KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

PHYSICO-CHEMICAL QUALITY OF DRINKING WATER OF MPOHOR, MPOHOR-FIASE DISTRICT OF THE WESTERN REGION, GHANA.

BY

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BSc. BIOCHEMISTRY AND BIOTECHNOLOGY

A Thesis Submitted to the Department of Theoretical and Applied Biology, College of Science, Kwame Nkrumah University of Science and Technology, Kumasi, In Partial Fulfilment of the Requirements for the Award of the Degree

of

Master of Science (Environmental Science)

NOVEMBER, 2014

DECLARATION

I hereby declare that this submission is my own work towards the M.Sc and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of another degree of the University, except due acknowledgement has been made in the text.

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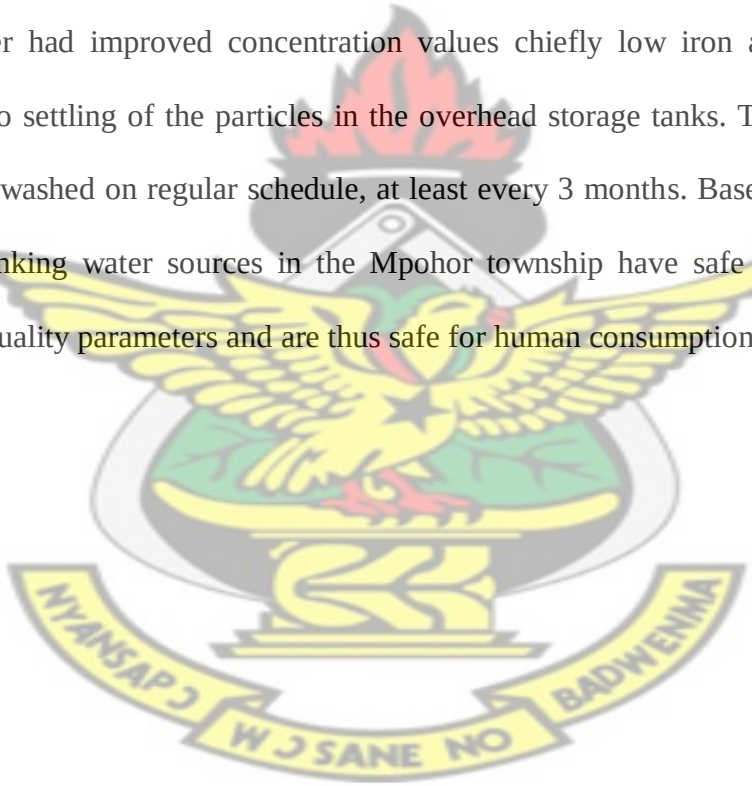
ABSTRACT

Physico-chemical quality of drinking water from Mpohor was conducted between January 2012 to September 2012. The study was to ascertain the concentration of the water quality parameters were within the WHO specification. The drinking water sources were analysed to assess the differences that existed between them, storage tank water and its supply lines and to assure of the quality of the water for drinking. Ten (10) sampling sites made up of four (4) boreholes, four (4) hand dug wells and two (2) points on the town distribution network were selected for the study. The parameters included physical (pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Electrical Coductivity (E.C.), Colour and Turbidity) , chemical (Total Alkalinity, Total Hardness, Nitrate, Nitrite, Phosphate, Sulphate, Fluoride, Calcium, Magnesium and Chloride) and trace metals Manganese (Mn), Iron (Fe), Arsenic (As) and Lead (Pb). A total of 50 samples were collected during the study duration made of one (1) sample from every site per sampling cycle. Significant statistical differences were found between concentration values for borehole and hand dug well sources for calcium, iron, sulphate, chloride, nitrate, total alkalinity, hardness, pH, total dissolved solids and electrical conductivity. Results showed hand dug well (HDW) sources (pH range 5.38 to 5.65) were slightly acidic compared to borehole water sources (pH range 6.45 to 6.67). Iron concentration values for borehole water (Fe range 0.17 to 0.58 mg/L) were relatively high compared to HDW sources (Fe range 0.05 to 0.18 mg/L). The iron values reflected in the high turbidity (ranging from 2.8 to 9.5 mg/L) and colour (1.25 to 25 mg/L) values for borehole water whereas HDW sources recorded minimal values for the two parameters with results ranging from 1.8 to 4.4 mg/L and 0 to 8.75 mg/L respectively. Borehole water also showed to be fresher than well water sources indicated by low conductivity (range 235 to 289 µS/cm) and TDS (range 128 to 154 mg/L) concentrations whereas HDW sources recorded 276 to 339 µS/cm and 151 to 175 mg/L respectively. Results for total hardness and alkalinity

for borehole ranged from 87 to 103 mg/L and 90 to 105 mg/L respectively whereas that for HDW ranged between 59 to 68 mg/L and 24 to 40 mg/L respectively. Hand dug well sources were relatively softer suggesting lower buffering characteristics exhibited by their low alkalinity. Variations between the means of concentration values for magnesium, manganese, fluoride, phosphates, nitrite, total suspended solids, turbidity and colour for the borehole and HDW sources were found to be statistically insignificant. Results for fluorine ranged from 0 to 0.24 mg/L for HDW sources whilst that for borehole ranged from 0 to 0.12 mg/L. Results recorded for manganese for borehole sources ranged from 0.03 to 0.14 mg/L and HDW sources ranged from 0.02 to 0.08 mg/L for the parameter. Analytical results showed distribution water had improved concentration values chiefly low iron and several other parameters due to settling of the particles in the overhead storage tanks. The overhead tank thus needs to be washed on regular schedule, at least every 3 months. Based on the research findings, the drinking water sources in the Mpohor township have safe levels of physic-chemical water quality parameters and are thus safe for human consumption.



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LIST OF ABBREVIATIONS

APHA	-	American Public Health Association
CSIR	-	Council for Scientific and Industrial Research
CWSA	-	Community Water and Sanitation Agency
DNA	-	Deoxyribonucleic acid
EC	-	Electrical Conductivity
EDTA	-	Ethylenediaminetetraacetic acid
EPA	-	Environmental Protection Agency
GMA	-	Ghana Meteorological Agency
GNWP	-	Ghana National Water Policy
GOG	-	Government of Ghana
GSA	-	Ghana Standards Authority
GSS	-	Ghana Statistical Service
GWCL	-	Ghana Water Company Limited
HDW	-	Hand Dug well
HU	-	Hounsfield unit
IRCWD	-	International Reference Center for Waste Disposal
ISODEC	-	Integrated Social Development Centre
MDGs	-	Millennium Development Goals
NTU	-	Nephelometric Turbidity Units
TDS	-	Total Dissolved Solids
TSS	-	Total Suspended Solids
UNEP	-	United Nations Environment Programme
UNESCO	-	United Nations Educational, Scientific and Cultural Organisation
U.S.A	-	United States of America
USEPA	-	United States Environmental Protection Agency
USGS	-	United States Geological Survey
WHO	-	World Health Organisation
WRC	-	Water Resources Commission
WRI	-	Water Research Institute

ACKNOWLEDGEMENTS

To the Almighty God for his favours and grace and all glory unto His Holy name for his mercies for a successful study.

My sincere appreciation goes to my supervisor Dr. Samuel Aikins for the immense devotion of time and effort in guiding me to the start and finish of my paper. Your direction did in fact propel this study to make it a worthwhile one. I will forever be grateful to you Dr. Fei Baffoe for your kindness and openness to me. I am highly indebted to Dr. Alexander Anning and Dr. Alfred Apetorgbor.

To Mr. Samuel Akot of Ghana Urban Water Laboratory, Takoradi and the lab team, I express my deepest thanks and gratitude for their inspiration, work, understanding and effort they exerted to help me grasp the basics and concept of my study. Indeed I couldn't have been blessed more than to have had your participation.

To the Water Board of Mpohor, I will forever be indebted and eternally grateful for the time you invested and assistance given me during the sampling period. The cooperation was overwhelming and I will always have you to thank for this successful outcome. I trust this paper will be of much benefit and a resource to the water situation in your wonderful town.

I wish to thank Mr. Sam Jonah of Community Water and Sanitation Agency for the insight you shed on my research and invaluable support given me when I visited your office.

And to you my able sampling partner Mr Richmond Mills, I am doubtful I could have achieved a successful sampling without your willing support and help. I remain in your debt.

I thank all of you not mentioned but have in heart that I will be forever grateful for all your help.

May God richly extend his blessings to you and refresh you all the days of your lives. May his countenance be ever favourable on you.

DEDICATION

To Isaac Kwamena Ansah, a priceless friend and brother.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Potable water is said to be life. However, its maximum impact on good health, productivity and life expectancy cannot be achieved if it is not matched with good quality treatment and provision/supply.

As at December 2008, the Community Water and Sanitation Agency (CWSA) in Ghana put the national coverage for potable water supply in rural communities and small towns at 57.14 percent. To achieve Ghana's water coverage target of 85 percent by 2015, it needs to reduce the un-served rural population by half, which is 21.43 percent (CWSA, 2014).

The Mpohor Township is situated off Apowa town after the town Kejabil. The population of Mpohor as at 2000 stood at over 9000 inhabitants with over 1900 households with an average household size of 4.7 (CWSA, 2000). The town is not on the national water grid even though one of the major regional water supply dam at Daboase is located very close to the Mpohor-Fiase district.

The people of Mpohor town rely on open wells, and other water bodies for their water needs. In the advent of the Golden Star Resources Company, located just on the fringes of the town, three boreholes have been made available to feed an existing overhead water tank by the company as a community assistance project.

The community instituted a Water Board, which, in liaison with the Community Dept of Golden Star Resources oversees and takes decisions on water concerns. The board is also charged with collection of minimal charges from the public for the cost of water supply. They are yet to carry out investigative

routine checks or analysis on the water to assure themselves of the drinking water quality which is being delivered to the people.

The cost of potable water supply is also an issue worth considering in the choice of water supply option of the populace. Information garnered from the Town Water Board revealed that patronage of distributed borehole water is rather low. This means even in the areas where they have access to tank water, they would prefer to utilize hand dug wells. This is so because most people would rather continue to drink from unapproved sources to avoid paying for the water which they consider expensive.

Ground water contains some impurities even if it is unaffected by human activities (WHO, 2008). The types and concentrations of natural impurities depends on the nature of the geological materials through which the groundwater moves and the quality of the recharge water.

Ground water moving through sedimentary rocks and soils may pick up a wide range of compounds such as magnesium, calcium and chlorides. Some aquifers have high natural concentration of dissolved constituents such as arsenic and selenium. The effect of these natural sources of contamination on drinking water quality depends on the type of contaminants and concentrations

Some of the contaminants that occur naturally are:

Aluminum, arsenic, barium, chloride, chromium, coliform bacteria, copper, fluoride, iron, lead, manganese, mercury, nitrate, selenium, silver, sodium, sulfate, zinc (USEPA, 1997).

Contamination may also result from the nearby activities which may otherwise affect its aesthetic and/or health quality.

1.2 Statement of the Problem

The Mpohor Township faces a water provision and supply challenge. Some measures have been initiated to increase access to potable water. However, the measures are not enough to guarantee the provision of the right quality of drinking water to the indigenes.

Upon a visit to the research area, particularly the overhead water storage facility, it was realized that the water is hardly ever treated and there is no provision for the resources to do so. Currently, the water from the treatment tank is considered the most potable, therefore there is the need to monitor its quality at specified time intervals to assure of the acceptability of its drinking quality using WHO guidelines as the criteria.

Also, due to the pricing of the tank water many people are deterred from using it and resort to hand dug well water. The well water has many qualitative qualities which make it unsuitable for usage for a variety of activities including washing. Additionally most of the shallow wells are sited within households close to the toilet manholes. This presents a contamination risk as seepage of manhole effluents into the ground water may increase risk of outbreak of diseases such as cholera when water is consumed.

1.3 Main Objectives

The main objectives of this study was to monitor the physico-chemical quality of the borehole and hand dug well water sources.

1.3.1 Specific objectives:

The specific objectives were to

- Determine the concentrations of the chemical parameters of drinking water and values of the physical parameters.
- Compare the results of water quality indicators obtained with their respective WHO guidelines.

1.4 Significance of the study

The results of the study will serve as baseline information on groundwater quality in terms of the selected physico-chemical parameters. The data obtained would be used to advise responsible authorities where applicable on enhancement of the drinking water quality.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The quality of drinking-water is a powerful environmental determinant of health. Assurance of drinking-water safety is a foundation for the prevention and control of waterborne diseases (WHO, 2004).

Community water supplies in both developing and developed countries are more frequently associated with outbreaks of waterborne disease than urban supplies. (WHO, 2004)

Groundwater is increasingly becoming the source of drinking water for inhabitants of both rural and urban settlements due to unavailability and intermittent water shortage which has been hitting most countries (UN-Water, 2007).

2.2 UN Declarations on Water

The United Nations declared 1981-1990 a water-and-sanitation decade. It has been estimated that lack of clean drinking water and sanitation services leads to water-related diseases globally and between five to ten million deaths occur annually, primarily of small children (Snyder and Merson, 1982). Millions exposed to unsafe levels of naturally-occurring arsenic and fluoride have an increased risk of contracting cancer and tooth/skeletal damage (WHO, 2008).

On 28 July 2010 the United Nations General Assembly declared safe and clean drinking water and sanitation a human right essential to the full enjoyment of life and all other human rights.

2.3 Ghana Water Policy

The goal of the Government through the Community Water and Sanitation Agency (CWSA) is to attain national water coverage of 85% by 2015 (CWSA, 2014).

The diversity of conceptualizations of water is at the heart of the debate on the policies and strategies to provide good water for all human communities particularly in the marginalized areas of societies.

"The Accra Declaration on the Right to Water" of 19th May 2001 (NFWP, 2001) highlighted certain principles including:

- Water is a fundamental human right;
- Water is not and should not be a common commodity and sold as an economic good;
- Water is a natural resource that is part of our common heritage;
- Water is an increasingly scarce natural resource and as a result, crucial to the securities of our societies and sovereignty of our country

Since the 1990s Ghana has made efforts to put in place and implement strategies for addressing the needs for water of the general populace.

2.4 Groundwater

Groundwater occurs in many different geological formations. Ground-water supplies are obtained from aquifers, which are subsurface units of rock and unconsolidated sediments capable of yielding water in usable quantities to wells and springs.

The volume of water contained in the rock depends on the percentage of these openings or pores in a given volume of the rock. This is termed the porosity of the rock. More pore spaces result in higher porosity and more stored water (UNESCO/WHO/UNEP, 1996).

The hydrologic characteristics of aquifers and natural chemistry of ground water determine the availability and suitability of ground-water resources for specific uses. Ground water is the part of precipitation that enters the ground and percolates downward through unconsolidated materials and openings in bedrock until it reaches the water table. The water table is the surface below which all openings in the rock or unconsolidated materials are filled with water. Water entering this zone of saturation is called recharge. Thus the phenomenon by which water seeps down from the land surface adding to the ground water is called recharge.

The ground-water level within an aquifer fluctuates constantly in response to rainfall, evapotranspiration, barometric pressure, ground-water movement (including recharge and discharge), and ground-water pumpage. However, the response time for most natural ground-water level fluctuations is controlled predominantly by the local and regional geology

Ground water is recharged from rain water and snowmelt or from water that leaks through the bottom of lakes and rivers.

Ground water may be obtained by drilling or digging wells and may also appear on the surface as spring. A well is usually an opening created to be able to gain access to groundwater. This may be in the form of a tube or bore lined with protective material or a shaft created by digging into the earth until the water table is reached. This water can then be brought to the land surface by a pump or a bucket and a rope.

Ground water can run out if more water is discharged than recharged. For example, during periods of dry weather, recharge to the aquifers decreases. If too much ground water is abstracted during these times, the water table can fall and wells may go dry.

2.5 Ground water quality

Groundwater is actually a complex, generally dilute, chemical solution. The chemical composition is derived mainly from the dissolution of minerals in the soil and rocks with which it is or has been in contact. The type and extent of chemical contamination of the groundwater is largely dependent on the geochemistry of the soil through which the waterflows prior to reaching the aquifers (Zuane, 1990). The chemical alteration of the groundwater depends on several factors, such as interaction with solid phases, residence time of groundwater, seepage of polluted runoff water, mixing of groundwater with pockets of saline water and anthropogenic impacts (Stallord and Edmond, 1983; Dethier, 1988; Umar and Absar 2003; Umar *et al*., 2006).

Groundwater in its natural state is generally of good quality (WHO, 2008). This is because rocks and their derivatives such as soils act as filters. However, not all soils are equally effective in this respect and therefore pathogens contained in human excreta such as bacteria and viruses are likely to be small enough to be transmitted through the soil and aquifer matrix to groundwater bodies (Lewis et. al., 1982).

Rainfall is a dilute chemical solution and contributes significant proportions to some constituents in groundwater, especially in regions with little soil cover where hard compact rocks occur at or near the surface. As water flows through the ground the dissolution of minerals continues and the concentration of dissolved constituents tends to increase with the length of the flow path. At great depths, where the rate of flow is extremely slow, groundwater is saline, with concentrations ranging up to ten times the salinity of the sea.

Groundwater can become unpotable if it becomes polluted and is no longer safe to drink. In areas where the material above the aquifer is permeable, pollutants can seep into groundwater. This is particularly in a fractured aquifer.

2.5.1 Physico-chemical indicators for water quality

Table 2.1 Showing the occurrence of ions in groundwater

Major constituents (1.0 to 1,000 mg l^{-1})	Secondary constituents (0.01 to 10.0 mg l^{-1})	Minor constituents (0.0001 to 0.1 mg l^{-1})
Sodium	Iron	Arsenic
Calcium	Aluminium	Barium
Magnesium	Potassium	Bromide
Bicarbonate	Carbonate	Cadmium
Sulphate	Nitrate	Chromium
Chloride	Fluoride	Cobalt
Silica	Boron	Copper
	Selenium	Iodide
		Lead
		Lithium
		Manganese
		Nickel
		Phosphate
		Strontium
		Uranium
		Zinc

Source: Todd, 1980

Many compounds and substances impact the drinking quality of water. Changes in water quality occur progressively, except for those substances that are discharged or leached intermittently to flowing surface waters or groundwater supplies, such as, contaminated landfill sites.

There are broad categories into which they can be placed in consideration of the consequence of drinking water containing such contaminants and the ease with which they can be removed from the drinking water supply and many others (WHO, 2008).

Some parameters basically affect the aesthetic properties for example high total iron and manganese content affect taste and colour of the water. Other parameters such as turbidity have no health effect but can interfere with disinfection and provide a medium for microbial growth. High concentration of sulphate may give bitter taste and also cause laxative effect. Saline taste may be imparted by high chloride and sodium contents, which may affect its acceptability for potability purposes (WHO, 2008).

Table 2.2 : Hardness Classification

Concentration	Classification
0 – 60 (mg/L)	Soft water
61 – 120 (mg/L)	Moderately hard
121 – 180 (mg/L)	Hard
Above 180 (mg/L)	Very hard

Source : Hem (1985)

Hardness is a property of water that determines its ability to easily form lather with soap. Hardness of water is mainly contributed by calcium and magnesium ions in water. Calcium is the most abundant metal in the human body. It is the main constituent of bones and teeth and it has key metabolic functions and thus beneficial in drinking water. Magnesium is also required for metabolic processes and bone formation.

Low pH levels can increase the solubility of certain heavy metals. This allows the metals to be more easily available. At certain pH some ions are leached out of rocks into the surrounding waters. Certain chemical reactions/processes can also occur at certain pH of water. Aluminium experience significant increase in leaching into surrounding waters at pH below 4.5. The pH measures the acidity or alkalinity of the water while the conductivity is the ability of the groundwater to conduct an electrical current.

Conductivity is a function of temperature, types of ions present and the concentrations of the ions. The total dissolved solids, (TDS) an index of conductivity, has a direct relationship to salinity and high total dissolved solids limits the suitability of water for potable use (Davis and DeWiest, 1966). Electrical conductivity and total dissolved solids basically reflect the salt concentrations in water. They affect the ability to which water can conduct electricity or heat.

Table 2.3 : Water Classification by Salinity

1 mg/L = 1 ppm

Water	TDS (mg/L)
Fresh water	<1000
Sligthly Saline	1000 to 3000
Brackish (moderately saline)	1000 to 10000
Very Saline	10000 to 35000
Sea Water	35000
Brine	>>35000

Source : Davies and DeWiest (1966)

Some compounds have been implicated in the causing of disease both in the long term and in the short such as Lead and Mercury. As far has been ascertained lead fulfils no essential function in the human body. Lead is significantly dangerous to living systems as it does not only accumulate in individual organism but in entire food chains.

Fluorine when present in moderate concentrations (approximately 2ppm) is essential for strong bones and good dentition. However at high concentrations above 4ppm it has been implicated in a condition called fluorosis which is characterized by the hardening of the bones consequently reducing bone elasticity leading to impaired mobility. Dental fluorosis eventually causes damage to the enamel and in severe forms stains the teeth.

Chlorine causes environmental harm at low levels. Chlorine is especially harmful to organisms living in water and in soil.

Generally, chemicals occurring in drinking-water are of health concern only after extended exposure for years. The only exception is nitrate. Nitrate and nitrite in water has been associated with methaemoglobinaemia, especially in bottle-fed infants. With a methaemoglobin level of 3-15%, skin can turn to a pale gray or blue. Nitrate may arise from the excessive application of fertilizers or from leaching of wastewater or other organic wastes into surface water and groundwater (WHO, 2008). The nitrite ion contains nitrogen in a relatively unstable oxidation state. Chemical and biological processes can further reduce nitrite to various compounds or oxidize it to nitrate (Anon, 1987). Nitrate is very

mobile in groundwater due to its solubility and its anionic form (Fytianos and Christophoridis, 2003). It tends not to adsorb or precipitate on aquifer solids (Hem, 1985).

Guideline values are derived for many chemical constituents of drinking-water. A guideline value normally represents the concentration of a constituent that does not result in any significant risk to health over a lifetime of consumption.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The Mpohor Township (Fig. 3.1) is located in the Western Region. It was formerly under the Wassa Mpohor East District, which was carved out from Wassa Fiase Mpohor District. However under the Parliament legistlative instrument implemented in June 2012, it is now a town under administration of the Mpohor Fiase District with Mpohor as a district capital. The current political administration is Mpohor Fiase District Assembly.

The general occupations of the indigenes are food crop farming which employ about 71.5% of the population (GSS, 2011) and minimal livestock farming There are some few industries scattered around which include the Ayiem Oil Mills which has been operating in the area over 30years and Benso Oil Palm Plantation. Small scale mining (Galamsey) operations have also been on the increase in the area.

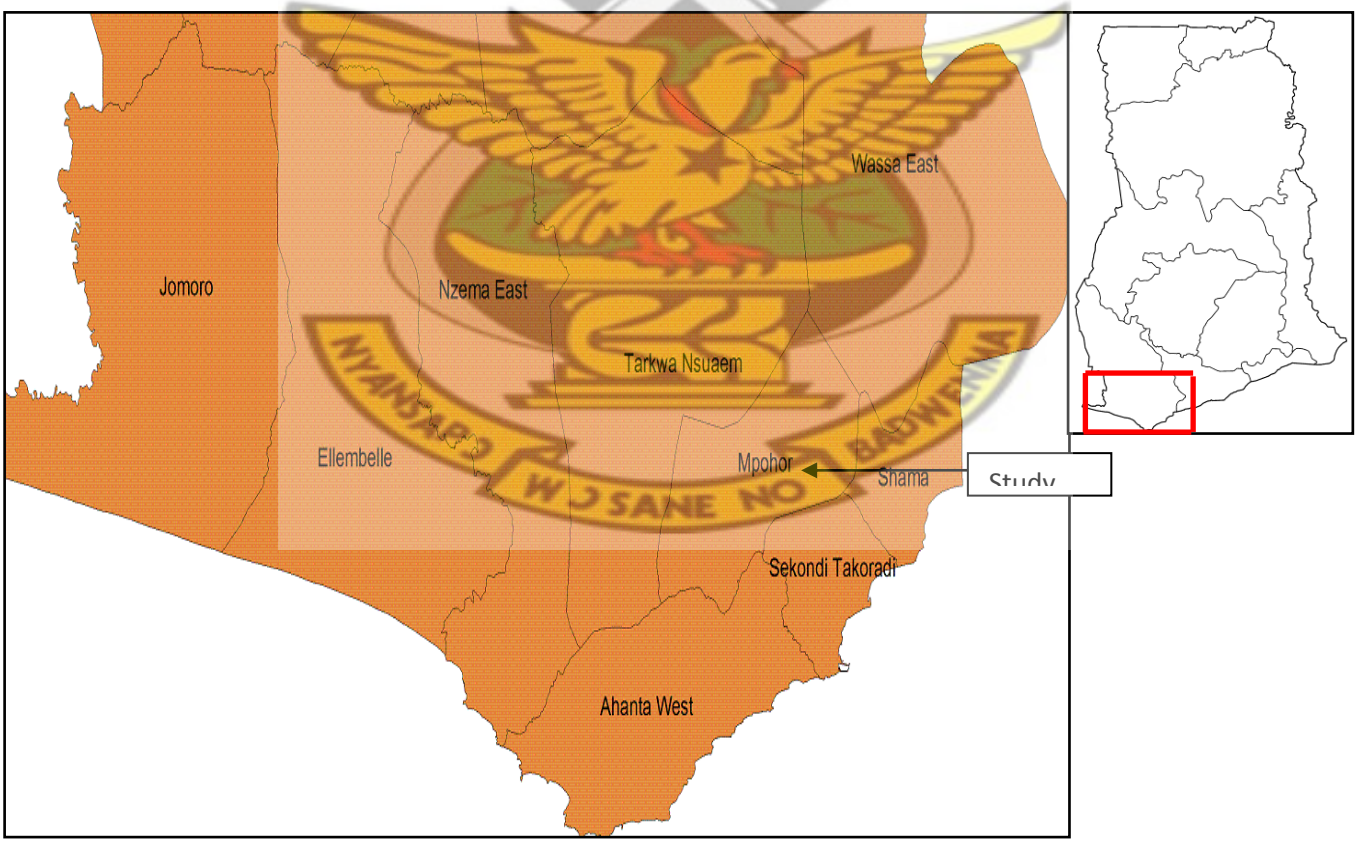

Fig 3.1 Map showing the study area (Mpohor) of the Western Region (inset is the map of Ghana showing position of the study area)

3.2 Climate and Vegetation

The vegetation is tropical rainforest type. Climate of the area falls within the tropical climate zone. The mean annual rainfall is 1500mm and ranges from 1300 to 2000mm (WED, 2006). The rainy season in the district is between March and July but November to January experiences no rain (WED, 2006).

