

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

KUMASI

KNUST
COLLEGE OF SCIENCE

DEPARTMENT OF ENVIRONMENTAL SCIENCE

**ASSESSMENT OF THE QUALITY OF WATER USED FOR DOMESTIC
ACTIVITIES IN ACHIMOTA SCHOOL**

BY:

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AUGUST, 2015

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KNUST

BY:

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A Thesis submitted to the Department of Environmental Science,

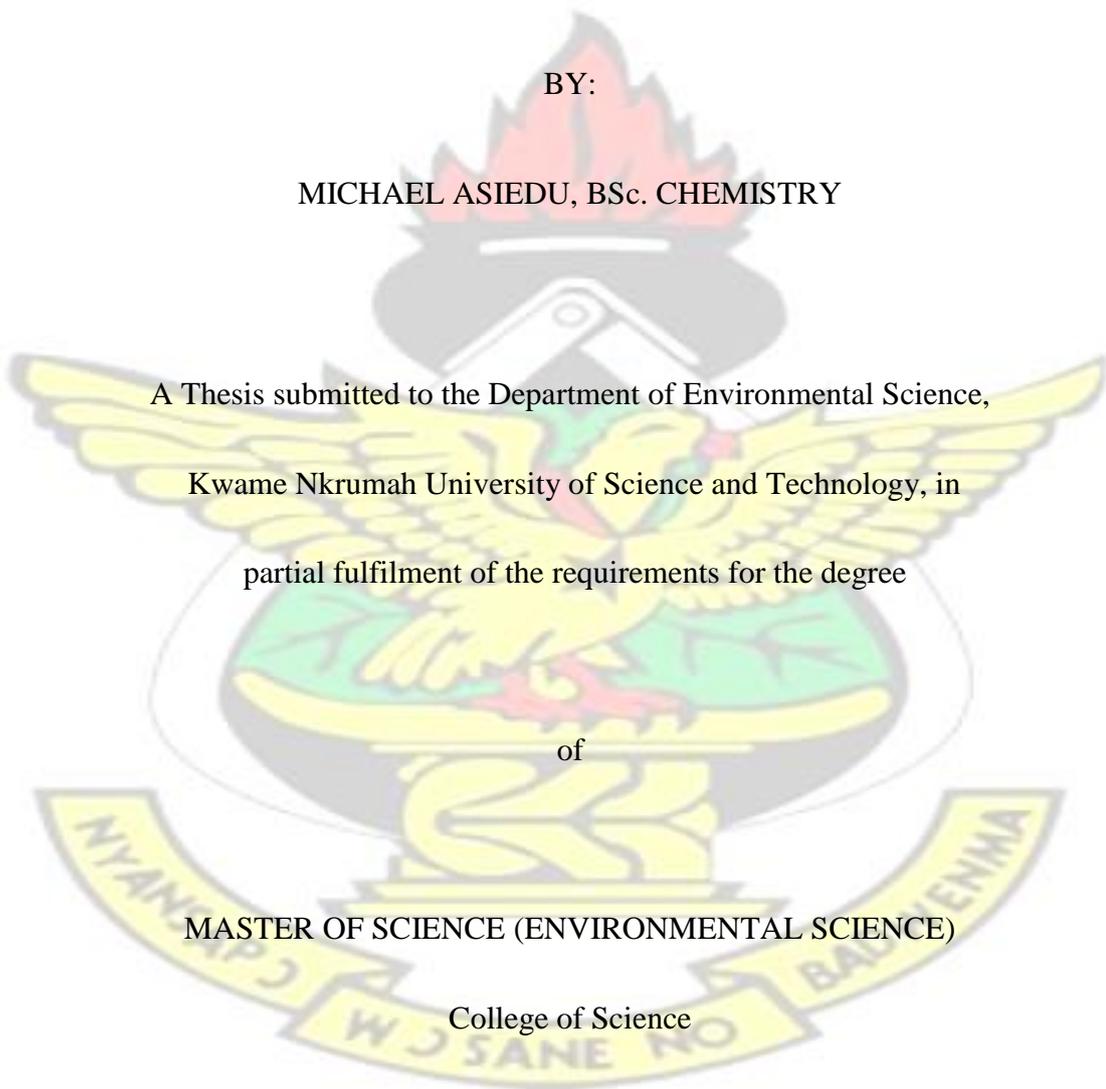
Kwame Nkrumah University of Science and Technology, in

partial fulfilment of the requirements for the degree

of

MASTER OF SCIENCE (ENVIRONMENTAL SCIENCE)

College of Science



AUGUST, 2015

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DECLARATION

I hereby declare that the material contained in this study is my own original work and has not been presented for a degree in any other University.

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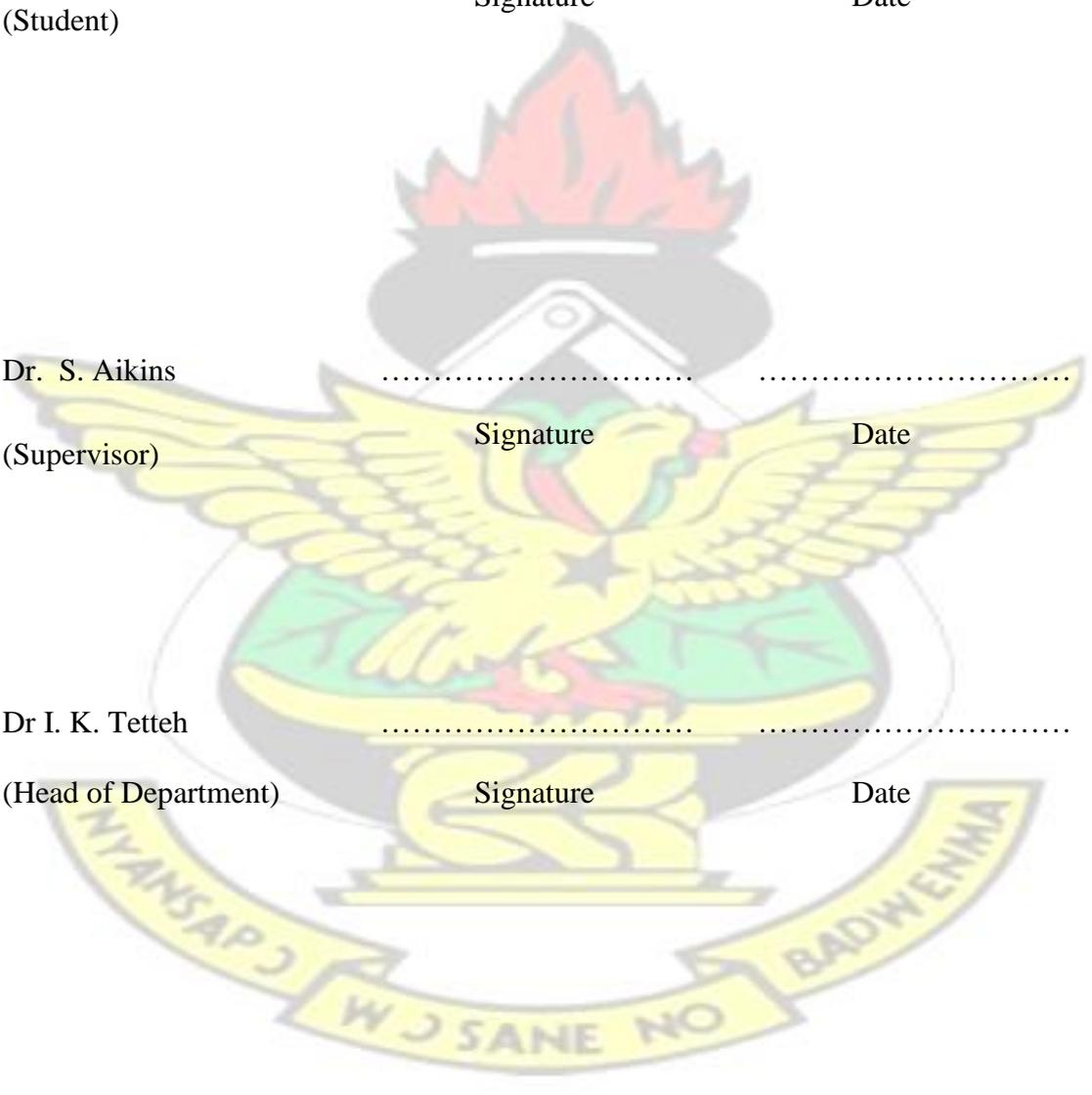
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DEDICATION

I dedicate this work to the Almighty God and to my wife Rejoice Elikem Asiedu and my lovely kids, Nana, Ben and Michelle.

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ACKNOWLEDGEMENT

I wish to express my heartfelt gratitude and profound appreciation to a number of people who have been extremely helpful to me in accomplishing this piece of research.

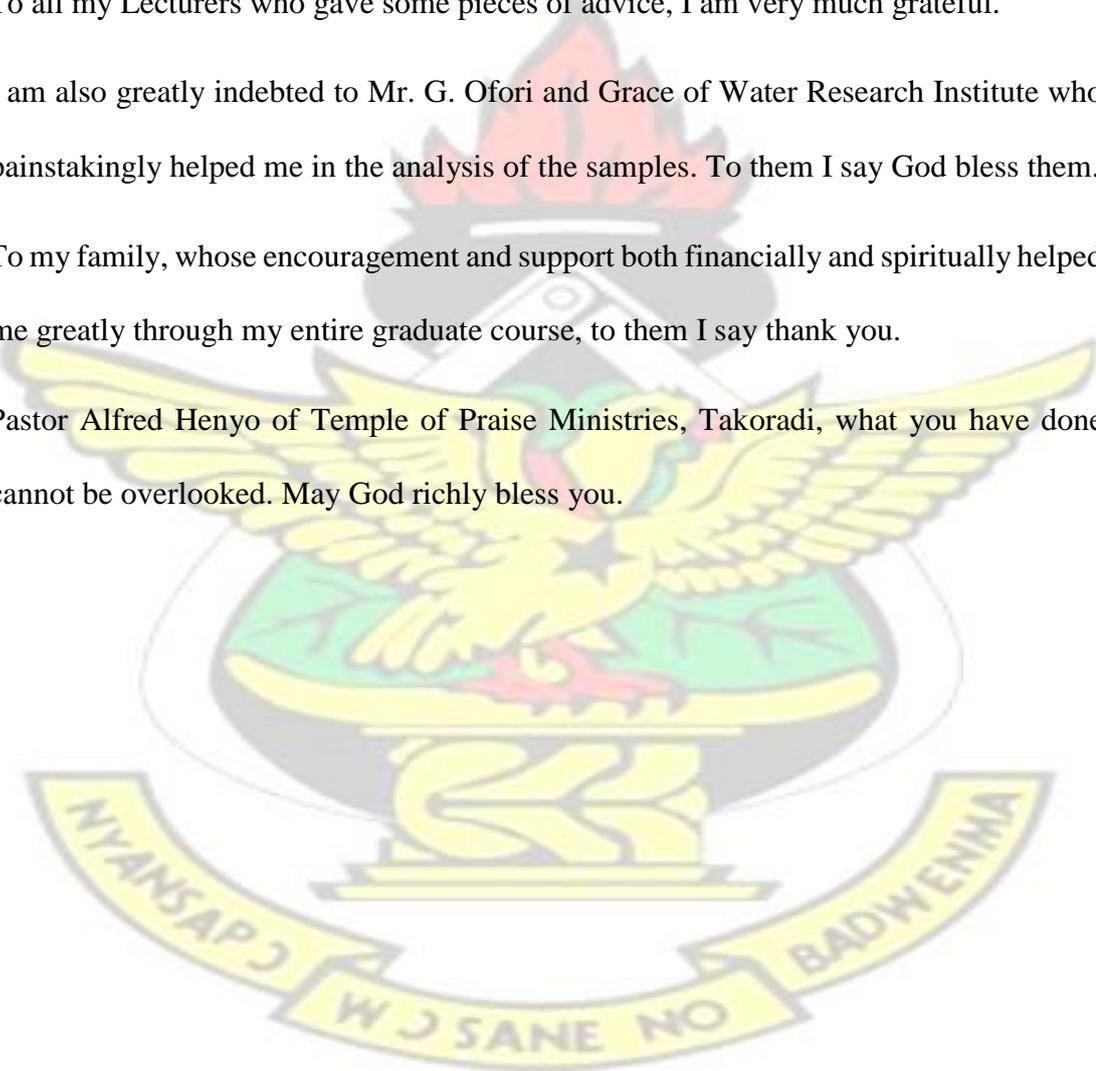
My utmost thanks go to my Supervisor, Dr. S. Aikins through whose assistance, and discipline helped me to see this project through.

To all my Lecturers who gave some pieces of advice, I am very much grateful.

I am also greatly indebted to Mr. G. Ofori and Grace of Water Research Institute who painstakingly helped me in the analysis of the samples. To them I say God bless them.

To my family, whose encouragement and support both financially and spiritually helped me greatly through my entire graduate course, to them I say thank you.

Pastor Alfred Henyo of Temple of Praise Ministries, Takoradi, what you have done cannot be overlooked. May God richly bless you.



ABSTRACT

The study was conducted to assess the bacteriological and physico-chemical quality of potable water provided by Ghana Water Company Limited and borehole (underground) water used as domestic water supply in Achimota School. People in this area use the water for cooking, bathing, washing clothes and some even drink it. Thirteen (13) samples of tap water were collected from thirteen different areas while four (4) samples from boreholes from different locations within the Achimota School in the Accra Metro West District in the Greater Accra Region of Ghana were analysed. It was conducted between August 2010 and December 2010.

Physico-chemical parameters such as calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulphate, chloride, total iron, manganese, fluoride, pH, total alkalinity, conductivity, total dissolved solids, nitrate, nitrite, turbidity and phosphate were determined using conventional methods. Indicators for bacteria contamination due to presence of total coliforms and faecal coliforms were also carried out.

All the pH recorded fell within WHO (2006) limits except tap water from Hospital Area that had a pH of 5.72. The remaining physio-chemical parameters for both waters fell within the desirable limits of WHO (2006) standards for drinking water.

Bacteriologically, total coliforms ranging from 15 - 651 CFU 100 ml⁻¹, were present in all the samples taken. Out of the tap water samples taken, about 50 % (McCarthy House, Anumle, Slessor House, Hospital Area and Achimota Preparatory School Area) and 25 % of borehole (thus Clark House) had faecal coliforms in them. But none of the waters sampled had *E. coli*.

Therefore, both tap and borehole waters within the study area need some suitable treatments to make them safe bacteriologically for drinking. Regular monitoring and effective disinfestations are also needed to reduce the bacteria contamination.

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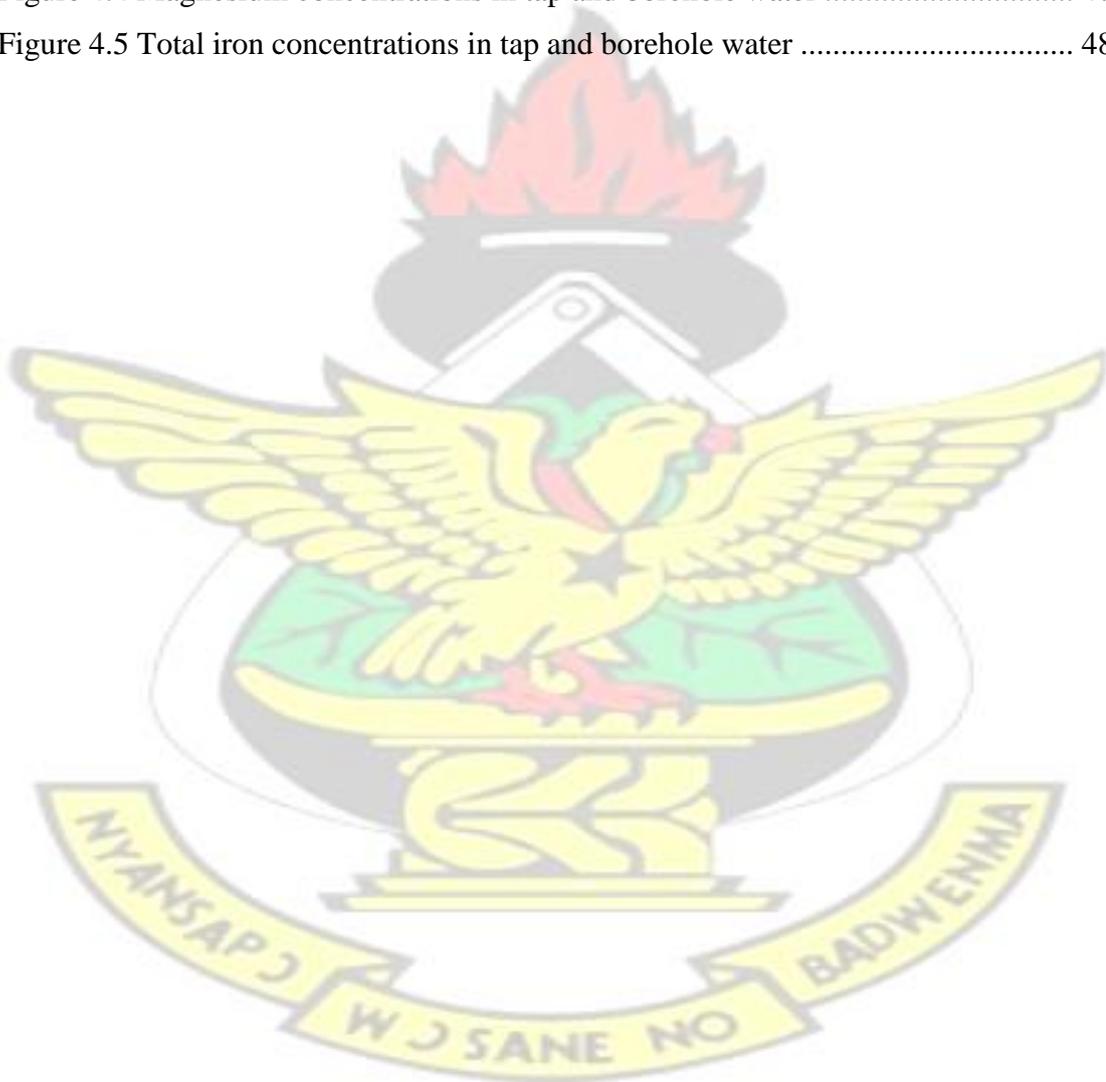
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LIST OF ABBREVIATIONS

GWCL	Ghana Water Company Limited
WRI	Water Resources Institute
GSS	Ghana Statistical Service
CWS	Community Water Solution
GOG	Government of Ghana
MOFA	Ministry Of Food and Agriculture
FAO	Food and Agriculture Organisation
WHO	World Health Organisation
CWSA	Community Water and Sanitation Agency
GMA	Ghana Meteorological Agency
CSIR	Council for Scientific and Industrial Research
WWC	World Water Council
APHA	American Public Health Association
AWWA	American Water Works Association
WEF	Water Environment Federation
US EPA	United State Environmental Protection Agency
VOC	Volatile Organcarbons

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CHAPTER ONE

INTRODUCTION

1.1 Background

Water is one of the most important natural resources because it is observed to be a key to prosperity and wealth (Arbués *et al.*, 2003). It sustains life in the same way that food does (Abane, 2005) and provision of safe drinking water is the aim of every government. In the year 2000, about a hundred and fifty governments all over the world launched an ambitious plan to halve the number of people without access to safe drinking water by the year 2015 (WRI, 2002). Water also facilitates other natural cycles including the hydrological, biogeochemical and climatic cycles. According to the World Resources Institute (2002), water is the commonest resource on earth and it is not only essential for life but has become interwoven with human livelihoods in various unexplainable ways. Most people do not consider it as a nutrient but it forms greater proportion of our diet and that results in forming 70 % of our body weight. So, any environmental factor that affects the activity, structure or physical state of water poses a threat to life (Somero *et al.*, 1992). In addition, any human activity that reduces the quantity (i.e. sufficient water supply for personal or domestic uses) and quality (i.e. safe water for personal or domestic use) of water may affect its access and management at all levels (WWC, 2005). Access to adequate safe drinking water is of prime importance to many governmental and international organizations since undebatably it is the core component of primary health care and a basic component of human development as well as a precondition for man's success to deal with hunger, poverty and death (WHO, 2005).

