KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

Assessment of Hand Dug Wells Water Quality at Atebubu in the Atebubu-Amantin District of Brong-Ahafo Region, Ghana

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In

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By

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CERTIFICATION

I hereby declare that this thesis is my own work towards the Master of Science (MSc) degree in Environmental Science 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 any other degree of the University, except where due acknowledgement has been made in the text.

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DEDICATION

I solemnly and humbly dedicate this piece to the only owner of my life our Lord and Saviour Jesus Christ for His protection, guidance and gift of life through this study period and forever.

ABSTRACT

Access to good quality drinking water is a challenge to the people in Atebubu who have for years depended on water from hand dug wells as the main source of drinking water. Unfortunately, water from this source is not treated before consumption. This has led to high incidence of water borne infections in the area. This study examined sixty water samples from ten hand dug wells in the area for their quality for consumption. The results of the study indicated ranges for the various parameters as follows: pH, 5.8 – 9.8; turbidity, 1.4 – 9.9 NTU; conductivity, 27- 398 µS/cm; colour, 4.0 - 105Hz; calcium, 4.0 – 58.4 mg/L; magnesium, 0.4 – 37.9 mg/L, chloride, 20 - 100 mg/L; fluoride, 0.05 – 2.2 mg/L, nitrate, 0.2 – 4.5 mg/l; nitrite, 0 – 0.2 mg/L, sulphate, 0 - 12 mg/L; phosphate, 0.2 – 2.6 mg/L; ammonia, < 0 mg/L; TDS, 11.0 - 194 mg/L; total hardness, 28.0 - 146 mg/L; Total coliform, $4.3 \times 10^2 – 9.1 \times 10^5$ MPN/100ml; Faecal coliform, $2.4 \times 10^1 – 4.02 \times 10^4$ MPN/100mL; *Escherichia coli*, 9.0×10^1- 2.0×10^3 MPN/100mL; *Salmonella*, $3.0 \times 10^0 – 1.12 \times 10^2$ MPN/100mL and *Enterococci*, $5.0 \times 10^0 – 1.46 \times 10^3$ CFU/100mL. The concentrations of most of the physico - chemical parameters in the water samples from Atebubu were below the permissible limits of the WHO drinking water quality guidelines except colour. All the bacteriological parameters far exceeded WHO guideline values for drinking water indicating unsuitability.

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ABBREVIATIONS

DHMT:	District Health Management Team
NTU:	Nephelometric Turbidity Unit
CFU:	Colony Forming Unit
TDS:	Total Dissolved Solids
TH:	Total Hardness
EDTA:	Ethylene Diamine Tetra Acetic Acid
APHA:	American Public Health Association
AWWA:	American Water Works Association
WHO:	World Health Organisaton
WVI:	World Vision International
WATSAN:	Water and Sanitation
VIP:	Ventilated Improved Pit
KVIP:	Kumasi Ventilated Improved Pit
MPN:	Most Probable Number
TV:	Titre Value
QC:	Quality Control
KVIP :	Kumasi Ventilated Improved Pit

CHAPTER ONE

1. INTRODUCTION

Accessibility and availability of fresh clean water is key to sustainable development in food production and poverty reduction. However, safe drinking water remains inaccessible to about 1.1 billion people in the world and the hourly toll from biological contamination of drinking water is 400 deaths of children below age five (Gadgil, 1998). Human water needs are usually met by water obtained from rainfall, streams, wells, boreholes and pipe borne water depending on the locality and the technology available.

Most organized societies depend on pipe borne water to meet their requirement but it is often taken for granted that, such water supplies are potable. Significant deterioration in microbiological quality of water between the source and the point of use in homes have been reported (Chant *et al*., 2007). According to WHO (1998), there were estimated 4 billion cases of diarrhoea and 2.2 million cases of death annually and consumption of unsafe drinking water has been implicated as the major cause of this occurrence.

According to Ogedengbe (2004), ground water constitutes the largest source of dug-well water which is located below the soil surface through which precipitation infiltrates and percolates into the underground aquifers due to gravity and it is the major source of drinking water for residents who do not have access to pipe borne water.

According to Musa *et al*. (1999), the drinking quality of dug well water is largely dependent on the concentration of biological, chemical and physical contaminants. Chemicals pollute water supply through industrial process and agrochemical applications while physical and biological contaminants result from erosion and these sources contribute to destruction of drinking water quality and consequently leading to

water borne diseases such as typhoid, cholera, diarrhoea and dysentery which are potentially communicable.

According to Dufuor *et al*. (2003), a significant proportion of water-borne illnesses are likely to go undetected by the communicable diseases surveillance reporting systems and the symptoms of gastrointestinal illness (nausea, diarrhea, vomiting and abdominal pain) are usually mild and generally last a few days to a week and only a small percentage of those affected will visit a health facility.

In Ghana, the supply of pipe borne water is inadequate in most communities. This inadequacy is both in quantity and quality of the public water supply and only about 10.3 million people (approx. 51% of the population) are reported to have access to improved water supplies (All Africa.Com). The most reliable source of drinking water is bottled water which may be of good bacteriological quality but it is expensive and thus only within the means of the affluent in the society (Obiri - Danso *et al*., 2003). Hence groundwater has become the major source of drinking water and there is the need to assess its quality since it has direct effects on the health of individuals.

A research carried out by Anim *et al.* (2010) on coliform status of waterbodies from two districts in Ghana, (Kwaebibirem and West Akim) revealed that water samples collected from wells in the wet season had comparatively more coliforms than similar water samples from the same wells in the dry season and total coliforms detected ranged from 0 - 680 cfu/100 ml.

Obiri – Danso *et al.* (2008) reported geometric mean for total coliforms ranged between 3.07×10^6 and 1.68×10^7 MPN 100 ml^{-1} in well water samples in some peri- urban communities in Kumasi.

Total coliform bacteria of well water varying from 30 - 78 MPN 100 ml^{-1} was observed by Quist (1999) in consumer homes within Kumasi metropolis. A project undertaken by Adetunde and Glover (2010), on bacteriological quality of well water used by students of the University For Development Studies (UDS), Navrongo campus indicated that, water from hand dug wells among other sources, were highly contaminated with total coliforms of mean range from 14 to 20 MPN/ 100ml.

Shittu *et al.* (2008), observed that well water close to refuse damp sites and septic systems contained more microbial counts of 1600 – 1800 MPN/100 ml than those wells away from septics and refuse sites.

Apart from anthropogenic sources of contamination, there is high possibility for high natural levels of metals and other chemicals that can be harmful to human health. The water analysis for physical and chemical parameters including trace element contents are vital for public health studies. This research will form part of pollution studies in the environment.

1.1 Problem statement

Access and affordability to potable drinking water is a major concern of the people in Atebubu - Amantin District. Numerous efforts were made by the District Assembly and other philanthropists in providing potable water but all have proved futile due to lack of electricity at the water treatment source. Running of diesel generators to pump the water became highly expensive leading to total failure of the system in the area.

To alleviate this problem, boreholes were introduced in the area by the Atebubu-Amantin District Assembly but could not fully meet the increasing demand of water for

the people. The situation became escalated as some of the borehole pumps broke down and became malfunctional.

Against this background, individuals began to provide hand dug wells at homes to mitigate the problem of water scarcity. These initiatives have resulted in hand dug wells in almost all homes in Atebubu leading to well water as the major source of water for domestic uses in the area.

Unfortunately, some of these wells were constructed close to pollution sources such as septic tanks, dumpsites, latrines. According to Craun (1985), septic tanks represent a significant threat to potability of groundwater, but also to human health and many cases of groundwater contamination have been found in areas of high septic density.

Most of the wells have no casing caps above the ground level and even some of those with casing caps were made of rusted aluminium sheet, old lorry tyres and wood. Domestic animals defecate around these wells and even drink from buckets used to fetch water from the well. Fetching buckets are mainly plastics and often not kept clean as they are normally left on the ground together with the fetching rope.

Animals roam the community in search of food and water and in the process indiscriminately contaminate the water with their feaces since there are no enclosures to restrict them from having access to them.

Furthermore, most of the wells are shallow and this prevents effective filtration and adsorption of bacteria and other contaminants by the soil layers.

Unfortunately, water fetched from the wells are not subjected to treatment before being used for domestic purpose especially for drinking. This poses significant health threats to its consumers especially water borne infections.

Data available at the District Health Directorate revealed that, there is high incidence of water borne diseases in the area for the past years of which many have died with children being the most vulnerable. Table1.1 shows the data of some water borne diseases morbidity from 2007 to 2009 provided in the District Health Directorate Annual Performance Report.

Table 1: 1 Water borne diseases morbidity 2007-2009

DISEASE	2007	2008	2009
Diarrhoea	3,970	2,371	4,276
Dysentery	98	102	113
Typhoid	113	79	85
Helminthiasis	2,126	3,363	2,816
Amoebiasis	14	62	8
Guinea Worm	12	1	0

Source: Atebubu district health directorate report (2009)

From table1.1, it is clear that diarrhoea, dysentery, typhoid and helminthiasis are some water borne diseases generally are on the ascendency in the area.

Unfortunately, there is no documentation on hand dug well water quality in Atebubu as no research so far has been conducted into the major source of drinking water (wells) in the district.

1.2 Main objective of research

The study therefore seeks to determine the suitability of well water for consumption in Atebubu.

1.3 Specific Objectives of research

The specific objectives of the research are to:

- Enumerate Total coliform, Feacal coliforms, *Escherichia coli, Salmonella* and *Enterococci* of well water.
- Determine pH, turbidity, colour, conductivity, calcium, magnesium, iron, chloride, fluoride, nitrate and nitrite, sulphate, phosphate, ammonia, total dissolved solids and total hardness content of the well water.
- Determine the safety of the water for drinking by comparing parameters to World Health Organization (WHO) guideline values for drinking water.
- Determine any variation in quality of the water between the wet and dry seasons.

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CHAPTER TWO

2. LITERATURE REVIEW

2.1 Bacteriological Pollutants

2.1.1 Total coliform bacteria

Total coliform bacteria include a wide range of aerobic and facultatively anaerobic, Gram-negative, non-spore-forming bacilli capable of growing in the presence of relatively high concentrations of bile salts with the fermentation of lactose and gas by-products when incubated at 35^0C for 48 hours. The total coliform group of bacteria includes species such as *Enterobacter, Klebsiella*, *Citrobacter* and *Escherichia.* Some of these bacteria are excreted in the faeces of humans and animals, but many are heterotrophic and able to multiply in water and soil environments. Total Coliform do not necessarily indicate recent water contamination by fecal waste, however the presence or absence of these bacteria in treated water is often used to determine whether water disinfection is working properly APHA/AWWA/WEF (2003).

The World Health Organisation guideline stipulated a coliform count of zero (0) per 100 ml. Total Coliform organisms per 100 ml is an indication of some degree of contamination (Health Canada, 2007).

2.1.2 Faecal coliform

Feacal coliforms exist in the intestine of warm blooded animals and humans and are good indicators of contamination from humans or animal wastes as they indicate greater risk of exposure to pathogenic organisms than total coliforms. Excessive amount of feacal bacteria in sewage and urban run-off have been known to indicate risk of

pathogens induced illnesses in humans (Fleisher *et al.,* 1998). Feacal coliforms are primarily used to indicate the presence of bacteria pathogens such as *Salmonella spp, Shigella spp, Vibrio cholera, Campylobacter jejuni, Campylobacter coli, Yersinia enterocolitica* and pathogenic *E. coli.* and may cause diseases such as gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever (Addo *et al.*, 2009).

McQuillan (2004), reported groundwater contamination by septic tanks with micro organisms and that feacal coliforms have been detected in some private domestic wells in areas contaminated by septic tank systems.

The proximity of domestic and grazing animals to water sources have been shown to play a role in the severity of faecal contamination of water sources (Tiedemann *et al.,* 1988).

According to Obiri – Danso *et al.* (2008), many researchers have reported feacal coliform count greater than 10^4 from rivers, ponds and wells in tropical countries. In Ghana, workdone by Nkansah *et al.* (2010), on microbial and physico-chemical quality of water from hand – dug wells in Kumasi metropolis, found out that the hand dug well water was satisfactory as feacal indicator bacteria were below the minimum detection level of 20 MPN/100ml.

A research carried by Adekunle *et al.* (2007) indicated that feacal and total coliform decrease with increasing distance from pollution source irrespective of the season.

Olowe *et al.* (2005), also reported on the unsuitability of hand dug well water with feacal coliform range of 1200 - 1800 CFU/100ml in the Osogbo Metropolis, Nigeria.

Adeyemi *et al.* (2004), reported an Overwhelming high coliform pollution index for hand dug wells near pollution sources in rainy season than in dry season and that people

living about 3m to landfills must not use hand dug wells and boreholes in their houses for domestic purposes due to health threats.

The World Health Organization guideline again stipulates a faecal coliform count of zero (0) per 100 ml. Coliform organisms per 100 ml show some degree of feacal contamination.

2.1.3 Escherichia coli

Escherichia coli is widely distributed in the intestine of humans and warm-blooded animals and is the predominant facultative anaerobe in the bowel and part of the essential intestinal flora that maintains the physiology of the healthy host (Conway, 1995). There are also pathogenic strains of *E. coli* that when ingested, causes gastrointestinal illness in healthy humans. The presence of *E. coli* in food or water is a specific indicator of recent fecal contamination and the possible presence of pathogens and the first choice in monitoring programme for investigation (Toranzos and McFeters, 1997). According to WHO (2004), *E. coli* is present in very high numbers in human and animal faeces.

Mean *E. coli* value of 2.7×10^3 was observed by Wright (1982) in dug well water samples in Sierra – Leone.

2.1.4 Salmonella

Salmonella is a genus of rod-shaped, Gram-negative, non-spore forming, microscopic living creatures (enterobacteria) that pass from the feaces of people or animals to other people or other animals and lives in the intestinal track of humans and other animals,

including birds causing illnesses like typhoid fever, paratyphoid fever, and the food borne illness. It can survive for weeks outside a living body and are found in dried excrement after more than 2.5 years and gives symptoms such as; diarrhea, abdominal cramps, chill, nausea, headache, vomiting and fever within 8 to 72 hours after the contaminated food was eaten. (Ryan and Ray, 2004).

Salmonella infections are due to ingestion of contaminated food. The organism enters through the digestive tract and is ingested in large numbers to cause disease in healthy adults. However, infants and young children are more susceptible to infection which is easily acquired by ingesting a small number of *salmonella*. According to WHO (2003), over 16 million people worldwide are infected with typhoid fever each year, with 500,000 to 600,000 being fatal cases. Food may also become contaminated by the unwashed hands of an infected food handler. Wright (1982), observed mean *salmonella* value of 1.3×10^3 in hand dug well water samples in Sierra Leone whiles 0.08 CFU of *salmonella* in hand dug wells was recorded by Fasunwon (2008) in Ago - Iwoye State, Nigeria

2.1.5 Enterococci

Enterococci are gram positive cocci that often occur in pairs (diplococci) or short chains. *Enterococci* bacteria are also found in the faeces of most humans and many animals. There are two types of *enterococci* associated with normal healthy people which also occasionally cause human disease. They are *Enterococcus faecalis* and *Enterococcus faecium*. The commonest infections caused by enterococci are urinary tract infections and wound infections, infection of the blood stream (bacteraemia),

endocarditis ; heart valve hardening and brain (meningitis) occurring in severely ill patients in hospital. *Enterococci* also frequently colonise open wounds and skin ulcers.

According to Jin *et al.* (2004), *Enterococcus spp.* provide a higher correlation than fecal coliform with many of the human pathogens often found in city sewage.

Obiri-Danso *et al. (*2008) observed levels of *enterococci* to be 8 times higher in wells than in boreholes. Godfrey *et al.* (2006), recorded higher counts of enterococci in wells at greater depth. This is explained by the robustness of the organism and its ability to survive, but not multiply under environmental conditions at depth (Mara, 2003). The degree of pollution varies with depth of well and the closeness to toilet/dumpsite (Omotoyibo, 2007).

2.2 Physico-chemical parameters

2.2.1 pH

pH is the measurement of the acid/base activity in solution; specifically it is the negative common logarithm of the activity/concentration of hydrogen ions;

$pH = -\log[H^+]$

pH is typically monitored for assessments of aquatic ecosystem health, recreational waters, irrigation sources and discharges, live stock, drinking water sources, industrial discharges and storm water run- off.

Lower values in pH are indicative of high acidity caused by the deposition of acid forming substances in precipitation, decomposition of high organic content resulting in humic and fluvic acid, exchange of carbon dioxide with the atmosphere and mineral acids.

High acidic water has the tendency to corrode metal piping and containers or has a bitter or metallic taste and alkaline water results in scale formation in piping systems (Oram *et al.*, 2010). WHO optimum limits of pH levels in drinking water is between 6.5 – 8.5. Nkansah *et al.,* (2010) and Shittu *et al.*, (2008) reported pH levels of 6.3 to 7.7 in dug wells in Kumasi, Ghana and 6.8 to 7.3 in Abeokuta, Nigeria respectively.

2.2.2 Turbidity

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level through sample (APHA/AWWA/WEF, 2003). Turbidity is also a measure of the degree to which the water loses its transparency due to the presence of suspended particulates and may be caused by clays, organic matter, planktons and other tiny inorganic particles U.S. EPA, (2005).

Turbidity itself is not a major health concern but high turbidity interferes with disinfection and makes water unattractive and provides a medium for microbial growth WHO (2004).

Turbidity range of 2.5 to 7.0NTU. was reported by Shittu *et al.* (2008) in dug well water samples in Abeokuta, Nigeria whilst the World Health Organization (WHO) guideline value of turbidity for drinking water is 0 - 5NTU.

2.2.3 Colour

The term ‘colour’ is used to mean true colour thus is the colour of water from which turbidity has been removed. Apparent colour includes not only colour due to substances in the solutions but also due to suspended matter. Colour is common in surface water

supplies, while it is virtually non-existent in spring water and deep wells. It is desirable that drinking water should be colourless.

A yellow tint water indicates the presence of humic acids referred to as "tannins". A reddish color indicates the presence of precipitated iron. Dark brown to black stains are created by manganese. Excess copper creates blue stains (http://www.statcounter.com).

The source of colour in water includes; organic materials and natural metallic ions (http://www.statcounter.com). Highly coloured water makes it aesthetically displeasing for consumption. WHO guideline value for colour in drinking water is 15 Hz

Boamah *et al.* (2010) reported 10 to 30 Hz as colour ranges for well water samples in three peri – urban communities in Kumasi.

2.2.4 Conductivity

According to Asubiojo *et al*. (1997), conductivity is a measurement of the ability of an aqueous solution to carry an electrical current.

Conductivity is affected by the presence of dissolved inorganic solids, mobility of the ion, oxidation state (valence) and temperature of the water (APHA/AWWA/WEF, 2003; Spellman, 2003). WHO recommended limit in drinking water is 1500µS/cm.

Conductivity measurement is used to determine a number of applications related to water quality such as noting variation or changes in natural water and wastewaters, determining the overall ionic effect in a water source and determining amounts of chemical reagents or treatment chemicals to be added to a water sample.

2.2.5 Calcium

The chemical element Calcium (Ca), atomic number 20, is the fifth element and the third most abundant metal in the earth's crust. This element is essential for the life of plants and animals, for it is present in the animal's skeleton, in tooth, in the egg's shell, in the coral and in many soils.

Calcium is the most abundant metal in the human body. It is the main constituent of bones and teeth and it has key metabolic functions. It is an essential component for the preservation of the human skeleton and teeth. It also assists the functions of nerves and muscles. Lack of calcium is one of the main causes of osteoporosis a disease in which the bones become extremely porous, and are subject to fracture and heal slowly (http://www.lenntech.com/periodic-chart-element.htm). Calcium is found mostly as limestone, gypsum and fluorite. WHO water quality standard for calcium is 200 mg/l. Calcium level observed by Ifayibi (2009), in well water is 53.85 mg/l.