3.3 Topography and Drainage

The district lies within the low-lying areas of the country with most parts below 150 metres above sea level. The landscape is generally undulating with an average height of about 70 metres (WED, 2006).

There are four main categories of rock and soil types which underlie the district namely Lower Birimian, Dixcove granite, Cape Coast granite and Tarkwaian. Other rocks types such as phyllites and and quartzites can be found in Mpohor (WED, 2006).

More than half of the soil consists of Cape Coast granitic sediments. The district has large deposits of gold, traces of iron and kaolin. The highest elevation ranges between 150 and 200 metres above sea level (WED, 2006). The drainage pattern of the area is largely dendriatic. There are small rivers and streams.

Many of the rivers drain from from the Akwapim ranges and flow southwards towards the coast. The main rivers are the Pra, Subri, Butre, Brempong, Suhyen, Abetumaso, Hwini and Tipae. Although most of them overflow their banks in the rainy season, majority of the rivers virtually dry out in the dry season leaving behind series of dry valleys and rapids (WED, 2006).

3.4 Population, Distribution and Education

The current population of Mpohor as at 2010 was 49,598 with growth rate of 3.2 (MMDA, 2013). Economically active population is 50.6 percent (MMDA, 2013).

The township has one secondary school, 16 Junior High School and 30 primary schools.

3.5 Water Supply Situation

The main source of water for the community is from rain water harvesting and wells. The projected water demand of the town was estimated in the year 2000 as 454 m^3 per day (CWSA, 2000). The number of standpipes in the study area was eighteen which were made up of fifteen public, two for the schools and one for the clinic. Other sources of water included private hand dug wells both covered and uncovered.

In 2000 a project was commissioned and implemented by CWSA to construct a Water Supply installation comprising of an overhead tank and a distribution system to be later managed by the Town Board. The tank of capacity 10,000 gallons was to be fed by two boreholes which were drilled by GWCL.

A number of complaints from the populace basically on taste and aesthetics prompted discontinued use of water from the two boreholes. Another project financed by the Golden Star Mine was implemented and three (3) boreholes were successfully constructed to supply water to the township in 2005.

The Water Board of Mpohor manages this supply system as well. Their most important roles include maintenance and operation of the supply network and collection of monies/ levies from the town members for the water supplied to them. The monies collected are purported to be used for paying the utility bills of the pumps and maintenance of equipments.

The number of boreholes in the area currently stands at six (6) but two have had their use discontinued.

Sources of threats to water system include but are not limited to

- diesel spillage from haulage trucks of the mining companies,
- small scale mining activities (galamsey) and the
- effluent waste from the palm oil mills, some of which are situated very close to the three boreholes which feed the overhead tank.

3.6 Procedure

3.6.1 Methods

3.6.2 Sampling Locations

Sampling sites as shown below in Fig 3.2 were chosen to represent a fair distribution of the drinking water supply in the locality with factors such as

- Population density around drinking water source
- Drinking water sources
- Fair distribution to ably represent a good coverage of drinking water supply systems

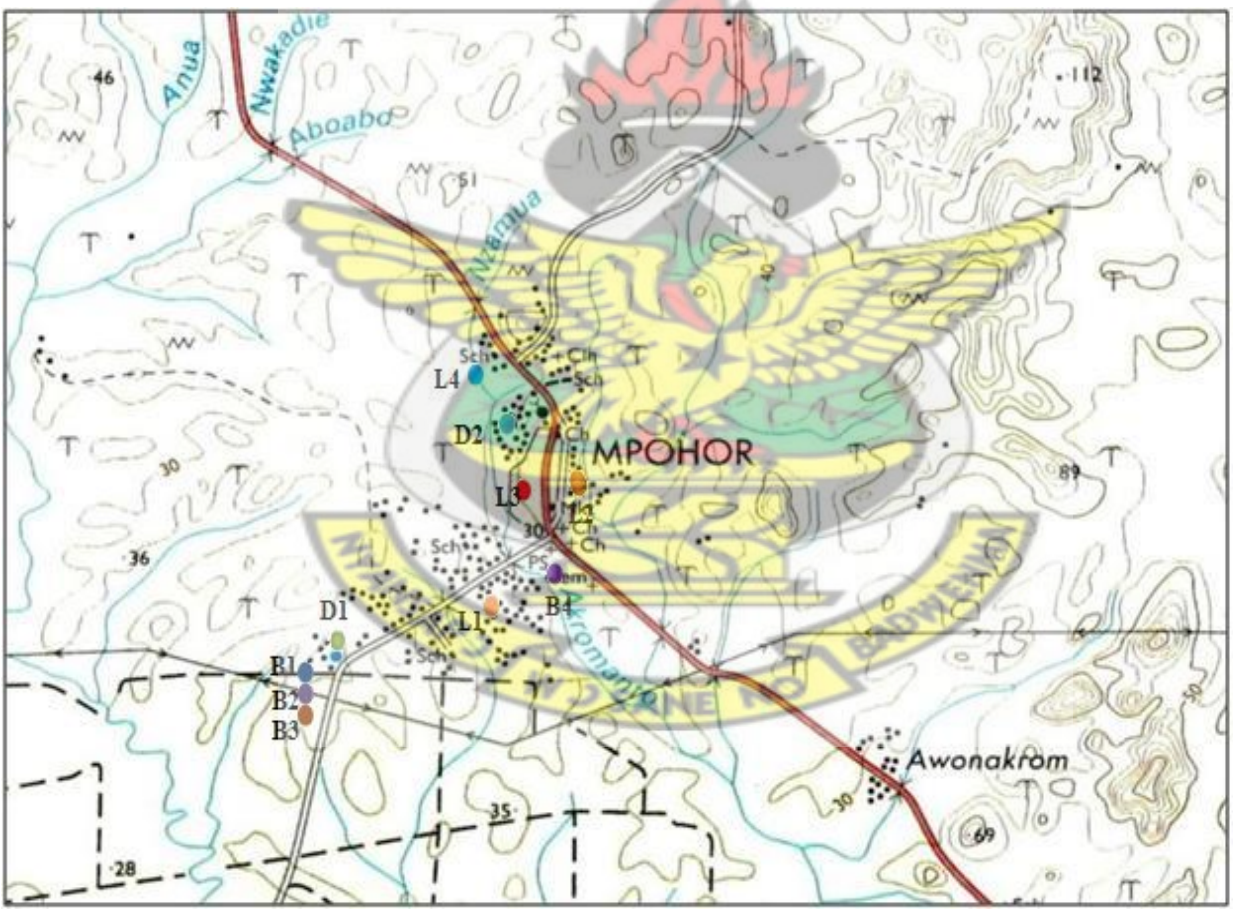

Fig 3.2 Showing the sampling Locations in Mpohor township

Key

Tarred Road
Feeder Road
Settlements

Sampling was done every other month starting from January 2012 through to September, 2012 for a five (5) total sampling events. In total ten (10) sampling sites were chosen from:

- Boreholes which feed community supply tank
- Distribution points from supply tank
- Hand dug wells in households and public places

3.6.3 Presampling preparations

3.6.3.1 Physicochemical Parameters

Sample bottles (volume 1500 ml) were thoroughly rinsed with distilled water. Upon reaching the sampling site, the bottle was rinsed with water from the respective borehole, thrice, before sample collection was undertaken.

3.6.4 Sampling

One sample of groundwater was collected at each site into a 1500ml bottle for physico-chemical analyses and labelled. The samples were collected directly from the drinking water source in the same manner as is done by the community using their water drawing container.

Each sample collected was preserved in a light-proof insulated box containing ice-packs to prevent possible alteration of parameters by light. Samples were then transported to the Ghana Urban Water Company Laboratory in Takoradi for analyses immediately.

3.6.5 Laboratory Analayses

All analyses were done at the Ghana Water Laboratory, Takoradi

pH

The pH was measured by a pH meter (Mettler-Toledo, Model: Seven Go) and an electrode probe. The electrode was first calibrated against a pH buffer 7 and 9 at a temperature of 25^{o}C. The electrode was then immersed in the sample and stirred gently and stopped, allowing for 1-2 minutes for a stable reading to be obtained and recorded.

Turbidity

The HACH turbidimeter model: 2100Q was used. It was first calibrated before use and the wavelength set to 810nm.

The sample was shaken vigorously and poured into the cell to at least two-thirds full. The cell was wiped with tissue and placed in holder. The cell was aligned with the arrow and closed. The readings were allowed to stabilize and recorded.

Conductivity and Total Dissolved Solids (TDS)

The conductivity and TDS were determined using WTW Inolab Series Meter (Model 720). The cells and beaker were rinsed with a portion of the sample. Then the beaker was filled completely. The cell was then inserted into the beaker. The temperature control was adjusted to that of the sample (automatically) and the probe was then inserted into the vessel and readings taken. Both parameters were read by toggling the mode button and recorded.

Total Suspended Solids (TSS)

The Photometer Method was used.

The spectrophotometer (Hach DR 2500) was used. For TSS the programme number was set to 431.

The sample was shaken to ensure even distribution of dissolved solids and 25 ml aliquot was taken and put in the sample holder and read. The results were displayed digitally in mg/L.

Total hardness

The EDTA titrimetric method was used.

Fifty millilitres (50 ml) of sample was pipetted into a conical flask and 1ml of a buffer solution was added to it to produce a pH of 10. One gram of Eriochrome Black T indicator was also added to it. It was then mixed constantly and titrated with a standard 0.01M EDTA until the last trace of purple disappeared and the colour turned bright blue.

Total hardness was then calculated using the formula:

$$\text{Total Hardness} = \frac{\text{ml EDTA x B x 1000}}{\text{ml of sample}}$$

where B = mg of $CaCO_3$ equivalent to 1ml of EDTA titrant

Calcium

The EDTA Titration Method was used.

Three drops of 4N NaOH was added to 100ml of sample. The mixture was stirred and a few drops of the meurexide indicator added to it. Titration was done immediately after the addition of the indicator. EDTA titrant (0.02N) was slowly added with continuous stirring until the colour changed from pink to violet. The end point was checked by adding 2 drops of titrant in excess to make sure that no further colour change occurred.

The value was calculated using the formula:

$$\text{Ca (mg/L)} = \frac{\text{A x B x 0.4}}{\text{ml of sample}}$$

where A = ml of EDTA titrant used

$$\text{B} = \frac{\text{ml of standard calcium solution}}{\text{ml of EDTA titrant}}$$

Magnesium

Calcium and total hardness were determined by the EDTA titration method. Magnesium hardness was calculated from the difference between the total hardness and the calcium hardness which is expressed in mg/L. The magnesium concentration was obtained by multiplying magnesium hardness by 0.243.

Mg (mg/L) = Magnesium hardness x 0.243

Chloride

The Argentometric Method was used

Fifty millilitres (50 ml) of sample was taken and one millilitre (1 ml) of K_2CrO_4 indicator solution was added and titrated with standard $AgNO_3$ titrant to a pinkish yellow end point.

Reagent blank value was established by titrating 50ml of distilled water with 1ml of K_2CrO_4 dropped in it, against standard $AgNO_3$.

The value was calculated using the following formula:

$$Cl^- \text{ (mg/L)} = \frac{(A-B) \times M \times 35{,}450}{\text{ml of sample}}$$

Where A = ml titration of sample

B = ml titration of blank

M= Molarity of $AgNO_3$

Nitrite Concentration

The Diazotization method was used.

The spectrophotometer (Hach DR 2500) was used. For Nitrite the equipment was set to programme 371. The cell was filled with 10ml of sample. The NitriVer 3 Nitrite Reagent Powder Pillow was added to the sample in cell, capped and shaken to dissolve completely the reagent pack. A pink colour

developed if nitrite was present. The solution was allowed time of approximately 20minutes for reaction to proceed. Calibration with blank followed after reaction time before reading sample. The reading was taken after reading stabilized. The method detection limit was 0.001mg/L.

Nitrate Concentration

The Cadmium Reduction Method was used.

The spectrophotometer (Hach DR 2500) was set to Programme No. 355, Nitrate (N) HR. The sample was filled to approximately 10ml with the sample. One reagent powder pillow NitrateVer 5 was added to sample and shaken vigorously to allow for thorough mixing for one minute. A five minute reaction time was allowed and an amber colour developed if nitrate was present. The blank (deionized water) was used to zero equipment before sample reading. The reading was recorded after measurement had stabilized. The method detection limit was 0.005 mg/L.

Sulphate

The SulfaVer 4 Method was used.

The spectrophotometer (Hach DR2500) was used. The programme number was set to 680 Sulfate.

The sample cell was filled with about 10ml of sample. One SulfaVer 4 Reagent powder pillow was added to sample in cell and swirled to mix thoroughly. A reaction time of five minutes was allowed. The equipment was zeroed with the blank before reading sample. Reading was recorded when the measurement had stabilized. Readings appeared in mg/L SO_4^{2-}.

Phosphate

The PhosVer 3 (Ascorbic acid) method was used.

The spectrophotometer (Hach DR2500) was used. The programme was set to 490 P React P.V. The sample cell was filled with about 10ml of sample. One PhosVer 3 powder pillow reagent to the sample. The sample was capped and inverted to enable mixing. It was allowed to react for two

minutes. The equipment was zeroed with the blank. Sample cell was placed in the equipment and read after measurement had stabilized. Readings appear in mg/L PO_4^{3-}.

Fluoride Concentration

The SPADNS method (sodium 2-(parasulphophenylazo)-1,8-dihydroxy-3,6-naphthalene disulphonate) was used.

The spectrophotometer (Hach DR2500) was used. The programme was set to 190 Fluoride. Two sample cells were prepared and made ready. The first cell was filled to about 10ml with sample and the same volume of deionized water was put into the second cell. Two ml of SPADNS reagent was added to each cell and swirled to achieve thorough mixing. One minute was allowed for reaction to take place. The blank was used to zero the equipment following the elapse of the reaction time. The sample was then measured and recorded after reading had stabilized. Reading appeared as mg/L F^-. Detection limit was 0.001 mg/L.

Total Iron Concentration

The FerroVer Method was used.

The spectrophotometer (Hach DR2500) was used. The programme was set to 265 Iron, FerroVer. The sample cell was filled with about 10ml of sample. One FerroVer reagent powder pillow pack was added to it and swirled to achieve thorough mixing. Solution was allowed to react for three (3) minutes. The blank was used to zero the equipment before reading the sample. Reading of sample was then taken after measurement had stabilized. The reading appeared in mg/L Fe.

Manganese

The 1-(2-Pyridylazo) -2- Naphthol Pan Method was used.

The spectrophotometer (Hach DR2500) was used. The programme was set to 290Manganese LR. The sample cell was cleaned and filled with 10ml of sample. Another cell was with approximately 10ml of

deionized water. One Ascorbic acid powder pillow reagent was added to each and inverted gently to mix. One Alkaline Cyanide reagent pack was added to each and inverted to mix. The turbidity would dissipate after a while. Twenty one (21) drops of PAN Indicator Solution (0.1%) was added was to each sample, capped and inverted to achieve mixing. An orange colour will develop to indicate presence of manganese. A reaction time of two minutes was allowed before reading. The equipment was zeroed with the blank before reading sample. Measurement was recorded after reading had stabilized. Results appeared in mg/L Mn.

Lead Concentration

100ml of sample was measured into beaker. Approximately 0.1g of xylenol orange was added to sample. The colour of sample changed from colourless to red. Nitric acid (0.01N) was added to solution. Colour would change to red to yellow. To the solution, 0.1g of hexamine was added. Colour changes from yellow to red. The solution was then titrated against EDTA (0.5N). Endpoint was reached when colour changed to yellow.

$$\text{Pb conc (mg/L)} = \frac{\text{Titre value} \times 0.05 \times 10.3605}{1000}$$

Arsenic

Hydrogen sulfide is first oxidized to sulfate to prevent interference, and the oxidizing environment is then neutralized. Sulfamic acid and powdered zinc react to create strong reducing conditions in which inorganic arsenic is reduced to arsine gas (AsH_3). The arsine gas then reacts with mercuric bromide in the test strip to form mixed arsenic/mercury halogenides that discolor the test strip. The color ranges from yellow through tan to brown, depending on the concentration.

Lift the flap on the black cap and slide a tests trip into the groove so that the reactive pad faces the small opening and completely covers it; secure by pressing the flap back in place.

Fill the reaction vessel with sample water to the fill line (50 mL). Add the contents of one Reagent #1 powder pillow to the sample and swirl to dissolve. Add the contents of one Reagent #2 powder pillow to the sample and swirl to dissolve.

Note: Solution may be cloudy at this point. Wait at least 3 minutes Add the contents of one Reagent #3 powder pillow to the sample and swirl to mix. Note: Not all of the powder will dissolve. Wait at least 2 minutes and swirl again to mix. Using the plastic scoop, add one level scoop of Reagent #4 to the sample and swirl to mix. Note: Most of the powder will dissolve at this time Add the contents of one Reagent #5 powder pillow to the sample. Immediately attach the black cap, with the test strip inserted, to the reaction vessel. Do not shake or invert. Swirl to mix. Do not allow sample to contact the test strip pad. Allow vessel to react for 30 minutes, but no more than 35 minutes; swirl twice during the reaction period. Remove the test strip and immediately compare the developed colour to the chart on the test strip bottle. Note: For best results, read the strip outdoors in a shady place. Direct sunlight will change the colour of the strip.

Data Analysis

All data were analysed with Microsoft Excel and R. The means of the analytical results of the various sampled water sources were compared over the months of the study with the WHO guideline as the criteria for acceptability amongst them.

CHAPTER FOUR

RESULTS

4.1 Summary of Physico-Chemical Analysis of Drinking Water Samples

Table 4.1 Summary of Physical Parameters

Physical Parameters	Minimum	Maximum	Mean
pH (units)	4.05	6.79	6.13
Colour (H.U.)	5	8	10.4
Turbidity (NTU)	0.25	29.3	2.98
Conductivity (µS/cm)	68	649	276.85
Total Dissolved Solids (mg/L)	35	357	150
Total Suspended Solids (mg/L)	0.1	18	3.91

Table 4.2 Summary of Chemical Parameters

Chemical Parameters	Minimum	Maximum	Mean
Total Alkalinity (mg/L)	4	260	80
Total Hardness (mg/L)	8	174	85

Table 4.3 Summary of Anions

Anions	Minimum	Maximum	Mean
Nitrate (mg/L)	0.2	11.8	2.59
Nitrite (mg/L)	0	0.02	0.01
Chloride (mg/L)	8	140	37.79
Sulphate (mg/L)	1	29	10.32
Fluoride (mg/L)	0.01	0.42	0.1
Phosphate (mg/L)	0.05	1.7	0.4

Table 4.4 Summary of Cations

Cations	Minimum	Maximum	Mean
Calcium (mg/L)	8	41	24.01
Magnesium (mg/L)	0.49	14.58	6.12

Table 4.5 Summary of Trace metals

Trace metals	Minimum	Maximum	Mean
Manganese (mg/L)	0.01	0.5	0.07
Iron (mg/L)	0.01	2	0.2

Lead and arsenic were not detected in any of the samples over the duration of the study.

4.2 Comparative Study of Drinking Quality of the Groundwater Sources.

The sampling points of the water sources comprised the following

- Boreholes
- Hand dug wells

The three main boreholes were commissioned in 2010 and have an approximate depth of 61 m each. They feed the overhead tank which feeds into the town's main water distribution. An additional borehole which is operated by a hand pump is situated at the town Police Station. It has a depth of about 21 m.

The hand dug wells are of various depths with a range of about 6.1 m (L2) to 14 m (L3). Some of them are situated close to pit latrines (L3) and others are uncovered, covered and semi-covered. The semi-covered includes those which are not covered by concrete (L1, L2). A wooden board has been used to cover L1 and L2. L3 is uncovered. The oldest well amongst them is L3 and it was constructed over 40 years ago.

pH

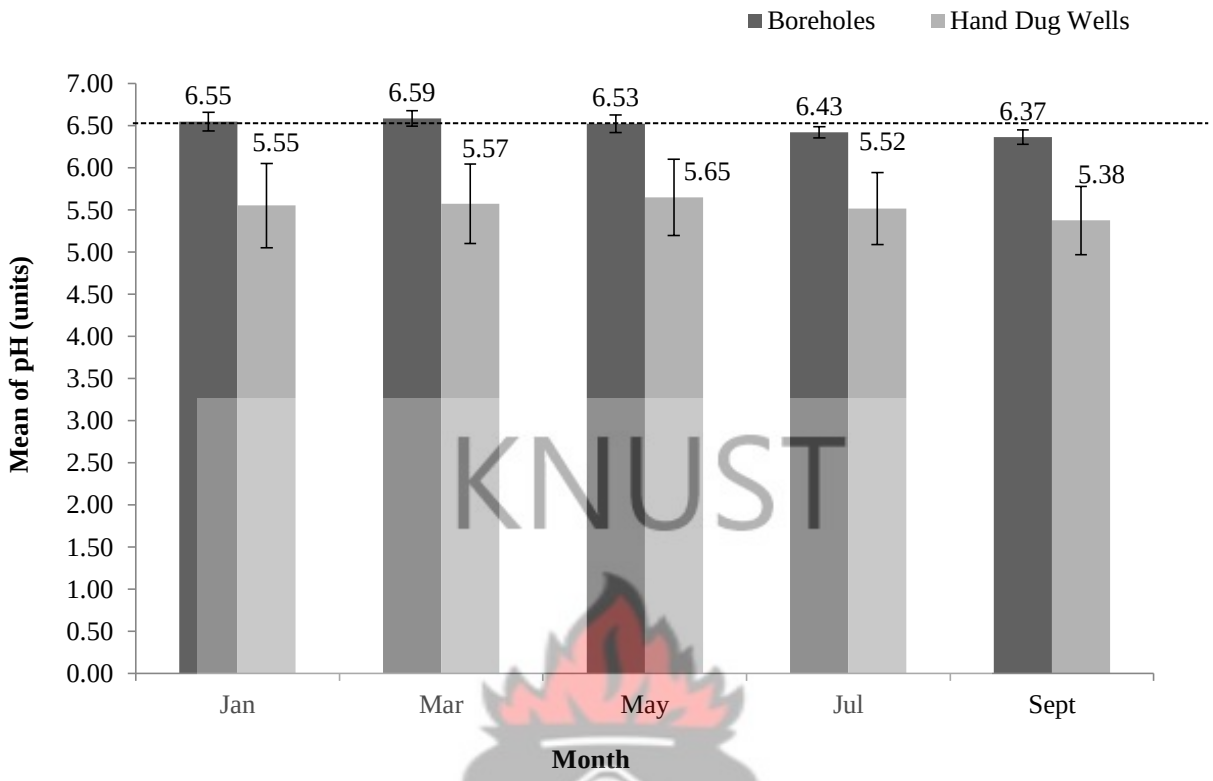

Fig 4.1 Mean pH values for borehole and hand dug well water sources. Bars indicate standard error. The line indicates the minimum WHO (2008) pH acceptable value.

