KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

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COLLEGE OF SCIENCE

DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

THE QUALITY OF WATER FROM HAND DUG WELLS IN THE AKIM ODA TOWNSHIP

BY

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A DISSERTATION SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY, KNUST, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE.

By:

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Date: July, 2011

DECLARATION

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

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DEDICATIONS

This work is dedicated to my lovely wife, Sussana and children, Nhyira and Aseda.

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I give thanks to the Almighty God for his countless blessing, protection, love, and favour upon my life for making it possible for me to complete this work.

I wish to give special thanks to Dr. John Asiedu Larbi, my project supervisor for his patience, creativity and innovative ideas he rendered to me.

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ABSTRACT

This study conducted in the Akim Oda Township which is the capital of the Birim Central Municipality sought to examine the suitability of water from hand dug wells in the township.

The town was categorized into four suburbs, Old town, Community 6, New town and Quarters respectively. For every suburb, four sample sites were selected. Samples were taken over a period of four months from selected wells in quadruples for 4 months (i.e. October – January).

Total coliform, faecal coliform and *Escherichia coli* were enumerated using the Most Probable Number technique. Some physiochemical parameters (pH, Conductivity, Turbidity, TDS, Total hardness and Fluoride, Nitrate and Sulphate anions) were also measured.

The Well water from all the suburbs within the community did not meet the WHO zero faecal coliforms guidelines for drinking water except water from Well B3. Community 6 showed good quality water compared with all the suburbs. All the physiochemical parameters measured were very low and below the WHO permissible standards.

Pollution sources such as closeness of well to KVIPs, septic systems, refuse dump, cemetery market etc which could have contribute to the microbial quality of the water did not have much influence on the water quality in this study.

The quality of water from the hand-dug wells in the Akim Oda was found to be unsuitable for drinking in accordance with WHO standards but could be used for other domestic purposes.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Water is very important in the life of all living things found in the world because it constitutes to a large extent, the major solvent in which many of the body's proteins and other substances are dissolved. It enables many metabolic activities of the body to take place (Davis, 2005).

Water covers 70.9% of the Earth's surface, and is vital for all known forms of life. On Earth, it is found mostly in oceans and other large water bodies, with 1.6% of water below ground in aquifers and 0.001% in the air as vapour and precipitation. Oceans hold 97% of surface water, 2.4% for glaciers and polar ice caps, and, 0.6% for other land surface water such as rivers, lakes and ponds. A very small amount of the Earth's water is contained within biological bodies and manufactured products (Wikipedia, 2010).

The preference of groundwater as a source of drinking water in rural areas is because of its relatively better quality than river water (Obiri Danso *et al*., 2009).

Water is a medium for thousands of microorganisms some of which are disease causing. Diseases in human can be caused by presence of certain pathogenic bacteria and other organisms such as virus, protozoa, and worms. Pathogens causing diarrhoea- related illness such as cholera are normally derived from human (Davis, 2005) and other contaminated sources of water for consumption.

Historically, (from time immemorial,) point of rural settlement was being determined by water source such as stream, river and spring (Okeola *et al.*, 2010). The inhabitants of these early settlements relied on underground water often within a few meters of the surface and which they exploited in well digging.

About 1.1 billion people in the world lack access to good quality drinking water. Globally, 4 billion cases of diarrhoea are reported every year causing 1.8 million deaths, out of which about 90% are children under five (UNESCO, 2007). Water related diseases are responsible for 80% of all illness or death in the developing countries and kill more than 5 million people every year (UNESCO, 2007).

The use of groundwater as a source of potable water supply is increasing worldwide. (Obiri- Danso *et al.*, 2009) though it can be contaminated due to pollution. In the United States, 90-95% of rural and sub-urban water come from these sources.

Lack of safe drinking water is a major problem in developing countries. Within Africa, most people rely mainly on local ground water source for their needs. Shallow wells are normally found in the poorer communities as they are the least expensive to construct. Over time, water from these sources can be contaminated leading to fatal consequences.

In Ghana however, 62-67% depend on groundwater (GEMS/Water Project, 1997) and many cities and towns have problems with the quality of water people use in their homes and work places (Nkansah *et al*., 2010; Obiri Danso *et al*., 2009).

1.2 Justification

The quality of drinking water in the Akim Oda Township has become a major concern to many. In addition, inhabitants are becoming increasingly dependent on wells, which have doubtful water quality, especially during the dry season.

The township has no standard treated pipe borne water supply system but depends on six boreholes. The entire township has 37 standpipes connected to the boreholes of which only 18 (48.6%) are working (Ghana Water Company, 2010). Due to the inefficiencies and the limited water supply in the township, most people depend on other alternative sources of water such as rainwater and hand- dug Wells constructed in many households with doubtful water quality. These alternative sources are to a large extent exposed to contaminants such as bacteria, viruses, metals, nitrates and salts have polluted water supplies because of inadequate treatment and disposal of waste (humans and livestock), industrial discharge and overuse of limited water resources (Nkansah *et* al., 2010).

1.3 General Objective

The aim of this study was to investigate the drinking suitability of water from the hand-dug wells in the Akim Oda Township.

1.3.1 Specific Objectives

Specifically, the study sought to:

a) determine the microbial quality of hand dug wells within different suburbs of the study community.

b) determine some physiochemical parameters including pH, Total Dissolved Solids, Electrical Conductivity, Turbidity, Total hardness, Nitrate, Sulphate and Fluorides levels.

c) assess the perception of hand dug well users on the quality of the water.

d) identify the pollution sources that influences the microbial and physiochemical qualities of the well water.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Water

Water is a liquid at ambient conditions, but it often co-exists on Earth with its solid state being ice, and gaseous state being water vapour or steam (Ameyibor and Wiredu, 1991). Human bodies are approximately 60% water, blood is at least 50% water and the human brain made of 77% water (Stanistski *et al*., 2000).

2.1.1 Sources of Water

Water can be grouped into Surface water comprising of oceans, rivers, lakes, reservoirs, lagoons, streams and many others, Ground water which is considered mostly as purer than the surface water and lastly the rain water which falls as a result of condensation and precipitation of the clouds (Stanistski *et al*., 2000).

Surface water frequently contains substances that must be removed before it can be used as drinking water while ground water is that pumped from wells and boreholes that have been drilled from underground aquifers and is usually free from harmful contaminants.

2.2 Wells

A Well is an excavation or a structure created in the ground by digging, driving, boring or drilling to access groundwater in underground aquifers (Roger,1982).The well water may

be drawn by an electric submersible pump, a vertical turbine pump, a hand pump or a mechanical pump (e.g. from a water-pumping windmill). It can also be drawn up using containers, such as buckets that are raised mechanically or by hand (Obiri Danso *et al*., 2009).Wells can vary greatly in depth, water volume and water quality. Well water typically contains more minerals in solution than surface water and may require treatment to soften the water.

There are basically three types of wells. They include hand-dug wells, driven wells and drilled wells. Hand-dug wells are constructed by hacking at the ground with pick and shovel to dig until the water table is reached. If the ground is soft and the water table is shallow, then dug wells can work. The well is lined with stones, brick, tile, or other material to prevent collapse, and is either covered with a cap of wood, stone, metal or concrete (Roger, 1982).

In Ghana, many of the wells we find in our homes are excavated until reaching the water table and are described as shallow (Obiri Danso *et al*., 2009) . The depth of the wells depends on how far the water table could be reached.

Driven wells are built by driving a small-diameter pipe into soft earth, such as sand or gravel (Roger, 1982). A screen is usually attached to the bottom of the pipe to filter out sand and other particles. They can only tap shallow water, and because the source of the water is so close to the surface, contamination from surface pollutants can occur.

Drilled wells require a fairly complicated and expensive drill rig. They use rotary drill bits that chew away at the rock, percussion bits that smash the rock. Drilled wells can be

drilled more than 1,000 feet deep. Often a pump is placed at the bottom to push water up to the surface (Roger, 1982).

2.3 Well contamination

Shallow pumping wells can often supply drinking water at a very low cost, but because impurities from the surface easily reach shallow sources, a greater risk of contamination occurs for these wells when they are compared to deeper wells. Contamination of the wells increases during the rainy seasons where the aquifer is "topped up" more rapidly and both vertical and horizontal migrations of water are accelerated (Morgan, 1990). Dug and driven wells are easy to contaminate because they are relatively shallow.

The quality of the well water can be significantly increased by lining the well, sealing the well head, fitting a self-priming hand pump, constructing an apron, ensuring the area is kept clean and free from stagnant water and animals.

Most of the bacteria, viruses, parasites, and fungi that contaminate well water come from faecal material from humans and other animals. Common bacterial contaminants include *E. coli*, *Salmonella*, *Shigella*, and *Campylobacter jejuni*. Common viral contaminants include *norovirus*, *sapovirus*, *rotavirus*, enteroviruses, and hepatitis A and E. Parasites include *Giardia lamblia*, *Cryptosporidium*, *Cyclospora cayetanensis*, and microsporidia .

2.4 Microbes associated with drinking water

2.4.1 Coliform bacteria

Coliform bacteria are rod- shaped bacteria that are normally found in the colons of warm blooded animals and become a serious contaminant when found in water or food.

Total and Faecal coliforms are one of the most important parameters to consider when assessing the suitability of drinking water because of the infectious disease risk (WHO, 1997). Faecal coliforms indicate contamination by mammals and birds waste (faeces) and signify the possible presence of pathogenic bacteria and virus which are responsible for water-related diseases such as cholera, typhoid and other diarrhoeal related illness (Pritchard *et al*., 2007).

The total and faecal coliform bacteria are primary indicators of potability of drinking water. It measures the concentration of coliform bacteria associated with the possible presence of disease causing organisms. (Wikipedia, 2010).

2.4.1.1 Sources of Coliform Bacteria

Human and animal wastes are primary source of coliform bacteria in water. These sources of bacterial contamination include runoff from feedlots, pastures, dog runs, and other land areas where animal wastes are deposited (Pritchard et *al*., 2007). Additional sources include seepage or discharge from septic tanks, sewage treatment facilities, and natural soil/plant bacteria. Bacteria from these sources can enter wells that are either open at the land surface, or do not have watertight casings or caps. Coliforms also enter

water in individual house wells via backflow of water from a contaminated source, carbon filters or leaking well caps that allow dirt and dead organism to fall into the water (Nkansah, *et al*., 2010).

Insects, rodents or animals entering the well are other sources of contamination. Old wells, which were constructed by hand and lined (cased) with rocks or bricks usually have large openings. This makes it easier for insects, rodents, or animals to enter the well.