2.2.6 Magnesium

According to Wester (1987) and Saris *et al*. (1996), magnesium is the fourth most abundant mineral in the body and is essential to good health. It helps maintain normal muscle and nerve functions, keeps heart rhythm steady, supports a healthy immune system, keeps bones strong, regulate blood sugar levels, promotes normal blood pressure, and is known to be involved in energy metabolism and protein synthesis. Rubenowitz *et al.* (1996) observed that magnesium in drinking water is an important protective factor for death from acute myocardial infarction among males and that

increase in water magnesium level of 6 mg/litre would decrease ischemic heart disease mortality by approximately 10 percent.

The main sources are rock minerals for example; Dolomite (calcium magnesium carbonate; $CaMg(CO_3)_2$), magnesite (magnesium carbonate; $MgCO_3$) which are washed from rocks and subsequently ends up in water as well as run- off from agricultural fields. WHO guideline value for magnesium in drinking water is 150 mg/l.

Mean magnesium level observed by Ifayibi (2009) in well water samples in Itaogbolu, Nigeria was 23.85 mg/l.

2.2.7 Iron

Iron in water imparts a disagreeable metallic taste. It causes red stains in toilets, plumbing fixtures, tableware and laundry. In humans, iron is an essential component of proteins involved in oxygen transport. It is also essential for the regulation of cell growth and differentiation. A deficiency of iron limits oxygen delivery to cells, resulting in fatigue, poor work performance, and decreased immunity (USDA, 2003). WHO limits for iron in drinking water is 0.1mg/l.

Iron occurs naturally as a mineral from sediment and rocks or from mining, industrial waste and corroding metal. Iron may also be present in drinking-water as a result of the use of iron coagulants or the corrosion of steel and cast iron pipes during water distribution.

2.2.8 Chloride

Chloride is a chemical compound containing chlorine. Most chlorides are salts that are formed either by direct union of chlorine with a metal or by reaction of hydrochloric acid (a water solution of hydrogen chloride) with a metal, a metal oxide, or an inorganic base. Most chloride salts are readily soluble in water, but mercurous chloride (calomel) and silver chloride are insoluble.

The health effects are; it is necessary for protein digestion (pepsin), vitamin B12 and absorption of metallic minerals, helps in regulation of acid – alkaline balance. Increased levels in humans give rise to male infertility, ringing noises in the ear (tinnitus), hypertension, coughing, chest pains, choking, and asthma, and headache, blue discoloration of skin, nausea, vomiting and detectable taste in water (http//www.acu-cell.com/dis-can.html).

Chloride in drinking-water originates from natural sources (sedimentary rocks), sewage, industrial effluents, the use of inorganic fertilizers, landfill leachates, septic tanks effluents, animal feeds, irrigation drainage, urban run-off and saline intrusion (WHO, 2003). WHO guideline for chloride in drinking water is 250 mg/l based on taste consideration.

Adefemi (2009), reported chloride levels of 78.10mg/L to 156.20 mg/L in well water in Itaogbolu, Nigeria.

2.2.9 Fluoride

Fluoride is the anion F^-, the reduced form of fluorine. Fluoride, like other halides, is a monovalent ion (−1 charge). Its compounds often have properties that are distinct relative to other halides. The range of fluorine-containing compounds is considerable as fluorine is capable of forming compounds with all the elements except helium and neon (Greenwood and Earnshaw, 1997).

The health effects of fluoride are; low concentrations provide protection against dental caries, both in children and in adults. Skeletal fluorosis (adverse changes in bone structure) may be observed when drinking water contains 3 to 6 mg/l of fluoride, particularly with high water consumption. Crippling skeletal fluorosis usually develops only where drinking-water contains over 10 mg/l of fluoride. Drinking water containing 0.7 to 1.2 mg/1 natural or added fluoride is beneficial to children during the time they are developing permanent teeth (Nemerow *et al.*, 2009). WHO guideline value for fluoride in drinking water is 1.0 to 1.5 mg/l.

According to WHO (2003), Fluorine exists in the form of fluorides in a number of minerals, such as fluorspar, cryolite and fluorapatite.

Nkansah *et al.* (2010), observed fluoride levels of 0.2 to 0.8 mg/l in dug wells water in Kumasi metropolis, Ghana.

2.2.10 Nitrate and Nitrite

Nitrate and nitrite are compounds that contain a nitrogen atom joined to oxygen atoms, with nitrate (NO_3) containing three oxygen atoms and nitrite (NO_2) containing two.

In nature, nitrates are readily converted to nitrites and vice versa. Nitrogen-fixing bacteria are important in keeping the soil supplied with nitrates. Because of the widespread use of artificial fertilizers containing nitrates, nitrates have contaminated both ground and surface waters in some agricultural areas (Wikipedia encyclopedia).

According to Kempster *et al*. (1997) and WHO (2004), high concentrations of NO_3- and NO_2- may give rise to potential health risks such as methaemoglobinaemia or 'blue-baby-syndrome' particularly in pregnant women and bottle-fed infants respectively. After drinking the water, the nitrate may be converted to nitrite by bacteria in the mouth and when absorbed into the bloodstream, the nitrites combine with haemoglobin to form a blue pigment, methaemoglobin which reduces blood ability to carry oxygen to the individual cells and NO_3 at elevated concentrations is also known to result in cyanosis in infants.

McQuillan (2004), reported that, the sources of ground water nitrate contamination include septic tanks, sewage treatment plants, animal wastes, commercial fertilizers, nitric acid wastes, natural geologic sources, Lightning and radiation create nitrates in the atmosphere, where rainstorms carry them to the ground.

Ifayibi (2009), observed nitrite concentration of 8.01 mg/l in well water.

WHO guideline value in drinking water for nitrate and nitrite are 50 mg/l and 3.0 mg/l respectively.

2.2.11 Sulphate

Sulphate ion is a polyatomic anion with the empirical formula SO_4^{2-} and a molecular mass of 96.06 daltons (96.06 g/mol). It consists of a central sulphur

atom surrounded by four equivalent oxygen atoms in a tetrahedral arrangement. Sulphate forms salts with a variety of elements including barium, calcium, magnesium, potassium and sodium.

Drinking water containing high concentrations of sulphate caused by the leaching of natural deposits of magnesium sulphate or sodium sulphate may be undesirable because of their laxative effects, offensive taste and increase in corrosive properties of water (Corbit, 2004). WHO guideline value for sulphate in drinking water is 250mg/l.

The sources of sulphate into water are; leaching from soils, decaying plant and animal matter which release sulphate into water, human activities such as the combustion of fossil fuels and sour gas processing release sulphur oxides to the atmosphere, some of which is converted to sulphate (http://www.health.gov.sk.ca/environmental-health). Nkansah *et al.* (2010), reported sulphate levels of 3.0 to 37.0 mg/l in dug wells in Kumasi metropolis.

2.2.12 Phosphate

The phosphate ion is a polyatomic ion with the empirical formula (PO_3^{-4}). It consists of one central phosphorus atom surrounded by four oxygen atoms in a tetrahedral arrangement.

Phosphorus is the body's source of phosphate, which helps create and manage energy, synthesize protein, fat and carbohydrates, contract muscles, maintain the body's fluid and electrolyte balance, stimulating hormone production and helping the body utilize the B vitamins, speeds up healing, helps treat bone diseases such as rickets and prevents stunted growth in children. Depletion of phosphorus results in health problems such as:

anxiety, bone problems, fatigue, irregular breathing, irritability, skin sensitivity, stress, teeth weakness, tremors, weight changes, malaise, stiff joints, bone pain, irregular heartbeat twitching, jerking, and convulsions (http://www.vitamins-nutrition.org/mineral/index.html). WHO guideline level in drinking water is 400 mg/l.

Salvato *et al.* (2003) has it that, phosphorus is usually associated with plant remains, animal wastes or fertilizer. Tjandraatmadja *et al.* (2010) stated other potential sources as; cleaning products, cosmetics, medicated shampoos, food products, faeces and urine.

2.2.13 Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) are solids in water that can pass through a filter. TDS is a measure of the amount of material dissolved in water. These materials include; carbonate, bicarbonate, chloride, sulphate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions.

The effects of TDS are; reduction in water clarity, combine with toxic compounds and heavy metals, and lead to an increase in water temperature, high TDS water often has a bad taste and/or high water hardness, and could result in a laxative effects. TDS is used to estimate the quality of drinking water, because it represents the amount of ions in the water.

The source of TDS are; Geology and soils which release ions very easily, urban and fertilizer run- off and decaying organisms. Permissible limits by WHO for TDS in drinking water is 1000 mg/l.

Olobaniyi (2007) reported TDS levels of 21.90 to 300.50 in well water.

2.2.14 Total Hardness

Water hardness is the traditional measure of the capacity of water to react with soap.

According to Spellman (2008), hardness of water represents the amount of dissolved calcium and magnesium in water.

Although hardness is caused by cations, it may also be discussed in terms of carbonate (temporary) and noncarbonate (permanent) hardness. Water with total hardness of 60mg/l are soft, from 60-120mg/l are moderately hard, from 120- 150mg/l are hard and 180^{+} are very hard (http://www.statcounter.com).

The effects of Total Hardness (TH) are; it increases soap consumption, starches laundry, leave a scratchy feeling after bathing, leaves hair hard to manage, scales glasses and dishes, and affects taste and tenderness of many cooked foods. There is evidence that death rates from cardiovascular diseases are inversely correlated with hardness of water and besides, no firm evidence in man that drinking hard water causes any adverse effects on health (WHO, 1984).

The principal natural sources of hardness in water are dissolved polyvalent metallic ions (calcium and magnesium) from sedimentary rocks (limestone and chalk), seepage, and run-off from soils.

Shittu *et al.* (2008) and Adefemi and Awokumi (2009) reported TH levels of 72 to 108mg/l and 130 to 298mg/l respectively in hand dug wells in Abeokuta, Nigeria. Fasunwon *et al.* (2008) observed TH range values of 25 to 61mg/l in dug wells of Ago – Iwoye State, Nigeria. WHO standard for Total hardness in drinking water is 500mg/l.

2.2.15 Ammonia

Ammonia is a compound of nitrogen and hydrogen with the formula NH_3. It is a colourless gas with a characteristic pungent odour. Ammonia is produced in the human body and is commonly found in nature. It is essential in the body as a building block for making proteins and other complex molecules. When ammonia enters the body as a result of breathing, swallowing or skin contact, it reacts with water to produce ammonium hydroxide which is very corrosive and damages cells in the body on contact. Inhaling lower concentrations result in coughing and throat irritation (http//www.statcounter.com). WHO guideline level in drinking water is 1.5mg/l.

In nature, ammonia occurs in soil from bacterial processes. It is also produced when plants, animals and animal wastes decay. Ammonia gets into surface supplies from the runoff in agricultural areas where it is used as fertilizer. It also finds its way to underground aquifers from animal feed lots and is released upon decomposition of proteinaceous matter and can be released into the atmosphere, used directly by microorganisms or converted into nitrite and nitrate (Liu, 1999).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of study area

Atebubu-Amanten District is one of the twenty-two districts in the Brong-Ahafo Region and has Atebubu as its administrative capital. It lies approximately between latitudes 0^o 23^o and longitudes 0^o 30^o W and 1^o 26^o W. The District shares common boundaries with Pru District to the North and south with Ejura-Sekyere dumasi District of the Ashanti Region, to the east with Sene District, west with Kintampo and Nkoranza Districts all in the Brong-Ahafo Region. The district has a total land area of 3990 square kilometers with a population of 84000 projected from the 2010 population census. There are about 196 settlements. The major occupation in the area is farming.

The District is a plain with general elevation of 60 – 300 meters above sea level. The district is therefore not associated with any significant highlands. The District has lot of water bodies, with the river Pru acting as the boarder to the North. River Nyamon, Tanfi and Nyina are some of the other important rivers/streams in the district.

The district lies within the transitional zones between the forest and savanna zones. It experiences sunny condition during most part of the year (November to May). It therefore has two main seasons. The wet season starts from May to October.

With respect to vegetation, the district is part of interior wooded savanna type however due to its transitional nature, it does not totally exhibit typical savanna conditions. It is believed that this transitional zone was forested and that the savanna conditions currently prevailing have been the result of human activities such as extensive tilling, charcoal burning and logging.

The sources of water for domestic use in the district are rivers, streams, boreholes and hand-dug wells. The district was one time endemic in terms of guinea worm infestation in the Region, thus provision of potable water still stands high on the agenda of the District Health Management Team (DHMT) and the District Assembly.

The World Vision International (WVI), who initiated the Water and Sanitation (WATSAN) concept in the district, has been very supportive in the provision of hand-dug wells, boreholes, laundry pads and household Ventilated Improved Pits (VIP) to several communities throughout the district.

Sanitation in the district is not the best with most households without toilet facilities and thus resorts to public toilets which are inadequate and sometimes choked to capacity. There is thus high incidence of water borne diseases.

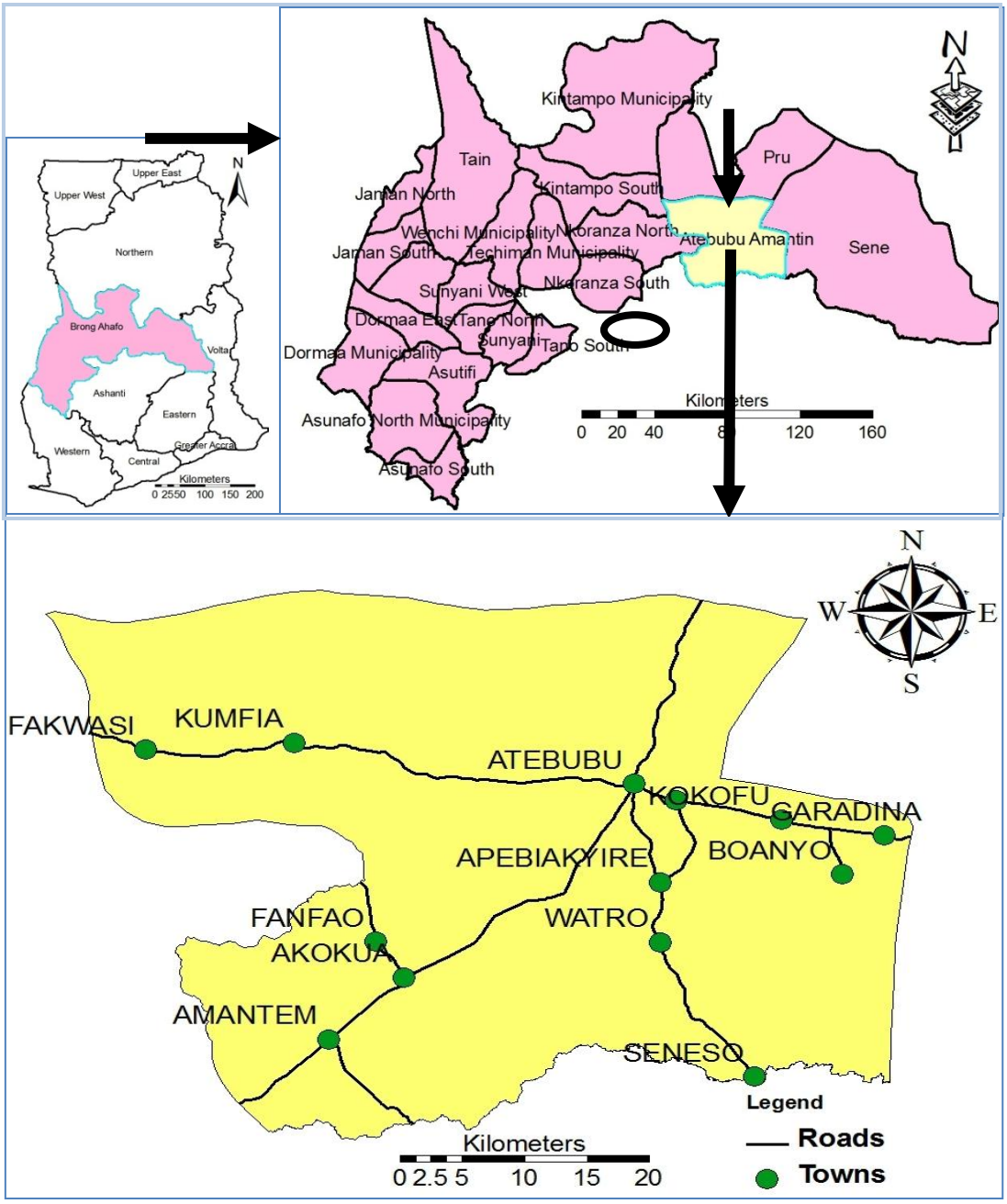


Figure 3. 1: Map of study area

3.2 Sampling sources

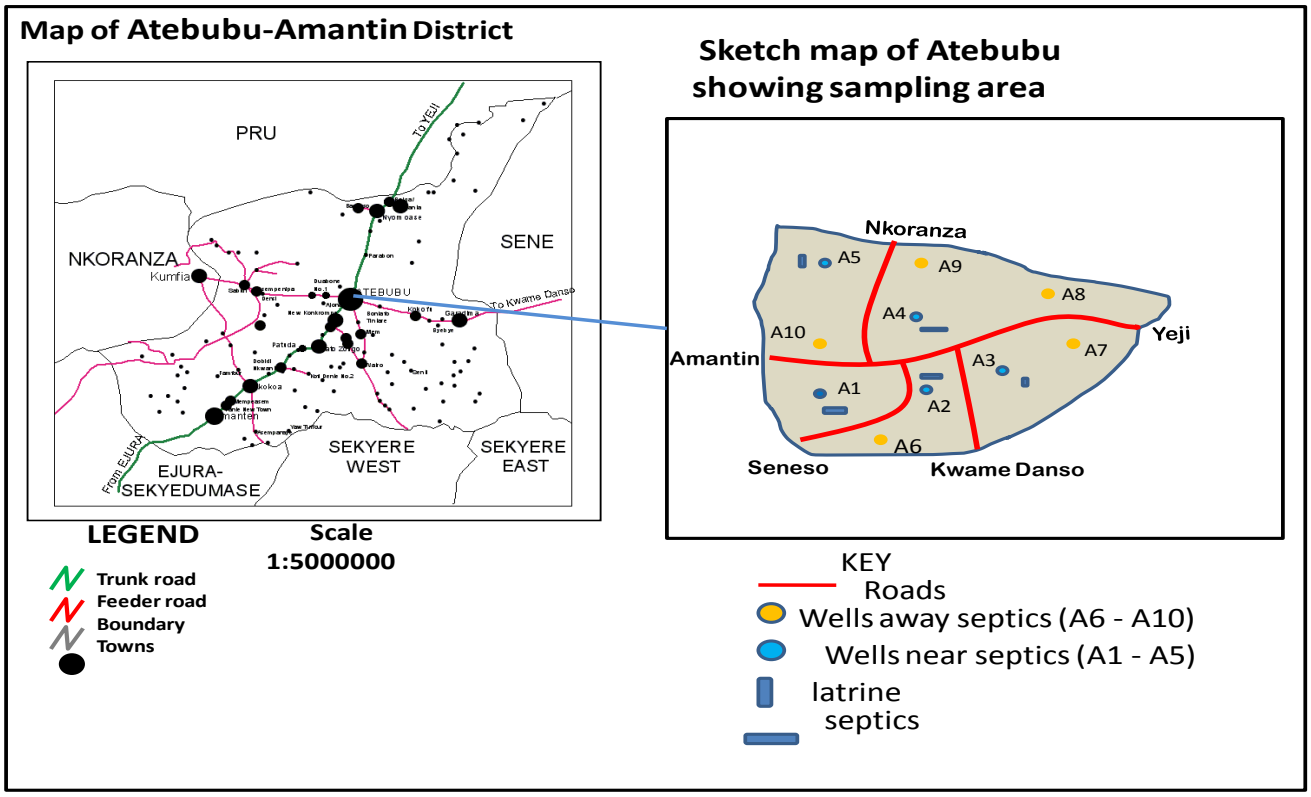


Figure 3. 2: Sketch of sampling points

Well A1

The depth of the well is 3.5m and it is located 9.2m from a latrine on a low lying ground. The fetching bucket is a plastic type. The well has a concrete case and a metal slab but the inside is not lined with concrete. Animals easily have access to the well as they roam in the community.