The highest desirable level for pH stipulated for drinking and domestic purposes is from 6.5 to 8.5 (WHO, 2008; EPA, 1997) (Appendix B). The mean pH values for boreholes ranged from 6.37 to 6.59 with a mean of 6.49. The maximum mean value for boreholes was in March and lowest in September (Fig 4.1). All the values, except those for July and September, were above the minimum stipulated value of 6.5 (WHO, 2008; EPA 1997). The mean pH values for hand dug wells ranged from 5.38 to 5.65 with an average of 5.53. All values were below the minimum stipulated value of 6.5 (WHO, 2008). The mean pH values for hand dug wells were highest in May and achieved the lowest value of 5.38 in September. There were significant differences between the pH values recorded for boreholes and hand dug wells ($p = 0.001$).

Colour

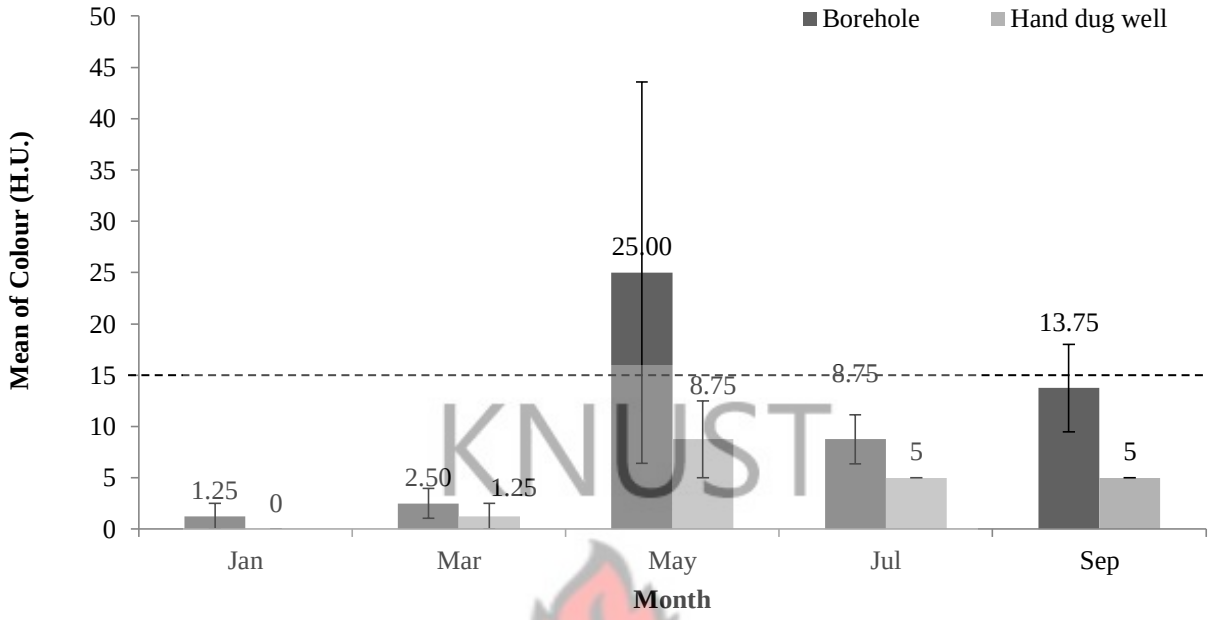

Fig 4.2 Mean colour values for borehole and hand dug well water sources. Bars indicate standard error. The line indicates the maximum colour acceptable value stipulated by WHO (2008)

The mean of colour for the water sources ranged from 0 to 25 H.U (Fig 4.2). Borehole water ranged from 1.25 to 25 H.U. with a mean of 10.25 H.U. whilst recorded values for colour for hand dug wells ranged from 0 to 8.75 H.U. with a mean of 4.00 H.U. There was an increase in colour in May for both sources to their respective maximum of 25 H.U. and 8.75 H.U. for borehole and hand dug wells. The optimum range as stipulated by the WHO, 2008 is from 0 to the maximum of 15 H.U. Throughout the study duration the recorded values for hand dug wells remained under the maximum specification for the parameter. However, the mean recorded for borehole source went above the maximum specification of 15 H.U. in May whilst mean value for September came close to the maximum specification with a value of 13.5 H.U.

Turbidity

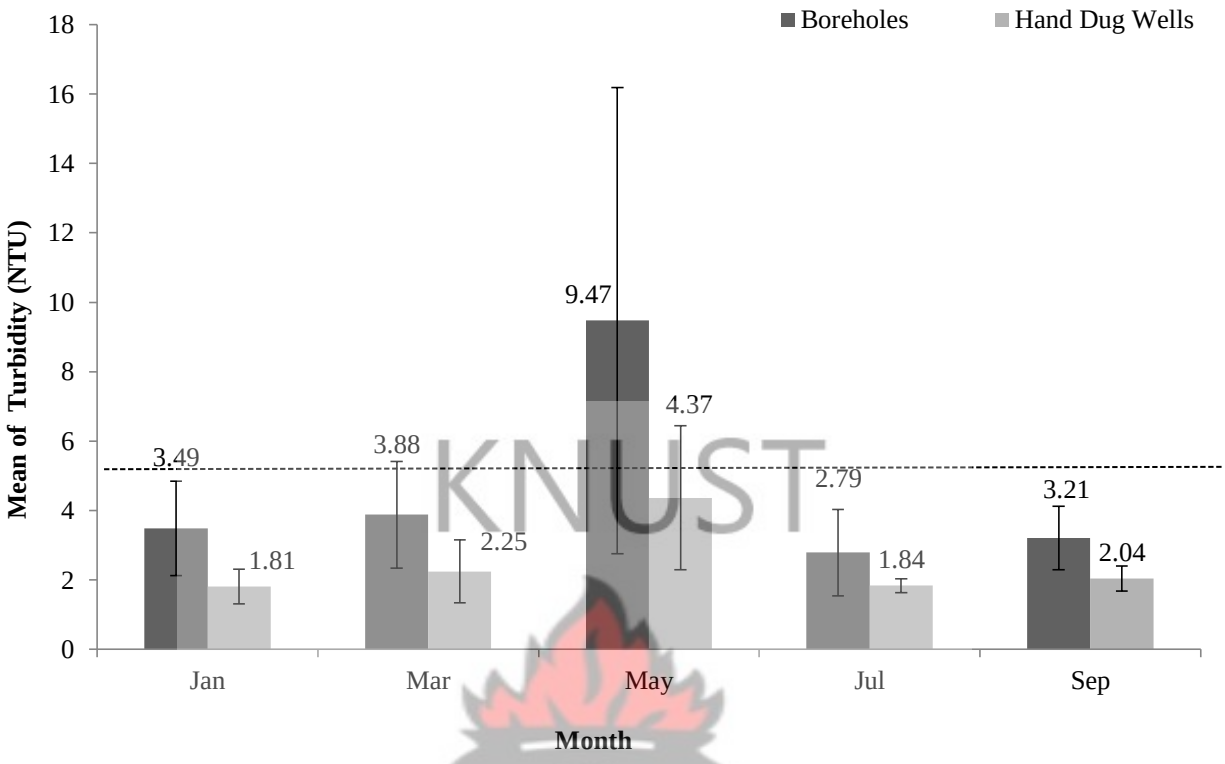

Fig 4.3 Mean turbidity values for borehole and hand dug well water sources. Bars indicate standard error. The line indicates the maximum acceptable turbidity value stipulated by WHO, (2008).

Turbidity values recorded for the duration of study ranged from 1.8 to 9.5 NTU for all water sources (Fig 4.3). Mean values recorded for the parameter for boreholes ranged from 2.8 to 9.5 NTU with a mean of 5.0 NTU whilst that for hand dug wells ranged 1.8 to 4.4 NTU with a mean of 2.6 NTU. The highest results for both sources were recorded in May with respective values being 9.5 and 4.4 NTU for borehole and hand dug wells. Values for turbidity for boreholes remained consistently higher than that for hand dug wells throughout the duration of the study. WHO, 2008 stipulates that for drinking water sources the maximum acceptable value should be below 5 NTU. Mean values recorded for hand dug well sources were below the maximum guideline limit. Borehole water values were below the guideline limit except in May where the mean recorded values went above the guideline limit. There was no significant differences in the turbidity values recorded for borehole and hand dug wells ($p = 0.1663$).

Conductivity

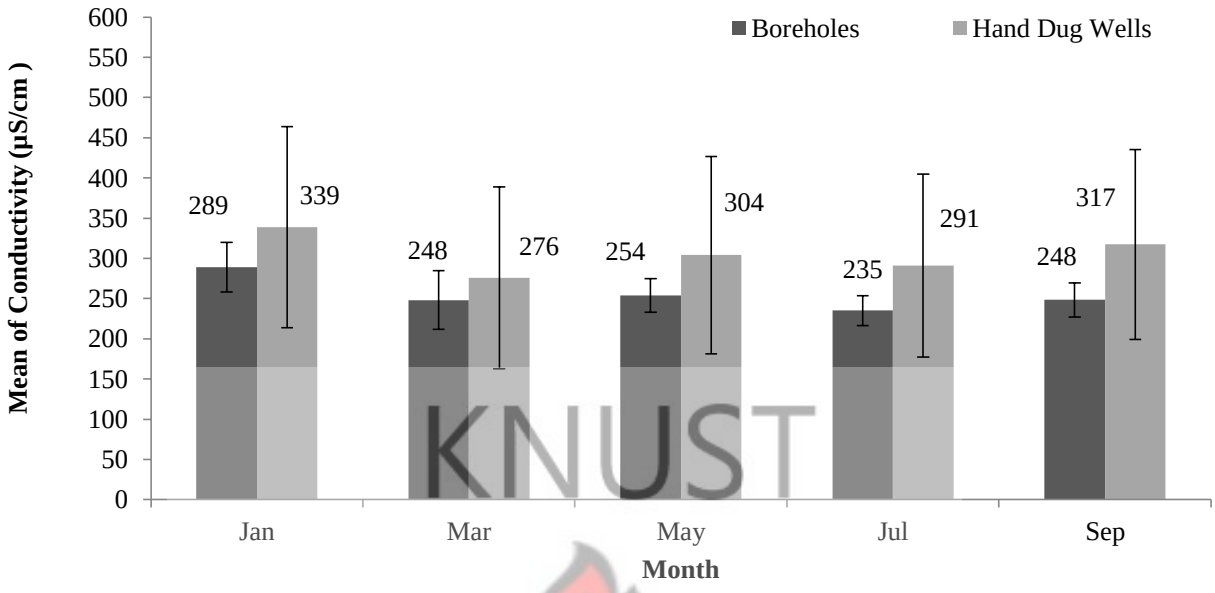

Fig 4.4 Mean conductivity values for borehole and hand dug well water sources. Bars indicate standard error.

Conductivity values recorded for hand dug wells were consistently above those of borehole water sources as shown in Fig 4.4. Values for conductivity ranged from 235 to 289 µS/cm with a mean of 257 µS/cm for borehole sources and 276 to 339 µS/cm with a mean of 306 µS/cm for hand dug wells. There is no WHO guideline value for the parameter. The values were generally low for all the sources. Maximum mean value for borehole was 289 µS/cm in January and minimum of 235 µS/cm in July. Maximum value for hand dug wells was 339 µS/cm in January and minimum of 276 µS/cm in March. The conductivity differences between borehole and hand dug well were statistically insignificant (p= 0.3121).

Total Dissolved Solids (TDS)

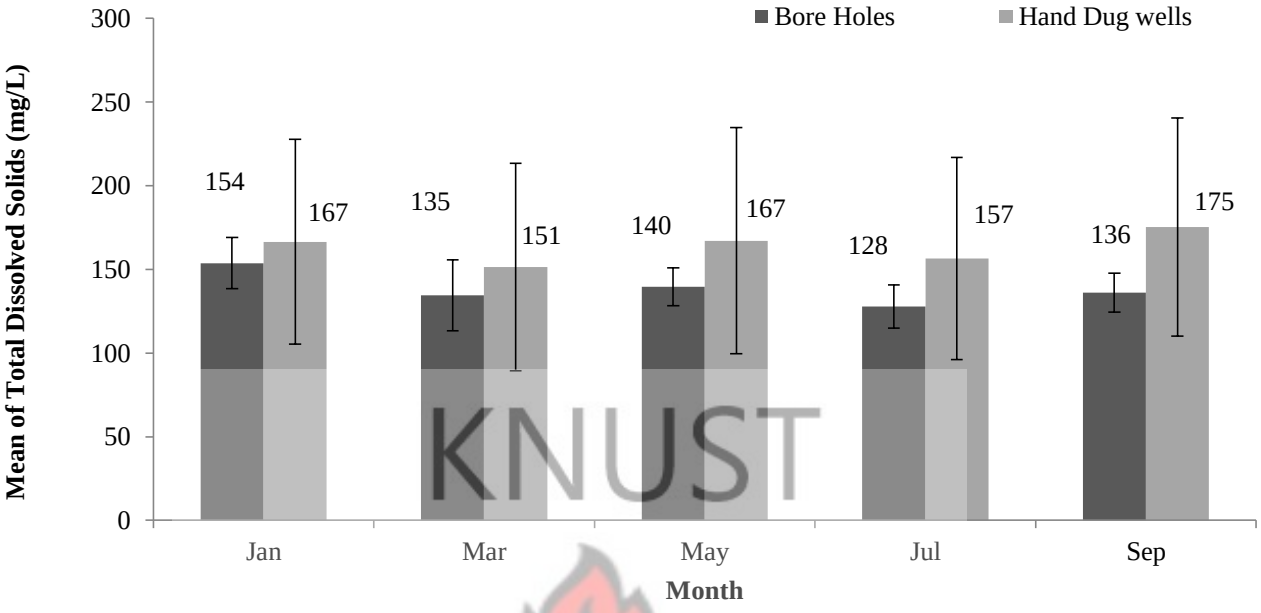

Fig 4.5 Mean TDS values for borehole and hand dug well water sources. Bars indicate standard error.

TDS values recorded for hand dug wells were consistently above those of borehole water sources. TDS values recorded for the sources ranged from 128 to 175 mg/L (Fig 4.5). Mean values for borehole ranged from 128 to 154 mg/L with a mean of 139 mg/L whilst mean values for hand dug wells ranged from 151 to 175 mg/L with a mean of 163 mg/L. WHO, 2008 guideline for the parameter is set at 1000 mg/L. Recorded mean values for both sources were significantly lower than the guideline value. Boreholes recorded maximum mean value of 154 mg/L in January while hand dug well recorded maximum value of 167 mg/L in September. Mean results for hand dug well remained consistently higher than that of borehole. Additionally, there were statistical insignificant differences between the recorded total dissolved solids concentrations of borehole and hand dug well water samples ($p = 0.34$).

Total suspended solids (TSS)

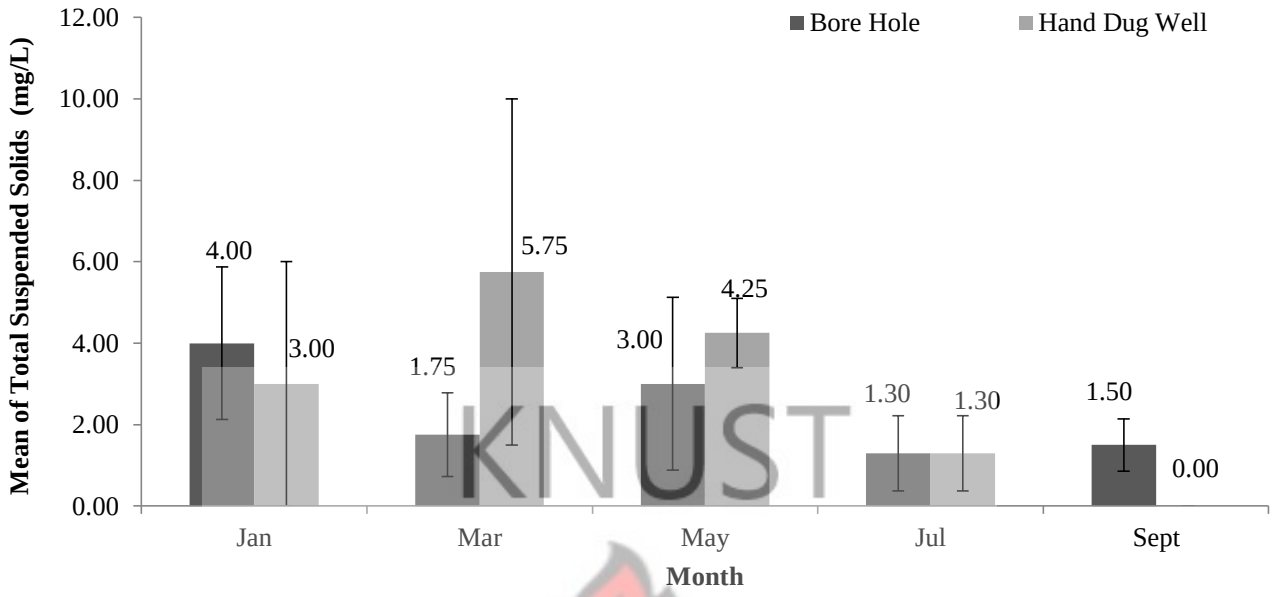

Fig 4.6 Mean TSS values for borehole and hand dug well water sources. Bars indicate standard error.

Total suspended solids (TSS) values recorded ranged from 0.0 to 5.8 mg/L (Fig. 4.6). Hand dug well sources results ranged from 0.0 to 5.8 mg/L with a mean of 2.9 mg/L whilst borehole water sources ranged from 1.3 to 4.0 mg/L with a mean of 2.4 mg/L. Maximum mean results for the study duration were observed with hand dug well sources in May. Mean values recorded for hand dug well sources were generally higher than that for borehole sources. Minimum mean concentration values were recorded for both sources in July and September. There was no significant statistical difference ($p = 0.6573$) between the total suspended solids concentration values of boreholes and hand dug wells.

Total Alkalinity (TA)

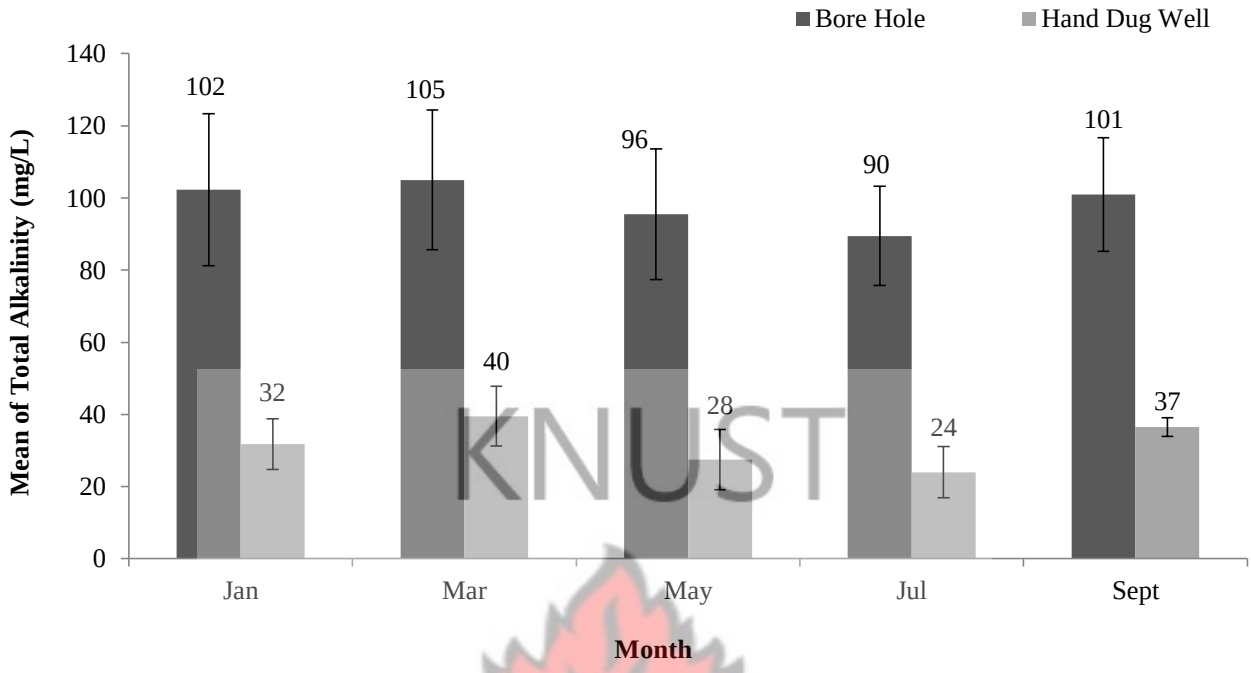

Fig 4.7 Mean Total Alkalinity values for borehole and hand dug well water sources. Bars indicate standard error.

Mean concentration values for the parameter ranged from 24 to 105 mg/L for the duration of study for all sources (Fig 4.7). Boreholes water sources recorded relatively higher values than hand dug well sources and peaked at 105 mg/L in March. Mean values for borehole ranged from 90 to 105 mg/L with a mean of 98 mg/L. Hand dug well sources mean values ranged from 24 to 40 mg/L with a mean of 32 mg/L. There is no WHO guideline value for the parameter. Maximum mean value of 105 mg/L was recorded for boreholes in March while maximum was observed in March for hand dug wells. Total alkalinity concentration values for borehole water differed significantly from that of hand dug wells ($p=0.001$).

Total Hardness (TH)

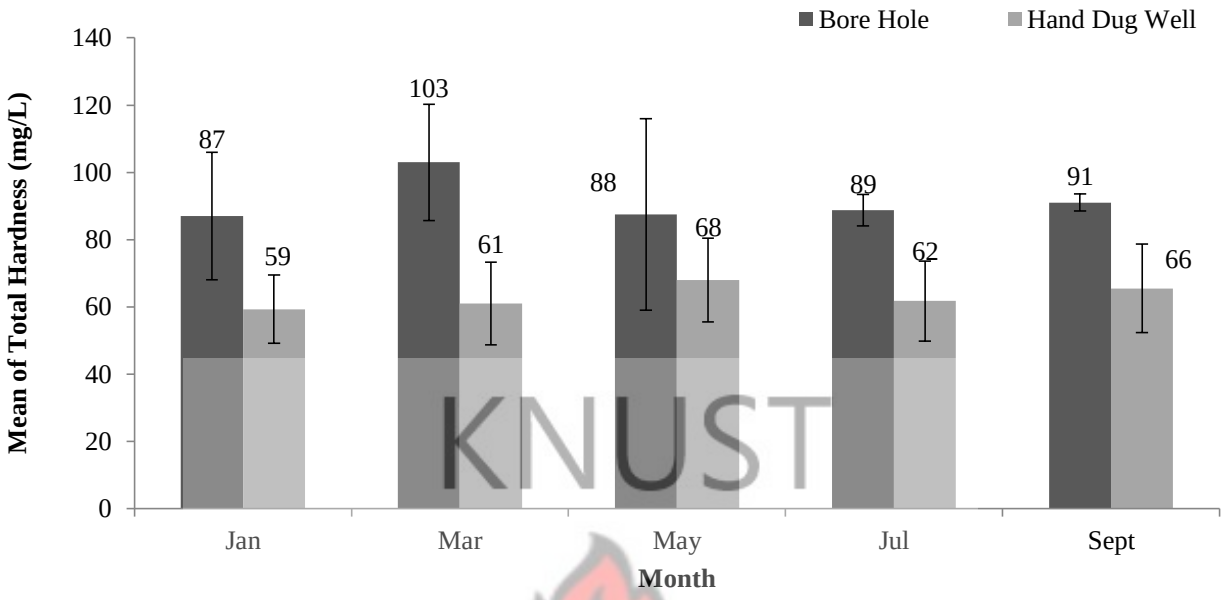

Fig 4.8 Mean TH values for borehole and hand dug well water sources. Bars indicate standard error.

Total hardness results recorded ranged from 59 to 103 mg/L with borehole water having consistently high values than well water sources as shown in Fig 4.8. Borehole water values ranged from 87 to 103 mg/L with a mean of 92 mg/L. Hand dug wells recorded values ranging from 59 to 68 mg/L with a mean of 63 mg/L. All values for all sources were well below the WHO, 2008 (not health-based) maximum guideline value of 500 mg/L. Maximum mean value recorded for total hardness for borehole waters was 103 mg/L in March whilst hand dug wells recorded its maximum mean of 68 mg/L value in May. Minimum mean values for borehole and hand dug well occurred in January. Borehole water recorded consistently higher mean values than hand dug wells. There were significant difference ($p=0.002$) between the total hardness concentration values of borehole and hand dug wells.