According to the World Health Organization (2006), Guidelines for Drinking-water Quality safe drinking water is water that does not represent any significant risk to health over a lifetime

of consumption, including different sensitivities that may occur between life stages suitable for all usual domestic purposes, including personal hygiene.

Water supply and safe disposal of excreta are the most important problems that developing countries face especially with the increasing technological advancement, urbanization and the increasing global population (Krämer *et al.*, 2011). Although the United Nations Mid-term Assessment Report (WHO, 2004), indicated that 80% of the world's population used an improved drinking water source in 2004, an increased from 71 % in 1990; every year 1.8 million people die still from diarrheal diseases, and 90 % of these deaths are of children under 5 years. A majority of these people with insufficient potable water or sanitation facilities live in Asia or Africa.

Ghana is fairly well endowed with water resources but like many developing countries in sub-Saharan Africa it is unfortunate to note that, the reasonable endowment of water resources in the country is at variance with access to safer drinking water and sanitation by the citizenry. Some of those sources include groundwater, surface waters (e.g. rivers, streams and ponds), rain-water and springs are the water available to the populace and the qualities of these water bodies vary widely depending on location and environmental factors.

According to Sobsey (2006) about 60 % of the population on the African continent has access to safe drinking water supplies that come from hand pumps, wells (underground water) and treated surface water supplied as tap water. In Ghana it has been reported that about 42.1% of Ghanaian populace main source of drinking water is pipe-borne/tanker water and about 33% of the populace use well or borehole as the main source of drinking water (GSS, 2007). Owusu and Lundehn (2006) also revealed that 87% of direct access GWCL customers are well-connected officials in the public service or otherwise high-standing individuals in the private sector.

Public water supplies are always treated and regularly tested by the GWCL to make sure they are safe for their intended uses. Most rural communities in Ghana obtained their drinking water from surface sources (ponds or rivers) and as a result many people have been affected by waterborne diseases, e.g. bilharzias and guinea worm (Kortatsi, 1994).

As many people as possible living in the urban areas have great difficulty accessing potable water, vis-à-vis the meagre income levels of many and so unable to afford water from service providers or water vendors. A report by Blakely *et al.*, (2005) observed that households that earn less than a dollar a day may be almost nine times more likely to lack access to improved water or sanitation than those earning more than two dollars per day. This problem is even more acute in peri-urban areas where there exist no municipal water distribution systems. People living in such areas have to rely on water transported by vendors or surface water sources such as rivers and canals or ground water. This suggests that many Ghanaians depend on other sources of water outside the GWCL networks. The safety of the water obtained from other sources apart from the GWCL cannot be ascertained; hence the water is mostly used for other household activities rather than for direct consumption. The most reliable source of drinking water is bottled water which is of good bacteriological quality (Obiri-Danso *et al.*, 2003) but it is expensive and thus only within the means of the affluent in the society. The flow of pipe water in many homes in urban communities is erratic, with many of such communities receiving piped water once a week or once every other week. This has been a significant push to drill boreholes in the regions of Ghana including Achimota and its environs.

Boreholes are constructed with a drilling rig and lined with PVC full pipes that are installed in water bearing sections of the holes. The quality of groundwater depends on the mineralogy, reactivity of drift materials and the degree of equilibrium that has been attained between water and rock (Robin, 2002). The initial quality testing of the ground water is usually done by the

company that drills the borehole and after that there seem to be no scheduled monitoring and testing of the borehole water by the community or private owners for possible contamination. However, this type of underground water is used in homes, restaurants, hospitals, and even in delivery rooms.

Boreholes are resistant to many forms of natural and man-made disasters. Although the components above ground may be damaged, the narrow opening at the top of the borehole often prevents contamination of the water source or damage to the pump components below ground. But then the quality of borehole water can be jeopardized by seepage of human waste, which contains bacteria and nutrients that may contaminate the drinking water sources if these and the sanitation facilities are not managed properly. Poor sanitation facilities may also increase the risk of spreading diseases. People with insufficient access to potable drinking water, i.e. consuming contaminated water, may suffer from illnesses on a short as well as long term basis. Toxic chemicals that percolate might be found in the borehole water can cause either acute or chronic health effects. An acute effect usually follows a large dose of a chemical and occurs almost immediately. Examples of acute health effects are nausea, lung irritation, skin rash, vomiting, dizziness, and, in the extreme, death.

1.2 Problem statement

Accra faces significant challenges in meeting the basic water and sanitation needs of its inhabitants. Only handful suburbs have complete access to this pipe-borne water (GOG, 2007). Areas where there is connection, the pipe-borne water is infrequent in flow with many urban communities only receiving piped water once a week or once every other week. Some even lack service lines in their areas, especially, the peri-urban communities. Individuals in those areas resorted to drilling boreholes to gain access to potable water. Those who cannot afford

the cost of drilling boreholes tend to buy water from those who have it at an exorbitant price (CWS, 2009). Furthermore, urban and peri-urban communities that are faced with unreliable piped water are forced to store their water for long periods, a practice which has been shown to lead to frequent and extensive recontamination (WHO/UNICEF, 2008).

There is continuous increased in number of people building on small pieces of land and mostly there is not much space left to accommodate both a borehole and a septic tank. The siting of these boreholes near to septic tanks can result in underground water contamination as a result of percolation of this human waste in the water table. Users of this type of water can suffer from diseases such as diarrhoea, cholera, typhoid etc when the water is used for drinking purposes.

The geology of the area also determines the type of trace and mineral elements as well as the physico-chemical parameters that may characterize the ground water quality in the study area. Achimota, a suburb of Accra, has a pipe-borne water challenge. The inhabitants have boreholes and hand-dug wells as alternatives to pipe-borne water.

1.3 Significance of the study

The outcome of this study will provide a baseline data on pipe-borne and groundwater quality in terms of selected physico-chemical parameters and bacteriological parameters. The information obtained would also assist in advising government on policy making. This will help to regulate groundwater provision in the country and also advise the players in the industry how to monitor groundwater quality for both domestic and commercial use in the country. The data gathered could help to develop a model on how to manage the environment in the Achimota zone.

1.4 Objectives

1.4.1 Main objective

To assess the quality of the water used for domestic activities in the Achimota School in the Okaikoi South District in the Greater Accra Region of Ghana.

1.4.2 Specific objectives

The specific objectives were:

- To determine the concentrations of the selected physico-chemical parameters such as pH, conductivity, total hardness, phosphate, chloride, sodium, turbidity, and calcium of the water used in the Achimota School.
- To measure the trace metals such as iron and manganese in water used for domestic activities in the Achimota School.
- To ascertain the bacteriological quality of the water in the Achimota School.

1.6 Research Question

- Is the quality of water used in the Achimota safe for drinking and domestic use?
- Is the sewage system in the Achimota school having an effect on the water quality used in the area?

1.7 Limitations

The study was designed to cover the entire Okaikoi South District in the Greater Accra Region, however due to financial and a time constraint, coupled with the specificity that the research objectives was designed to be achieved, the study was restricted to only Achimota School and its environment.

CHAPTER TWO

LITERATURE REVIEW

2.1 Water Quality

The term water quality is used to express that which makes it suitable for the needs of the consumer (Osei and Marfo, 1995) without the risk from microbiological or chemical content. The World Health Organization's drinking water guidelines (WHO, 2006) specify levels for physical, chemical and microbiological purity of potable water. Anthropological and natural activities can have much influence on the quality of the tap and borehole water. The most essential of the natural influences are geological, hydrological and climatic, since these affect both the quantity and quality of the available water.

In general groundwater contains no or low levels of harmful pathogens but it can be polluted with naturally occurring chemicals. Unfortunately, the quality of water drawn from handpumps fitted to boreholes is variable. Contamination can be caused by anthropological activities and if not managed properly, can jeopardize underground water source as a result of the seepage of human waste containing bacteria and nutrients, which may increase the risk of spreading diseases.

2.2 Use of Groundwater in Ghana

Groundwater is abstracted from all the Hydrogeological Provinces in the country (Agyekum, 2004). Kortatsi (1994) reported that the main structures for accessing groundwater in Ghana are boreholes, hand-dug wells and dug-outs and this was made up of about 10,500 boreholes, 45,000 hand-dug wells and some dugouts. These numbers of abstraction systems were increased to 71,500 in the year 2000 and comprised of 11,500 boreholes and 60,000 hand-dug wells (Dapaah-Siakwan and Gyau-Boakye, 2000). Currently, the number of boreholes in the country is over 15,000 (Gyau-Boakye *et al.*, 2008) though the costs limit its usage. Most boreholes have been drilled as a result of communities' contribution or few private

organizations. In some instances very few individuals have drilled their own boreholes as a result of infrequent flow or lack of treated water (pipe borne water). After drilling, the boreholes are normally fitted with hand pump but where the water is lifted into overhead water storage tank, motorized pump is connected.

Reports in 2000 reveal that groundwater sources (mainly boreholes and hand-dug wells) constitute 33 % of the main sources of drinking water supply in Ghana (GSS, 2007). It is estimated that over 95 % of groundwater use in the country is for domestic purposes (GyauBoakye *et al.*, 2008). In another study, Martin and van de Giesen (2005) reported that 11 of the 20 towns on the Ghana side of the Volta Basin, each with population of over 10,000 inhabitants, depend exclusively on groundwater for domestic water supply.

It is also used for irrigation of crops. These irrigators are mostly small-scale farmers who use shallow groundwater for their small plot sizes that have vegetables like cabbage, spring onions, carrots, tomatoes, green pepper, okra and shallots for readily available markets in nearby cities and towns. Agodzo *et al.*, (2003) reported that ropes / buckets and low powered pumps are the devices used in accessing such shallow groundwater to irrigate shallots and other vegetables on average farm sizes ranging from 0.08 ha to 1.5 ha on year round basis.

Cornish and Aidoo (2000) revealed that 50 % of 410 vegetable farmers interviewed in the peri-urban areas of Kumasi mentioned that they irrigate their crops with shallow groundwater abstracted from dugouts wells some times during the crop season.

Watering of livestock with groundwater is not widespread in Ghana but limited to the certain regions such as Upper East, Upper West, and Northern regions. Livestock reared in these areas include goats, cattle, sheep and pigs; are allowed to range in search of food and water.

Watering troughs constructed about 5 - 10 m from the borehole collect water for these animals to access. About 70 % of Ghana's 1.34 Million Heads (MH) cattle (2003 estimated figure) and

40 % of other livestock and poultry (sheep-3.02 MH; goats -3.56 MH; pigs-3.03 MH; and poultry-2.64 MH) are produced in these 3 regions and are watered exclusively using groundwater (MOFA, 2004).

Usage of groundwater for industries is very recent and is gradually on the increase in Ghana. Investigations on the source of water for rapidly booming commercial bottled water industries in the south of the country showed a number of boreholes that have been drilled purposely for accessing groundwater on a large scale basis (Gyau-Boakye *et al.*, 2008).

Conclusively, the use of ground water is gradually on the ascendency.

2.3 Drinking water coverage in Ghana

In Ghana, over nine million people have inadequate access to potable water (WA, 2006). The country's population was estimated at about 20 million in year 2000 and it has been observed that about 43 percent of this population currently lives in urban areas, with some cities having growth rates as high as 4.4 percent (Cofie *et al.*, 2003).

Government of Ghana also indicated that urban areas are overpopulated as a result of movement of people from rural areas in search of greener pastures (GOG, 2007). Rockström (2001) showed that population growth directly or indirectly is expected to shift about 55 % of the World's population towards water stress or severe water scarcity over the next generation. This proved that an adequate supply of safe water (by Ghana Water Company Limited) to the inhabitants would be very difficult.

According to Ghana Statistical Service Accra the capital city of Ghana covers an area of about 170 km². It has an estimated population of about 2 million and a functional population of between 3 million to 3.4 million (GSS, 2002). It daily experiences influx of people from the

various regions and rural areas and has an estimated population growth rate of 3.4 percent per annum in the city itself but up to 10 percent in its peri-urban districts (Drechsel *et al.*, 2004).

The fixed conventional water treatment facility cannot meet the increasing demand for potable water of the city making individuals to resort to providing their own water supplies from wells (mainly underground water) and natural sources. In 1999, the Ga District placed first in the incidence of the Buruli ulcer, a disease which was partially caused by inadequate potable water supply (Kofie and Nabila, 2004).

Table 1.0 below describes the distribution of drinking water access in Ghana in more detail:

Table 1:0 Sources of drinking water in Ghana

Source of drinking water	Ghana	Urban	Rural
Pipe-borne	41.6	80.3	18.8
Well	33.9	10.8	47.2
Natural Sources	24.6	8.8	33.9
Total	100.0	100.0	100.0

Source: Ghana Statistical Service (2003)

As at 2003, nearly 80 % of the urban population have access to pipe borne provided by Ghana Water Company Limited water whilst 10.8 % of the urban population access safe drinking water from well (hand dug wells and boreholes). About 24 % of Ghanaian populace use rivers, streams, ponds or unprotected springs and stored rain water (GSS, 2003) as their source of drinking water. It is well known that groundwater is a safer source compared to surface water or natural sources since it is protected from direct contamination and filtered through the soil (VanCalcar, 2006).

Accessing drinking water from such natural source without filtering and treatment can have adverse effects on human health. For instance, in 2003 Ghana Statistical Service estimated that 12 % of deaths occurring in children under five in Ghana were due to diarrheal diseases and this was mostly from drinking unsafe water. Access to sufficient potable drinking water is a basic human right (Annan, *et al.*, 2002), cited in WHO, (2002) and its provision has the capability of saving millions of lives (GSS, 2003).

2.4 Sanitation situation in Ghana

Ghana has one of the highest sanitation coverage in West Africa with 58 % compared to 34, 32, 38, and 26 %, respectively for Togo, Benin, Nigeria and Liberia (WHO, 2002). The poor sanitation situation in Accra is likely to have major impacts on infectious disease burden and quality of life (Hutton *et al.*, 2007). The volume of wastewater produced in Accra as a result of human activities is very high. Raschid-Sally and Jayakody (2008) defined wastewater as “a combination of one or more of: domestic effluent consisting of black water (excreta, urine and faecal sludge) and grey water (kitchen and bathing wastewater); water from commercial establishments and institutions, including hospitals; industrial effluent, storm water and other urban run-off; agricultural, horticultural and aquaculture effluent, either dissolved or as ‘suspended matter.’

2.5 The need for improved water and sanitation

According to the WHO (2004), 1.1 billion people did not have access to an improved water supply in 2002, and 2.3 billion people suffered from diseases caused by contaminated water.

Nath, *et al.*, (2006) estimated that 88 % of these deaths are due to unsafe water supply, inadequate sanitation, and hygiene, and that 99.8 % of water and sanitation-related deaths occur in developing countries. Fig. 1.0 below shows the global per-capita deaths per million related to water and sanitation in each country in 2000.

They further estimated that globally, diarrheal deaths account for only 3.2 % of total deaths; however, the relative disease burden is twice as high in Africa with 6.6 % of deaths attributable to diarrheal disease (including cholera, cryptosporidiosis, giardiasis, and *Escherichia coli* based diarrhoea, among other causes) (Nath *et al.*, 2006) and other waterrelated diseases of concern include typhoid, hepatitis, schistosomiasis, trachoma and guinea worm (Cairncross and Feachem, 2003).

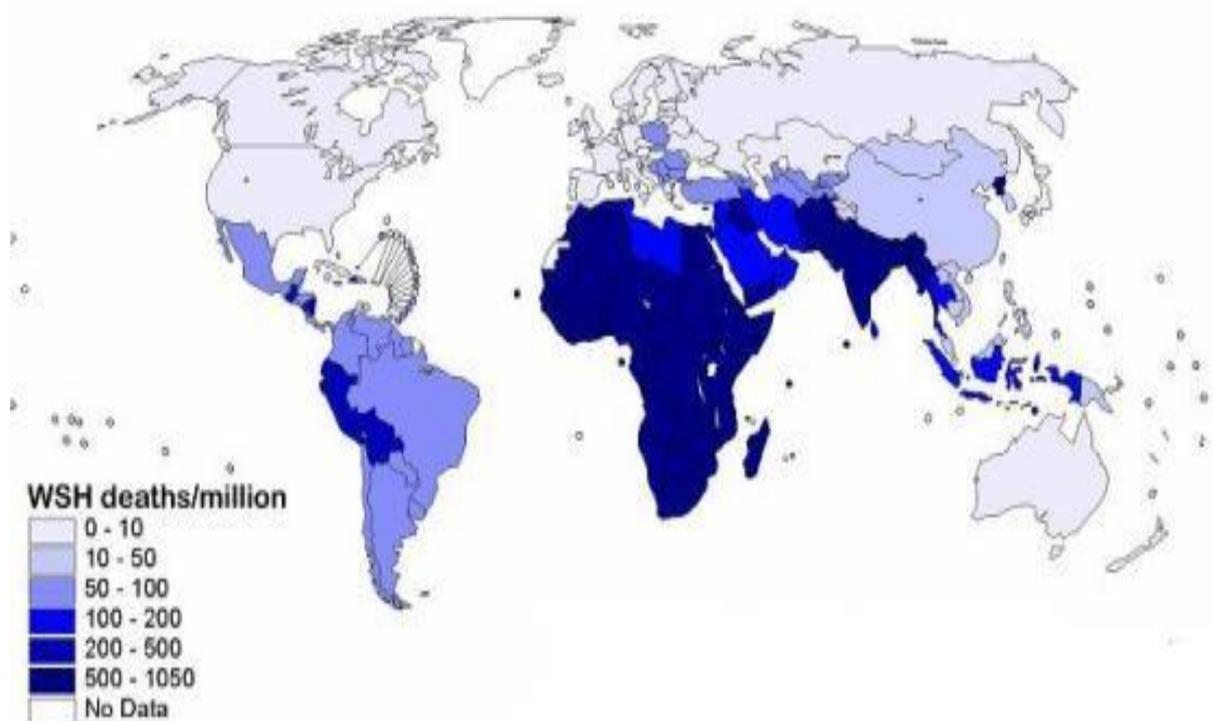


Fig. 1.0 Per-capita deaths caused by unsafe water, sanitation and hygiene for the year 2000 by country (WHO, 2002)

Besides the deaths, water-related diseases also make people inactive thus preventing them from working effectively thereby lowering per capita income.