Another way bacteria can contaminate a water supply is through inundation or infiltration by floodwaters or by surface runoff. Floodwaters commonly contain high levels of bacteria. Small depressions filled with floodwater provide an excellent breeding ground for bacteria. Whenever a well is inundated by floodwaters or surface runoff, bacterial contamination is likely. Shallow wells and wells that do not have watertight casings could be contaminated by bacteria infiltrating the water through the soil near the well, especially in coarse-textured soils (Conboy and Gross, 1999).

2.4.1.2 Potential Health Effects

Coliform bacteria are indicators of pathogenic organisms that cause diseases. They could cause intestinal infections, dysentery, hepatitis, typhoid fever, cholera and other illnesses. However, these illnesses are not limited to disease-causing organisms in drinking water.

Intestinal infections and dysentery are generally considered minor health problems. They can however, prove fatal to infants, the elderly, and those who are ill (WHO, 2006). Other bacteria may also be present in water.

Coliform bacteria are not pathogenic (disease causing) organisms, and are only mildly infectious. For this reason these bacteria are relatively safe to work with in the laboratory (Obiri-Danso *et al*., 2009). If large numbers of coliforms are found in water, there is a high probability that other pathogenic bacteria or organisms, such as *Giardia, Salmonella* and *Cryptosporidium*, may be present.

2.4.1.3 Standards of Coliform in Drinking Water

Public drinking water supplies must demonstrate absence of total and faecal coliform per 100mls of drinking water (Conboy and Gross, 1999). There are no regulations however, governing individual water wells. It is up to the private well owner to have his or her water tested.

The EPA Maximum Contaminant Level (MCL) for coliform bacteria in drinking water is zero per 100 ml of water (EPA, 2006).

2.4.2 *Escherichia coli*

Escherichia coli (*E. coli*); is a Gram negative rod-shaped bacterium that is commonly found in the lower intestine of warm-blooded organisms (Wikipedia, 2010). Most *E. coli* strains are harmless, but some, such as serotype O157:H7, can cause serious food poisoning in humans, and are occasionally responsible for product recalls. The harmless strains are part of the normal flora of the gut, and can benefit their hosts by producing vitamin K_2, and by preventing the establishment of pathogenic bacteria within the intestine (Hole, 1999).

E. coli are not always confined to the intestine, and their ability to survive for brief periods outside the body makes them an ideal indicator organism to test environmental samples for contamination (Dzwairo *et al*., 2006).

2.4.3 Salmonella

Salmonella is a microbe found in cold and warm blooded animals (including humans), and in the environment (Ryan and Ray, 2004). They cause illnesses like typhoid fever, paratyphoid fever, and food borne illness.

2.4.3.1 Sources of Salmonella

Salmonella infections are zoonotic and can be transferred between humans and nonhuman animals. They are found in foods and water contaminated with animal faeces. Raw foods and vegetables can become contaminated (Ryan and Ray, 2004).

2.4.4 Giardia

Giardia is a one-celled parasite that can cause a gastrointestinal illness. *Giardia* is a microscopic parasite (Ryan and Ray, 2004), that can be found in water. *Giardia* causes an intestinal illness called giardiasis or "beaver fever."

2.4.4.1 Sources of Giardia

Giardia is often found in mammalian faeces. Drinking water sources become contaminated when faeces containing the parasites are deposited or flushed into water. If treatment is inadequate, drinking water may contain sufficient numbers of parasites to

cause illness (Davis, 2005). Other sources include direct exposure to the faeces of infected humans and animals, eating contaminated food, and accidental ingestion of contaminated recreational water.

Table 1: WHO Bacteriological Quality of Drinking Water

Organisms	Guideline value
All water intended for drinking *E.coli* or thermotolerant Coliform bacteria	Must not be detectable in any 100ml sample
Treated water entering the distribution system *E.coli* or thermotolerant Coliform bacteria	Must not be detectable in any 100ml sample
Total Coliform	Must not be detectable in any 100ml sample
Giardia	Must not be detectable in any 100ml sample
Salmonella	Must not be detectable in any 100ml sample

(Source; WHO, 2006)

2.5 Physiochemical Properties of water

2.5.1 pH of Water

The pH is a measure of the activity of the hydrogen ion [H^+]; also, it is the reciprocal of the logarithm of the hydrogen ion concentration (Silberberg, 2000). The pH scale ranges from 0 to 14 (Ameyibor and Wiredu, 1991).

In general, water with a pH less than 7 is considered acidic, soft and corrosive. pH more than 7 is considered basic (Ameyibor and Wiredu, 1991).

2.5.1.1 Standards of pH

The pH of pure water is 7 at 25^oC (Silberberg, 2000), but when exposed to the carbon dioxide in the atmosphere, equilibrium results in the pH of approximately 5.2. The WHO optimum limit of pH values is between 6.5 and 8.5. Because of the association of pH with atmospheric gases and temperature, it is strongly recommended that the water be tested as soon as possible.

2.5.1.2 Potential Health Effect of pH

Water with a low pH could contain elevated levels of toxic metals, cause premature damage to metal piping, and have associated aesthetic problems such as a metallic or sour taste, staining of laundry and the characteristic "blue-green" staining of sinks and drains.

Water with a pH more than 8.5 could indicate that the water is hard (Ameyibor and Wiredu, 1991). Hard water does not pose a health risk, but can cause aesthetic problems. These problems include formation of a "scale" or precipitate on piping and fixtures causing water pressures and interior diameter of piping to decrease, causes an alkali taste to the water and can make coffee taste bitter, formation of a scale or deposit on dishes, utensils, and laundry basins, difficulty in getting soaps and detergents to foam and formation of insoluble precipitates on clothing.

2.5.1.3 Treatment

The primary method to treat the problem of low pH water is with the use of a neutralizer (Staniski *et al*., 2000). The neutralizer feeds a solution into the water to prevent the water from reacting with the house plumbing or contributing to electrolytic corrosion; a typical neutralizing chemical is soda ash. Neutralizing with soda ash increases the sodium content of the water.

2.5.2 Total Dissolved Solids

Dissolved solids refer to any minerals, salts, metals, cations or anions dissolved in water. Total Dissolved Solids (TDS) comprises of inorganic salts (principally, calcium, Magnesium, Potassium, Sodium, Bicarbonate, Chlorides and Sulphates) and some small amount of organic matter that are dissolved in water (Wikipedia, 2010).

2.5.2.1 Sources of Total Dissolved Solids

TDS originate from natural sources such as, sewages, urban run-offs industrial waste water and chemicals used in the water treatment process. Total Dissolved Solids concentration is the sum of the cations and the anions in the water.

2.5.2.2 Potential Health Effect of TDS

An elevated TDS concentration is not a health hazard. The TDS concentration is a secondary drinking standard and therefore is regulated because it is more of an aesthetic rather than health hazard (Nkansah *et al*., 2010). An elevated TDS also indicate the following;

i) the concentration of the dissolved ions may cause the water to be corrosive, salty or brackish taste, result in scale formation and interfere and decrease efficiency of hot water heaters and

ii) Many contain elevated levels of ions that are above the primary or secondary drinking water standard such as an elevated level of nitrate, arsenic, aluminum copper, lead etc.

2.5.2.3 Standards of TDS

The EPA establishes standards for drinking water in two categories; that is primary standards and secondary standards. The primary standard is based on health consideration and the secondary is based on taste, odor, and colour, corrosivity, foaming and staining properties of water. There is no primary drinking water standard for TDS but secondary standard for TDS is 500mg/L (EPA, 2006).

2.5.3 Turbidity

Turbidity is an optical property where suspended and dissolved materials such as silt, clay, finely divided organic and inorganic cause light to be scattered rather than penetrate in a straight lines (Wikipedia, 2010).

Turbidity is a measure the amount of light scattered by suspended particles and can be considered as the "cloudiness" of a water sample (Stanistski *et al*., 2000). Turbidity is contributed mainly by suspended sediment and /or plankton, which are solid particles of inorganic or biological origin.

2.5.3.1 Sources of Turbidity

Human activities, including logging, grazing, agriculture, mining, road building, urbanization and commercial construction contribute to periodic pulse or chronic levels of suspended sediment in streams and other water bodies (Zoeteman, 1980).

2.5.3.2 Potential Health Effect of Turbidity

In drinking water the higher the turbidity level, the higher the risk that people may develop gastrointestinal diseases. This is especially problematic for immuno-compromised people, because contaminant like viruses or bacteria can become attached to the suspended solids (Stanistski *et al*., 2000).

2.5.3.3 Standards of Turbidity

The Environmental Protection Agency (EPA) establishes standards for drinking water which fall into two categories; Primary Standards and Secondary Standards. Primary Standards are based on health considerations and Secondary Standards are based on taste, odor, color, corrosivity, foaming, and staining properties of water. There is no Primary drinking water standard for total dissolved solids, but the Secondary standard for TDS is 500 mg/L. (EPA, 2006)

2.5.4 Electrical Conductivity

Electrical Conductivity or simply Conductivity is a measure of water's ability to conduct an electric current. The measurement is important because it indicates the concentration of dissolved ions in the water (Pritchard, *et al*., 2007), which in turn reflects ground water input, catchment geology or diverse human impact. As the number of charged ions in the water increases, so does the electrical conductivity. Conductivity varies with temperature. High and low humidity result in evapouration of the water but leaves the ions behind giving the water a higher concentration of the salt and other compounds.

Ground water has higher electrical conductivity than surface water because the ground water is able to react with mineral in the soil and rocks in the ground. (Staniski *et al*., 2000).The WHO permissible limit for electrical conductivity of water is 300μS/cm (WHO, 1997).

2.5.5 Hardness of Water

Hard water is water that has high mineral content. Hard water has high concentration of Ca^{2+} ions and Mg^{2+} ions (Ameyibor and Wiredu, 1991). Hard water is generally not harmful to ones' health but can pose serious problems in the industrial setting.

It is the measure of quantity of divalent ions (salts with 2 positive charges) such as Calcium, Magnesium and / or Iron in water.

The presence of Iron characteristically confers a brownish (rust-like) colour calcification, instead of white which is the colour of most of the other compounds. These ions enter water supply or ground water by leaching (Nkansah *et al*., 2010) from minerals within an aquifer.

Water hardness is measured by adding up the concentration of Calcium, Magnesium and converting the value to an equivalent concentration of Calcium Carbonate ($CaCO_3$) in milligram per liter (mg/L) [APHA, 1998].

