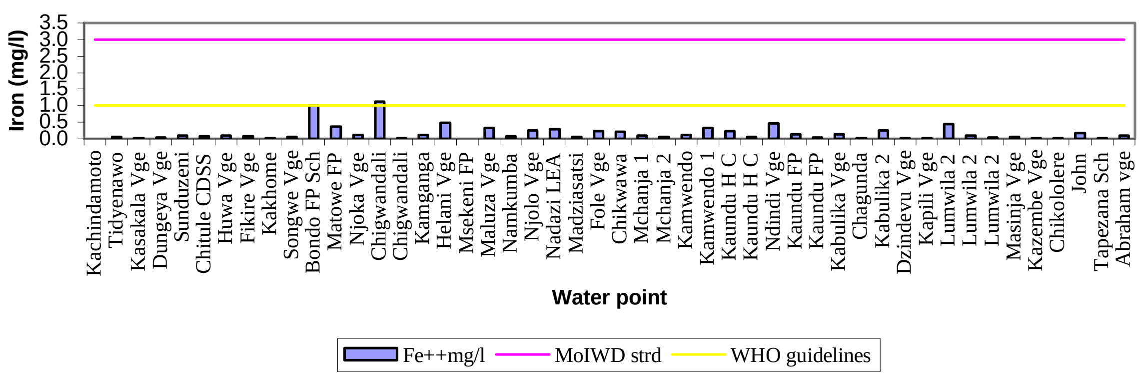

Figure 5.14 Iron concentration in groundwater of Kachindamoto Traditional Authority (March 2009)

5.1.17 Manganese

Manganese was less than detectable levels of 0.001mg/l with a mean of <0.001 mg/l (Table 5.1). This shows that the levels were insignificantly low such that they could not be traced. BGS (2004) noted that concentrations of manganese have not been reported in Malawian groundwater. The principle controls on manganese concentration in groundwater are acidic and redox conditions and the concentration can be higher in acidic groundwater (BGS, 2003). Under aerobic conditions typical of many shallow aquifers and surface waters, manganese is stable in its oxidised form, $Mn(IV)O_2$ which is highly insoluble. Hence, concentrations of manganese in aerobic water are usually low and commonly below analytical detection limits (BGS, 2003). Manganese in concentrations more than the acceptable limits of the WHO guidelines of 0.5 mg/l can cause black staining of food, laundry and sanitary ware and can impact on the metallic taste of water (BGS, 2003). Studies in Japan have shown a link between consumption of manganese and the motor neuron disease (Iwami et al., 1994). It was concluded that manganese was not a problem in groundwater in the study area.

5.1.18 Turbidity

Turbidity values ranged from 1.5 NTU to 12.5 NTU with a mean of 3.1 NTU (Table 5.1) and these were within the recommended limits by the MoIWD. Using the WHO guidelines and MBS standards, 2.1% of the sampled water points were found with turbidity higher than the recommended limits of 5 NTU. The values reported in the study are far much lower than those reported for Bindura district in Zimbabwe which ranged from 0.75 to 428 NTU (Hoko, 2008). Mkandawire (2008) reported the ranges of turbidity 0.35-61.76 NTU for the dry season and 0-8.99 NTU for some boreholes in Blantyre with high values mostly obtained in dry season. Pritchard et al. (2008) reported values ranging from 0-209 NTU for shallow wells in Balaka, Chikwawa and Zomba for both the dry and wet season. The value (12.5 NTU) at Bondo Full Primary School coincided with the concentration of iron and total suspended solids and can be attributed to the condition of the pump. Suspended solids are rarely harmful, yet elimination of turbidity increases the aesthetic quality and acceptability of the water. Pritchard et al. (2007) suggest that the impact of turbidity is that the colloidal particles which cause turbidity can harbor pathogens thereby making disinfection ineffective. Turbid waters demand relatively higher dosage of disinfectants if disinfection, which is the only treatment method for groundwater in rural areas, is deemed necessary (Hoko, 2008).

Secondly, toxic contaminants can adsorb to suspended particles, which in turn may be ingested by humans and cause health problems (ODNR, 1997). Turbidity also makes the water aesthetically unacceptable. Water with less 5 NTU is more appealing to drink (WHO, 1996). It is important to look for causes of the turbidity when trying to treat the water. For instance in a borehole look for improperly installed casing, cracked casing, missing well cap or cracked sanitary pack. One of the simplest methods of treating water from turbidity is a filtration. It was concluded that the water was of good quality in relation to turbidity in the study area and only one point was found with elevated value.

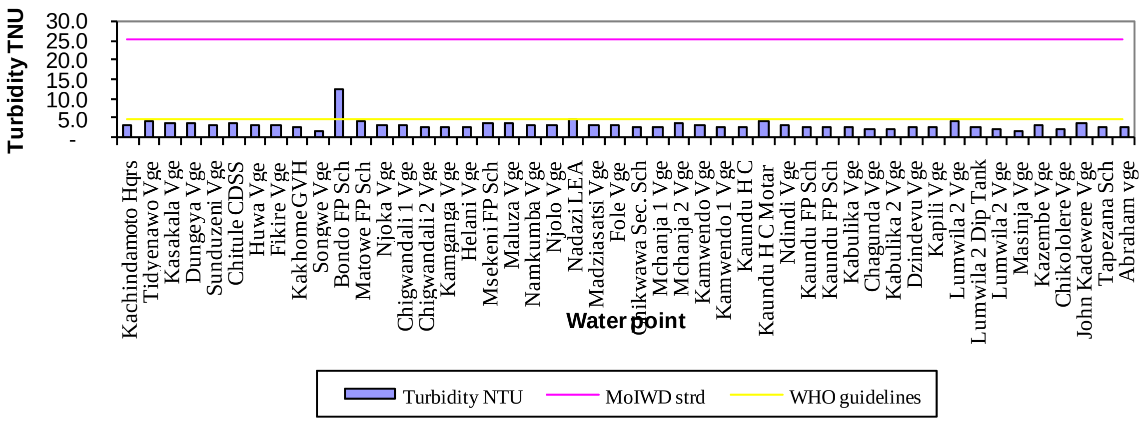

Fig 5.15 Turbidity in groundwater of Kachindamoto Traditional Authority (March 2009)

5.1.19 Total Suspended Solids

The values of total suspended solids (TSS) ranged from 0 mg/l to 20 mg/l with a mean of 2.8 mg/l (Table 5.1) and the levels were not significant in the majority of the water points. In all the points the values were below the recommended limits of the MoIWD, which is below 30 mg/l. The slightly higher value of 20 mg/l was reported at Bondo Primary School (Figure 5.16). This coincided with a higher value for iron and turbidity. TSS affects the aesthetic nature of the water and consequently affects the acceptability of the water. The suspended solids can also harbor pathogenic organisms. It was concluded that the groundwater in the study area was of acceptable aesthetic quality.

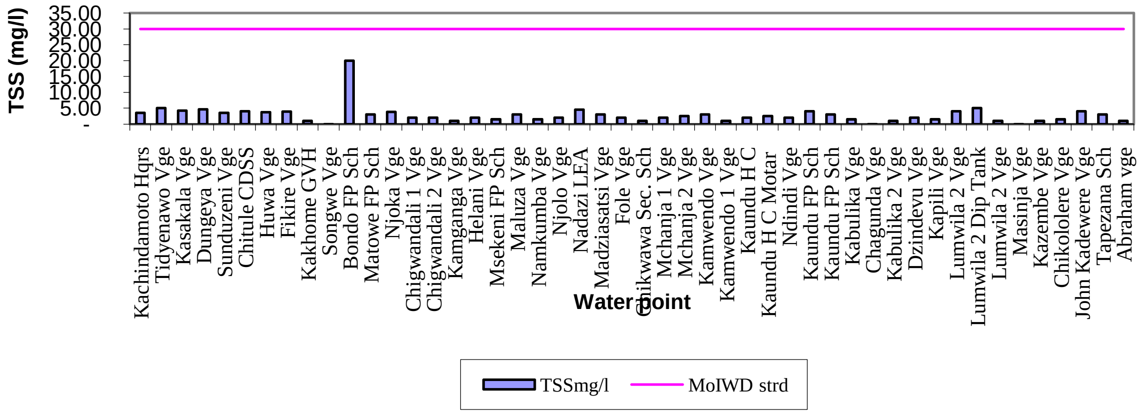

Fig 5.16 Total suspended Solids in groundwater of Kachindamoto T.A. as of March 2009

5.2. Description of water quality using major ions

The trilinear diagrams (Figure 5.17) of Piper (1953) as recommended Freeze and Cherry (1979), Fetter (1994), were used to classify the water in relation to major ions. The diagrams show that the major ion concentration of water in the area is of calcium sulphate and calcium carbonate type.

For most points the groundwater was weakly to moderately mineralized, with sulphate and bicarbonate concentrations generally above 100 mg/l. The range includes Ca-HCO_3 type and Ca-SO_4 type of waters, the latter commonly associated with local anaerobic conditions in weakly permeable deposits (Robins, 2002) which is typical of the swamps and clayey formations of some parts of the area under study. Larsen at al. (2002) classified the groundwater of Zimbabwe as follows: water with calcium concentration of 28-98 mg/l and carbonate concentration of 206-534 mg/l and a pH of 6.5-7.2 was classified as calcium-carbonate type and the one with sodium concentration of 87-154 mg/l and carbonate concentration of 27-457 mg/l and a pH of 9.1-9.4 was classified as sodium-carbonate type.

The chemical facies that determined the water type for Kachindamoto area were calculated by first converting the concentration to (meq/l) of the major cations (Na^+, K^+, $Ca^{2+,}$ Mg^{2+}) and anions (Cl^-, SO_4^{2-} , HCO^{3-}) and to percentages of the total cations or anions as suggested by Piper (1953). All ions with concentrations surpassing 10% of the molar concentration in the solution are considered to be major ions (Guler et al. 2002). The diagram indicates dominance of the major ions Ca^{2+}, Na^{+}, and SO_4^{2}, HCO_3^{-} while other ions, such as K^{+}, Mg^{2+}, and Cl^{-}, are comparatively less represented. Cetindag and Okan (2003) noted that such situation indicates natural input from the geological material in the groundwater system. The groundwater samples collected indicated natural input into the groundwater system from the dissolution of calcium from calcium sulphate (gypsum), clay materials and sediments from calcite and dolomite along with leachates or dilution of groundwater in various proportions with rainwater.

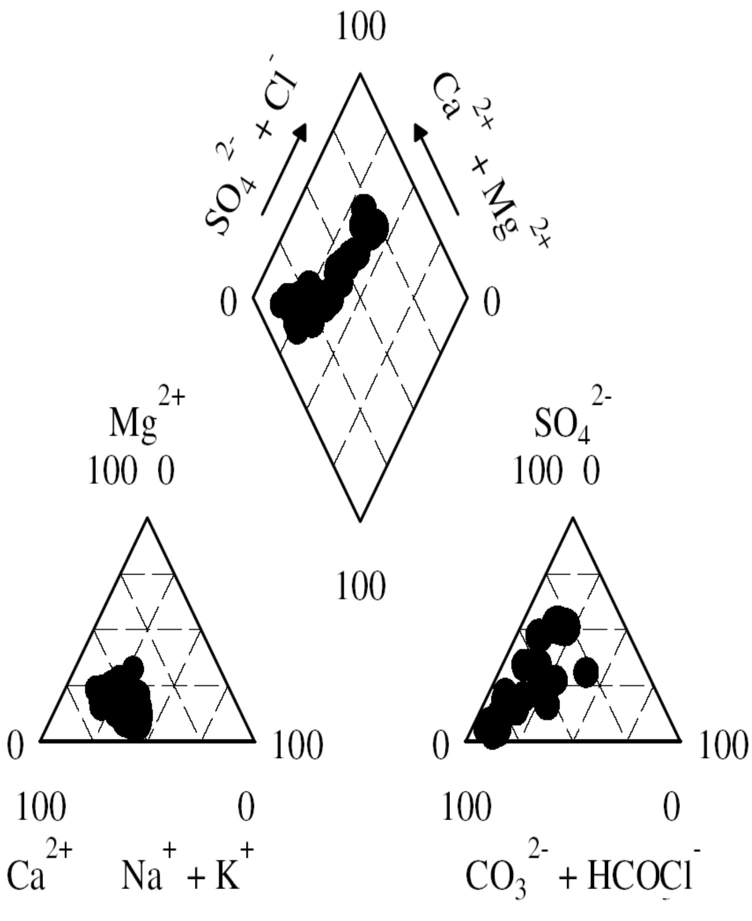

Fig. 5.17 Trilinear diagrams of the major ions (%) in groundwater of Kachindamoto Traditional Authority

Sodium may have derived from clay materials and evaporite such as sodium chloride. Sulphate may have derived from oxidation of sulphide ores and dissolution of gypsum and anhydrite.

