KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

INSTITUTE OF DISTANCE LEARNING

PHYSICO-CHEMICAL AND BACTERIOLOGICAL ASSESSMENT OF SELECTED BOREHOLES AND HAND-DUG WELLSIN NEW EDUBIASE, ASHANTI REGION

MARCH, 2013

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A Thesis Submitted to the Department of Theoretical and Applied Biology

In Partial Fulfillment of the Requirement for the Award of

Master of Science Degree

IN

ENVIRONMENTAL SCIENCE

NKRUMAH KARIKARI BERNARD

(PG4179210)

MARCH 2013

DECLARATION

I declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the qualification of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made.

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DEDICATION

This work is dedicated to my unborn child

ABSTRACT

This study was carried out to assess the physicochemical and bacteriological quality of water from 5 boreholes and 5 hand-dug wells within the town's main residential areas. 60 water samples were collected from 5 main residential areas within the town from November 2011 to April 2012 and analysed for physicochemical characteristics and microbial quantity and quality. Total coliforms, faecal coliforms, salmonella and enterococci were enumerated using the standard most probable number method. The other parameters were also determined by various standard methods of water analysis. Total and faecal coliforms count in the borehole samples ranged from a mean of 7 to 142CFU/100mL and 2 to 55CFU/100mL respectively. For the hand-dug well samples, mean numbers of total coliforms, faecal coliforms and enterococci counts ranged from 293 to 5267CFU/100mL, 87 to 175 CFU/100mL and 1 to 21CFU/100ml respectively. All samples tested did not meet the GSB/WHO bacteriological standards for drinking water. However, the physicochemical parameters measured were within the GSB/WHO acceptable levels for drinking water. Generally the boreholes were comparatively better in quality than the hand-dug wells. Sanitary surveillance revealed that 5 of the sampling points were littered with eitheranimal and fowl droppings, or septic tanks/latrines were near the sampling points. The surrounding environments near most of the hand-dug wells were unkept and dirty. The presence ofTotal coliforms, Faecal coliforms and *Enterococci* should particularly raise serious public health concerns over the quality of the town's boreholes and hand-dug wells. Intervention measures including creating awareness and educating residents on borehole and hand-dug well construction, siting and care, boiling of water and improving sanitation should be urgently instituted.

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CHAPTER ONE

INTRODUCTION

Water is an indispensible resource for life quality and subsistence. In many developing countries, availability of water has become a critical and urgent problem and it is a matter of great concern to families and communities depending on non-public water supply system (Okonko *et al*., 2008; Agbabiaka and Sule, 2010). Globally however, 1.1 billion people, mostly in developing countries, do not have access to safe water and 2.4 billion have no access to sanitation facilities (WHO/UNICEF, 2000). Water scarcity becomes a severe concern to most sub-Saharan African countries (Osei-Asare, 2004) and Rosen and Vincent, (1999) indicated that 67% of the rural population have no access to safe water supply while 81% do not have access to sanitation services. Surface water bodies are highly vulnerable to contamination due to natural alteration and anthropogenic intervention. In the long term, groundwater resources are reliable, consistent, safe, and more importantly accessible to people.

Mygatt (2006) estimated that about 2 billion people in urban and rural communities worldwide depend on groundwater for their daily consumption. Groundwater is often the sole water resource in arid and semi-arid regions; therefore the assessment of quantity and quality of groundwater is vital (Anayah, 2006). Such an assessment will provide better understanding of the dynamics of groundwater for sustainable use and help in planning and management of such resources.

Water resources in Ghana play a central role in the promotion of living standards, enhancing economic growth, provision of food security and livelihood, and eventually alleviation of poverty. As in most parts of the world, Ghana is also experiencing population growth and associated demand on food production. Therefore, demand on water increases steadily while producing stress on available water resources. In addition,

climate change impacts on the limited water resources in semi-arid regions can be significant (Herrera-Pantoja and Hiscock, 2008).

A number of authors have reported significant deterioration in microbiological quality of water between the source and the point of use in homes and that drinking water should be examined on physico-chemical and microbiological quality (Chant *et al.*, 2007). According to World Health Organisation (WHO., 1998), there were estimated 4 billion cases of diarrhoea and 2.2 million cases of death annually and the consumption of unsafe drinking water has been implicated as the major cause of this incidence.

Groundwater serves as the alternative source of water largely due to shortage of piped water or its erratic supply. Groundwater is water held within the interconnected openings of saturated rock beneath the land's surface. The constant movement of this water is often called "the hydrologic cycle". For this category of water, protection of the sources by lining and covering, diversion of surface drainage, catchment protection to restrict human and animal access and paving of surroundings have been recommended as means of preventing pollution of the water.

The suitability of ground water for drinking purpose largely depends on the concentration of biological, chemical and physical contaminants as much as environmental and human activities. Chemicals pollute water supply through industrial process and agrochemical applications while physical contaminants result from erosion and disposal of solid wastes. These sources contribute to deterioration of drinking water quality standards thereby degenerating into prohibitive water pollution situations. Consequently, water borne diseases such as typhoid, cholera, diarrhoea and dysentery become potentially communicable (Musa et., 1999). Drinking water quality must be within tolerable use-limits for human consumption.

In Ghana, the supply of piped water is inadequate in most communities. This inadequacy is both quantitative and qualitative. Those who do not have access to safe water, as well as those who have access but cannot afford, rely on other sources of water with questionable quality. The microbiological quality of drinking water remains a concern to consumers and water suppliers, regulators and public health authorities. The potential of drinking water to transmit microbial pathogens to great number of people causing subsequent illness is well documented in many countries at all levels of economic development (Dufuor *et al*., 2003). The number of outbreaks that have been reported throughout the world demonstrates that transmission of pathogens by drinking water remains a significant cause of illness.

The most reliable source of drinking water is bottled water which is 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).

Groundwater has become the major source of drinking water for people living in new settlements and some residents who do not have access to treated water. The need to assess the quality of water from some of these alternative sources has become significant because they have direct effects on the health of individuals.

Contaminants such as bacteria, viruses, heavy metals, nitrates and salts have polluted water supplies as a result of inadequate treatment and disposal of waste from humans and livestock, industrial discharges and over-use of limited water resources. Even in the absence of anthropogenic sources of contamination, there is a possibility for natural levels of metals and other chemicals to be harmful to humans' health.

1.1 Problem Statement

In New Edubiase, accessibility and affordability of potable drinking water remains a major challenge to the people. The only stream that served the community in the early

days was destroyed during construction of the Kumasi-Tarkoradi highway. The Busia government at the time constructed an engineered borehole from which water was pumped to serve the whole community as part of its social responsibilities to the people. This water was accessed at various pipe-stands in the community and few affluent homes. Owing to the poor maintenance culture of the inhabitants, most of the pipe stands which broke down could not be restored. Subsequent governments up to the present have not been able to expand this water system and only a small section of the community has access to this supposed "pipe-borne water". As human population in the community increased, pressure on this water system also increased and there was the need to look for an alternative source of water to augment the existed one.

As an effort to relieve the people of this problem, boreholes were constructed in the community but could not fully meet the increasing demand for water by the people due to strong competition for water at the borehole sites. The situation worsened as some of these boreholes broke down and became non-operational.