Nitrate

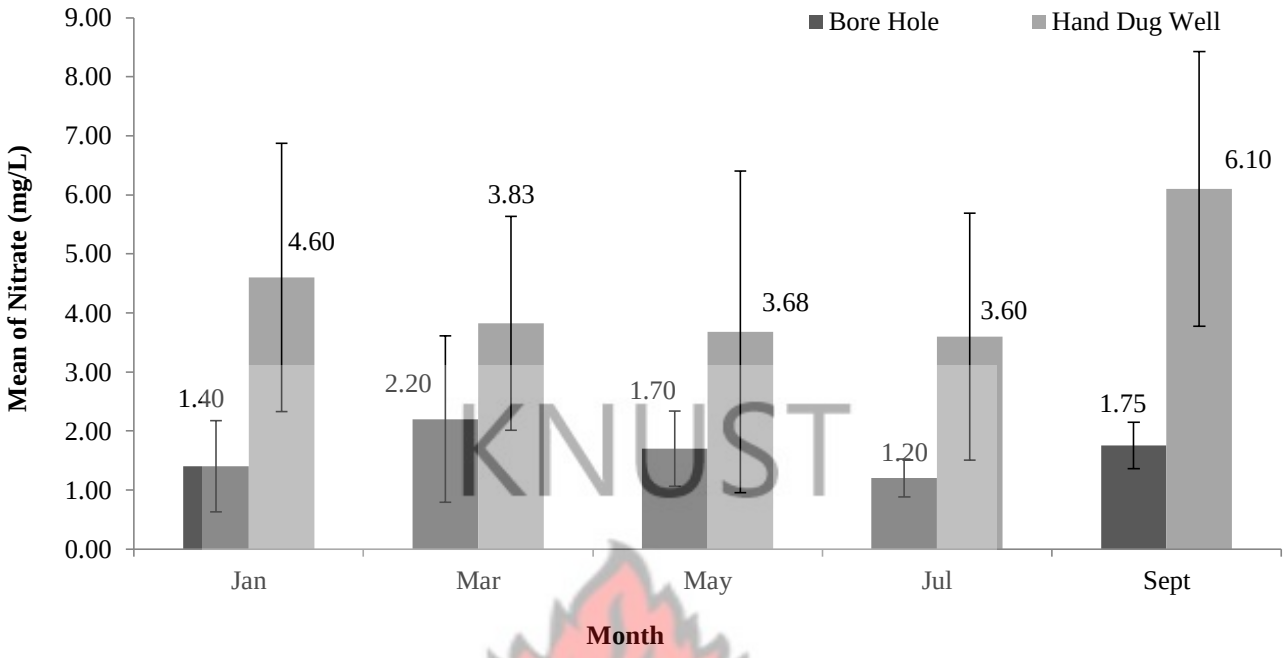

Fig 4.9 Mean nitrate values for borehole and hand dug well water sources. Bars indicate standard error.

Nitrate concentration values recorded for all sources ranged from 1.2 to 6.1 mg/L (Fig 4.9). Hand dug well sources recorded very high mean values for the parameter relatively to borehole water. Borehole values ranged from 1.2 to 2.2 mg/L with a mean of 1.7 mg/L. Hand dug well sources ranged from 3.6 to 6.1 mg/L with a mean of 4.5 mg/L. All the values were below the stipulated WHO guideline level of 10 mg/L. Hand dug wells recorded the maximum mean value for nitrates of 6.1 mg/L in September and had consistently higher values than that of borehole. Borehole recorded maximum mean value of 2.2 mg/L in March. Nitrate concentration values for boreholes differed significantly ($p=0.011$) from that of hand dug wells.

Nitrites

Fig 4.10 Mean nitrite values for borehole and hand dug well water sources. Bars indicate standard error.

Nitrite concentrations were significantly lower than the maximum WHO guideline value of 3.0 mg/L for all sources (Fig 4.10). Peak value was recorded for both hand dug wells and boreholes at 0.009 mg/L with mean values of 0.006 and 0.005 mg/L respectively. The differences in nitrite concentration values between borehole and hand dug well were statistically insignificant (p= 0.2898).

Chloride

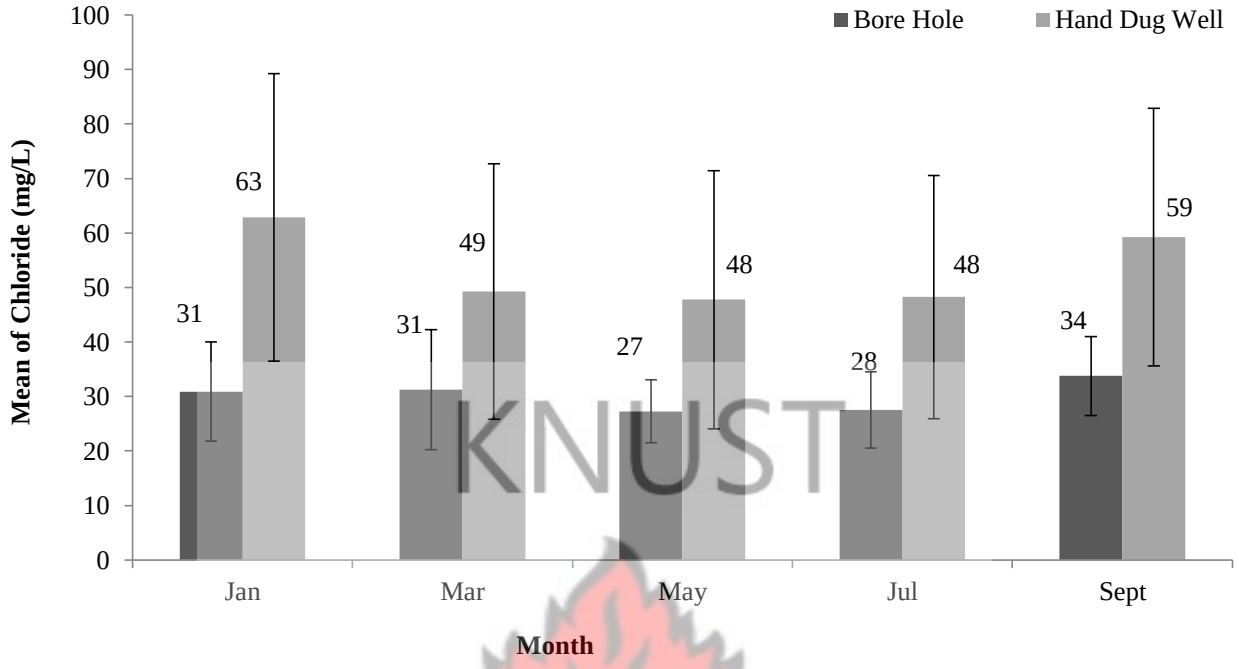

Fig 4.11 Mean chloride values for borehole and hand dug well water sources. Bars indicate standard error.

Mean concentration values for chloride ranged from 27 to 63 mg/L for all water sources during the study duration (Fig 4.11). Borehole sources recorded mean concentration values ranging from 27 to 34 mg/L with a mean of 30 mg/L whilst values for hand dug well sources ranged from 48 to 63 mg/L with a mean of 54 mg/L. Maximum value of 63 mg/L was recorded for hand dug well sources in January whilst that for boreholes was 34 mg/L in September. Mean concentration values for hand dug wells were consistently higher than that of borehole sources. All mean values for all sources were lower than the WHO stipulated maximum guideline value of 250 mg/L. The recorded chloride concentrations for borehole and hand dug well water samples were significantly different (p=0. 031).

Sulphate

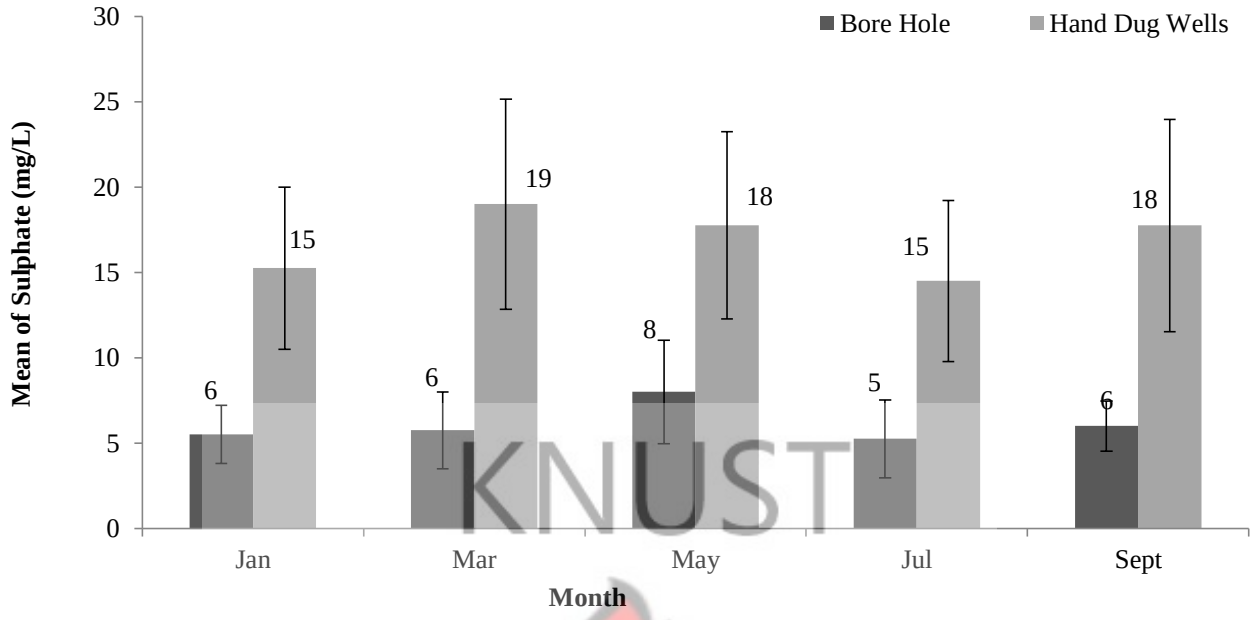

Fig 4.12 Mean sulphate values for borehole and hand dug well water sources. Bars indicate standard error.

Mean concentration values for sulphate was generally low in the study area and duration of study with values ranging from 5 to 19 mg/L (Fig 4.12). Borehole water sources ranged 5 to 8 mg/L with a mean of 6 mg/L and well water sources ranged from 15 to 19 mg/L with a mean of 17 mg/L. Hand dug well sources mean values were higher than values recorded for borehole sources during entire study duration. All values for all sources were below the WHO set maximum guideline (not health based) value of 400 mg/L. Hand dug well concentration values differed significantly (p=0.001) from that of borehole water values.

Phosphate

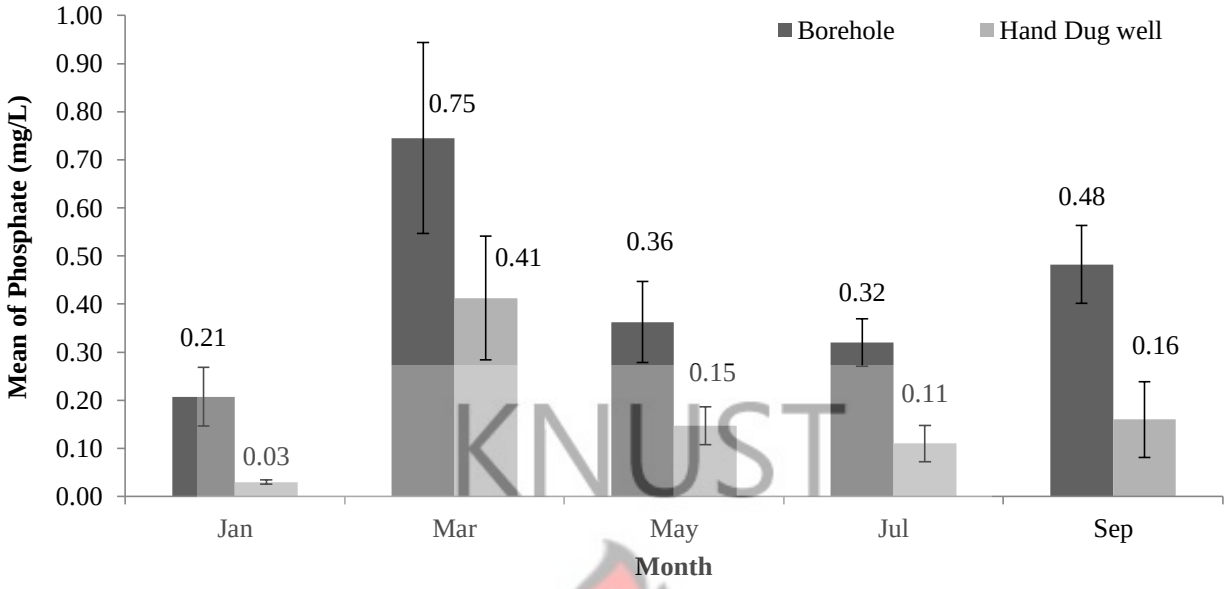

Fig 4.13 Mean phosphate values for borehole and hand dug well water sources. Bars indicate standard error.

Phosphate mean concentrations ranged from 0.03 to 0.75 mg/L for all sources (Fig 4.13). All source mean values were below the WHO (2008) guideline maximum value of 2.50 mg/L. Concentration values recorded for hand dug wells ranged from 0.03 to 0.41 mg/L with a mean of 0.19 mg/L whilst that for boreholes ranged from 0.21 to 0.75 mg/L with a mean of 0.44 mg/L. Borehole sources recorded consistently higher values than well water sources. Maximum mean value for borehole and hand dug well was 0.75 mg/L and 0.41 mg/L in March respectively. The concentration values of phosphates in borehole water differed significantly from that of hand dug well water ($p = 0.001$).

Fluorine

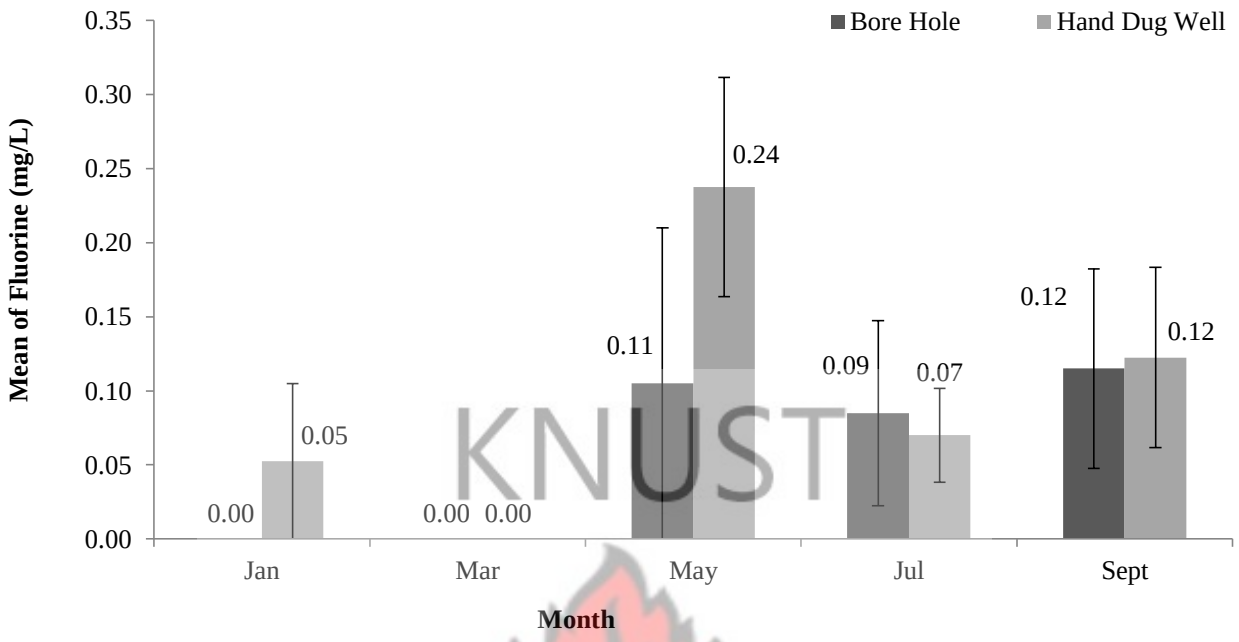

Fig 4.14 Mean fluorine values for borehole and hand dug well water sources. Bars indicate standard error.

Mean concentrations of fluorine for all sources ranged from 0.00 to 0.24 mg/L (Fig 4.14). Hand dug wells recorded highest results peaking at 0.24 mg/L. Boreholes sources recorded relatively lower concentrations with a maximum of 0.12 mg/L in September. Mean values for boreholes ranged from 0.00 to 0.12 mg/L with a mean of 0.06 mg/L whilst that for hand dug well sources ranged from 0.00 to 0.24 mg/L with a mean of 0.10 mg/L. All values were below the WHO health based maximum guideline value of 1.5 mg/L. The concentrations of fluorine in borehole and hand dug well did not differ significantly ($p=0.3652$)

Iron

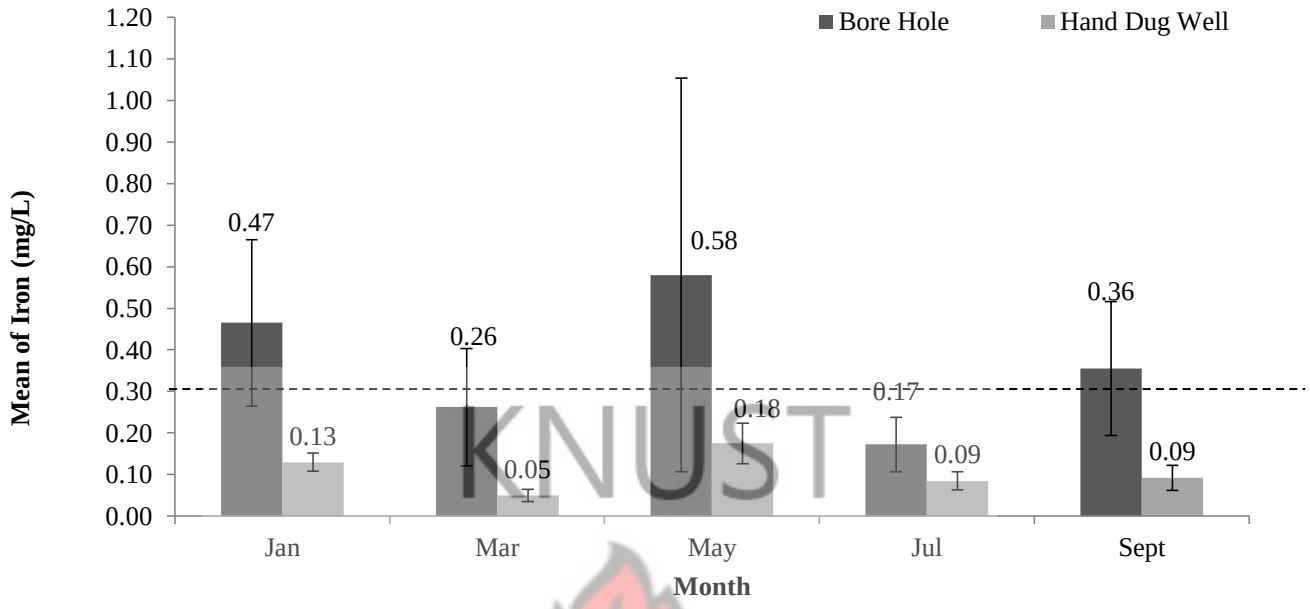

Fig 4.15 Mean total iron values for borehole and hand dug well water sources. Bars indicate standard error. The line indicates the maximum acceptable iron value stipulated by WHO (2008).

The mean concentration values for all sources ranged 0.05 to 0.58 mg/L (Fig 4.15). Values for borehole sources ranged from 0.17 to 0.58 mg/L with a mean of 0.37 mg/L. Hand dug well sources ranged from 0.05 to 0.18 mg/L with an average of 0.11 mg/L. The mean values for borehole were observed to be consistently higher than the values recorded for well water sources. Additionally mean values exceeded the maximum WHO (2008) guideline value of 0.3 mg/L in January, May and September with 0.47, 0.58 and 0.36 mg/L. All values recorded for well water sources were below the specification value peaking at 0.18 mg/L. Both sources recorded maximum values in May. The differences in iron concentration values between borehole and hand dug well were statistically different (p=0.023).

Manganese

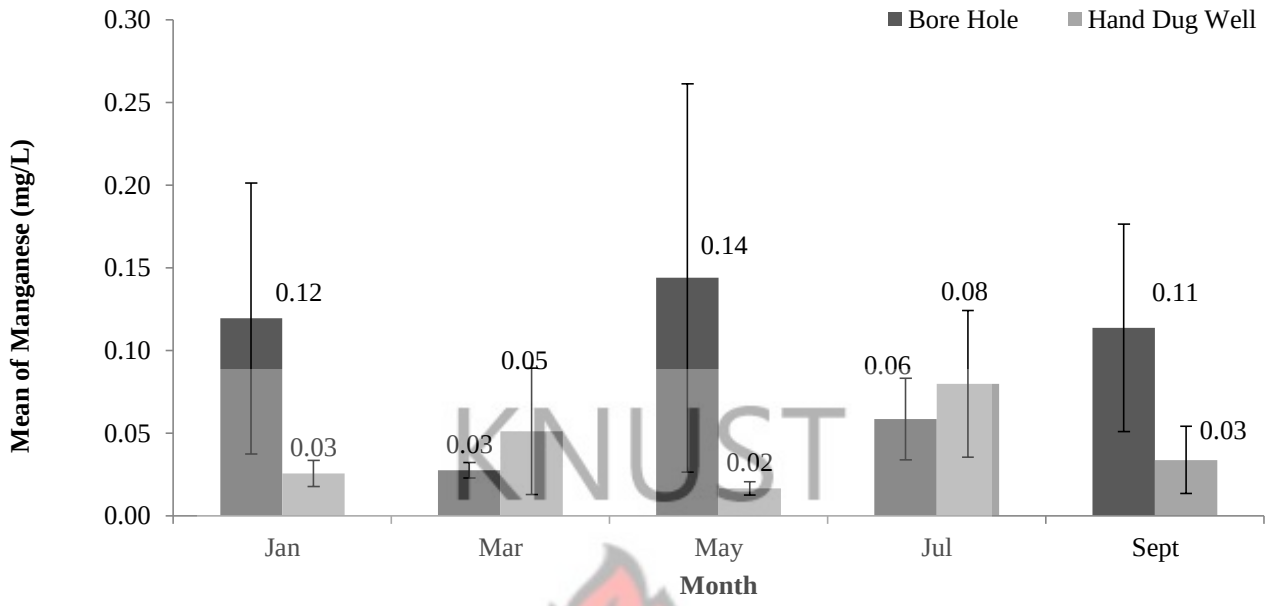

Fig 4.16 Mean manganese values for borehole and hand dug well water sources. Bars indicate standard error.

Manganese mean values for all sources ranged from 0.02 to 0.14 mg/L (Fig 4.16). Mean values for boreholes ranged from 0.03 to 0.14 mg/L with a mean of 0.09 mg/L whilst values recorded for hand dug wells ranged from 0.02 to 0.08 mg/L with a mean of 0.04 mg/L. Mean values recorded for boreholes were observed to be higher than values for hand dug wells in January, May and September. Maximum value of 0.14 mg/L was recorded for borehole in May whilst that for hand dug well of 0.08 mg/L occurred in July. All values for both sources were below the maximum guideline value proposed by WHO (2008) of 0.4 mg/L. Differences between manganese concentration values in borehole and hand dug well water samples were statistically insignificant (p=0.124).

Calcium

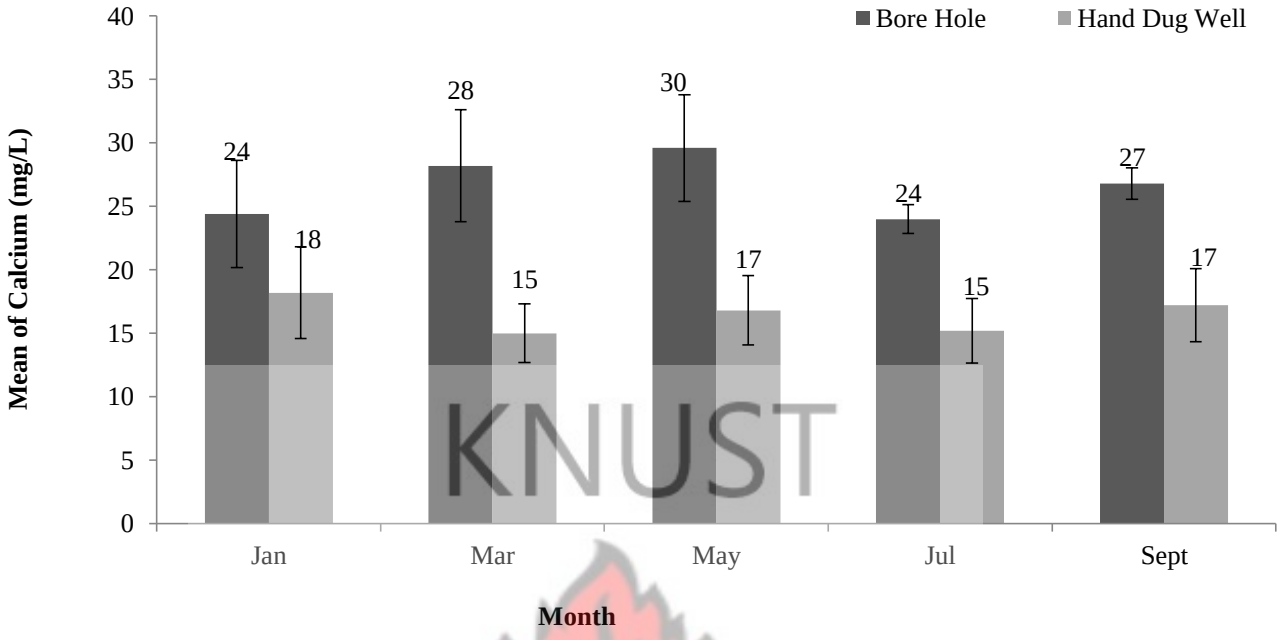

Fig 4.17 Mean calcium values for borehole and hand dug well water sources. Bars indicate standard errors.