Bicarbonate may have derived from sediments of calcite and dolomite in contact with rain water. Concentrations of major cations and major anions were classified as Ca^{2+}, Na^{+}+ K^{+}, Mg^{2+}, SO_4^{-}, HCO_3^{-}, and Cl^{-}. Most of the samples show decreasing order of cation facies with $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ and decreasing order of anions in groundwater samples as $SO_4^{\ 2-} > HCO_3^{-} > Cl^{-}$, while a few samples showed different trends, indicating some localized changes in quality which can be attributed to the human activities such are agriculture, manure from animal waste and damping places. It was therefore concluded that the chemical quality of water of Kachindamoto Traditional Authority was dominated by calcium, sodium, sulphate and bicarbonate and that the water was classified as $CaSO_4$, $CaHCO_3$, $NaSO_4$ and $NaHCO_3$ type. The rest of the chemical ions were in lesser concentrations.

5.3. Spatial variation and water quality

Spatial variation was considered for selected parameter in order to determine the impact of lithology, climate and anthropogenic activities on the chemical quality of groundwater as recommended by McNeil (2005). It was observed that the chemical trends were consistent with the geology and climatic conditions of the area. Lithology had the greatest impact on the distribution of fluoride and iron since they indicated localized occurrence. Most of the parameters indicated impacts of uniform lithology, climatic conditions and the flow direction of groundwater. The following parameters were considered for the spatial analysis because of their impact of the health and/or human perception of the water quality for drinking.

5.3.1 pH

The pH values were increasing eastwards and southwards (Fig. 5.18). The acidic water was reported south-west of the area while alkaline water was reported on the central, east, and south-eastern parts of the area. The high pH indicates high concentrations of TDS and consequent hardness of the groundwater was increasing towards the east and south.

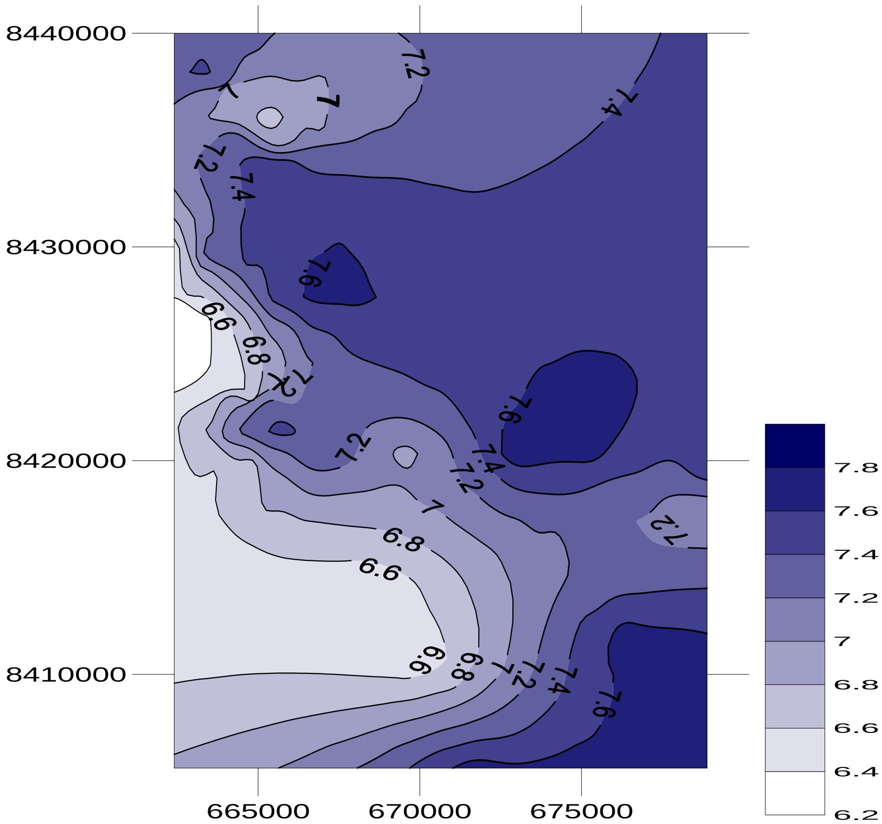

Figure 5.18 spatial variation of pH

5.3.2 Conductivity

Conductivity was high in the eastern part of the Kachindamoto Traditional Authority area (Fig. 5.19). The WHO guidelines do not specify the limit for EC however any value above 1380 (µS/cm) of EC indicate high TDS above 1000mg/l using an average correlation factor f 0.725 (Hoko, 2005). The MBS indicates that EC value above 1400 (µS/cm) signifies high TDS and the water quality will depend on the type of solids dissolved. The eastern part of the study area had some places such as Lumwira and Chagunda which had blackish water.

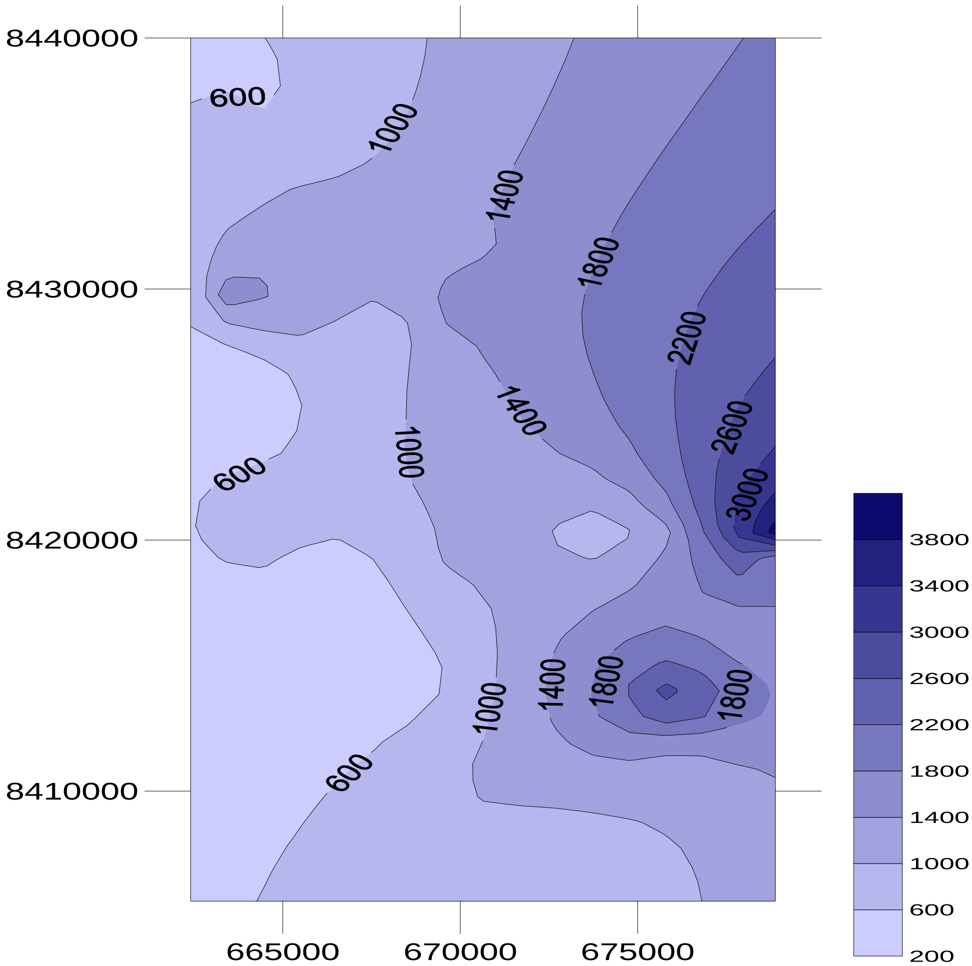

Figure 5.19 spatial variation electrical conductivity (µS/cm)

5.3.3 TDS

The total dissolved solids concentration increased eastwards and southwards of the Kachindamoto area (Fig. 5.20). The increase in TDS eastwards indicates the increase in concentration as water flows in the direction of the Lake Malawi. It also indicates the residence time the water and the interaction with the chemical elements. The trend shows that the sources of the chemical compounds are mostly natural and that they are confined in the uniform lithology of the area.

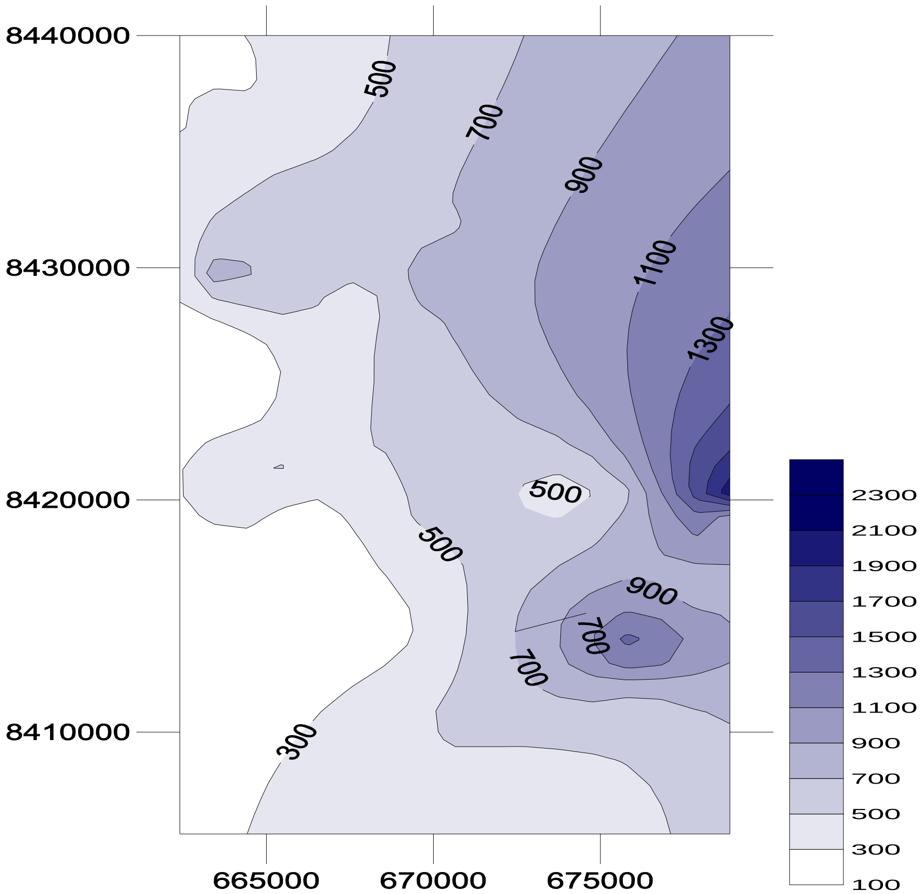

Figure 5.20 spatial variation of TDS (mg/l)

5.3.4 Hardness

The hardness of the water in the area also increased eastwards and southwards (Fig. 5.21). The trend indicates that interaction between water and Ca^{2+}, Ma^{2+}, CO_3^- and HCO_3^- was increasing towards the east. These elements were derived from gypsum, clay materials, and calcite and dolomite sediments. The trend also reveals the direction of groundwater flow and the residence time of groundwater and the influence of climatic conditions the quality of water. There is increase in hardness with distance as it interacts with the geological material and with longer period of interaction. On the other hand the water increased in hardness with high temperature close to the lake as more evaporation occurs and less dilution due to aridity of areas on the rain shadow areas.