2.6 Sources of water contamination

Water (pipe or underground) can be polluted by substances that dissolve in it or by solid particles and insoluble liquid droplets that become suspended in it (Plant *et al.*, 2001). The

sources are contaminated as result of pollutants from different sources which include residential, agricultural, industrial and natural processes. Any products such as gasoline, oil, road salts and chemicals that can cause water to become unsafe and unfit for human use are termed as contaminant.

Bacterial contamination of groundwater is also a legitimate concern. A primary source of bacterial contamination is septic systems. Other potential sources include landfills, animal feedlots, surface impoundments, broken pipelines and sewers systems (Bernhardt *et al.*, 2008).

2.6.1 Residential Sources of Contamination

These sources include wastewater from toilets, sinks, showers, and washing machines which are collected in city sewer system. Septic systems are designed to slowly drain away human waste underground at a slow and harmless rate. An improperly designed, located, constructed, or unmaintained septic system can leak bacteria, viruses and household chemicals such as paints, oils, detergents and other contaminants into the groundwater causing serious problems. Outflow from improperly functioning sewage systems and cesspools are a major cause of groundwater contamination. Residential wastewater can be a source of many types of contaminants, including bacteria, viruses, nitrates and organic compounds. If such chemicals are stored in basements or garages with floor drains, spillage may introduce these chemicals into the groundwater.

Landfills in the residential areas are another major source of contamination. Landfills are the places that our garbage is taken to be buried. The sites are supposed to have a protective bottom layer to prevent contaminants from getting into the water. However, if there is no layer or it is cracked, contaminants from the landfill (car battery acid, paint, household cleaners, etc.) can leach into the groundwater.

2.6.2 Agricultural Sources of Contamination

Groundwater contamination can also stem from agricultural activities. Fertilizers, pesticides, herbicides, and animal wastes all pose a potential threat to groundwater quality. For example, common problems include the spillage of fertilizers and pesticides during handling, runoff from the loading and washing of chemical application equipment, and the use of chemicals uphill from or within a few hundred feet of a well. Contamination may also result from the storage of chemicals in uncovered areas, or in locations where groundwater flows from the direction of the chemical storage to the well (Bernhardt *et al.*, 2008).

Fields with over applied or misapplied chemicals may introduce contaminants such as organic compounds, excess nitrogen, cadmium, chloride, mercury and selenium into the groundwater. Runoff from animal waste may result in nitrate, coliform bacteria, and sulphate contamination. Animal waste and feed fertilizer account for 75 % of the nitrogen and phosphorous content in US rivers, streams, and lakes (Bernhardt *et al.*, 2008).

2.6.3 Industrial Sources of Contamination

Chemical contamination of drinking water, commonly by arsenic or fluoride from industrial source, is a concern in some regions of the world, particularly where groundwater is used. Radionuclides are another source of drinking water contamination although total exposure is expected to be very small under normal circumstances. Taste, odour and appearance of drinking water can also cause concern to consumers, however; there may be no direct health effects from these (WHO, 2006). Another source can be from spillage, leakage, or improper handling of materials used in manufacturing, processing, and construction activities and improperly protected storage stockpiles of certain chemicals for example sodium may result in groundwater contamination. The clean-up of such spills can also pose a threat if the spills are flushed with water rather than with absorbent substances. Use of dry holes, cesspools, and

septic systems to dispose of industrial wastes poses a serious threat to groundwater, as it is probable that much of this industrial waste contains toxic materials (Bernhardt *et al.*, 2008).

Although many businesses are conscientious about groundwater contamination, small amounts of waste fluids can accidentally be spilled on the floor, and then washed down floor drains. In addition, underground and above ground storage tanks may contribute to groundwater contamination as a result of leakage, improper installation, or mechanical failure (Bernhardt *et al.*, 2008).

Direct contamination of surface waters with metals in discharges from mining, smelting and industrial manufacturing is a long standing phenomenon (Pearse, 1996). Contamination of water by synthetic micro pollutants results either from direct discharge into surface waters or after transport through the atmosphere. Today, there is trace contamination not only of surface waters but also of ground water bodies, which are susceptible to leaching from waste dumps, mine tailings and industrial production sites (Pearse, 1996).

2.6.4 Natural Sources of Contamination

Some substances found naturally in rocks or soils, such as iron, manganese, arsenic, chlorides, fluorides, sulphates, or radionuclides, can become dissolved in ground water. Other naturally occurring substances, such as decaying organic matter, can move in ground water as particles. Whether any of these substances appears in ground water depends on local conditions. Some substances may pose a health threat if consumed in excessive quantities; others may produce an undesirable odour, taste, or colour. Ground water that contains unacceptable concentrations of these substances are not used for drinking water or other domestic water uses unless it is treated to remove these contaminants.

2.7 Microbial Quality of Water

The quality of water has implications for crop productivity; soil productivity and consumers' health. The FAO and WHO guidelines on quality of water are the basis for national guidelines in many countries. Underground water can be contaminated with a myriad of different components such as pathogens, organic compounds, synthetic chemicals, nutrients, and heavy metals.

Although microorganism had been observed in the 17th century, the recognition of water as a source of pathogenic organism was in the late 1800's when Von Fritsch described *Klesbsiella pneumonia* and *K. rhinoscleromatis* as microorganism characteristically found in human faeces (Ashbolt *et al.*, 2001). By 1914, the U.S Public Health Service (U.S.P.H.S.) had adopted the coliform group as an indicator of faecal contamination of drinking water (Bitton, 2005). Feachem *et al.* (1983) found that enteric pathogens enter the environment in the faeces of infected hosts and can enter water directly through defecation into water, contamination with sewage effluent or runoff from soil and surface water. A total coliform count in water bodies is an important parameter for checking possible sewage contamination (Elmund *et al.*, 1999). Where domestic wastewater is the main source of water pollution, the two main indicators from the health perspective are Faecal Coliforms (FC colonies/100ml) and Helminth eggs (eggs/100 ml). These components can have biocumulative, persistent and synergistic characteristics affecting ecosystem, health and function, food production, human health and well-being, and undermining human security (Pimentel and Pimentel, 2008).

2.8 Potential Health Problems

A number of microorganisms and thousands of synthetic chemicals have the potential to contaminate ground water. Drinking water containing bacteria and viruses can result in illnesses such as hepatitis, cholera, or giardiasis. **Methemoglobinemia** or “blue baby

syndrome,” an illness affecting infants, can be caused by drinking water that is high in nitrates. Benzene, a component of gasoline, is a known human carcinogen. The serious health effects of lead are well known—learning disabilities in children; nerve, kidney, and liver problems; and pregnancy risks. Concentrations in drinking water of these and other substances are compared with WHO allowable limits. Preventing contaminants from reaching the ground water is the best way to reduce the health risks associated with poor drinking water quality.

Part of the difficulty in assessing the health effects of contamination is uncertainty about the dose-response relationship. In addition, we must realize that addressing one type of contamination does not necessarily eliminate, and may even increase, other sources of contamination. For example, restricting agricultural activity about a groundwater recharge zone may result in increased industrial activity in the restricted area, thereby increasing the risk of chemical contamination. The potential health effects from groundwater contamination are vast, due in part to the large number of groundwater contaminants. However, the following presents a brief overview of some of the more accepted adverse health effects that can occur from certain contaminants.

Nitrate contamination can stem from many sources: nitrogen fertilizer use, animal feeding activities, cesspools, septic tanks, and sewage pipelines. Excessive levels of nitrates in drinking water have been linked to two health problems: methaemoglobinaemia and the potential formation of carcinogenic nitrosamines. Methaemoglobinaemia results from the acute toxicity of nitrate, as it reduces to nitrite, which oxidizes hemoglobin to methaemoglobin in one's blood. Methaemoglobin does not act as an oxygen carrier to tissue, resulting is what is commonly termed “oxygen starvation.”

In addition, bacteria in the human body may convert nitrates into nitrites and N-nitroso compounds, which include potentially carcinogenic nitrosamines. Some evidence suggests

correlation between nitrate intake and stomach cancer incidence. However, critics argue that it is not clear at what level nitrates in drinking water become a health hazard, and that humans may consume nitrates from other sources (Hanley and Spash, 1993).

Volatile organocarbons such as vinyl chloride, ethylene dibromide, benzene, toluene, and xylenes have been linked to human reproduction problems such as infertility, sterility, chromosomal damage, increased incidence of spontaneous abortions, and prolonged menstrual bleeding. Burmaster and Harris (1982) report that many compounds commonly found in groundwater depress the central nervous system, resulting in dizziness, nausea, fatigue, poor coordination, mental dullness and blurred vision.

Trichloroethylene, which is widely used as an industrial solvent and degreaser, has been shown to cause liver cancer in mice. Benzene has been proven to be a cause of leukaemia. Many VOCs are also suspected of causing kidney and liver damage. It is important to note that even if these chemicals are not directly ingested through drinking water, they may be inhaled or absorbed into the skin. Thus, activities involving contaminated groundwater, such as showering or bathing, may pose a human health threat.

Consequently, purchasing bottled water for drinking purposes may not provide adequate protection from chemical contamination of one's primary water supply. Finally, even if a particular chemical is banned, groundwater contamination may persist much longer due to the slow process of purification in aquifers. Sodium contamination may pose a serious threat to those suffering from hypertension. Studies have shown that increased levels of sodium intake elevate blood pressure, even in young children (Calabrese *et al.*, 1985). High blood pressure is considered a strong factor in the risk of cardiovascular disease. Elevated sodium levels may also pose a health threat to those with liver or kidney ailments.

The health effects that stem from exposure to microbial contaminants range from mild cases, lasting only a few days, to more serious infections that can linger for several weeks. The mild or moderate symptoms of infection typically include vomiting, diarrhoea, and dehydration. Such exposure may be life threatening in populations with weakened immune systems.

2.9 History of Household Water Treatment

Throughout the 1990s, water quality received relatively little attention among interventions to reduce the diarrheal disease burden in the developing world. The lack of investment in water quality generally was significantly influenced by a meta-analysis by Esrey *et al.* (1991) that concluded that sanitation and hygiene education yielded greater reduction of diarrheal disease than water supply or water quality interventions. However, more recently, a study by Fetwell and Colford (2004) commissioned by the World Bank found that hygiene education and water quality improvements have a greater impact on the incidence of diarrhoeal disease (42 % and 29 % respectively), than sanitation and water supply 24 % and 23 % respectively. In a survey conducted by Water and Sanitation Agency in 2005 in Ghana revealed that rural communities and small towns constitute about 12.6 million (60 %) of the total population and that safe drinking water supplies in small towns and rural communities has improved considerably within the last six years from about 41 % in 2001 to 52 % in 2005 (CWSA, 2005). Yet, the rest 48 %, mainly rural communities, continue to face major shortage in the supply of good quality water.

Currently, there is evidence to suggest that safe water in the home can reduce diarrheal disease by 6-50 %, independent of improved sanitation or hygiene (Nath *et. al.*, 2006). Furthermore a recent review of more than 38 studies covering 53,000 people found that household water quality interventions were nearly twice as effective in preventing diarrheal disease 47 % as community infrastructure such as improved wells and standpipes 27 % (Clasen, 2008).

Research on the health benefits of household water treatment has helped draw international attention however; a consensus has not emerged about which treatment option is most effective. Although it is not a water treatment method, ‘sachet’ water provides a safe drinking water option for target and has emerged as a popular water choice throughout Ghana (Okioga, 2007).

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CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study area, Achimota School and its environs is situated within the Accra Metropolis District in Greater Accra region. It is bounded to the north by Ga East, to the east by Tema Municipal and to west by Ga West District.

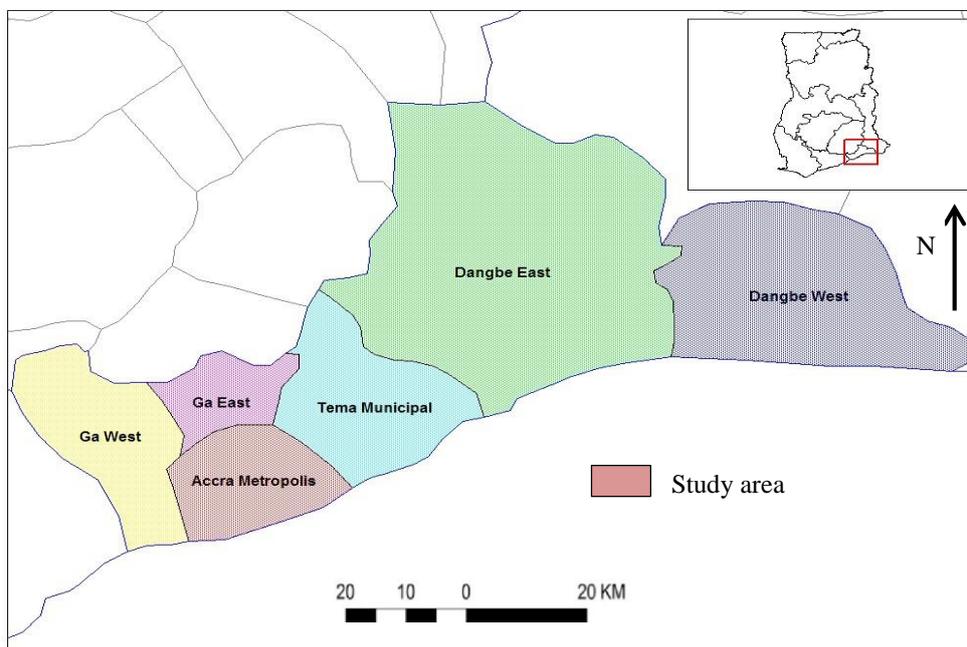


Fig 3.1: Map of Accra Metropolis District in the Greater Accra Region

Achimota School consists of first (Primary and Junior High Schools) and second (Secondary School) cycle units. The secondary school has fifteen houses (dormitories), Primary and Junior High School. The campus size is approximately 1300 acres with total population size of about 5000 (including staff; staff dependents; pupils and students). The School has two campuses – western and eastern campuses. There are fifteen houses on all the campuses and each house accommodates about 120 students on the average.

The Table below indicates the identities of the sampling areas indicated in Fig. 3.1 considered for study

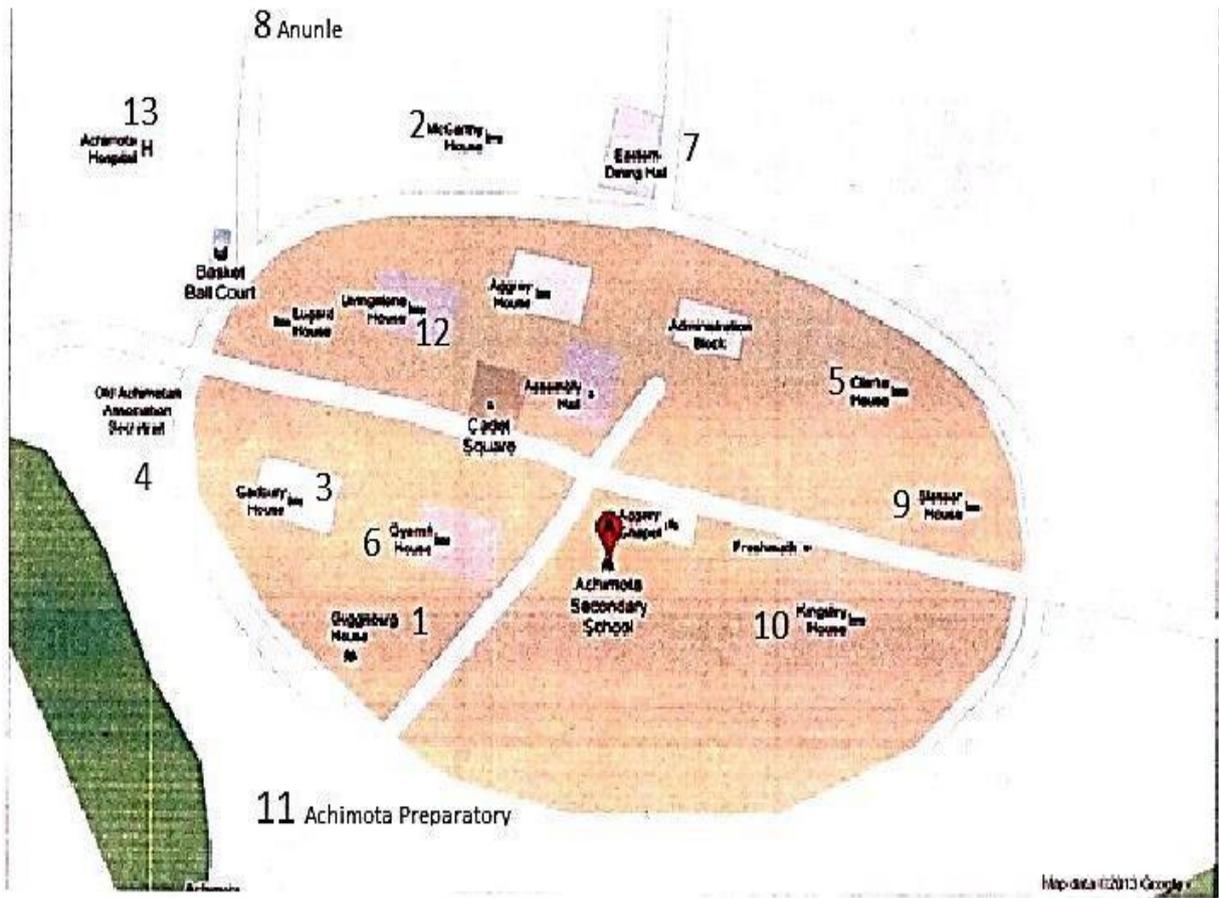


Fig 3.3: Map of sampling site showing sampling points Table 3.1: Names of the sample sites and type of water available

Code	Location	Source of water
1	Guggisberg House	Borehole and Tap water
2	McCarthy House	Tap water
3	Cadbury House	Tap water
4	Club House	Tap water
5	Clark House	Borehole and Tap water
6	Gyamfi House	Tap water
7	Eastern Dining Hall	Tap water
8	Anumle House	Borehole and Tap water
9	Slessor House	Tap water
10	Kingsley House	Borehole and Tap water
11	Achimota Preparatory Area	Tap water
12	Livingstone House	Tap water
13	Hospital Area	Tap water

3.2 Climate

The study area falls into the coastal-savannah zone. It has two wet seasons (major and minor) and one dry season in a year. The major rainy season occurs between May and July with the peak occurring in June while the minor one occurs between September and October with the peak occurring in October (Dickson and Benneh, 2004). The dry season begins from November to March. Annual rainfall ranges between 740 - 890 mm and the mean annual temperature is about 27°C. The highest rainfall recorded by Ghana Meteorological Authority (GMA) was 166 mm for Accra in 2007 was in June whilst the lowest for the season was 66.1 mm in October (GMA, 2007). The recorded highest temperature in Accra was 33°C attained in April 2007 whilst the lowest temperature ever recorded was 28.5°C in July (GMA, 2007). Average relative humidity for Accra is 77 %. The highest relative humidity of 83 % for Accra was obtained in July 2007 with a value of 83 % whilst the lowest was in January with a value of 57 % (GMA, 2007).