All values recorded for calcium were lower than the WHO (2008) maximum guideline value (not health based) of 200 mg/L. Mean values recorded for calcium ranged from 15 to 30 mg/L during the study duration for all sources (Fig 4.17). Borehole sources recorded mean values ranging from 24 to 30 mg/L with a mean of 27 mg/L whilst hand dug wells recorded a range from 15 to 18 mg/L with a mean of 17 mg/L. Mean values for borehole sources were higher than that for hand dug wells throughout the duration of study. Maximum mean value for calcium was 2.96 mg/L and occurred in May for borehole while that for hand dug well was 18.2 mg/L recorded in January. Concentration values of calcium in borehole sources were significantly different from that recorded for hand dug well sources ($p=0.001$).

Magnesium

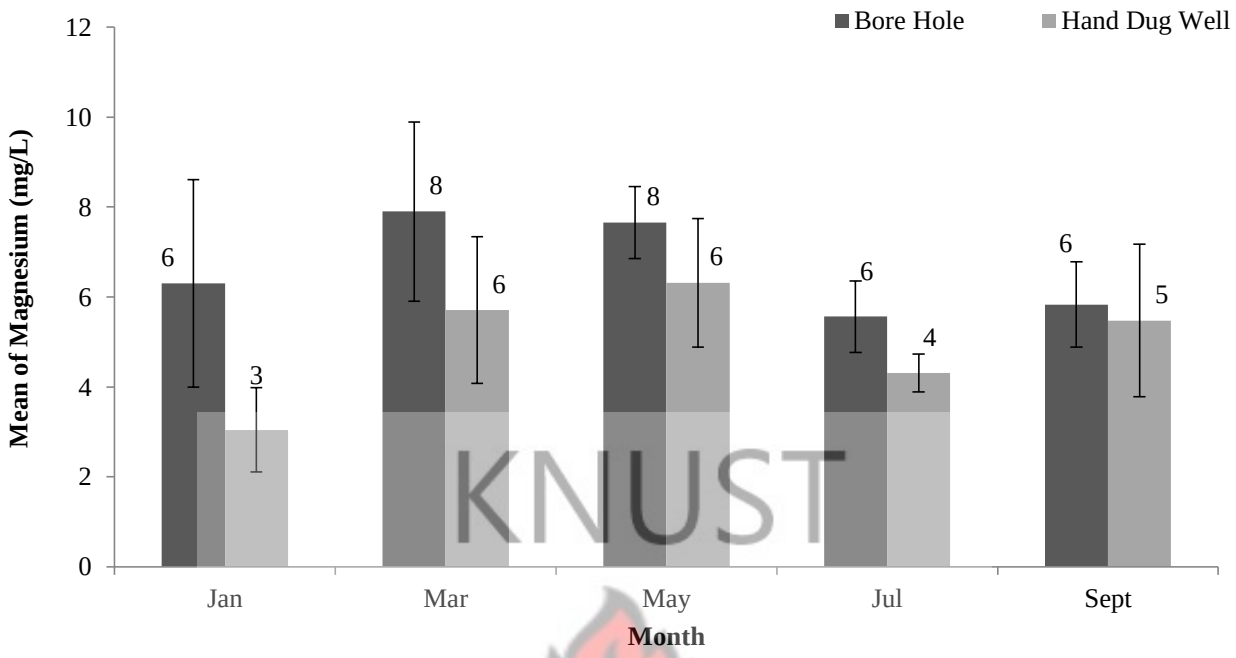

Fig 4.18 Mean magnesium values for borehole and hand dug well water sources. Bars indicate standard error.

Magnesium mean values recorded ranged from 3.0 to 7.9 mg/L (Fig 4.18) and all values were observed to be below the WHO (2008) maximum guideline value of 150 mg/L. All results recorded for borehole sources were higher than that recorded for hand dug well sources. Mean values recorded for borehole sources ranged from 5.6 to 7.9 mg/L with a mean of 6.7 mg/L whilst that for hand dug wells ranged from 3.0 to 6.3 mg/L with a mean of 4.9 mg/L. Maximum mean values for magnesium recorded for borehole was 7.90 mg/L in March whilst that for hand dug wells occurred in May with a value of 6.32 mg/L. Concentration values recorded for boreholes did not differ significantly from that of hand dug wells ($p=0.060$)

Lead and Arsenic

The WHO guideline value are <0.01 mg/L for both parameters. All sample sources recorded undetectable levels of these metals in them.

4.3 Distribution Line Monitoring

pH

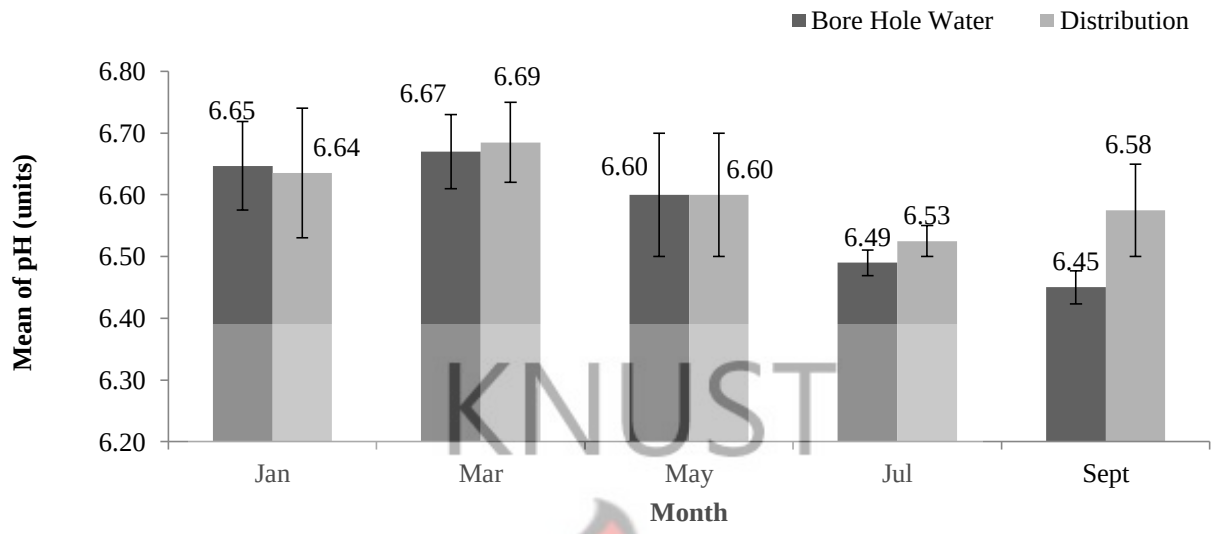

Fig 4.19 Mean pH values for borehole and distribution water. Bars indicate standard error.

pH increased in the distributions lines by at least 0.22%. The mean pH in the distribution lines ranged between 6.53 to 6.69 units with a mean of 6.60 (Fig 4.19). Mean values were within the WHO stipulated guideline range of 6.50 to 8.5 units.

Colour

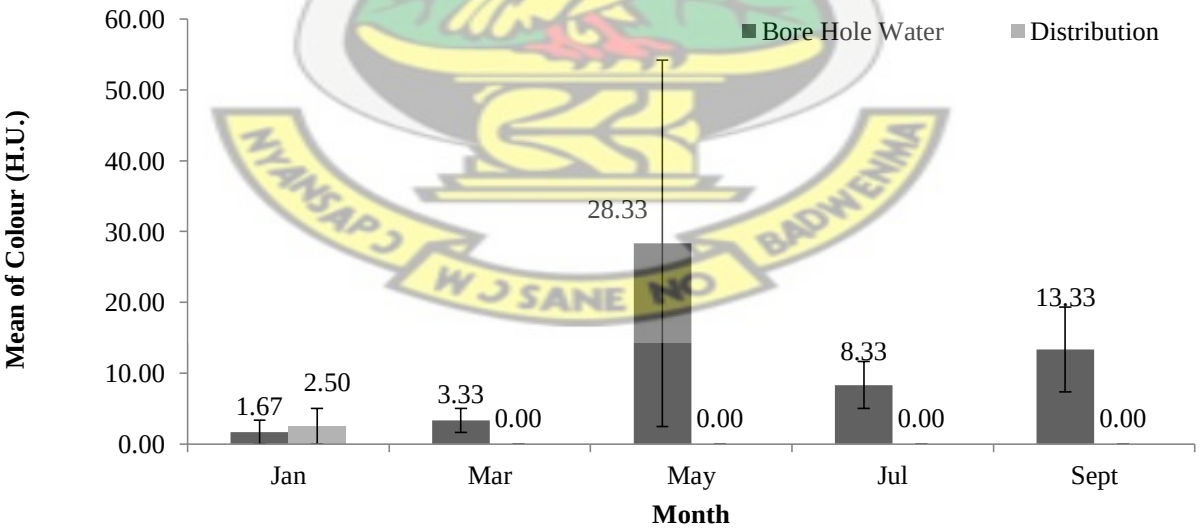

Fig 4.20 Mean colour values for borehole and distribution water. Bars indicate standard error.

Colour was not detected in all distribution samples except in January (Fig 4.20). However, results for January were within the WHO stipulated guideline range.

Turbidity

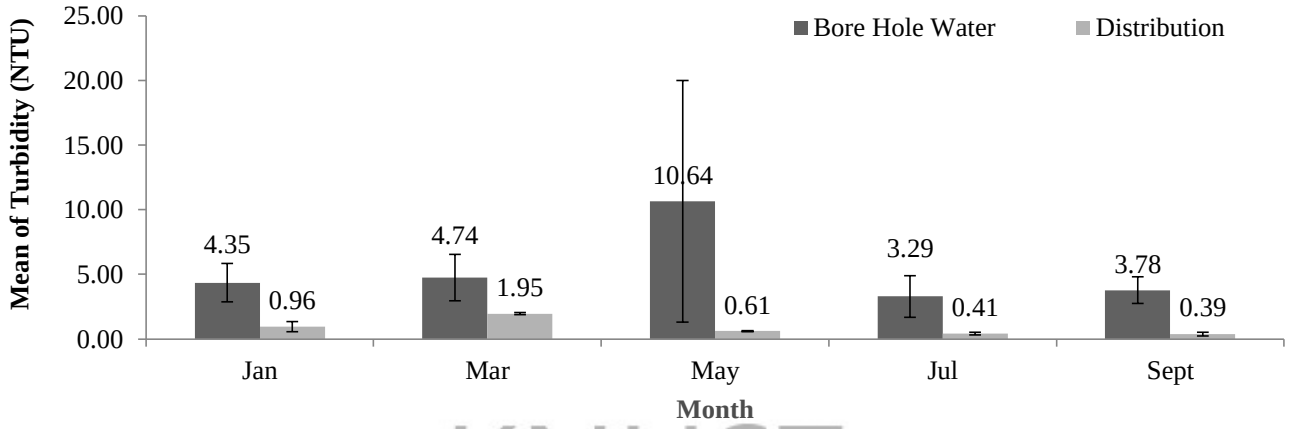

Fig 4.21 Mean turbidity values for borehole and distribution water. Bars indicate standard error

Mean turbidity concentration values for distribution water reduced by at least 59% in the lines with the highest reduction in May (Fig 4.21). Mean turbidity values recorded for distribution water ranged from 0.39 to 1.95 NTU with a mean of 0.95 NTU. All values recorded were below the maximum guideline value stipulated by WHO, 2008.

Conductivity

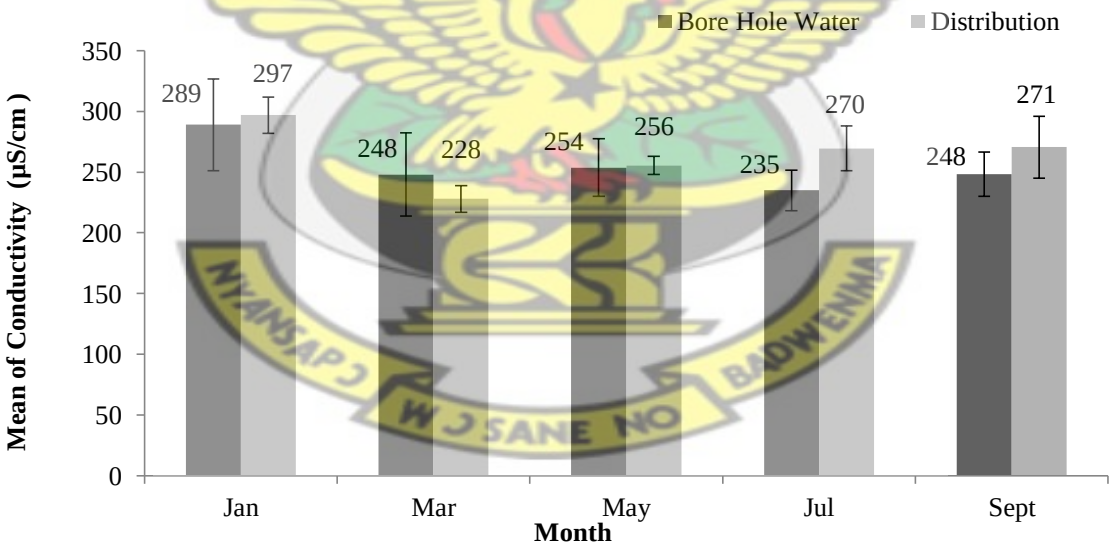

Fig 4.22 Mean conductivity values for borehole and distribution water. Bars indicate standard error

Mean conductivity values exhibited minimal increase with at 3% increase in values from source borehole water (Fig 4.22). Conductivity values for distribution water ranged between 228 to 297 mg/L with a mean of 264 mg/L.

Total Dissolved Solids

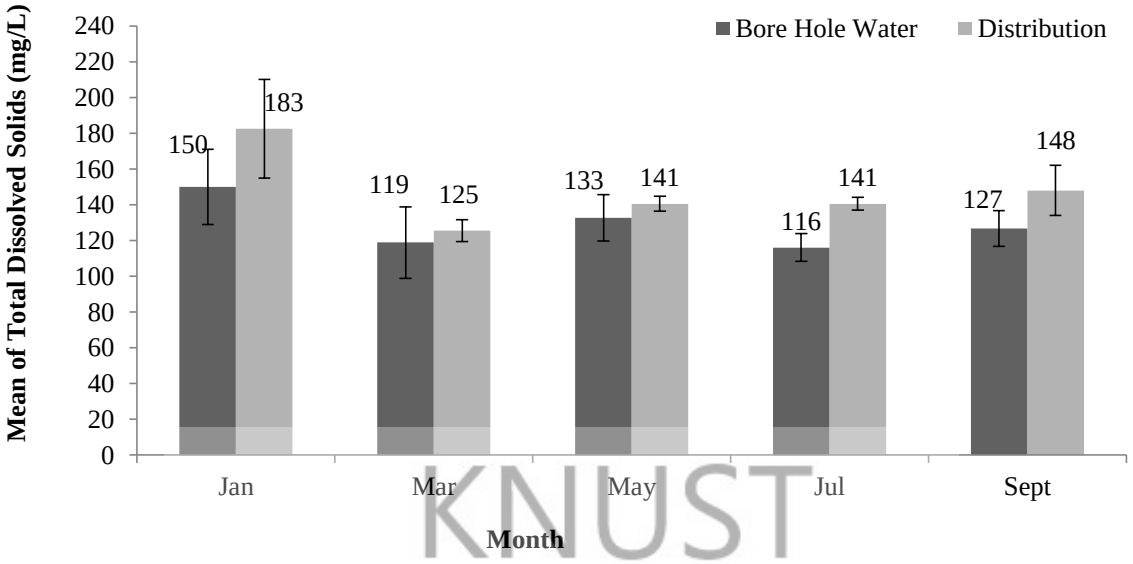

Fig 4.23 Mean TDS values for borehole and distribution water. Bars indicate standard error.

Mean values for total dissolved solids increased slightly by at least 6% and maximum increase of 21% in the distribution lines. Concentration values for distribution water ranged from 125 to 183 mg/L with a mean of 149 mg/L (Fig 4.23)

Total Suspended Solids

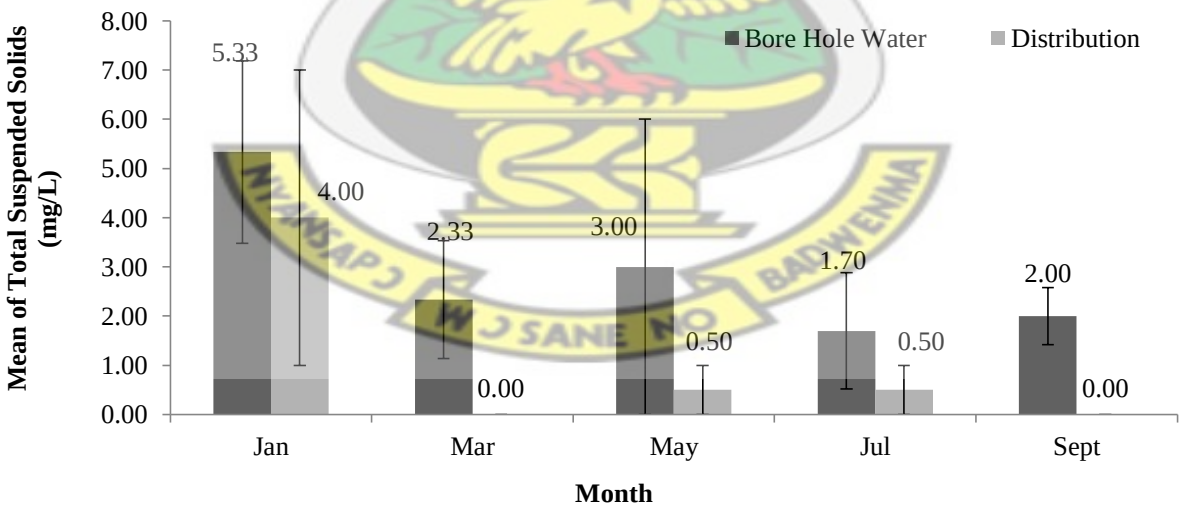

Fig 4.24 Mean TSS values for borehole and distribution water. Bars indicate standard error.

Values recorded for TSS for distribution water ranged from 0 to 4 mg/L (Fig 4.24). Mean values for the parameter indicated at least 27 % decrease from that recorded for the source borehole

Total Alkalinity

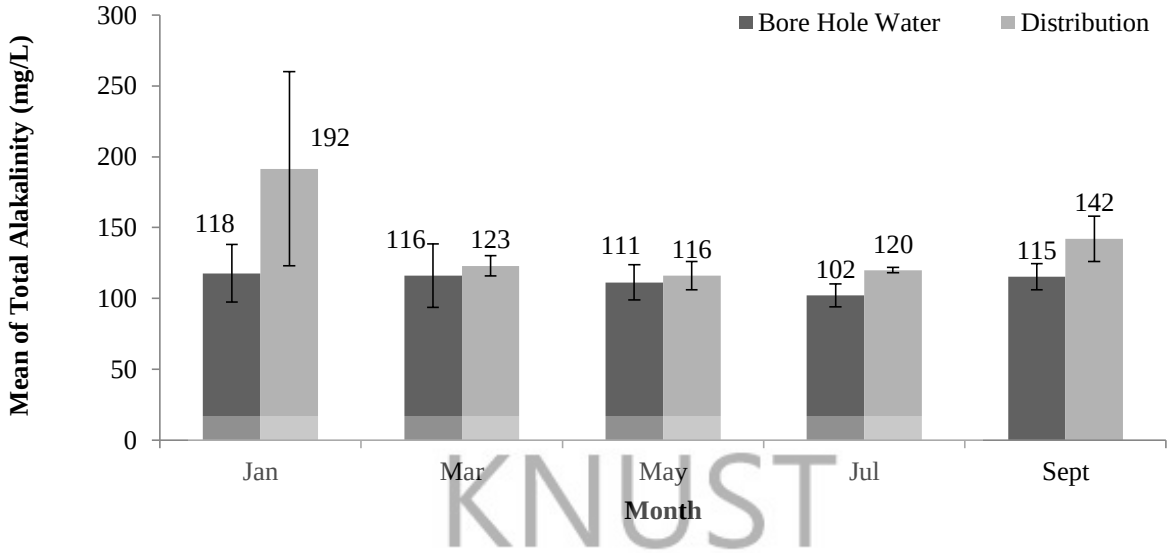

Fig 4.25 Mean total alkalinity values for borehole and distribution water. Bars indicate standard error.

Mean values for total alkalinity increased by at least 4% in the distribution pipeline. Values recorded ranged from 116 to 192 mg/L with a mean of 139 mg/L (Fig 4.25). Maximum increase (63%) was observed in January.

Total Hardness

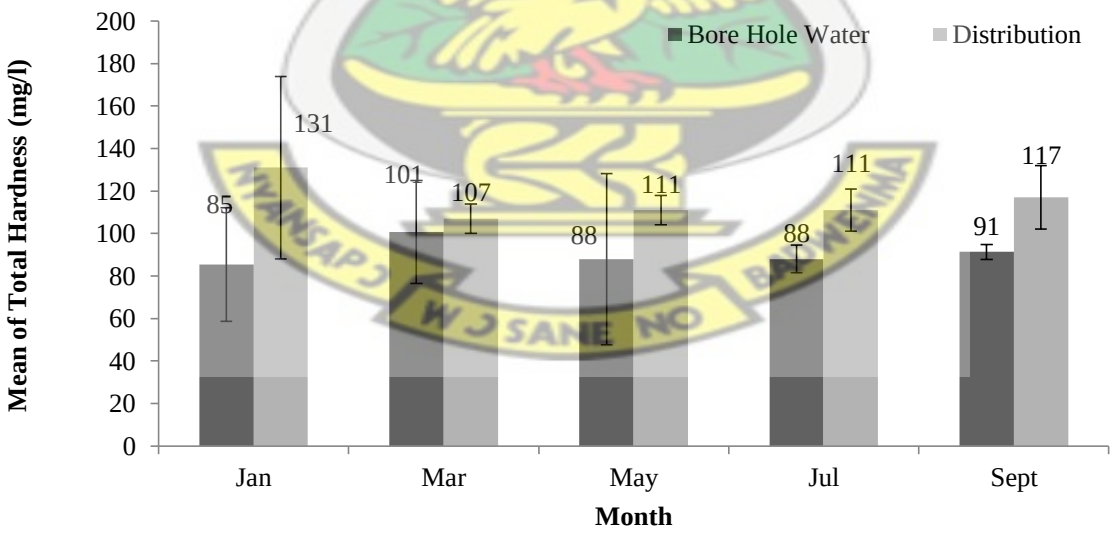

Fig 4.26 Mean total hardness values for borehole and distribution water. Bars indicate standard error.

Total hardness appreciated at least 6% (March) in the distribution lines. Mean concentration values recorded ranged from 107 to 131 mg/L with a mean of 115 mg/L (Fig 4.26). Maximum increase (54%) was recorded in January.

Nitrate

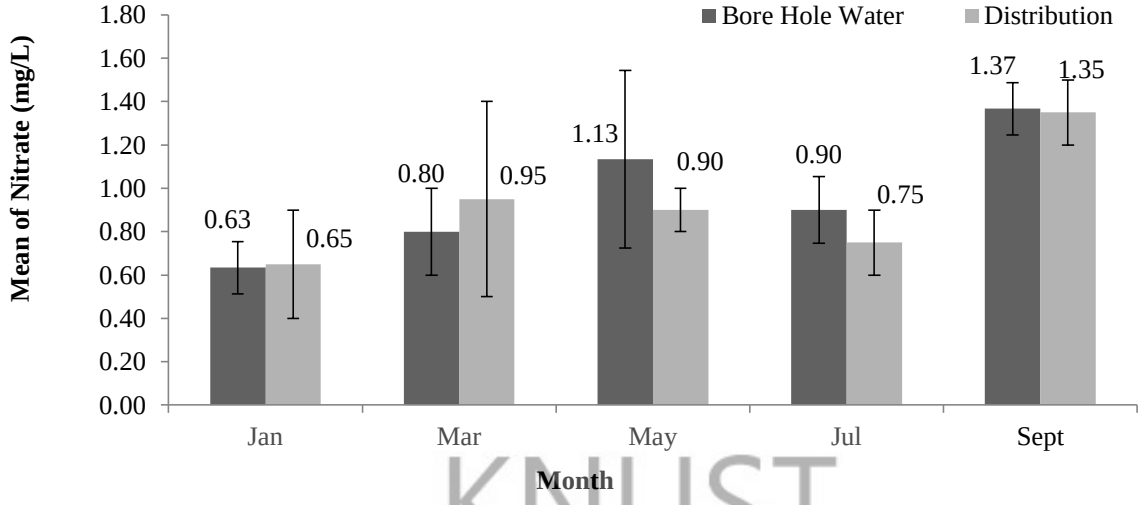

Fig 4.27 Mean nitrate values for borehole and distribution water. Bars indicate standard error.