2.5.5.1 Potential Health Effect of Hard water

Hardness does not pose a health risk and is not regulated by state agencies. In fact, Calcium and Magnesium in drinking water can help ensure average daily requirement for these minerals in a diet (Salami and Okafor, 2003).

With hard water, soap solution forms a white precipitate instead of producing lather. The effect arises because the dications destroy the surfactant properties of the soap by forming a solid precipitate (Ameyibor and Wiredu, 1991).

It also forms deposit also called scale that cause clog plumbing. This scale mainly caused by $CaCO_3$, $Mg(OH)_2$ and $CaSO_4$ (Silberberg, 2000). It often causes aesthetic problems, such as an alkali taste to the water that makes coffees taste bitter.

2.5.6 Nitrate in water

Nitrate is a colourless, odourless, and tasteless compound (Ameyibor and Wiredu, 1991) that is present in some groundwater. Nitrate can be expressed as either NO^-_3 (nitrate) or NO_3-N (nitrate-nitrogen) [Silberberg, 2000].

Nitrate (NO^-_3) is a naturally occurring form of nitrogen found in soil. Nitrogen is essential to all life. Most crop plants require large quantities to sustain high yields.

The formation of nitrates is an integral part of the nitrogen cycle in our environment. In moderate amounts, nitrate is a harmless constituent of food and water. Plants use nitrates from the soil to satisfy nutrient requirements and may accumulate nitrate in their leaves and stems. Due to its high mobility, nitrate can leach into groundwater (Self and Waskom, 2008).

Nitrates form when microorganisms break down fertilizers, decaying plants, manures or other organic residues. Usually plants take up these nitrates, but sometimes rain or irrigation water can leach them into groundwater.

2.5.6.1 Sources of Nitrate

Although nitrate occurs naturally in some groundwater, in most cases higher levels are thought to result from human activities.

Common sources of nitrate include fertilizers and manure, animal feedlots, municipal wastewater and sludge, septic systems, and N-fixation from atmosphere by legumes, bacteria and lightning.

2.5.6.2 Potential Health Effect of Nitrate

High nitrate levels in water can cause methemoglobinemia or blue baby syndrome, a condition found especially in infants less than six months.

This causes an increase in bacteria that can readily convert nitrate to nitrite (NO^-_2). Nitrite is absorbed in the blood, and heamoglobin (the oxygen-carrying component of blood) is converted to methemoglobin. Methemoglobin does not carry oxygen efficiently. This results in a reduced oxygen supply to vital tissues such as the brain. Methemoglobin in infant blood cannot change back to heamoglobin (Hole, 1999), which normally occurs in adults. Severe methemoglobinemia can result in brain damage and death (Self and Waskom, 2008). Infants should not be allowed to drink water that exceeds 10 mg/l NO_3-N. This includes formula preparation.

The most obvious symptom of methemoglobinemia is a bluish color of the skin, particularly around the eyes and mouth. Other symptoms include headache, dizziness, weakness or difficulty in breathing. If recognized in time, methemoglobinemia is treated easily with an injection of methylene blue (Self and Waskom, 2008).

Nitrate in water is undetectable without testing because it is colorless, odorless, and tasteless (Silberberg, 2000). A water test for nitrate is highly recommended for households with infants, pregnant women, nursing mothers, or elderly people. These

groups are the most susceptible to nitrate or nitrite contamination. Nitrate-nitrogen occurs naturally in groundwater, usually at concentrations far below a level of concern for drinking water safety.

2.5.6.3 Standards of Nitrate

Nitrate values are commonly reported as either nitrate (NO^-_3) or as nitrate-nitrogen (NO_3-N). The maximum contaminant level (MCL) in drinking water as nitrate (NO^-_3) is 45 mg/l (EPA, 2006).

Protecting your drinking water supply from contamination is important for health and to protect property values and minimize potential liability. High nitrate levels often are associated with poorly constructed or improperly located wells (Zoeteman, 1980).

Although there is no enforceable drinking water standard for livestock, it is not advisable to allow animals to drink water with more than 100 mg/l NO_3-N.

This is especially true of young animals. They are affected by nitrates the same way as human babies. Older animals may tolerate higher levels.

2.5.7 Fluorides in water

Fluoride naturally occurs in food and drinking water source. Fluoride does not alter the taste, colour or smell of water (Ameyibor and Wiredu, 1991). A water test is the only way to determine the presence of fluoride in drinking water. Public water system containing fluoride in excess of 4.0mg/L requires defluoriation (EPA, 2006). Children under 12years should not be allowed to drink such water.

2.5.7.1 Sources of Fluorides

Fluorides may be discharged as by product from fertilizer and aluminum factories and it can enter ground water Bedrock wells to create greater risk for high levels of fluoride. Fluoridated toothpaste may contain a large concentration of fluoride.

2.5.7.2 Potential Health Effect of Fluorides

Optimal levels, fluoride can have beneficial effects on children dental health making teeth more resistant to long life tooth decay. However, excessive fluorides consumption can mottle enamel, also known as fluorosis (Nkansah *et al*., 2010).

Fluorosis is an aesthetic problem without health effect. Very high fluoride exposures can cause crippling skeletal fluorosis.

2.5.7.3 Standards of Fluorides

According to the EPA, the Maximum Contaminant Level Goal (MCLG) for fluoride in drinking water is 4.0mg/L. In addition, it has set a Secondary Maximum Contaminant Level Goal (SMCLG) of 2.0mg/L as guideline in areas that have high levels of naturally occurring fluoride.

The best level of fluoride in drinking water is between 0.7mg/L to 1.2mg/L. This range is based on the temperature of the area (EPA, 2006).

2.5.8 Sulphate in water

Sulphate (SO^{2-}_4) is a combination of Sulphur (S) and Oxygen (O). It occurs naturally in many soil and rock formation (Silberberg, 2000). Sulphate also occurs naturally in most groundwater. At high levels, sulphate can give water a bitter or astringent taste and can have laxative effects.

2.5.8.1 Sources of Sulphate

As water moves through soil and rock formations that contain sulphate minerals, some of the sulphate dissolves into the groundwater. Minerals that contain sulphate include Magnesium sulphate (Epsom salt), Sodium Sulphate (Glauber's salt), and Calcium Sulphate (gypsum).

Salt water intrusion and acid rock drainage are also sources of sulphate in drinking water. In addition, manmade sources include industrial discharge and deposition from burning of fossil fuel (Okeola *et al*., 2010).

2.5.8.2 Potential Health Effect of Sulphate

People unaccustomed to drinking water with elevated levels of sulphate can experience diarrhoea and dehydration. Infants are often more sensitive to sulphate than adults. As a precaution, water with a sulphate level exceeding 400 mg/L should not be used in the preparation of infant formula. Older children and adults become accustomed to high sulphate levels after a few days. High sulphate levels may also corrode plumbing, particularly copper piping.

2.5.8.3 Standards of Sulphate

According to Minnesota Health Department, if sulphate in water exceeds 250 mg/L, a bitter of medicinal taste may render the water unpleasant to drink.

Sulphate above 500mg/L in water may affect the taste of the water (EPA, 2006). At levels above 1000mg/L, sulphate in drinking water can have a laxative effect, although, these levels are not normally found in drinking water.

2.6 Treatment of Water

Bacteria are removed by disinfection and/or filtration. Filtration alone may not be completely effective, but can improve the performance of disinfectants by removing sediment that can shelter the bacteria (Staniski *et al*., 2000). Methods of adding chlorine to water include solution feeders for dry chlorine or liquid chlorine or by feeding gas chlorine directly from 100, 150, or 200 lb. cylinders. Gas chlorination is recommended only for larger systems that can support the services of a trained water treatment plant operator. Chlorine is normally dosed to a concentration sufficient to maintain a free residual of at least 0.2 parts per million (PPM) [Staniski *et al*., 2000].

Other disinfectants include iodine, ozone, ultraviolet light, and physical methods such as boiling or steam sterilization. Chlorination is still the most common disinfection method widely used, although recent concerns have been raised about the reaction of chlorine with organic matter in water (Silberberg, 2000). Such a reaction can result in the formation of trihalomethane, which are suspect carcinogenic compounds. More

advanced techniques exist, such as reverse osmosis. It is important that the well is cleaned with 1% chlorine solution after construction and periodically every 6 months

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study area

This study was conducted in the Akim Oda Township within the Birim Central Municipal area which lies south west of the Eastern region and covers about 500 sq.km. The municipal area constitutes about 3% of the total area of the Eastern region with about 400 settlements, most of them rural (Ghana Water Company, (2010).

Akim Oda lies in the semi deciduous rain forest. The climate is semi equatorial and wet with significant precipitation during the rainy season from April to June and again in September to November. A dry period is experienced between December and February.