3.3 Water Supply and Sanitation Situation in Achimota School

Achimota School initially had one of the best constructed sewers systems that connected the whole of the area and its environs to a central processing unit where sewage was treated. Products after treatment were used on farms. Due to rapid development at the study area currently the central processing unit has been destroyed and indeed it is not uncommon to find liquid sewage gushing out septic tanks and flowing freely with offensive smell within the study area.

Accessing safe water, the inhabitants depend on Ghana Water Company Limited. But then the infrequent flow of the tap water prompted some of the houses (dormitories) on the campus to go in for borehole. Boreholes at the study site are constructed with a drilling rig and lined with PVC full pipes that are installed in water bearing sections. They mostly abstract groundwater

from deep aquifers and they are also fitted with motorized pump so that water can be lifted into overhead water storage tank and supplied water to over 120 students per house for use.

3.4 Pre-sampling preparation i) Physico-chemical Parameters

The bottles of volume 1500 ml for samples were thoroughly washed with soap and hot water and further rinsed with distilled water. Each bottle was rinsed with respective sample water at the sample site twice, before actual sample collection was undertaken.

ii) Microbiological Parameters

The bottles of volume 500 ml were also used in collecting samples for bacteriological analyses. These bottles were washed thoroughly with soap and hot water and later rinsed with hot water and finally rinsed with distilled water. The bottles were later sterilized in the Gallenkamp autoclave at a temperature of 170 °C for three (3) hours, with an Aluminium foil around the cover. These were done to remove all traces of microorganism and washing compounds that might be hidden in the sample bottles.

3.5 Samples collection

Two samples were collected from bore-holes and tap water sites into two types of clearly labelled bottles; one for physicochemical analyses (1500 ml), and the other for bacteriological analyses (500 ml). These samples were collected directly without them going through the storage tanks. The samples were then put into an ice chest at 4°C and taken to the CSIR WRI laboratories, Accra, for further analysis. All the analyses were analysed according to standard procedures outlined in the *Standard Methods for the Examination of Water and Wastewater* (APHA, AWWA and WEF, 1998), at the Water Research Institute of the Council for Scientific and Industrial Research (CSIR) and the Research Laboratory of the International Water Management Institute Accra, Ghana.

3.6 Physico-chemical analyses i) Field Analyses

Turbidity, pH and conductivity of the water sample were measured *in-situ* (in the field) using the pH/Cond 340i SET (WTW, Wissenschaftlich-Technische Werkstätten, Germany). Turbidity was detected by means of the HACH model: 2100P turbidimeter, and the pH and conductivity of the water samples were measured using pH meter (Suntex Model SP 701) and conductometer (Orion Model 120) respectively with strict adherence to the sampling protocol described by Claasen (1982) and Barcelona *et al.*, (1985).

a) Conductivity

The conductivity was determined by means of a Field conductivity meter (Orion Model 120) (APHA, 1998). The conductivity 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 and the probe was then inserted into the vessel and the conductance read. The conductance was equilibrated to 25 °C before the sample measurement.

b) Turbidity determination

Turbidity of the samples was determined by nephelometric method (APHA, 1998). The method is based on a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension under the same conditions. The turbidimeter was calibrated with standard turbidity solution of 0.1 NTU and the knob adjusted to read 0.1. The samples were shaken vigorously and poured into the sample cells (HACH model: 2100 P) to at least two-thirds full. The appropriate range was selected, when the red light came on, the knob was moved to the next range till it was stable, and then the turbidity value was read and recorded

c) pH

The pH was measured by a pH meter (Orion Model 120) (APHA, 1998) and a combination electrode (a set of glass electrode and a reference electrode). The pH electrode was first calibrated using WTW technical buffer solutions (pH values at 25 °C: 2.00/4.01/7.00/10.01) to adjust to the response of the glass electrode. After the calibration, the electrode was thoroughly rinsed with de-ionized water before the sample measurement is taken. The electrode was then immersed in the sample and stirred gently and stopped, allowing for 1-5 minutes for a stable reading to be obtained and recorded.

3.7.1 Laboratory analysis of physico-chemical samples

All Laboratory analyses were done at the Water Research Institute Microbiology Dept. and Water Quality Laboratories of the CSIR, in Accra

a) Colour determination

Colour was determined by Lovibond® Nessleriser 2150 (APHA, 1998). The sample colour was observed by filling a Nessler tube to the 50 ml mark with the water sample. The sample was placed in the right hand compartment of the Nessleriser lighted cabinet whiles distilled water was placed in the left hand compartment for reference. The colour disk was placed in the disk compartment after which the light of the Nessleriser was switched on. The disk was rotated to obtain a colour match. The colour was read in Hazen from the disk.

b) Total solids determination

Total solid was determined by the gravimetric method (APHA, 1998). A 50 ml glass petri dish was conditioned at 105.0 °C for one hour. The dish was stored and cooled in a desiccator until needed which was weighed immediately before use. The sample was shaken vigorously after which 100 ml was transferred by means of graduate cylinder. The sample was evaporated on a

water bath and then dried in an oven at 105.0 °C for about one hour until a constant weight was obtained. It was then cooled in a desiccator to balance temperature and weight.

Calculations:

$$\text{Total Solids (TS) (mg/l)} = \frac{[(A-B)]}{C} \times 10^6$$

Where: A = Weight of dried residue and dish (g)

B = Weight of dish alone (g)

C = Volume of sample (ml)

Total Suspended solids determination was done by the gravimetric method. Filter papers of diameter 47.0 mm and a pore size of 2.0 µm were first conditioned by washing the filter paper with distilled water several times. The traces of water in the filter papers were removed by applying the vacuum continuously. The filter papers were then placed in clean petri dishes and then put in the oven at 105.0 °C for one hour after which they were cooled in a dessicator. After conditioning the filter papers and the petri dishes, they were then weighed. The filtration apparatus with the filter was assembled. The sample was vigorously shaken and a suitable volume (100 ml) transferred to the funnel. The filter was washed with three successive 10ml volume of distilled water to allow complete drainage. The sample was suctioned for about three minutes after titration was complete. The filtrate from the filter holder was carefully removed and transferred into a weighing dish. The filter papers with their residues were then dried to constant weight at 105.0 °C. It was then cooled in a dessicator to balance temperature and weight. The difference in weight between the filter paper with residue and the filter paper without the residue gave the total suspended solids.

Calculation:

$$\text{Total suspended solids (TSS) mg/l} = \frac{(A-B)}{C} \times 10^6$$

Where: A = weight of filter + dish + residue, (g)

B = weight of filter + dish, (g)

C = volume of sample filtered (ml)

Total dissolved solids (TDS) for the samples were obtained by the difference between the total solids and the corresponding total suspended solids.

Calculation: Total dissolved solids (TDS) mg/l = TS – TSS

c) Total alkaline determination

Total Alkalinity was derived from the determination of the alkalinity by the Strong Acid Titration method (APHA, 1998). Thus hydroxyl ions present in the samples as a result of dissociation or hydrolysis of solute reacts with the standard acid added. Alkalinity thus depends on the end-point pH used. Titration to the end point of pH 8.3 determines the phenolphthalein alkalinity (P); titration to the end point of pH 4.5 gives the total (methyl orange) alkalinity (T). The sulphuric acid was standardized using (0.1N) sodium carbonate.

50 ml of the sample was mixed with one drop of phenolphthalein indicator in a conical flask. If there was colour change that is if it turned pink then the alkalinity to phenolphthalein was determined by titration with the standard 0.02 N sulphuric acid until the pink colour changed to colourless or disappears. This was then followed with the addition of two drops of methyl orange to the same solution and the sample was titrated with the standard acid till the yellow colour turned orange.

Calculation:

$$\begin{aligned} \text{Phenolphthalein alkalinity as CaCO}_3 \text{ (P)} &= \frac{50,000 \times A \times N \text{ mg/l}}{V} \\ &= \frac{50,000 \times B \times N \text{ mg/l}}{V} \\ \text{Total alkalinity as CaCO}_3 \text{ (T)} &= \frac{V}{V} \end{aligned}$$

A = ml of standard acid solution added to obtain the Phenolphthalein end point of 8.3 pH.

B = ml of standard acid solution added to obtain the methyl orange end point of 4.5 pH.

N = Normality of the mineral acid

V = Volume of sample use

d) Total hardness determination

Total Hardness was determined by Complexometric Titration using Ethylenediaminetetraacetic acid (EDTA) (APHA, 1998). 50 ml of the sample was put into a conical flask and 1 ml of a buffer solution (prepared from ammonium chloride 16.9 g conc. Ammonium hydroxide 143.0 ml and magnesium salt of EDTA, 1.25 g) was added to produce a pH of 10.0 ± 0.1 . This was followed by the addition 0.1 g of Eriochrome Black T indicator, it was mixed thoroughly and titrated against standardized 0.01 M EDTA solution until the last traces of purple disappeared or the colour turned bright blue. 50.0 mg/l calcium solution was used as the control standard.

Calculation: Total Hardness = $\frac{\text{ml EDTA} \times B \times 1000}{\text{ml sample}}$

B = mg of CaCO₃ equivalent to 1.00ml EDTA titrant, that is ml CaCO₃/ml EDTA

e) Dissolved Oxygen (DO) determination

The determination of dissolved oxygen (DO) and biological oxygen demand (BOD) was carried out using a modified version of Winkler's method (Winkler, 1988; APHA, 1998). Two drops of concentrated H₂SO₄ was added along the neck of the DO bottle and shaken till dissolution was complete. 100ml of the solution was taken and titrated with M/80 sodium thiosulphate solution to straw yellow colour. 2 ml starch solution was added to give a blue colour. It was then titrated to the point where the blue colour changed to a colourless endpoint.

Calculation: $\text{mgO}_2 / \text{l} \propto \frac{\text{Volume of M/580 thiosulphate used} \propto 101.6}{\text{Volume of sample used}}$

f) Determination of Biological oxygen demand (BOD)

Sample for BOD determination was incubated at 20°C for five days and treated with Winkler I (MnSO₄) followed by Winkler II (alkaline-iodide-azide) solutions before titrimetric analysis (APHA, 1998; Winkler, 1988). The bottles for the water sample were corked carefully to exclude air bubbles and shaken thoroughly by inverting several times. The precipitate was allowed to settle at the bottom of the sample followed by addition of 2 ml of conc. H₂SO₄. The bottle was corked again and inverted several times to dissolve the precipitate, which gave intense yellow colour. 100 ml of the solution was then titrated with M/80 thiosulphate to a pale yellow colour and 1ml starch was added as an indicator to give a blue colour. It was then titrated to the point where the blue colour changed to a colourless endpoint.

Calculation

$$\text{BOD}_5, \text{mg/l} = (\text{BOD}_1 - \text{BOD}_2) / p$$

Where: BOD_1 = DO of sample immediately after preparation, mg/l,
 BOD_2 = DO of the sample after 5 days incubation at 20°C, mg/l p
= Decimal volumetric fraction of sample used.

3.7.2 Determination of ions

The ions determined under the study are Bicarbonate (HCO_3^-), Sulphate (SO_4^{2-}), Calcium (Ca^{2+}), Chloride (Cl^-), Magnesium (Mg^{2+}), Potassium (K^+) and Sodium (Na^+).

a) Sulphate ion

Sulphate was determined by the turbidimetric method (APHA, 1998). Sulphate ion is precipitated in an acidic medium with barium chloride to form a barium sulphate crystal with uniform size. The absorbance of $BaSO_4$ suspension is measured by a photometer at 420 nm and the sulphate concentration is determined by comparison of the reading with a standard curve. 100 ml of the sample was measured into a 250 ml Erlenmeyer flask. 5ml conditioning reagent was added and mixed by stirring. A spoonful of barium chloride crystals was added while stirring. The stirring was done at a constant speed for 60 second. The absorbance at 420 nm was determined with the spectrophotometer within 5 minutes.

b) Calcium ion

Calcium was determined by the EDTA Titrimetric Method (APHA, 1998). Two millilitres (2.0 ml) of 1M NaOH solution was added to fifty millilitre of the sample. The solution was stirred and 0.1- 0.2 g of murexide indicator added and then titrated immediately after the addition of the indicator. Ethylenediaminetetraacetic acid disodium salt (EDTA) was added slowly to the titrant with continuous stirring until the colour changed from salmon to orchid purple. 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: $\text{Ca (mg/l)} = \frac{A \times B \times 400.8}{\text{ml of sample}}$

Where; $A = \text{ml of EDTA titrant used}$

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

c) Magnesium ion

Magnesium hardness was determined by following the Total hardness and Calcium hardness values (APHA, 1998) and calculated it from the difference between the two. Magnesium content was therefore obtained by multiplying the magnesium hardness value by 0.243.

Calculation:

From the calcium titration, $\text{Ca (mg/l)} = \frac{A \times B \times 400.8}{\text{ml sample}}$

$A = \text{ml of EDTA titrant used}$

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

Then calcium hardness as $\text{mg CaCO}_3/\text{l} = \frac{\text{concentration calcium}}{0.4}$

0.4 is the atomic weight of Ca/molecular weight of CaCO_3 .

Magnesium hardness as $\text{mg CaCO}_3/\text{l} = \text{Total hardness} - \text{Calcium hardness}$

$\text{Mg/l Mg} = (\text{Total hardness} - \text{Calcium hardness}) \times 0.243$

Where 0.234 = atomic weight of Mg/molecular weight of CaCO_3 .

d) Fluoride Concentration

SPADNS method (APHA, 1998)

SPADNS (sodium 2-(parasulphophenylazo)-1,8-dihydroxy-3,6-naphthalene disulphonate) was mixed with zirconyl-acid reagent and added to the sample. The absorbance was read at 570 nm and compared to identically-prepared standard and blank solutions. Detection limit was 0.001 mg/l.

e) Chloride

The presence of chloride ions were determined by the Argentometric method (Kraemer and Stamm, 1924; APHA, 1998). Fifty millilitre (50 ml) of sample was taken and one milliliter (1 ml) of K_2CrO_4 indicator solution was added and titrated with standard Silver nitrate ($AgNO_3$) 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

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

Where; A = ml titration for sample

B = ml titration for blank

M = Molarity of $AgNO_3$

f) Potassium ion

Potassium was determined by the Photometric method (APHA, 1998). Trace amount of potassium was determined in a direct reading flame photometer as a wavelength of 768 μm . The sample was sprayed into a gas flame and excitation is carried out under a carefully

controlled and reproducible conditions. The desired spectra line was isolated by the use of interference filter. The intensity of light was measured by a phototube potentiometer. The intensity of light at $768 \mu\text{m}$ is approximately proportional to the concentration of potassium in the sample.

g) Ammonium ion

Ammonia-Nitrogen was determined by the Direct Nesslerization method (APHA, 1998). This method is based on the colorimetric determination of ammonia after the addition of Nessler's reagent. The yellow to brown colour produced by the Nessler-ammonia reaction absorbs strongly in the range of 400 to 425 nm when a 1 cm light path is used. 50 ml of the supernatant of the sample was pipetted into a conical flask. Five drops of Rochelle salt were added to the sample which was allowed to mix well after which 2 ml of Nessler's reagent was added. A blank solution was prepared from 50 ml ammonia free water, 5 drops Rochelle salt solution and 2 ml Nessler's reagent. They were allowed to stand for 10 minutes to allow for colour development, and their absorbance was measured on a UV/VIS spectrophotometer at a wavelength of 410 nm (range of absorbance 400 to 425 nm) using a 1 cm light path cuvette. The blank solution was used to zero the spectrophotometer.

h) Nitrate ion and nitrite ion

Nitrate ion concentration – Nitrogen was determined by the Hydrazine Reduction Method (Ultraspec Model II) (APHA, 1998). The method is based on the principle that, nitrate is reduced to nitrite with hydrazine sulphate. The nitrite ion originally present, plus reduced nitrate ion is determined by diazotization with sulphanilamide and coupling with N-(1-naphthyl)-ethylenediamine dihydrochloride to form a highly coloured azo dye which is measured spectrophotometrically. In the determination, 10 ml of the sample was pipetted into a

test-tube. 1.0 ml of 0.3 NaOH was added and mixed gently. This was heated at 60°C for 10 minutes in a water bath and allowed to cool to room temperature and one millilitre (1 ml) of colour developing reagent was added. The solution was shaken to mix and the absorbance at 520 nm read and this was compared to identically-prepared standard and blank solutions. The nitrate concentration was obtained by subtracting the original nitrite concentration, determined from a duplicate sample. The detection limit was 0.005 mg/l.

i) Nitrite – Nitrogen was determined by the Diazotization method (Ultraspec II model 80 – 2091 – 73) (APHA, 1998). Nitrite reacts in strongly acid medium with sulfanilamide. The resulting diazo compound is coupled with N-(1-naphthyl)-ethylenediamine dihydrochloride to form an intensely red-coloured azo-compound. The absorbance of the dye is proportional to the concentration of nitrite present. In the determination, place 50ml of the sample in a Nessler tube which was set aside for until preparation of standard are complete. 2 ml of buffer-colour-reagent was added to the standard sample, mixed and the colour allowed to develop for about 15 minutes. The absorbance in the spectrophotometer at 540nm against the blank solutions was measured. The method detection limit was 0.001 mg/l.

j) Phosphate ion

Phosphate was determined by the Stannous Chloride method (UV / VIS Ultraspec II) (APHA, 1998). The principle behind the method is that, molybdophosphoric acid is formed and reduced by stannous chloride to intensely coloured molybdenum blue. The absorbances of the molybdenum blue at a wavelength of 690 nm are proportional to the concentration of the phosphate in the sample. The determination started by adding 0.05 ml (1 drop) phenolphthalein indicator to a 100 ml sample free from colour and turbidity. When the sample turns pink, strong acid solution is added to discharge the colour. By thorough mixing after each addition, 4.0ml molybdate reagent I and 0.5 ml (10 drops) stannous chloride reagent 1 was added. After 10

minutes, but before 12 minutes, the absorbance at a wavelength of 690nm was measured by the spectrophotometer.

3.8 Determination of traces elements

The measurement of trace metals: Iron (Fe) and Manganese (Mn) were done by the Atomic Absorption Spectrophotometry (Model Unicam 969 AAS with 50 mm burner) (APHA, 1998).

a) Iron Concentration

Atomic Absorption Spectrometry – Direct Aspiration

The sample aliquot was digested in nitric acid, diluted appropriately, then aspirated and the absorbance was measured spectrometrically at 248.3 nm with the aid of a UNICAM 969 SOLAAR 32 Atomic Absorption Spectrophotometer and compared to identically-prepared standard and blank solutions, using an air-acetylene oxidizing flame (APHA, 1998).

b) Manganese Concentration

Atomic Absorption Spectrometry – Direct Aspiration

The sample was preserved in the field with nitric acid. The sample aliquot was then digested with nitric acid. The solution was aspirated and the absorbance measured spectrometrically at 279.8 nm with the aid of a UNICAM 969 SOLAAR 32 Atomic Absorption Spectrophotometer and compared to identically-prepared standard and blank solutions, using an air-acetylene oxidizing flame (APHA, 1998). Instruments detection limit was 0.005 mg/l.