In the light of this, individuals began to hand dig wells in their homes and the District Assembly also constructed few additional boreholes to mitigate the problem of water scarcity. Most of the wells after they were constructed have scarcely been maintained, rehabilitated or any major assessment carried out on the quality of water being pumped from it. Also, some of these boreholes were sited at places of questionable sanitation. Sanitation survey of some selected hand-dug wells and boreholes gave startling revelations.

Some of the hand-dug wells are not well raised above the ground level. They get submerged in the surface runoff during heavy down pour and as a result became contaminated. Most of the hand-dug wells are shallow and this prevents effective filtration and adsorption of bacteria and other contaminants by the soil layers. Some of

the hand-dug wells are under trees and with poor slabs. Tree debris, dead leaves and flowers easily fall into and decay in them thereby increasing the contamination levels. Buckets used for drawing water are usually left on the ground together with their ropes. As a result contaminants cling to the ropes and later get into the water. Sometimes roaming animals drink water from these receptacles containing water in them. These animals eventually contaminate them with faecal matter which infiltrate into the aquifers thereby, polluting the groundwater with pathogenic organisms responsible for water borne infections.

Where there are no permanent fetching devices, some people use buckets meant for bathing and washing to draw water which finally end up contaminating the wells. Wells with permanent fetching buckets are not often washed and this creates a conducive environment for microbial growth. Most people also draw the water by standing on the slabs with their footwear and spill of water splash contaminants on the footwear into the wells.

Most of the wells are poorly protected without an enclosure to prevent roaming animals from accessing them. As a result, household animals such as dogs, cats, goats, sheep and poultry relax on the slabs especially at nights, defecate and urinate on them and eventually pollute them with faecal matters. Some of these wells are also not too far from septic tanks, refuse sites and latrines. Some inhabitants also prepare food, wash materials close to the wells and sometimes dry kitchen utensils on them. Some of the wells are covered by old wood slabs which easily trap and release contaminants into the well water while others have rusted iron and aluminium sheets with perforations in them which serve as entry points for contaminants into the wells.

Unfortunately, water from the boreholes and wells is not treated before consumption exposing consumers to high risk of health problems such as 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 some have died and children are more vulnerable. Table 1 below is the statistics of some water borne diseases morbidity January 2011 – August 2011 by the District Health Directorate Monthly Performance Report.

Table 1.1: Water Borne Diseases Morbidity January 2011- August 2011

DISEASE	MALE	FEMALE	TOTAL
Typhoid / Enteric Fever	143	185	328
Diarrhoea	1920	3065	4985

Source: New Edubiase District Health Directorate (Monthly Out-Patient Morbidity

1.2 Justification of Research Objectives

There is less documentation on groundwater quality in Ghana just as in other parts of Africa. Mostly, preliminary analyses are made on construction of boreholes and wells but there is no periodic monitoring of these sources of water to examine the variation of water quality with time and other environmental conditions. In New Edubiase, there is no periodic research on the quality (both physico-chemical and bacteriological) of boreholes and hand-dug wells which are a major source of drinking water. Hence the need to conduct this research to provide health information about the state of these important sources of water in the community.

1.3 General Objective of Research

To determine the quality of ground water (borehole and hand dug-well) in New Edubiase community.

1.4 Specific Objectives of the Research

1. To determine Total coliform, Feacal coliform, *Salmonella* and *Enterococci* of boreholes and water from wells.
2. To determine the physico-chemical parameters; pH, turbidity, colour,chloride, fluoride, nitrate and nitrite, sulphate, phosphate, total dissolved solids, total hardness of the well and borehole water.

CHAPTER TWO

LITERATURE REVIEW

2.1 Potential for Ground Water Contamination

There are a number of important factors that determine whether a chemical is likely to reach and become groundwater contaminants. These major factors are:

• Properties of the chemical

• Properties of the soil

• Existing conditions at the site

• Human actions or properties

2.1.1 Properties of the Chemical

Each chemical that comes into contact with soil moisture has the characteristics of solubility, absorption, volatility and degradation. Solubility is a measure of how readily a chemical dissolves in water. Water moving down through soil carries water-soluble chemicals with it. This leaching occurs continuously as water moves from the surface down to the ground water aquifers. Absorption is the ability of a chemical to be held on the surface of the soil particles or soil organic matter. A chemical that is held tightly by soil is less likely to be carried downwards by leaching. Volatility determines the ability of a chemical to be lost to the atmosphere.

A highly volatile chemical may escape to the atmosphere before it becomes dissolved in water. This may not be true of chemicals that are also highly water-soluble. Degradation is the chemical breakdown of a substance in the soil by microorganisms and other chemical and physical agents. A chemical that degrades slowly is more likely to be moved downwards by leaching. A type of contaminant that is especially troublesome is the group of chemicals known as dense non-aqueous phase liquids or DNAPLs. These

include chemicals used in dry cleaning, wood preservation, asphalting, machining and in the production and repair of automobile, aviation equipments, ammunition and electrical equipments. These substances are heavier than water and they sink quickly into the ground. This makes spills of DNAPLs more difficult to handle than spills of petroleum products. Except in large cities, drinking water is rarely tested for these contaminants (Vandre, 1995).

2.1.2 Properties of the Soil

The important characteristics of soil which helps to determine groundwater contamination are texture, permeability and organic matter content. Soil texture is the relative proportions of sand and clay, coarse, sandy soils allow more water movement by percolation and have less capability to absorb chemicals than clay. The coarser the texture of the soil, the greater the chance of a chemical reaching the groundwater. Soil permeability is a measure of how fast water moves downwards through a soil. Highly permeable soils have a greater capability to lose chemicals to leaching. Applying pesticides or fertilizers to highly permeable soils should be done in such a way that leaching is kept to a minimum. Soil organic matter influences soil capability to hold water and to adsorb chemicals. The incorporation of organic matter into a soil will increase the capability and decrease the downward movement of chemicals by leaching (Vandre, 1995).

2.1.3 Existing Conditions at the Site

The depth to groundwater at a specific location is important because the soil between the surface and groundwater acts as a filter. Less soil means more leaching, less adsorption and less degradation. When groundwater is close to the surface, care must be taken whenever pesticides or fertilizers are applied or incorporated. Smaller applications, spilt

applications or no application may be the best alternative. The geologic conditions of a site should be determined to assess groundwater vulnerability. Layers of gravel above the groundwater area do not offer much protection against peculation or leaching. A layer of clay does create an effective filter for many chemicals. A steeper slope increases the potential for surface runoff and the subsequent movement of chemicals to other vulnerable areas.

Climate is another consideration at every location. Excessive rainfall increases peculation and leaching. Cold soils slow the rate of degradation and increases the time the chemical is available for leaching (Vandre, 1995).

2.1.4 Human Actions or Practices

The application of pesticides, fertilizer or any other chemical is regulated by the landowner or applicator. Application methods and dosage can influence the leaching of the chemical. Soil incorporation or injection of a pesticide poses a greater groundwater hazard than foliage or surface application. Decreasing the amount of the pesticide applied through the use of effective alternatives will also protect groundwater resources. This can be accomplished by using pesticides which are less susceptible to leaching and surface runoff.

The timing of pesticide application can be important in minimizing groundwater risk. Application prior to heavy rains or irrigation may result in leaching rather than effective use (Vandre, 1995).