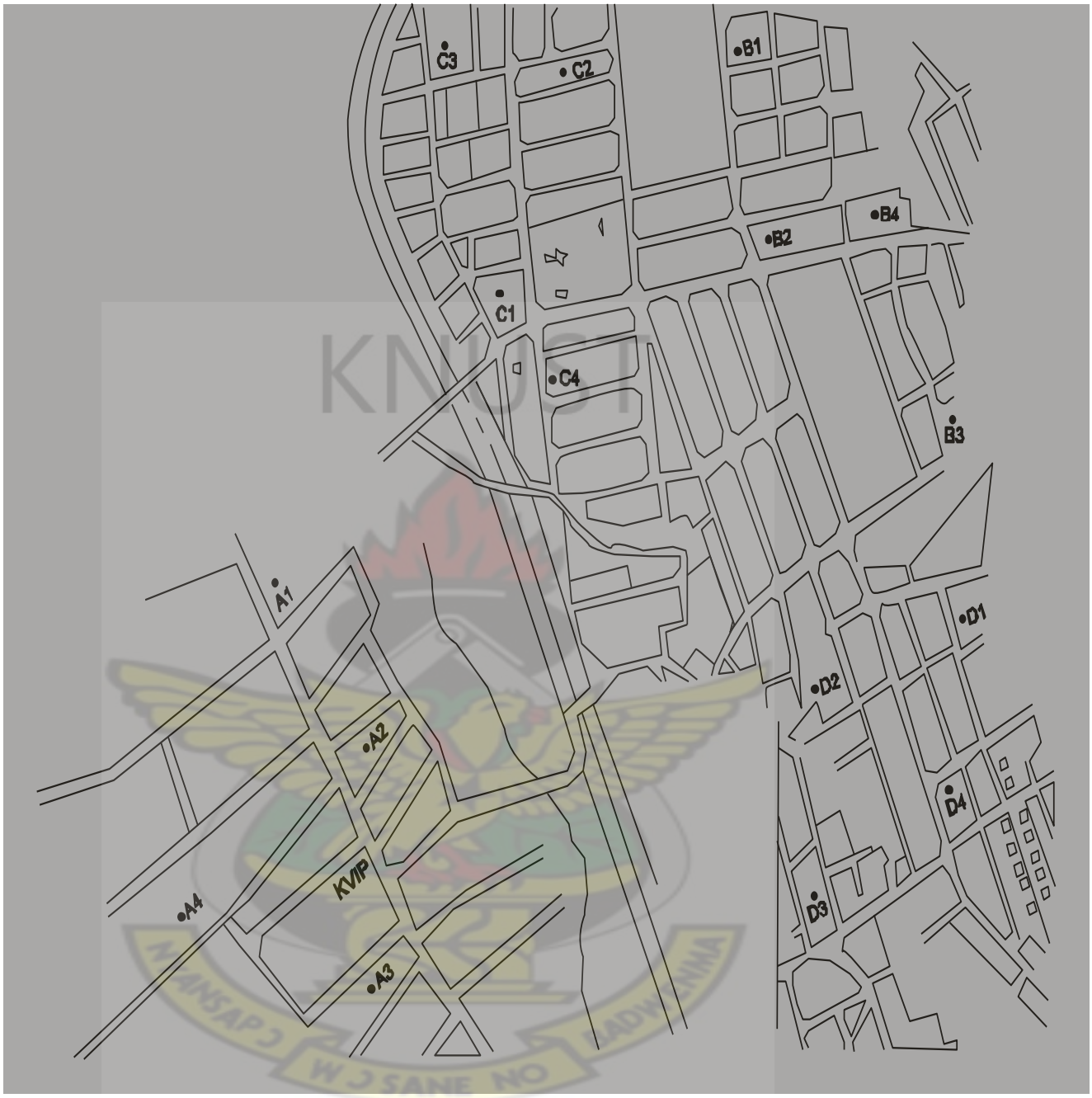

Figure 1: Map of the Akim Oda township showing sampling points

3.2 Sampling sites

The town was categorized into four suburbs based on the main road network in the town, Old town, Community 6, New town and Quarters respectively. There are many wells in the study community used as sources of domestic water, however, only perennial hand-dug wells that were open for communal use were considered in this study. Four wells were selected from each of the four suburbs for sampling, which gave a total of sixteen sample sites. All the wells found in Old town were designated **A**. **B** for wells in New town, **C** for wells in Community 6 and **D** for wells in Quarters.

3.3 Sampling collection

Samples were consistently taken monthly from selected wells in quadruples for 4 months (i.e. October – January). Samples were consistently taken between 06:00 - 07:00 hrs, when wells were in use by the community members. The water from the wells were collected using a sterile plastic bag with about 10m rope (Obiri- Danso *et al*., 2009). They were collected in 500ml sterilized bottles and transported in ice-cold containers to the laboratory for analysis within three hours of collection.

3.4 Microbial Laboratory Procedure

Preparation of MacConkey Broth

In preparing the MacConkey broth, 17.5g of the powder was weighed and dissolved in 500cm^3 of ionized water. It was mixed well, disposed into tubes, and sterilized for 15 minutes at 121^{o}C in an autoclave.

Preparation of Tryptophan Broth

Eight gram of the powder was dissolved in 500ml of distilled water. It was distributed into containers and sterilized in the autoclave at 121^{o}C for 15 minutes.

3.4.1 Total and Faecal coliforms

Total and Faecal coliforms were analysed using the Most Probable Number (MPN) method. Serial dilutions of 10^{-1} to 10^{-8} were prepared by serially diluting 1 ml of the water sample. One-milliliter aliquots from each of the dilutions were inoculated into 5 ml of MacConkey Broth with inverted Durham tubes and incubated at 37 °C for total coliforms and 44 °C for faecal coliforms for 18-24 hrs. Tubes showing colour change from purple to yellow and gas collected in the Durham tubes after 24 hrs were identified as positive for both total and faecal coliforms. Counts per 100 ml were calculated from MPN Tables (Anon, 1992).

3.4.2 *E.coli*

From each of the positive tubes identified, a drop was transferred into 5ml test tube of Trypton water and incubated at 44^{o}C for 24hours Kovac's reagent was then added. to the tube of trypton water. All tubes showing a red ring colour development after gentle agitation denoted the presence of indole and recorded as presumptive for thermotolerant coliform *(E.coli*). Counts per 100ml were calculated using the MPN tables

3.5 Physiochemical Laboratory Analyses

3.5.1 pH Determination

pH was determined on site. For pH, an aliquot of 100ml of the sample was measured into 500ml beaker. The pH meter probe was immersed in the water sample. The reading on the pH was then recorded after 2 minutes (Anon, 1992).

3.5.2 Turbidity Determination

Turbidity values were taken using a cybercan IR TB 100 Turbidimeter. The turbidimeter was calibrated with 1000 NTU, 100 NTU, 10NTU and 0.02 NTU calibrated standards. The cuvette was rinsed three times with the sample to be tested. The light shield cap was replaced and all outside surface were cleaned and made dry. The cuvette was pushed firmly into the optical well and index to the lowest reading. The NTU values were measured by pressing and releasing the arrow button and the value was recorded after the display has stopped flashing (APHA, 1998).

3.5.3 Conductivity Determination

Conductivity was measured using Hana instrument HI 9032 microcomputer conductivity meter. The conductivity meter was calibrated by immersing the electrode in a reference buffer of 12,880µS/cm. When the "Buf" signal was displayed on the screen and blinking the reading was not stable yet until "CON" appeared on the screen. The "CON" key was depressed to confirm for accepting the reading and the equipment was returned to the OPERATION mode for measurement. The electrode of the conductivity meter was rinsed

and replaced in storage-distilled water. The water sample was out in a beaker and the electrode rinsed with distilled water and lowered into the sample in the beaker. The conductivity in μS/cm of the sample was displaced on the screen and recorded (AHPA, 1998).

3.5.4 TDS Determination

A cellulose nitrate membrane filter with pore size 0.45μm was placed on the Teflon-faced glass filter holder and wetted by filtering about 20ml distilled water using the Millipore vacuum filtration. This process was used to open the pores of the filter paper. The wet filter paper was removed carefully using a pair of forceps and placed on a watch glass. The watch glass and its content were put in a Memmert electric oven at 105^{o}C for 15 minutes to dry. The filter paper together with the watch glass was removed from the oven and placed in desiccators for about 1hour to cool. The filter was marked, weighed on BHD analytical balance and its weight recorded (W_1).

The sample of water was shaken to obtain a homogenous mixture, and therefore, a reasonable quantity was measured in a graduated glass cylinder. The volume of the sample was recorded (V ml). The test contents of the measuring cylinder were rinsed with distilled water and poured into the funnel whilst vacuum filtration continued.

The filter paper, with the solids, was removed using a pair of forceps and put on a clean dry watch glass. The watch glass and its content were dried in the oven at a temperature of 104^{o}C for 30 minutes and thereafter removed into desiccators to cool to room temperature. The filter paper and its content were weighed and the weight recorded (W_2) [APHA, 1998].

Calculation: TDS (mg/l) = $\frac{(W_2 - W_1) \times 106}{V}$

Where;

W2 = weight of the filter paper and solids, in grams

W1 = weight of the filter paper only, in grams

V = volume of test sample, in milliliters

3.5.5 Total Hardness Determination

A 100ml of the water sample was put into a 250ml conical flask and 10L ammonium chloride buffer added to the contents in the conical flask. 2 drops of Erichome Black T indicator was added. The content in the conical flask changed from wine or red to blue at the end point. Titration was repeated until a consistent value was obtained. The value of the average titre was recorded (APHA, 1998).

Calculation: Total Hardness, as $CaC0_3$ (mg/l) = titre value ×20

3.5.5.1 Ca Hardness Determination

A 100ml of the water sample was put into a 250ml conical flask. 4 ml sodium hydroxide solution added to the contents of the flask followed by the addition of about 0.2g murexide indicator. The content in the conical flask was titrated against 0.02M EDTA to the end point. This is indicated by a pink colouration. Titration was repeated until a consistent titre was obtained (APHA, 1998).

Calculation: Calcium Hardness as $CaCO_3$ (mg/L) = Average Titre Value × 20

3.5.5.2 Mg Hardness Determination

The Magnesium hardness of a sample was calculated as the difference between the total hardness and Calcium hardness values obtained from analysis of the sample.

3.5.8 Nitrate Determination

The nitrate test tube for the various water samples were filled to the 20 mark. One level spoonful of Nitratest powder and one Nitratest tablet were added to each sample. The tablets were crushed. The screw caps were replaced and well shaken for one minute.

The tubes were allowed to stand for about one minute and gently inverted three or four times to aid flocculation. The tubes were then allowed to stand for two minutes to ensure complete settlement.

The screw caps and the wipes around the top of the tubes were removed with a clean tissue and the solution was carefully decanted into a round test tube filling to the 10 mark.

At this point, one tablet of Nitricol was crushed and mixed to dissolve in each tube. It was then allowed to stand for 10 minutes to allow full colour development.

The photometer readings were taken and compared with Nitratest calibration chart. The wavelength of the photometer selected was 570nm.

3.5.9 Fluoride Determination

The Wagtech Fluoride test kit was used. The kit contained Fluoride No.1 and No.2 tablets, Wagtech photometer and Round Test Tube of 10ml glass.

The test tubes were filled with the various water samples to the 10ml mark of the tubes. One Fluoride No.1 tablet was crushed and mixed to dissolve, followed by Fluoride No.2, which was also crushed and mixed to dissolve in each of the water samples.

The test tubes were allowed to stand for 5 minutes until full colour development. The photometer readings were taken and compared with the Fluoride Calibration Chart.

3.5.10 Sulphate Determination

The Wagtech sulphate test kit was used. It was based on a single tablet reagent containing Barium Chloride in a slightly acidic formulation.

Various water samples were placed in a test tube to the 10ml mark of the glass. One sulphate tablet was added. It was crushed and mixed to dissolve in each sample. Cloudy solution indicated the presence of sulphate. The water samples were allowed to stand for 5 minutes then mixed again to ensure uniformity.

The readings of the photometer were taken and compared to the sulphate calibration chart. The wavelength for the photometer was selected at 520nm.

3.6 Questionnaire Administration

Structured questionnaire was administered to regular users of wells within each suburb in the community to gather their views on the quality of the well water. Five regular users of each well were interviewed, but care was taken that the respondents were from different households. The survey was conducted in the dry season because that is when community members used the wells most. In addition, water from alternative sources like rainwater and pipe water is scarce during the dry season. 80 interviews were conducted.