3.9 Bacteriological analyses

The membrane filtration method (APHA, 1998) was used in the determination of two parameters, namely; Total Coliform and Fecal Coliform.

a) Total Coliform determination

Aliquots of 100 ml of the groundwater samples were separately filtered through 47 mm membrane filters of 0.45 μm pore size membrane filters (APHA1998). The membrane filter was incubated an inoculated membrane filter on M- Endo Agar Les (Difco) and alternatively on Mac Conkey Agar at $37\pm 0.5^\circ\text{C}$ for 16 - 18 hours.

For total heterotrophic bacteria analysis, the pour plate was used. Aliquot of 1ml of the sample water was cultured on Nutrient Agar (supplemented with yeast). Incubation was at 37°C for 48 hours. All colonies that appeared on the plate after incubation period were counted to represent the viable counts in the water.

b) Faecal Coliform determination

Aliquots of 100 ml samples of the water sample were filtered through 47 mm membrane filters of 0.45 μm pore size (APHA, 1998). The membrane filter was incubated on M-FC agar at 44°C for 24 hours. Faecal coliform was detected as blue colonies on the M-FC agar. The total numbers of colonies appearing were counted for each plate.

c) Procedure for bacteriological analyses

The samples were removed from storage and allowed to cool to room temperature and the incubation chamber for the analyses was cleaned with ethanol to prevent contamination. The porous plate of the membrane filtration unit and the membrane filter forceps were sterilized by being applied with 98 % alcohol which was burnt off in a Bunsen flame. The sterile forceps were then used to transfer the sterile membrane filter onto the porous plate of the membrane filtration unit with the grid side up and a sterile meshed funnel placed over the receptacle and locked in place. The required volume of water samples (100 ml) were added to the membrane filtration unit using the funnel measure. The flame from the Bunsen burner was kept on throughout the whole analyses and the forceps was flamed intermittently to keep it sterile. The

samples were filtered through the membrane filter under partial pressure created by a syringe fitted to the filtration unit. The filtrates were discarded and the funnel unlocked and removed. The sterile forceps were then used to transfer the membrane filter onto a sterile labelled petri dish containing the appropriate growth medium (M. F.C agar for Faecal coliform and M. Endo agar for Total coliform). The membrane filters were placed on the medium by rolling action to prevent air bubbles from forming at the membrane (APHA, 1998).



CHAPTER FOUR

RESULTS

4.1 Bacteriology of the tap and borehole water

4.1.1 Tap water

Tap water samples from all the thirteen sites (n) within Achimota School Area had total coliform counts ranging from 15 – 558 CFU 100ml⁻¹ and faecal coliform counts ranged from 1.0 – 108 CFU 100ml⁻¹. There is no *E. coli* counts in any of the tap water samples collected (Table 4.1).

Table 4.1: Microbiological record on tap water samples from thirteen sites (n)

Sample ID	TC/100 ml	FC/100 ml	<i>E. coli</i> /100 ml	THB/100 ml
1	192	0	0	81
2	244	1	0	1344
3	15	0	0	2
4	122	0	0	10
5	96	0	0	3
6	128	0	0	15
7	144	0	0	122
8	207	1	0	156
9	216	1	0	5
10	20	0	0	26
11	558	108	0	127
12	70	0	0	5184
13	28	1	0	8

4.1.2 Borehole

The borehole within the study Area had total coliform counts from four sampling sites (n) ranging from 1.40×10^2 – 6.51×10^2 CFU 100ml⁻¹. Out of the borehole samples only one sampling site (Clark House) recorded faecal coliform. None of the borehole samples had recorded *E. coli* (Table 4.2).

Table 4.2: Microbiological record on samples taken from boreholes at Achimota School

Sample ID	TC/100ml	FC/100ml	E. coli /100ml	THB / 100ml
Kingsley	651	0	0	448
Clark	288	1	0	384
Slessor	558	0	0	164
Guggisberg	140	0	0	188

4.2 Physicochemical parameters of tap and borehole water.

4.2.1 Tap water

The pH of tap water ranged from 5.72 – 7.52 pH units with a mean of 7.45. Total dissolved solids (TDS) of the water also ranged from 148.0 – 299.0 mg/l with a mean of 180.31 mg/l. Total hardness values of the water samples ranged from 58.0 – 84.0 mg/l with a mean of 71.39 mg/l. Electrical conductivity of the samples also ranged from 7.44 – 421 μ S/cm with a mean of 188.56 μ S/cm (Table 4.3).

Table 4.3: Summarized data on the chemical parameters of Tap water

Parameter	unit	n	Minimum	Maximum	Mean (\pm)	Std. Dev.
Total susp. solids	mg/l	13	1.00	2.00	1.5000	0.707
Total Dis. Solids	mg/l	13	148.00	299.00	180.3077	41.630
Na	mg/l	13	17.70	49.50	26.7615	11.227
K	mg/l	13	3.30	5.50	4.6923	0.588
Ca	mg/l	13	12.80	22.40	16.4923	2.583
Mg	mg/l	13	5.80	9.20	7.3154	1.036
NH ₃	mg/l	13	0.00	0.00	0.0000	0.000
Chloride	mg/l	13	20.80	53.60	27.1600	9.634
Sulphate	mg/l	13	17.30	48.00	26.5400	12.867
Phosphate	mg/l	13	0.21	1.06	0.6400	0.306
Mn	mg/l	13	0.01	0.02	0.0100	0.007

Nitrate	mg/l	13	0.03	0.20	0.0900	0.079
Nitrite	mg/l	13	0.03	2.44	0.3600	0.783
Total hardness	mg/l	13	58.00	84.00	71.3900	8.181
Total Iron	mg/l	13	0.01	0.293	0.0900	0.087
Calcium Hardness	mg/l	13	32.10	56.10	41.3300	6.457
Mg hardness	mg/l	13	23.90	37.90	29.9900	4.287
Fluoride	mg/l	13	0.45	58.00	5.1400	15.884
Bicarbonate	mg/l	13	26.80	78.10	65.5100	12.253
Carbonate	mg/l	13	0.00	0.00	0.0000	0.000
Conductivity	$\mu\text{S}/\text{cm}$	13	7.44	421.00	188.5600	155.268
<u>pH</u>	<u>pH unit</u>	<u>13</u>	<u>5.72</u>	<u>7.52</u>	<u>7.4500</u>	<u>0.302</u>

4.2.2 Borehole

For borehole the pH recorded ranged from 6.04 – 7.52 pH units with a mean of 6.805 pH units.

The total dissolved solids ranged from 135.0 – 402.0 mg/l and total hardness also ranged from 46.0 – 80.0 mg/l with the mean of 63.0 mg/l. The borehole recorded higher conductivity than

tap water with the range of 246 – 731 $\mu\text{S}/\text{cm}$ (Table 4.4). **Table 4.4: Summarized data on the chemical parameters of borehole water**

<u>Parameter</u>	<u>Unit</u>	<u>n</u>	<u>Minimum</u>	<u>Maximum</u>	<u>Mean (\pm)</u>	<u>Std. Deviation</u>
TDS	mg/l	4	135.00	402.00	283.2500	111.195
Na	mg/l	4	14.60	112.00	69.1000	40.323
K	mg/l	4	2.18	4.73	3.8750	1.202
Ca	mg/l	4	7.20	20.80	12.2000	6.477
Mg	mg/l	4	6.80	9.70	7.9000	1.393
Total iron	mg/l	4	0.02	0.18	0.1025	0.090
Chloride	mg/l	4	25.80	175.00	110.4500	62.040
Sulphate	mg/l	4	13.10	36.30	23.9750	11.155
Phosphate	mg/l	4	0.16	0.28	0.2350	0.053
Mn	mg/l	4	0.01	0.21	0.1175	0.108

Nitrate mg/l	4	0.33	1.92	1.2300	0.725
Nitrite mg/l	4	0.02	0.39	0.1325	0.174
Tot Hard mg/l	4	46.00	80.00	63.0000	16.533
Tot alkalin. mg/l	4	16.00	36.00	23.5000	9.000
Ca Hardness mg/l	4	18.00	52.10	30.5500	16.248
Mg Hardness mg/l	4	27.90	39.90	32.4500	5.727
Fluoride mg/l	4	0.09	0.14	0.1250	0.024
Bicarbonate mg/l	4	19.50	43.90	28.6750	10.969
Carbonate mg/l	4	0.00	0.00	0.0000	0.000
pH (pH unit)	4	6.04	7.52	6.805	0.6129
<u>Conduct.(μS/cm)</u>	<u>4</u>	<u>246</u>	<u>731</u>	<u>515</u>	<u>174.844</u>

Below is the key to the various sampling sites within the study area.

Table 4.5: Names of the sample sites and type of water available

Code	Location	Source of water
1	Guggisberg House	Borehole and Tap water
2	McCarthy House	Tap water
3	Cadbury House	Tap water
4	Club House	Tap water
5	Clark House	Borehole and Tap water
6	Gyamfi House	Tap water
7	Eastern Dining Hall	Tap water
8	Anumle House	Borehole and Tap water
9	Slessor House	Tap water
10	Kingsley House	Borehole and Tap water

11	Achimota Preparatory Area	Tap water
12	Livingstone House	Tap water
13	Hospital Area	Tap water

4.3 Sodium contents in the water

The Fig. 4.1 below shows the sodium concentration in the tap and borehole water respectively. The sodium concentration for tap water is lower than that of the borehole with the minimum value of 17.70 mg/l at site 6 (Gyamfi House) and a maximum value of 49.50 mg/l at site 1 (Guggisberg House); the values of borehole ranges from minimum 14.60 at site 10 (Kingsley House) to a maximum of 112.0mg/l at site 1 (Guggisberg House).

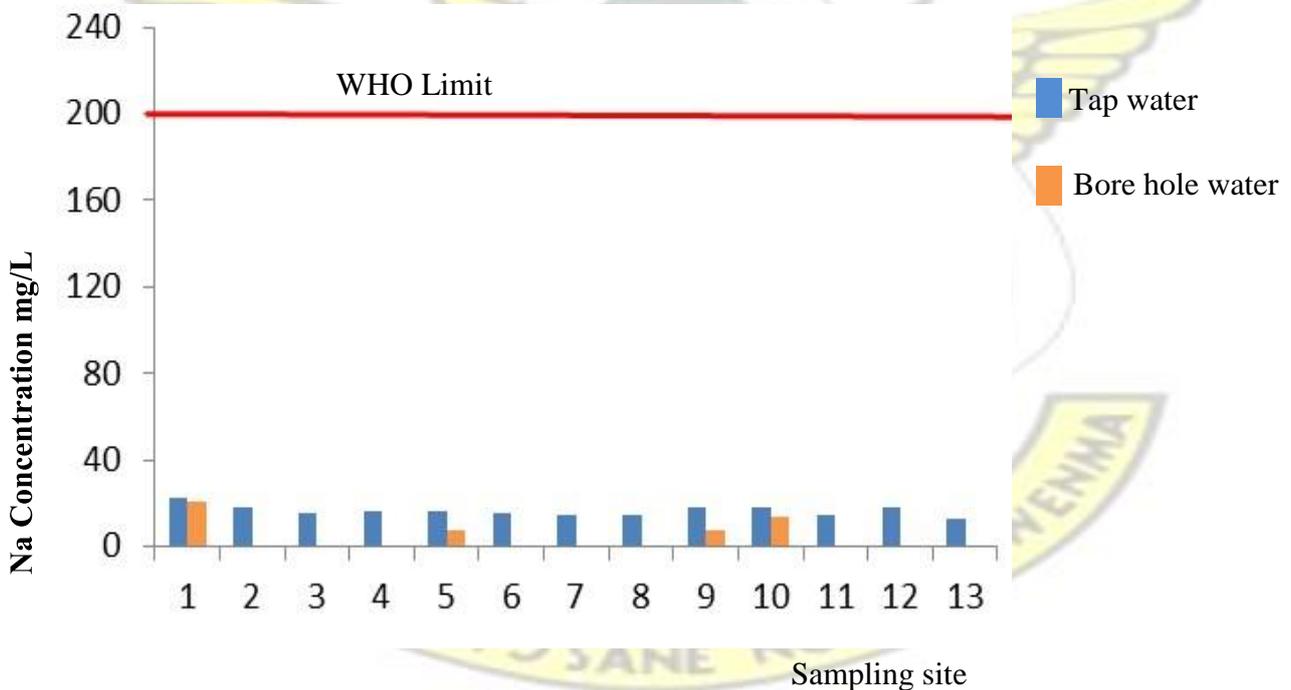


Figure 4.1 Sodium concentrations in tap water and bore hole water

4.4 Calcium content in tap and borehole water

The concentration of calcium in both water in shown in Fig. 4.2 below. It can be deduced from the graph that the amount of calcium (measured) in the tap water is higher than that of the borehole water. The amount measured at site 1 (Guggisberg House) has the highest concentration in both tap water and groundwater with the value of 22.4 mg/l and 20.8 mg/l respectively.

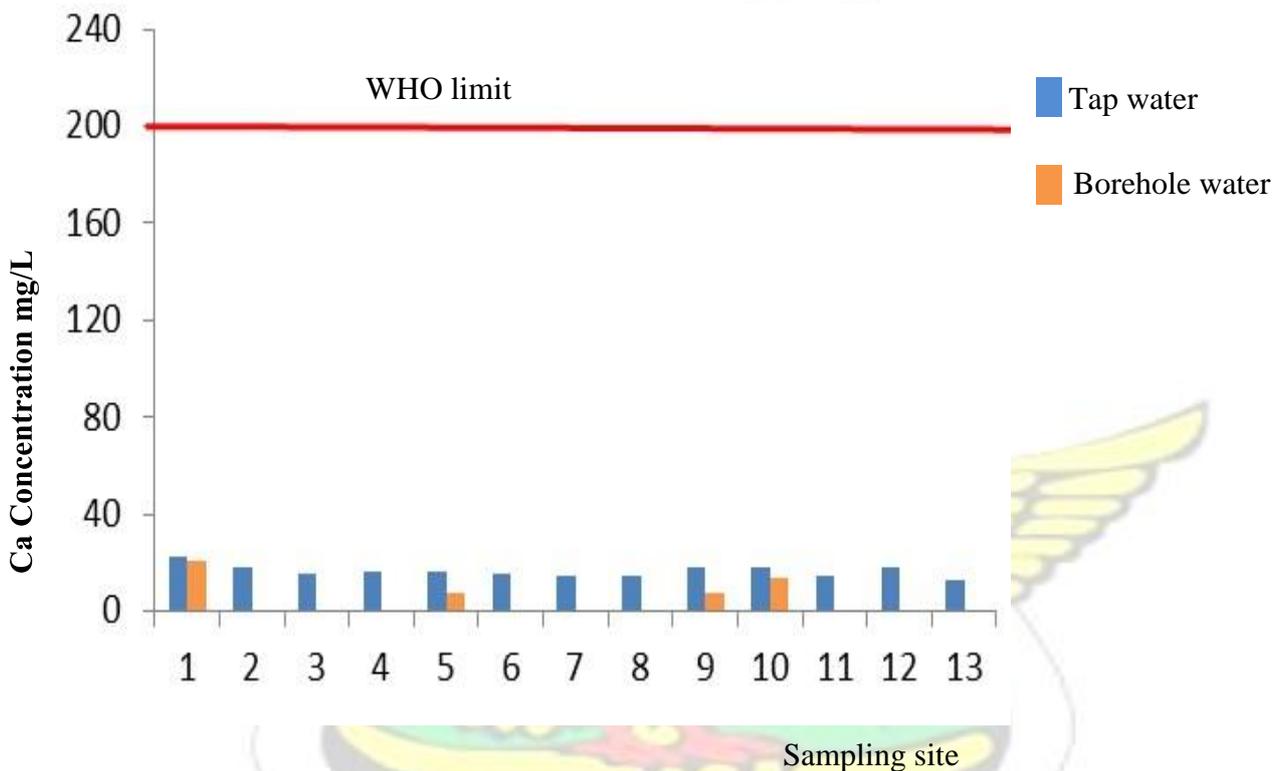


Figure 4.2 Calcium concentrations in tap and borehole water

4.5 Potassium content in tap and borehole water

In general, the potassium content of the tap water is higher than that of the borehole and this is indicated in the Fig 4.3 below. The maximum value of 5.5 mg/l was found in the tap water at site 9 (Slessor House) and minimum of 3.30 mg/l at site 13 (Hospital area).

Potassium level in borehole ranged from 2.18 at site10 (Kingsley House) to 4.73mg/l at site 1 (Guggisberg House) with the mean value $3.88 \pm 1.20\text{mg/l}$.

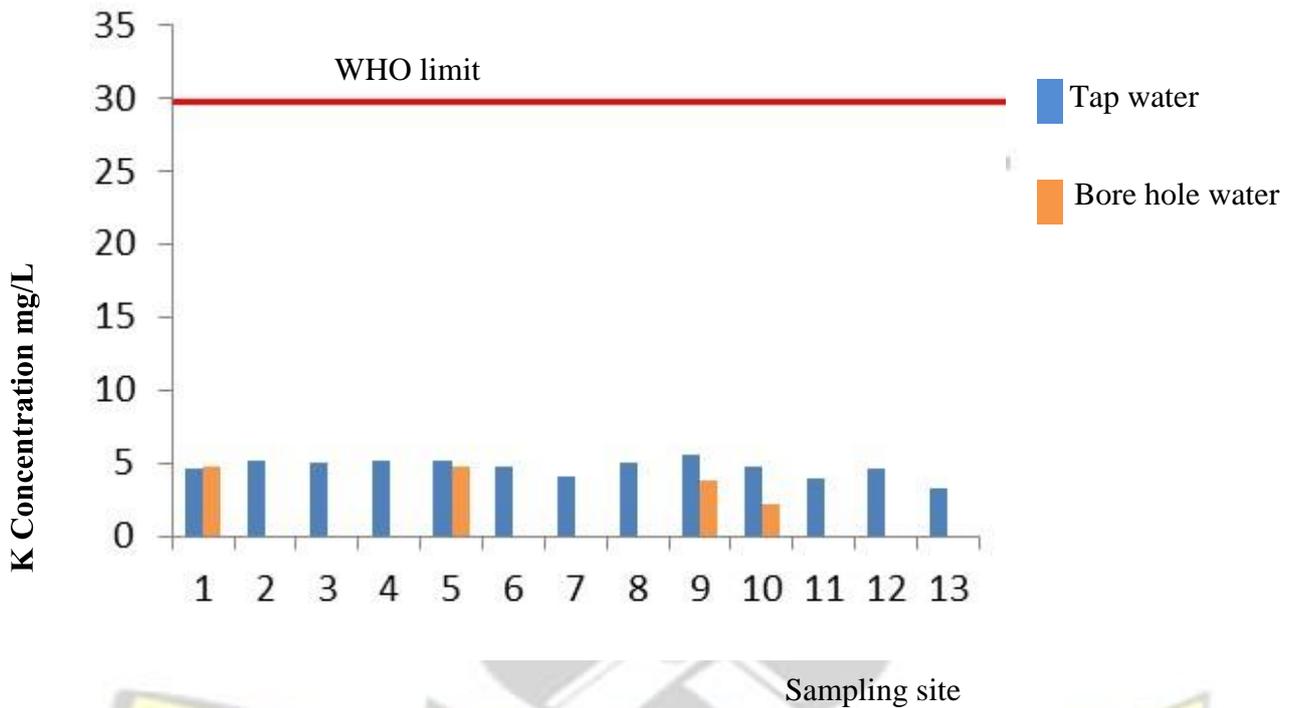


Figure 4.3 Potassium concentrations in tap water and bore hole water

4.6 Concentration of Magnesium in the water

Fig. 4.4 shows the magnesium concentration of the tap and borehole water collected from the sampling sites. The minimum and maximum values for the tap water are 5.80 and 9.20 mg/l respectively. That of the borehole ranges from 6.80 and 9.70 mg/l respectively. The concentration of magnesium in the borehole is higher than that of the tap water.