Fig. 3.2. 1: Picture of Well A1

Well A2

The well is 3m deep and surrounded by two septic tanks. One septic tank is located inside the house 8m from the well and the other about 12m behind the house. The well lies on a lower ground than the two septic tanks. The well is also 15m from an untarred road frequently used by vehicles generating dust within the environ. The well has a concrete case and a wooden slab above the ground level but the inside is not lined with concrete. Being an open area, animals usually feed on the vegetation around the well. During grazing, these animals defaecate around the well and at night, some sleep on the well slab. Fetching bucket is an old plastic type which is not often kept clean and always exposed.

Fig. 3. 2.2: Picture of Well A2

Well A3

This well is 7.8m from a septic tank and 3.5m deep. It has a concrete case above the ground and a metallic slab. It is located under a tree. Being under a tree, roaming animals usually relax and defaecate around it. The fetching bucket is usually exposed and sometimes put on the ground together with the rope.

Fig. 3.2.3: Picture of Well A3

Well A4

The well is 3.6m deep and 17.3m away from a latrine. The well has an old weak concrete case above the ground and an old disjointed wooden slab. It has an old fetching bucket. The well is close to a main street. Animals on roam sometimes defecate around the well.

Fig. 3. 2.4: Picture of Well A4

Well A5

The well is 12.4m from a latrine and 4.3m deep. It has a concrete case above the ground. It is located on a ground tower than the latrine. Animals feaces are sometimes found around the well. The well is not lined inside with concrete.

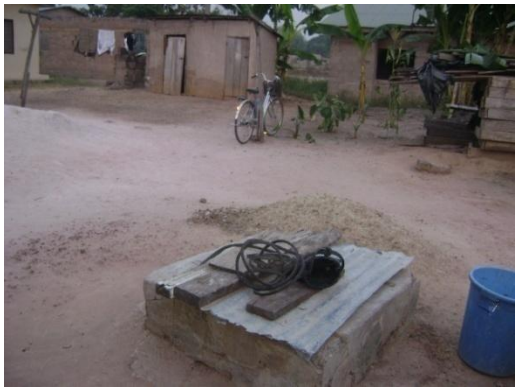


Fig. 3.2. 5: Picture of Well A5

Well A6

This well is 6m deep and inside is lined almost to the bottom. The well is provided with a concrete case above the ground. The fetching bucket is usually kept clean. The well is not close to either a septic tank or a latrine.

Fig.3.2. 6: Picture of Well A6

Well A7

The well is 5m deep and located under a mango tree. It has a concrete case above ground and an iron sheet as a slab. Fetching bucket is a plastic type and most of the time kept inside the well. Animals on roam normally take shelter under the mango tree and defecate around it. The well is located close to a common path used by people and vehicles. The inside is not lined with concrete.

Fig. 3. 2.7: Picture of Well A7

Well A8

It is 3.5m deep. It has no concrete case but a disjointed wooden slab. Animals easily have access to the well. It is located under a mango tree. A plastic type of fetching bucket is used.

Fig. 3. 2.8: Picture of Well A8

Well A9

It is 6m deep with a concrete case above the ground level. Fetching bucket is a plastic type. Only the upper portion of the well is provided with concrete.

Fig. 3. 2.9: Picture of Well A9

Well A10

It is 7.4m deep. It is concreted above the ground with a well covered slab. It is located higher than the ground and close to a teak plantation. Animals have easy access to it. Fetching bucket is mainly a plastic type. The surrounding of the well is a neat one.

Fig. 3.2.10: Picture of Well A10

3.3 SAMPLING AND SAMPLE TREATMENT

In order to avoid microbial contamination of sample containers, fresh bottled water (500ml) was bought and carefully emptied by preventing any contamination from handling at the sampling site prior to sampling. New fresh bottles were used for subsequent sampling.

For physico chemical analysis, 1.5 litre plastic bottles were rinsed with distilled water before used for sampling. Sample bottles were labeled A1 – A10 to represent the wells. Ice-box to convey the samples was also rinsed with distilled water and ice packs kept inside to preserve the samples during transportation to the laboratory for analysis.

3.4 SAMPLING

Samples were collected once during each month for a period of six months from September 2010 to February 2011.

Samples were collected for both microbiological and physico-chemical analysis from the ten hand dug wells at different parts of the town. Sample collection was done using the available bucket between the period of 6 a.m and 7 a.m and transportation to the laboratory was carried out within three hours from Atebubu to Kumasi. Test on bacteriological parameters was conducted within 24 hours after sampling. Samples were stored in refrigerator at a temperature of 4^{o}C until completion of analysis.

3.5 Bacteriological Determination

Standard methods for the determination of total coliform and fecal coliform, *E. coli, Salmonella and Enterococci* were employed.

3.5.1 Determination of Total and Feacal coliform

The Most Probable Number (MPN) method was used to determine total and faecal coliforms in the samples. Serial dilutions of 10^{-1} to 10^{-4} were prepared by picking 1ml of the sample into 9 ml sterilized distilled water. One millilitre aliquots from each of the dilutions were inoculated into 5ml of macConkey broth with inverted Durham tubes and incubated at 35^{o}C for total coliforms and 44^{o}C for faecal coliforms for 18 – 24 hours. Tubes showing colour change from purple to yellow and gas collected in the Durham tubes after 24 hours were identified as positive for both total and faecal coliforms. Counts per 100ml were calculated from the Most Probable Number (MPN) table.

3.5.2 *Escherichia coli* (Thermotolerant coliform)

One millilitre from each of the faecal positive tubes identified, was transferred into 5ml trypton water and incubated at 44^{o}C for 24 hours. A drop of Kovac's reagent was added to each tube of trypton water. All tubes showing a red ring colour development after gentle agitation showed the presence of indole and recorded as presumptive for thermotolerant coliforms (*E. coli*). Counts per 100ml were calculated from the Most Probable Number (MPN) tables.

3.5.3 *Salmonella* determination

One ml each of the samples was put into 10 ml sterilized peptone water and incubated at 37^{o}C for 24 hours. After 24 hours, 1ml of the incubated sample was transferred to a selenite broth and again incubated at 37^{o}C for 48 hours after which streaking was done on Salmonella Shigella Agar (S.S.A.) with a loop. Final incubation at 37^{o}C for 48 hours was carried out. After 48 hours, black spots which showed the presence of salmonella were counted.

3.5.4 *Enterococci* determination

Slanetz bartley agar was prepared. Ten ml was poured into petri dishes and allowed to solidify. Serial dilutions of 10^{-1} to 10^{-4} were prepared. One ml aliquots each from the dilutions were inoculated into the petri dishes with already prepared slanetz bartley agar. The plates were then incubated at 37^{o}C for a maximum of 4 hours and transferred to 44^{o}C incubation for 48 hours after which the colony counter was used to count the enterococci and values recorded in Colony Forming Unit (CFU).

3.6 Chemical Analysis

Analytical water test tablets prescribed for Palintest Photometer 5000 (Wagtech, Thatcham. Berkshire, UK) series and procedures outlined in the Palintest Photometer Method for the examination of water were used. A photometric method was used for the determination of calcium, fluoride, magnesium, sulphate, phosphate, nitrate, iron and chloride. In the procedure, a required wavelength was chosen and a blank tube inserted into the test chamber and the ON button pressed and held until display read 100. Blank tube was removed and sample tube after colour development was put into the test chamber and the displayed reading taken and compared to a calibration chart for that parameter for concentration. Intensity of colour formation shows the degree of concentration.

Comparator method was used for nitrite. Determination of total hardness was done by titration method using EDTA. A pH meter was used for pH determination; turbidity meter was used for turbidity; multifunctional conductivity meter was used for conductivity and total dissolved solids and spectrophotometer for colour determination. Each sample was analyzed for all the parameters in triplicate.

3.6.1 pH Determination

In the laboratory, pH meter (HANNA model 209) was used to determine the pH of water samples. Buffer solutions of pH 4.0, 7.0 and 9.0 prepared from tablets of BDH buffer were used to calibrate the pH meter.

Fifty (50) ml of water sample was poured into a clean glass beaker and the electrode inserted into it. The button selector of the pH meter was turned and the pH was read and recorded. This was repeated for all other water samples.

3.6.2 Turbidity Determination

Turbidity of water samples was determined with HACH turbidimeter (model number CO 150). The turbidity meter was first calibrated with Formazin standard solutions of 0.2 NTU, 10 NTU, 100 NTU and 1000 NTU by filling consecutively a clean dry cuvette with the well mixed standard solutions. It was then returned to the measurement mode and used.

A clean dry cuvette was rinsed three times with the water sample to be tested. The cuvette was filled with 10ml water sample to be analysed. The light shield cap was replaced. The outer surface of the cuvette was wiped dry with a clean tissue paper. It was then pushed firmly into the optical well and the lid closed. The NTU values were measured by pressing and releasing the arrow and about five minutes, the value was recorded after the display has stopped flashing.

3.6.3 Conductivity and Total Dissolved Solids (TDS) Determination

A multifunctional conductivity meter (HANNA model HI 9032) was used to determine the conductivity and TDS of water samples in the laboratory. It was calibrated by using sodium chloride standard solution of 12880µS/cm. The conductivity meter was then returned to the operation mode to facilitate measurement. About 50ml of the water sample was poured into a clean glass beaker and the conductivity meter electrode was

then inserted into the water sample. The value was read and recorded after five (5) minutes, in µS/cm.

TDS was determined by pouring about 50ml of water sample into a clean glass beaker. The electrode was then immersed into the sample and stirred to ensure uniformity. After the reading stabilized, the value was read and recorded in mg/L. The same procedure was repeated for all other water samples.

3.6.4 Colour Determination

The apparent colour of water samples were determined by HACH Lange Spectrophotometer (model DR-5000). The Spectrophotometer was first checked, using distilled water in the 25ml nessler cell at a wavelength of 455nm and platinum-cobalt unit of 50mm. The 25ml cell was then filled to the mark with water sample and outside wiped dry with tissue paper to eliminate figure prints and moisture. The cell was inserted into the cell chamber and the lid closed. After five (5) minutes, the apparent colour was read and recorded in Hazen units.

3.6.5 Calcium Determination (Photometer Method)

Test tubes were filled with sample to 10ml mark. One calcicol No.1 tablet was added, crushed and mixed to dissolve followed by addition of calcicol No.2 tablet. Sample was allowed for five minutes for full colour development. Wavelength of 570 nm was selected on the photometer. Photometer reading was taken and calcium calibration chart was used to determine calcium concentration in mg/L.

3.6.6 Magnesium determination (Photometer Method)

Test tubes were filled with sample to 10ml mark. One Magnecol tablet was added, crushed and mixed to dissolve and allowing five minutes for full colour development. Wavelength of 520 nm on the photometer was selected for photometer reading followed by the application of Magnecol calibration chart for magnesium concentration in mg/L.

3.6.7 Total iron Determination (Photometer Method)

Test tubes were filled with sample to 10ml mark. One iron tablet was added, crushed and mixed to dissolve. One minute was allowed for full colour development. Wavelength of 520nm on the photometer was selected for photometer reading after which iron calibration chart was used to determine iron concentration in mg/L.

3.6.8 Chloride Determination (Photometer Method)

Test tubes were filled with sample to 10ml mark. One Chloridol tablet was added and allowed to disintegrate for two minutes. Wavelength of 520nm on the photometer was selected for photometer reading. Chloridol calibration chart was used to determine the concentration of chloride in mg/L.

3.8.9 Fluoride determination (Photometer Method)

Test tubes were filled with water samples to 10ml mark. Fluoride No.1 and No. 2 tablets were added, crushed and mixed to dissolve. Five minutes was allowed for full colour development and wavelength of 570 nm was selected for photometer reading and then compared to the calibration chart for fluoride concentration in mg/L.

3.8.10 Nitrite Determination (Comparator Method)

The Lovibond Nessleriser (model 2150) was used to measure nitrite after the instrument was calibrated. In this, there was measurement of 50ml of sample into Erlenmeyer flask, 2ml of Griess - Ilosvay's No.1 and 2 were added. The mixture was allowed to stand for fifteen minutes after swirling gently. The samples were then transferred into a nesseler's tube and the value of the matching colour using the nitrite disc Comparator read (the markings on the disc represent the actual amount of nitrogen (N) present as nitrite). The final value was obtained as disc reading x 0.02.

3.8.11 Nitrate Determination (Photometer Method)

The nitratest tube was filled with sample to the 20ml mark. One level spoonful of nitratest powder and one nitratest tablet were added. Screw cap was replaced and tube well shaken for one minute. Tube was allowed to stand for 1 minute and gently inverted three times to aid flocculation and complete settlement. Screw cap was removed and the top of the tube wiped with a clean tissue and the clear solution was decanded into a round test tube to the 10ml mark. One nitricol tablet was added, crushed and mixed to dissolve and ten minutes allowed for full colour development. Wavelength of 570nm on photometer was selected. Photometer reading was taken and compared to the calibration chart for nitrate concentration in mg/L.

3.6.12 Sulphate Determination (Photometer Method)

Test tubes were filled with water sample to 10ml mark and one sulphate tablet was added, crushed and mixed to dissolve. Cloudy solution indicated the presence of

sulphate. Five minutes was allowed then mixed again to ensure uniformity after which wavelength of 520nm was selected on the photometer. Photometer reading was taken and sulphate calibration chart was used to determine the concentration of sulphate in mg/L.

3.6.13 Phosphate Determination (Photometer Method)

Test tubes were filled with water sample up to 20ml mark followed by addition of one phosphate No.1 LR tablet, crushed and mixed to dissolve. One phosphate No.2 tablet was also added, crushed and mixed to dissolve. The mixture was allowed to stand for ten minutes for full colour development. Wavelength of 640 nm was chosen on the photometer followed by photometer reading after which phosphate LR calibration chart used for phosphate concentration in mg/L.

3.6.14 Total Hardness Determination

Total hardness was determined using the EDTA Titration Method. Fifty (50) ml of the samples was measured into a conical flask and 1ml of buffer solution was added. This was followed by the addition of few grams of Eriochrome Black T. indicator. Titration was done using 0.01M EDTA solution, mixing gently until the colour changes from red to blue. The titre value (Tv) was read and concentration computed as;

Total Hardness (mg/L) = Tv x 20.

3.7 Quality Control (QC) Procedures

To ensure reliability of results, all water monitoring equipment were calibrated with standard and known concentrations. Samples were taken in duplicates and the average

taken for the analysis. Field blanks were used to identify errors during sample collection. Ice packs were used to preserve the samples for transportation. Samples were analysed using defined methods based on text: Standard Methods for the Examination of Water and Wastewater. Concentrations of analyte samples were read from calibration tables and averages of three laboratory replicates were taken for each determination to enhance precision of measurements.

3.8 Statistical Analysis

Statistical analysis was carried out using MS Excel 2007 edition for mean values and graphs for parameters. T-test at 5% significant level was carried out using SPSS to find out if significant differences exist between the values of the parameters for wet and dry seasons. Correlation analysis was also carried out to check whether well distances from sanitary facilities and well depth affect the parameters.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Physico-chemical Parameters

4.1.1 pH

Levels of pH recorded for the wet season and dry seasons had ranged of 5.85 - 7.87 and 5.92 - 9.85 respectively. All but well A4 showed lower levels of pH in the dry season relative to the wet season (Figure 4.1). For the whole sampling period, well A7 recorded the highest pH of 9.85 during the dry season with well A4 recording the lowest pH of 5.85 during the wet season. Generally, pH levels of the wells exceeded the maximum limit of 8.5 during the dry season and were below the minimum limit of 6.5 during the wet season (Figure 4.1). pH values lower than 6.5 are considered too acidic for human consumption and can cause health problems such as acidosis whiles those greater than 8.5 are considered to be too alkaline for human consumption. Moreover, acidic water have the tendency to corrode metallic containers or has a bitter or metallic taste whiles alkaline water may be associated with scale formation in piping systems (Oram, *et al.*, 2010).

pH in the wet season was highly significant than in the dry season ($p = 0.006$) and shows the impact of rainfall on the pH levels of the wells. The pH values of this research were in conformity with those observed by other authors (Shittu *et al.*, 2008 and Nkansah *et al.*, 2010).

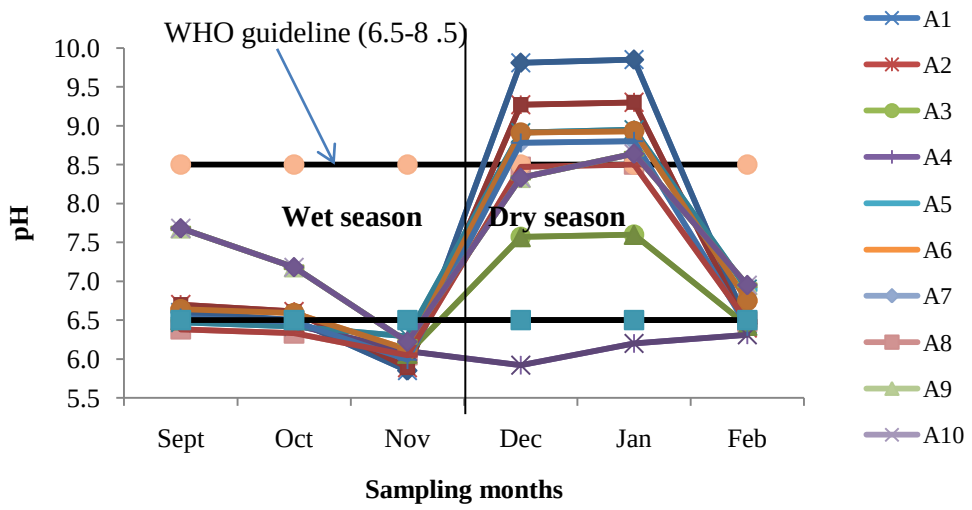


Figure 4.1: pH of water from sampled wells Sept.2010 – Feb.2011

4.1.2 Turbidity

Turbidity for the wells ranged from 2.6 NTU to 9.4 NTU in the dry season and 1.4 NTU to 9.9 NTU in the wet season. It was generally higher in the dry season compared to the wet season with the exception of well A5 which recorded the maximum turbidity of 9.99NTU during the wet season (Figure 4.2). In general, the turbidity of the wells was predominantly below the recommended guideline value of 5.0NTU by WHO during the wet season but consistently exceeded this value during the dry season (Figure 4.2). Turbidity could be caused by clays, organic matter, algae and other tiny inorganic particles. Apart from rendering water aesthetically displeasing, these substances can also cause taste and odour problems in water. Moreover, bacteria, viruses and parasites such as giardia and cryptosporidium can attach themselves to the suspended particles in turbid water and thus interfere with disinfection by shielding contaminants from the disinfectant Metcalf and Eddy, 2003).

Turbidity was highly significant in the wet season than in the dry season ($p = 0.018$).