Observational studies of the wells were carried out in the communities for two weeks. Observations made include the nature of wells, cover of the well, water usage and closeness of wells to any potential pollution sources such as public latrines, refuse dump, market, cemetery etc.

3.7 Data Analysis

The questionnaire was entered into Statistical Package for Social Sciences (SPSS) version 16 for analysis of percentage of respondents. Analysis of variance (ANOVA) for indicator organisms and other parameters among the sampling locations were also determined with SPSS.

CHAPTER FOUR

4.0 RESULTS

4.1 Perceptions on hand dug well water quality

4.1.1 Demographic characteristics of respondents

Respondents to the questionnaires administered in the different suburbs consisted of 40.6% male and 59.4% female. The demographic characteristic of the respondents is presented in Table 2. The survey showed that 73% of respondents were living in compound house, 24% single room and 3% hostels. Mothers constituted majority of those women interviewed with a mean household size of 5.2.

Table 2: Demographic Characteristics of respondents

	Old Town	New Town	Community 6	Quarters
No. of samples	(n =20)	(n =20)	(n =20)	(n =20)
Gender of respondent				
Male	36.0%	40.0%	49.0%	37.7%
Female	64.0%	60.0%	51.0%	62.3%
Position of respondent in household				
Mother	38.8%	40.2%	66.2%	45.7%
father	8.0%	11.0%	6.8%	15.1%
Son	23.1%	17.0%	10.0%	9.2%
Daughter	30.1%	31.8%	17.0%	30.0%
Mean no. of people per household (Range of age of household members)	4.5(1-45)	5.2(1 -50)	4.9 (less1-38)	6.1 (1-55)

Table 3: Responses to Questionnaire

Water Dependency	Both piped water and well 77%	Only piped water 20%	Only well water 3%
Well Construction	By private people 87%	By company 13%	
Treatment of Well Water	No treatment 94.8%	Treatment 5.2%	
Method of Treatment	Boiling 94.2%	Local filtration system 5.8%	
Reasons for Treatment	Removal of impurities 76%	Kill Germs 24%	
Perception on Well Quality	Good quality for drinking without treatment 80.5%	Poor quality for drinking 19.5%	
Hardness of Well Water	Lather with soap 85.2%	Not lather with soap 14.8%	

4.1.2 Response to Questionnaire

Piped water and hand-dug wells were the main sources of water in the community, however, whenever pipe was not running, most people use water from the wells.

All those who treated the water before using it stated that, treatment does not have any influence on taste, colour and smell (odour) of the water. All the well users mentioned

that they used the water for domestic purposes such as bathing, cooking, washing and even drinking if they do not have piped water in their homes.

Most of the wells were away from pollution sources such as septic tank, refuse dump, cemetery and many others, therefore possibility of leaching and infiltration into groundwater to contaminate the wells was minimal. The characteristic features of the wells sampled are shown below.

Table 4a: Characteristic features of wells sampled in Old Town

Suburb	Well I.D	Well characteristics
Old Town	A1	• Well is not covered • Surroundings not too tidy • Inside lined with cement to about 3m • Multiple receptacle being used • Used for domestic purposes • 8m away from the cemetery
	A2	• It is cover with metallic slap and under lock • surroundings tidy • 5m from a pit latrine • Inside lined with concrete • Used for domestic purposes • One receptacle being used
	A3	• It is not covered with any material • Well is 15cm above the ground surface • Located in a backyard garden • Inside lined, spirogyra patches on wall • 15m away from KVIP • Used for domestic purposes • Multiple receptacle being used
	A4	• Well not covered with any material • Very close to a backyard garden • Surroundings tidy • Inside lined with concrete • Multiple receptacle being used • Used for domestic purposes

Table 4b: Characteristic features of wells sampled in New Town

New Town	B1	• It not covered • 0.5m above the ground surface • Surroundings is not tidy • Inside lined with concrete • Multiple receptacle being used • Used for domestic purposes
	B2	• Tidy Surroundings • well has wind lass • Inside lined with concrete • Used for domestic purposes
	B3	• It is covered with metallic lid • Tidy Surroundings • 0.7m above the ground surface • Inside lined with concrete • Depth of 11m • One receptacle for all users • Used for domestic purposes
	B4	• It is covered and locked • Surroundings decorated with stones • 5m close to pit latrine • Inside lined • Used for domestic purposes

Table 4c: Characteristic features of wells sampled in Community 6

Community 6	C1	• Well covered with wooden material • Surroundings somewhat tidy • 2m away from septic tank • Inside lined concrete but with spirogyra patches • Has apron • Used for domestic purposes
	C2	• Well covered wooden board • Surroundings tidy • Inside lined with concrete • Used for domestic purposes
	C3	• It is covered with wooden board • Surroundings not too tidy • Inside lined concrete • Used for domestic purposes
	C4	• It is covered with metallic lid • 4m close pit latrine • Surroundings not too tidy • Inside lined concrete • Used for domestic purposes

Table 4d: Characteristic features of wells sampled in Quarters

Quarters	D1	• Well is covered with metallic lid and under lock • Inside lined concrete • Tidy surroundings • 6m from septic tank • One receptacle for all users • Used for domestic purposes • Located uphill
	D2	• Well is not covered with any material • Surroundings not too tidy • Inside lined with concrete • One receptacle for all users • 2m away from backyard garden • Used for domestic purposes • Located uphill
	D3	• It is covered with wooden board • Surroundings tidy • Cemented floor around the well • Inside lined concrete • One receptacle for all users • Used for domestic purposes
	D4	• Cemented floor around the well • It is covered with metallic lid and under lock • Surroundings tidy • Multiple receptacle being used • Inside lined with concrete • Used for domestic purposes

Plate 1: Photograph showing a well at site A3

Plate 2: Photograph showing a well at site B3

Plate3: Photograph showing a well at site C1

Plate 4: Photograph showing a well at site D4

4.2 Microbial Quality of the Water

4.2.1 Total Coliform counts

Microbial indicators were present in all the well waters sampled. There were slight variations which were significant ($p<0.05$) in total coliform counts between wells in the Old Town suburb [Appendix 1A]. Well A3 had the highest total coliforms (1.60×10^3MPN/100ml) within the Old town suburb while Well A4 had the lowest (1.40×10^2MPN/100ml). However, within the New Town suburb, well B3 showed the lowest total coliform counts (2.0×10^0 MPN/100ml) while B1 showed the highest counts (3.20×10^0 MPN/100ml). Statistical analysis showed significant difference ($p<0.05$) between wells in the New town (Appendix 1B).

Variations were observed in total coliform counts in wells sampled from Community 6. However, these differences were not significant ($p>0.05$) [Appendix 1C]. Well C2 had the highest coliform counts (8.30×10^2 MPN/100ml) while C4 recorded the lowest (9.60×10^1MPN/100ml).

Well water within the Quarters suburb showed little variations in total coliforms which were not significant ($p>0.05$) [Appendix 1D]. Well D4 had highest total coliform counts (3.50×10^2MPN/100ml) while D1 had the lowest counts.

There were variations which were statistically significant ($p<0.05$) in the total coliform counts of well water within all the suburbs. Old town had the highest total coliform counts while

Community 6 had the lowest

Table 5: Total coliform counts in well waters from different suburbs

Suburb	Well I.D	Total coliforms (MPN /100 ml)	
		Geometric mean	Range
Old Town	A1	9.90×10^2	2.35×10^2 - 9.15×10^3
	A2	1.80×10^2	9.15×10^1 - 4.35×10^2
	A3	1.60×10^3	9.15×10^2 - 4.15×10^3
	A4	1.40×10^2	4.15×10^1 - 4.60×10^2
New Town	B1	3.20×10^2	9.15×10^1 - 2.35×10^3
	B2	1.40×10^2	0.0 - 4.50×10^2
	B3	2.0×10^0	0.0 - 4.00×10^0
	B4	1.00×10^2	2.35×10^1 - 1.10×10^3
Community 6	C1	9.60×10^1	4.15×10^1 - 9.15×10^2
	C2	8.30×10^2	2.35×10^2 - 1.10×10^3
	C3	1.50×10^2	4.25×10^1 - 1.10×10^3
	C4	9.60×10^1	2.35×10^1 - 4.20×10^2
Quarters	D1	2.10×10^2	4.00×10^1 - 9.15×10^2
	D2	2.80×10^2	2.30×10^1 - 2.35×10^3
	D3	2.10×10^2	4.00×10^1 - 2.35×10^3
	D4	3.50×10^2	2.30×10^2 - 4.60×10^2

4.2.2 Faecal Coliform Counts

Well water within the Old town did not show significance differences ($p>0.05$) [Appendix 1A] in the faecal coliform counts. Well A1 recorded the highest faecal coliform counts while A2 had the lowest. Within the New town suburb, there was significant difference between of the well water faecal coliform counts ($p< 0.05$). Well B4 had the highest faecal coliform counts while B3 showed no faecal coliform counts.

Wells within the Community 6 showed significance difference ($p<0.05$) [Appendix 1C]. Well C2 had the highest faecal coliform counts while C1 showed the lowest counts.

Wells within Quarters were not significant ($p>0.05$) [Appendix1D]. Well D4 had the highest faecal counts while D2 had the lowest counts.

Faecal coliform counts showed variations in the various samples within the different suburbs. Wells within the suburbs showed significant differences ($p=0.05$) [Appendix 2], in the faecal coliform counts, with Old town recording the highest faecal coliform counts while Community 6 had the lowest counts.

Table 6: Faecal coliform counts in well waters from different suburbs

Suburb	Well I.D	Faecal coliforms (MPN /100 ml)	
		Geometric mean	Range
Old Town	A1	1.70×10^2	9.15×10^1 - 2.35×10^2
	A2	5.60×10^1	4.15×10^1 - 9.15×10^1
	A3	9.30×10^1	2.35×10^1 - 1.50×10^1
	A4	5.80×10^1	2.30×10^1 - 9.30×10^1
New Town	B1	5.78×10^1	9.00×10^0 - 2.40×10^2
	B2	4.60×10^1	0.0 - 2.30×10^1
	B3	1.00×10^0	0.0 - 1.00×10^0
	B4	2.70×10^2	9.00×10^0 - 9.15×10^1
Community 6	C1	2.00×10^1	9.00×10^0 - 4.30×10^1
	C2	1.50×10^2	9.15×10^1 - 4.20×10^2
	C3	4.40×10^1	4.00×10^1 - 9.30×10^1
	C4	3.20×10^1	9.00×10^0 - 9.20×10^1
Quarters	D1	6.10×10^1	2.30×10^1 - 2.40×10^2
	D2	4.20×10^1	9.00×10^0 - 9.30×10^1
	D3	4.40×10^1	2.30×10^1 - 9.30×10^1
	D4	7.00×10^1	4.00×10^1 - 9.30×10^1

4.2.3 E. coli Counts

E.coli counts in the various wells were minimal. The *E.coli* counts found in Old town were not significant ($p>0.05$). However, Well A4 had the lowest while A1 recorded the highest *E. coli* counts. New town wells showed significant difference ($p<0.05$) [appendix1B]. There was no detection of *E. coli* in well B3 while well B1 showed the highest.