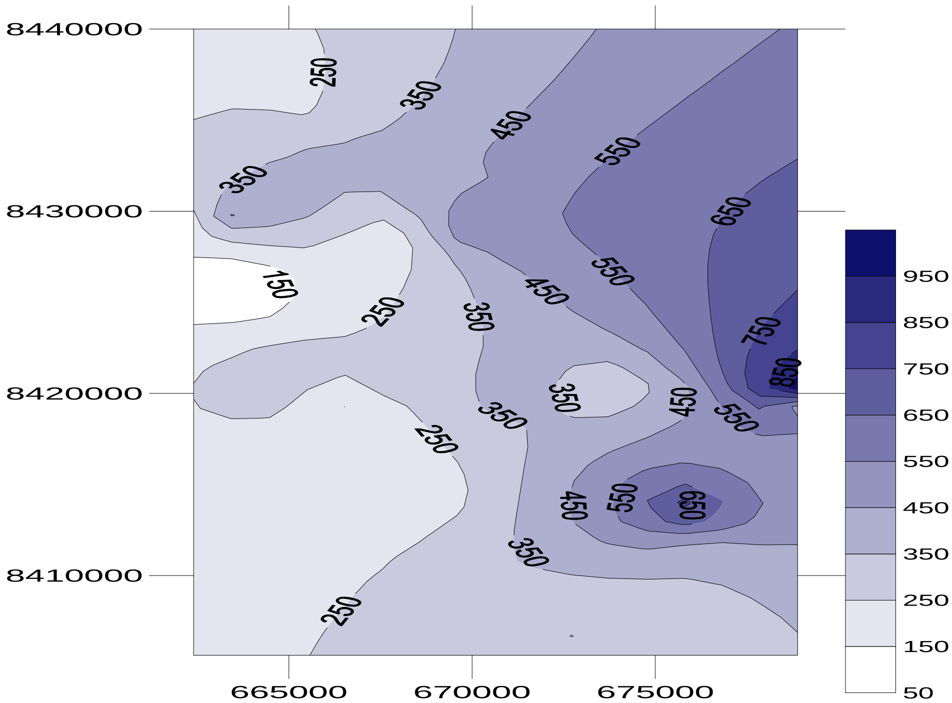

Figure 5.21 spatial variation of hardness ($CaCO_3$ mg/l)

5.3.5 Iron

Iron was reported in the north western part of the study area (Fig. 5.22). This indicates that water in the north western part of the study area interacts with igneous rocks and sediments originating from igneous rocks such as sand stone, oxides, and clay materials. Iron in Malawi occur almost in all types of lithological formations, however the concentrations recorded in Kachindamoto were less which concur with what BGS (2004) reported of most alluvial formations of Lake shore in Malawi.

5.3.6 Fluoride

Fluoride at the Kachindamoto area was widely spread (Fig. 5.23). Fluoride in water derives mainly from dissolution of natural minerals in the rocks and soils with which water interacts and the most common fluoride-bearing minerals are fluorite, apatite and micas (BGS, 2004). Groundwater in the area interact with sediments originating from crystalline rocks, especially granites are particularly susceptible to fluoride build-up because they often contain abundant fluoride-bearing minerals.

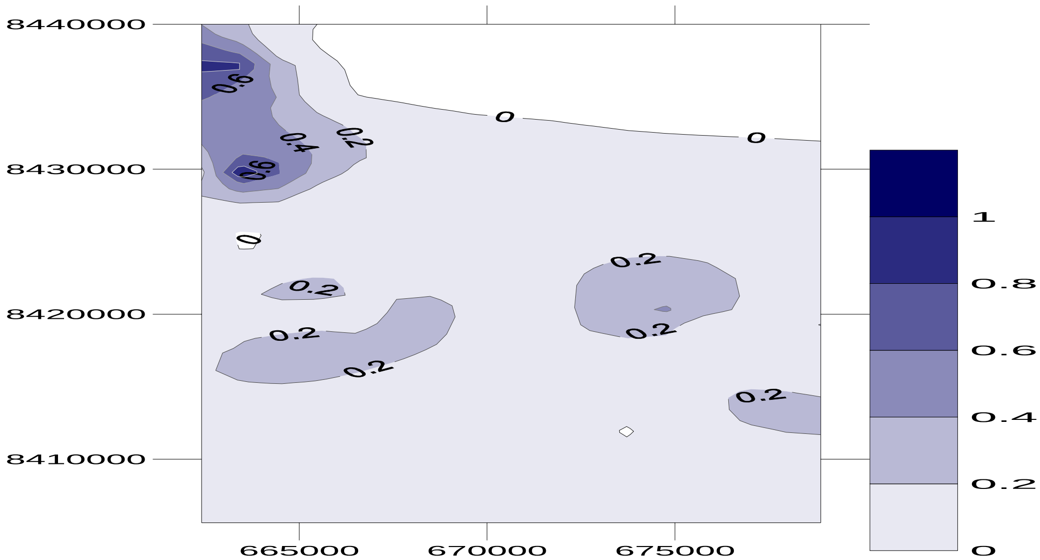

Figure 5.22 spatial variation of Iron (mg/l)

Fluoride build-up is less pronounced in the humid tropics because of high rainfall inputs and their diluting effect on groundwater chemical composition (BGS, 2004). Therefore the low values for fluoride in the area can be attributed to the dilution effect of the rainy season. It was concluded that the fluoride bearing geological materials underlie the area and that higher values than recorded are expected during the dry season.

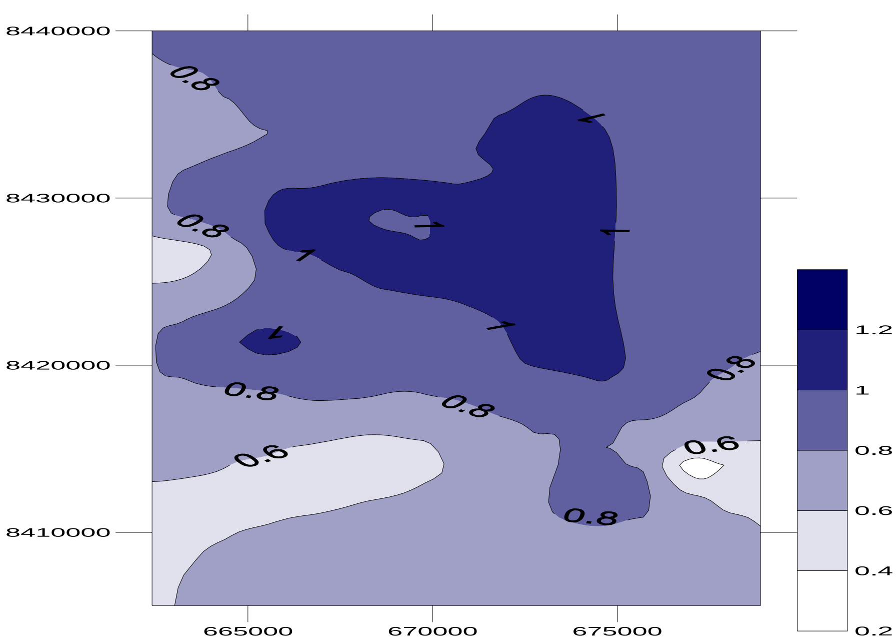

Figure 5.23 spatial variation of fluoride (mg/l)

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following conclusions were made:

- The study indicates that out of the 20 parameters which were tested 15 (75%) satisfied the standard limits while 5 (25%) parameters had values which were out side the acceptable limits for drinking and other domestic uses as recommended by the Ministry of Irrigation and Water Development. The parameters which did not satisfy the requirements were conductivity in 29%, TDS 4%, Ca 6%, SO^4, 4.2% and hardness 6.3% of the area sampled. The taste and soap consumption perceptions were satisfactory in most water points. However unsatisfactory taste perceptions were reported by 6% of the consumers while high soap consumption was reported by 15% of the consumers.
- The spatial variation shows the trend that most of the parameters increased eastwards which imply that the direction of groundwater flow was towards the Lake Malawi increasing concentration with distance from the recharge points.

6.2 Recommendations

- It is therefore recommended that areas of safe limits of chemical quality of groundwater should be opted for development notwithstanding their convenience and reliability.
- It is further recommended that thorough groundwater quality investigations should be carried out before drilling of boreholes to avoid investing in construction of boreholes which will not be used. The maps showing spatial variation produced in this study should be used as a guide in future groundwater development in locating areas on safe limits of groundwater chemistry.
- A longitudinal study should be carried out on the seasonal variations of chemical compounds and the health impacts associated with consumption of groundwater with high concentration of natural inorganic compounds especially at Chagunda and Lumwira villages.

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APPENDICES

Appendix 1

Checklist for the collection of data relating to the perception of people on the quality of groundwater which they use.

The information gathered through this document is intended for the study of James Kushe with University of Zimbabwe. It will never be used elsewhere except for the purpose of Masters Programme in IWRM, being pursued by the author. No name of the respondent shall be recorded and be used in any other way. *Circle the option*

Does the water have color?	Y	N
Does it have any odor/smell?	Y	N
Does it have any taste?	Y	N
Any suspended material?	Y	N
Where these come from?	Y	N
What do you use water for?		
Drinking	Y	N
Bathing	Y	N
Washing	Y	N
Watering	Y	N
All	Y	N
Is there any treatment before use?	Y	N
Yes. Why?		
No. Why?		
What are the attributes of the water point?		
Land use of the surrounding area.		
• Agriculture	Y	N
• Industrial	Y	N
• Natural/planted forest	Y	N
• Settlement	Y	N
Type of pump		
Afridev		
Mada		
JL		

Appendix 2

Ref. WQPC 12/1

Telephone: (265) 770 344
Fax No.: (265) 773 737 / 774 678

E-mail: waterquality@malawi.net
Communications should be addressed to:
The Secretary for Irrigation & Water Development

MINISTRY OF IRRIGATION & WATER DEVELOPMENT
PRIVATE BAG 390
CAPITAL CITY
LILONGWE 3
MALAWI

23rd February, 2009

Mr. J. Kushe,
Mzuzu University,
P/Bag 201,
Luwinga,
Mzuzu 2.

Dear Sir/Madam,

WATER QUALITY TEST RESULTS OF WATER SAMPLES FROM SELECTED WATER POINTS IN KACHINDAMOTO TRADITIONAL AUTHORITY IN DEDZA DISTRICT.

Attached, please find physical and chemical test results of 48 water samples collected from selected water points in Traditional Authority (T/A) Kachindamoto in Dedza district. As per your request, sampling of water from these water points was carried out by our personnel during the period 3rd -5th February, 2009.

Analysis for the variables presented in the tables of results was conducted in accordance with Standard Methods for the Examinations of Water and Wastewater, 21st Edition.

Note that some of the parameters were conducted on site and these were the power of hydrogen ion activity (pH) and Electrical Conductivity (EC).

2.0 DISCUSSION ON THE PRESENT WATER QUALITY TEST RESULTS

2.1 Physical and Chemical Quality

Chemically, water delivered from these water points can be said to be ranging from soft to very hard, acidic and alkaline. This classification is basing on Total Hardness ($CaCO_3$) and the power of hydrogen ion activity (pH) values registered.

Total hardness values registered in the water samples ranged from 69-1094 mg/l. Only three (3) of the total water points (Changunda, Lumwila I and Lumwila II Villages) were at the time of sampling delivering water with Hardness values above the limit of 800 mg/l (MS733:2005). The values registered in these three water points ranged from 906-1094 mg/l. Very hard water

tends to consume a lot of soap before form formation and for those people drinking such water for the first time may find it not palatable.
This scenario therefore forces the community to get water from unprotected water points that may have soft water but grossly contaminated by disease causing organisms. Very hard water is also responsible for formation of scales in heating elements like kettles.

The pH values registered in the water points ranged from 6.57-7.91. Note that 26 of the total water points were at the time of sampling delivering acidic water while the remainder was of alkaline state. It is however, pleasing to note that none of the water points were at the time of sampling delivering water with pH values outside the acceptable limit of 6.0-9.5 (MS733:2005). Acidic water tends to be aggressive to metal materials.

The physical parameters, namely Suspended Solids and Turbidity registered values ranging from <0.10-20 mg/l and <0.01-23 NTU respectively. These physical parameters are of concern in drinking water because they tend to encourage the proliferation of bacteria and also lead to high chlorine demand where such water treatment is required. None of the water points were at the time of sampling delivering water with values above the limits of 25 units for the two parameters. It is however important to note that one of the water points (Bongo F.P. School BH) registered higher values though within the acceptable limit. Depending on when this water point was constructed, these values registered are very unusual for a groundwater source.

In general, most of the parameters tested registered values within the Malawi Standards for drinking water delivered from boreholes and shallow wells (MS733:2005).