Mean values recorded for nitrates exhibited a decrease of at least 1 % (September) in the distribution pipes with a maximum of 21% (May). Concentration values ranged from 0.65 to 1.35 mg/L with a mean of 0.92 mg/L (Fig 4.27). All values were below the maximum guideline value stipulated by WHO, 2008.

Nitrite

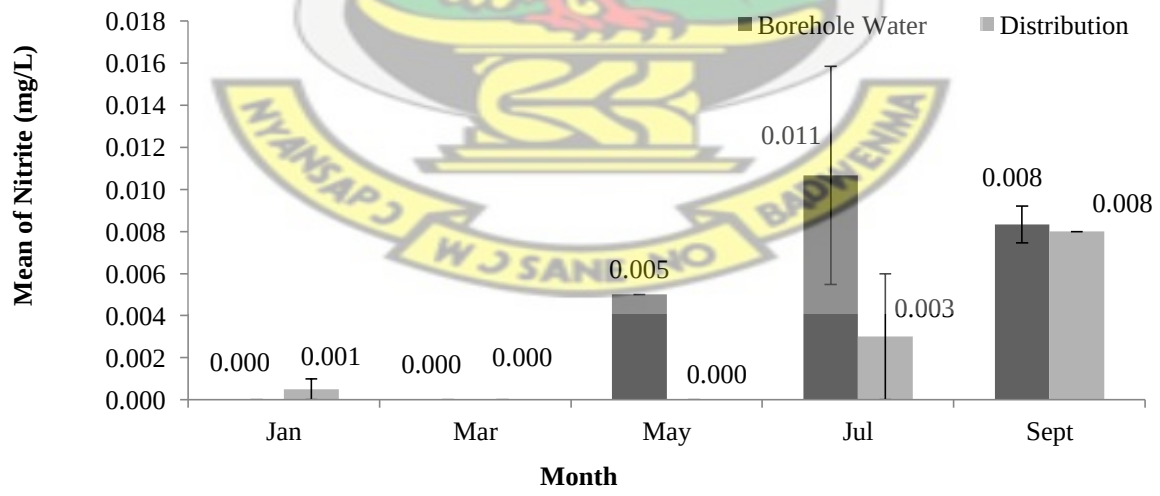

Fig 4.28 Mean nitrite values for borehole and distribution water. Bars indicate standard error.

Nitrite values were barely detectable in the distribution lines. Mean values for the parameter ranged from 0 to 0.008 mg/L with a mean of 0.002 mg/ as shown in Fig 4.28. All values exhibited decrease of at least 4 % and a maximal decrease of 100% in May.

Chloride

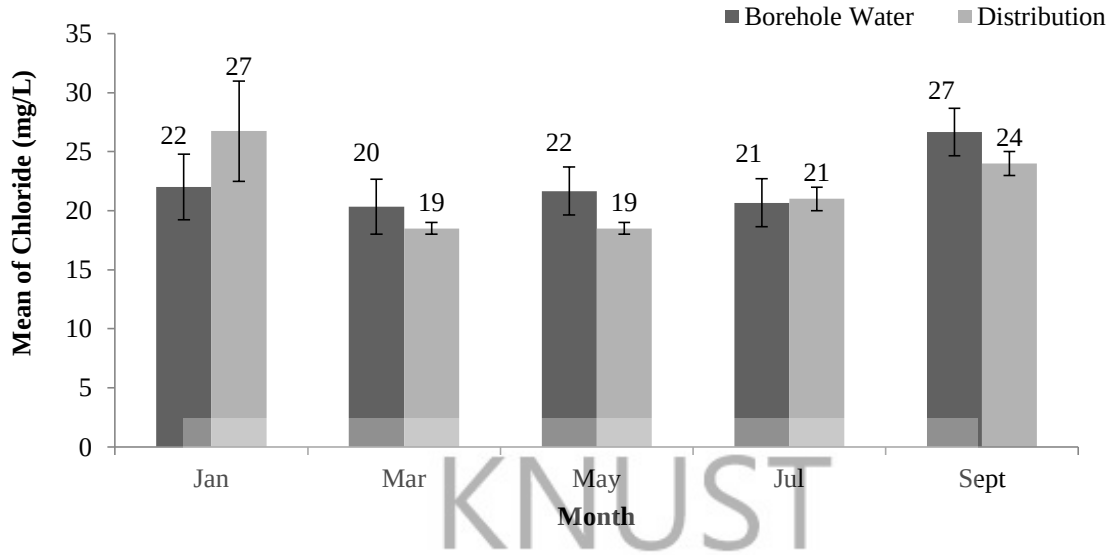

Fig 4.29 Mean chloride values for borehole and distribution water. Bars indicate standard error.

Mean chloride values for distribution lines ranged from 19 to 27 mg/L with a mean of 22 mg/L (Fig 4.29). Concentration values for the parameter in the distribution lines exhibited varying changes throughout the study duration. There was a decrease of at least 9% in March.

Sulphate

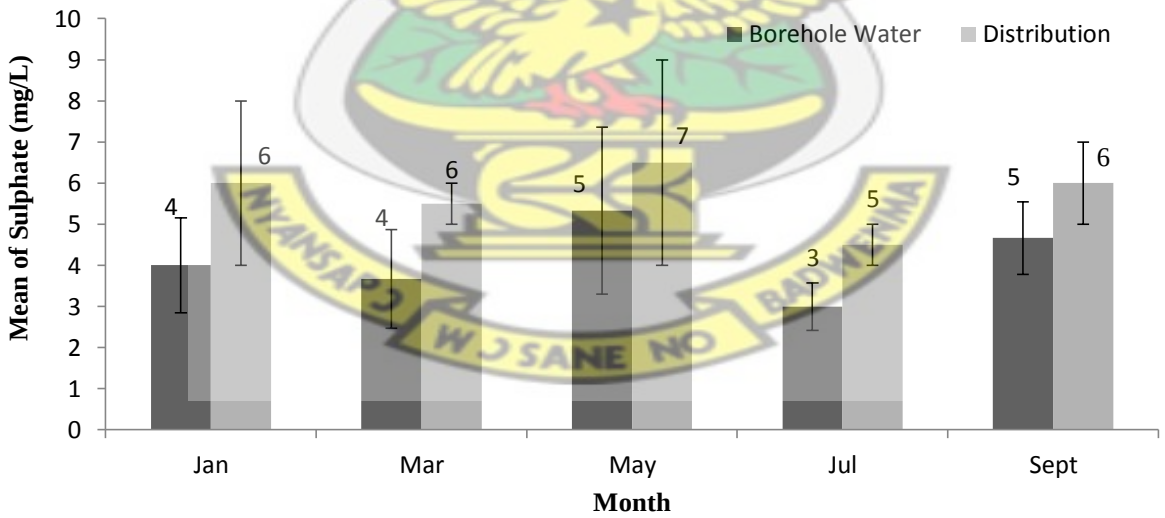

Fig 4.30 Mean sulphate values for borehole and distribution water. Bars indicate standard error.

Sulphate concentrations in the distribution lines remained fairly unchanged throughout the duration of the study. Mean values recorded for the parameter in the distribution lines ranged from 5 to 7 mg/L with a mean of 6 mg/L (Fig 4.30). Mean values increased by at least 22% in May.

Fluoride

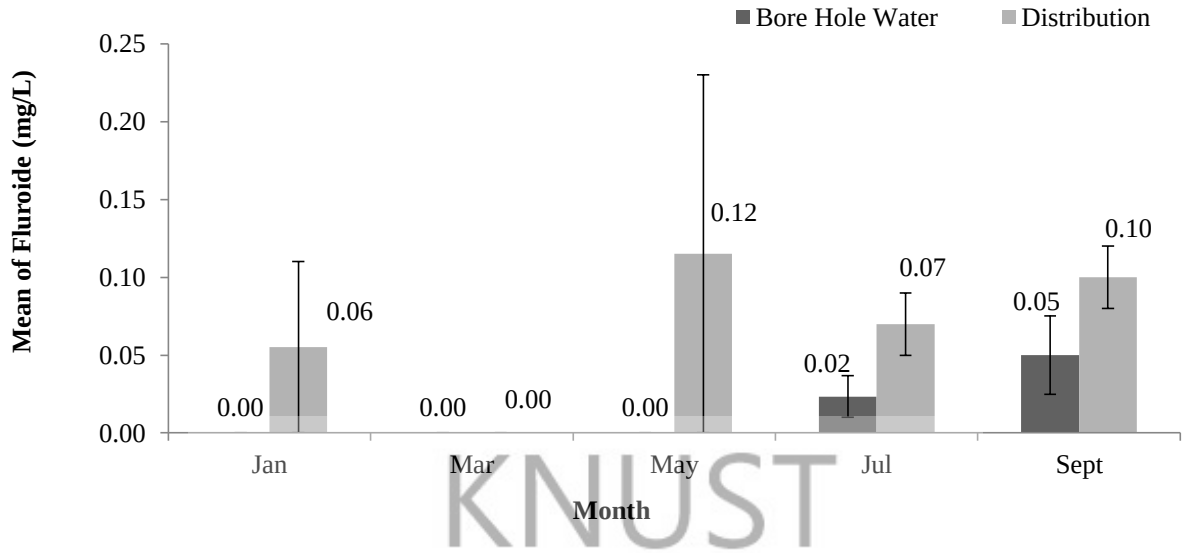

Fig 4.31 Mean fluoride values for borehole and distribution water. Bars indicate standard deviation

Mean values for fluoride concentrations in the distribution lines increased slightly throughout the study duration with the maximum increase occurring in May. Values recorded ranged from 0 to 0.115 mg/L with a mean of 0.068 mg/L (Fig 4.31).

Phosphate

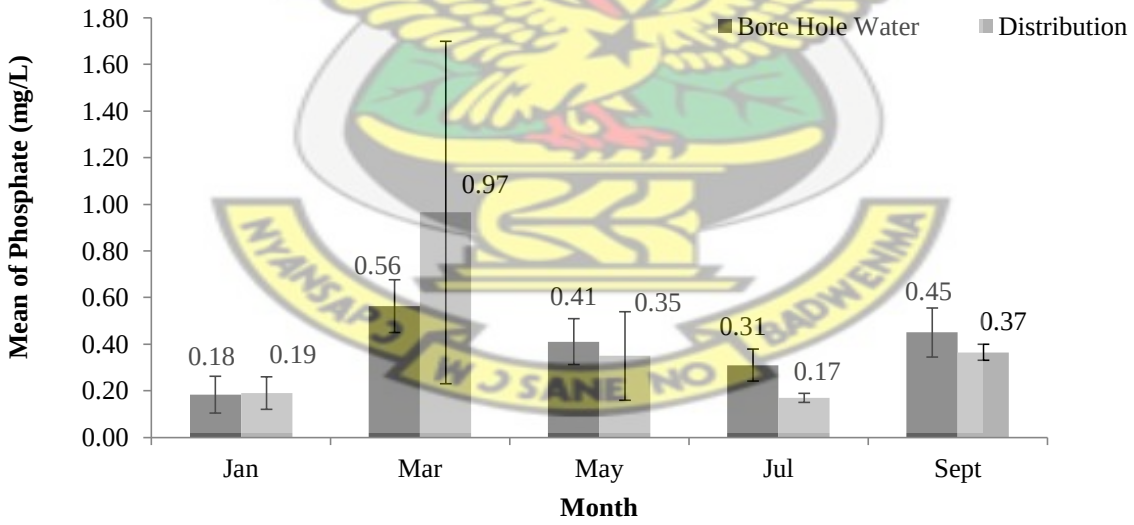

Fig 4.32 Mean phosphate values for borehole and distribution water. Bars indicate standard error.

Mean concentration values of phosphate ranged between 0.17 to 0.97 mg/L with a mean of 0.41 mg/L for distribution water (fig 4.32). Concentration values showed a minimum decrease of 1% for May from the borehole water. It however experienced a higher decrease in July and September.

Iron

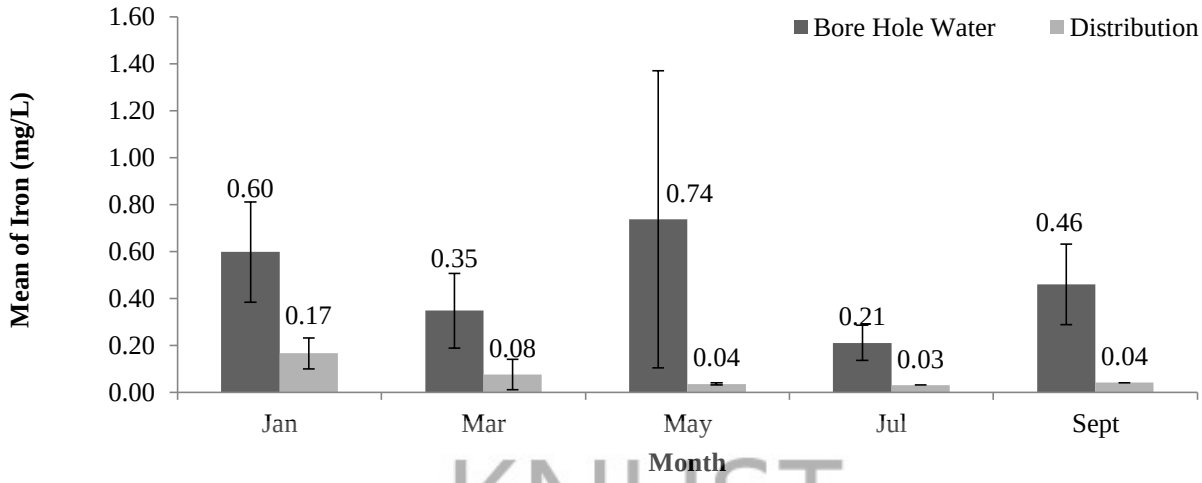

Fig 4.33 Mean iron values for borehole and distribution water. Bars indicate standard error.

Iron concentration values recorded very marked decrease in the distribution water. Minimum decrease of 72% was recorded in January whilst the maximum decrease of 95% occurred in May. All results were below WHO, 2008 specification. Concentration values for the parameter ranged from 0.030 to 0.165 mg/L with a mean 0.069 mg/L for distribution water (Fig 4.33).

Manganese

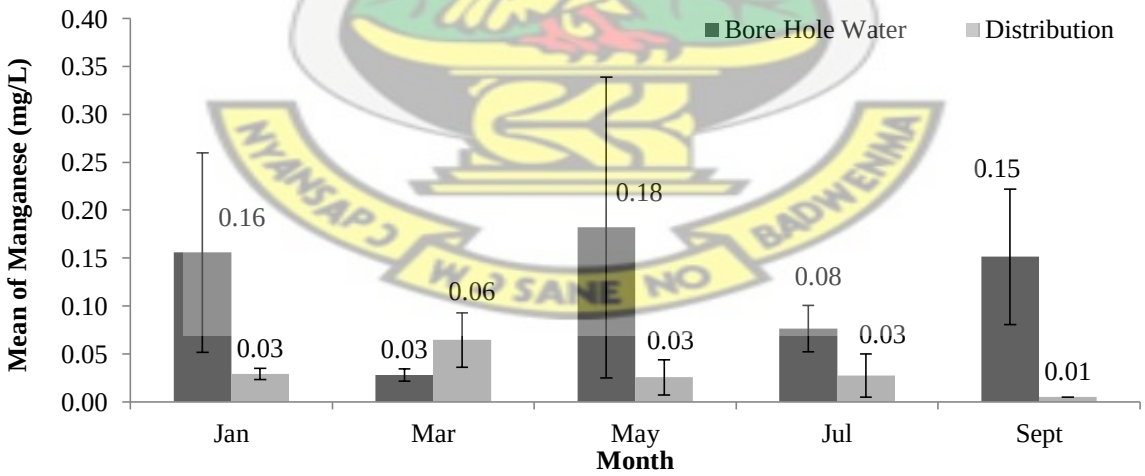

Fig 4.34 Mean manganese values for borehole and distribution water. Bars indicate standard error.

Mean concentration values for manganese ranged from 0.01 to 0.06 mg/L with a mean of 0.03 mg/L for distribution water (Fig 4.34). Results decreased from the source borehole water by at least 64% throughout the duration of study. However there was a 130% increase in results in March.

Calcium

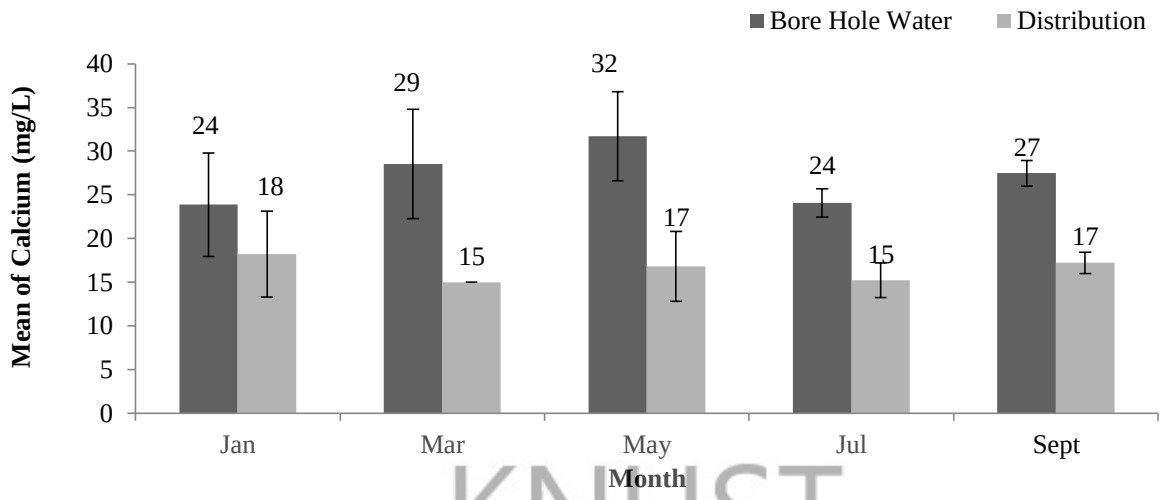

Fig 4.35 Mean calcium values for borehole and distribution water. Bars indicate standard error.

There was an increase in the mean concentration values of calcium by at least 11% in the distribution water. However maximum increase was realized at 51% in January. Results for calcium ranged from 31 to 36 mg/L with a mean of 34 mg/L (Fig 4.35).

Magnesium

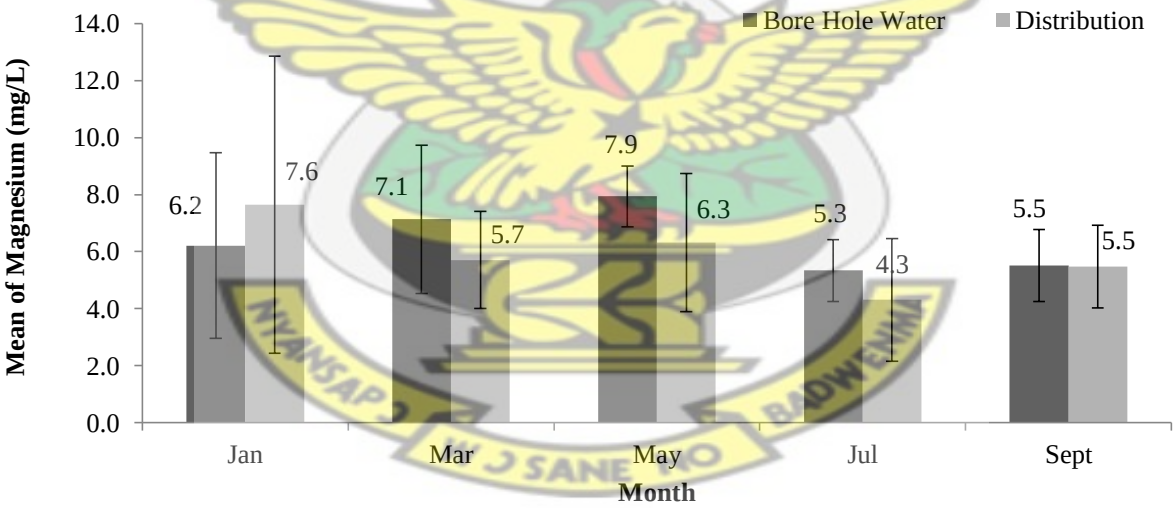

Fig 4.36 **Mean** magnesium values for borehole and distribution water. Bars indicate standard error.

Mean concentration values of magnesium ranged from 4.3 to 7.6 mg/L with a mean of 5.9 mg/L for distribution water (Fig 4.36). Apart from January and May all the other months experienced a decrease in concentration values by at least 3% in distribution water from the source borehole water.

Lead and arsenic were not detected in the distribution water during the study period.

CHAPTER FIVE

DISCUSSION

5.1 Physico-chemical Parameters and Water Quality

pH

The values for pH of all the sampling points were slightly acidic. According to Hounslow (1995) and Langmuir (1997), carbonic acid is produced in the groundwaters due to the dissolution of atmospheric CO_2, or CO_2 is generated in the soil zone from a result of the oxidation of soil organic matter. Ground waters become acidic as a result. However the borehole water met the minimum specification for the WHO (2008) guideline throughout the duration of the study except in the months of July and September where values fell slightly below the minimum specification. Well water was the most acidic of the sources ranging from 4.05 to 6.20 units. The most desirable range stipulated for pH of domestic drinking water is between 6.5 to 8.5 (USEPA, 1997; WHO 2008). As anthropogenic effects on the groundwater is generally low in the area this phenomenon trend can be attributed to natural geochemical and biochemical processes within the aquifers (Edwards, 1981). This is due to the presence of sulphides and carbonaceous matter in the ore formation. The consequence is a natural geochemical and biochemical degradation (oxidation) of these rocks which occurs when they are in contact with oxygen gas containing water leading to acid production. However, these natural production of acidified water can be neutralized by a natural means of reactions with lime containing ores.

Acidity increases the capacity of the water to attack geological materials and leach toxic trace metals into the water making it potentially harmful for human consumption. Acidity gives sour taste to water. The trend of pH results suggests the influence of seasonal changes on the natural mineral composition of the groundwater thus the steady decrease in pH to the more acidic region especially for hand dug wells.

Colour

Colour is normally more prevalent in surface water sources (Nova Scotia Environment, 2012) There was a sharp elevation of colour value in the month of May to study duration peak of 25 H.U. for borehole water whilst hand dug well peaked at 8.75 H.U. for the same month. Recorded values for hand dug well sources remained under the maximum value for the parameter throughout the duration of the study. Borehole water values remained consistently higher than hand dug well water with the suggestion of influence from seasonal changes. The red colour as seen in the water suggests high iron concentration (of which a higher Fe^{3+} proportion is suspected) in the borehole water also contributed to the consistent high results.

The presence of colour in drinking water may be indirectly linked to health, although its primary significance in drinking water is aesthetic.

Turbidity

Turbidity values were mostly under the WHO guideline specification. However a sharp increase in all sources was observed in May where values, except for hand dug water were within the guideline value of 15 NTU. There was another increase in September but all results remained below the guideline value. Turbidity in drinking-water is caused by particulate matter that may be present from source water as a consequence of inadequate filtration or from re-suspension of sediment in the distribution system (WHO, 2008). High iron concentrations have the tendency to influence high turbidity values (USEPA Guidance Manual: Turbidity Provisions 1999). High iron levels in borehole water was implicated in the high turbidity values in borehole water. However variations in values of turbidity were found to be insignificant ($p=0.1663$) between the two sources.

Although turbidity is not a direct indicator of health risk, numerous studies show a strong relationship between removal of turbidity and removal of protozoa.

Strong correlations have implicated turbidity levels and protozoa removal in water. In fact, in every study to date where pathogens and turbidity occur in the source water, pathogen removal coincides with turbidity/particle removal (Fox, 1995).

Data gathered by LeChevallier and Norton (1993) from three drinking water treatment plants using different watersheds indicated that for every log removal of turbidity, 0.89 log removal was achieved for the parasites *Cryptosporidium* and *Giardia* although this exact relationship does not hold for all treatment plants.