Statistically, there were significant difference in the *E.coli* counts of the wells within the community 6 ($p<0.05$) with C2 recording the highest *E. coli* counts whiles C1 had the lowest counts. Within the Quarters suburb, *E.coli* counts were not significant ($p>0.05$) [Appendix 1D], with well D1 having the lowest while well D 2, the highest.

Wells within all the suburbs did not show significant differences ($p>0.05$) in the *E.coli* counts. Old town had the highest *E.coli* count while Community 6 had the lowest counts.

Table 7: *E. coli* counts in well waters from different suburbs

Suburb	Well I.D	E.coli (MPN / 100 ml)	
		Geometric mean	Range
Old Town	A1	5.40×10^1	4.00×10^1 - 9.30×10^1
	A2	2.35×10^1	1.50×10^1 - 4.30×10^1
	A3	3.20×10^1	9.00×10^0 - 4.30×10^1
	A4	2.05×10^1	9.00×10^0 - 4.30×10^1
New Town	B1	2.03×10^1	4.00×10^1 - 9.30×10^1
	B2	1.90×10^1	0.0 - 2.30×10^1
	B3	0.00	0.0 - 0.0
	B4	1.20×10^1	9.00×10^0 - 2.30×10^1
Community 6	C1	6.90×10^0	4.00×10^0 - 9.00×10^0
	C2	3.60×10^1	2.30×10^1 - 9.30×10^1
	C3	1.50×10^1	9.00×10^0 - 4.20×10^1
	C4	1.70×10^1	9.00×10^0 - 2.30×10^1
Quarters	D1	9.00×10^0	9.00×10^0 - 9.00×10^0
	D2	1.90×10^1	4.00×10^0 - 9.30×10^1
	D3	1.68×10^1	9.00×10^0 - 2.30×10^1
	D4	1.20×10^1	9.00×10^1 - 2.30×10^1

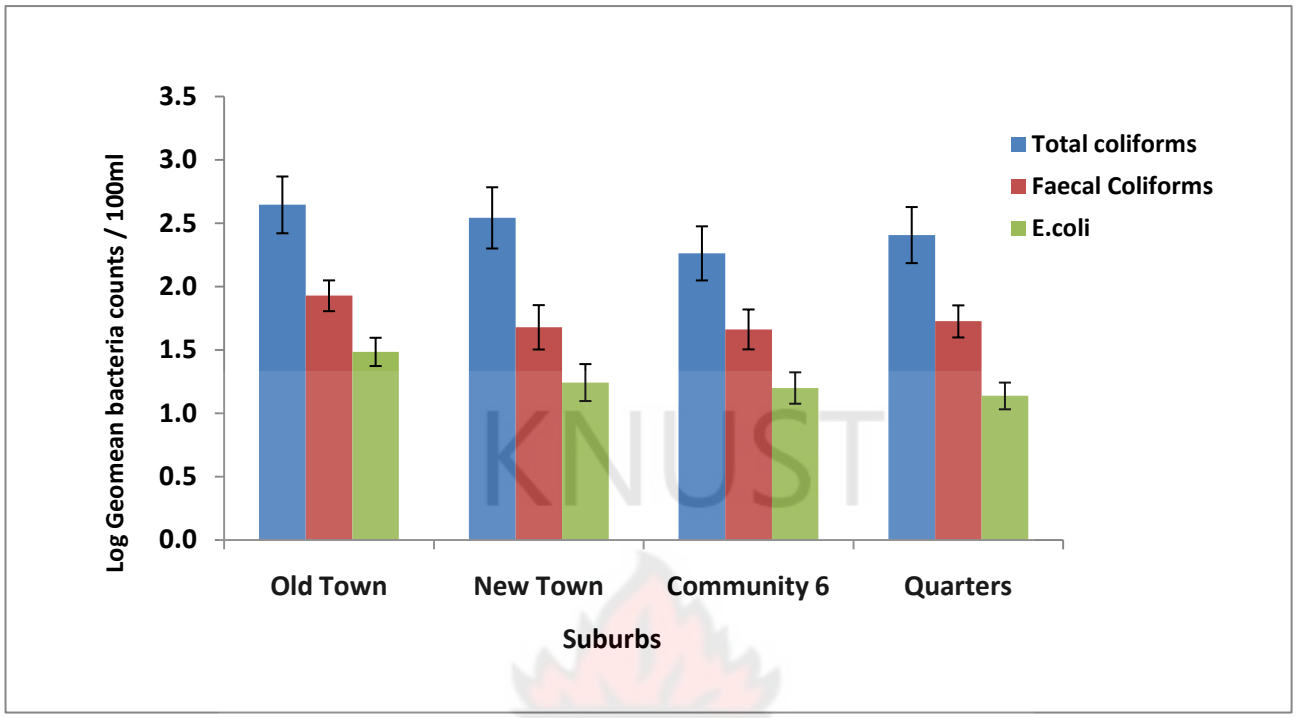

Figure 2: Variation of microbial indicators in well waters from different suburbs

4.3 Physiochemical Properties

4.3.1 pH, Turbidity, Conductivity and Total dissolved solids

The physical quality of water describes the physical characteristics or nature of the water.

The well water sampled from the various suburbs within the community showed varying degree of variations. Within the Old Town, well A4 had the highest pH of 5.86 while well A2 had the lowest (5.72). Values for Conductivity and TDS were the highest for A4 (93.4µS/cm and 69.5mg/l respectively) while A2 had the lowest (85.4µS/cm and 63.6mg/l respectively).

Within the New town, B4 had the lowest Turbidity (0.12NTU) while B2 had the highest (0.24NTU).Well B3 recorded the highest Conductivity value of 108µS/cm while B2 had the lowest (96.8µS/cm).

Well C3 in the Community 6 showed the highest Conductivity value (101.9µS/cm) while C2 recorded the lowest values in Conductivity and Turbidity (70.2µS/cm) and (0.10 NTU) respectively.

Within the Quarters suburb, D1 had the highest TDS (72.0mg/l) while D3 had the lowest values in TDS and turbidity (57.2mg/l and 0.10NTU respectively).

There were slight differences in the levels of the physical parameters assessed between the wells from the same suburb which were statistically significant ($p<0.05$). Significant difference was recorded in pH of waters from the different suburbs whiles conductivity, turbidity and TDS did not show any significant differences ($p>0.05$) [Appendix 3].

Table 8: Physiochemical Properties of well waters in the indicated suburbs

Suburb	Well I.D	Mean ± Standard Deviation of			
		pH	Conductivity (uS/cm)	Turbidity (NTU)	Total Dissolved Solids (mg/l)
Old Town	A1	5.80 (± 0.34)	92.3(± 1.43)	0.18 (± 0.04)	68.7 (± 1.87)
	A2	5.72 (± 0.14)	85.4 (± 2.45)	0.12 (± 0.07)	63.6 (± 2.06)
	A3	5.86 (± 0.87)	86.7 (± 1.65)	0.19 (± 0.05)	64.5 (± 1.23)
	A4	5.83 (± 0.30)	93.4 (± 1.57)	0.14(± 0.08)	69.5 (± 1.98)
New Town	B1	5.69 (± 0.15)	103.4 (± 2.76)	0.21 (± 0.04)	76.9 (± 0.98)
	B2	5.50 (± 0.60)	96.8 (± 3.09)	0.24 (± 0.07)	72.1 (±1.01)
	B3	5.53 (± 0.49)	108 (± 2.35)	0.22 (± 0.06)	80.4 (± 1.08)
	B4	5.49 (± 0.57)	102.4 (± 3.12)	0.12 (± 0.14)	76.2 (± 2.35)
Community 6	C1	5.80 (± 0.30)	95.6(± 2.64)	0.12 (± 0.13)	71.2 (± 1.59)
	C2	5.78 (± 0.16)	70.2 (± 3.30)	0.10 (± 0.12)	52.3 (± 2.04)
	C3	5.77 (± 0.37)	101.9 (± 5.04)	0.22 (± 0.44)	75.8 (± 2.86)
	C4	5.78 (± 0.61)	86.4 (± 1.20)	0.18 (± 0.67)	64.3 (± 1.54)
Quarters	D1	5.81 (± 1.07)	96.7 (± 0.78)	0.13 (± 0.05)	72.0 (± 1.09)
	D2	5.82 (± 0.98)	79.6 (± 0.19)	0.14 (± 0.04)	59.3 (± 0.96)
	D3	5.81 (± 0.95)	76.8 (± 0.12)	0.10 (± 0.08)	57.2 (± 0.18)
	D4	5.82 (± 0.11)	87.6 (± 0.39)	0.20 (± 0.02)	65.2 (± 0.21)

4.3.2 Water Hardness

The hardness of water indicates the ability of water to lather with soap. The result showed that, there were little variations in the different hardness measured (Table 9). Well A4 had the highest level of total hardness from the Old Town suburb whiles in the New Town suburb, B1 had the highest level. In addition, C3 had the highest total hardness in the Community 6 suburb. At Quarters, well D4 had the highest total hardness. However, these varying degree of hardness

shown within the wells in same suburb and different suburbs were not statistically significant (*p>0.05)* [Appendix 4].