3.0 **Remark(s)/Recommendation(s)**

Please note that whatever conclusions are made in this report are basing on a single set of data collected from these water samples analysed.

- Chemically, water delivered from these water points can be said to be ranging from soft to very hard. Three of the total water points registered values above the acceptable limit according to National Standards for water delivered from boreholes and shallow wells (MS733:2005).

- The pH values registered ranged from 6.57-7.91. Basing on this range, 26 of the total water points were at the time of sampling delivering water that can be classified as acidic.

- Only one of the total water points (Bondo F.P. School BH) registered values of 23 NTU and 20 mg/l for Suspended Solids and Turbidity respectively. Though these values are within the acceptable limits, these values are of concern especially when such water is from a groundwater source which has existed for sometime. Re-sampling of such water source is recommended to check if the values registered were of intermittent scenario and if not carry out sanitary survey to establish the possible source(s) of such pollution.

- Parameters like Sulphate, Sodium and Calcium were observed to register higher values in selected water points located in Chagunda, Lumwila I & II Villages. Note that these are the villages that also registered higher Total Hardness values. It will therefore be interesting to learn from the community on how they feel about the taste of water from these water points.

Please feel free to contact this office should you need more clarification in the laboratory test results provided.

J. Peaches Phiri
CHIEF WATER CHEMIST
for: **SECRETARY FOR IRRIGATION & WATER DEVELOPMENT**

cc: *The Director of Water Resources, Ministry of Irrigation & Water Development, Private Bag 390, Capital City, Lilongwe 3.*

“ *The Deputy Director of Water Resources (Groundwater), Ministry of Irrigation & Water Development, Private Bag 390, Lilongwe.*

“ *The Regional Water Development Officer (C), Regional Water Office, P.O. Box 458, Lilongwe.*

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MINISTRY OF IRRIGATION & WATER DEVELOPMENT

WATER QUALITY TEST RESULTS

LAB No.	01	02	03	04
DATE SAMPLED	03/02/09	03/02/09	03/02/09	03/02/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**KACHINDAMOTO HQRS BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**TIDYENAWO VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**KASAKALA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**DUNGEYA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	7.06	7.09	7.91	7.53
CONDUCTIVITY (µs/cm at 25^0C)	1128	1452	830	1740
TOTAL DISSOLVED SOLIDS, mg/l	580	770	402	870
CARBONATE (as CO_3^{2-}), mg/l	0.00	0.00	22	4.8
BICARBONATE (as HCO_3^{2-}), mg/l	455	466	210	715
CHLORIDE (as Cl^-), mg/l	49	67	65	54
SULPHATE (as SO_4^{2-}), mg/l	98.8	172	53	128
NITRATE (as NO_3^-), mg/l	0.053	0.057	0.055	0.046
FLUORIDE (as F^-), mg/l	0.55	0.82	0.06	0.90
SODIUM (as Na^+), mg/l	36	104	65	108
POTASSIUM (as K^+), mg/l	1.6	1.1	0.40	0.10
CALCIUM (as Ca^{++}), mg/l	117	131	68	181
MAGNESIUM (as mg $^{++}$), mg/l	38	24.4	12.6	40.4
IRON (Fe $^{++}$), mg/l	0.006	0.050	0.036	0.023
MANGANESE (Mn $^{++}$), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	449	428	219	617
TOTAL ALKALINITY (as $CaCO_3$), mg/l	373	382	209	594
SILICA (as SiO_2) mg/l	21	22	19	27
TURBIDITY, NTU	3.0	4.0	3.0	3.0
SUSPENDED SOLIDS, mg/l	6.0	6.0	6.0	1.0

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

FORM No. WQPC 12/1

MINISTRY OF IRRIGATION & WATER DEVELOPMENT

WATER QUALITY TEST RESULTS

LAB No.	05	06	07	08
DATE SAMPLED	03/02/09	03/02/09	03/02/09	03/02/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**SUNDUZENI VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**CHITULE CDSS BH No., KACHINDAMOTO TRADITIONAL AUTHORITY,DEDZA DISTRICT**	**HUWA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**FIKIRE VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	7.07	6.88	6.87	6.89
CONDUCTIVITY (μs/cm at 25^0C)	800	688	840	566
TOTAL DISSOLVED SOLIDS, mg/l	430	360	421	284
CARBONATE (as CO_3^{2-}), mg/l	0.00	0.00	0.00	0.00
BICARBONATE (as HCO_3^{2-}), mg/l	298	257	376	227
CHLORIDE (as Cl^-), mg/l	38.5	44	28	38
SULPHATE (as SO_4^{2-}), mg/l	60	36	44	6.6
NITRATE (as NO_3^-), mg/l	0.026	0.250	0.037	0.146
FLUORIDE (as F^-), mg/l	0.87	0.76	0.08	0.87
SODIUM (as Na^+), mg/l	63	56	49	32
POTASSIUM (as K^+), mg/l	0.90	1.3	1.5	0.70
CALCIUM (as Ca^{++}), mg/l	76	65.2	97.2	59
MAGNESIUM (as mg^{++}), mg/l	13.8	12.3	16.6	11.5
IRON (Fe^{++}), mg/l	0.059	0.079	0.008	0.133
MANGANESE (Mn^{++}), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	24	212	311	195
TOTAL ALKALINITY (as $CaCO_3$), mg/l	244	211	308	186
SILICA (as SiO_2) mg/l	22	16	17	13
TURBIDITY, NTU	4.0	6.0	2.0	3.0
SUSPENDED SOLIDS, mg/l	5.0	8.0	<0.10	1.0

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

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MINISTRY OF IRRIGATION & WATER DEVELOPMENT

WATER QUALITY TEST RESULTS

LAB No.	09	10	11	12
DATE SAMPLED	03/02/09	03/02/09	03/02/09	03/02/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**G.V.H KAKHOME BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**SONGWE VGE bh No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**BONDO F.P. SCHOOL BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**MATOWE F.P. SCHOOL BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	6.63	6.83	6.95	6.88
CONDUCTIVITY (µs/cm at 25^0C)	187	554	1786	748
TOTAL DISSOLVED SOLIDS, mg/l	94	288	880	400
CARBONATE (as CO_3^{2-}), mg/l	0.00	0.00	0.00	0.00
BICARBONATE (as HCO_3^{2-}), mg/l	97	290	402	318
CHLORIDE (as Cl^-), mg/l	8.5	10.1	149	22
SULPHATE (as SO_4^{2-}), mg/l	2.9	26	222	7.4
NITRATE (as NO_3^-), mg/l	0.091	0.680	0.053	0.032
FLUORIDE (as F^-), mg/l	0.41	0.55	0.79	0.64
SODIUM (as Na^+), mg/l	11	17	137	47
POTASSIUM (as K^+), mg/l	1.0	6.5	1.2	0.6
CALCIUM (as Ca^{++}), mg/l	15.2	74.4	132.6	94
MAGNESIUM (as mg^{++}), mg/l	7.7	13.6	34	9.4
IRON (Fe^{++}), mg/l	0.005	0.019	1.56	0.013
MANGANESE (Mn^{++}), mg/l	<0.001	<0.001	0.80	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	69	241	473	273
TOTAL ALKALINITY (as $CaCO_3$), mg/l	79	241	238	261
SILICA (as SiO_2) mg/l	13	13	16	15
TURBIDITY, NTU	3.0	2.0	23	3.0
SUSPENDED SOLIDS, mg/l	1.0	<0.10	20	3.0

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

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MINISTRY OF IRRIGATION & WATER DEVELOPMENT

WATER QUALITY TEST RESULTS

LAB No.	13	14	15	16
DATE SAMPLED	03/02/09	03/02/09	03/02/09	03/02/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**NJOKA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**CHIMGWANDALI I VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY,DEDZA DISTRICT**	**CHIMGWANDALI II VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**KAMGANGA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	6.78	6.76	6.79	6.92
CONDUCTIVITY (µs/cm at 25^0C)	1078	676	679	533
TOTAL DISSOLVED SOLIDS, mg/l	600	340	344	270
CARBONATE (as CO_3^{2-}), mg/l	0.00	0.00	0.00	0.00
BICARBONATE (as HCO_3^{2-}), mg/l	402	244	272	274
CHLORIDE (as Cl^-), mg/l	18.6	28	33.5	18.5
SULPHATE (as SO_4^{2-}), mg/l	144	57	38	10.5
NITRATE (as NO_3^-), mg/l	<0.001	<0.001	0.046	0.078
FLUORIDE (as F^-), mg/l	0.57	0.68	0.79	0.84
SODIUM (as Na^+), mg/l	68	48	54	22
POTASSIUM (as K^+), mg/l	0.60	1.5	0.30	0.30
CALCIUM (as Ca^{++}), mg/l	105	63	70	58
MAGNESIUM (as mg $^{++}$), mg/l	20	13.6	10	20.5
IRON (Fe $^{++}$), mg/l	0.023	0.149	0.008	0.122
MANGANESE (Mn $^{++}$), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	346	214	216	229
TOTAL ALKALINITY (as $CaCO_3$), mg/l	368	282	223	225
SILICA (as SiO_2) mg/l	24	25	22	32
TURBIDITY, NTU	3.0	4.0	2.0	3.0
SUSPENDED SOLIDS, mg/l	4.0	2.0	3.0	1.0

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

FORM No. WQPC 12/1

MINISTRY OF IRRIGATION & WATER DEVELOPMENT

WATER QUALITY TEST RESULTS

LAB No.	17	18	19	20
DATE SAMPLED	03/02/09	04/02/09	04/02/09	04/02/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**HELANI VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**MSEKENI F.P. SCHOOL BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**MALUZA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**NAMKUMBA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	6.69	6.62	6.96	6.73
CONDUCTIVITY (µs/cm at 25^0C)	569	474	1160	743
TOTAL DISSOLVED SOLIDS, mg/l	298	248	610	372
CARBONATE (as CO_3^{2-}), mg/l	0.00	0.00	0.00	0.00
BICARBONATE (as HCO_3^{2-}), mg/l	255	275	402	410
CHLORIDE (as Cl^-), mg/l	11.8	22	54.1	15.2
SULPHATE (as SO_4^{2-}), mg/l	25.3	12	112	20.8
NITRATE (as NO_3^-), mg/l	0.051	0.298	0.026	0.214
FLUORIDE (as F^-), mg/l	0.64	0.73	0.86	0.74
SODIUM (as Na^+), mg/l	14.8	22	77	22
POTASSIUM (as K^+), mg/l	1.2	1.2	0.50	4.2
CALCIUM (as Ca^{++}), mg/l	70.8	55.6	128	90
MAGNESIUM (as mg $^{++}$), mg/l	14.6	10.5	8.5	25.3
IRON (Fe^{++}), mg/l	0.059	0.007	0.566	0.098
MANGANESE (Mn^{++}), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	236	182	356	329
TOTAL ALKALINITY (as $CaCO_3$), mg/l	217	176	330	336
SILICA (as SiO_2) mg/l	43	29	24	32
TURBIDITY, NTU	4.0	3.0	3.0	3.0
SUSPENDED SOLIDS, mg/l	2.0	1.0	3.0	2.0

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

FORM No. WQPC 12/1

MINISTRY OF IRRIGATION & WATER DEVELOPMENT

WATER QUALITY TEST RESULTS

LAB No.	21	22	23	24
DATE SAMPLED	04/02/09	04/02/09	04/02/09	04/02/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**NJOLO VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**NADAZI L.E.A. SCHOOL BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**MADZIASATSI VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**FOLE VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	6.64	6.57	6.68	6.94
CONDUCTIVITY (µs/cm at 25^0C)	482	466	391	990
TOTAL DISSOLVED SOLIDS, mg/l	280	250	200	518
CARBONATE (as CO_3^{2-}), mg/l	0.00	0.00	0.00	0.00
BICARBONATE (as HCO_3^{2-}), mg/l	230	245	190	398
CHLORIDE (as Cl^-), mg/l	10.1	12.8	10.1	50.7
SULPHATE (as SO_4^{2-}), mg/l	27	1.8	8.4	67
NITRATE (as NO_3^-), mg/l	0.034	0.201	0.008	0.096
FLUORIDE (as F^-), mg/l	0.80	0.64	0.84	0.80
SODIUM (as Na^+), mg/l	18	18	15	57
POTASSIUM (as K^+), mg/l	0.70	0.50	1.9	1.1
CALCIUM (as Ca^{++}), mg/l	61	56	40	91
MAGNESIUM (as mg $^{++}$), mg/l	11.4	11.7	12.4	28
IRON (Fe^{++}), mg/l	0.39	0.061	0.012	0.101
MANGANESE (Mn^{++}), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	198	189	151	343
TOTAL ALKALINITY (as $CaCO_3$), mg/l	189	201	156	326
SILICA (as SiO_2) mg/l	42	30	30	40
TURBIDITY, NTU	2.0	3.0	3.0	3.0
SUSPENDED SOLIDS, mg/l	2.0	4.0	5.0	3.0