Conductivity

The conductivity values for all sources were generally low with the maximum being 339 µS/cm for well water sources. Low conductivity in the area indicates that the water is unable to react with the rock matrix to equilibrium which indicates short resident times (Kortatsi, 2004). Statistical analysis of the means of concentration values of electrical conductivity shows insignificant differences between results for borehole and HDW sources ($p=0.3121$)

Total Dissolved Solids

Trends observed with total dissolved solids concentrations with the maximum value recorded at 175 mg/L for hand dug well water sources. Davis & DeWiest (1966) regard groundwater as fresh water if the groundwater TDS value is less than 1000 mg l^{-1} (Table 2.3). Total dissolved solids (TDS) comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and small amounts of organic matter that are dissolved in water. The low values indicate that the groundwaters are generally fresh.

Total Suspended Solids

The highest value for the total suspended solids was observed with well water sources with a value of 5.8 mg/L. Though there is no guideline value, high total suspended solids to a great extent affect quality of drinking water. WHO (2008) contends that pathogens are often clumped or adherent to suspended solids in water affect disinfection treatment of the water.

Alkalinity

Alkalinity refers to the total amount of bases in water expressed in mg/L of equivalent calcium carbonate. In most waters these bases are principally bicarbonate (HCO^-) ions and carbonate ions (CO_3^{2-}). These ions are the buffers in water; that is they buffer the water against sudden changes in pH. Alkalinity management also contributes to the stability of water and controls its aggressiveness to pipe and appliance, WHO (2008). Consistency in relatively high values was observed in borehole water and same consistency in relatively lower values was observed for well water. However concentrations were higher in borehole water peaking at 105 mg/L while that for well water peaked at 40 mg/L. These values give an indication of the buffering capacity of the sources of water in the area. Waters of low alkalinity have a low buffering capacity and can, therefore, be susceptible to alterations in pH, for example from atmospheric, acidic deposition. It follows the borehole water has higher buffering capacity than the hand dug well sources.

Total Hardness

The values for the borehole was observed to be moderately hard, Hem (1985) with values ranging from 87 to 103 mg/L whilst results for well water was in the soft classification. Earlier studies done in Wassa West which borders Mpohor to the north suggests that the groundwaters from the Wassa West District vary largely in total hardness from 10 mg l^{-1} to 358 mg l^{-1} with generally the waters ranging from moderately hard to very hard with only

40% of the boreholes having soft water, Kortatsi (2004). The difference in the values of the parameter in the two districts can be due to the underlying terrain. A paper by Neri and others (1975) presented data from Canada supporting the hypothesis that hard water provided some protection from heart disease because of its increased magnesium content. Hard water has been found to be generally acceptable and insignificant until it reaches a level over 100 mg/L, Hem (1985). Very noticeable taste and increased scale deposition in pipe network is realized at levels above 500 mg/L, WHO (2008). Generally soap consumption with its resultant scum formation is also increased.

Nitrates

Nitrates are considered to be non-cumulative toxins. Shallow or unconfined aquifers can be subject to contamination from discharges or seepages associated with agricultural practices (e.g., pathogens, nitrates and pesticides). Methaemoglobinaemia caused by excess nitrate exposure affects infants up to approximately 3–6 months of age.

Nitrate values for all sources were below the WHO guideline value of 10 mg/L. The location (situated on the outskirt of town) and depth of the boreholes can be credited with the low values of nitrate values thereby reducing the risk which could have resulted from nitrate contamination. Nitrate values remained at consistent high of close to 5 mg/L for well water.

Nitrite

Nitrite values were almost below detection and very small with the maximum recorded for all sources being 0.011 mg/L against the minimum WHO guideline of 3.0 mg/L. Differences between the concentration values of the source drinking waters are not significant. The low concentration values recorded for nitrites for both borehole and HDW indicates that the parameter does not give cause for concern and it makes the water sources suitable for direct domestic use.

Chloride

All values for all sources were below the WHO guideline (not health based) of 250 mg/L. The concentrations of chloride, though, not considered a water quality parameter can affect the taste of the water when in excess of 250 mg/L. High chloride levels close to and above 250 mg/L impact a salty taste to drinking water. In fact the low levels in all sources indicate suitability for drinking.

Sulphate

Sulphate is not considered a water quality indicator. However, it has been reported that above a level of 500 mg/L cathartic effects are felt by drinkers. Additionally a bitter astringent taste is imparted at high levels of sulphate concentration. All samples were below the WHO guideline value of 400 mg/L. Levels in borehole water were very low peaking at 5 mg/L in May. Relatively high levels were however observed with well water where values peaked at 19 mg/L.

Phosphate

Concentration values for the parameter showed varying levels during study duration. Borehole water peaked at 0.75 mg/L in March against a WHO guideline value of 2.5 mg/L. Phosphate value for well water was relatively lower and also peaked at 0.41 mg/L also in March suggesting the possible seasonal influence in the elevation of the parameter for the two ground water drinking sources. High phosphate levels have been found to accelerate eutrophication process in surface waters as phosphorus is a very essential nutrient for plants. Various forms of phosphorus as phosphates are applied to drinking water supply network as anti-corrosives to protect the pipes.

Fluoride

The 1958 and 1963 WHO International Standards for Drinking-water referred to fluoride, stating that concentrations in drinking-water in excess of 1.0–1.5 mg of fluorine per litre may give rise to dental fluorosis in some children, and much higher concentrations may eventually result in skeletal damage in both children and adults. Additionally epidemiological evidence has also demonstrated that concentrations above this value carry an increasing risk of dental fluorosis, and progressively higher concentrations lead to increasing risks of skeletal fluorosis (WHO, 2008). Concentration values for the parameter were found to be below detection for January and March. Levels increased to a peak of 0.42 mg/L for semi-borehole water but values for borehole remained very low peaking to 0.050 mg/L in September.

Total Iron

Borehole water concentration value for the total iron exceeded the WHO guideline value of 0.3 mg/L for all months except in the month of July peaking at 0.74 mg/L in May. However, values for well water remained well below 0.2 mg/L during the duration of study. The significant difference in iron concentration in the water sources suggests the influence of underlying terrain to be a contributory factor. Presence of iron in groundwater resources is explained by the chemical weathering (oxidation) of iron bearing rocks by weak carbonic acids formed either in the air or soil. The variations in iron levels in the aquifers can be attributed to the geology as wells within the Birimian Formation rocks have higher levels than those within the Tarkwaian rocks. As observed by Kuma (2003), iron concentration in Tarkwa-Tarkwaian rocks was high because of higher iron minerals in the rocks. The high levels of iron values would affect aesthetic properties of the borehole water and consequently stain laundry and plumbing fixtures. Statistical analysis indicated that mean iron concentration values of the source waters was significantly different and results shows that iron contamination of the borehole water was higher than in hand dug wells.

Manganese

The availability of this mineral is about one-fiftieth of iron in the earth's crust. Manganese (Mn) is one of the more biogeochemical and active transition metals in aquatic environment (Evans et al., 1977) and often occurs with iron (Fe). It is found in Lower Birimian and the granite of Discove and Cape Coast which the study area is rich in. The concentration values for the water sources followed a trend similar to that of total iron. All sources had values below the WHO guideline value. Borehole water had the highest concentration value peaking at 0.18 mg/L against the WHO guideline value of 0.40 mg/L. Hand dug well sources remained relatively low also peaking at 0.08 mg/L. However variations in Mn concentration values between borehole and hand dug well water was found to be insignificant. This implies that the rate at which Mn contaminates the borehole water does not differ significantly from that of hand dug wells in the study area. Manganese at high concentration greater than 0.4 mg/L has been found to leave a dark stain to materials and imparts an undesirable taste to water.

Calcium

Calcium contribute to the hardness of water. It also form a major constituent of total dissolved solids. An elevated level of this mineral leaves a deposit of scale in appliance and in pipes. It has also been linked to improvement in cardiovascular conditions (WHO, 2008). All sources exhibited a consistent concentration values during the duration of the study which were below the guideline values.

Magnesium

Variations between the means of the concentration values for magnesium showed to be statistically insignificant. This suggests that the risk level of contamination of drinking water sources with this chemical is not significantly different. Magnesium is an ingredient of many

enzymes. Magnesium and calcium often perform the same functions within the human body and are generally antagonistic. The human body contains about 25 g of magnesium, of which 60% is present in the bones and 40% is present in muscles and other tissue. It is a dietary mineral for humans, one of the micro elements that are responsible for membrane function, nerve stimulant transmission, muscle contraction, protein construction and DNA replication. Magnesium is an ingredient of many enzymes. Results recorded for borehole (5.6 to 7.9 mg/L) and HDW sources (3.0 to 6.3 mg/L) were far below the WHO guideline of 150mg/L

Lead and Arsenic

The WHO guideline value are <0.01 mg/L for both parameters. All sample sources recorded undetectable levels of these metals in them.

5.2 Comparative Study of Drinking Quality of Borehole Water and its Distribution Points

A study of the results of the analysis revealed that the water quality of the borehole improved during distribution with unfavourable parameters which were above WHO guidelines reducing to acceptable level and favourable qualities experiencing significant appreciation.

pH values were within the range of the allowed WHO guideline specification (6.5 – 8.5) though the results leaned to the acidic range. In fact the significant increase in the pH to the stipulated range could result in a minimum wearing of the pipes and ensure reduction of acidic leaching of the elements in the pipes. Increase in pH could be attributed to the minimal presence of CO_2 in the tank.

Colour and turbidity values reduced significantly with colour disappearing in the distribution lines and turbidity reducing to less than 1.00 NTU. TSS also reduced significantly reduced from peaks of 5.33 mg/L in source water to under 2 mg/L and disappeared in September.

Reduction of colour, turbidity and TSS could be as a result of settling of the elements and particles which contributed to those parameters in the tank as they are more physical in nature.

Conductivity and TDS experienced slight changes in the distribution due to their chemical nature and maintained their mean concentrations in the distribution lines within a very small margin.

Total hardness and Total Alkalinity experienced significant elevations in the distribution lines. This suggests that there are other ions which are contributing to the concentrations of these parameters in the tank and distribution. Elevations in the total alkalinity and total hardness emphasises the increased buffering ability of the water in distribution. However, increased total hardness suggests the increasing scum-forming properties of the water. Major implications of this phenomenon (total hardness) are the possibility of scaling in the distribution pipes.

Other ionic constituents maintained their concentration values in the distribution lines. The ions include sulphate, nitrite, phosphate and fluoride.

Iron levels reduced from above 0.3 mg/L to below 0.1 mg/L in the distribution lines. Manganese as occurs with iron also reduced in the distribution lines to 0.05 mg/L from peaks of 0.18 mg/L in borehole source. Fe^{3+} ions are more readily oxidised in oxygen rich environment to Fe (III) oxide but Fe^{2+} exists more in the soluble form and is not readily oxidised. The significant reduction in the concentration is due to the higher proportions of the Fe^{3+} in the borehole water.

Lead and arsenic were not detected in any of the lines. This shows that leaching of the pipes are minimal and do not contribute significant quantities of these two trace metals into the water.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSIONS

The drinking water quality of Mpohor as subjected to WHO (2008) guideline values were found to be of good quality. The ionic quality was found to be within guideline limits. High iron content of the borehole sources were mitigated and concentrations reduced through mixing and settling in the overhead water storage facility and distributed in the lines.

The quality of the water in the distribution lines was found to be of a relatively better quality as a result of the mixing and settling.

Based on the research findings, the drinking water sources in the Mpohor Township have safe levels of water quality parameters and are thus safe for human consumption.

6.2 RECOMMENDATIONS

Continuous monitoring would be beneficial to establish the influence of rainfall and geological trends on the ground water drinking quality.

A monitoring scheme for the drinking water quality of the township should be established and a supervisor be selected to oversee this.

The floor of the tank is expected to become dirty due to rate of settling of the particles in the borehole water. As such a program (including work instruction/procedure) for washing of the overhead tank should be developed. This program should be adhered to and cleaning sessions recorded. It is recommended that the tank should be washed at least every 3 months under proper supervision.

Any complaint of the quality of the water should be registered and recorded.

The involvement of CWSA and GWCL in the education of the populace on implementation of regulations on safe drinking water would, to a greater extent would reduce incidences of water pollution and the associated water borne diseases.

The relatively high nitrate level in one of the sampling point suggests the influence of closeness of the toilet manhole as the main contributor to the high concentration values. Obiri-Danso et. al (2009) posits that future wells should be planned and monitored to ensure that risk of microbial contamination could be avoided by:

- Keeping clean receptacles for drawing water from open wells and permanently attaching it to a windlass when not in use;
- Keeping lids dry and clean and should be constructed as a single unit and not in pieces.
- Openings at the joints to allow water through the apron run-off and seepage area should be kept clean.
- Lining wells with concrete rings instead of cementing the upper 1 – 2 m as this would prevent the development of fissures within wells.
- Siting wells at higher elevations so as not to serve as a sink during rainfall.
- Siting wells at least 30 m away from septic tanks, latrines and rubbish dumps.

REFERENCES

Adzaku, J.C. (1989). A study of the effect of groundwater quality on pump materials in the tropical rain forest zone of Ghana. Water Research Institute Annual Report. Accra.

Agbaire, P.O., & Oyibo, I.P. (2009). Seasonal variation of some physico-chemical properties of borehole water in Abraka, Nigeria, *African Journal of Pure and Applied Chemistry, 3* (6), 116-118.

Alhassan, O.A. R. (2003). *Landcover Change and Woodfuel Resource Management in the Densu Basin (*Doctoral dissertation). University of Ghana, Legon, Ghana.

Anon (1987). Drinking water criteria document on nitrate/nitrite. Washington, DC, US 1987. ICAIR Life Systems, Inc.

Appelo, C.A.J., & Postma, D. (1999). Chemical analysis of groundwater. *Geochemistry, Groundwater and Pollution*. A.A. Balkema/Rotterdam/Brookfield.

APHA (1998). Standard methods for the examination of water and wastewater (20th ed). Washington, D.C.

Ashbolt, N.J., & Veal D.A. (1994). Testing the waters for a redundant indicator. *Today's Life Science* 6, 28-29.

Barrel, R.A.E., & Rowland M.G.M. (1979). The relationship between rainfall and well water pollution in a West African (Gambian) village. *The Journal of Hygiene, 83* (1), 143-150.

Community Water and Sanitation Agency (CWSA) (2000). Pre-project official report on Mpohor District.

Community Water and Sanitation Agency (CWSA) (2014). District operational manual volume 1, Ghana. Retrieved from http://www.cwsagh.org/downloads/DOM.pdf

Dapaah-Siakwan, S., & Gyau-Boakye P. (2000). Hydrological framework and borehole yield in Ghana. *Hydrogeological Journal, 8,* 400-416.

Darko, P.K., Barnes, E.A., & Sekpey, N.K. (1995). Ground water assessment of the Greater Accra Plains. Water Research Institute, C.S.I.R., Accra, Ghana.

Davis, S. N., & DeWiest, R. J. M. (1966). *Hydrology*. New York, NY: John Wiley & Sons, Inc.

Dethier, D. P., (1988). A hydrochemical model for stream chemistry and cascade range, Washington U.S.A. *Earth Surface Processes Land Forms*, *13*, 321-333.

Dickson, K., & Benneh, G. (1995). *A New Geography of Ghana*. U.K: Longman.

Edwards, R. W. (1981). The impact of coal mining on river ecology, scientific section symposium on mining and water pollution. Institute of Water Engineers and Scientist, Athens, Ohio.

Evans, D. W., Cutshall, N. H., Cross, F. A., & Wolfe, D. A. (1977). Manganese cycling in the Newport River estuary, North Carolina. *Estuarine and Coastal Marine Science*, *5*(1), 71–80. doi:10.1016/0302-3524(77)90074-3.

Fox, K.R. (1995). *Turbidity as it relates to waterborne disease outbreaks*. Presentation at M/DBP Information Exchange, Cincinnati, Ohio. AWWA white paper.

Fytianos, K., & Christophoridis, C. (2003). Nitrate, arsenic and chloride pollution of drinking water in Northern Greece. Elaboration by Applying GIS. *Environmental Monitoring and Assessment*, 1–13.

Ghana Statistical Service (2002). *2000 Population and Housing Census.* Accra.

GMA (2007). Ghana Meteorological Service Report. Accra.

GOG (2007). Ghana national water policy. Ministry of Water Resources, Works and Housing, Ghana

Hem, J. D. (1985*). Study and interpretation of the chemical characteristic of natural water* (3rd ed). U.S. Geological Survey Dept.

Hounslow, A. W. (1995). *Water Quality Data Analysis and Interpretation*. Boca Raton, New York: Lewis Publishers.

Kesse, G.O. (1985). The mineral and rock resources of Ghana: Rotterdam, A.A. Balkema, 95-156.

Kortatsi, B.K. (2004). *Hydrochemistry of Groundwater in the Mining Area of Tarkwa-Prestea,* Ghana-University of Ghana, Legon.

Kuma, J.S. (2003). *Is Groundwater in the Tarkwa gold mining district of Ghana potable*? Department of Geological Engineering, Western University College, Tarkwa-Ghana.

Langmuir, D. (1997). *Aqueous environmental geochemistry*. Prentice Hall Upper Saddle River, New Jersey.

LeChevallier, M.W., & Norton, W.D. (1993). *Treatments to address source water concerns: Protozoa. safety of water disinfection: Balancing chemical and microbial risks*. Washington, D.C: ILSI Press.

Lenntech B.V. (2005). *Iron in Groundwater*. Rotterdamseweg, The Netherlands. Retrieved from http://www.lenntech.com/index.htm.

Lewis, W.J., Foster, S.S.D., & Drasar, B.S. (1982). *The risk of groundwater pollution by on-site sanitation in developing countries*. IRCWD Report 01/82, IRCWD, Duebendorf,

Metropolitan, Municipal and District Assemblies (2013). *The composite budget of the Mpohor Wassa East District Assembly.* Retrieved from http://www.mofep.gov.gh/sites/default/files/budget/2013/WR/Mpohor_Wassa_East.pdf .

National Forum on Water Privatization (2001). *Meeting Resolution.* Accra, Ghana. Retrieved from http://www.iatp.org/files/451_2_97679.pdf

Nkansah, M.A, Boadi, O.N., & Badu, M (2010). Assessment of the quality of water from hand-dug wells in Ghana. *Environmental Health Insights*, *4*, 7–12.

Nouar, T., Messadi, D., & Nouar, L. (2007). Hydrogeology and ground water quality of the aquifer of Guelma in North-East of Algeria. *Journal of Earth Sciences 1*, 119-123.

Nova Scotia Environment (2012). Retrieved from http://www.novascotia.ca/nse/water/thedroponwater.TasteSmellColour.asp

Nyarko, A. (2008). *Assessment of groundwater quality and urban water provision: A case of Taifa township in the Ga-East District of the Greater Accra Region, Ghana*. KNUST, Kumasi, Ghana.

Obiri-Danso, K., Adjei, B., Stanley, K. N., & Jones, K. (2009). Microbiological quality and metal levels in wells and boreholes water in some peri-urban communities in Kumasi, Ghana. *African Journal of Environmental Science and Technology*, *3*(1), 059-066.

Snyder, J.D., & Merson, M.H. (1982). Diarrhea disease bulletin of the World Meteorological Organization, *60*, 605-613.

Stallord, R. F., & Edmond, J. M., (1983). Geochemistry of Amazon river: The influence of the geology and weathering environment on the dissolved load. *Journal of Geophysical Research, 88*, 9671-9688.

Tay, C., & Kortatsi, B. (2008). Groundwater quality studies: A case study of the Densu Basin, Ghana. *West African Journal of Applied Ecology*, *12*.

Third World Network, (2000). Boom and Dislocation, by Thomas Akabzaa and Third World Network, Ghana.

Todd, D.K., (1980). *Ground-water hydrology* (2nd ed). New York: John Wiley and Sons.

Umar, R., & Absar, A., (2003). Chemical characteristics of groundwater in parts of the Gambhir river basin, Bharatpur District, Rajasthan, India. *Environmental Geology*, *44*, 535-544.

Umar, R., Muqtada, M., Khan, A., & Absar, A., (2006). Groundwater hydrochemistry of a sugarcane cultivation belt in parts of Muzaffarnagar district, Uttar Pradesh, India. *Environmental Geology*, *49*, 999-1008.

UN-Water, Food and Agriculture Organization (2007*). Coping with water scarcity: Challenge of the twenty-first century*. Retrieved from http://www.fao.org/nr/water/docs/escarcity.pdf

UNESCO/WHO/UNEP (1996). *Water quality assessments: A guide to use of biota, sediments and water in environmental monitoring* (2nd ed). Retrieved from http://www.who.int/water_sanitation_health/resourcesquality/wqachapter9.pdf

United States Environmental Protection Agency (USEPA) (1997). *Secondary drinking water regulations: guidance for nuisance chemicals*. Retrieved from http://water.epa.gov/drink/contaminants/secondarystandards.cfm

USEPA Guidance Manual 7-8 Turbidity Provisions (April 1999). Retrieved from http://www.epa.gov/ogwdw000/mdbp/pdf/turbidity/chap_07.pdf

Wassa East District (2006). *District Information*. Retrieved from http://mpohorwassaeast.ghanadistricts.gov.gh/

World Health Organisation (2004). Guidelines for drinking-water quality vol. 1 (3rd ed). Retrieved from http://www.who.int/water_sanitation_health/dwq/GDWQ2004web.pdf

World Health Organisation (2008). Guidelines for drinking-water quality incorporating 1st and 2nd addenda, Vol.1, Recommendations. – 3rd ed. pgs 57,142, 217, 21. Retrieved from http://www.who.int/water_sanitation_health/dwq/secondaddendum20081119.pdf

APPENDIX A: MEASURED PARAMETERS

Table A-1: Measured parameter results for January, 2012

Parameters	Sampling Points									
	B1	**B2**	**B3**	**B4**	**D1**	**D2**	**L1**	**L2**	**L3**	**L4**
pH	6.57	6.58	6.79	6.25	6.74	6.53	5.98	6.04	4.05	6.14
Colour (H.U)	5	<5	<5	<5	<5	5	<5	<5	<5	<5
Turbidity (NTU)	7.01	4.19	1.84	0.91	0.55	1.36	1.27	1.14	3.29	1.53
Conductivity (µS/cm)	262	343	214	337	282	312	414	219	649	72.4
Total Dissolved Solids (mg/L)	144	189	117	165	155	210	203	108	319	36
Total Suspended Solids (mg/L)	9	4	3	<0.1	1	7	<0.1	12	<0.1	<0.1
Total Alkalinity (mg/L)	110	156	87	56	123	260	46	39	14	28
Total Hardness (mg/L)	98	34	124	92	88	174	58	67	80	32
Nitrate (N) (mg/L)	0.4	0.7	0.8	3.7	0.4	0.9	5.4	1.6	10.7	0.7
Nitrite (N) (mg/L)	<0.005	<0.005	<0.005	0.009	0	0.001	0.022	0.009	0.004	0.001
Chloride (mg/L)	27.5	18.5	20	57.5	22.5	31	52.5	36	140	23
Sulphate (mg/L)	2	6	4	10	4	8	20	20	20	1
Fluoride (mg/L)	<0.01	<0.01	<0.01	0	<0.01	0.11	0.21	0	0	<0.10
Phosphate (mg/L)	0.34	0.12	0.09	0.28	0.12	0.26	0.03	0.02	0.04	0.03
Iron (mg/L)	0.99	0.54	0.26	0.07	0.1	0.23	0.08	0.11	0.16	0.17
Manganese (mg/L)	0.087	0.02	0.36	0.01	0.023	0.035	0.027	0.005	0.043	0.027
Calcium (mg/L)	30	12	29.6	26	31.2	41	22.4	18.4	24	8
Magnesium (mg/L)	5.59	0.9	12.15	6.57	2.43	12.85	0.49	3.89	4.86	2.92
Arsenic (mg/L)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lead (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005

Table A-2: Measured parameter results for March, 2012

Parameters	Sampling Points									
	B1	**B2**	**B3**	**B4**	**D1**	**D2**	**L1**	**L2**	**L3**	**L4**
pH	6.55	6.72	6.74	6.34	6.75	6.62	6.15	6.04	4.16	5.94
Colour (H.U)	5	5	<5	<5.0	<5	<5.0	5	<5.0	<5.0	<5.0
Turbibidity (NTU)	5.66	7.29	1.27	1.31	2.04	1.86	4.92	1.83	1.14	1.09
Conductivity (µS/cm)	183	289	190	330	239	217	241	190	598	73
Total Dissolved Solids (mg/L)	100.7	158.9	97	181.5	131.5	119.4	132.6	104.5	328	40.2
Total Suspended Solids (mg/L)	4	3	<0.1	<0.1	<0.1	<0.1	5	<0.1	18	<0.1
Total Alkalinity (mg/L)	86	160	102	72	130	116	56	48	18	36
Total Hardness (mg/L)	68	148	86	110	114	100	60	60	92	32
Nitrate (N) (mg/L)	1	1	0.4	6.4	0.5	1.4	2.7	2	9.2	1.4
Nitrite (N) (mg/L)	<0.005	0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.006	<0.005
Chloride (mg/L)	25	18	18	64	18	19	35	31	118	13
Sulphate (mg/L)	2	6	3	12	6	5	18	29	27	2
Fluoride (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Phosphate (mg/L)	0.37	0.56	0.76	1.29	0.23	1.7	0.48	0.09	0.37	0.71
Iron (mg/L)	0.58	0.42	0.04	0.01	0.14	0.011	0.08	0.06	0.01	0.05
Manganese (mg/L)	0.03	0.038	0.016	0.026	0.093	0.036	0.023	0.007	0.009	0.165
Calcium (mg/L)	17.6	39.2	28.8	27.2	32	32	16	15.2	20	8.8
Magnesium (mg/L)	5.85	12.15	3.4	10.2	8.26	4.86	4.86	5.34	10.2	2.43
Arsenic (mg/L)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lead (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005