2.2 Sources of Ground Water Pollution

Pesticides, fertilizers, herbicides and animal waste are agricultural sources of ground water contamination. The means of agricultural contamination are varied and numerous. Some examples are spillage of fertilizers and pesticides during handling runoff from the

loading and washing of pesticides sprayers or other application equipments, using chemicals uphill from within a few hundred feet of a well.

Agricultural land that lacks sufficient drainage is considered by many farmers to be lost income land. So they may install drain tiles or drainage wells to make the land more productive. The drainage well then serves as a direct conduit to groundwater for agricultural waste which is washed down with the runoff (http://www.lenntech.com/groundwater/pollution-sources.htm). Storage of agricultural chemicals near conduits to ground water, such as open and abandoned wells, sink holes or surface depressions where water is likely to accumulate. Contamination may also occur when chemicals are stored in uncovered areas. Unprotected from wind and rain or are stored in locations where the ground water flows from the direction of the chemical storage.

Mixing and distributing pesticides and fertilizer with irrigation water can cause ground water contamination (http://www.waterscape.org/projects/vanduo/dw_gen/grdshorts/ag.htm). If chemicals such as fertilizers, herbicides and insecticides and fungicides are over applied in the crop field could also introduce these contaminants into the ground water. Organic compounds, cadmium, chlorides, mercury and selenium which occur naturally in the soil and also contaminate ground water. Feedlots are potential contaminant sources. Animal waste is often collected in impoundments from which the waste may infiltrate the ground water (http://www. infohouse.p2ric.org/ref/01/00065.htm).

Runoff could also enter an aquifer through a poorly sealed well casting. Livestock waste is a source of nitrate, coliform bacteria, total dissolved solids and sulphates. Within the garage or farm equipments shed, chemicals that are improperly stored or disposed off

that could potentially contaminate ground water include paint containing lead and barium, gasoline and oils containing volatile organic compounds.

Many sources of ground water contamination can originate in the house or other forms such as trailers or dormitories, leaks from underground storage tanks, oil spills, overloading or poor maintenance of septic systems can result in the following contaminants entering ground water. Coliform bacteria, nitrate, total chloride, sodium, sulphates, detergents and chromium. Both aboveground and underground storage tanks (USTs) of hydrocarbons are at risk of leaking and releasing gasoline which contains benzene.

Abandoned wells that have not been plugged or dismantled provide a potential pathway (direct route) for water to flow directly from the surface into the ground water. Open wells can become contaminated by the working fluids such as grease and oils from the pump or from contaminants from the surface if the well cap is not tightly closed or incase the lining of the well is cracked or corroded. In addition, many older farm wells were merely shallow holes dug into the ground. These wells can easily be contaminated and are also a safety hazard to children and animals (USEPA, 1997).

2.2.1 Industrial Sources of Groundwater Contamination

Modern economic activity requires transportation and storage of materials used in manufacturing, processing and construction. Along the way, some of these materials can be lost through spillage, leakage or improper handling. Even the cleanup of spills may pose a threat to ground water when the spills are flushed with water rather than cleaned up with absorbent substances

(http://www.waterscape.org/projects/vanduo/dw_gen/grdshort/src/indust.htm)

The disposals of waste associated with the above activities contribute other sources of ground water contamination. Some businesses usually without access to sewer systems

rely on shallow underground disposal. They use cesspool or dry holes, or send the wastewater into septic tanks. Any of these forms of disposal can lead to contamination of underground sources of drinking water. Dry holes and cesspools introduce waste directly into the ground. Septic systems cannot treat industrial waste. Wastewater disposal practices of certain types of business, such as automobile service stations, dry cleaners, electrical component or machines manufacturer, photo-processors and metal platters or fabricators are of particulars concern because the waste they generate is likely to certain toxic chemicals.

Other industrial sources of contamination include cleaning of holding tanks or spraying equipment on the open ground. Disposal of waste in septic systems or dry wells and storing hazardous materials in uncovered areas or in areas that do not have pads with drains or catchments basins.

Although business may run a 'clean shops' small amounts of waste fluids can end up on the shops floors and be washed down floor drains. These drains may be connected to shallow injection well systems, which are not designed to handle the industrial chemical typically used by businesses such as those listed above. Even low concentrations of certain contaminants can accumulate through time.

Underground and above ground tanks holding petroleum products, acids, solvents and chemicals can develop leaks from corrosion, defects, improper installation or mechanical failure of the pipes and fittings. Mining of fuel and non-fuel minerals can create many opportunities for ground water contaminations. The problems stem from the mining process itself disposal of wastes and processing of the ores and the waste it creates (USEPA, 1997).

2.2.2 Domestic Sources of Ground Water Contamination

A major cause of ground water contamination is effluent (outflow) from septic tanks and cesspools. Misuse of these systems for disposal of anything other than domestic or sanitary waste can pose a substantial threat to ground water. Residential wastewater systems can be a source of many categories of contaminants including bacteria, viruses and nitrates from human waste and organic compounds.

Injection wells used for domestic wastewater disposal (septic systems, cesspool drainage wells for storm water runoff, ground water recharge wells) are of particular concern to ground water quality if located close to and up gradient of drinking water wells. Improper storing or disposal of household chemicals such as paints, synthetic detergents, solvents, oils, medicines, disinfectants, pool chemicals, pesticides, batteries, gasoline and diesel fuel can lead to ground water contamination. When stored in garages or basements with floor drains, spills and flooding may introduce such contaminants into the ground water because community landfills are not equipped to handle hazardous materials. Similarly, waste dumped or buried in the ground can contaminate the soil and leach into the ground water.

As urban areas grow, there is an increase in rain water runoff caused by the additions of paved surfaces. Some municipalities use storm water drainage wells to dispose-of this additional runoff particularly if the area is not served by storm sewers nor has a limited sewer system. These low-cost low-tech wells and landscaped areas. Storm water drainage wells that communities use to control water during storm events pose a threat to ground water particularly in kart area or areas with a high water table. Fertilizers, herbicides, insecticides, fungicides and pesticides applied to the lawn and garden contain hazardous chemicals that can travel through the soil and contaminate the ground water.

In the garage, items that are improperly used, stored or disposed off may potentially contaminate ground water especially if there is a drain to the ground in the floor of the garage. Sources include batteries that contain lead, cadmium or mercury. Paints containing lead and barium, gasoline and oils containing compounds, barium from diesel fuel combustion.

Water used in the home and entering a septic system or sewer system may contain detergents from dishwashing and laundry, organic compounds from garbage, disposal bacteria, nitrates, and sulphates from sewage, greases and oils. Cleaning agents, aerosol sprays coolants and solvents which all contain carbon tetrachloride household pesticides.

Water percolating through landfills is known as Leachate. From landfills that contain household and other waste may pick up dissolved solids and volatile organic compounds. Lawns with over applied or misapplied fertilizers, herbicides and fungicides might introduce these contaminants tetrachloride and heavy metals such as manganese into ground (USEPA, 1997).

2.2.3 Natural Sources of Groundwater Contamination

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

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

Some of the contaminants that occur naturally include; Aluminum, arsenic, barium, chloride, chromium, coliform bacteria, copper, fluoride, hardness, iron, lead. Manganese, mercury, nitrate, selenium, silver, sodium, sulfate, zinc (USEPA, 1997).