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

FORM No. WQPC 12/1

MINISTRY OF IRRIGATION & WATER DEVELOPMENT

WATER QUALITY TEST RESULTS

LAB No.	25	26	27	28
DATE SAMPLED	04/02/09	04/02/09	04/02/09	04/02/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**CHIKWAWA SCHOOL BH No. KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**MCHANJA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**MCHANJA VGE BH No. BVIDP/008, KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**KAMWENDO VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	6.97	6.92	7.04	7.30
CONDUCTIVITY (μs/cm at 25^{0}C)	790	1934	975	1560
TOTAL DISSOLVED SOLIDS, mg/l	420	940	510	802
CARBONATE (as CO_3^{2-}), mg/l	0.00	0.00	0.00	0.00
BICARBONATE (as HCO_3^{2-}), mg/l	290	239	378	630
CHLORIDE (as Cl^-), mg/l	38.9	267.9	45.7	71
SULPHATE (as SO_4^{2-}), mg/l	70	210	83	108
NITRATE (as NO_3^-), mg/l	0.027	0.027	0.048	0.051
FLUORIDE (as F^-), mg/l	0.75	0.77	0.66	0.90
SODIUM (as Na^+), mg/l	60	120	62	104
POTASSIUM (as K^+), mg/l	1.2	1.3	1.2	0.20
CALCIUM (as Ca^{++}), mg/l	71.6	165	92	167
MAGNESIUM (as mg^{++}), mg/l	15.0	35	21.4	27.2
IRON (Fe^{++}), mg/l	0.197	0.069	0.013	0.164
MANGANESE (Mn^{++}), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	242	556	316	528
TOTAL ALKALINITY (as $CaCO_3$), mg/l	238	196	310	517
SILICA (as SiO_2) mg/l	34	36	37	50
TURBIDITY, NTU	2.0	3.0	3.0	4.0
SUSPENDED SOLIDS, mg/l	<0.10	2.0	1.0	3.0

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

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MINISTRY OF IRRIGATION & WATER DEVELOPMENT

WATER QUALITY TEST RESULTS

LAB No.	29	30	31	32
DATE SAMPLED	04/02/09	04/02/09	04/02/09	04/02/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**KAMWENDO I VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**KAUNDU Health Centre BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**KAUNDU Health Centre TAP (BH Water), KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**NDINDI VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	7.68	7.30	7.14	7.09
CONDUCTIVITY (µs/cm at 25^0C)	699	1476	1260	950
TOTAL DISSOLVED SOLIDS, mg/l	349	780	640	500
CARBONATE (as CO_3^{2-}), mg/l	24	0.00	0.00	0.00
BICARBONATE (as HCO_3^{2-}), mg/l	221	580	455	398
CHLORIDE (as Cl^-), mg/l	22	52	76	48.6
SULPHATE (as SO_4^{2-}), mg/l	54.3	128	102	62
NITRATE (as NO_3^-), mg/l	0.052	0.094	0.124	0.002
FLUORIDE (as F^-), mg/l	0.85	0.89	0.85	0.92
SODIUM (as Na^+), mg/l	50	92	90	62
POTASSIUM (as K^+), mg/l	1.8	0.40	3.6	0.90
CALCIUM (as Ca^{++}), mg/l	60.6	138	105	91
MAGNESIUM (as mg $^{++}$), mg/l	10.7	36	30	22
IRON (Fe^{++}), mg/l	0.082	0.089	0.074	0.483
MANGANESE (Mn^{++}), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	197	493	386	319
TOTAL ALKALINITY (as $CaCO_3$), mg/l	221	476	373	326
SILICA (as SiO_2) mg/l	30	28	26	27
TURBIDITY, NTU	3.0	2.0	4.0	2.0
SUSPENDED SOLIDS, mg/l	1.0	3.0	3.0	2.0

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

FORM No. WQPC 12/1

MINISTRY OF IRRIGATION & WATER DEVELOPMENT

WATER QUALITY TEST RESULTS

LAB No.	33	34	35	36
DATE SAMPLED	04/02/09	04/02/09	04/02/09	04/02/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**KAUNDU F.P. SCHOOL BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**KAUNDU F.P. SCHOOL BH No. KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**KABULIKA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY,DEDZA DISTRICT**	**CHAGUNDA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	7.36	7.50	6.88	6.95
CONDUCTIVITY (µs/cm at 25^0C)	1082	1,590	2,420	4,230
TOTAL DISSOLVED SOLIDS, mg/l	570	840	1,280	2,200
CARBONATE (as CO_3^{2-}), mg/l	0.00	0.00	0.00	0.00
BICARBONATE (as HCO_3^{2-}), mg/l	461	514	376	525
CHLORIDE (as Cl^-), mg/l	40	87.9	115	213
SULPHATE (as SO_4^{2-}), mg/l	55.5	140	550	1,000
NITRATE (as NO_3^-), mg/l	0.012	3.2	4.7	2.8
FLUORIDE (as F^-), mg/l	0.87	0.20	0.31	0.26
SODIUM (as Na^+), mg/l	57	129	164	308
POTASSIUM (as K^+), mg/l	0.80	21.6	3.7	8.8
CALCIUM (as Ca^{++}), mg/l	114	141	194	331
MAGNESIUM (as mg^{++}), mg/l	28.4	20.4	38.9	58.3
IRON (Fe^{++}), mg/l	0.250	0.014	0.005	0.002
MANGANESE (Mn^{++}), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	400	435	645	1065
TOTAL ALKALINITY (as $CaCO_3$), mg/l	385378	422	308	431
SILICA (as SiO_2) mg/l	23	14	46	30
TURBIDITY, NTU	1.0	3.0	2.0	<0.01
SUSPENDED SOLIDS, mg/l	<0.10	3.0	2.0	<0.10

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

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MINISTRY OF IRRIGATION & WATER DEVELOPMENT

WATER QUALITY TEST RESULTS

LAB No.	37	38	39	40
DATE SAMPLED	04/02/09	04/02/09	04/02/09	04/02/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**KABULIKA II VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**DZINDEVU VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**KAPILI II VGE BH No. Y 121, KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**LUMWILA II VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	7.26	7.08	7.08	7.17
CONDUCTIVITY (µs/cm at 25^0C)	1560	1846	1450	2490
TOTAL DISSOLVED SOLIDS, mg/l	810	970	757	1290
CARBONATE (as CO_3^{2-}), mg/l	0.00	0.00	0.00	0.00
BICARBONATE (as HCO_3^{2-}), mg/l	470	541	570	560
CHLORIDE (as Cl^-), mg/l	54.1	60.9	56	82.9
SULPHATE (as SO_4^{2-}), mg/l	198	282	117	496
NITRATE (as NO_3^-), mg/l	0.008	3.5	2.9	0.15
FLUORIDE (as F^-), mg/l	0.25	0.34	0.28	0.22
SODIUM (as Na^+), mg/l	120	146	102	189
POTASSIUM (as K^+), mg/l	2.5	7.1	3.7	4.3
CALCIUM (as Ca^{++}), mg/l	131	153	160	204
MAGNESIUM (as mg^{++}), mg/l	19.4	29.2	19.4	38.9
IRON (Fe^{++}), mg/l	0.194	0.012	0.022	0.452
MANGANESE (Mn^{++}), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	407	502	478	670
TOTAL ALKALINITY (as $CaCO_3$), mg/l	385	443	467	459
SILICA (as SiO_2) mg/l	12	12	14	15
TURBIDITY, NTU	1.0	3.0	2.0	4.0
SUSPENDED SOLIDS, mg/l	<0.10	2.0	1.0	4.0

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

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MINISTRY OF IRRIGATION & WATER DEVELOPMENT

WATER QUALITY TEST RESULTS

LAB No.	41	42	43	44
DATE SAMPLED	04/02/09	04/02/09	04/02/09	04/02/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**LUMWILA II VGE BH No. DT 004, KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**LUMWILA II VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**MASINJA VGE BH No. BB 99, KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**KAZEMBE VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY,DEDZA DISTRICT**
pH Value	7.04	7.08	7.68	6.98
CONDUCTIVITY (µs/cm at 25^0C)	4,090	3210	1,330	1,469
TOTAL DISSOLVED SOLIDS, mg/l	2,150	1,640	665	762
CARBONATE (as CO_3^{2-}), mg/l	0.00	0.00	40	0.00
BICARBONATE (as HCO_3^{2-}), mg/l	663	906	512	480
CHLORIDE (as Cl^-), mg/l	244	151	47.4	99.8
SULPHATE (as SO_4^{2-}), mg/l	850	442	77.2	151
NITRATE (as NO_3^-), mg/l	5.5	4.6	0.006	0.140
FLUORIDE (as F^-), mg/l	0.27	0.28	0.31	0.23
SODIUM (as Na^+), mg/l	307	244	101	112
POTASSIUM (as K^+), mg/l	6.0	2.4	1.6	0.50
CALCIUM (as Ca^{++}), mg/l	351.8	315	117.8	139.6
MAGNESIUM (as mg^{++}), mg/l	52.5	29.2	28.3	20.4
IRON (Fe^{++}), mg/l	0.051	0.066	0.053	0.034
MANGANESE (Mn^{++}), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	1094	906	410	432
TOTAL ALKALINITY (as $CaCO_3$), mg/l	543	742	486	393
SILICA (as SiO_2) mg/l	15	16	23	16
TURBIDITY, NTU	3.0	2.0	1.0	<0.01
SUSPENDED SOLIDS, mg/l	5.0	1.0	<0.10	<0.10

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

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MINISTRY OF IRRIGATION & WATER DEVELOPMENT

WATER QUALITY TEST RESULTS

LAB No.	45	46	47	48
DATE SAMPLED	04/02/09	04/02/09	04/02/09	04/02/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**CHIKOLOLERE KACHINDAMOTO TRADITIONAL AUTHORITY DEDZA**	**JOHN KADEWELE VGE KACHINDAMOTO TRADITIONAL AUTHORITY DEDZA**	**TAPEZANA SCHOOL KACHINDAMOTO TRADITIONAL AUTHORITY DEDZA**	**ABRAHAM VGE KACHINDAMOTO TRADITIONAL AUTHORITY DEDZA**
pH Value	7.12	7.56	6.83	6.80
CONDUCTIVITY (µs/cm at 25^0C)	698	1010	1054	404
TOTAL DISSOLVED SOLIDS, mg/l	350	490	550	209
CARBONATE (as CO_3^{2-}), mg/l	0	18	0	0
BICARBONATE (as HCO_3^{2-}), mg/l	330	430	430	210
CHLORIDE (as Cl^-), mg/l	23	10.1	38.9	14.8
SULPHATE (as SO_4^{2-}), mg/l	24.8	10.9	85.9	11
NITRATE (as NO_3^-), mg/l	0.190	0.033	0.007	0.119
FLUORIDE (as F^-), mg/l	0.34	0.14	0.38	0.12
SODIUM (as Na^+), mg/l	38	56	65	16
POTASSIUM (as K^+), mg/l	1.8	0.5	0.5	1.4
CALCIUM (as Ca^{++}), mg/l	67	100	100	55
MAGNESIUM (as mg^{++}), mg/l	23.3	21.4	20.1	9.8
IRON (Fe^{++}), mg/l	0.02	0.231	0.046	0.037
MANGANESE (Mn^{++}), mg/l	<0.01	<0.01	<0.01	<0.01
TOTAL HARDNESS (as $CaCO_3$), mg/l	263	338	332	178
TOTAL ALKALINITY (as $CaCO_3$), mg/l	271	383	353	169
SILICA (as SiO_2) mg/l	13	14	20	11
TURBIDITY, NTU	1.0	3.0	2.0	3.0
SUSPENDED SOLIDS, mg/l	2.0	4.0	3.0	1.0

ANALYSIS CARRIED OUT BY CENTRAL WATERLABORATORY

Appendix 3

Ref. WQPC 12/1

Telephone: (265) 770 344
Fax No.: (265) 773 737 / 774 678

E-mail: waterquality@malawi.net
Communications should be addressed to:
The Secretary for Irrigation & Water Development

MINISTRY OF IRRIGATION & WATER DEVELOPMENT
PRIVATE BAG 390
CAPITAL CITY
LILONGWE 3
MALAWI

16th April, 2009

Mr. J. Kushe,
Mzuzu University,
P/Bag 201,
Luwinga,
Mzuzu 2.