Table A-3: Measured parameter results for May, 2012

Parameters	Sampling Points									
	B1	**B2**	**B3**	**B4**	**D1**	**D2**	**L1**	**L2**	**L3**	**L4**
pH	6.4	6.7	6.7	6.3	6.7	6.5	6.2	6.2	4.31	5.9
Colour (H.U)	5	80	<5	15	<5	<5.0	5	20	5	5
Turbibidity (NTU)	2.16	29.3	0.46	5.97	0.55	0.66	3.27	10.5	1.43	2.27
Conductivity (µS/cm)	211	288	225	291	263.01	248	286	206	649	75.1
Total Dissolved Solids (mg/L)	116.1	158.4	123.8	160.1	144.7	136.4	157.3	113.3	356.9	41
Total Suspended Solids (mg/L)	<0.1	9	<0.1	3	<0.1	1	2	5	6	4
Total Alkalinity (mg/L)	98	136	100	48	126	106	42	36	4	28
Total Hardness (mg/L)	8	136	120	86	104	118	74	62	98	38
Nitrate (N) (mg/L)	1	1.9	0.5	3.4	1	0.8	0.2	1.7	11.8	1
Nitrite (N) (mg/L)	0.005	0.005	0.005	0.006	<0.005	<0.004	<0.005	0.007	0.013	0.008
Chloride (mg/L)	25	22	18	44	18	19	36	28	117	10
Sulphate (mg/L)	5	2	9	16	9	4	14	25	28	4
Fluoride (mg/L)	<0.01	<0.01	<0.01	0.42	<0.01	0.23	0.33	0.04	0.37	0.21
Phosphate (mg/L)	0.59	0.25	0.39	0.22	0.54	0.16	0.21	0.09	0.07	0.22
Iron (mg/L)	0.15	2	0.06	0.11	0.03	0.04	0.15	0.31	0.08	0.16
Manganese (mg/L)	0.031	0.496	0.019	0.029	0.044	0.007	0.022	0.021	0.005	0.018
Calcium (mg/L)	22.4	40	32.8	23.2	39.2	31.2	19.2	16	22.4	9.6
Magnesium (mg/L)	5.832	8.75	9.234	6.804	14.58	9.72	6.318	5.346	10.206	3.402
Arsenic (mg/L)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lead (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005

Table A-4: Measured parameter results for July, 2012

Parameters	Sampling Points									
	B1	**B2**	**B3**	**B4**	**D1**	**D2**	**L1**	**L2**	**L3**	**L4**
pH	6.45	6.52	6.5	6.23	6.5	6.55	6.01	5.92	4.23	5.91
Colour (H.U)	5	15	5	10	<5	<5.0	5	5	5	5
Turbibidity (NTU)	2.8	6.3	0.76	1.3	0.31	0.51	2.3	1.85	1.32	1.87
Conductivity (µS/cm)	253	210	198	279	251	288	275	210	608	71
Total Dissolved Solids (mg/L)	120.1	127	101	163	137	144	161	110	320	35
Total Suspended Solids (mg/L)	1	4	0.1	0.1	<0.1	1	1	0.1	0.1	4
Total Alkalinity (mg/L)	102	116	88	52	122	118	39	25	5	27
Total Hardness (mg/L)	75	94	95	91	101	121	69	59	88	31
Nitrate (N) (mg/L)	0.8	1.2	0.7	2.1	0.6	0.9	1.3	2.4	9.8	0.9
Nitrite (N) (mg/L)	0.006	0.021	0.005	0.005	0.006	<0.006	0.005	0.007	0.008	0.007
Chloride (mg/L)	24	21	17	48	20	22	38	35	112	8
Sulphate (mg/L)	3	2	4	12	4	5	17	17	23	1
Fluoride (mg/L)	0.05	0.01	0.01	0.27	0.05	0.09	0.15	0.03	0.09	0.01
Phosphate (mg/L)	0.44	0.21	0.28	0.35	0.15	0.19	0.22	0.06	0.09	0.07
Iron (mg/L)	0.21	0.34	0.08	0.06	0.03	0.03	0.07	0.05	0.07	0.15
Manganese (mg/L)	0.028	0.101	0.1	0.005	0.05	0.005	0.03	0.06	0.019	0.21
Calcium (mg/L)	27.3	22.5	22.4	23.8	28.6	32.6	17.3	13	21.1	9.4
Magnesium (mg/L)	3.20	6.1	6.712	6.237	3.045	7.34	4.9	5.146	3.4	3.78
Arsenic (mg/L)	0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lead (mg/L)	0.005	<0.005	0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005

Table A-5: Measured parameter results for September, 2012

Parameters	Sampling Points									
	B1	**B2**	**B3**	**B4**	**D1**	**D2**	**L1**	**L2**	**L3**	**L4**
pH	6.5	6.41	6.44	6.11	6.5	6.65	5.94	5.86	4.19	5.51
Colour (H.U)	10	25	5	15	<5	<5.0	5	5	5	5
Turbibidity (NTU)	3.4	5.7	2.23	1.5	0.25	0.53	3	1.93	1.26	1.98
Conductivity (µS/cm)	267	220	207	299	245	296	363	217	621	68
Total Dissolved Solids (mg/L)	146	121	113	164	134	162	201	120	343	37
Total Suspended Solids (mg/L)	2	3	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Alkalinity (mg/L)	132	114	100	58	126	158	42	40	32	32
Total Hardness (mg/L)	90	86	98	90	102	132	76	64	92	30
Nitrate (N) (mg/L)	1.3	1.6	1.2	2.9	1.5	1.2	7.8	3.4	11.8	1.4
Nitrite (N) (mg/L)	0.008	0.01	0.007	0.006	0.008	0.008	0.005	0.007	0.011	0.014
Chloride (mg/L)	30	27	23	55	25	23	53	43	126	15
Sulphate (mg/L)	6	3	5	10	5	7	29	16	25	1
Fluoride (mg/L)	0.08	0.07	<0.01	0.31	0.12	0.08	0.29	0.09	0.11	<0.01
Phosphate (mg/L)	0.62	0.26	0.47	0.58	0.33	0.4	0.39	0.07	0.13	0.05
Iron (mg/L)	0.33	0.8	0.25	0.04	0.04	0.04	0.05	0.06	0.08	0.18
Manganese (mg/L)	0.049	0.118	0.287	<0.005	<0.005	<0.005	<0.005	<0.005	0.082	0.053
Calcium (mg/L)	30.4	25.6	26.4	24.8	34.4	36.8	22.4	16	20.8	9.6
Magnesium (mg/L)	3.402	5.346	7.776	6.804	3.888	6.804	4.86	5.832	1.488	9.72
Arsenic (mg/L)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lead (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005

APPENDIX B: WHO / EPA DRINKING WATER GUIDELINE LIMITS

Table B – 1: EPA AND WHO Guidelines for Drinking Water

Parameter	WHO Guideline Values	GSA Standard
pH	6.5 - 8.5	6.5 - 8.5
Colour (H.U)	0 - 15	0 - 15
Turbidity (NTU)	< 5.0	< 5.0
Conductivity (µS/cm)	-	-
Total Dissolved Solids (mg/L)	<1000	< 1000
Total Suspended Solids (mg/L)	-	-
Total Alkalinity (mg/L)	-	-
Total Hardness (mg/L)	<500	< 500
Nitrate (N) (mg/L)	< 10	0 - 10
Nitrite (N) (mg/L)	< 3.0	0 - 3.0
Chloride (mg/L)	< 250	0 - 250
Sulphate (mg/L)	< 400	0 - 250
Fluoride (mg/L)	< 1.5	0 - 1.5
Phosphate (mg/L)	< 2.5	< 2.5
Iron (mg/L)	< 0.3	0 - 0.3
Manganese (mg/L)	< 0.4	0 - 0.4
Calcium (mg/L)	<200	-
Magnesium (mg/L)	< 150	-
Arsenic (mg/L)	< 0.01	< 0.01
Lead (mg/L)	< 0.01	< 0.01

APPENDIX C: PARAMETER RANGE, MEAN AND STANDARD DEVIATION VALUES AGAINST MONTHS

C – 1: SOURCE WATER

Table C – 1.1: SOURCE WATERS – pH RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Hand Dug Well			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	6.25	6.79	6.55	0.22	4.05	6.14	5.55	1.00
Mar	6.34	6.74	6.59	0.19	4.16	6.15	5.57	0.95
May	6.3	6.7	6.53	0.21	4.31	6.2	5.65	0.91
Jul	6.23	6.52	6.43	0.13	4.23	6.01	5.52	0.86
Sept	6.11	6.5	6.37	0.17	4.19	5.94	5.38	0.81

Table C – 1.2: SOURCE WATERS – COLOUR RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Hand Dug Well			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0	5	1.3	2.5	0	0	0.0	0.00
Mar	0	5	2.5	2.9	0	5	1.3	2.50
May	0	80	25.0	37.2	5	20	8.8	7.50
Jul	5	15	8.8	4.8	5	5	5.0	0.00
Sept	5	25	13.8	8.5	5	5	5.0	0.00

Table C –1.3: SOURCE WATERS – TURBIDITY RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Hand Dug Well			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0.91	7.01	3.49	2.72	1.14	3.29	1.81	1.00
Mar	1.27	7.29	3.88	3.07	1.09	4.92	2.25	1.82
May	0.46	29.30	9.47	13.42	1.43	10.50	4.37	4.16
Jul	0.76	6.30	2.79	2.49	1.32	2.30	1.84	0.40
Sept	1.50	5.70	3.21	1.84	1.26	3.00	2.04	0.72

Table C – 1.4: SOURCE WATERS – CONDUCTIVITY RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Hand Dug Well			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	214	343	289	62	72	649	339	250
Mar	183	330	248	73	73	598	276	226
May	211	291	254	42	75	649	304	246
Jul	198	279	235	38	71	608	291	228
Sept	207	299	248	43	68	621	317	236

Table C – 1.5: SOURCE WATERS – TOTAL DISSOLVED SOLIDS RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Hand Dug Well			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	117	189	154	31	36	319	167	123
Mar	97	182	135	42	40	328	151	124
May	116	160	140	23	41	357	167	135
Jul	101	163	128	26	35	320	157	121
Sept	113	164	136	23	37	343	175	130

Table C – 1.6: SOURCE WATERS – TOTAL SUSPENDED SOLIDS RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Hand Dug Well			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0.00	9.0	4.0	3.7	0.0	12.0	3.0	6.0
Mar	0.00	4.0	1.8	2.1	0.0	18.0	5.8	8.5
May	0.00	9.0	3.0	4.2	2.0	6.0	4.3	1.7
Jul	0.10	4.0	1.3	1.8	0.1	4.0	1.3	1.8
Sept	0.00	3.0	1.5	1.3	0.0	0.0	0.0	0.0

Table C – 1.7: SOURCE WATERS – TOTAL ALKALINITY RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Hand Dug Well			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	56	156	102	42	14	46	32	14
Mar	72	160	105	39	18	56	40	17
May	48	136	96	36	4	42	28	17
Jul	52	116	90	27	5	39	24	14
Sept	58	132	101	32	32	42	37	5

Table C – 1.8: SOURCE WATERS – TOTAL HARDNESS RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Hand Dug Well			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	34	124	87	38	32	80	59	20
Mar	68	148	103	35	32	92	61	25
May	8	136	88	57	38	98	68	25
Jul	75	95	89	9	31	88	62	24
Sept	86	98	91	5	30	92	66	26

Table C – 1.9: SOURCE WATERS – NITRATES RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Hand Dug Well			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0.4	3.7	1.4	1.5	0.7	10.7	4.6	4.5
Mar	0.4	6.4	2.2	2.8	1.4	9.2	3.8	3.6
May	0.5	3.4	1.7	1.3	0.2	11.8	3.7	5.5
Jul	0.7	2.1	1.2	0.6	0.9	9.8	3.6	4.2
Sept	1.2	2.9	1.8	0.8	1.4	11.8	6.1	4.6

Table C – 1.10: SOURCE WATERS – NITRITES RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Hand Dug Well			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0.000	0.009	0.002	0.005	0.001	0.022	0.009	0.009
Mar	0.000	0.000	0.000	0.000	0.000	0.006	0.002	0.003
May	0.005	0.006	0.005	0.001	0.000	0.013	0.007	0.005
Jul	0.005	0.021	0.009	0.008	0.005	0.008	0.007	0.001
Sept	0.006	0.010	0.008	0.002	0.005	0.014	0.009	0.004

Table C – 1.11: SOURCE WATERS – CHLORIDE RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Hand Dug Well			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	19	58	31	18	23	140	63	53
Mar	18	64	31	22	13	118	49	47
May	18	44	27	12	10	117	48	47
Jul	17	48	28	14	8	112	48	45
Sept	23	55	34	14	15	126	59	47

Table C – 1.12: SOURCE WATERS – SULPHATE RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Hand Dug Well			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	2	10	6	3	1	20	15	10
Mar	2	12	6	5	2	29	19	12
May	2	16	8	6	4	28	18	11
Jul	2	12	5	5	1	23	15	9
Sept	3	10	6	3	1	29	18	12

Table C – 1.13: SOURCE WATERS – FLUORIDE RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Hand Dug Well			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0.00	0.00	0.00	0.00	0.00	0.21	0.05	0.11
Mar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
May	0.00	0.42	0.11	0.00	0.04	0.37	0.24	0.15
Jul	0.01	0.27	0.09	0.21	0.01	0.15	0.07	0.06
Sept	0.00	0.31	0.12	0.12	0.00	0.29	0.12	0.12

Table C – 1.14: SOURCE WATERS – PHOSPHATE RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Hand Dug Well			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0.09	0.34	0.21	0.12	0.02	0.04	0.03	0.01
Mar	0.37	1.29	0.75	0.40	0.09	0.71	0.41	0.26
May	0.22	0.59	0.36	0.17	0.07	0.22	0.15	0.08
Jul	0.21	0.44	0.32	0.10	0.06	0.22	0.11	0.07
Sept	0.26	0.62	0.48	0.16	0.05	0.39	0.16	0.16

Table C – 1.15: SOURCE WATERS – IRON RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Hand Dug Well			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0.07	0.99	0.47	0.40	0.08	0.17	0.13	0.04
Mar	0.01	0.58	0.26	0.28	0.01	0.08	0.05	0.03
May	0.06	2.00	0.58	0.95	0.08	0.31	0.18	0.10
Jul	0.06	0.34	0.17	0.13	0.05	0.15	0.09	0.04
Sept	0.04	0.80	0.36	0.32	0.05	0.18	0.09	0.06

Table C – 1.16: SOURCE WATERS – MANGANESE RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Hand Dug Well			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0.01	0.36	0.12	0.16	0.01	0.04	0.03	0.02
Mar	0.02	0.04	0.03	0.01	0.01	0.17	0.05	0.08
May	0.02	0.50	0.14	0.23	0.01	0.02	0.02	0.01
Jul	0.01	0.10	0.06	0.05	0.02	0.21	0.08	0.09
Sept	0.00	0.29	0.11	0.13	0.00	0.08	0.03	0.04

Table C – 1.17: SOURCE WATERS – CALCIUM RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Hand Dug Well			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	12	30	24	8	8	24	18	7
Mar	18	39	28	9	9	20	15	5
May	22	40	30	8	10	22	17	5
Jul	22	27	24	2	9	21	15	5
Sept	25	30	27	2	10	22	17	6

Table C – 1.18: SOURCE WATERS – MAGNESIUM RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Hand Dug Well			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0.9	12.2	6.3	4.6	0.5	4.9	3.0	1.9
Mar	3.4	12.2	7.9	4.0	2.4	10.2	5.7	3.3
May	5.8	9.2	7.7	1.6	3.4	10.2	6.3	2.9
Jul	3.2	6.7	5.6	1.6	3.4	5.1	4.3	0.8
Sept	3.4	7.8	5.8	1.9	1.5	9.7	5.5	3.4

C – 2: DISTRIBUTION LINE WATER MONITORING

Table C – 2:1: DISTRIBUTION LINE MONITORING – pH RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Distribution			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	6.25	6.79	6.65	0.22	6.53	6.74	6.64	0.15
Mar	6.34	6.74	6.67	0.19	6.62	6.75	6.69	0.09
May	6.3	6.7	6.60	0.21	6.50	6.70	6.60	0.14
Jul	6.23	6.52	6.49	0.13	6.50	6.55	6.53	0.04
Sept	6.11	6.5	6.45	0.17	6.50	6.65	6.58	0.11

Table C – 2:2: DISTRIBUTION LINE MONITORING – COLOUR RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Distribution			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0	5	1.7	2.5	0.00	5.00	2.5	3.54
Mar	0	5	3.3	2.9	0.00	0.00	0.0	0.00
May	0	80	28.3	37.2	0.00	0.00	0.0	0.00
Jul	5	15	8.3	4.8	0.00	0.00	0.0	0.00
Sept	5	25	13.3	8.5	0.00	0.00	0.0	0.00

Table C – 2:3: DISTRIBUTION LINE MONITORING – TURBIDITY RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Distribution			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0.91	7.01	4.3	2.7	0.55	1.36	0.96	0.57
Mar	1.27	7.29	4.7	3.1	1.86	2.04	1.95	0.13
May	0.46	29.30	10.64	13.4	0.55	0.66	0.61	0.08
Jul	0.76	6.30	3.3	2.5	0.31	0.51	0.41	0.14
Sept	1.50	5.70	3.8	1.8	0.25	0.53	0.39	0.20

Table C – 2:4: DISTRIBUTION LINE MONITORING – CONDUCTIVITY RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Distribution			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	214	343	273	62	282	312	297	21
Mar	183	330	221	73	217	239	228	16
May	211	291	241	42	248	263	256	11
Jul	198	279	220	38	251	288	270	26
Sept	207	299	231	43	245	296	271	36

Table C – 2:5: DISTRIBUTION LINE MONITORING – TDS RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Distribution			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	117	189	150	31	155	210	183	39
Mar	97	182	119	42	119	132	125	9
May	116	160	133	23	136	145	141	6
Jul	101	163	116	26	137	144	141	5
Sept	113	164	127	23	134	162	148	20

Table C – 2:6: DISTRIBUTION LINE MONITORING – TSS RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Distribution			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0.0	9.0	5.3	3.7	1.0	7.0	4.0	4.2
Mar	0.0	4.0	2.3	2.1	0.0	0.0	0.0	0.0
May	0.0	9.0	3.0	4.2	0.0	1.0	0.5	0.7
Jul	0.1	4.0	1.7	1.8	0.0	1.0	0.5	0.7
Sept	0.0	3.0	2.0	1.3	0.0	0.0	0.0	0.0

Table C – 2:7: DISTRIBUTION LINE MONITORING – TOTAL ALKALINITY RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Distribution			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	56	156	118	42	123	260	192	97
Mar	72	160	116	39	116	130	123	10
May	48	136	111	36	106	126	116	14
Jul	52	116	102	27	118	122	120	3
Sept	58	132	115	32	126	158	142	23

Table C – 2:8: DISTRIBUTION LINE MONITORING – TOTAL HARDNESS RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Distribution			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	34.00	124.00	85	38	88.00	174.00	131	61
Mar	68.00	148.00	101	35	100.00	114.00	107	10
May	8.00	136.00	88	57	104.00	118.00	111	10
Jul	75.00	95.00	88	9	101.00	121.00	111	14
Sept	86.00	98.00	91	5	102.00	132.00	117	21

Table C – 2:9: DISTRIBUTION LINE MONITORING – NITRATE RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Distribution			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0.4	3.7	0.6	1.5	0.4	0.9	0.7	0.4
Mar	0.4	6.4	0.8	2.8	0.5	1.4	1.0	0.6
May	0.5	3.4	1.1	1.3	0.8	1.0	0.9	0.1
Jul	0.7	2.1	0.9	0.6	0.6	0.9	0.8	0.2
Sept	1.2	2.9	1.4	0.8	1.2	1.5	1.4	0.2

Table C – 2:10: DISTRIBUTION LINE MONITORING – NITRITE RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Distribution			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0.000	0.009	0.000	0.005	0.000	0.001	0.001	0.001
Mar	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
May	0.005	0.006	0.005	0.001	0.000	0.000	0.000	0.000
Jul	0.005	0.021	0.011	0.008	0.000	0.006	0.003	0.004
Sept	0.006	0.010	0.008	0.002	0.008	0.008	0.008	0.000

Table C – 2:11: DISTRIBUTION LINE MONITORING – CHLORIDE RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Distribution			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	18.50	57.50	22	18	22.50	31.00	27	6.0
Mar	18.00	64.00	20	22	18.00	19.00	19	0.7
May	18.00	44.00	22	12	18.00	19.00	19	0.7
Jul	17.00	48.00	21	14	20.00	22.00	21	1.4
Sept	23.00	55.00	27	14	23.00	25.00	24	1.4

Table C – 2:12: DISTRIBUTION LINE MONITORING – SULPHATE RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Distribution			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	2	10	4	3	4	8	6	3
Mar	2	12	4	5	5	6	6	1
May	2	16	5	6	4	9	7	4
Jul	2	12	3	5	4	5	5	1
Sept	3	10	5	3	5	7	6	1

Table C – 2:13: DISTRIBUTION LINE MONITORING – FLUORIDE RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Distribution			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0.00	0.00	0.00	0.0	0.00	0.11	0.06	0.1
Mar	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.0
May	0.00	0.42	0.00	0.0	0.00	0.23	0.12	0.2
Jul	0.01	0.27	0.02	0.2	0.05	0.09	0.07	0.0
Sept	0.00	0.31	0.05	0.1	0.08	0.12	0.10	0.0

Table C – 2:14: DISTRIBUTION LINE MONITORING – PHOSPHATE RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Distribution			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0.09	0.34	0.25	0.12	0.12	0.26	0.19	0.10
Mar	0.37	1.29	0.74	0.40	0.23	1.70	0.97	1.04
May	0.22	0.59	0.35	0.17	0.16	0.54	0.35	0.27
Jul	0.21	0.44	0.33	0.10	0.15	0.19	0.17	0.03
Sept	0.26	0.62	0.49	0.16	0.33	0.40	0.37	0.05

Table C – 2:15: DISTRIBUTION LINE MONITORING – IRON RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Distribution			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0.07	0.99	0.60	0.40	0.10	0.23	0.17	0.09
Mar	0.01	0.58	0.35	0.28	0.01	0.14	0.08	0.09
May	0.06	2.00	0.74	0.95	0.03	0.04	0.04	0.01
Jul	0.06	0.34	0.21	0.13	0.03	0.03	0.03	0.00
Sept	0.04	0.80	0.46	0.32	0.04	0.04	0.04	0.00

Table C – 2:16: DISTRIBUTION LINE MONITORING – MANGANESE RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Distribution			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0.01	0.36	0.16	0.16	0.02	0.04	0.03	0.01
Mar	0.02	0.04	0.03	0.01	0.04	0.09	0.06	0.04
May	0.02	0.50	0.18	0.23	0.01	0.04	0.03	0.03
Jul	0.01	0.10	0.08	0.05	0.01	0.05	0.03	0.03
Sept	0.00	0.29	0.15	0.13	0.01	0.01	0.01	0.00

Table C – 2:17: DISTRIBUTION LINE MONITORING – CALCIUM RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Distribution			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	12.00	30.00	24	8	31.20	41.00	36	7
Mar	17.60	39.20	29	9	32.00	32.00	32	0
May	22.40	40.00	32	8	31.20	39.20	35	6
Jul	22.40	27.30	24	2	28.60	32.60	31	3
Sept	24.80	30.40	27	2	34.40	36.80	36	2

Table C – 2:18: DISTRIBUTION LINE MONITORING – MAGNESIUM RANGE, MEAN AND STANDARD DEVIATION VALUES

	Bore Hole Water				Distribution			
Months	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
Jan	0.90	12.15	6.2	4.6	2.43	12.85	7.6	7.4
Mar	3.40	12.15	7.1	4.0	2.43	10.20	5.7	3.3
May	5.83	9.23	7.9	1.6	3.40	10.21	6.3	2.9
Jul	3.20	6.71	5.3	1.6	3.40	5.15	4.3	0.8
Sept	3.40	7.78	5.5	1.9	1.49	9.72	5.5	3.4