2.2.4 Speciation of Metals

Legislation governing the maximum permissible levels of a polluting element in environmental samples such as surface or ground water refers to total concentrations rather than the chemical form of the element. This total concentration however provides no information concerning the fate of the elements in terms of its interactions with sediments its ability to cross biological membranes (bioactivity) or its resultant toxicity.

Changes may dramatically affect the toxicity of metal for example mercury species are generally unable to cross biological membranes and this has low toxicity. Akylmercury species are lipids soluble and hence extremely toxic to aquatic organisms. It is therefore imperative to have information concerning the chemical form of an element (speciation) in order to assess its environmental impact (Fifields and Haines, 1997).

2.3 Bacteriological Pollutants

Coliform bacteria are described and grouped, based on their common origin or characteristics, as either Total or Fecal Coliform. The Total group includes Fecal Coliform bacteria such as *Escherichia coli (E.coli)*, as well as other types of coliform bacteria that are naturally found in the soil.

Microbial examination of water samples is usually undertaken to ensure that the water is safe for drinking. Coliform bacteria usually live in the intestines of humans and warm blooded animals, though were not known to cause any illness, are referred to as indicator organisms since a quantity of their presence is used to indicate the potential presence of

pathogens in water and if water contains such bacteria over the recommended limits, this shows pollution of the water (Barrel *et al.*, 1987).

2.3.1 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.

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 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. 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.

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).

2.3.2 FaecalColiform

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.* These organisms are transmitted through feacal or oral route by contaminated or poorly treated water and may cause diseases such as gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever (Addo *et al*., 2009).

Drinking water contaminated with these organisms can cause stomach and intestinal illness including diarrhoea and nausea, and even lead to death. These effects may be more severe and possibly life threatening for babies, children, the elderly or people with immune deficiencies or other illnesses (Health Canada, 2007).

A number of authors have reported significant deterioration in microbiological quality of water between the source and point of use in homes (Chant *et al*., 2007). According to Marylynn (1985), Septic tanks leachate is the cause of most cause of groundwater contamination. The consumption of untreated or inadequately treated groundwater is responsible for outbreaks of water borne diseases. The potability of groundwater is threatened by leachate from septic tanks. The outbreak of water borne- diseases have been reported in areas of high septic density (Craun, 1985). 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; Doran and Linn, 1979; Gary *et al*., 1983).

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.

Quist, (1999) reported feacal coliform range of 0 -18 MPN /100 ml on wells within urban Kumasi. Adetunde and Glover, (2010) also reported faecal coliform mean range values of 10–14 MPN/100 ml of water from hand dug wells used by UDS students, Navrongo campus.

Olowe *et al.,* (2005), also reported on the unfitness 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 3km to landfills must not use hand dug wells and boreholes in their houses for domestic purposes due to health threats.

Workdone on the assessment and comparism of microbial quality of drinking water in Chikwawa- Malawi, indicated that feacal coliforms were below the minimum detection level of 20 MPN/100 ml in water samples taken from 27 bore wells (Jabu, 2008). .

The World Health Organization guideline stipulated a faecal coliform count of zero (0) per 100 ml. Coliform organisms per 100 ml are an indication of some degree of feacal contamination.

2.3.3 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 zoonotic and can be transferred between humans and nonhuman animals. Many 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, easily

achieved by ingesting a small number of *salmonella*. Children with sickle cell anaemia who are infected with *Salmonella* may develop osteomyelitis. According to the World Health Organization, over 16 million people worldwide are infected with typhoid fever each year, with 500,000 to 600,000 fatal cases (http://www.meducation.net/community_notes/3091-Salmonella). Food may also become contaminated by the unwashed hands of an infected food handler.

Wright (1982), observed mean *salmonella* value of 1.3 x 10^3 in dug well water samples in Sierra Leone whilest 0.08 CFU of *salmonella* in dug wells was recorded by Fasunwon (2008) in Ago- Iwoye State, Nigeria.

2.3.4 Enterococci

Enterococci are gram positive cocci that often occur in pairs (diplococcic) 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.

They are not capable of forming spores and tolerant to a wide range of environmental conditions, extreme temperature (10 - 45^{o}C), pH (4.5 - 10.0) and high sodium chloride (Fisher *et al*., 2009).

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., (*2009) observed levels of *enterococci* to be eight 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).

Shawky and Saleh (2007), detected high total coliform, feacal coliform and enterococci counts in the summer season than in the winter season.

2.3.5 Sources of Bacteriological Contaminants (Total, Feacal Coliforms, *E.Coli, Salmonella*and *Enterococci)*

Groundwater are found to be contaminated due to improper construction, shallowness, animal wastes, refuse damp sites, proximity to toilet facilities, sewages and various human activities around wells (Bitton, 1994). According to Shittu *et al.*, (2008), the sources of groundwater contamination include surface run-off, pasture, seepage from septic tanks, sewages from treatment plants, natural soils or plant bacteria, infiltration of domestic animal wastes, infested fetching buckets which are left on the ground etc. Biological contaminants are primarily from animal and human wastes, feedlots, dairies and septic systems. However, biological and physical contaminants are controllable through proper disposal of wastes; separation of septic systems, feedlots and other sources from polluting drinking surface water supplies, as well as treatment of drinking water before consumption.

2.4 PHYSICO-CHEMICAL PARAMETERS

2.4.1 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 scale runs from 0 to 14. A pH value of 7 is neutral; a pH less than 7 is acidic and greater than 7 represents base saturation or alkalinity. 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 runoff.

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 pH causes a bitter taste, water pipes and water-using appliances become encrusted, depresses the effectiveness of the disinfection of chlorine. Low- pH water will corrode or dissolve metals and other substances (Waller, 1982).

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. Rizwan and Gurdeep (2009) reported pH value of ground water samples variation between 6.4 to 7.4 and 7.0 to 9.2 during pre and post monsoon season respectively. GSB/WHO optimum limits of pH levels in drinking is between 6.5 – 8.5

2.4.2 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. Turbidity is also a measure of the degree to which the water loses its transparency due to the presence of suspended particulates. The more total suspended solids in the water, the murkier and the higher the turbidity.

Source of turbidity are; Phytoplankton, sediments from erosion, re-suspended sediments from the bottom, waste discharge, algae growth and urban runoff.

Turbidity itself is not a major health concern but high turbidity interferes with disinfection and provides a medium for microbial growth. It indicates the presence of microbes.

Turbidity range of 2.5 to 7.0 NTU was reported by Shittu *et al.*, (2008) in dug well water samples in Abeokuta, Nigeria whiles 0.07 to 30.74 NTU was observed by Boamah *et al.*, (2010) in three peri – urban communities in Kumasi. GSB/WHO guideline value of turbidity for drinking water is 0 - 5 NTU.

2.4.3 COLOUR

The term ‘’Color’’ 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. Highly coloured water makes it aesthetically displeasing for consumption.

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

GSB/WHO guideline value for drinking water is 15 True Colour Unit (TCU).

2.4.4 CONDUCTIVITY

Conductivity is defined as the ability of a solution to carry electric current. This is normally dependant on the presence of mobile ions. Their concentration, mobility, valency, relative concentration and temperature of measurement.