WATER QUALITY TEST RESULTS OF WATER SAMPLES FROM SELECTED WATER POINTS IN KACHINDAMOTO TRADITIONAL AUTHORITY IN DEDZA DISTRICT.

Attached, please find physical and chemical test results of 47 water samples collected from selected water points in Traditional Authority (T/A) Kachindamoto in Dedza district. As per your request, sampling of water from these water points was carried out by our personnel during the period 18-19th March, 2009.

Analysis for the variables presented in the tables of results was conducted in accordance with Standard Methods for the Examinations of Water and Wastewater, 21st Edition.

Note that some of the parameters were conducted on site and these were the power of hydrogen ion activity (pH) and Electrical Conductivity (EC).

2.0 DISCUSSION ON THE PRESENT WATER QUALITY TEST RESULTS

2.1 Physical and Chemical Quality

Chemically, water delivered from these water points can be said to be ranging from soft to very hard, acidic and alkaline. This classification is basing on Total Hardness ($CaCO_3$) and the power of hydrogen ion activity (pH) values registered.

Total hardness values registered in the water samples ranged from 72-1006 mg/l compared to last time when a range of 69-1094 mg/l was observed. As observed last time only three (3) of the total water points were at the time of sampling delivering water with Hardness values above the limit of 800 mg/l (MS733:2005). Note that a total of six (6) water points were this time observed to register Hardness values of above the World Health Organisation (WHO)

guideline standards for drinking water of 500 mg/l. Very hard water tends to consume a lot of soap before form formation and for those people drinking such water for the first time may find it not palatable.
There also reports that very hard water is also responsible for formation of scales in heating elements like kettles.

The pH values registered this time in the water points ranged from 6.00-8.23 compared to 6.57-7.91 observed last time. Note that 10 of the total water points were at the time of sampling delivering acidic water compared to 26 last time. It is however, pleasing to note that none of the water points were at the time of sampling delivering water with pH values outside the acceptable limit of 6.0-9.5 (MS733:2005). Acidic water tends to be aggressive to metal materials.

The physical parameters, namely Suspended Solids and Turbidity registered values ranging from <0.10-5 mg/l and 1-5 NTU respectively. Compared to what was observed last time, there has been a decrease as last time the values ranged from <0.10-20 mg/l and <0.10-23 NTU for Suspended Solids and Turbidity respectively. You may wish to note that these physical parameters are of concern in drinking water because they tend to encourage the proliferation of bacteria and also lead to high chlorine demand where such water treatment is required. None of the water points were at the time of sampling delivering water with values above the limits of 25 units for the two parameters..

In general, most of the parameters tested registered values within the Malawi Standards for drinking water delivered from boreholes and shallow wells (MS733:2005).

3.0 **Remark(s)/Recommendation(s)**

- Chemically, water delivered from these water points can be said to be ranging from soft to very hard. Three of the total water points registered values above the acceptable limit according to National Standards for water delivered from boreholes and shallow wells (MS733:2005).

  Note that there has been both a decrease and increase in the values for the parameter this time compared to last time. However, there has not been a change in the number of water points that registered Hardness values of above 800 mg/l.

- The pH values registered ranged from 6.00-8.23 this time compared to 6.57-7.91 observed last time. Basing on this range, 10 of the total water points were at the time of sampling delivering water that can be classified as acidic compared to 26 observed last time. This means that most of the water points were delivering alkaline water this time compared to last time.

- None of the water points registered Suspended Solids and Turbidity values of above the acceptable limit of 25 units. The values registered for these parameters this time ranged from 1.0-5 NTU and <0.10-5 mg/l compared to the range of
  <0.01-23 NTU and <0.10-20 mg/l for Suspended Solids and Turbidity respectively.

- Parameters like Sulphate, Sodium and Calcium were observed to register higher values in selected water points located in Kaundu, Bondo, Kabulika, Mchanja, Dzindevu, Kamwendo, Chagunda, Lumwila Villages, just to mention a few.

  Note that these are the villages whose water points were delivering water that can be classified as very hard water. It is however, interesting to also note that it's not the whole Traditional Authority Kachindamoto that has a Hardness problem. The geology of the area may help you in the interpretation of the scenario being observed.

  As pointed out last time, it will therefore be interesting to learn from the community on how they feel about the taste of water from these water points as usage of water from a lay man's view is based on its clarity and taste.

Please feel free to contact this office should you need more clarification in the laboratory test results provided.

J. Peaches Phiri
CHIEF WATER CHEMIST
for: <u>SECRETARY FOR IRRIGATION & WATER DEVELOPMENT</u>

cc: The Director of Water Resources, Ministry of Irrigation & Water Development, Private Bag 390, Capital City, Lilongwe 3.

" The Deputy Director of Water Resources (Groundwater), Ministry of Irrigation & Water Development, Private Bag 390, Lilongwe.

" The Regional Water Development Officer (C), Regional Water Office, P.O. Box 458, Lilongwe.

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MINISTRY OF IRRIGATION & WATER DEVELOPMENT

WATER QUALITY TEST RESULTS

LAB No.	134	135	136	137
DATE SAMPLED	18/03/09	18/03/09	18/03/09	18/03/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**MTAKATAKA TRADING CENTRE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**MSEKENI F.P. SCHOOL BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**MALUZA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**NAMKUMBA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	6.10	6.30	8.20	6.40
CONDUCTIVITY (μs/cm at 25^0C)	204	488	1166	738
TOTAL DISSOLVED SOLIDS, mg/l	104	254	568	380
CARBONATE (as CO_3^{2-}), mg/l	0.00	0.00	22	0.00
BICARBONATE (as HCO_3^{2-}), mg/l	95	244	350	410
CHLORIDE (as Cl^-), mg/l	10.1	27	69	16.9
SULPHATE (as SO_4^{2-}), mg/l	7.2	5.3	93	21.3
NITRATE (as NO_3^-), mg/l	0.030	0.10	<0.001	0.180
FLUORIDE (as F^-), mg/l	0.580	0.90	1.24	1.08
SODIUM (as Na^+), mg/l	12	36	90	24
POTASSIUM (as K^+), mg/l	1.1	1.2	0.40	4.3
CALCIUM (as Ca^{++}), mg/l	16.4	42	101	97
MAGNESIUM (as mg^{++}), mg/l	7.7	14.6	18.5	17.5
IRON (Fe^{++}), mg/l	0.02	0.01	0.09	0.06
MANGANESE (Mn $^{++}$), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	72	165	329	313
TOTAL ALKALINITY (as $CaCO_3$), mg/l	77	200	324	336
SILICA (as SiO_2) mg/l	19	21	19	25
TURBIDITY, NTU	2.0	4.0	4.0	3.0
SUSPENDED SOLIDS, mg/l	<0.01	2.0	3.0	1.0

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

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MINISTRY OF IRRIGATION & WATER DEVELOPMENT
WATER QUALITY TEST RESULTS

LAB No.	138	139	140	141
DATE SAMPLED	18/03/09	18/03/09	18/03/09	18/03/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**NJOLO VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**NADAZI L.E.A SCHOOL BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**MADZIASATSI VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**FOLE VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	7.50	7.30	7.80	7.61
CONDUCTIVITY (µs/cm at 25^0C)	485	481	377	831
TOTAL DISSOLVED SOLIDS, mg/l	250	246	180	420
CARBONATE (as CO_3^{2-}), mg/l	0.00	0.00	28.4	12.4
BICARBONATE (as HCO_3^{2-}), mg/l	210	220	120	270
CHLORIDE (as Cl^-), mg/l	24	22.6	6.8	48
SULPHATE (as SO_4^{2-}), mg/l	20.5	9.1	12.5	59.5
NITRATE (as NO_3^-), mg/l	<0.001	<0.001	<0.001	<0.001
FLUORIDE (as F^-), mg/l	1.07	0.94	1.13	0.94
SODIUM (as Na^+), mg/l	34	17	30	62
POTASSIUM (as K^+), mg/l	0.70	0.40	1.9	1.2
CALCIUM (as Ca^{++}), mg/l	46.2	52	30.2	80.2
MAGNESIUM (as mg^{++}), mg/l	12.6	14.5	8.6	12
IRON (Fe^{++}), mg/l	0.12	0.51	0.09	0.36
MANGANESE (Mn^{++}), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	167	203	110	250
TOTAL ALKALINITY (as $CaCO_3$), mg/l	172	180	145	242
SILICA (as SiO_2) mg/l	25	33	24	25
TURBIDITY, NTU	4.0	6.0	3.0	3.0
SUSPENDED SOLIDS, mg/l	2.0	5.0	1.0	1.0

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

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MINISTRY OF IRRIGATION & WATER DEVELOPMENT

WATER QUALITY TEST RESULTS

LAB No.	142	143	144	145
DATE SAMPLED	18/03/09	18/03/09	18/03/09	18/03/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**CHIKWAWA SCHOOL BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**MCHANJA VGE BH BH No BVIDP 008., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**MCHANJA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**KAMWENDO VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	6.70	6.90	7.62	7.81
CONDUCTIVITY (μs/cm at 25^0C)	780	904	1603	1568
TOTAL DISSOLVED SOLIDS, mg/l	410	467	780	730
CARBONATE (as CO_3^{2-}), mg/l	0.00	0.00	22	38
BICARBONATE (as HCO_3^{2-}), mg/l	296	348	225	504
CHLORIDE (as Cl^-), mg/l	42.3	42.3	154	94
SULPHATE (as SO_4^{2-}), mg/l	60	68	223	80
NITRATE (as NO_3^-), mg/l	<0.001	<0.001	<0.001	<0.001
FLUORIDE (as F^-), mg/l	0.98	1.06	1.0	1.17
SODIUM (as Na^+), mg/l	56	60	96	108
POTASSIUM (as K^+), mg/l	1.1	1.3	1.3	0.30
CALCIUM (as Ca^{++}), mg/l	82	90.2	142	142
MAGNESIUM (as mg^{++}), mg/l	9.4	15.3	24	30.4
IRON (Fe^{++}), mg/l	0.24	0.11	0.12	0.07
MANGANESE (Mn^{++}), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	244	287	454	479
TOTAL ALKALINITY (as $CaCO_3$), mg/l	243	285	221	477
SILICA (as SiO_2) mg/l	25	20	25	13
TURBIDITY, NTU	3.0	4.0	2.0	2.0
SUSPENDED SOLIDS, mg/l	1.0	4.0	<0.01	<0.01

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

FORM No. WQPC 12/1

MINISTRY OF IRRIGATION & WATER DEVELOPMENT
WATER QUALITY TEST RESULTS

LAB No.	146	147	148	149
DATE SAMPLED	18/03/09	18/03/09	18/03/09	18/03/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**KAMWENDO I VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**KAUNDU HEALTH CENTRE TAP (BH Water), KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**KAUNDU HEALTH CENTRE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**NDINDI VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	7.78	7.67	7.60	8.10
CONDUCTIVITY (μs/cm at 25^0C)	692	1070	1480	914
TOTAL DISSOLVED SOLIDS, mg/l	340	510	726	454
CARBONATE (as CO_3^{2-}), mg/l	24	42	36	36.8
BICARBONATE (as HCO_3^{2-}), mg/l	205	344	521	350
CHLORIDE (as Cl^-), mg/l	32	40	27.1	20.3
SULPHATE (as SO_4^{2-}), mg/l	53.2	56.7	114	47.4
NITRATE (as NO_3^-), mg/l	<0.001	0.16	0.010	<0.001
FLUORIDE (as F^-), mg/l	1.19	1.16	1.14	1.07
SODIUM (as Na^+), mg/l	46	82	92	38
POTASSIUM (as K^+), mg/l	1.8	4.8	0.40	0.90
CALCIUM (as Ca^{++}), mg/l	64	91.2	142	90
MAGNESIUM (as mg $^{++}$), mg/l	11.7	19.4	33.1	21.1
IRON (Fe $^{++}$), mg/l	0.57	0.04	0.39	0.43
MANGANESE (Mn $^{++}$), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	210	307	491	354
TOTAL ALKALINITY (as $CaCO_3$), mg/l	208	352	487	349
SILICA (as SiO_2) mg/l	21	25	19	37
TURBIDITY, NTU	2.0	4.0	3.0	4.0
SUSPENDED SOLIDS, mg/l	<0.01	2.0	1.0	2.0