Levels of turbidity recorded in this research were above the reported level by Shittu *et al.* (2008) in dug well water samples in Abeokuta, Nigeria.

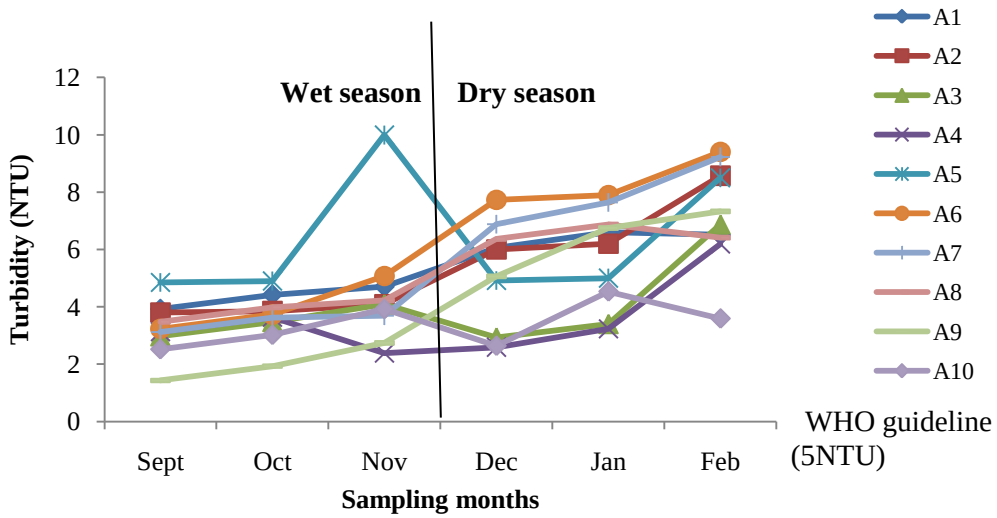


Figure 4.2: Turbidity of water from sampled wells Sept. 2010 –Feb.2011

4.1.3 Colour

The colour of water in the wells was relatively higher at the commencement of the wet season; September and October and at the latter part of the dry season; February (Figure 4.3). During this period also, the colour of water in the wells was consistently above the WHO limit of 15Hazen. Relatively, the colour of water in the wells was higher during the wet season than in the dry season (Figure 4.3). In the wet season, the colour of the water in the wells was between 4Hazen and 105Hazen and was highly variable. However in the dry season, the colour of water in the wells ranged from 6Hazen to 78Hazen. Colour in the wet season was significantly higher than in the dry season ($p = 0.01$) indicating that rainfall significantly increases the concentration of total solids that

cause colour in water. According to Corbit (2004), colour is not objectionable from a health perspective but its presence is aesthetically displeasing and connotes that the water needs appropriate treatment. Boamah *et al*. (2010) reported 10 to 30Hazen as colour ranges in dug well water samples in three peri – urban communities in Kumasi which were far below the ranges obtained in this research.

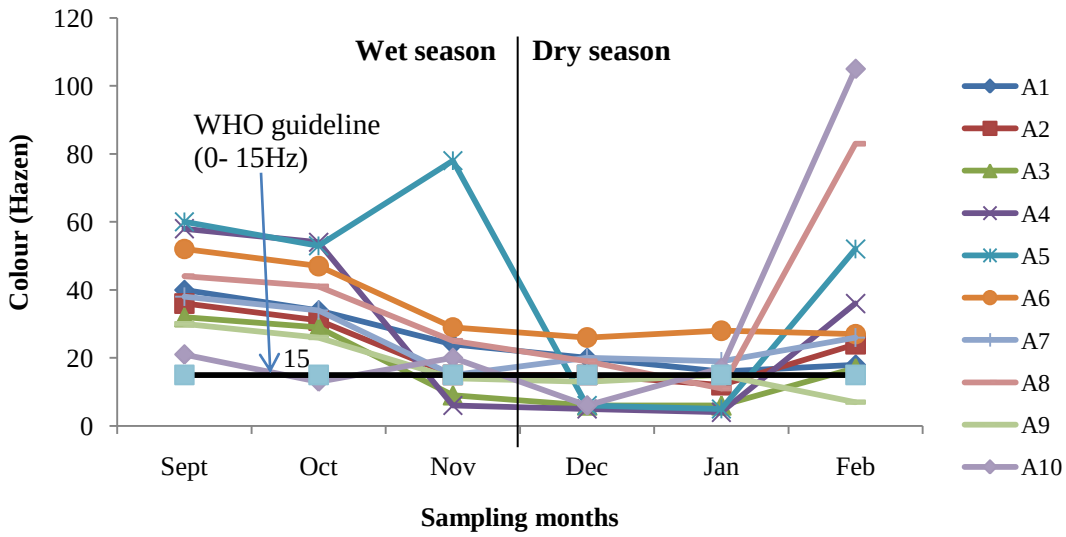


Figure 4.3: Colour of water from sampled wells Sept. 2010- Feb.2011

4.1.4 Total Dissolved Solids and Conductivity

Total Dissolved Solids (TDS) and Conductivity of the water in the sampled wells was relatively higher during the wet season than the dry season (Figures 4.4 and 4.5). The range of TDS and conductivity of water in the wells were respectively 11 - 126mg/L and 27 - 351µS/cm for the dry season. For the wet season, the ranges of TDS and conductivity were respectively 72 - 194mg/L and 149 - 398µS/cm. Literature (APHA/AWWA/WEF, 2003 and Spellman, 2003) has it that, conductivity is affected by

the presence of dissolved inorganic solids. The higher levels of TDS during the wet season show the impact of rainfall on the soil strata which facilitates the dissolution of solids in the water. Generally, the TDS and conductivity of the water in the wells were below their respective guideline values for drinking water as recommended by WHO (Figure 4.4). TDS in the wet season was highly significant than in the dry season ($p = 0.02$). Conductivity was also highly significant in the wet season than in the dry season ($p = 0.005$).

The range of TDS obtained in this research fell below the reported range by Olobaniyi (2007) in well water samples.

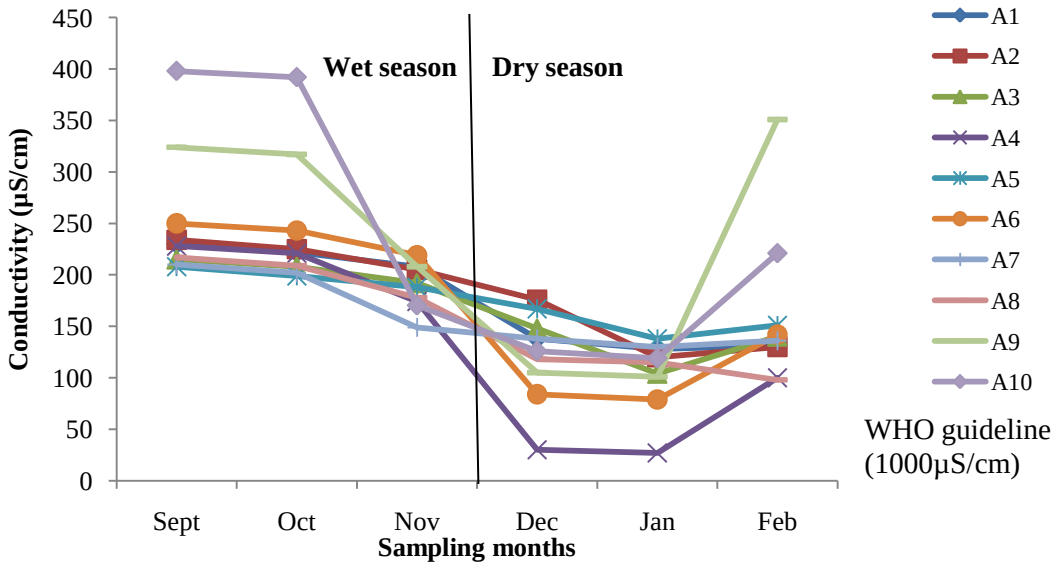


Figure 4.4: Conductivity of water from sampled wells Sept.2010- Feb2011

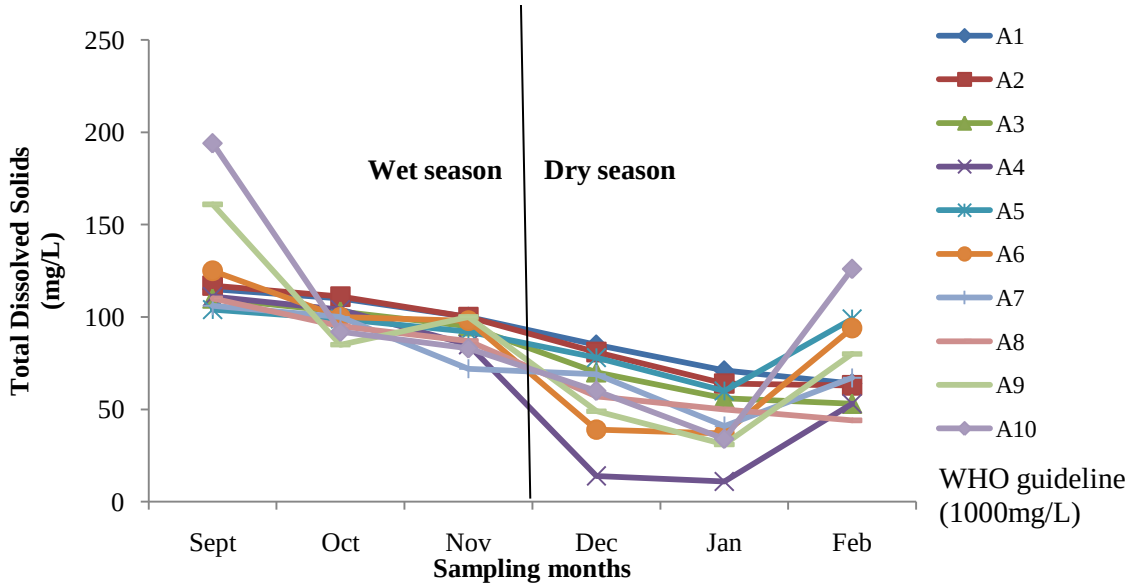


Figure 4.5: Total dissolved solids of water from sampled wells Sept.2010-Feb.2011

4.1.5 Total Solids

Total solids, made up of both dissolved and suspended solids, also showed a similar trend as TDS. It depicted a decreasing trend from the wet season to the dry season and increased at the latter part of the dry season (Figure 4.6). Predominantly, levels of total solids in the wells were higher in the wet season (73 - 200mg/L) as compared to the dry season (39 - 224mg/L) and also explain the high level of colour of water in the wells during the wet season. Total solids between the wet and dry season was significant ($p = 0.016$). This shows that rainfall facilitates the ingress of more solids into the wells.

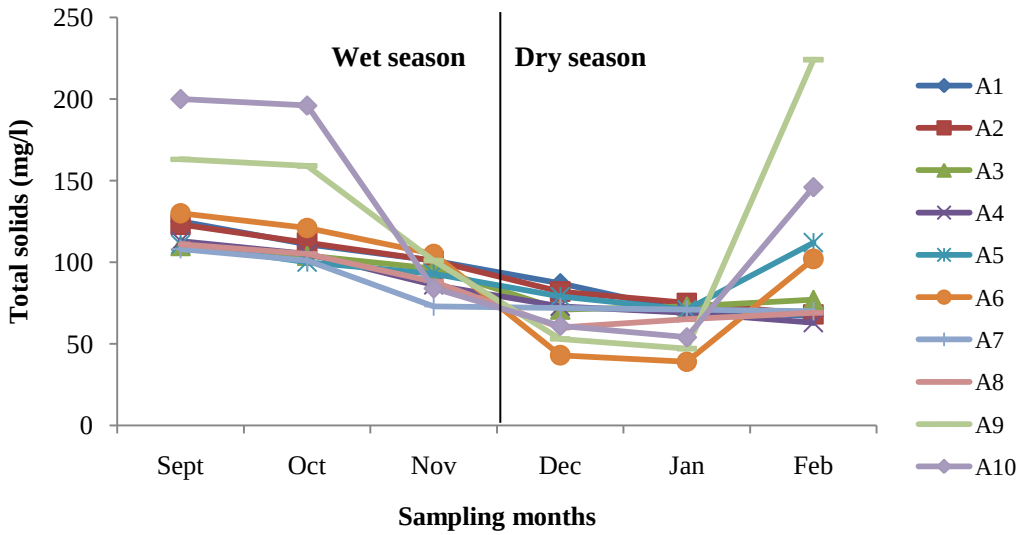


Figure 4.6: Total solids of water from sampled wells Sept.2010 – Feb.2011

4.1.6 Calcium, Magnesium and Total Hardness

Spellman (2008) asserts that, hardness of water represents the amount of dissolved calcium and magnesium in water. According to him, this property of water causes soap and detergents to be less effective and also contributes to scale formation in pipes and boilers. In the sampled wells, Calcium hardness was relatively higher in the wet season (especially in November) compared to the dry season (Figure 4.7). Levels of Calcium hardness in the wells were between 14.4mg/L and 58.4mg/L for the wet season. For the dry season, it ranged from 4mg/L to 32mg/L. Calcium hardness was highly significant in the wet season than in the dry season ($p = 0.009$). However, the difference in Magnesium hardness during both seasons was not considerable except for wells A9 and A10 which had elevated levels of Magnesium hardness in November (Figure 4.8). Magnesium hardness of water in the wells was between 0.4mg/L and 17.9mg/L for the dry season and ranged from 0.9mg/L to 37.9mg/L for the wet season. Magnesium

hardness between the wet and dry season was significant (p = 0.01). The levels of Calcium and Magnesium hardness obtained in this research were higher than those obtained by Nkansah *et al.* (2010) for some wells in the Kumasi Metropolis. Conversely, they are below the levels reported by Ifayibi (2009) for hand dug wells in Nigeria.

Total hardness ranged from 50mg/L to 140mg/L for the wet season and 25mg/L to 146mg/L for the dry season. Total hardness showed a decreasing trend in most of the wells from September to January but increased in wells A5, A6, A9 and A10 in February. Although the hardness of water (Calcium, Magnesium and Total) in the sampled wells were all below their respective recommended guideline values by WHO, low hardness as per Spellman (2003; 2008) contributes to corrosive tendencies of water. The total hardness of water in all the wells were below the 150mg/L (Figure 4.9) and thus could be classified as soft to moderately hard with regards to classification of water hardness by Spellman (2003). Total hardness was highly significant in the wet season than in the dry season (p = 0.007).

The levels of total hardness recorded in this research were above the reported range by Shittu *et al*. (2008) and Fasunwon *et al*. (2008) but below the reported range by Adefemi and Awokumi (2009).

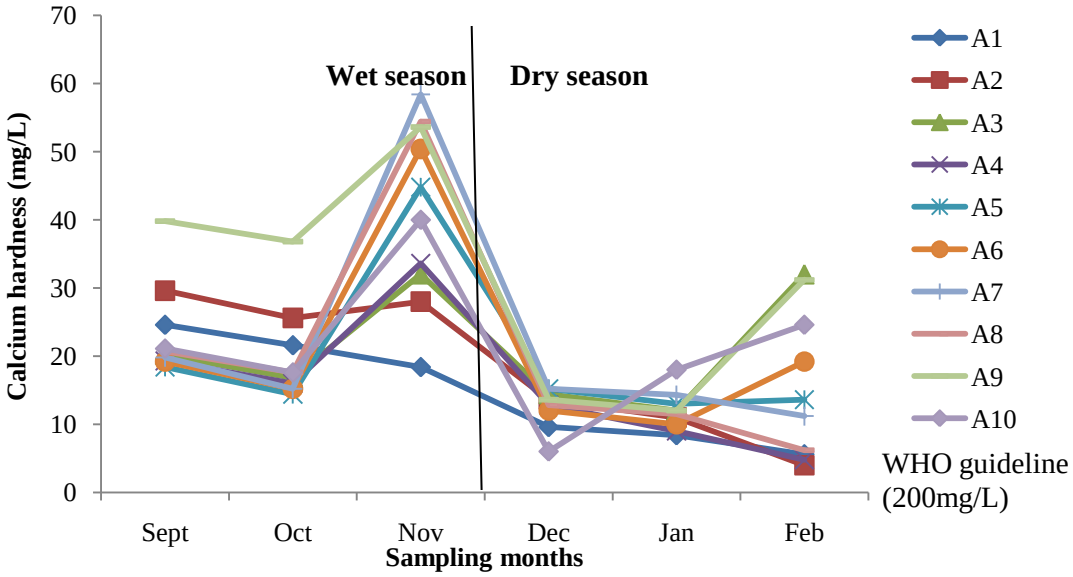


Figure 4. 7: Calcium hardness of water from sampled wells Sept.2010- Feb.2011

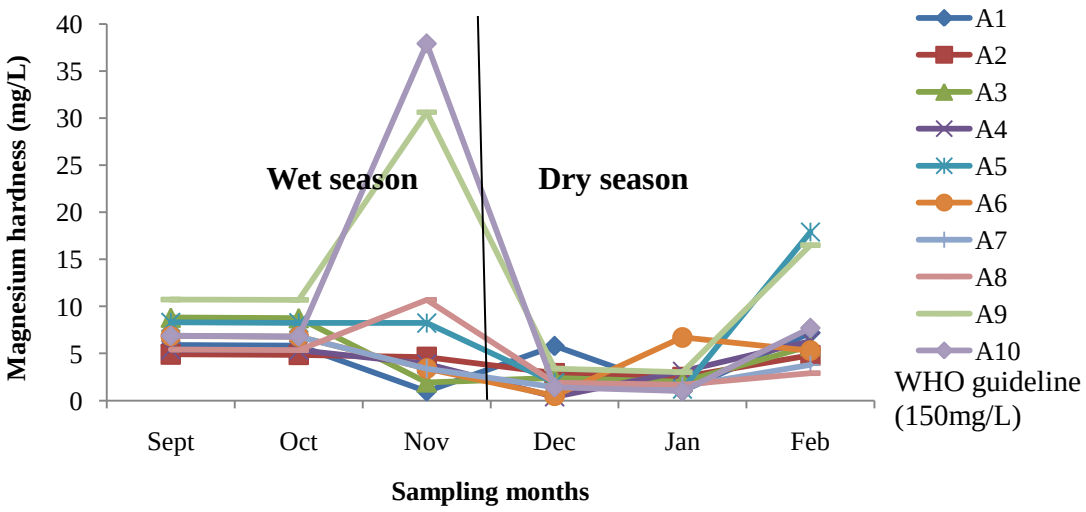


Figure 4.8: Magnesium hardness of water from sampled wells Sept.2010- Feb.2011

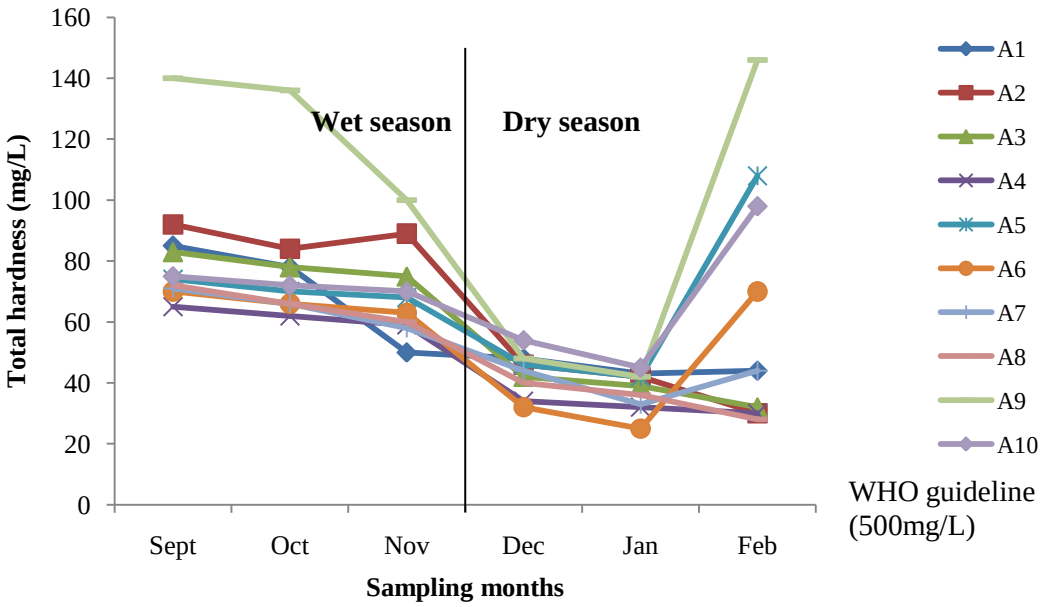


Figure 4.9 : Total hardness of water from sampled wells Sept.2010- Feb.2011

4.1.7 Nitrite, Nitrate and Ammonia

Metcalf and Eddy (2003) assert that, nitrogen compounds mostly emanate from nitrogenous compounds of plant and animal origin, sodium nitrate and atmospheric nitrogen. In groundwater, nitrate results from leaching or runoff from agricultural land or contamination from human or animal wastes as a consequence of the oxidation of ammonia and similar sources (WHO, 2004). Ammonia, according to Liu (1999), is released upon decomposition of proteinaceous matter and can be released into the atmosphere, used directly by microorganisms or converted into nitrite and nitrate.