Compounds which dissociates easily in solution are good conductors whiles those which do not dissociate easily are poor conductors. Inorganic, bases, and salts are good conductors whiles organic compounds are poor conductors. In a laboratory determination, conductivity is measured as resistance measured in ohms. The conductivity of fresh distilled water is in the range of 0.5-2.0 micro-ohms/cm. the conductivity of portable water is in the range of 50-10000μmhos/cm.

Laboratory conductivity measurements are used to:

• Establish degree of mineralization, to assess the effect of the total concentration of ions on chemical equilibria, physiological effects on living things and the rate of corrosion

• To assess the degree of mineralization of distilled water and deionised water.

• To check the result of a chemical analysis and estimate the sample size to be used for simple chemical determinations.

• Determine the amount of ionic reagents in the precipitation and neutralization reactions. The end point of such reactions is determined by plotting a graph of conductivity verses burette readings.

• When conductivity is multiplied by a factor, total dissolved solids of water can be determined. This factor may vary from 0.055 to 0.9 depending on the soluble component of the water and on the temperature of measurement.

2.4.5 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. Chloride salts include sodium chloride (common salt), potassium chloride, calcium chloride, and ammonium chloride. Most chloride salts are readily soluble in water, but mercurous chloride (calomel) and silver chloride are insoluble, and lead chloride is only slightly soluble.

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, and urban runoff containing de-icing salt and saline intrusion.

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

GSB/WHO guideline for chloride in drinking water is 250 mg/l based on taste consideration.

2.4.6 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 Earnshaw, 1997).

The health effects of fluoride are; Low concentrations provide protection against dental caries, both in children and in adults. However, fluoride can also havean adverse effect on tooth enamel and may give rise to mild dental fluorosis (prevalence:12–33%) at drinking-water concentrations between 0.9 and 1.2 mg/litre, depending on drinking-water intake and exposure to fluoride from other sources. 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. According to World Health Organization (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.

GSB/WHO guideline value for fluoride in drinking water is 1.0 to 1.5 mg/l.

2.4.7 NITRATE AND NITRITE

Nitrate and nitrite are compounds that contain anitrogen atom joined to oxygen atoms, with nitrate (NO_3) containing three oxygen atoms and nitrite (NO_2)containing two. Nitrates are salts or esters of nitric acid (HNO_3), formed by replacing the hydrogen with a metal (e.g., sodium or potassium) or a radical (e.g., ammonium or ethyl). In nature, nitrates are readily convertedto 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. Organic nitrates are esters formed by reaction

of nitric acid with the hydroxyl (−OH) group in an alcohol. (Wikipedia encyclopedia, 2010).

The health effect is mainly Methaemoglobinaemia. According to World Health Organisation (WHO., 2003), Methaemoglobinaemia occurs as a result of extremely high nitrate intake in adults and children, the most familiar situation is its occurrence in bottle-fed infants. After drinking the water, the nitrate may be converted to nitrite by bacteria in the mouth. Once 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 causing the veins and the skin to appear blue especially around the eyes and mouth. According to Human Health Fact Sheet, (2005), long-term exposure to lower levels of nitrates and nitrites can cause diuresis (an increase in the amount of urine, and starchy deposits and hemorrhaging of the spleen).

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.

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

2.4.8 SULPHATE

The 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. Sulphate is generally considered to be non-toxic.

The consumption of drinking water containing high amounts of magnesium or sodium sulphate may result in intestinal discomfort, diarrhea and consequently dehydration. High amounts of various sulphate salts give drinking water an offensive taste, interfere in the efficiency of chlorination in water supplies and increase the corrosive properties of water.

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.

GSB/WHO guideline value for sulphate in drinking water is 400mg/l

2.4.9 PHOSPHATE

A phosphate, an inorganic chemical, is a salt of phosphoric acid. In organic chemistry, a phosphate, or organophosphate, is an ester of phosphoric acid.

The phosphate ion is a polyatomic ion with the empirical formula (PO_3^{-4}) and a molar mass of 94.973 g/mol. 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, and maintain the body's fluid and electrolyte balance. It is also essential for stimulating hormone production and helping the body utilize the B vitamins. Phosphorus speeds up healing, helps to prevent and treat osteoporosis, helps treat bone diseases such as rickets and prevents stunted or slow growth in children. Phosphorus also helps to keep the mind alert and active, helps stimulate the glands to secrete hormones, and keeps the muscles and heart contracting regularly and smoothly. 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 (Obikoya-http://www.vitamins-nutrition.org/vitamins/index.html).

Phosphates are the naturally occurring form of the element phosphorus, found in many phosphate minerals.

Nkansah *et al*., (2010), observed phosphate levels of 0.67 to 76.0 mg/l in well water in Kumasi metropolis, Ghana.

GSB/WHO Guideline level in drinking water is 400 mg/l

2.4.10 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 and changes in TDS concentrations affect the density of the water which determines the flow of water into and out of an organism's cells. 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. Olobaniyi (2007) reported TDS levels of 21.90 to 300.50 in well water. GSB/WHO permissible limits for TDS in drinking water is 1000 mg/l .

2.4.11 TOTAL HARDNESS (TH)

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.

GSB/WHO standard for Total hardness in drinking water is 500mg/l.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of study area

New Edubiase is the district capital of the Adansi South District in the Ashanti Region of Ghana. Its geographical coordinates are 6◦ 4' 0" North, 1° 24' 0" West. The District shares boundaries with the Central and Eastern regions to the south and east respectively, and with the Adansi North, Amansie East and Asante Akim South Districts of the Ashanti Region to the north-west, north-east and south-east respectively. New Edubiase is about 92km south of Kumasi on the Kumasi Cape Coast trunk road (Figure 3.1).