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

FORM No. WQPC 12/1

MINISTRY OF IRRIGATION & WATER DEVELOPMENT
WATER QUALITY TEST RESULTS

LAB No.	150	151	152	153
DATE SAMPLED	18/03/09	18/03/09	18/03/09	18/03/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**KAUNDU SCHOOL BH No. 1, KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**KAUNDU SCHOOL BH No. 2, KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**KABULIKA VGE No. X132, KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**KABULIKA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	7.77	7.63	7.66	7.81
CONDUCTIVITY (µs/cm at 25^0C)	1570	1066	1565	2490
TOTAL DISSOLVED SOLIDS, mg/l	770	510	770	1210
CARBONATE (as CO_3^{2-}), mg/l	48	43.2	43.2	61
BICARBONATE (as HCO_3^{2-}), mg/l	475	408	370	322
CHLORIDE (as Cl^-), mg/l	76.1	28.6	47.4	115
SULPHATE (as SO_4^{2-}), mg/l	118	50.3	242	478
NITRATE (as NO_3^-), mg/l	3.1	<0.001	<0.001	<0.001
FLUORIDE (as F^-), mg/l	1.25	1.03	1.21	1.25
SODIUM (as Na^+), mg/l	90	40	106	160
POTASSIUM (as K^+), mg/l	22.2	0.90	2.6	4.2
CALCIUM (as Ca^{++}), mg/l	147	147	124	171
MAGNESIUM (as mg $^{++}$), mg/l	26.2	10.8	26.2	61.2
IRON (Fe $^{++}$), mg/l	0.06	0.04	0.30	0.26
MANGANESE (Mn $^{++}$), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	474	412	417	678
TOTAL ALKALINITY (as $CaCO_3$), mg/l	469	406	375	365
SILICA (as SiO_2) mg/l	50	20	21	45
TURBIDITY, NTU	2.0	4.0	3.0	3.0
SUSPENDED SOLIDS, mg/l	<0.01	4.0	1.0	1.0

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

FORM No. WQPC 12/1

MINISTRY OF IRRIGATION & WATER DEVELOPMENT
WATER QUALITY TEST RESULTS

LAB No.	154	155	156	157
DATE SAMPLED	18/03/09	18/03/09	18/03/09	18/03/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**CHAGUNDA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**DZINDEVU VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**KAPILI VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**LUMWIRA II VGE BH No. DT004, KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	7.81	8.01	6.90	7.71
CONDUCTIVITY (µs/cm at 25^0C)	4100	1760	1620	4066
TOTAL DISSOLVED SOLIDS, mg/l	2040	880	810	2060
CARBONATE (as CO_3^{2-}), mg/l	67.2	45	0.00	62.4
BICARBONATE (as HCO_3^{2-}), mg/l	683	443	325	400
CHLORIDE (as Cl^-), mg/l	210	54.1	232	252
SULPHATE (as SO_4^{2-}), mg/l	773	244	96.1	838
NITRATE (as NO_3^-), mg/l	1.98	1.7	<0.001	0.04
FLUORIDE (as F^-), mg/l	1.27	1.17	1.13	1.22
SODIUM (as Na^+), mg/l	300	96	106	320
POTASSIUM (as K^+), mg/l	9.1	7.2	3.6	6.2
CALCIUM (as Ca^{++}), mg/l	339	181	139	350
MAGNESIUM (as mg $^{++}$), mg/l	38.9	26.2	29.2	19.4
IRON (Fe $^{++}$), mg/l	0.03	0.02	0.01	0.14
MANGANESE (Mn $^{++}$), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	1006	558	466	954
TOTAL ALKALINITY (as $CaCO_3$), mg/l	671	443	266	431
SILICA (as SiO_2) mg/l	50	47	49	24
TURBIDITY, NTU	2.0	2.0	3.0	2.0
SUSPENDED SOLIDS, mg/l	<0.01	2.0	2.0	<0.01

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

FORM No. WQPC 12/1

MINISTRY OF IRRIGATION & WATER DEVELOPMENT
WATER QUALITY TEST RESULTS

LAB No.	158	159	160	161
DATE SAMPLED	18/03/09	18/03/09	18/03/09	18/03/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**LUMWIRA II BH No. LO, KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**MASINJA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**KAZEMBE VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**CHIKOLOLERE VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	7.69	7.65	7.59	7.66
CONDUCTIVITY (μs/cm at 25^0C)	3112	1246	1478	679
TOTAL DISSOLVED SOLIDS, mg/l	1480	602	690	310
CARBONATE (as CO_3^{2-}), mg/l	91.2	58	48	42
BICARBONATE (as HCO_3^{2-}), mg/l	550	420	325	202
CHLORIDE (as Cl^-), mg/l	162	35.5	107	25
SULPHATE (as SO_4^{2-}), mg/l	444	60.3	128	13.2
NITRATE (as NO_3^-), mg/l	4.1	<0.001	0.02	<0.001
FLUORIDE (as F^-), mg/l	1.33	1.29	1.17	1.05
SODIUM (as Na^+), mg/l	204	80	105	45
POTASSIUM (as K^+), mg/l	2.6	1.7	0.50	1.8
CALCIUM (as Ca^{++}), mg/l	290	111	117	61
MAGNESIUM (as mg^{++}), mg/l	35	27.2	29.2	14.5
IRON (Fe^{++}), mg/l	0.01	0.07	0.02	0.02
MANGANESE (Mn^{++}), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	868	388	411	212
TOTAL ALKALINITY (as $CaCO_3$), mg/l	602	436	346	236
SILICA (as SiO_2) mg/l	49	25	25	25
TURBIDITY, NTU	2.0	2.0	3.0	3.0
SUSPENDED SOLIDS, mg/l	<0.01	<0.01	1.0	1.0

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

FORM No. WQPC 12/1

MINISTRY OF IRRIGATION & WATER DEVELOPMENT
WATER QUALITY TEST RESULTS

LAB No.	162	163	164	165
DATE SAMPLED	18/03/09	18/03/09	18/03/09	19/03/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**JOHN KADEWERE VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**TAPEZANA SCHOOL BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**ABRAHAM VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**SONGWE VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	7.88	6.10	6.20	6.00
CONDUCTIVITY (µs/cm at 25^0C)	1011	1048	436	500
TOTAL DISSOLVED SOLIDS, mg/l	480	538	230	250
CARBONATE (as CO_3^{2-}), mg/l	31	0.00	0.00	0.00
BICARBONATE (as HCO_3^{2-}), mg/l	309	468	208	245
CHLORIDE (as Cl^-), mg/l	56	42	13.5	15.2
SULPHATE (as SO_4^{2-}), mg/l	42	58.7	18.3	22.3
NITRATE (as NO_3^-), mg/l	0.01	<0.001	0.44	0.10
FLUORIDE (as F^-), mg/l	1.23	1.13	0.81	0.86
SODIUM (as Na^+), mg/l	67	74	20	14
POTASSIUM (as K^+), mg/l	0.50	0.60	1.5	8.4
CALCIUM (as Ca^{++}), mg/l	113	84.8	56	57.6
MAGNESIUM (as mg^{++}), mg/l	6.7	33	9.7	16.5
IRON (Fe^{++}), mg/l	0.10	0.01	0.143	0.100
MANGANESE (Mn^{++}), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	310	347	180	211
TOTAL ALKALINITY (as $CaCO_3$), mg/l	305	384	170	200
SILICA (as SiO_2) mg/l	25	30	17	12
TURBIDITY, NTU	4.0	3.0	2.0	1.0
SUSPENDED SOLIDS, mg/l	4.0	<0.01	<0.01	<0.01

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

FORM No. WQPC 12/1

MINISTRY OF IRRIGATION & WATER DEVELOPMENT
WATER QUALITY TEST RESULTS

LAB No.	166	167	168	169
DATE SAMPLED	19/03/09	19/03/09	19/03/09	19/03/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**BONDO SCHOOL BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**MATOWE SCHOOL BH No. KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**NJOKA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**CHIMGWANDALII VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	7.59	7.73	8.10	8.20
CONDUCTIVITY (µs/cm at 25^{0}C)	1598	720	845	756
TOTAL DISSOLVED SOLIDS, mg/l	770	310	380	340
CARBONATE (as CO_3^{2-}), mg/l	28.8	41	41	28
BICARBONATE (as HCO_3^{2-}), mg/l	329	259	268	308
CHLORIDE (as Cl^-), mg/l	137	28	28	21
SULPHATE (as SO_4^{2-}), mg/l	159	7.7	39.8	11.5
NITRATE (as NO_3^-), mg/l	<0.001	<0.001	0.05	<0.001
FLUORIDE (as F^-), mg/l	1.08	0.81	0.98	0.86
SODIUM (as Na^+), mg/l	103	36	32	36
POTASSIUM (as K^+), mg/l	1.2	0.50	0.40	1.4
CALCIUM (as Ca^{++}), mg/l	163	62.3	92	80
MAGNESIUM (as mg $^{++}$), mg/l	10.7	26	11.7	14.6
IRON (Fe $^{++}$), mg/l	0.46	0.73	0.21	2.1
MANGANESE (Mn $^{++}$), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	451	265	303	284
TOTAL ALKALINITY (as $CaCO_3$), mg/l	318	281	288	299
SILICA (as SiO_2) mg/l	16	16	15	19
TURBIDITY, NTU	2.0	5.0	3.0	2.0
SUSPENDED SOLIDS, mg/l	<0.01	3.0	3.7	2.0

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

FORM No. WQPC 12/1

MINISTRY OF IRRIGATION & WATER DEVELOPMENT
WATER QUALITY TEST RESULTS

LAB No.	170	171	172	173
DATE SAMPLED	19/03/09	19/03/09	19/03/09	19/03/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**HELANI VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**KAMGANGA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**CHIMGWANDALI II VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**FALIKIRE VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	6.67	7.58	6.50	7.60
CONDUCTIVITY (µs/cm at 25^0C)	618	497	652	572
TOTAL DISSOLVED SOLIDS, mg/l	320	250	350	286
CARBONATE (as CO_3^{2-}), mg/l	0.00	24	0.00	24
BICARBONATE (as HCO_3^{2-}), mg/l	262	197	319	232
CHLORIDE (as Cl^-), mg/l	24	16.4	20	20
SULPHATE (as SO_4^{2-}), mg/l	44	12.8	28	8.1
NITRATE (as NO_3^-), mg/l	<0.001	<0.001	<0.001	0.12
FLUORIDE (as F^-), mg/l	0.92	0.97	1.14	1.11
SODIUM (as Na^+), mg/l	39	26	47	33
POTASSIUM (as K^+), mg/l	1.4	0.30	0.30	0.60
CALCIUM (as Ca^{++}), mg/l	68	52	67	58
MAGNESIUM (as mg^{++}), mg/l	10.7	11.7	12.7	14.3
IRON (Fe^{++}), mg/l	0.91	0.10	0.05	0.07
MANGANESE (Mn^{++}), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	216	179	220	203
TOTAL ALKALINITY (as $CaCO_3$), mg/l	215	201	262	230
SILICA (as SiO_2) mg/l	20	15	15	24
TURBIDITY, NTU	1.0	2.0	3.0	4.0
SUSPENDED SOLIDS, mg/l	<0.01	<0.01	1.0	2.0