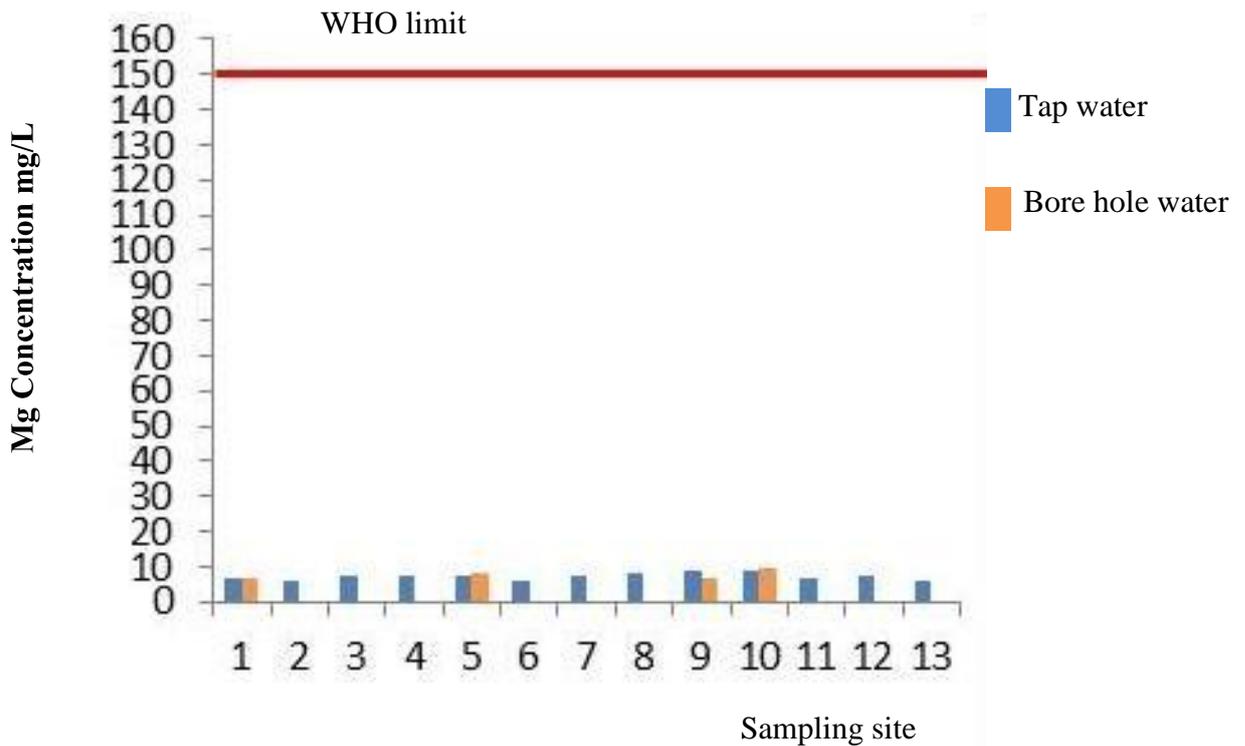


Figure 4.4 Magnesium concentrations in tap and borehole water

4.7 The quantity of Iron in the water

Fig. 4.5 shows the total iron content of tap water and borehole water collected from the indicated sites. Generally the iron concentration in the tap water is higher than the borehole water. The minimum and maximum values for the tap water are 0.014mg/l at site 13 (Hospital area) and 0.293mg/l at site 9 (Slessor House). The values of the borehole water ranges from 0.02 at site 10 (Kingsley House) and 0.18 mg/l at site 1 (Guggisberg House).

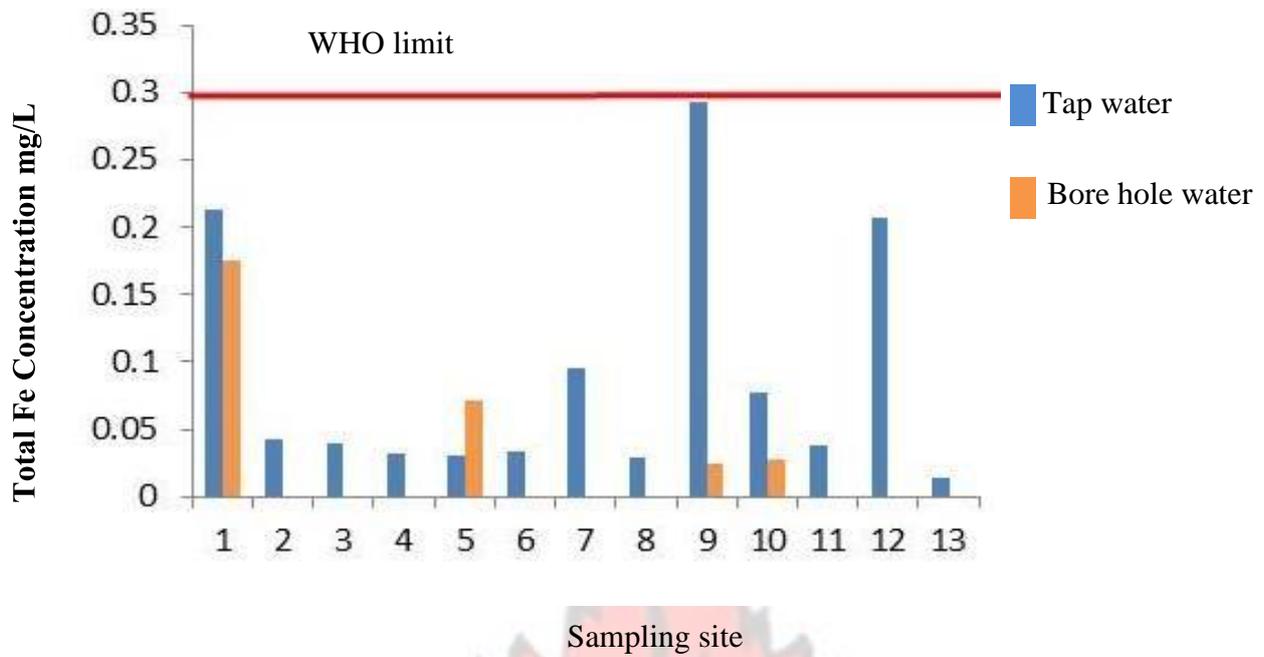
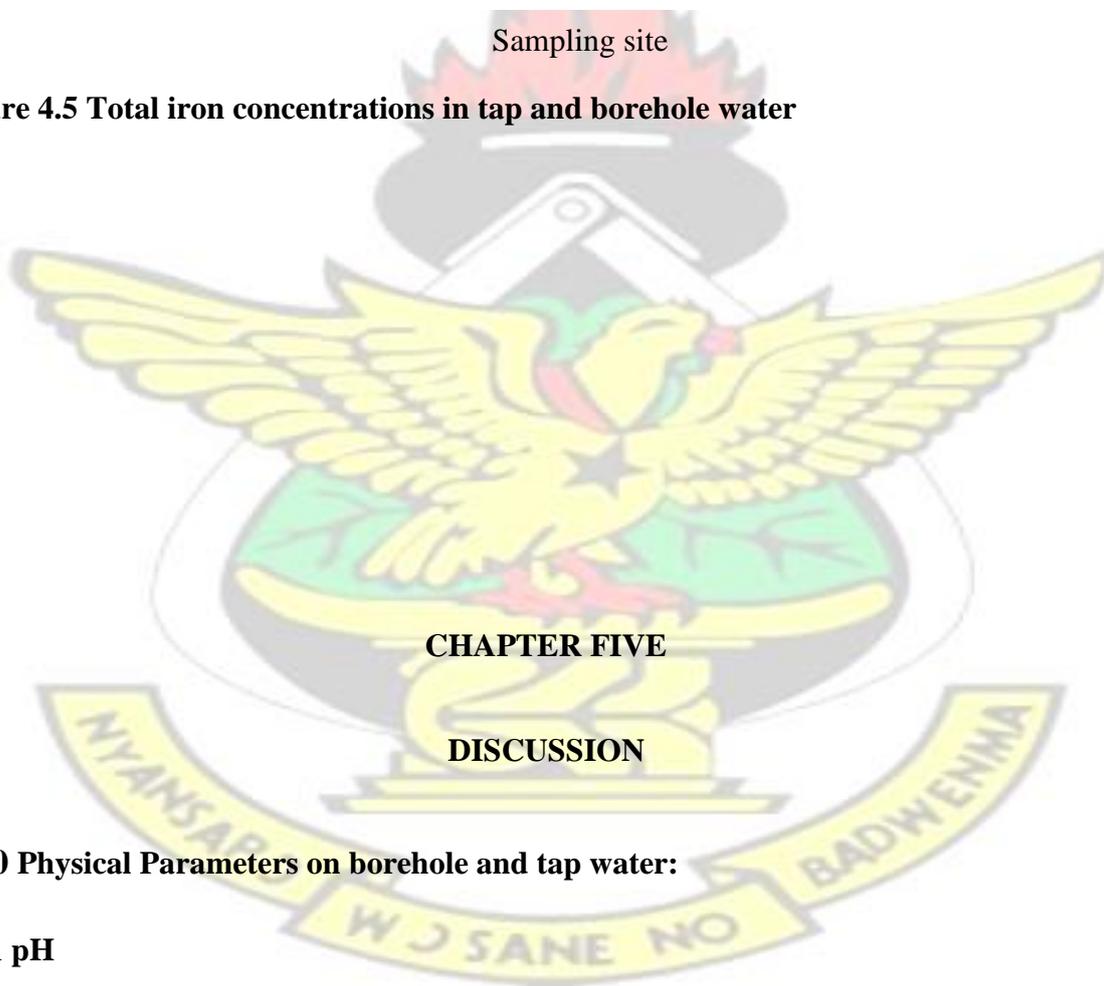


Figure 4.5 Total iron concentrations in tap and borehole water



5.1.0 Physical Parameters on borehole and tap water:

5.1.1 pH

None of the samples had any objectionable appearance, odour, colour or taste. The pH indicates the intensity of acidic or basic character of a solution. Water with a pH below 7 is acidic and is soft and corrosive. Such water can leach metals from pipes and fixtures (Chandra *et al.*, 2012).

Water with pH greater than 7 is alkaline. With the exception of water from the site 13 (Hospital Area) which had a pH of 5.72 indicating slightly acidic water, the other pH values for tap water from sampling sites ranged from 7.02 to 7.52, which were all within the WHO (2006) guidelines of 6.5 – 8.5. Water with a pH below 6.5 allows dissolution of metals especially the heavy metals beyond the permissible limit, which affects the mucous membrane of cells of human (Nishtha *et al.*, 2012).

The pH for borehole water ranged from 6.04 to 7.28. Water samples from sites 1 and 5 (Guggisberg and Clark Houses respectively) were slightly acidic because they had pH values 6.04 and 6.38 respectively which falls outside WHO guidelines. This finding is similar to studies carried out by Quagraine and Adokoh (2010) on the Assessment of dry season surface, ground and treated water quality in the Cape Coast municipality of Ghana. Ground waters with high pH values are exceptional and may reflect contamination by strong bases such as NaOH and Ca(OH)₂. High and the low pH indicate that the equilibrium of carbon dioxide, carbonate and bicarbonate equilibrium is affected (Chandra *et al.*, 2013).

5.1.2 Conductivity

Conductivity is a measure of the ability of water to conduct electrical current. This depends on the ionic strength of the water sample. The conductivity of water is influenced by the concentration of ions and its nutrient status. The determination of the electrical conductivity provides a rapid and convenient way of estimating concentrations of electrolytes in solution. Conductivity is a good measure of dissolved solids and excessive presence of sodium in water. The conductivity levels for the entire tap water samples ranged from 244 μS/cm (sample 8) to 421 μS/cm which fell below WHO (2006) guidelines of 700 μS/cm. On the other hand the conductivity values obtained for the borehole water ranged from 246 μS/cm to 731 μS/cm.

The highest borehole value 731 $\mu\text{S}/\text{cm}$ was recorded at sampling site 1 (Guggisberg House). It means that the borehole contains more ions that need to be treated. Similar studies carried out in Greater Visakhapatnam City by Srinivas and Nageswara (2011) yielded similar results below the WHO (2006) guidelines.

5.1.3 Turbidity

It is an expression of the optical property of a solution which causes light to be scattered. The turbidity of the water determines the depth to which light is transmitted. It is caused by the presence of suspended matter such as clay, silt, organic and inorganic matter and microorganisms. Turbidity values recorded ranges from 1.01 NTU at Achimota Preparatory School to 4.24 NTU at Guggisberg House (Appendix 1 to Appendix 3).

Borehole water samples also ranged from 1.17 NTU to 3.40 NTU. The values thus suggest that turbidity of water from the sample sites fall within WHO (2006) guidelines value of 5 NTU. Yadav *et al.*, (2008) obtained similar results on physico-chemical analysis of selected ground water samples of Agra city, India.

5.1.4 Total Dissolved Solid (TDS)

The total dissolved solids in water indicate the nature of water quality for salinity. TDS are due to the presence of sodium, potassium, calcium, magnesium, manganese, carbonates, bicarbonates, chlorides, phosphate, organic matter and other particles. The maximum allowable limit of total dissolved solids in drinking water is 500 mg/l (WHO, 2006) standards. Above this permissible level, palatability decreases and may cause gastro intentional irritation (Nishtha *et al*, 2012). Total dissolved solids for all the sampling sites ranged from 148 mg/l to 229 mg/l. All the values obtained fell below the WHO (2006) guidelines of 1000 mg/l indicating that all the water samples fall into the fresh water category.

5.1.5 Alkalinity

Alkalinity values for all tap water from the sample sites ranged between 22 mg/l and 64.0 mg/l. The permissible level of alkalinity is 200 mg/l (WHO, 2006). Water sample from Livingstone House recorded the highest value but it is still acceptable.

The underground water alkalinity level ranged from 16 mg/l to 36 mg/l making it acceptable by WHO (2006) standard. High amount of alkalinity in water is harmful for irrigation which leads to soil damage and reduce crop yields. The result from the current study is similar to that carried out by Mishra and Saksena (1990). Alkalinity of water is a measure of its capacity to neutralize acids and besides carbonates and bicarbonates, any salts of weak acids such of silicates, phosphates and borates also cause alkalinity Mishra and Saksena (1990).

5.1.6. Total Hardness

Hardness is the property of water which prevents lather formation with soap and increases the boiling points of water as a result of presence of calcium and magnesium salts (Patil and Patil, 2010). The permissible level of hardness is 300 mg/l (WHO standards). Encrustation in water supply structure and adverse effects on domestic use occur beyond this permissible level.

Saravanakumar and Kumar (2011) classified water having hardness up to 75 mg/l as soft, 76-150 mg/l as moderately soft, 151-300 mg/l as hard and more than 300 mg/l as very hard. Total hardness of tap water ranged between 62.0mg/l at site 6 (Gyamfi House) to 84.0 mg/l at site 12 (Livingstone House) and were all within the WHO limits. All the tap water collected from the sample sites were soft except tap water from site 1 (Guggisberg House), site 9 (Slessor House) and site 10 (Kingsley House) which were moderately soft.

Borehole water hardness values ranged from 46 mg/l from site 9 (Slessor House) to 80 mg/l at site 1 (Guggisberg House). Generally all the water from the Achimota area can be classified as

soft and moderately soft and will not give problem when used for laundry activities. This results obtained were in agreement with a work done by Alaoui *et al.*, (2008) on water samples collected from Environmental pollutions impacts on the bacteriological and physicochemical quality of suburban and rural groundwater supplies in Marrakesh area (Morocco). They were all within the WHO limits.

5.2 Chemical characteristics

Contrary to study conducted by Nahar and Zhang (2010) on the potable water quality in Toyoma, Japan where major ions exceeded WHO limits, the examination of the chemical parameters of both tap and borehole water in the current study revealed all the major ions were within the WHO limits. This agrees with the level of the major ions found in similar studies conducted by Srinivas and Nageswara (2011).

5.2.1 Calcium

Depending on the source and treatment of the water the calcium content may range from zero to several hundred milligrams per litre (Srinivas and Nageswara, 2011). The levels of calcium in the tap water ranged from 12.8mg/l at site 13 (Hospital area) to 22.4 mg/l at site 1 (Guggisberg House) and these were all below the WHO (2006) guidelines of 200 mg/l.

Concerning the borehole water, calcium level ranged from 7.20 mg/l at site 9 (Slessor House) to 20.8 mg/l at site 1 (Guggisberg House) with the mean value of 12.20 ± 6.48 mg/l. These values fell within the desirable limit of WHO (2006) guidelines ie 200 mg/l, hence satisfactory.

5.2.2 Magnesium

Increase in Magnesium value can be attributed to domestic waste, industrial effluents and also fall in water level (Srinivas and Nageswara, 2011).

In the current study, values for tap water ranged from 5.8 mg/l to 9.2 mg/l (mean value of 7.32 \pm 1.04 mg/l) and that of borehole ranged from 6.80 mg/l to 9.70 mg/l (with a mean value of the borehole of 7.90 \pm 1.39 mg/l). Both tap and borehole water values fell below WHO (2006) guidelines value of 150 mg/l and therefore, acceptable.

5.2.3 Sodium

Sodium is an important cation in the groundwater. The ratio of sodium to total cations is important in human physiology. In high concentrations it may affect persons with cardiac difficulties (Srinivas and Nageswara, 2011). Borehole varied from 14.6 mg/l to 112 mg/l with a mean value of 68 mg/l tap water varied from 17.07 mg/l to 49.50 mg/l with mean value of 26.76 mg/l. Both borehole and tap water values were below the WHO (2006) guidelines of 200 mg/l.

5.2.4 Potassium

Potassium is an essential element in both plant and human nutrition and occurs in ground waters as a result of mineral dissolution from decomposing plant material, and from agricultural run-off (Srinivas and Nageswara, 2011). The potassium values determined in the borehole water ranged from 2.18 mg/l to 4.73 mg/l and that of the tap water ranged from 3.30 mg/l to 5.50 mg/l. The mean values for both borehole and tap waters were 2.20 mg/l and 4.69 mg/l respectively. The sodium content of the both waters is acceptable since they fell below the WHO (2006) permissible limit of 30 mg/l.