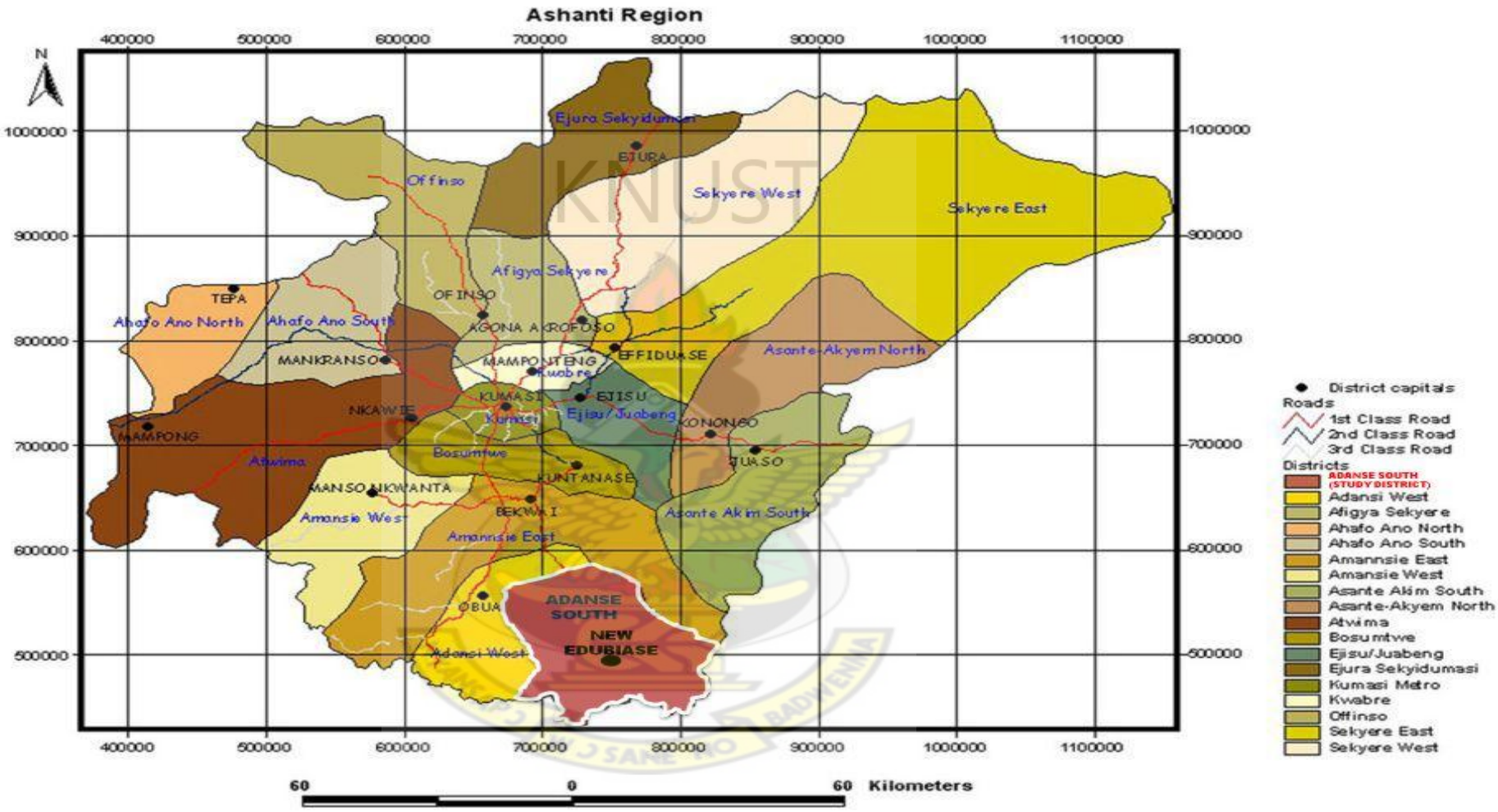

Figure 3.1: Map of Ashanti Region showing New Edubiase

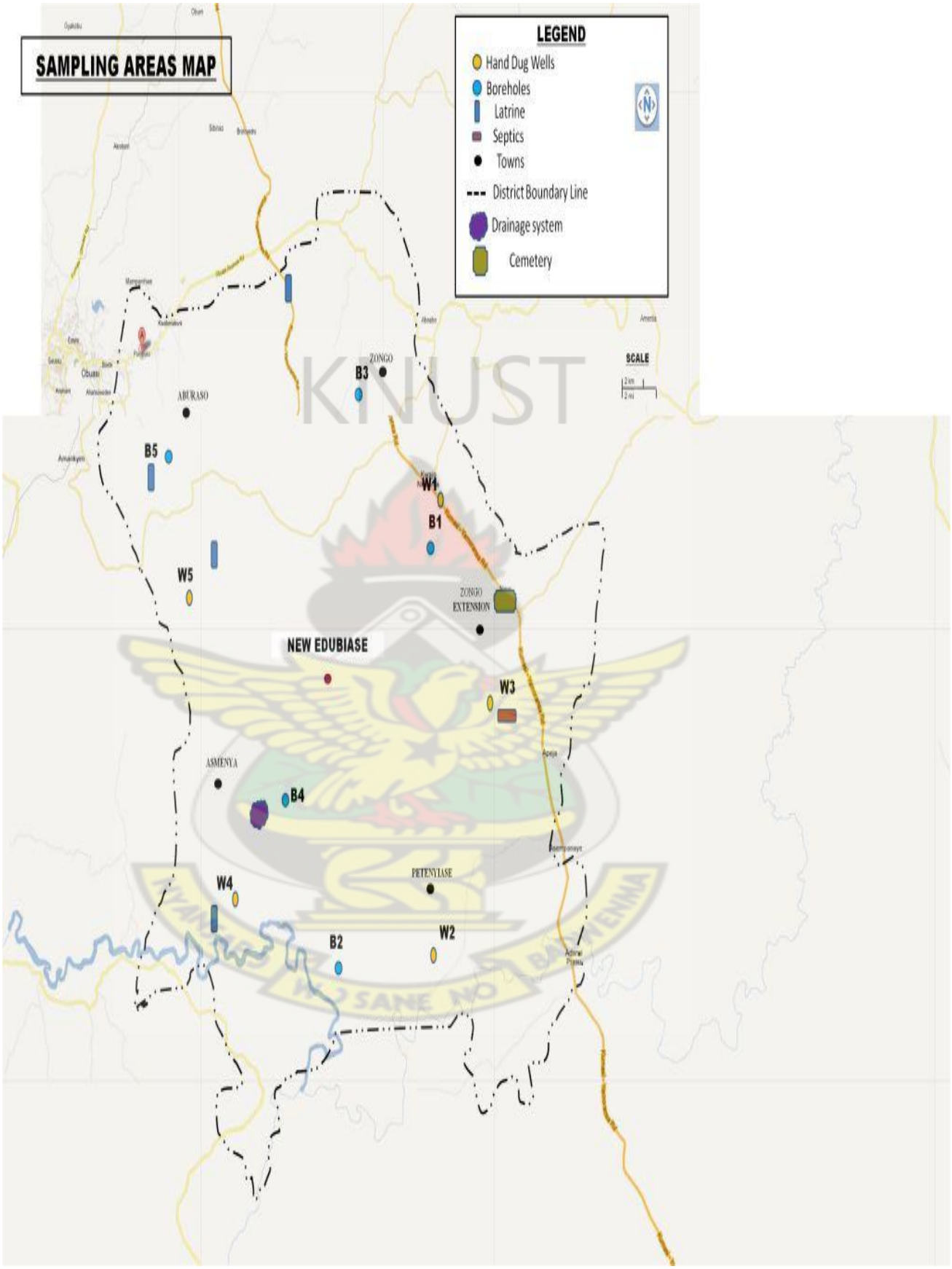

Figure 3.2 Map of New Edubiase showing sampling points

3.2 Description and Sanitary Conditions Prevailing around the Boreholes and Wells Under investigation

Five boreholes and five hand-dug wells were studied in this research. The boreholes and hand-dug wells were selected based on; existing conditions at the site, properties of the soil and anthropogenic activities at the site (Figure 3.2).

Borehole B1

Borehole B1 is 15m from the main Kumasi-Tarkoradi highway and 60m away from the community cemetery. The borehole is situated on a silty-loam soil and on a leveled ground. The hand-pump of the borehole is well built on a concrete platform **(**Plate 3.1**)**.

Plate 3.1: Picture of borehole B1

Borehole B2

The borehole is under palm tree on a gentle slope(Plate 3.2**)**. It is situated on a slightly clayey soil. Birds dwelling on the palm tree usually liter the borehole with their droppings. There is no septic condition within its vicinity. Its immediate surrounding is concreted.