Table 9: Hardness levels in the different well waters from indicated location

Suburb	**Well I.D**	**Mean ± Standard Deviation of**		
		Ca^{2+} Hardness (mg/l)	**Mg^{2+} Hardness (mg/l)**	**Total Hardness (mg/l)**
Old Town	A1	16 (± 1.25)	5.04(± 0.05)	21.04 (± 1.67)
	A2	15 (± 1.86)	3.36 (± 0.35)	18.36 (± 1.98)
	A3	14 (± 1.09)	6.72 (± 0.76)	20.72 (± 1.54)
	A4	15(±1.64)	5.80 (± 0.55)	20.80(± 1.24)
New Town	B1	30 (± 2.10)	6.72(± 0.12)	36.72 (± 1.55)
	B2	15 (± 0.96)	4.20(± 0.50)	19.20 (± 1.32)
	B3	12 (± 1.00)	5.04 (± 0.88)	17.04 (± 0.99)
	B4	19(±1.23)	4.04 (± 0.55)	23.04(± 1.37)
Community 6	C1	12(±2.00)	4.20(± 0.30)	16.20 (± 1.20)
	C2	14(± 1.78)	3.36(± 0.53)	17.36 (± 0.92)
	C3	14(± 1.50)	4.20(± 0.88)	18.20 (± 1.20)
	C4	12(±1.55)	2.80(± 0.49)	14.80(± 1.07)
Quarters	D1	19(±1.89)	3.30(± 0.23)	22.30 (± 1.70)
	D2	13(± 1.46)	3.72(± 0.45)	16.72 (± 1.32)
	D3	11(± 1.21)	5.04(± 0.67)	16.04(± 1.75)
	D4	16(±1.05)	4.72(± 0.83)	20.72(± 2.00)

4.3.3 Anion Levels of the Well Water

The levels of anion determined were in minute quantities. They include fluoride, nitrate and sulphate. Differences however existed for anion levels recorded in the water within the same suburb as well as from different suburbs. However, these differences were not statistically significant ($p>0.05$) [Appendix 5].

Table 10: Anion levels in sampled well water

Suburb	**Well I.D**	**Mean ± Standard Deviation of**		
		Fluoride (mg/l)	**Nitrate (mg/l)**	**Sulphate (mg/l)**
Old Town	A1	0.40 (± 0.01)	0.09(± 0.01)	32 (± 1.54)
	A2	0.10(± 0.02)	0.08 (± 0.01)	30 (± 1.29)
	A3	0.55(± 0.15)	0.08 (± 0.02)	28(± 1.60)
	A4	0.25(± 0.02)	0.09 (± 0.20)	24 (± 1.10)
New Town	B1	0.60(± 0.03)	0.10 (± 0.01)	38 (± 1.76)
	B2	0.40(± 0.01)	0.90 (± 0.02)	32(± 0.94)
	B3	0.45(± 0.02)	0.12 (± 0.02)	29(± 1.20)
	B4	0.50(± 0.01)	0.08 (± 0.01)	30 (± 1.40)
Community 6	C1	0.60(± 0.01)	0.12 (± 0.03)	12 (± 1.09)
	C2	0.05(± 0.01)	0.06 (± 0.01)	24 (±0.09)
	C3	0.65(± 0.02)	0.12 (± 0.02)	30 (± 1.54)
	C4	0.30(± 0.01)	0.08 (± 0.01)	14 (± 1.79)
Quarters	D1	0.10(± 0.01)	0.11(± 0.03)	12 (± 1.89)
	D2	0.05(± 0.02)	0.09(± 0.01)	14 (± 1.24)
	D3	0.45(± 0.03)	0.08 (± 0.02)	26 (± 1.55)
	D4	0.30(± 0.04)	0.10 (± 0.02)	32 (± 1.92)

CHAPTER FIVE

5.0 DISCUSSION

5.1 Discussion

The quality of well water has become a major concern to many, because most people depend on this source of water for their livelihood. In this study, all the wells sampled did not meet the WHO and EPA total and faecal coliform standards of zero per 100ml. However, all the physiochemical parameters measured were within the WHO permissible limits.

5.1.1 Bacteriological Indicators

Microbial indicators were present in all the well waters sampled. In this study, there were slight variations in total coliform counts between wells in the Old Town suburb. The difference in the total coliform counts between wells was significant ($p < 0.05$). Well A3 from Old Town had the highest total coliform while A4 had the lowest, which may be to due to the fact that, A3 was about 15cm above the ground surface and not covered so could be contaminated with plants and other organic materials from the environment. A4 was 0.9m above the ground surface. According to Obiri Danso *et al*., (2009), the upper part of wells should be between 1-2m above the ground surface to prevent contamination.

Well B3 found in the New Town showed the lowest total coliform counts while B1 showed the highest counts. This might be attributed to the fact that, B3 had a very tight and well-fitted lid to help prevent contamination from the environment (Plate 2). In addition, it was 0.7m above the ground surface while B1 was about 0.5m and not covered.

Variations were observed in total coliform counts in wells sampled from Community 6. However, these differences were not significant ($p>0.05$). Well C2 had the highest coliform counts while C4 showed the lowest counts, because C2 though covered, was not well fitted to prevent contamination from the environment.

Wells in the Community 6 showed little variations which were statistically not significant ($p>0.05$). This could be attributed to the reason that, Community 6 is a newly developing area, and the wells were in good conditions, which might influence positively on the water quality. Most of the wells were constructed with concrete rings instead of cementing (Obiri Danso, *et al*., 2009) to appreciable standards. In addition, all the wells in Community 6 and Quarters sampled were tightly covered and mostly under lock. Furthermore, members in the various household found in these two suburbs could be categorised into middle to upper income levels with middle to higher level educational background which might have impacted positively on their well's conditions, hence, the low values for the total coliform counts recorded (1×10^1-1×10^2 MPN/100ml). Since Community 6 and the Quarters were peri-urban, the coliform counts were low, similar to a study done on the peri-urban and rural wells in Sudan by Musa, *et al*., (1999), showed that, coliform bacteria counts were less in peri-urban wells compared to rural wells.

Well water within the Old town did not show significant difference ($p>0.05$) in the faecal coliform counts. Well A1 recorded the highest faecal coliform counts while A2 had the lowest. This could be attributed to the fact that, A1 was not covered and could easily be contaminated by animals and birds that moved around the well. In addition, only the upper part was cemented to about 3m, which meant that faecal matter could filtrate into the well water depending on the groundwater flow direction.

There were minimal faecal coliform counts in well A3 although it was about 15m away from a KVIP and not covered. This contrast a study by Dzwairo, *et al*., (2006) in Marondera district, Zimbabwe, which indicated that pit latrines microbiologically influenced groundwater up to 25m lateral distance.

The faecal coliform counts in A3 well, however, could be attributed to grazing animals and birds that moved around the Well. This confirms the report by Obiri Danso, *et al*., (2009), in the Kumasi Metropolis, Ghana, which showed that animals that were reared by free-range system introduced faecal matter into uncovered or unprotected wells. In addition, the wells found in the Kumasi Metropolis had defective lining as they were fissured and showed higher levels of total coliform (1×10^6- 1×10^7 MPN/100ml) and faecal coliform (1×10^4 MPN/100ml, contrary to this study which showed lower levels of total coliform (1×10^0- $\times10^3$MPN/100ml), faecal coliform (1×10^0-$\times10^2$ MPN/100ml) and *E. coli* count (1×10^0-1×10^1 MPN/10ml).

Pritchard, *et al*., (2007) who assessed ground water quality in shallow wells within the southern district of Malawi showed, that 80% of the samples from covered wells failed to meet the WHO guidelines and Malawi Bureau of Standards of zero total and faecal coliform counts, indicating gross contamination and the probability of pathogens being present. Similar results were obtained in the present study since all samples except Well B3 failed to meet the WHO standard.

In well B3, no faecal coliform were detected (Table 6). This could be attributed to the fact that, there was no pollution source close to the well and the nature of the soil, could filtrate the leachate before reaching the ground water whenever it rained. Similar work done by Conboy, *et al*., (1999), in Ontario, Canada on the natural protection of ground water against bacteria of

faecal origin, showed that the presence of sandy soil might offer some protection to the ground water resource. Well B3 had a depth of 11m, which could help in filtration of groundwater whenever it rained. This contrasts the findings of Obiri- Danso, *et al*., (2009) on shallow wells of 1.2- 4.3m depth, which showed higher faecal coliform counts (1×10^4MPN/100ml).

The presence of *E. coli* in drinking water denotes that the water has been contaminated by faecal matter and therefore presents a potential health risk to households that use them untreated (Nkansah, *et al*., 2010).

E. coli counts in the water from the various suburbs were not significant ($p>0.05$).That is, there was minimal detection of *E. coli* in the water. The low microbial counts recorded could be attributed to the fact that most of the wells were further away from pollution sources.

Nkansah, *et al*., (2010) recorded a coliform and *E. coli* counts below the MDL of 20MPN/ 100ml in the Kumasi Metropolis, similar to this study with minimal detection range of 1×10^0-1×10^1MPN/100ml

The minimal detection of *E.coli* counts might be attributed to the fact that the study was done in the dry season. Morgan, (1990) stated that the aquifer is 'topped up' more rapidly after periods of rainfall and both vertical and horizontal migration of water are accelerated and that, more bacteria are held in the water which are carried through greater distances.

5.1.2 Physiochemical characteristics

The physical quality of the water from the various wells were all below the WHO and EPA standards. There were however, slight differences in the levels of the physical parameters assessed in the well from same suburb as well as in Wells from different suburbs.

Statistically, pH variations showed significant difference ($p<0.05$) [Appendix 3]. The pH values were all below the WHO standards of 6.5-8.5. It ranged between 5.5-5.8 indicating that the water samples were acidic, soft and corrosive. The low pH range might be due to the materials used in the construction of the wells and the soil type. The soil might have low levels of dissolved CO_3^{2-} and HCO_3^-, which lowered the pH of groundwater.

Similar work done by Akoto and Adiyiah, (2007) reported pH range of 5.47- 7.54 which was within the WHO permissible limits.

Electrical conductivity, Turbidity and TDS were all below the WHO standards of 300µS/cm, 5NTU and 500mg/l respectively.

Conductivity values ranged between 85.4µS/cm and 103.4µS/cm. Low Conductivity values indicated that the groundwater might have low concentration of dissolved ions. Turbidity values ranged between 0.10-0.24 NTU and that of TDS were 57.2 -76.9mg/L.

Similar work done by Akoto and Adiyiah, (2007), reported low conductivity values ranging from 53-253µS/cm. However, higher values were recorded for Turbidity greater than the WHO permissible limit of 5 NTU.

The low levels of Turbidity and TDS in this study could be attributed to the fact that human activities including logging, agriculture, mining and road construction, which contributed to periodic pulse or chronic levels of suspended sediment in water, may not have affected the wells sampled.

Water with Total Hardness over 180mg/L could be described as very hard according to the WHO guidelines for drinking water. Total Hardness was between 14.80-36.72mg/L, which was below

the WHO permissible limit. Similar work done by Nkansah, *et al*., (2010) in the Kumasi Metropolis showed that Total Hardness ranged from 8.0 to 103 mg/L. In addition, samples found in the Kumasi Metropolis had the Total hardness, Conductivity and TDS all below the WHO permissible limits.