Levels of nitrite (Figure 4.10) and nitrate (Figure 4.11) in sampled wells were far below their respective WHO guideline values for drinking water of 3mg/L and 50mg/L. The major health concern regarding nitrate and nitrite in drinking water according to WHO

(2004) and Kempster *et al*. (1997), is the formation of methaemoglobinaemia, also called “blue-baby syndrome” in infants.

Nitrite showed a statistically insignificant difference between the dry and wet seasons ($p = 0.08$) but showed an increasing trend in most wells except well A7 from the wet season (0 – 0.021mg/L) to the dry season (0.002 – 0.023mg/L). The nitrite levels obtained in this research were far below the concentration reported by Ifayibi (2009) in well water samples.

Nitrate on the other hand decreased from the wet season (1.2 – 4.5mg/L) to the dry season (0.2 – 4.3mg/L). Nitrate in the wet season was significantly higher than in the dry seasons ($p = 0.034$). Although, levels of ammonia in the wet season (0 – 0.99mg/L) were higher than that of the dry season (0 - 0.1mg/L), no visible seasonal pattern was observed in the levels of ammonia in the wells (Figure 4.12). This could possibly be due to the different amount of organics in the soils encompassing the water. The presence of ammonia in the wells indicates possible bacterial, sewage and animal waste pollution as observed by WHO (2004). Because ammonia in drinking water is not of immediate health relevance, the WHO has no recommended guideline value for this parameter but can however compromise the disinfection efficiency of drinking water and also cause taste and odour problems (WHO, 2004). There was no significant difference in ammonia between the wet and dry season ($p = 0.06$).

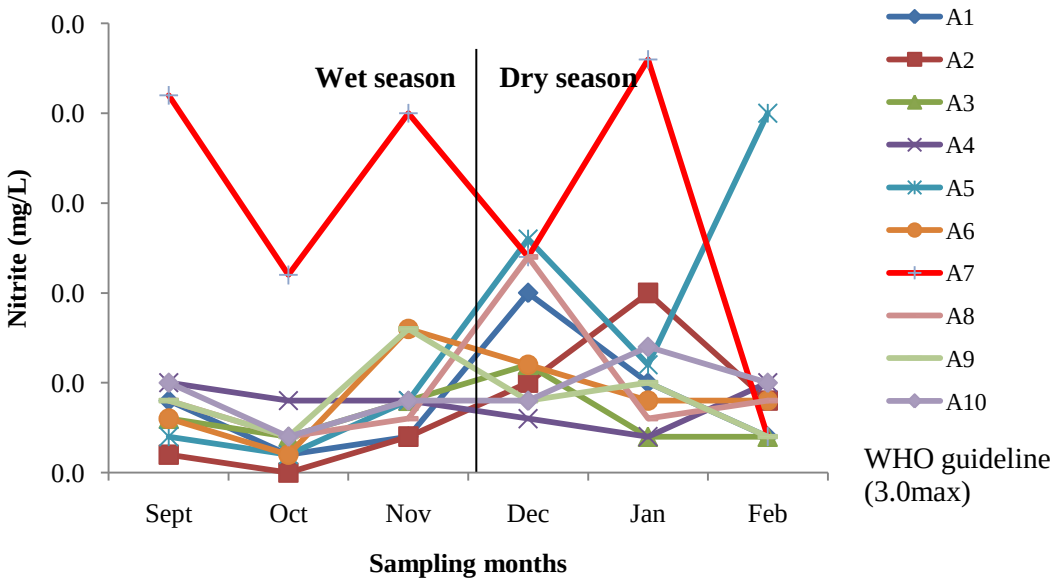


Figure 4.10: Nitrite in water from sampled wells Sept.2010 –Feb.2011

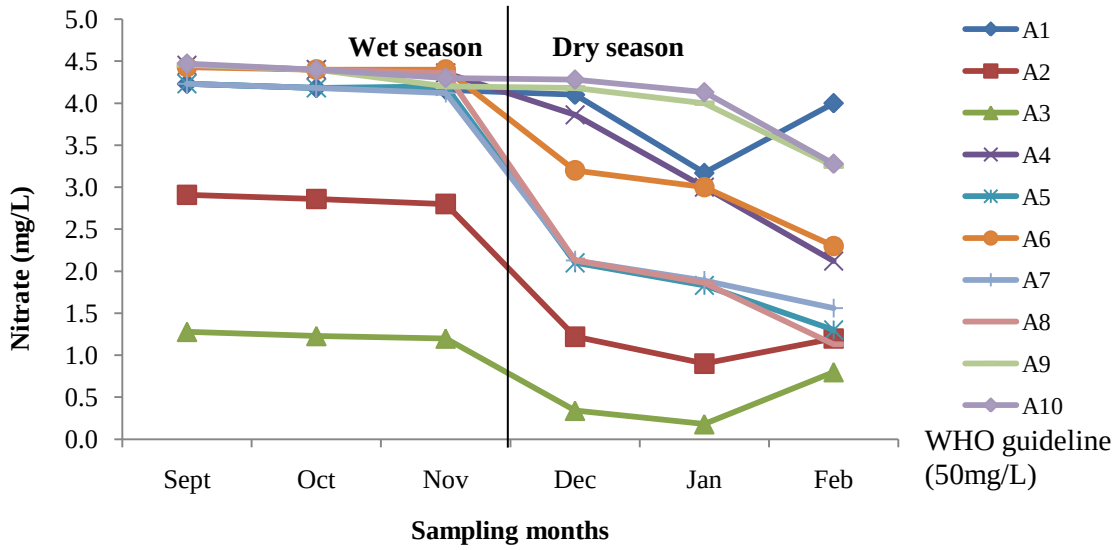


Figure 4.11: Nitrate in water from sampled wells Sept.2010 –Feb.2011

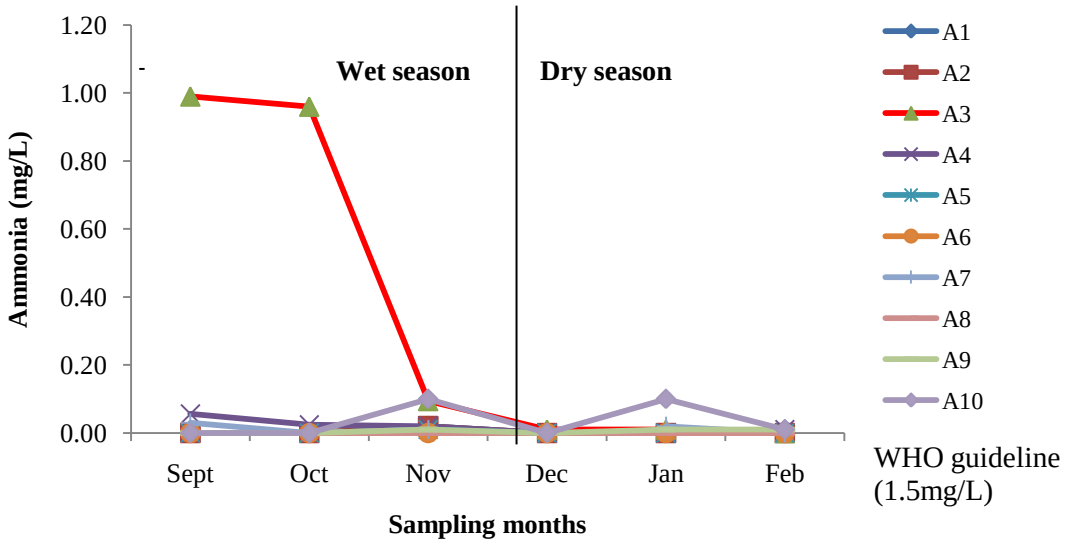


Figure 4.12: Ammonia in water from sampled wells Sept.2010 – Feb.2011

4.1.8 Fluoride

Drinking water containing 0.7 to 1.2 mg/L natural or added fluoride is beneficial to children during the time they are developing permanent teeth (Nemerow *et al.*, 2009). However, according to the WHO guidelines, mottling and discoloration of teeth in children has been reported at concentrations above 1.5mg/L especially greater than 4mg/L. However, values of fluoride in this research will have no health effect on consumers of the water. In groundwater, fluoride occurs as a natural constituent ranging from trace to 5mg/L.

The concentration of fluoride in the sampled wells was relatively higher in the wet season (0.3 – 2.2mg/L) than the dry season (0.05 – 0.25mg/L). In the wet season, wells A3, A4, A5 and A6 particularly showed consistent high levels of fluoride and even exceeded the maximum WHO guideline value of 1.5mg/L in September (Figure 4.13).

Fluoride levels was significantly higher in the wet season than in the dry season (p = 0.008) and indicates that infiltration of rainfall possibly increases the dissolution of fluoride in the sampled wells. The levels of fluoride in the wells obtained in this research are similar to that observed by Nkansah *et al.* (2010).

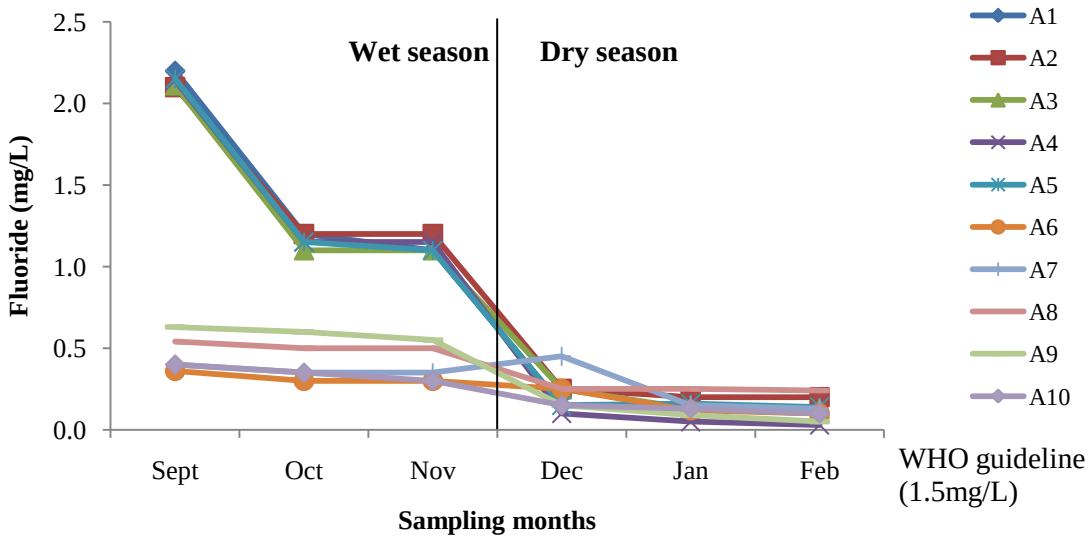


Figure 4.13: Fluoride in water from sampled wells Sept.2010- Feb.2011

4.1.9 Phosphate

Phosphate Literature (Salvato *et al.* 2003) has it that, phosphorus is usually associated with plant remains, animal wastes or fertilizer. Other potential sources of phosphates as stated by Tjandraatmadja *et al.* (2010) include, cleaning products, cosmetics, medicated shampoos, food products, faeces and urine. Thus high levels of phosphate in groundwater could indicate the possible pollution from faecal origin or agro products.

In the sampled wells, levels of phosphates were below the recommended guideline value by WHO (Figure 4.14). On the average, levels of phosphates in the wet season were somewhat higher (0.3 – 2.6mg/L) compared to the dry season (0.3 – 2.3mg/L). There

was significant difference in phosphate between the wet and dry seasons (p = 0.02). The higher level of phosphates in the sampled wells during the rainy season could be attributed to the infiltration of contaminants from plant and animal wastes as well as artificial fertilizer within the vicinity of the wells.

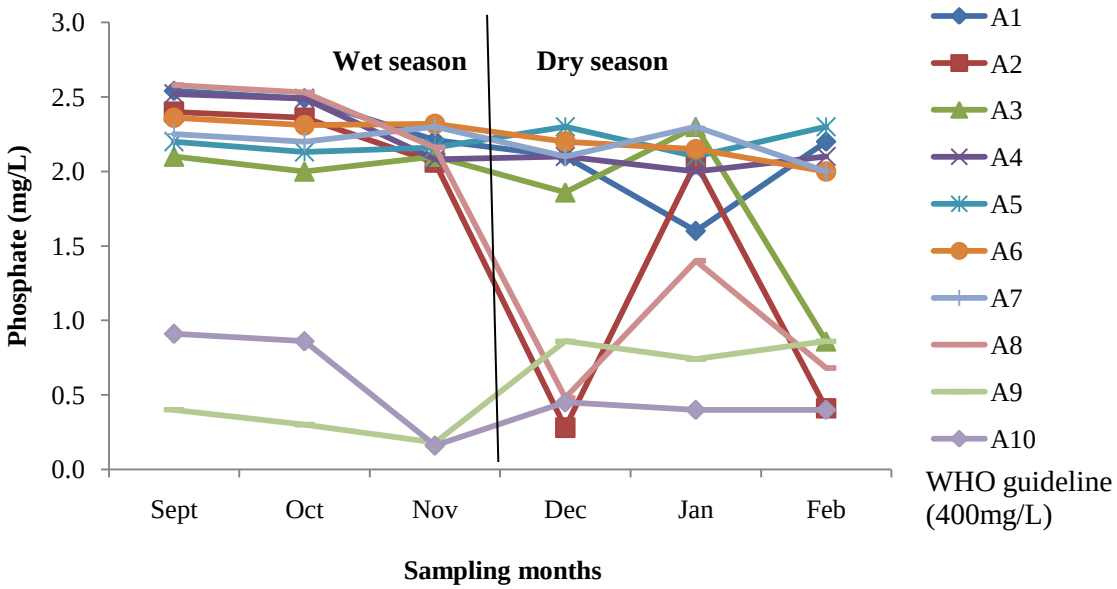


Figure 4.14: Phosphate in water from sampled wells Sept.2010 – Feb.2011

4.1.10 Sulphate

Levels of sulphate in the sampled wells mostly reduced from September to December (except wells A8 and A10), increased in January and finally reduced again in February but were far below the maximum limit of 250mg/L as recommended by WHO (Figure 4.15). Levels of sulphate were relatively lower and highly variable (0 - 10mg/L) in the dry season but was consistently higher in the wet season (0 - 12mg/L). Sulphate in the sampled wells was significantly higher in the wet season than in the dry season (p = 0.036). Corbit (2004) assert that, waters containing high concentrations of sulphate

caused by the leaching of natural deposits of magnesium sulphate or sodium sulphate may be undesirable because of their laxative effects. According to WHO (2004), this effect is mostly manifested at concentrations between 1000 and 1200mg/L.

The levels of sulphate recorded in this research were below the levels in hand dug well water samples reported by Nkansah *et al*. (2010).

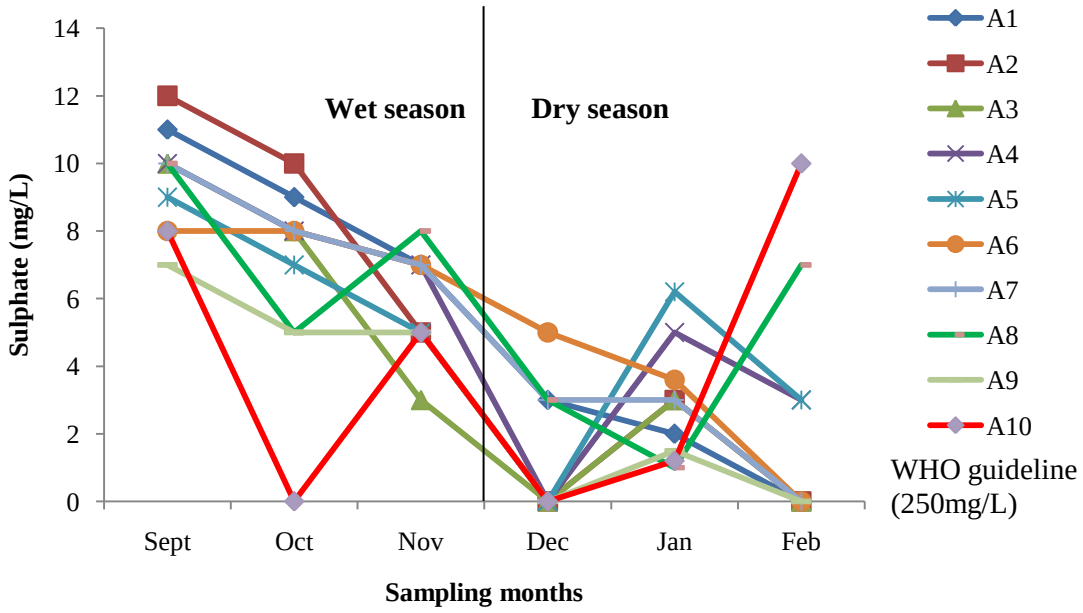


Figure 4.15: Sulphate in water from sampled wells Sept.2010-Feb.2011

4.1.11 Chloride

The concentration of chloride in the wells depicted a decreasing trend mostly throughout the sampling period but increased in February (Figure 4.16). The levels of chloride in the wet season (28 - 100mg/L) exceeded that of the dry season (20 - 64mg/L) although they were all below the maximum limit of 250mg/L for drinking water. Chloride levels

in this research were below the range reported by Adefemi and Awokumi (2009) in hand dug well water samples in Itaogbolu, Nigeria. Chloride in the wells was statistically significant between the wet and dry season (p = 0.016).

Chloride in surface and groundwater emanate from both natural and anthropogenic sources, such as run-off, the use of inorganic fertilizers, landfill leachates, septic tank effluents, animal feeds, industrial effluents, irrigation drainage, and seawater intrusion in coastal areas (WHO, 2003). Although there is no health-based guideline value for chloride, WHO (2004) assert that, chloride concentrations in excess of 250mg/L can result in detectable taste in water.