Plate 3.2: Picture of borehole B2

Borehole B3

Its surroundings are well covered with concrete material. The borehole is situated on a loamy-clay soil with a gentle slope (Plate 3.3). There is no vegetation near this borehole and there is no septic condition within its immediate surroundings.

Plate 3.3: Picture of borehole B3

Borehole B4

The borehole is located on a school compound about 4.5m from an unconcreted drainage but its immediate surrounding is covered with concrete. It is on a low lying ground about 50m away from a pit latrine (Plate 3.4**)**. Its hand pump is not tightly mounted on the concrete platform and therefore permits easy backflow of spilled water.

Plate 3.4: Picture of borehole B4

Borehole B5

This borehole is also located on a school compound about 14.3 m away from a pit latrine on a low lying ground. It is situated on a gravel soil and about 30m from the school's urinal (Plate 3.5). The immediate surroundings of the borehole is cemented and has some vegetation close to it.

Plate 3.5: Picture of borehole B5

Well W1

The well is about 4.5m deep and the inner part is lined with concrete. The well has a concrete case above the ground and a metal slab over it. The fetching bucket is usually kept clean. It is occasionally disinfected with chlorine. The well is not close to either a septic tank or a latrine (Plate 3.6). It is located on mainly gravel and sand stone soil.

Plate 3.6: picture of well W1

Well W2

It is 6m deep. It is concreted above the ground with a well covered slab. It is located higher than the ground and close to an apple plantation. Roaming animals have easy access to it and usually defecate around (Plate 3.**7)**. The well is not close to either a septic tank or a latrine. Fetching bucket is made of plastic.

Plate 3.7: Picture of well W2

Well W3

The well is 3.8m deep and surrounded by two septic tanks. One septic tank is located inside the house 7.5m 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 18m from an untarred road frequently used by vehicles generating dust within the environs. The well has a concrete case and a wooden slab above the ground level and the inside is partially 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 slab of the well (Plate 3.8**)**. Fetching bucket is an old plastic type which is not often kept clean and always exposed. It is occasionally disinfected with chlorine

Plate 3.8: Picture of well W3

Well W4

The well is about 5m deep. It has a poor wooden covering with perforations. The inner part is partially cemented and found under a tree. It is located on a sandy soil and on a low lying ground about 10m from a major road. There is a latrine about 6.8m from the well. The fetching bucket is a plastic type and its supporting rope is usually kept on the ground. A motor-bike mechanic shop is also located within the vicinity of the well (Plate 3. 9). It is located very close under a tree with perching birds at night. The well has a concrete case slightly raised above the ground.

Plate 3. 9: Picture of Well W4

Well W5

This well is about 4.5m deep and has an old wooden slab as its covering. It is about 8m from a latrine and also 3m away from the branches of a coconut tree on which fowls sleep at night. It is located on a sandy soil and has a poor inner eroded concrete lining (Plate 3.10**)**. It has an old fetching plastic bucket that is not usually washed. The well has a partially broken concrete case.

Plate 3.10: Picture of Well W5

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 physicochemical analysis, 1.5 litre plastic bottles were rinsed with distilled water before used for sampling. Sample bottles were labeled **B1-B5** and **W1-W5** to represent the boreholes and wells respectively. 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

Three samples were collected from each borehole and hand-dug well once each month for a period of six months from October 2011 to April 2012.

Samples were collected for both microbiological and physico-chemical analysis from five boreholes and five hand-dug wells at different parts of the town. Sample collection was done using the available receptacle between the period of 6 a.m and 7 a.m. Collected water samples were then kept in an ice chest loaded with ice block, transported to the laboratory in Kumasi and stored in a refrigerator until they were analysed. 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, *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 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.

3.5.3 *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 enterococciand 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 and nitrate. Colorimetric method was used for nitrite. Determination of total hardness was done by titration method using EDTA. Field and Argent metric method was used for total iron and chloride concentrations respectively. 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.

Calibration procedures outlined in the manufacturers' manuals were used to calibrate the various instruments before measurements were taken.

3.6.1 pH Determination

pH was determined in the laboratory using the model 209 pH meter of HANNA brand. The electrode of pH meter was put into buffer solution of pH (4, 7 and 9) and adjusting the instrument to agree with the standard buffers and rinsing the electrode with distilled water afterwards. 50ml of each water sample was taken into a beaker and the electrode immersed. The button selector of the pH meter was rotated to pH to take pH of the readings of the samples from the meter.

3.6.2 Turbidity Determination

Turbidity was measured in each sample by the use of the turbidity meter with brand number 2100N. The meter was calibrated with Formazin standards by filling a clean sample cell with well mixed 20 NTU, 200 NTU and 400 NTU with CAL key pressed each time and this enables the instrument to store the new calibration and returns to the measurement mode. 10ml of each sample was placed into a nessler and inserted into the cell compartment of the instrument and covered. The RATIO setting was selected using its key followed by the measurement unit of NTU by pressing UNITS EXT key. After five minutes, displayed value on the instrument screen was read and recorded in Nephelometric Turbidity Unit (NTU).

3.6.3 Colour Determination

HACH Lange Spectrophotometer Model DR 5000 was used to determine the colour of the water samples. Calibration was done by placing a blank cuvette into the sample cell

holder and the ZERO and OPTION keys depressed. The water samples were put into a 10ml size nessler and placed into the instrument compartment for some minutes to allow reading to be done thus measuring the absorbance of the analyte solution. The shown value on the screen was read and recorded in Hertz (Hz) as colour of the sample.

3.6.4 Conductivity and Total Dissolved Solids (TDS) Determination

A multifunctional Conductivity meter of brand, HANNA HI 9032 was used to determine the conductivity and total dissolved solids of all samples in the laboratory. Calibration was done by putting the electrode in buffer of 12880 us/cm to show the 'buf' sign and blinking till 'CON' appeared and its key pressed to confirm reading. The meter was returned to operation mode to enable measurement. The conductivity meter electrode was rinsed in a deionised distilled water, and placed into 50ml of each sample poured into a beaker and after some few minutes, displayed value on the screen was read and recorded for conductivity. TDS key was chosen as electrode still remained in the same sample and displayed value on the screen recorded for TDS in mg/l.

3.6.5 Determination of Chloride (Argent Metric Method)

In neutral or slightly alkaline solution Potassium Chromate indicates the end point of silver nitrate titration of chloride. Silver Chloride is precipitated quantitatively before the red silver chromate is formed. In this method, Potassium Chromate indicator solution and standard Silver nitrate titrant, 0.0141N solution were used. The silver nitrate titrant solution was prepared by dissolving 2.395g $AgNO_3$ in distilled water and diluted to 1000ml. In this, 50ml of each sample is measured into an Erlenmeyer flask, 1ml of 5% potassium chromate as an indicator was added to the measured samples. Titration against silver nitrate solution was done by swirling gently until the colour changes from yellow to brick red. The titre value (Tv) recorded and concentration calculated as

$$\text{Cl (mg/l)} = \frac{(A - 0.2)x\ 0.5\ x\ 1000\ )}{\text{Sample volume}} \qquad \text{where A= titre value}$$

3.6.6 Fluoride determination (Photometer Method)

In the palintest fluoride test, two tablets reagents were used by adding the tablets to the samples for colour development which is an indicative of the fluoride concentration and measured using a palintest photometer.