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

FORM No. WQPC 12/1

MINISTRY OF IRRIGATION & WATER DEVELOPMENT
WATER QUALITY TEST RESULTS

LAB No.	174	175	176	177
DATE SAMPLED	19/03/09	19/03/09	19/03/09	19/03/09
WATER RESOURCE UNIT				
MAP SHEET/GRID REF.				
SOURCE TYPE/LOCATION	**CHITULE SCHOOL BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**HUWA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**SUNDUZENI VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**	**TIDYENAWO VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY, DEDZA DISTRICT**
pH Value	7.75	8.10	8.23	7.67
CONDUCTIVITY (µs/cm at 25^0C)	727	820	782	1630
TOTAL DISSOLVED SOLIDS, mg/l	368	412	391	821
CARBONATE (as CO_3^{2-}), mg/l	14	19.2	33	28.8
BICARBONATE (as HCO_3^{2-}), mg/l	320	330	239	787
CHLORIDE (as Cl^-), mg/l	28	27.1	28.6	52.4
SULPHATE (as SO_4^{2-}), mg/l	23.3	38.5	44	13
NITRATE (as NO_3^-), mg/l	<0.001	<0.001	<0.001	<0.001
FLUORIDE (as F^-), mg/l	0.95	1.06	1.26	1.28
SODIUM (as Na^+), mg/l	47	49	42	94
POTASSIUM (as K^+), mg/l	1.2	1.5	0.90	1.0
CALCIUM (as Ca^{++}), mg/l	67	78.8	77	208
MAGNESIUM (as mg^{++}), mg/l	18.5	23.3	16.5	23.3
IRON (Fe^{++}), mg/l	0.06	0.04	0.15	0.05
MANGANESE (Mn^{++}), mg/l	<0.001	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	243	292	261	615
TOTAL ALKALINITY (as $CaCO_3$), mg/l	286	307	251	693
SILICA (as SiO_2) mg/l	18	21	22	22
TURBIDITY, NTU	2.0	3.0	2.0	4.0
SUSPENDED SOLIDS, mg/l	1.0	2.0	2.0	4.0

ANALYSIS CARRIED OUT BY CENTRAL WATER LABORATORY

FORM No. WQPC 12/1

MINISTRY OF IRRIGATION & WATER DEVELOPMENT
WATER QUALITY TEST RESULTS

LAB No.	178	179	180
DATE SAMPLED	19/03/09	19/03/09	19/03/09
WATER RESOURCE UNIT			
MAP SHEET/GRID REF.			
SOURCE TYPE/LOCATION	**KASAKALA VGE BH No. KACHINDAMOTO TRADITIONAL AUTHORITY DEDZA DISTRICT**	**DUNGEYA VGE BH No., KACHINDAMOTO TRADITIONAL AUTHORITY DEDZA DISTRICT**	**KACHINDAMOTO HEADQUARTERS BH No., KACHINDAMOTO TRADITIONAL AUTHORITY DEDZA DISTRICT**
pH Value	7.88	7.61	8.00
CONDUCTIVITY (μs/cm at 25^0C)	818	1615	1038
TOTAL DISSOLVED SOLIDS, mg/l	390	708	520
CARBONATE (as CO_3^{2-}), mg/l	24	96	37
BICARBONATE (as HCO_3^{2-}), mg/l	322	569	338
CHLORIDE (as Cl^-), mg/l	18.6	13.5	23.7
SULPHATE (as SO_4^{2-}), mg/l	34.6	65.2	81.8
NITRATE (as NO_3^-), mg/l	0.16	<0.001	<0.001
FLUORIDE (as F^-), mg/l	1.22	1.22	1.19
SODIUM (as Na^+), mg/l	51	96	70
POTASSIUM (as K^+), mg/l	0.40	0.20	1.7
CALCIUM (as Ca^{++}), mg/l	81.2	181	79
MAGNESIUM (as mg $^{++}$), mg/l	15.6	16.5	29.2
IRON (Fe $^{++}$), mg/l	0.10	0.20	0.01
MANGANESE (Mn $^{++}$), mg/l	<0.001	<0.001	<0.001
TOTAL HARDNESS (as $CaCO_3$), mg/l	267	520	317
TOTAL ALKALINITY (as $CaCO_3$), mg/l	304	627	339
SILICA (as SiO_2) mg/l	20	32	19
TURBIDITY, NTU	3.0	4.0	3.0
SUSPENDED SOLIDS, mg/l	1.0	2.0	1.0

ANALYSIS CARRIED OUT BY CENTRAL WATERLABORATORY

Appendix 4

GUIDE FOR A DISCUSSION/INTERVIEW FOR KACHINDAMOTO AREA FOR COLLECTION OF DATA ON WATER QUALITY

This questionnaire/checklist is meant to collect information relating to groundwater points of Kachindamoto Traditional Authority. The information collected will be used for the purpose of study in Master IWRM at the University of Zimbabwe by James Kushe. No name of respondent will be indicated on this questionnaire. The information will be treated with the utmost confidentiality.

Section A: Fill in the option in the space provided or Circle your option on each item 1 is for satisfactory and 2 is for unsatisfactory

1	Name of Village		
2	Name of Traditional Authority/Chief		
3	District		
4	Date of Interview		
5	Population on the users of water point		
6	Type of water pump		
7	Condition of the water pump and point	**1**	**2**
8	Date of construction of water point		
9	Date of major rehabilitation		
10	Reliability in time of the day	**1**	**2**
11	Reliability in season	**1**	**2**
12	Location of grave yard		
13	Land use around the water point		
14	Location of water point in relation to sanitary facilities (toilet, rubbish pit)		

Section B information on water point and human perception fill in the space provided or circle your option

25	Population of users of each water point		
26	Breakdown/maintenance frequency		
27	History of major rehabilitation	**Yes**	**No**
28	Any problems facing the pump	**Yes**	**No**
29	Any regular water quality monitoring	**Yes**	**No**
30	Strategies for funding	**Yes**	**No**
31	Bank account	**Yes**	**No**
32	Perception on color	**1**	**2**
33	Perception on odor	**1**	**2**
34	Perception on hardness	**1**	**2**
35	Perception on taste	**1**	**2**
36	Alternative sources of water	**Yes**	**No**
37	Perception on alternative sources of water	**1**	**2**
38	Perception on uses of the water; domestic (drinking, cooking, washing) and-domestic uses of water.	**1**	**2**
39	Opinion on health perception		
40	Prevalence of health conditions related to water chemistry	**Yes**	**No**

Section C Institutional arrangements for water point management

41	Legal institutions and policies in use	**Yes**	**No**
42	Who enforces the rules and regulation		
43	Any other institutions working in water sector in the area	**Yes**	**No**
44	Any incentives given for development work	**Yes**	**No**
45	Any links between water committees with national water institutions	**Yes**	**No**

Thanks to all participants

Section D Water uses information fill in the space provided or <u>tick</u> where appropriate

This questionnaire/checklist is meant to collect information relating to groundwater points of Kachindamoto Traditional Authority. The information collected will be used for the purpose of study in Master IWRM at the University of Zimbabwe by James Kushe. No name of respondent will be indicated on this questionnaire. The information will be treated with the utmost confidentiality.

15	Sex of respondent		
16	Age		
17	Marital status	Single Married Divorced Widowed	
18	Number of members in the household		
19	Level of education	None Primary Secondary Diploma Tertiary Vocational training Others (specify)	
20	What is your occupation?	Formal Informal Farming Self Business	
21	Water uses	Drinking Washing Bathing Cooking Watering plants Watering animals	
	Does the soap produce foam when washing?	**1**	**2**
	Does soap easily remove when bathing?	**1**	**2**
22	Teeth molting/fluorosis in respondents	**Yes**	**No**
23	Any knowledge of health problems associated with water quality	**Yes**	**No**
24	Any recent waterborne disease occurrence in the family	**Yes**	**No**

Appendix 5

Seasonal variation of fluoride concentration 2004/5 at Liwonde in Machinga

Water point	Dry season	Rainy season	Ratio factor
B1	3.2	2.32	1.4
B2	4.08	2.7	1.5
B3	5.86	3.98	1.5
B4	10.3	8.19	1.3
B5	8.88	7.35	1.2
B6	1.15	0.66	1.7
B7	7.59	7.05	1.1
B9	0.71	0.45	1.6
B10	1.48	2.77	0.5
B11	6.92	6.83	1.0
B12	8.22	8.23	1.0
B13	7.28	7.46	1.0
B14	7.5	7.72	1.0
B15	6.54	6.17	1.1
B16	1.39	1.05	1.3
B17	0.46	0.35	1.3
B18	4.32	3.83	1.1
B19	0.78	0.53	1.5
B20	1.08	0.68	1.6
B21	6.25	6.29	1.0
B22	6.44	6.23	1.0
B23	5.42	5.46	1.0
Total			26.6
Av ratio			1.2

Appendix 6

Location of water points at Kachindamoto Traditional Authority area

Location	Name of Vge	Eastings	Northings	Elevation asl	Depth of BH
1	Kachindamoto Hqrs	668969	8428442	538m	37m
2	Tidyenawo Vge	669475	8429142	480m	34m
3	Kasakala Vge	670658	8431956	500m	36m
4	Dungeya Vge	670880	8432214	494m	36m
5	Sunduzeni Vge	667944	8428828	495m	24m
6	Chitule CDSS	665924	8429024	506m	35m
7	Huwa Vge	665801	8427622	503m	34m
8	Fikire Vge	668785	8427607	508m	38m
9	Kakhome GVH	663745	8426708	525m	22m
10	Songwe Vge	662404	8429962	525m	30m
11	Bondo FP Sch	663380	8429816	492m	33m
12	Matowe FP Sch	664591	8435022	501m	30m
13	Njoka Vge	665402	8434644	501m	30m
14	Chigwandali 1 Vge	663577	8437520	490m	30m
15	Chigwandali 2 Vge	665260	8435070	550m	32m
16	Kamganga Vge	663925	8438196	484m	30m
17	Helani Vge	663858	8437068	484m	34m
18	Msekeni FP Sch	664398	8423308	543m	30m
19	Maluza Vge	664921	8421876	540m	34m
20	Namkumba Vge	664776	8419572	539m	32m
21	Njolo Vge	667232	8419136	509m	30m
22	Nadazi LEA	665212	8418780	501m	32m
23	Madziasatsi Vge	666196	8419664	511m	32m
24	Fole Vge	667831	8420080	514m	35m
25	Chikwawa Sec. Sch	669482	8420466	528m	36m
26	Mchanja 1 Vge	670035	8420404	521m	44m
27	Mchanja 2 Vge	671112	8420468	506m	44m
28	Kamwendo Vge	672072	8420504	540m	46m
29	Kamwendo 1 Vge	672973	8420470	538m	40m
30	Kaundu H C	675552	8419496	541m	46m
31	Kaundu H C Motar	675610	8419476	537m	45m
32	Ndindi Vge	675520	8419646	514m	33m
33	Kaundu FP Sch	675725	8419594	517m	34m
34	Kaundu FP Sch	675725	8419593	531m	35m
35	Kabulika Vge	678161	8419188	495m	45m
36	Chagunda Vge	678852	8419970	523m	55m
37	Kabulika 2 Vge	678881	8419528	516m	38m
38	Dzindevu Vge	678684	8417584	525m	44m
39	Kapili Vge	677851	8415992	502m	42m
40	Lumwila 2 Vge	676617	8413660	482m	46m
41	Lumwila 2 Dip Tank	678174	8419188	493m	50m
42	Lumwila 2 Vge	676313	8413608	499m	50m

43	Masinja Vge	676257	8411700	497m	45m
44	Kazembe Vge	674435	8509602	513m	44m
45	Chikololere Vge	672607	8406946	519m	42m
46	John Kadewere Vge	671413	8405616	504m	44m
47	Tapezana Sch	670404	8410362	500m	30m
48	Abraham vge	668980	8414402	506m	18m

Appendix 7

Summary of water quality perceptions usage and altenative sources for the study area			
Parameter	**Perception**	**Freq**	**%**
Taste	Satisfactory	135	94
	Unsatisfactory	9	6
	No response	0	0
Soap Consumption	Satisfactory(normal)	123	85
	Unsatisfactory(high)	21	15
	No response	0	0
Colour of water	Satisfactory (clear)	144	100
	Unsatisfactory (not clear)	0	0
Odor	Satisfactory (no odor)	141	98
	Unsatisfactory	3	2
Uses of water	All	123	85
	Selected	21	15
Treatment at home	Boil	0	0
	No treatment	135	94
	No response	9	6
Reliability	Reliable	141	98
	Not reliable	3	2
	No response	0	0
Other sources	Wells	72	50
	River	30	21
	Lake	9	6
	Gravity fed tap	24	17
	None	9	6