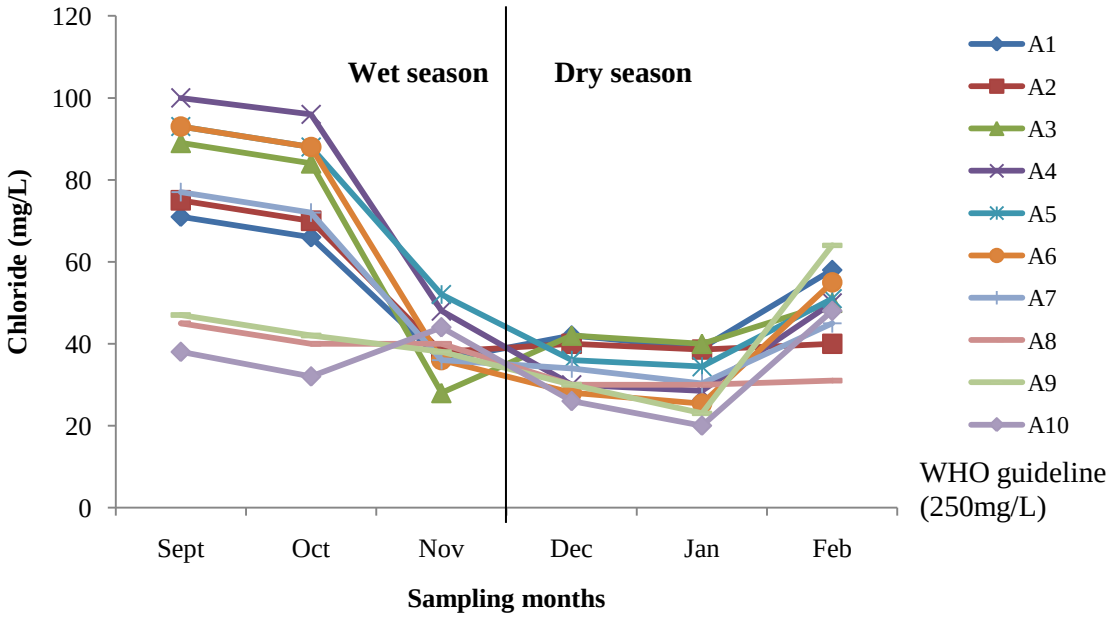


Figure 4 16: Chloride in water from sampled wells Sept.2010- Feb.2011

4.2 Bacteriological Parameters

4.2.1 Total coliforms

Total coliform counts in the wet season were mostly higher than that of the dry season and showed a declining trend from September to February except wells A4 and A6 which increased in January and February (Figure 4.17). In the wet season, total coliform count in the wells ranged from 740 - 910000MPN/100mL. However, in the dry season a range of 430 - 240000MPN/100mL of total coliform in the wells were recorded. This finding confirms that of Anim *et al*. (2010) who recorded higher coliform in the wet season than in the dry season.

The levels of total coliforms recorded in this research far exceeded those reported by other authors (Obiri – Danso, 2008; Quist, 1999; Adetunde and Glover, 2010 and Shittu *et al*., 2008).

Total coliforms was significantly higher in the wet season than in the dry season ($p = 0.001$) and shows the contribution of rainfall to the increment of coliforms in the wells. The presence of total coliforms in water supplies can reveal regrowth and possible biofilm formation or contamination through ingress of foreign material, including soil or plants.

Levels of total coliform recorded in this work highly exceeded WHO guideline value of 0.0mg/L in drinking water. This therefore poses health threats to consumers of such water supplies.

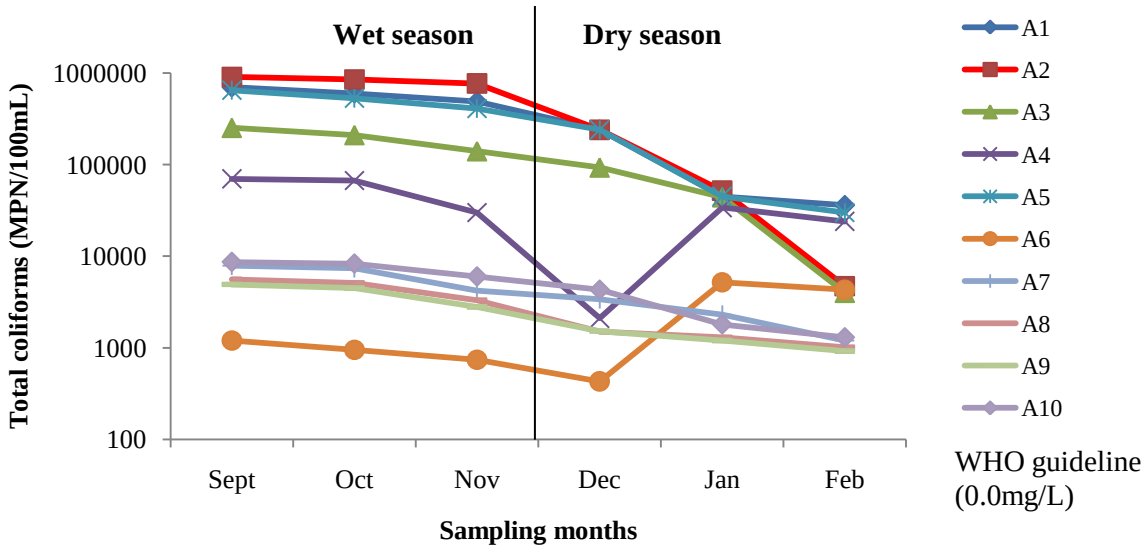


Figure 4.17: Total coliform content of water from sampled wells Sept.2010 – Feb.2011

4.2.2 Faecal coliform

Faecal coliform count in the wells showed a decreasing trend from the wet season to the dry season (Figure 4.18). In the wet season, faecal coliform count ranged from 310 - 40200MPN/100mL whiles it drastically reduced to 24 - 9300MPN/100mL in the dry season. Faecal coliform count in the wells between the wet and dry season was statistically significant ($p = 0.003$), with the maximum value recorded in well A2 in the wet season. The higher levels of faecal coliform present in well A2 is due to an open vegetation around the well which animals usually feed on and defecate. This confirms the assertion made by Tiedemann *et al*. (1988), that the proximity of domestic and grazing animals to water sources play role in severity of faecal contamination of water sources.

The ranges of faecal coliforms recorded in this research were above the reported levels by Olowe *et al*. (2005) in hand dug well water samples.

Presence of faecal coliform in drinking water is associated with sewage or animal wastes. The large quantities of faecal coliform bacteria recorded in the wells exceeded WHO recommended limit of 0.0mg/L for drinking water. This is an indication of higher risk of pathogens being present in the water. Some waterborne pathogenic diseases include dysentery, typhoid fever, viral and bacterial gastroenteritis, and hepatitis A.

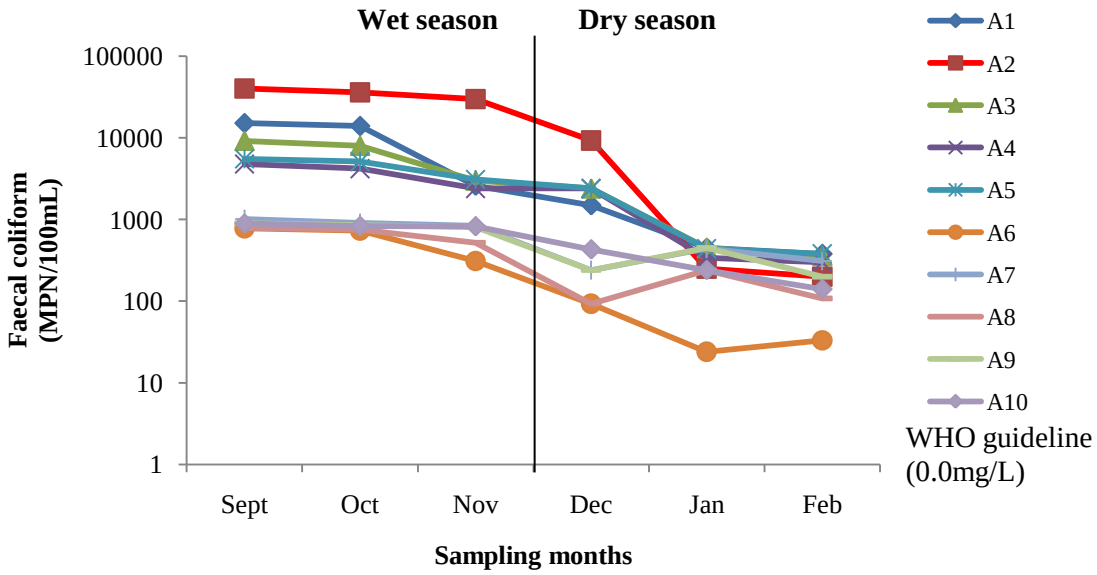


Figure 4.18: Faecal coliforms content of water from sampled wells Sept.2010- Feb.2011

4.2.3 Escherichia coli

Levels of *E. coli* in the wells showed a decreasing trend from the wet season to the dry season (Figure 4.19). *E. coli* in the wells for the wet season ranged from 26 - 2000MPN/100mL and 9 - 240MPN/100mL for the dry seasons. *E. coli* content in the wells was significantly higher in the wet season than in the dry season ($p = 0.029$). The levels of *E. coli* recorded in this research were below the reported values by Wright (1982).

According to WHO (2004), *E. coli* is present in very high numbers in human and animal faeces and its presence provides conclusive evidence of recent faecal pollution and should not be found in drinking water. Thus, its presence in the wells poses health risk to consumers. *E. coli* levels in the wells were above WHO permissible limit of 0.0mg/L for drinking water.

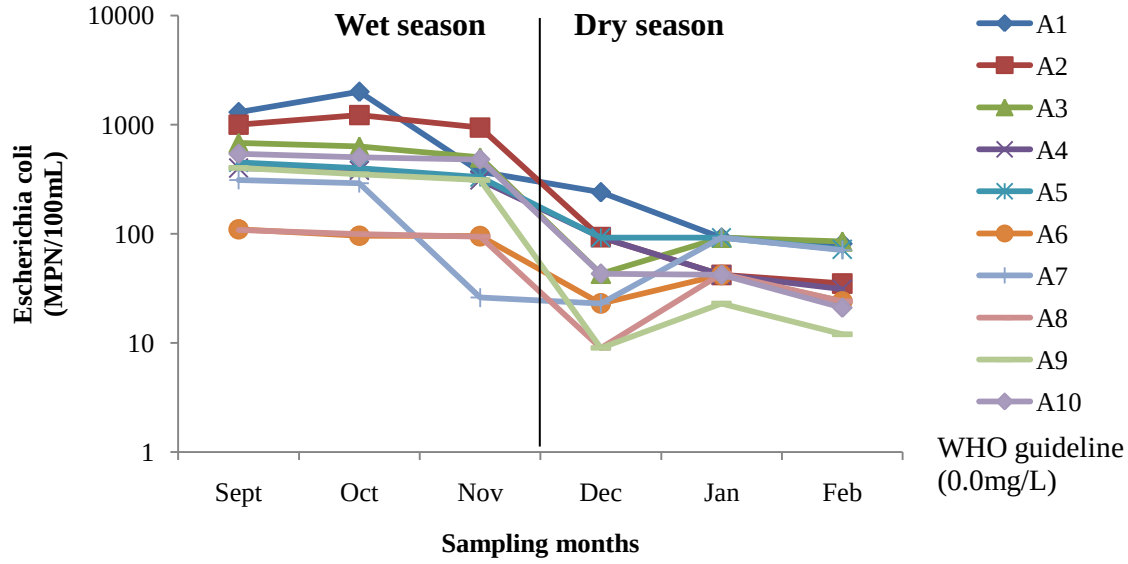


Figure 4.19: *E. coli* content of water from sampled wells Sept.2010 – Feb.2011

4.2.4 Salmonella

Concentration of Salmonella in the wells did not show any appreciable reduction from the wet season to the dry season with the exception of wells A2, A4 and A5 (Figure 4.20). In the dry and wet seasons, levels of *Salmonella* had ranges of 3 - 93MPN/100mL and 16 - 112MPN/100mL respectively. *Salmonella* content in the sampled wells was significantly higher in the wet season than in the dry seasoon ($p = 0.008$) with the

maximum levels mostly recorded in September showing the impact of rainfall on *Salmonella* in the wells.

Salmonella content obtained in the research far exceeded the reported values by Fasunwon (2008) and Wright (1982) in dug well water samples.

Salmonella typically gain entry into water systems through faecal contamination and when ingested poses several health risks including gastroenteritis, bacteraemia and typhoid fever (WHO, 2004).

Salmonella levels recorded in the wells were above WHO limit of 0.0mg/L for drinking water.

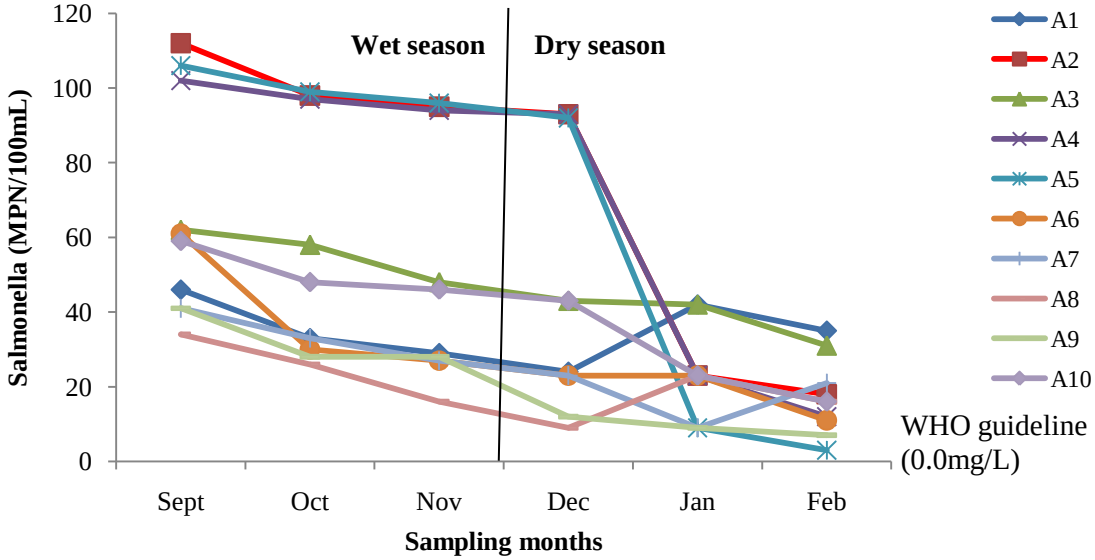


Figure 4.20: *Salmonella* content of water from sampled wells Sept. 2010 – Feb.2011

4.2.5 Enterococci

Levels of enterococci in the wells during the wet and dry seasons did not differ much although that of the wet season was relatively higher (Figure 4.21). Ranges of

enterococci in the wet season was 15 – 1460MPN/100mL and 5 – 978MPN/100mL in the dry season. In general, the concentration of enterococci showed a decreasing trend from the wet season to the dry season with a statistically significant difference between both seasons (p = 0.005). This shows the inconsistent levels of enterococci in the wells during both seasons. Intestinal enterococci, according to WHO (2004), are present in large numbers in sewage and water environments polluted by sewage or wastes from humans and animals. Thus, the high levels of enterococci in the wells indicate possible pollution by sewage and/or wastes from humans and animals. Enterococci levels in the wells were above WHO limit (0.0mg/L) for drinking water.

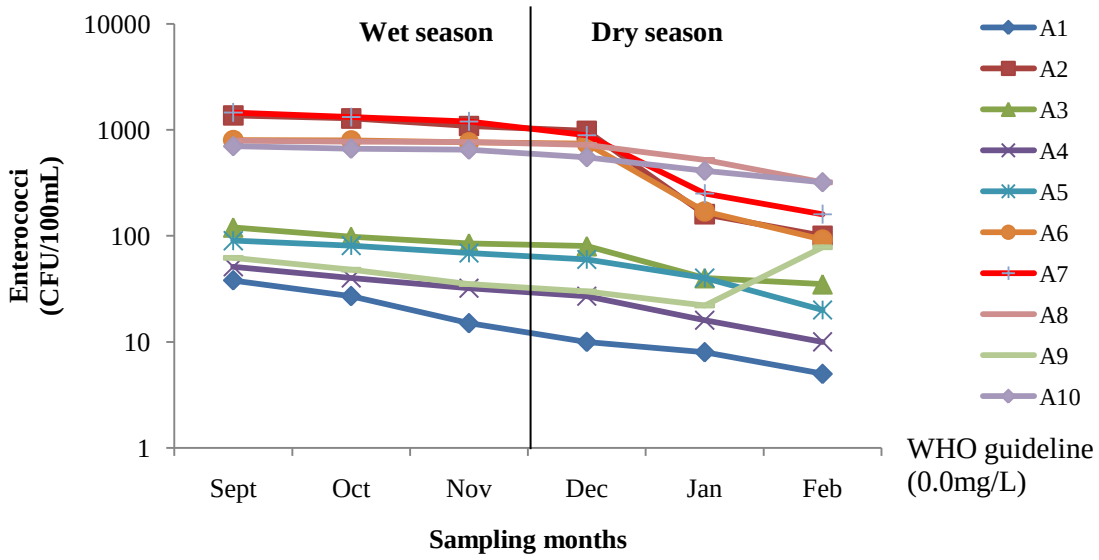


Figure 4. 21: Enterococci content of water from sampled wells Sept.2010 – Feb.2011

4.3 Relationship between bacteriological parameters and depth of sampled wells

Data was subjected to correlation analysis and the results show that, correlation between total coliform count and the depth of the wells depicted a moderately strong negative

correlation during both seasons (r = -0.6). This means that the total coliform count in the wells reduces as the depth of wells increases. Moreover, this indicates coliform levels in the wells increases with depth irrespective of the season.

The correlation between faecal coliform levels and the depth of the wells during the dry and wet seasons were somehow equivalent. Fairly strong negative correlation (r = -0.6) was recorded for both the dry and wet seasons respectively. This indicates that faecal coliforms in the wells increase with decreasing depth for both seasons.

*Salmonell*a counts in the wells showed a relatively weaker negative correlation (r = -0.4) between the depth of sampled wells in the wet season as compared to the dry season (r = -0.6). This indicates that for both seasons, the levels of *salmonella* in the wells increases with decreasing depth of the wells but it is relatively more pronounced in the dry season. The presence of *salmonella* in the wells could possibly emanate from the containers used to fetch the water since they were observed to be unclean during field surveys.

E. coli showed a relatively stronger negative correlation with the depth of the sampled wells in the dry season (r = -0.5) as compared to the wet season (r = -0.4). This means that the levels of *E. coli* in the wells increases with decreasing depth and the relative increment is higher in the dry season as compared to the wet season. Thus, shallow wells will have more levels of *E. coli* in the dry season than the wet season as compared to deep wells.

There was no correlation between enterococci and the depth of wells for both seasons (r = 0.2, dry season; r = 0.1, wet season). This finding contradicts that of Godfrey *et al*. (2006) who reported higher levels of enterococci in greater depth.

4.4 Relationship between bacteriological parameters and distance from sanitary facilities

Total coliform count in the wells showed a stronger negative correlation with distance from the sanitary facilities during the wet season (r = -0.6) as compared to the dry season (r = -0.5). This shows that total coliforms in the wells increases with decreasing distance from the sanitary facilities and this is higher during the wet season than the dry season. This observation was in line with the assertion made by Shittu *et al*. (2008), recording more coliforms in wells close to septic tanks and latrines.

Faecal coliform levels in the wells increases with decreasing distance from sanitary facilities especially in the wet season. Thus, there is a negative correlation between faecal coliforms and distance of well from sanitary facilities and is stronger during the wet season (r = -0.6) than the dry season (r = -0.4). This could be attributed to the ingress of coliforms through the soil during the wet season compared to the dry season. Adeyemi *et al*. (2004) and Adekunle *et al*. (2004) have also reported high feacal coliforms in dug wells water samples with increasing distance from pollution sources which confirms the findings of this research.