5.1.3 Anion levels

The anion levels determined were all below the WHO standards. There were differences in the anions measured within the same suburb as well as from different suburb, which were not statistically significant ($p > 0.05$) [Appendix 5].

The low nitrate levels detected ranged from 0.06-0.09mg/L, which was well below the WHO standards of 45mg/L. The average nitrate levels detected in the New Town showed the highest while Old Town showed the lowest. The low values could be attributed to the absence of manure spill, fertilizer application, animal feedlots, municipal wastewater, sludge and septic tank systems, which are the main contributors to nitrate concentration in water.

High nitrate levels in water could cause methemoglobinemia or blue baby syndrome, a condition found especially in infants less than six months and pregnant women (Nkansah, *et al*., 2010). This results in a reduced oxygen supply to vital tissues such as the brain. Severe methemoglobinemia can result in death because of the brain damage.

Low values for nitrate, fluoride and sulphate ranging from 0.09-0.99mg/L, 0.32-1.03mg/L and 3.33-8.2mg/L respectively have been reported in a study by Akoto and Adiyiah, (2007) in the Brong Ahafo Region of Ghana.

Fluorides levels were also below the WHO and EPA standards of 1.5mg/L, it ranged from 0.10 - 0.65 mg/L. New Town showed the highest average Fluoride level while Quarters showed the lowest. This might be due to the soil type found in these areas. Fluorides may be discharged as a by-product from fertilizer. Optimal levels of fluoride can have beneficial effects on children dental health making teeth more resistant to long life tooth decay. However, excessive fluorides consumption can cause mottle enamel, also known as fluorosis. Fluorosis is an aesthetic problem without health effect. Drinking fluoridated water or applying a fluoride solution to teeth helps prevent fluorosis (Hole, 1999). Very high fluoride exposures can cause crippling skeletal fluorosis.

The sulphate levels ranged from 12 to 38mg/L, well below the WHO and EPA standards of 250mg/l. New Town recorded the highest sulphate level while Community 6 recorded the lowest value. The sulphate levels might be due to low levels of sulphate minerals found in the soil type of the area, which might include magnesium sulphate, sodium sulphate and calcium sulphate, which occur naturally in soil and in rock formation. Water with elevated levels of sulphate can cause diarrhoea and dehydration. Infants are often more sensitive to sulphate than adults. Since the levels were below the WHO permissible limits, the water could be used domestically.

5.2 Conclusion

In this study, except for Well B3, the microbial quality of the wells was found to be above the WHO permissible standard for drinking water of zero total and faecal coliform counts. Among the four suburbs, wells in the Community 6 showed relatively good microbial quality whiles those from the Old Town had higher counts.

The physiochemical parameters which included pH, Conductivity, TDS, Total hardness, Turbidity were found to be acceptable and below the WHO standards. Nitrate, fluoride and sulphate levels were all found below the WHO guidelines for drinking water.

Pollution sources such as closeness of well to KVIPs, septic systems, refuse dump, cemetery market etc which might contribute to the microbial quality of the water did not have much influence on the water quality in this study.

The quality of water from the hand-dug wells sampled in the Akim Oda Township, therefore could not be used as drinking water; however, it could be used for other domestic purposes.

5.3 Recommendation

Since contamination of water after collection, transportation and storage are increasingly becoming public health issue, it may require treatment such as boiling or treatment with hypochlorite solution since that can kill most pathogens before drinking.

Contamination could also come from the receptacles and ropes that were used since most wells had various receptacles from different household with various degree of hygiene. It is recommended that one receptacle be used on every well and not left in the soggy water around the wells. Windlass should be mounted on each well with the receptacles to improve their hygienic conditions.

Wells should be constructed with concrete rings instead of cementing because cementing could develop fissures easily. Wells should be sited at higher elevation to prevent runoffs from entering

them. Domestic and grazing animals should be prevented from the wells by constructing fence around them.

Wells should be raised at least 1m above the ground surface and tightly covered to prevent runoffs, and other contaminates from contaminating the water.

It is recommended that further work be conducted to assess the seasonal variation in the water quality and the geology of the area to ascertain the groundwater direction.

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APPENDICES

Appendix 1A: Anova between well waters from suburb A

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Total coliforms	Between Groups	4.927	3	1.642	6.528	.003
	Within Groups	5.031	20	.252		
	Total	9.958	23			
Faecal coliforms	Between Groups	.937	3	.312	3.134	.048
	Within Groups	1.992	20	.100		
	Total	2.929	23			
E.coli	Between Groups	.612	3	.204	2.201	.119
	Within Groups	1.853	20	.093		
	Total	2.465	23			

Appendix 1B: Anova between well waters from suburb B

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Total coliforms	Between Groups	19.324	3	6.441	9.963	.000
	Within Groups	12.930	20	.646		
	Total	32.254	23			
Faecal coliforms	Between Groups	9.877	3	3.292	9.058	.001
	Within Groups	7.269	20	.363		
	Total	17.146	23			
E.coli	Between Groups	5.911	3	1.970	8.342	.001
	Within Groups	4.724	20	.236		
	Total	10.634	23			

Appendix 1C: Anova between well waters from suburb C

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Total coliforms	Between Groups	3.602	3	1.201	4.421	.015
	Within Groups	5.431	20	.272		
	Total	9.033	23			
Faecal coliforms	Between Groups	2.487	3	.829	6.808	.002
	Within Groups	2.435	20	.122		
	Total	4.922	23			
E.coli	Between Groups	1.583	3	.528	7.261	.002
	Within Groups	1.454	20	.073		
	Total	3.037	23			

Appendix 1D: Anova between well waters from suburb D

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Total coliforms	Between Groups	.224	3	.075	.158	.923
	Within Groups	9.484	20	.474		
	Total	9.708	23			
Faecal coliforms	Between Groups	.205	3	.068	.460	.713
	Within Groups	2.975	20	.149		
	Total	3.180	23			
E.coli	Between Groups	.382	3	.127	1.401	.272
	Within Groups	1.819	20	.091		
	Total	2.202	23			

Appendix 2: Anova between well waters from different suburbs

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Total coliforms	Between Groups	9.150	3	3.050	4.305	.010
	Within Groups	31.172	44	.708		
	Total	40.322	47			
Faecal coliforms	Between Groups	4.859	3	1.620	4.957	.005
	Within Groups	14.375	44	.327		
	Total	19.234	47			
E.coli	Between Groups	2.741	3	.914	4.373	.009
	Within Groups	9.193	44	.209		
	Total	11.933	47			

Appendix 3

ANOVA TABLE FOR PHYSICAL PARAMETERS

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.186	3	.062	19.818	.000
	Within Groups	.038	12	.003		
	Total	.223	15			
Conductivity	Between Groups	709.485	3	236.495	3.084	.068
	Within Groups	920.355	12	76.696		
	Total	1629.840	15			
Turbidity	Between Groups	.008	3	.003	1.054	.405
	Within Groups	.029	12	.002		
	Total	.036	15			
Total Dissolved solids	Between Groups	391.635	3	130.545	3.089	.068
	Within Groups	507.075	12	42.256		
	Total	898.710	15			

Appendix 4

ANOVA FOR HARDNESS IN WATER

		Sum of Squares	df	Mean Square	F	Sig.
Calcium Hardness	Between Groups	77.188	3	25.729	1.350	.305
	Within Groups	228.750	12	19.063		
	Total	305.938	15			
Magnesium Hardness	Between Groups	6.458	3	2.153	1.842	.193
	Within Groups	14.027	12	1.169		
	Total	20.485	15			
Total Hardness	Between Groups	113.588	3	37.863	1.659	.228
	Within Groups	273.926	12	22.827		
	Total	387.514	15			

Appendix 5

ANOVA FOR NUTRIENT LEVELS IN WATERS

		Sum of Squares	df	Mean Square	F	Sig.
Fluoride	Between Groups	.149	3	.050	1.265	.330
	Within Groups	.472	12	.039		
	Total	.621	15			
Nitrate	Between Groups	.130	3	.043	1.078	.395
	Within Groups	.484	12	.040		
	Total	.615	15			
Sulphate	Between Groups	356.750	3	118.917	2.276	.132
	Within Groups	627.000	12	52.250		
	Total	983.750	15			

Appendix 6

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

QUESTIONNIRE, ADMINSTERED BY PHILIP VICTOR MINTAH, MSC. ENVIRONMENTAL SCIENCE

THIS QUESTIONNAIRE IS INTENDED TO SOLICIT INFORMATION ON THE HAND DUG WELLS THE RESPONDANT USES. IT MUST BE NOTED THAT THIS IS PURELY FOR ACADEMIC PURPOSES AND THE INFORMATION TO BE PROVIDED WOULD BE KEPT IN ALL CONFIDENCE.

Characteristics of respondent

1. Age group 18-25[ ] 26-35[ ] 35-45[ ] above 45[ ]

2. Position in family mother [ ] father [ ] daughter [ ] son [ ] other [ ]

3. Number of people in household
   Above 50 ……
   Less than 1 yr…….
   4yrs-10yrs ……
   11yrs-49yrs …….
   Total …….

4. Type of home : Compound house [ ] single family [ ] hostel [ ]

Water quality

5. Where do you get your water? Pipe and well [ ] Pipe [ ] well [ ] others [ ]

6. How was it built? Private [ ] Company [ ]

7. Do you treat with chemicals? YES [ ] NO [ ]

8. How often is it treated? Only once[ ] once a month [ ] once a year [ ] never[ ] Other [ ]

9. Does it have a taste? YES [ ] NO [ ]
10. Does it have odour or smell YES [ ] NO [ ]
11. Does have colour [YES] [NO]

12. What do you use the water for?
    a) Bathing
    b) Cooking
    c) Drinking
    d) Washing

13. What do you do before you drink it?
    a) Boil
    b) Filter
    c) Refrigerate
    d) Leave it out in the sun
    e) Nothing

    14) What is your reason why you do the above thing(s) to the water before you drink it
    a) To give taste [ ]
    b) To kill the germs [ ]

c) To take away some impurities [ ]

d) It's my general practice [ ]

e) No reason [ ]

f) Others [ ]

14. Do you think your water is safe for drinking? YES [ ] NO [ ]

15. Do you have toilet facility in your house YES [ ] NO [ ]

16. If yes, which type WC [ ] Pit latrine [ ] bucket latrine [ ]

17. Does your water lather with soap? YES [ ] NO [ ]

18. Closeness of KVIP/ soak away/ reference to the water source

- Distance…….

Location…….

Observations and other comments