5.2.5 Chlorides

Chlorides in the form of sodium (NaCl), potassium (KCl) or calcium (CaCl₂) is one of the major inorganic anions in the potable water. Its salty taste produced varies and depends upon chemical composition of the water. The amount of chlorides recorded in the tap water ranged from 20.8

mg/l to 53.6 mg/l, which fell below the WHO guide limit of 250 mg/l. The chloride content in the borehole water is quite low and varied from 25.8 mg/l to 175 mg/l. None of the samples in the study area exceeded 250 mg/l which has been recommended as the desirable limit for drinking water supplies (WHO, 2006). Excessive chloride in potable water is particularly not harmful but the criteria set for chloride value is based on its potentially high corrosiveness. Soil porosity and permeability also play an important role in building up the chloride value. Increase of chlorine level in water is injurious to people suffering due to heart and kidney diseases (Jain *et al.*, 2005).

5.2.6 Fluoride

The fluoride content in the groundwater is a function of many factors such as availability and solubility of fluoride minerals, velocity of flowing water, temperature, pH, concentration of calcium and bicarbonate ions in water, *etc.* (Khairwal and Garg, 2006). Long term use of groundwater with higher levels of fluoride for drinking can result in fluorosis symptoms, from mild forms of dental fluorosis to crippling skeletal fluorosis. Levels recorded ranged between 0.450 mg/l and 0.968 mg/l which were below WHO (2006) guidelines value of 1.5 mg/l. The fluoride content of the borehole water (0.087 mg/l to 0.138 mg/l) is low, and fell below the WHO (2006) permissible limit of 1.5mg/l.

5.2.7 Sulphate

Sulphates occur naturally in drinking water and its health concerns regarding its level have been linked with diarrhoea due to its laxative effects (EPA, 2011). The amount of sulphate may also increase in the groundwater by industrial or anthropogenic additions in the form of sulphate fertilizers (Narain and Chauhan, 2000). The values recorded for all samples of tap water (17.3 mg/l and 48 mg/l) and borehole water (13.1 mg/l to 36.3 mg/l) in the study area were all low.

Even though all the values fell within WHO (2006) acceptable limits, the sulphate content of the tap water was higher than that the borehole water in the study area.

5.2.8 Phosphate

Phosphate enters into groundwater from phosphate containing rocks, fertilizers and percolation of sewage and industrial wastes. The phosphate levels for the entire tap water samples were satisfactory. The phosphate content of the boreholes in the study area ranged from 0.164 mg/l to 0.27 mg/l, lower than what is presented by WHO (2006). However phosphate levels in borehole (0.21 mg/l - 1.06 mg/l) was higher than tap water (0.16mg/l to 0.28 mg/l). High levels in the borehole water may be attributed to leakage from domestic sewage.

5.3 Nutrients

The assessment of nutrient concentrations (organic nitrogen, ammonium nitrogen, nitrate, nitrite and total phosphorus) in water is an indicator of the potential risk of eutrophication.

The results from the current studies are similar to studies conducted by Srinivas and Nageswara (2011).

5.3.1 Nitrate

Nitrate content in water is considered important because it is an essential nutrient for plants nutrition. Sources of nitrogen and nitrate may include runoff or seepage from fertilized agricultural lands, municipal and industrial waste water, refuse dumps, animal feedstuffs, septic tanks, private sewage disposal systems and urban drainage (WHO, 2006). High concentration of nitrate is an indicator of poor sanitary condition as a result of increasing anthropogenic activities. High concentration of nitrate in drinking water is toxic. It causes blue babies disease in infants and gastric carcinomas (Srinivas and Nageswara, 2011). Water samples from tap water ranged from 0.028 mg/l to 0.196 mg/l while that of borehole ranged from 0.325 mg/l to

1.92 mg/l. All these values were below WHO (2006) limits of 10 mg/l and therefore satisfactory. This agrees with the studies carried out by Ahmad and Qadir (2011).

5.2.3 Nitrite

Most of the nitrite were below detectable limits. The other samples lie within WHO guideline. Nitrite level in the borehole water ranged from 0.22 mg/l to 0.388 mg/l which were all below WHO guidelines and so acceptable. This indicates low level of anthropogenic activities in the study area.

5.2.4 Ammonium

The concentration for ammonium was below the detectable limits of 0.001 mg/l for tap water. The ammonium concentrations in the borehole water were all below the detected limit indicating low anthropogenic activity within the study area.

5.4. The level of Trace metals

5.4.1 Iron

Iron was derived from different minerals present in the soils (Ahmad and Qadir, 2011). The high concentration of iron pose problems to laundry industry since it causes discolouration of clothes, plumbing fixtures and porcelain wares. The concentrations of iron levels in the tap and borehole waters were 0.014 to 0.293 mg/l and 0.024 mg/l to 0.176 mg/l respectively. The maximum allowable concentration of iron is 0.3 mg/l according to WHO (2006). Since all the values did not exceed the WHO (2006) value of 0.3mg/l, they are all satisfactory. Beyond the WHO (2006) limit, taste and appearance of waters would be affected.

5.4.2 Manganese

In the water was derived from different mineral present in the soil (Ahmad and Qadir, 2011). Its level for most samples was below detectable limit. However tap water from Achimota Preparatory School recorded the highest of 0.018 mg/l, but it was satisfactory since it did not exceed the WHO (2006) guideline of 0.4 mg/l. Manganese concentration in the borehole (0.011mg/l to 0.214 mg/l) was low and therefore fell within the permissible limit for WHO (2006) value of 0.4mg/l for drinking water. It was evident from the study that manganese level in the borehole water was slightly higher than that of tap water.

5.5 Microbiological quality of the tap and borehole water analysed

The population of coliform group is the criteria used to determine the degree of contamination for bacteriological water quality standard. *E. coli*, a member of the *Enterobacteriaceae* family, is a normal inhabitant of the intestinal tract and is at present seen as the most appropriate indicator of faecal contamination in drinking water (WHO, 1993). In an ideal situation, all the samples taken should be free from coliform organisms but in practice, it is not attainable always.

The result obtained from the microbial analysis indicated that tap and borehole water samples showed signs of bacterial contamination. From the study, five samples of the tap water [from sites; McCarthy House, Anumle, Slessor House, Achimota Preparatory Area and Hospital Area and a borehole water from Clark House registered presence of faecal coliform above the WHO limit. This contamination of the water source by faecal material might be as a result of spillage and leakage of sewage. The coliform group of bacteria is the principal indicator of the unsuitability of the water for domestic, industrial or other uses. This means that the numbers of people who rely on that source were presumably exposed to faecally contaminated water and therefore they are at risk of developing diarrhoea and other gastrointestinal diseases. This was

similar to studies conducted by Kumar *et al.*, (2011) on physico-chemical and microbiological assessment of recreational and drinking waters in India.

A drinking water requirements given by the GSB (1998), WHO (2006) Guidelines and US EPA (2006) is that:

- 95% of water samples should not contain any coliform organisms in 100 ml throughout the year.
- No water sample should contain *E. coli* in 100 ml water.
- No water sample should contain more than ten coliform organisms per 100 ml.
- Coliform organisms should not be detected in 100 ml of any two consecutive water samples.

The presence of faecal coliforms in water indicates a potential public health problem, because faecal matter is a source of pathogenic bacteria and viruses.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

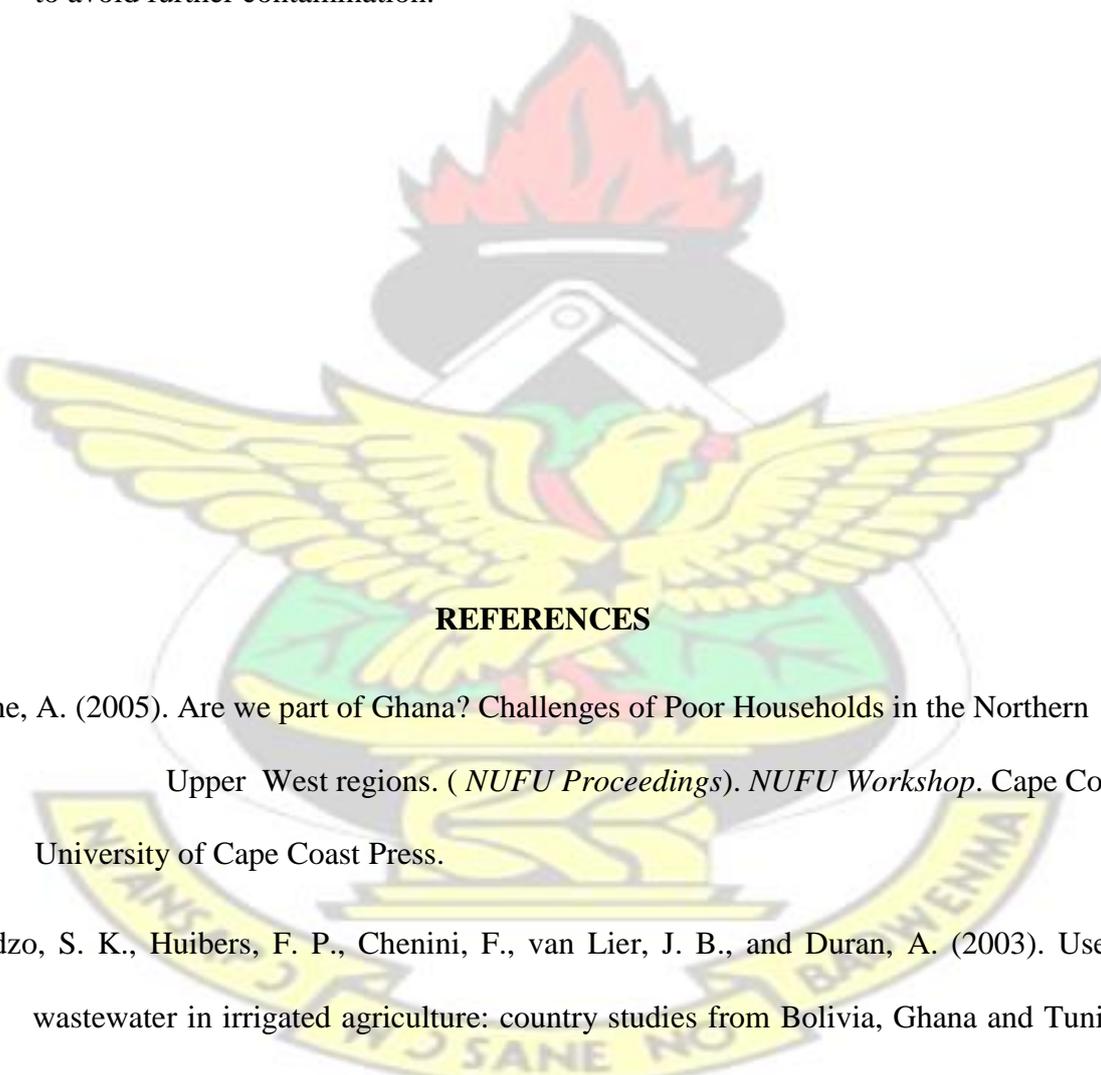
6.1 Conclusion

The study has shown that

- physico-chemically the waters were fit for domestic purposes.
- bacteriologically the waters did not conform to WHO Guidelines and Ghana Standard of zero total and faecal coliform counts per 100 ml of tested sample. Therefore they were unsafe for drinking.

6.2 Recommendations

- Pipelines must be checked regularly for leakages to reduce recontamination of the treated tap water.
- For safe drinking water, there must be effective disinfection either by chlorination or boiling.
- Anthropogenic activities such as farming should be properly regulated in the study area to avoid further contamination.



REFERENCES

- Abane, A. (2005). Are we part of Ghana? Challenges of Poor Households in the Northern Upper West regions. (*NUFU Proceedings*). *NUFU Workshop*. Cape Coast: University of Cape Coast Press.
- Agodzo, S. K., Huibers, F. P., Chenini, F., van Lier, J. B., and Duran, A. (2003). Use of wastewater in irrigated agriculture: country studies from Bolivia, Ghana and Tunisia. Vol. 2, Ghana. Wageningen: Wageningen Agricultural University and Research Centre.
- Agyekum, W. A. (2004). Groundwater resources of Ghana with the focus on international shared aquifer boundaries. UNESCO-ISARM International Workshop – Managing shared aquifer resources in Africa. B. Appelgreen. Tripoli, Lybia, June 2002. United

Nations Educational, Scientific and Cultural Organisation, IHP-VI Series on groundwater no. 8, 600 pp.

Ahmad, Z and Qadir, A. (2011) Source evaluation of physicochemically contaminated groundwater of Dera Ismail Khan area, Pakistan. *Environmental Monitoring and Assessment* 175 : 9 – 21.

Alaoui, H. L., Oufdou, K. and Mezrioui, N. (2008). Environmental pollutions impacts on the bacteriological and physicochemical quality of suburban and rural groundwater supplies in Marrakesh area (Morocco). *Environmental Monitoring and Assessment* 145:195–207.

Annan, K. A., Flavin, C., and Starke, L., (2002). State of the world, 2002: *A World Watch Institute Report on progress toward a sustainable society*. New York: W.W. Norton and Co.

APHA, AWWA and WEF (1998). Standard methods for the examination of water and wastewater (20th ed). Prepared and published by the American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF).

Arbués, F., Garcia-Valiñas, M. Á. and Martínez-Espiñeira, R. (2003). Estimation of residential water demand: a state-of-the-art review, *Journal of Socio-Economics*, 32, pp. 81-102.

Ashbolt, N. J., Grabow, W. O. K. and Snozzi, M. (2001). Indicators of microbial water quality, In: WHO (2001), *Water Quality Guideline, Standards and Health*. Edited by Fewtrell, L. and Bartram, J. Published by IWA Publishing, London, UK pp. 291-295.

Barcelona, M. J., Gibbs, J. P. and Miller, R. A. (1985). *Practical Guide for Ground Water Sampling*, SWS Contract Report 374, EPA 600 / 52-52 / 104 USEPA, Ada OK

- Bernhardt, S. E., Band, L. E., Walsh, C. J., and Berke, P. E. (2008). Understanding, Managing, and Minimizing Urban Impacts on Surface Water Nitrogen Loading. New York: Academy of Sciences, Wiley.
- Bitton, G. (2005). Microbial indicators of faecal contamination: Application to microbial source tracking, Report submitted to the Florida Storm-water Association, 719 East Park Avenue, Tallahassee, 32301. pp 4-6
- Blakely, T., Hales, S., Kieft, C., Wilson, N. and Woodward, A. (2005). The Global distribution of risk factors by poverty level. *Bulletin of World Health Organisation* 83(2), 118-126.
- Burmaster, D. E. and Harris, R. H. (1982). Groundwater contamination: an emerging threat. *Technology review*, 85(5): 50-62.
- Cairncross, S. and Feachem, R. G., (2003). Environmental Health Engineering in the Tropics, An Introductory Text, 2nd Edition, John Wiley and Sons, England
- Calabrese, E. J., Tuthill, R. W., Condie, L, United States. Environmental Protection Agency. (1985). Inorganics in drinking water and cardiovascular disease. Princeton, N.J.: Princeton Scientific Pub. Co.
- Chandra, S., Rizvi, N., Gangwar, R. K., Singh, J., and Singh, A. P. (2013). Assessment of diverse resources of ground water quality in Bareilly district (U.P.). *Journal of Chemical and Pharmaceutical Research*, 5(8):54-58.
- Clasen, T. F. (2008). World Health Organization Guidelines for Drinking-water Quality Scaling Up Household Water Treatment: Looking Back, Seeing Forward, World Health Organization, Geneva, Switzerland.

- Cofie, O., Veenhuizen, R. and Drechsel, P. (2003). Contribution of Urban and Peri-urban Agriculture to Food Security in Sub-Saharan Africa. Paper presented at the Africa session of 3rd WWF, Kyoto, Japan. 37 – 43pp.
- Community Water and Sanitation Agency (CWSA), (2005) *Annual Report* Ministry of Water Resources, Works and Housing Accra. Ghana, 67 pp.
- Community Water Solutions (2009). Interview with Community Water Solutions founders, Tamale, Ghana
- Cornish, G. A., and Aidoo, J. B. (2000). Informal Irrigation in the peri-urban zone of Kumasi, Ghana: Findings from an initial questionnaire survey. Report OD/TN 97. HR Wallingford, UK.
- Dapaah-Siakwan, S. and Gyau-Boakye, P., (2000). Hydrological framework and borehole yields in Ghana. *Hydrogeology Journal* 8:405-416.
- Dethier, D. P. (1988). A hydrochemical model for stream chemistry, cascade range, Washington U.S.A. *Earth Surface Processes Land Forms* 13: 321–333.
- Dickson, K. B. and Benneh, G. (2004). *A New Geography of Ghana*. Longmans Group Limited, London
- Drechsel, P., Cofie, O., Fink, M., Danso, G., Zakari, F. M., and Vasquez, R. (2004). Closing the rural-urban nutrient cycle. Options for municipal waste composting in Ghana. Final Scientific Report submitted to IDRC (Project 100376)
- Elmund, G. K., Allen, M. J. and Rice, E. W. (1999). Comparison of *Escherichia coli*, total coliform and faecal coliform populations as indicators of wastewater treatment efficiency. *Water Environmental Research*; 71(3): 332– 339.

- Esrey, S. A., Potash, J. B., Roberts, L. and Shiff, C. (1991). Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma. Geneva: World Health Organization.
- Feachem, R., Bradley, D., Garelick, H. and Mara, D. D. (1983). Sanitation and Disease: Health Aspects of Excreta and Wastewater Management, John Wiley & Sons, Chichester; <http://www.leeds.ac.uk/civil/ceiri/water/tphe/publicat/watsan/sandis>
- Fewtrell, L. and Colford, J. M. (2004). Water, Sanitation and Hygiene: Interventions and Diarrhoea, a systematic review and meta-analysis, World Bank Report.
- Ghana Poverty Reduction Strategy (2003). Document, February, pp.19
- Ghana Meteorological Agency (2007). Ghana Meteorological Service Report. Accra.
- Ghana Standard Board. (1998). Ghana Standards 175 Part 1:1998. Water quality – requirement for drinking water.
- Ghana Statistical Service (2002). 2000 Population and Housing Census: Summary Report of Final Results. Accra: Ghana Statistical Service. 22 – 30pp.
- Ghana Statistical Service (2003). Core Welfare Indicators Questionnaire (CWIQ) *Survey*. Accra: Ghana Statistical Service. Pp. 33 – 45.
- Ghana Statistical Service (2007). Pattern and trends of poverty in Ghana, 1991-2006. Accra: Ghana Statistical Service. Ghana. Final Scientific Report submitted to IDRC (project 100376).
- Government of Ghana (2007). Ghana National Water Policy. Ministry of Water Resources, Works and Housing, Ghana
- Gyau-Boakye, P., Kankam-Yeboah, K., Darko, P. K., Dapaah-Sekyiwaa, S. and Duah, A. A.