No correlation exists between the levels of *salmonella* in the wells and the distance from the sanitary facilities for the dry season (r = 0.1) but there was a positive correlation for the wet (r = 0.5) season. This indicates that *salmonella* counts in the wells increases with increasing distance from sanitary facilities especially in the wet season. However, this could be due to the fact that, the *salmonella* present in the wells are not emanating from the sanitary facilities but from elsewhere possibly the containers used in fetching water from the wells.

A strong negative correlation (r = -0.7) was obtained between the levels of *E. coli* and the distance of well from sanitary facilities indicating that wells closer to sanitary facilities had higher levels of *E. coli* as compared to those further away. Comparatively, the correlation was stronger in the wet season whiles no correlation existed in the dry season (r = -0.3). This implies that rainfall increases the ingress of *E. coli* through the soil into the wells thereby increasing coliform counts in the wells during the wet season. Levels of enterococci showed a weak negative correlation (r = -0.4) with distance of wells from sanitary facilities for both seasons indicating that wells closer to sanitary facilities have higher counts of enterococci. The constant correlation coefficient for both seasons indicates that changes in the seasons do not affect the correlation between the enterococci levels and the distance from sanitary facilities.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSIONS

The well water analyzed in the present study is suitable for drinking in terms of physico-chemical quality because the tested parameters were below WHO guideline values for drinking water except colour. On the other hand, there were high bacteriological indicator counts in samples of the wet season than the dry season which were extremely above WHO recommended guideline values for drinking water. Thus the well water in Atebubu bacteriologically, is not suitable for consumption and could be the major cause of the water borne infections in the area.

5.2 RECOMMENDATIONS

Due to extreme contamination of the wells, the following measures are proposed;

- Wells must be disinfected with hypochlorite.
- Receptacles for drawing water from the wells should be kept clean and away from contamination.
- Well lids/slabs must be kept dry and clean and should be made up as a single unit and not in fragments with openings at the joints to prevent water going through.
- Wells must be well lined with concrete rings as this would prevent the development of fissures within wells instead of cementing the upper 1 - 2 m
- Provision of hand pumps and maintenance will provide maximum protection as they seal off the well from external sources of contamination

- Construction of wells should be high above ground to prevent sinking of wells during wet periods
- Wells should be sited far away from septic tanks, latrines and rubbish dumps
- Access to wells by domestic and grazing animals should be restricted with an enclosure by fencing

REFERENCES

Addo, K. K., Mensah, G. I., Bokoe, M., Bonsu, C. and Akyeh, M. L. (2009). Bacteriological quality of sachet water produced and sold in Teshie – Nungua suburbs of Accra, Ghana. *African Journal of Food Agriculture Nutrition Development*. 9 : 1023 - 1024

Adefemi, S. O. and Awokumi, E. E. (2009). Determination of physico chemical parameters and heavy metals in water in water samples from Itaogbolu area of ondo- state. *Int. Journal of Natural and Applied Sciences.* 2 **(4):** 332-335

Adenkunle, M., Adekunle, M. T., Gbadebo, A. M. and Banjoko, B. A. (2007). Assessment of Hand dug Wells Water Quality in a Typical Rural Settlement in Southwest Nigeria. *Journal of Environmental Research and Public Health*. 4: 307 – 318.

Adetunde, L. A. and Glover, R. L. K. (2010). Bacteriological Quality of Borehole Water Used by Students of University for Development Studies, Navrongo Campus in Upper-East Region of Ghana. *Current Research Journal of Biological Sciences.* 2(6): 361-364.

Adeyemi, O., Odeyede, O. B. and Oladiji, A. T. (2004). Physico chemical and Microbial Characteristics of leachates of Hand-dug well water contamination. A Case Study in Ojota-Lagos, Nigeria. *J Health Popul Nutr*. 3: 351-358

All Africa.com: The supply side constraints of Ghana's water sector, 2006. allafrica.com/stories/200611281208.

Anim, F., Nyame, F. K. and Armah, T. K. (2010). Coliform status of water bodies from two districts in Ghana, West Africa. Implication for rural water resource management. IWA Publishers. Pp 1-12

APHA/AWWA/WEF (2003). Standard Methods for the Examination of Water and Wastewater. 20th Edition, Washington, D.C., New York.

Asubiojo, O. I., Nkono, N. A. Ogunsua, A. O., Oluwole, A. F., Wardi, N. I., Akanle, O. A. and Spyrou, N. M. (1997). Trace elements in drinking and groundwater samples in southern Nigeria. *The Science of the Total Environment*. 208 : 1- 8.

Atebubu District Health Directorate Annual Performance Report (2009). Water borne diseases morbidity 2007 to 2009.

Boamah, V. E., Gbedema, S. Y., Adu, F. and Ofori- Kwakye, K. (2010). Microbial quality of household water sources and incidence of diarrhoea in three peri-urban communities in Kumasi, Ghana. *Journal of Pharmaceutical Sciences and Researches*. 3: 1087- 1092

Chant, C. L., Zalifah, M. K. and Narrakiah, A. S. (2007). Microbiological and Physico-chemical Quality of Drinking Water. *Malaysian Journal of Analytical Science*. 11: 414-420.

Conway, P. L. (1995). Microbial ecology of the human large intestine. In: G. R. Gibson, and G. T. Macfarlane, (Eds). *Human colonic bacteria; role in nutrition, physiology and pathology*. CRC press, Boca Raton, FL. eds. pp.1 – 24

Corbit, R. A. (2004). Standard Handbook of Environmental Engineering. McGraw – Hill Companies. New York, USA. 2nd edition, pp 6-19.

Craun, G. F. (1985). Health aspects of groundwater pollution. In: V. Y. Marylynn, (Eds). Septic tank density and groundwater contamination. Environmental Research Laboratory, Ada, Oklahoma 74820

Dufour, A., Snozzi, M., Koster, W., Bartram, J., Ronchi, E. and Fawtrell, L. (2003). Assessing microbial safety of drinking water, improving approaches and methods, OECD, p.11.

Fasunwon, O., Olowofela, J., Akinyemi, O., Akintokun, O. (2008). Contaminants evaluation as water quality indicator in Ago- Iwoye, South - Western, Nigeria. *Africa Physical Review* 2 : 12- 14

Fleisher, J. M., Kay, D., Wyer, D. and Godfrey, A. F. (1998). Estimate of the severity of illness associated with bathing in marine recreational water contaminated with domestic sewage. *International Journal of Epidemiology*. 27: 722-726

Gadgil, A. (1998). Drinking water in developing countries. *Annual Review of Energy and the Environment*. 23: 253-286.

Godfrey, S., Timo, F. and Smith, M. (2006). Microbiological risk assessment and management of shallow groundwater sources in Lichinga, Mozambique. *Water and Environment Journal*. 2: 3- 4.

Greenwood, N. N. and Earnshaw, A. (1997), Chemistry of the Elements (2nd ed.), Oxford: Butterworth-Heinemann, ISBN 0080379419 p. 804

Health Canada (2007). Guidelines for Canadian Drinking Water Quality Supporting Documents.http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/doc_sup-appui/index_e.html

http://www.acu-cell.com/dis-can.html. Assessed as of 20/10/10 at 14GMT.

http://www.health.gov.sk.calcium//environmental-health. Assessed on 30/02/11

http://www.lenntech.com/periodic-chart-element.htm. As of 28/10/10 at 11.00 GMT

http://www.statcounter.com. Assessed on 21/10/10 at 18 GMT

http://www.vitamins-nutrition.org/mineral/index.html. Assessed on 13/10/10

http//www.statcounter.com. Assessed on 15/03/11

Ifayibi, I. P. (2009). Depth of Hand Dug Wells and Water Chemistry: Example from Ibadan Northeast Local Government Area (L. G. A.), Oyo-State, Nigeria. *Journal of Social Science*. 17:261-267.

Jin, G., Jeng, H. W., Bradford, H. and Englande, A. J. (2004). "Comparison of *E. coli*, enterococci, and fecal coliform as indicators for brackish water quality assessment". *Water Environ. Res*. 76 (3): 245–55

Kempster, P. L, Van Vliet, H. R. and Kuhn, A. (1997). The Need for Guideline to Bridge the Gap between Ideal Drinking Water Quality and Quality which is racticably Available and Acceptable. *Water SA.* 23:163 – 167.

Liu, D. (1999). *Environmental Engineers Handbook*. CRC press LLC. Florida, USA, Pp 539 – 546.

Mara, D. D. (2003). Faecal Indicator Organisms. In: S. Godfrey, F. Timo, and M. Smith, (Eds). Microbiological risk assessment and management of shallow groundwater sources in Lichinga, Mozambique. *Water and Environment Journal*. 3: 3 - 4.

McQuillan, D. (2004). Groundwater impacts from on-site septic systems. Proceedings of the National On-Site Wastewater Recycling Association. 13th Annual Conference Albuquer, N.M – USA.

Metcalf and Eddy, Inc. (2003). Wastewater Engineering Treatment and Reuse. McGraw – Hill, New York. 4th Edition, Pp 1, 10, 58, 69.

Musa, H. A., Shears, P., Kafi, S. and Elsabag, S. K. (1999). Water quality and public health in northern Sudan: a study of rural and peri - urban communities. *J. Appl. Microbiol*. 87: 676 - 682.

Nemerow, N. L., Agardy, J. F., Sullivan, P. and Salvato, J. A. (2009). Environmental Engineering: Water, Wastewater, Soil and Groundwater Treatment and Remediation. John Wiley and Sons Inc. New Jersey, USA. 6th edition. pp 55.

Nkansah, M. A., Boadu, N. O. and Badu, M. (2010). Assessment of quality of water from hand-dug wells in Ghana. *Environmental health insight*. 4 : 7- 11.

Obiri - Danso, B., Adjei, K. W., Stanley, K. N. and Jones, K. (2008). Microbiological Quality and Metal levels in Wells and Boreholes Water in some Peri - Urban Communities in Kumasi. *African Journal of Environmental Science and Technology.* 3: 59 – 66.

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 Biology. 37: 334.

Ogedengbe, K. (2004). Introduction to Agricultural Engineering. (1st Eds). Stirling, Horden Publishers. Ibadan, Nigeria. pp. 24- 25

Olobaniyi, S. B. (2007). Comparative assessment of rainwater and groundwater quality in an oil producing area of Nigeria: *Environmental and Health Implications*. 6 : 2 – 4.

Olowe, O. A., Ojurongbe, O., Opaleye, O. O., Adedosu, O. T., Olowe, R. A. and Eniola, K. I. T. (2005). Bacteriological quality of water in Osogbo metropolis. *African Journal of Clinical and Experimental Microbiology*. 6 : 220 - 221.

Omotoyinbo, O. S. (2007). Determination of the Level of Contamination of Underground Water (hand- dug well) by Organic Waste. *Ethiop. J. Education and Science on Chemical Safety*. 3: 33 – 37.

Oram, B., Halsor, S. and Redmond, B. (2010). Water Quality. Your private well: what do the results mean? Wilkes University. Wilkes-Barre, USA. Available online at www.wilkes.edu/water

Quist, K. A. (1999). Faecal indicators in drinking water in the urban area of Kumasi. M.Sc. dissertation, Biological Sciences, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Rubenowitz, E., Gosta, A. and Ragnar, R. (1996). Magnesium in Drinking Water and Death from Acute Myocardial Infarction. *American Journal of Epidemiology* 143: 456 - 462

Ryan, K . J. and Ray, C. G. (2004). Sherris Medical Microbiology (4th ed). McGraw Hill. Pp. 29-34

Salvato, J. A., Nemerow, N. and Agardy, F. (2003). Environmental Engineering. John Wiley and Sons, Inc. New Jersey, USA. 5th Edition. pp 257, 538, 570.

Saris, N. E., Mervaala, E. K., Khawaja J. A. and Lewenstam, A. (1996). Magnesium: an update on physiological, clinical, and analytical aspects. *Clinica Chimica Acta* ; 294:1-26.

Shittu, O. B., Olaiton, J. O. and Amusa, T. S. (2008). Physico-chemical and bacteriological analysis of water used for drinking and swimming purposes in Abeokuta, Nigeria. *Africa Journal of Biomedical Research*. 11: 285–290

Spellman, R. F. (2003). Handbook of water and wastewater treatment plant operations. Lewis Publishers, CRC Press Company. Florida, USA, pp 547, 551.

Spellman, R. F. (2008). The Science of Water: Concepts and Applications. CRC Press, Taylor and Francis Group. Florida, USA. 2nd edition, pp 112

Tiedemann, A. R., Higgins, D. A., Quigley, T. M., Sanderson, H. R. and Bohn, C. C. (1988). Bacterial water quality responses to four grazing strategies comparisons with Oregon standards. *J. Environ.* 17: 492 - 498.

Tjandraatmadja, G., Pollard, C., Sheedy, C. and Gozukara, Y. (2010). Sources of Contaminants in Domestic Wastewater: Nutrients and Additional Elements from Household Products. CSIRO: Water for a Healthy Country National Research Flagship, Australia. 12 - 13.

Toranzos, G. A. and McFeters, G. A. (1997). Detection of indicator microorganisms in environmental freshwater and drinking water. *Applied and Environmental Microbiology*. 73: 953 - 960

U.S. EPA (2005). National measure to control non- point source pollution from urban areas. EPA 841-B-05-004. Washington, D.C.

USDA (2003). Nutrient Database for Standard Reference, Release 16. Nutrient Data Laboratory. http://www.nal.usda.gov/fnic/foodcomp

Wester, P. O. (1987). Magnesium. *Am J Clin Nutr* 45: 1305-12.

WHO (1984). Guidelines for Drinking Water Quality. Volume 1, WHO - Geneva

WHO (1998). Guidelines for drinking water quality. Health criteria and other supporting information. Geneva: World Health Organization. Vol. 2. WHO/OECD, p.11

WHO (2003). Chloride in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality. Geneva, World Health Organization. (WHO/SDE/WSH/03.04/3).

WHO (2003). Fluoride in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality. Geneva, World Health Organization

Wikipedia Encyclopedia (2010). The Columbia Electronic Encyclopedia. Sixth Edition. Columbia University Press. Licensed from Columbia University Press. www.cc.columbia.edu/cu/cup/.

WHO (2004). Guidelines for Drinking-water Quality. Volume 1 WHO - Geneva.

Wright, R. C. (1982). A comparism of levels of feacal indicator bacteria in water and human faeces in a rural area of a tropical developing country (Sierra Leone). *Journal of Hygiene.* 88: 265 - 273

APPENDICES

APPENDIX 1: RESULTS

pH values

Month	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sep	6.6	6.7	6.5	6.49	6.47	6.64	6.53	6.38	7.68	7.87
Oct	6.5	6.61	6.46	6.44	6.42	6.59	6.48	6.33	7.18	7.37
Nov	5.85	5.89	6.07	6.1	6.29	6.12	5.99	6.05	6.22	6.04
Dec	9.81	9.27	7.57	5.92	8.91	8.91	8.78	8.47	8.33	8.87
Jan	9.85	9.3	7.6	6.2	8.95	8.93	8.8	8.5	8.64	8.9
Feb	6.45	6.4	6.43	6.31	6.9	6.75	6.42	6.48	6.95	7.29
Range	5.85 - 9.85									

TURBIDITY (NTU)

Months	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	3.92	3.8	2.97	3.13	4.85	3.23	3.12	3.48	1.43	2.52
Oct.	4.42	3.85	3.47	3.63	4.9	3.73	3.62	3.98	1.93	3.02
Nov.	4.7	4.09	4.09	2.38	9.99	5.07	3.69	4.22	2.74	3.92
Dec.	6.06	6	2.93	2.59	4.92	7.73	6.88	6.37	5.06	2.64
Jan.	6.6	6.2	3.4	3.23	5	7.9	7.64	6.87	6.75	4.53
Feb.	6.51	8.57	6.87	16.9	8.5	9.4	9.23	6.1	7.33	5.9
Range	1.43 - 9.9									

CONDUCTIVITY (µS/cm)

Month	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	230	234	215	228	208	250	210	217	324	398
Oct.	222	225	208	221	199	243	202	209	317	392
Nov.	208	205	192	174	188	219	149	177.7	208	170.3
Dec.	138	176	148	30.1	167	84	138	118	105	126
Jan	128	120	104	27	138	79	130	115	101	119
Feb.	131	130	140	100	151	142	136	98	351	221
Range	27 - 398									

COLOUR (Hz)

Month	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	40	36	32	58	60	52	38	44	30	21
Oct.	34	31	29	54	53	47	34	41	26	13
Nov.	24	15	9	6	78	29	15	25	14	20
Dec.	20	15	6	5	6	26	20	19	13	6
Jan.	16	12	6	4	5	28	19	11	15	17
Feb.	18	24	17	36	52	27	26	83	7	105
Range	4 - 105									

CALCIUM (Mg/l)

Months	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	24.6	29.6	20.2	19.3	18.4	19.2	19.8	20.7	39.8	21.1
Oct.	21.6	25.6	16.8	16	14.4	15.2	15.2	17.6	36.8	17.6
Nov.	18.4	28	32	33.6	44.8	50.4	58.4	54.4	53.6	40
Dec.	9.6	13.6	14.4	12.8	15.2	12	15.2	12.8	13.6	6
Jan	8.4	11	12	9	13	10	14.3	11.5	12	18
Feb	5.6	4	32	4.8	13.6	19.2	11.2	6.2	31.2	24.6
Range	4 - 58.4									

MAGNESIUM (Mg/l)

Months	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	5.91	4.9	8.81	5.4	8.31	6.85	6.9	5.41	10.73	6.87
Oct	5.83	4.86	8.75	5.34	8.26	6.8	6.8	5.35	10.69	6.8
Nov	0.97	4.62	1.94	3.89	8.23	3.4	3.4	10.69	30.62	37.91
Dec	5.8	2.9	2.4	0.4	1.9	0.5	1.4	1.9	3.4	1.4
Jan	1	2.5	2	3.1	1.2	6.7	1.5	1.7	3	1
Feb	7.2	4.8	5.8	6.3	17.9	5.3	3.8	2.9	16.5	7.7
Range	0.4 - 37.81									

IRON (Mg/l)

Month	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	0	0	0	0	0	0	0	0	0	0
Oct.	0	0	0.2	0	0	0	0	0	0	0
Nov.	0	0	0	0	0	0	0	0	0	0
Dec.	0	0	0	0	0	0	0	0	0	0
Jan	0	0	0	0	0	0	0	0	0	0
Feb.	0	0	0		0	0	0	0	0	0
Range	0 - 0.2									

CHLORIDE (Mg/l)

Month	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	71	75	89	100	93	93	77	45	47	38
Oct.	66	70	84	96	88	88	72	40	42	32
Nov.	36	38	28	48	52	36	36	40	38	44
Dec.	42	40	42	30	36	28	34	30	30	26
Jan.	39	38.6	40	28.5	34.4	25.4	30.3	30	23	20
Feb.	58	40	50	50	51	55	45	31	64	48
Range	20 - 100									

FLUORIDE (Mg/l)

Months	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	2.2	2.1	2.11	2.14	2.15	0.36	0.4	0.54	0.63	0.4
Oct.	1.2	1.2	1.1	1.15	1.15	0.3	0.35	0.5	0.6	0.35
Nov.	1.1	1.2	1.1	1.15	1.1	0.3	0.35	0.5	0.55	0.3
Dec.	0.15	0.25	0.25	0.1	0.15	0.25	0.45	0.25	0.15	0.15
Jan	0.13	0.2	0.13	0.05	0.16	0.12	0.15	0.25	0.09	0.13
Feb	0.1	0.2	0.13	0.03	0.14	0.1	0.13	0.24	0.05	0.1
Range	0.05 - 2.2									

NITRATE (Mg/l)

Months	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	4.23	2.91	1.28	4.45	4.23	4.43	4.23	4.45	4.46	4.47
Oct	4.18	2.86	1.23	4.4	4.18	4.4	4.18	4.4	4.4	4.4
Nov	4.16	2.8	1.2	4.36	4.2	4.4	4.12	4.36	4.2	4.3
Dec	4.1	1.22	0.34	3.86	2.1	3.2	2.13	2.13	4.18	4.28
Jan	3.17	0.9	0.2	3	1.8	3	1.9	1.9	4	4.13
Feb	4	1.2	0.8	2.12	1.3	2.3	1.56	1.13	3.25	3.28
Range	0.2 - 4.5									

NITRITE (Mg/l)

Month	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	0.004	0.001	0.003	0.005	0.002	0.003	0.021	0.004	0.004	0.005
Oct.	0.001	0	0.002	0.004	0.001	0.001	0.011	0.002	0.002	0.002
Nov.	0.002	0.002	0.004	0.004	0.004	0.008	0.02	0.003	0.008	0.004
Dec.	0.01	0.005	0.006	0.003	0.013	0.006	0.012	0.012	0.004	0.004
Jan	0.005	0.01	0.002	0.002	0.006	0.004	0.023	0.003	0.005	0.007
Feb.	0.002	0.004	0.002	0.005	0.2	0.004	0.002	0.004	0.002	0.005
Range	0 - 0.2									

SULPHATE (Mg/l)

Month	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	11	12	10	10	9	8	10	10	7	8
Oct.	9	10	8	8	7	8	8	5	5	0
Nov.	7	5	3	7	5	7	7	8	5	5
Dec.	3	0	0	0	0	5	3	3	0	0
Jan.	2	3	3	5	6.2	3.6	3	1	1.5	1.2
Feb.	0	0	0	3	3	0	0	7	0	10
Range	0 - 12									

Ammonia (mg/L)

		AMMONIA							
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
SEPT	0	0	0.99	0.056	0	0	0.03	0	0	0
OCT	0	0	0.96	0.024	0	0	0	0	0	0
NOV	0.02	0.02	0.094	0.02	0.01	0	0.01	0	0.01	0.1
DEC	0	0	0.01	0	0	0	0	0	0	0
JAN	0	0	0.01	0	0	0	0.02	0	0.01	0.1
FEB	0.01	0	0	0.01	0	0	0	0	0.01	0.01

PHOSPHATE (Mg/l)

Months	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	2.54	2.4	2.1	2.52	2.2	2.36	2.25	2.58	0.4	0.91
Oct.	2.49	2.36	2	2.49	2.13	2.31	2.2	2.53	0.3	0.86
Nov.	2.21	2.06	2.1	2.08	2.16	2.32	2.3	2.16	0.18	0.16
Dec.	2.1	0.3	1.86	2.1	2.3	2.2	2.1	0.48	0.86	0.45
Jan	1.6	2.06	2.3	2	2.1	2.15	2.3	1.4	0.74	0.4
Feb	2.2	0.41	0.86	2.1	2.3	2	2	0.68	0.86	0.4
Range	0.3 - 2.6									

TOTAL SOLIDS (Mg/l)

Months	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	125	123	110	113	111	130	108	111	163	200
Oct	111	112	104	105	100	121	101	105	159	196
Nov	101	101	96	86	93	105	73	88	101	84
Dec	87	82	71	73	79	43	72	60	53	61
Jan	70	75	73	69	71	39	71	65	47	54
Feb	67	68	77	63	112	102	70	69	224	146
Range	43 - 224									

TOTAL DISSOLVED SOLIDS (Mg/l)

Months	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	115	117	110	111	104	125	106	110	161	194
Oct.	110	111	103	104	99	100	100	95	85	92
Nov.	100	100	95	85	92	98	72	87	100	83
Dec.	85	81	70	14	78	39	69	57	49	60
Jan	71	64	56	11	60	37	41	50	31	34
Feb	64	63	53	53	99	94	67	44	80	126
Range	11 - 194									

TOTAL HARDNESS (Mg/L)

Months	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	85	92	83	65	74	70	71	72	140	75
Oct	78	84	78	62	70	66	66	66	136	72
Nov	50	89	75	59	68	63	58	60	100	70
Dec	48	46	42	34	46	32	44	40	48	54
Jan	43	42	39	32	42	25	33	36	42	45
Feb	44	30	32	30	108	70	44	28	146	98
Range	25 - 146									

BACTERIOLOGICAL PARAMETERS

TOTAL COLIFORM (MPN/100ML)

Months	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	7.0×10^5	9.1×10^5	2.52×10^5	7.0×10^4	6.5×10^5	1.2×10^3	7.9×10^3	5.6×10^3	$4.92 \times 1\,0^3$	8.65×10^3
Oct.	6.0×10^5	8.5×10^5	2.1×10^5	6.7×10^4	5.3×10^5	9.5×10^2	7.4×10^3	5.1×10^3	4.5×10^3	8.3×10^3
Nov.	4.9×10^5	7.7×10^5	1.4×10^5	3.0×104	4.1×10^5	7.4×10^2	4.2×10^3	3.3×10^3	2.8×10^3	6.0×10^3
Dec.	2.4×10^5	2.4×10^5	9.3×10^4	2.1×10^3	2.4×105	$4.3 \times 1\,0^2$	3.4×10^3	1.5×10^3	1.521×10^3	4.3×10^3
Jan	$4.5 \times$	$5.2 \times$	$4.4 \times$	$3.4 \times$	$4.5 \times$	$5.2 \times$	$2.3 \times$	$1.3 \times$	1.2×10^3	1.8×10^3

	10^4	10^4	10^3	10^4	10^4	10^3	10^3	10^3		
Feb	3.6×10^4	4.7×10^3	4.0×10^3	2.4×10^4	3.0×10^4	4.3×10^3	1.2×10^3	1.01×10^3	9.2×10^3	1.3×10^3
Range	4.3×10^2 - 9.1×10^5									

FAECAL COLIFORM (MPN / 100ML)

Months	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	1.52×10^4	4.02×10^4	9.2×10^3	4.8×10^3	5.514×10^3	7.8×10^2	1.01×10^3	7.91×10^2	9.01×10^2	8.9×10^2
Oct.	1.4×10^4	3.62×10^4	8.0×10^3	4.2×10^3	5.122×10^3	7.3×10^2	9.1×10^2	7.5×10^2	8.5×10^2	8.3×10^2
Nov.	2.6×10^3	3.0×10^4	3.0×10^3	2.4×10^3	3.112×10^3	3.1×10^2	8.4×10^2	5.2×10^2	8.05×10^2	8.25×10^2
Dec.	1.5×10^3	9.3×10^3	2.4×10^3	2.4×10^3	2.4×10^3	9.3×10^1	2.4×10^2	9.3×10^1	2.4×10^2	4.3×10^2
Jan	$4.5 \times$	2.5	$4.5 \times$	$3.4 \times$	$4.4 \times$	$2.4 \times$	$4.4 \times$	2.40	4.5	$2.4 \times$
Feb	3.8×10^2	2.0×10^2	3.6×10^2	3.0×10^2	3.8×10^2	3.3×10^1	3.1×10^2	1.08×10^2	2.0×10^2	1.4×10^2
Range	2.4×10^1 - 4.02×10^4									

ESCHERICHIA COLI (MPN/ 100ML)

Months	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	1.3 x 10^3	2.0 x 10^3	6.8 x 10^2	4. 0 x 10^2	4.5 x 10^2	1. 1 x 10^2	3.1 x 10^2	1.08 x 10^2	4.01 x 10^2	5.39 x 10^2
Oct.	1.0 x 10^3	1.22 x 10^3	6.3 x 10^2	3.8 x 10^2	4.0 x 10^2	9.6 x 10^1	2.9 x 10^1	9.9 x 10^1	3.5 x 10^2	5.0 x 10^2
Nov.	3.7 x 10^2	9.4 x 10^2	5.0 x 10^2	3.1 x 10^2	3.3 x 10^1	9.5 x 10^1	2.6 x 10^1	9.4 x 10^1	3.1 x 10^2	4.8 x 10^2
Dec.	2.4 x 10^2	9.3 x 10^1	4.3 x 10^1	9.3 x 10^1	9.2 x 10^1	2.3 x 10^1	2.3 x 10^1	9.0 x 10^0	9.0 x 10^0	4.3 x 10^1
Jan	9.2 x 10^1	4.2 x 10^1	9.2 x 10^1	4.2 x 10^1	9.2 x 10^1	4.2 x 10^1	9.2 x 10^1	4. 3 x 10^1	2.3 x 10^1	4.2 x 10^1
Feb	8.1 x 10^1	3.5 x 10^1	8.5 x 10^1	3.1 x 10^1	7.2 x 10^1	2.4 x 10^1	7.1 x 10^1	2.4 x 10^1	1.2 x 10^1	2.1 x 10^1
Range	9.0 x 10^0 - 2.0 x 10^3									

Salmonella (MPN/100ML)

Months	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	4.6×10^1	1.12×10^2	6.2×10^1	1.02×10^2	1.06×10^2	6.1×10^1	4.1×10^1	3.4×10^1	4.1×10^1	5.9×10^1
Oct.	3.3×10^1	9.8×10^1	$5.8 \times$	$9.7 \times$	$9.9 \times$	$3.0 \times$	$3.3 \times$	$2.6 \times$	$2.8 \times$	$4.8 \times$
Nov.	2.9×10^1	9.5×10^1	4.8×10^1	9.4×10^1	9.6×10^1	2.7×10^1	2.7×10^1	1.6×10^1	2.8×10^1	4.6×10^1
Dec.	2.4×10^1	9.3×10^1	4.3×10^1	9.3×10^1	9.2×10^1	2.3×10^1	2.3×10^1	9.0×10^0	1.2×10^1	4.3×10^1
Jan	4.2×10^1	2.3×10^1	4.2×10^1	2.3×10^1	9.0×10^0	2.3×10^1	9.0×10^0	2.3×10^1	9.0×10^0	2.3×10^1
Feb	3.5×10^1	1.8×10^1	3.1×10^1	1.2×10^1	3.0×10^0	1.1×10^1	2.1×10^1	1.6×10^1	7.0×10^0	1.6×10^1
Range	3×10^0 - 1.12×10^2									

ENTEROCOCCI (CFU/100ML)

Months	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sept.	3.8 x 10^1	1.37 x 10^3	1.2 x 10^2	5.1 x 10^1	9.0 x 10^1	8.02 x 10^2	1.46 x 10^3	7.91 x 10^2	6.2 x 10^1	7.01 x 10^2
Oct.	2.7 x 10^1	1.28 x 10^3	9.8 x 10^1	4.0 x 10^1	8.1 x 10^1	7.94 x 10^2	1.32 x 10^3	7.75 x 10^2	4.8 x 10^1	6.63 x 10^2
Nov.	1.5 x 10^1	1.09 x 10^3	8.5 x 10^1	3.2 x 10^1	6.9 x 10^1	7.62 x 10^2	1.20 x 10^3	7.0 x 10^2	3.5 x 10^1	6.5 x 10^2
Dec.	1.0 x 10^1	9.78 x 10^2	8.0 x 10^1	2.7 x 10^1	6.0 x 10^1	7.4 x 10^2	8.9 x 10^2	7.2 x 10^2	3.0 x 10^1	5.51 x 10^2
Jan	8 x 10^0	1.6 x 10^0	4.0 x 10^1	1.6 x 10^1	4.0 x 10^1	1.7 x 10^2	2.5 x 10^2	5.2 x 10^2	2.2 x 10^1	4.1 x 10^2
Feb	5.0 x 10^0	1.0 x 10^0	3.5 x 10^1	1.0 x 10^1	2.0 x 10^1	9.2 x 10^1	1.6 x 10^2	3.2 x 10^2	7.8 x 10^1	3.2 x 10^2
Range	5.0 x 10^0 – 1.46 x 10^3									

APPENDIX 2 : WHO Guideline Values for some Physico-Chemical and Bacteriological Parameters

pHYSICO – CHEMICAL PARAMETERS	WHO GUIDELINE VALUES
pH	6.5 – 8.5
Turbidity (NTU)	0 - 5
Colour (Hz)	0 - 15
Calcium	200
Magnesium	150
Iron	0 – 0.3
Manganese	0.1
Chloride	250
Fluoride	1.5
Nitrite	3.0 Max
Nitrate	50.0 Max
Sulphate	250
Phosphate	400
Ammonia	1.5
Total Dissolved solids	1000
Total Hardness	500
Bacteriological parameters	
Total coliform	0.0

Faecal coliform	0.0
Escherichia coli	0.0
Salmonella	0.0
Enterococci	0.0

APPENDIX 3: Results of Statistical Analysis

Results of T-test for seasonal variation of parameters

Physico-chemical Parameters	**p-value for T-test at α = 5%**
1. pH	0.006
2. Turbidity	0.018
3. Colour	0.014592
4. Conductivity	0.005
5. Total Dissolved Solids	0.017592
6. Total Solids	0.016
7. Calcium Hardness	0.009
8. Magnesium Hardness	0.00665
9. Total Hardness	0.007
10. Nitrogen-ammonia	0.060868*
11. Nitrogen-nitrate	0.034
12. Nitrogen-nitrite	0.082484*
13. Fluoride	0.008
14. Phosphate	0.022875

15. Sulphate	0.036
16. Chloride	0.016
Bacteriological Parameters	**p-value for T-test at α = 5%**
17. *Escherichia coli*	0.029
18. Salmonella	0.008
19. Enterococci	0.005158
20. Faecal coliforms	0.003464
21. Total coliforms	0.001395

*p-value > 0.05; seasonal variation not statistically significant

Relationship between bacteriological parameters and depth of sampled wells

Total coliform

Well	Dry season	Depth	Wet season	Depth
A1	107000	3.5	596666.7	3.5
A2	98900	3	843333.3	3
A3	47000	3.8	200666.7	3.8
A4	20033.3333	3.6	55666.67	3.6
A5	105000	4.3	530000	4.3
A6	3310	6	963.3333	6
A7	2300	5	6500	5
A8	1270.66667	3.5	4666.667	3.5
A9	1213.66667	6	4073.333	6

A10	2466.66667	7.4	7650	7.4
Correlation coefficient, r	-0.6		-0.6	

Faecal coliform

Well	Dry season	Depth	Wet season	Depth
A1	776.666667	3.5	10600	3.5
A2	3250	3	23406.67	3
A3	1070	3.8	6733.333	3.8
A4	1013.33333	3.6	3800	3.6
A5	1073.33333	4.3	4582.667	4.3
A6	50	6	606.6667	6
A7	330	5	921	5
A8	147	3.5	687	3.5
A9	296.666667	6	852	6
A10	270	7.4	848.3333	7.4
Correlation coefficient, r	-0.6		-0.6	

Escherichia coli

Well	Dry season	Depth	Wet season	Depth
A1	137.666667	3.5	890	3.5
A2	56.6666667	3	973.3333	3
A3	73.3333333	3.8	603.3333	3.8
A4	55.3333333	3.6	363.3333	3.6
A5	85.3333333	4.3	393.3333	4.3
A6	29.6666667	6	100.3333	6
A7	62	5	208.6667	5
A8	25.3333333	3.5	100.3333	3.5
A9	14.6666667	6	353.6667	6
A10	35.3333333	7.4	506.3333	7.4
Correlation coefficient, r	-0.5		-0.4	

Salmonella

Well	Dry season	Depth	Wet season	Depth
A1	33.6666667	3.5	36	3.5
A2	44.6666667	3	101.6667	3
A3	38.6666667	3.8	56	3.8
A4	42.6666667	3.6	97.66667	3.6
A5	34.6666667	4.3	100.3333	4.3
A6	19	6	39.33333	6

A7	17.6666667	5	33.66667	5
A8	16	3.5	25.33333	3.5
A9	9.33333333	6	32.33333	6
A10	27.3333333	7.4	51	7.4
Correlation coefficient, r	-0.6		-0.4	

Enterococci

Well	Dry season	Depth	Wet season	Depth
A1	7.66666667	3.5	26.66667	3.5
A2	412.666667	3	1246.333	3
A3	51.6666667	3.8	101	3.8
A4	17.6666667	3.6	41	3.6
A5	40	4.3	80	4.3
A6	334	6	786	6
A7	433.333333	5	1328	5
A8	520	3.5	778.6667	3.5
A9	43.3333333	6	48.33333	6
A10	427	7.4	671.3333	7.4
Correlation coefficient, r	0.2		0.1	

Well	Dry season	Distance	Wet season	Distance
A1	107000	9.2	596666.7	9.2
A2	98900	8	843333.3	8
A3	47000	7.3	200666.7	7.3
A4	20033.33	17.3	55666.67	17.3
A5	105000	12.4	530000	12.4
Correlation coefficient, r	-0.5		-0.6	

Relationship between bacteriological parameters and distance from sanitary facilities.

Total coliforms

Faecal coliforms

Well	Dry	Distance	Wet	Distance
A1	776.6667	9.2	10600	9.2
A2	3250	8	23406.67	8
A3	1070	7.3	6733.333	7.3
A4	1013.333	17.3	3800	17.3
A5	1073.333	12.4	4582.667	12.4
Correlation coefficient, r	-0.4		-0.6	

Escherichia coli

Well	Dry season	Distance	Wet season	Distance
A1	137.6667	9.2	890	9.2
A2	56.66667	8	973.3333	8
A3	73.33333	7.3	603.3333	7.3
A4	55.33333	17.3	363.3333	17.3
A5	85.33333	12.4	393.3333	12.4
Correlation coefficient, r	-0.3		-0.7	

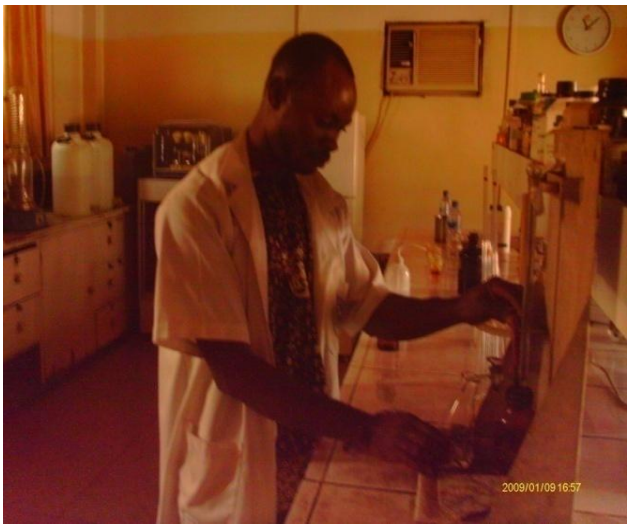
Salmonella

Well	Dry	Distance	Wet	Distance
A1	33.66667	9.2	36	9.2
A2	44.66667	8	101.6667	8
A3	38.66667	7.3	56	7.3
A4	42.66667	17.3	97.66667	17.3
A5	34.66667	12.4	100.3333	12.4
Correlation coefficient, r	0.1		0.5	

Enterococci

Well	Dry season	Distance	Wet season	Distance
A1	7.666667	9.2	26.66667	9.2
A2	412.6667	8	1246.333	8
A3	51.66667	7.3	101	7.3
A4	17.66667	17.3	41	17.3
A5	40	12.4	80	12.4
Correlation coefficient, r	-0.4		-0.4	

APPENDIX 4: Some Laboratory Analytical Processes



Physico chemical process

Bacteriological process