- (2008). Groundwater as a vital resource for rural development: An example from Ghana. In: S. Adelana, A. MacDonald, T.A. Alemayehu and C. Tindimugaya, eds. *Applied groundwater studies in Africa, IAH selected papers Q3 on hydrogeology*. vol. 13.
- Hanley, N and Spash, C. L. (1993). Cost-benefit analysis and the environment. England: Brookfield.
- Hutton G., Haller, L. and Bartram, J. (2007). Economic and health effects of increasing coverage of low cost household drinking-water supply and sanitation interventions to countries off-track to meet MDG target 10. Geneva, Switzerland, World Health Organization.
- Jain, C. K., Bhatia, K. K. and Kumar, S. R. (2005). Ground water quality in Malaprabha subbasin Karnataka. *International Journal of Environmental Protection*. 23, 321-329.
- Khaiwal, R. and Garg, V..K. (2006). Distribution of fluoride in groundwater and its suitability assessment for drinking purpose. *International Journal of Environmental Health Research*, 16,163-166.
- Kofie, R., and Nabila, J. S. (2004). Poverty and Buruli Ulcer (*Mycobacterium ulcerans*) in Ghana. NUFU Proceedings (pp. 42 – 48). Accra: University of Ghana, Legon.
- Kortatsi, B. K. (1994). Management of Groundwater Supply for the urban areas: Groundwater exploration and techniques for siting of high yielding borehole in the Accra plains of Ghana. Advanced International Training Programme in Gothenburg Sweden, 29th August - 6th October, 1994.
- Kraemer, E. O. and Stamm, A. J. (1924). Mohr's Method for the Determination of Silver and

- Halogens in other than Neutral Solutions, *Journal of American Chemical Society*; 46(12); 2707 – 2709.
- Krämer, A , Hossain, M., Khan, H and Kraas, F. (2011). Health in Megacities and Urban Areas. New York : Physica-Verlag Publishers.
- Kumar, S., Tripathi, V. R. and Garg, S. K. (2011). Physicochemical and microbiological assessment of recreational and drinking waters. *Environmental Monitoring Assessment* report, 184:2691–2698. DOI 10.1007/s10661-011-2144-1
- Martin, N. and van de Giesen, N. (2005). Spatial distribution of groundwater use and groundwater potential in the Volta River basin of Ghana and Burkina Faso. *IWRA Water International*, 30 (2), 239–249.
- Mishra, S. R and Saksena, D. N (1990). Seasonal abundance of zooplankton of waste water from the industrial complex at Birla Nagar (Gwalior), India: *Acta Hydrochimica Hydrobiologica*, 18: 215-220.
- Ministry of Food and Agriculture, (2004). Projected livestock population for 1997-2007. Ministry of Food and Agriculture, Accra, Ghana.
- Nahar, S. and Zhang, J. (2010). Assessment of potable water quality including organic, inorganic, and trace metal concentrations. *Environmental Geochemical Health*, 34:141–150.
- Narain, S., and Chauhan, R. (2000). Water quality status of river complex Yamuna at Panchnada dist. Etawah, U.P. (India) I: An integrated management approach. *Pollution Research*, 19 (3), 351–364.
- Nath, K. J., Bloomfield, S. and Jones, M., (2006). Household water storage, handling and point-of-use treatment. A review commissioned by the International Forum of Home Hygiene (IFH), www.ifh-homehygiene.org,

- Nishtha, K., Lokhande, R. S. and Dhar, J. K. (2012). 'Physicochemical, bacteriological and pesticide analysis of tap water in millennium city Gurgoan, Haryana, India.' *International Research Journal of Environment Science* vol. 1(2), pp 1 - 7.
- Obiri-Danso K., Okore-Hanson, A. and Jones, K. (2003). The Microbiological quality of drinking water sold on the streets in Kumasi, Ghana". *Letters in Applied Microbiology*, 37,334-339. The Society for Applied Microbiology
- Okioga, T. (2007). Water Quality and Business Aspects of Sachet-Vended Water in Tamale, Ghana. Massachusetts Institute of Technology, Cambridge, MA.
- Osei, D. and Marfo, E. K. (1995). Water Quality Standards and Water Quality Assessment. Proceedings of National Workshop on Water Quality, Sustainable Development and Agenda 21, Accra 21 – 23 February 1995.
- Owusu, E. S. and Lundehn, C. (2006). Consumer Attitude and Trust in Accra Water Supply (Ghana). Chalmers University of Technology, Gothenburg, Sweden.
- Patil, V. T. and Patil, R. R. (2010). Physicochemical analysis of selected groundwater samples of Amalner Town in Jalgaon District, Maharashtra, India. *E- Journal of Chemistry*, Vol. 7(1), pp. 111-116
- Pearse, T. D. (1996). Mining and the Environment. T.D. Pearse Resource Consulting pp. 14.
- Pimentel, D. and Pimentel M. (2008). Food, energy, and society. Boca Raton, Fla., CRC; London: Taylor & Francis
- Plant, J. S., David, S., Barry, F. and Lorraine W. (2001). Environmental geochemistry at the global scale. *Journal Science Direct*. 16: 1291-1308.
- Quagraine, E. K. and Adokoh, C. K. (2010). Assessment of dry season surface, ground, and treated water quality in the Cape Coast municipality of Ghana. *Environmental Monitoring and Assessment*. 160(1-3):521–539.

- Rahman, M. (2002). Groundwater quality of Oman, groundwater quality (pp. 122–128). London: Chapman and Hall.
- Raschid-Sally, L. and Jayakody, P. (2008). Drivers and characteristics of wastewater agriculture in developing countries: Results from a global assessment, Colombo, Sri Lanka. IWMI Research Report 127, International Water Management Institute, Colombo. 35 pp.
- Robin, N. S. (2002). Groundwater quality in Scotland: Major ion chemistry of the key groundwater bodies. *Science of the Total Environment*, 294, 48–49
- Rockström, J. (2001). Water-balance accounting: for designing and planning rainwaterharvesting systems for supplementary irrigation. Nairobi: Regional Land Management Unit.
- Saravanakumar, K. and Kumar, R. R. (2011). Analysis of water quality parameters of groundwater near Ambattur Industrial Area, Tamil Nadu, India. *Indian Journal of Science and Technology*, Vol. 4, No. 5, pp. 560-562
- Sarpong, G. A. (2004). Going Down the Drain? Customary Water Law and Legislative Onslaught in Ghana, Paper commissioned by FAO as part studies on effect of legislation on Customary Water Rights.
- Sobsey, M. (2006). Drinking water and health research: a look to the future in the United States and globally. *Journal of Water Health* 4, 17–21.
- Somero, G., Osmond, C., and Bolis, C. (1992). Water and life – Comparative Analysis of Water Relationship at organismic, cellular and Molecular level. Berlin: SpringsVerlag.
- Srinivas, R. G. and Nageswara, R. G. (2011). Study on Ground Water Quality of Greater Visakhapatnam City, Andhra Pradesh from July, 2007 to June, 2008. *Asian Journal of Research Chemistry*. 4(3): March, 2011.

- Sundar, M. L. and Saseetharan, M. L. (2008). Groundwater quality in Coimbatore, Tamil Nadu along Noyyal River. *Journal of Environmental Science. Engineering* , 50, 187190.
- US EPA, (2006). Drinking water contaminants, basic information about *E. coli* 0157:H7 in drinking water. US Environmental Protection Agency Website. <http://www.epa.gov/safewater/contaminants/ecoli.html> (Accessed 24. 11. 12)
- VanCalcar, J. (2006). Collection and Representation of GIS Data to Aid Household Water Treatment and Safe Storage. Washington: University of Washington Press.
- Water Aid (2006). Water point mapping in West African, by Katherina Welle.
- Water Resource Institute (2002). Info Water. Quarterly Newsletter of the CSIR Water Research Institute. Volume1, Issue 1. June 2002
- Winkler, L.W. (1988). Die Bestimmung des in Wasser gelösten Sauerstoffes. *Berichte der Deutschen Chemischen Gesellschaft*, 21: 2843–2855.
- WHO/UNICEF (2008). Progress on drinking water and sanitation: special focus on sanitation by Joint Water Supply and Sanitation Monitoring Programme. Geneva: World Health Organization.
- World Health Organization (2006). Mortality Country Fact Sheet 2006. WHO Statistical Information System: Retrieved from: http://www.who.int/whosis/mort/profiles/mort_afro_gha_ghana.pdf
- World Health Organization (2006). Guidelines for Drinking-water Quality, third edition, incorporating the first addendum, Volume 1. Recommendations. Geneva: World Health Organization.
- WHO (2005). Drinking Water Quality in the Pacific Island Countries: Situation Analysis and Needs Assessment. World Health Organisation, Geneva, Switzerland.

World Health Organization (2004). WHO Guidelines for drinking water quality, 3rd ed.
Volume 1. Recommendations. World Health Organization – Geneva

World Health Organization (2004). Water, sanitation and hygiene links to health.

http://www.who.int/water_sanitation_health/publications/facts2004/en/index.html

World Health Organization (2002). World health report 2002: Reducing risks, promoting healthy life. WHO, Geneva ([www. who.int/whr/2002/ en/](http://www.who.int/whr/2002/en/)).

World Health Organization (1996). Guidelines for drinking-water quality. Volume 2, Health criteria and other supporting information. Geneva:

World Health Organization World Health Organisation (1993). WHO Guidelines for Drinking Water Quality, 2nd ed. Recommendations, vol. 1. WHO, Geneva.

World Resources Institute (2000). People and Ecosystems: The Fraying Web of Life. Washington: WRI press.

World Water Council (2005). Making Potable water accessible. World Water Council. www.worldwatercouncil.org.

Yadav, K. K., Gupta, N., Kumar, V., Arya, S. and Singh, D. (2008). Physico-chemical analysis of selected ground water samples of Agra city, India. *Recent Research in Science and Technology*, 4(11): 51-54

APPENDICES

Appendix 1: Results for physicochemical analyses for tap water (samples 1 -5)

Parameter	Unit	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Turbidity	NTU	4.26	1.30	1.49	1.27	1.32
Colour (apparent)	Hz	10.0	2.50	2.50	2.50	2.50
pH	pH Units	7.03	7.48	7.52	7.51	7.49
Conductivity	μS/cm	421	269	263	268	265
Tot. Susp. Solids	mg/l	1.00	<1.00	<1.00	<1.00	<1.00
Tot. Dis. Solids	mg/l	229	156	148	151	159
Sodium	mg/l	49.5	19.4	19.2	19.2	19.3
Potassium	mg/l	4.60	5.10	5.00	5.10	5.10
Calcium	mg/l	22.4	18.4	15.2	16.0	16.0
Magnesium	mg/l	6.80	5.80	7.30	7.80	7.30
Total Iron	mg/l	0.213	0.043	0.040	0.032	0.031
Ammonia	mg/l	<0.001	<0.001	<0.001	<0.001	<0.001
Chloride	mg/l	53.6	23.8	21.8	21.8	22.8
Sulphate	mg/l	43.0	18.4	17.3	18.4	18.3
Phosphate	mg/l	0.802	0.964	1.06	0.880	0.814
Manganese	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005
Nitrate	mg/l	0.184	0.196	0.056	0.033	<0.001
Nitrite	mg/l	<0.001	<0.001	<0.001	<0.001	0.146
Total Hardness	mg/l	84.0	70.0	68.0	72.0	70.0
Total Alkalinity	mg/l	58.0	58.0	56.0	56.0	54.0
Cal. Hardness	mg/l	56.1	46.1	38.1	40.1	40.1
Mag Hardness	mg/l	27.9	23.9	29.9	31.9	29.9
Fluoride	mg/l	0.876	0.968	0.517	0.770	0.508
Bicarbonate	mg/l	70.8	70.8	68.3	68.3	65.9
Carbonate	mg/l	0.00	0.00	0.00	0.00	0.00

Appendix 2: Results for physicochemical analyses for tap water (samples 6 - 10)

Parameter	Unit	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
Turbidity	NTU	1.25	1.69	1.40	4.04	1.29
Colour (apparent)	Hz	2.50	2.50	2.50	7.50	2.50
pH	pH Units	7.50	7.49	7.45	7.45	7.44
Conductivity	μS/cm	244	265	267	322	335
Tot. Susp. Solids	mg/l	<1.00	<1.00	<1.00	2.00	<1.00
Tot. Dis. Solids	mg/l	149	160	162	193	204
Sodium	mg/l	17.7	19.0	18.2	35.5	34.5
Potassium	mg/l	4.80	4.10	5.00	5.50	4.80
Calcium	mg/l	15.2	14.4	14.4	18.4	18.4
Magnesium	mg/l	5.80	7.80	8.20	8.70	9.20
Total Iron	mg/l	0.033	0.096	0.029	0.293	0.077
Ammonia	mg/l	<0.001	<0.001	<0.001	<0.001	<0.001
Chloride	mg/l	20.8	22.8	20.8	26.8	27.8
Sulphate	mg/l	17.6	17.5	19.7	41.7	48.0
Phosphate	mg/l	0.976	0.666	0.600	0.434	0.211
Manganese	mg/l	<0.005	<0.005	<0.005	0.008	<0.005
Nitrate	mg/l	0.033	<0.001	<0.001	0.028	<0.001
Nitrite	mg/l	0.141	0.032	0.041	0.159	0.035
Total Hardness	mg/l	62.0	68.0	70.0	82.0	84.0
Total Alkalinity	mg/l	52.0	56.0	54.0	58.0	64.0
Cal. Hardness	mg/l	38.1	36.1	36.1	46.1	46.1
Mag Hardness	mg/l	23.9	31.9	33.9	35.9	37.9
Flouride	mg/l	0.816	0.450	0.914	0.793	0.884
Bicarbonate	mg/l	63.4	68.3	65.9	70.8	78.1
Carbonate	mg/l	0.00	0.00	0.00	0.00	0.00

Appendix 3: Results for physicochemical analyses for tap water (samples 11-13)

Parameter	Unit	Sample 11	Sample 12	Sample 13
Turbidity	NTU	1.01	1.55	1.23

Colour (apparent)	Hz	<2.50	2.50	2.50
pH	pH Units	7.41	7.02	5.72
Conductivity	µS/cm	262	331	335
Tot. Susp. Solids	mg/l	<1.00	<1.00	<1.00
Tot. Dis. Solids	mg/l	160	201	202
Sodium	mg/l	18.4	34.0	44.0
Potassium	mg/l	4.00	4.60	3.30
Calcium	mg/l	14.4	18.4	12.8
Magnesium	mg/l	6.80	7.30	6.30
Total Iron	mg/l	0.038	0.207	0.014
Ammonia	mg/l	<0.001	<0.001	<0.001
Chloride	mg/l	20.8	28.8	40.7
Sulphate	mg/l	19.5	47.0	18.6
Phosphate	mg/l	0.235	0.340	0.273
Manganese	mg/l	<0.005	0.018	<0.005
Nitrate	mg/l	<0.001	<0.001	<0.001
Nitrite	mg/l	0.033	0.212	2.44
Total Hardness	mg/l	64.0	76.0	58.0
Total Alkalinity	mg/l	52.0	58.0	22.0
Cal. Hardness	mg/l	36.1	46.1	32.1
Mag Hardness	mg/l	27.9	29.9	25.9
Flouride	mg/l	0.865	0.450	0.580
Bicarbonate	mg/l	63.4	70.8	26.8
Carbonate	mg/l	0.00	0.00	0.00

Appendix 4: GSB and WHO guidelines for physico-chemical and bacteriological parameters

Parameter	Unit	GSB / WHO guidelines
Turbidity	NTU	5
Colour (apparent)		15
pH	pH unit	6.5 – 8.5
Conductivity	µS/cm	700
Tot. Susp. Solids	mg/l	-
Tot. Dis. Solids	mg/l	1000
Sodium	mg/l	200
Potassium	mg/l	30
Calcium	mg/l	200
Magnesium	mg/l	150

Total Iron	mg/l	0.3
Ammonia	mg/l	
Chloride	mg/l	250
Sulphate	mg/l	250
Phosphate	mg/l	-
Manganese	mg/l	0.4
Nitrate	mg/l	10
Nitrite	mg/l	-
Total Alkalinity As CaCO ₃	mg/l	-
Hardness (Calcium carbonate)	mg/l	500
Flouride	mg/l	1.5
Bicarbonate	mg/l	-
Carbonate	mg/l	
Calcium	mg/l	200

Appendix 5: Results for physicochemical analyses for bore hole water

Parameter	Unit	G. berg	Clark	Kingsley	Slesser
Turbidity	NTU	3.40	1.20	1.36	1.17
Colour (apparent)	Hz	5.00	2.50	5.00	2.50
Ph	pH Units	6.04	6.38	7.52	7.28
Conductivity	μS/cm	731	572	246	511
Tot. Susp. Solids	mg/l	<1.00	<1.00	<1.00	<1.00
Tot. Dis. Solids	mg/l	402	315	135	281
Sodium	mg/l	112	74.9	14.6	74.9
Potassium	mg/l	4.73	4.73	2.18	3.86
Calcium	mg/l	20.8	7.20	13.6	7.20
Magnesium	mg/l	6.80	8.30	9.70	6.80
Total Iron	mg/l	0.176	0.072	0.027	0.024

Ammonia	mg/l	<0.001	<0.001	<0.001	<0.001
Chloride	mg/l	175	123	25.8	118
Sulphate (SO ₄)	mg/l	30.4	13.1	36.3	16.1
Phosphate	mg/l	0.237	0.260	0.279	0.164
Manganese	mg/l	0.214	0.041	0.041	0.011
Nitrate	mg/l	1.92	0.974	0.326	1.70
Nitrite	mg/l	0.388	0.094	0.022	0.028
Total Hardness	mg/l	80.0	52.0	74.0	46.0
Total Alkalinity	mg/l	24.0	18.0	36.0	16.0
Cal. Hardness	mg/l	52.1	18.0	34.1	18.0
Mag Hardness	mg/l	27.9	34.0	39.9	28.0
Flouride	mg/l	0.137b	0.087	0.127	0.138
Bicarbonate	mg/l	29.3	22.0	43.9	19.5
Carbonate	mg/l	0.00	0.00	0.00	0.00

Appendix 6: Microbiological Report on samples taken from tap water

Sample ID	TC/100ml	FC/100ml	E. coli/100ml	THB/100ml
1	192	0	0	81
2	244	1	0	1344
3	15	0	0	2
4	122	0	0	10
5	96	0	0	3
6	128	0	0	15
7	144	0	0	122
8	207	1	0	156
9	216	1	0	5
10	20	0	0	26
11	558	108	0	127
12	70	0	0	5184
13	28	1	0	8

Appendix 7: Microbiological Report on samples taken from bore hole

Sample ID	TC/100ml	FC/100ml	E. coli /100ml	THB / 100ml
Kingsley	651	0	0	448
Clark	288	1	0	384
Slessor	558	0	0	164
Guggisberg	140	0	0	188

Ghana Standard GS 175

THB - 1000

6.5 < BC 8.5 (>11)

Sample ID

TC ----- Total Coliform sect.

FC----- Feecal coliform sect.

E. coli ----- *Escherichia coli*

THB----- Total heterotrophic bacteria