Test Procedure

Three test tubes were filled with water samples to 10ml mark. Fluoride No.1 and 2 tablets were crushed and successively added 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.

3.6.7 Nitrite Determination (Colorimetric Method)

In determining nitrite, Griess- Ilosvay's No. 1 and 2 solutions were used. In this, there was measurement of 50ml of water samples into Erlenmeyer flask; 2 ml 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 matching colour using the nitrite disc Comparator (the markings on the disc represent the actual amount of nitrogen (N) present as nitrite) value read. The final value was obtained as disc reading x 0.02.

3.6.8 Nitrate determination (Photometer method)

The nitra test tube was filled with water sample to the 20ml mark. One level spoonful of nitratest powder and one nitratest tablet were added. Screw cap was replaced and tube was well shaken for one minute. The tube was then allowed to stand for 1 minute and gently inverted three times to aid flocculation and complete settlement. Screw cap was

removed and wiped around the top of the tube with a clean tissue and the clear solution was decanted into a round test tube to the 10ml mark. One nitricol tablet was crushed, added and mixed to dissolve and allowed ten minutes for full colour development. Wavelength of 570nm on photometer was selected. Photometer reading was taken and compared to the calibration chart for nitrate concentration.

3.6.9 Sulphate Determination (Photometer Method)

The palintest sulphate test is a simple method of measuring sulphate over the range of 0 – 200 mg/l SO_4 which depends on a single tablet reagent containing barium chloride in a slightly acidic formulation. The barium salts react with sulphate to form insoluble barium sulphate. Sulphate level is encountered in the sample as turbidity in the test sample. The degree of turbidity is proportional to sulphate concentration which is measured with palintest photometer.

Test Procedure

A test tube was filled with water samples to 10ml mark and one sulphate turb tablet was crushed, added and mixed to dissolve. Cloudy solution indicated the presence of sulphate. The solution was allowed to stand for five minutes, then mixed again to ensure uniformity after which wavelength of 520nm was selected on the photometer. Photometer reading was taken and sulphate calibration chart consulted for transmittance.

3.6.10 Phosphate Determination (Photometer Method)

The palintest phosphate LR (low range) test measures phosphate levels over the range of 0 – 4mg/l PO_4. In this method, phosphate reacts under acidic conditions with ammonium molybdate to form phosphor – molybdic acid. This compound is reduced by ascorbic acid to form the intensely coloured ‘molybdenum blue’ complex. A catalyst is incorporated to ensure complete and rapid colour development and an inhibitor is used to prevent

interference from silica. The reagent are provided in form of two tablets by adding one of each tablet to the water sample for colour development intensity which is proportional to the phosphate concentration and is measured using palintest photometer.

Test Procedure;

A test tube was filled with the water sample water 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 stood for ten minutes to allow for full colour development. Wavelength of 640 nm was chosen on the photometer proceeded by photometer reading after which phosphate LR calibration chart used for phosphate concentration.

3.6.11 Total Hardness Determination

Total hardness was determined using the EDTA Titration Method. Fifty (50) ml of each water sample 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. The water samples were taken in duplicates and the average taken for the analysis. Field blanks were used to identify errors during the sample collection. Ice packs were used to preserve the samples through the transportation process. 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

Analysis of variance (ANOVA) was used to examine the apparent differences in observed data between the different sampling locations (boreholes and hand-dug wells). Standard error difference (s.e.d) at 5% was used to compare treatment means. Correlation analysis was also carried out to check whether sampling sources' distances from sanitary facilities and depth (for wells) affected the parameters. All descriptive statistics and graphs were executed using the Graph-Pad Prism 5 Software.

CHAPTER FOUR

RESULTS

4.1 PHYSICO-CHEMICAL PARAMETERS

4.1.1 pH

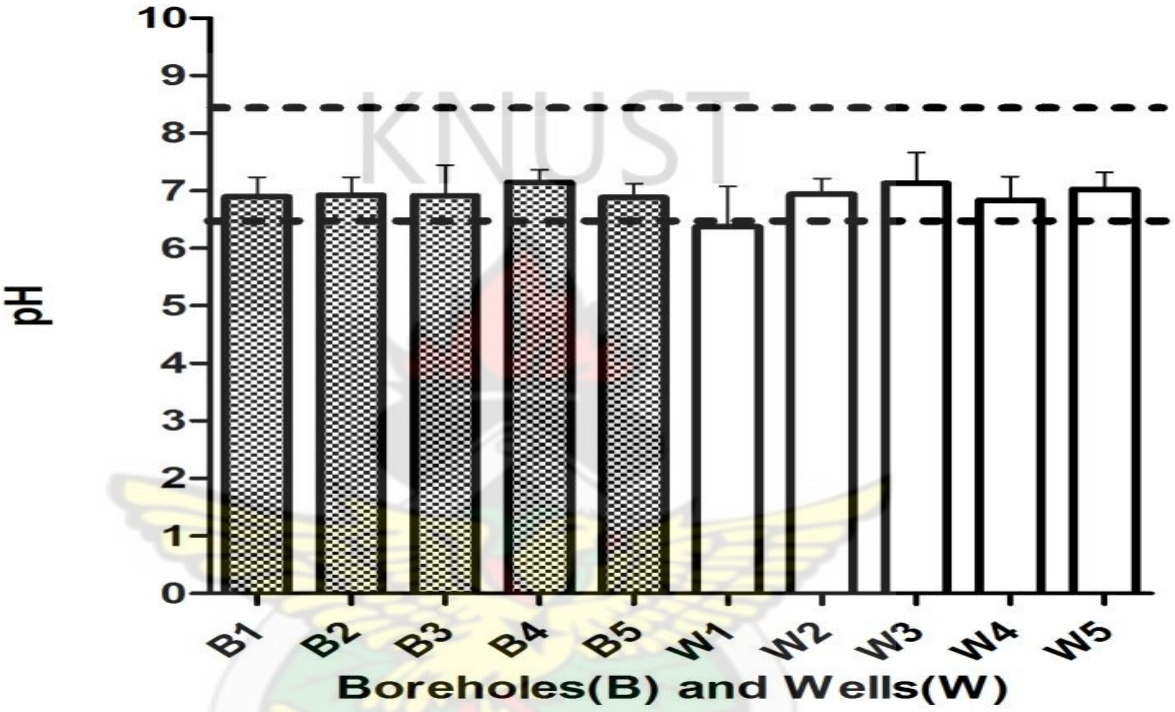

Figure 4.1: Mean pH values and GSB/WHO minimum and maximum levels of water from sampled boreholes and hand dug wells: (the dotted lines shows GSB/WHO acceptable limit 6.5-8.5).

The pH values for the boreholes ranged from a mean of 6.89 to 7.15. The highest pH of 7.15 was recorded for B4 and the lowest of 6.7 for B1 (figure 4.1). In hand -dug wells, the pH also ranged from a mean of 6.37 to 7.13. The highest pH of 7.13 was recorded for W3 and the lowest of 6.37 for W1. All the boreholes and hand dug wells were moderately acidic to neutral except Well W1 which was a bit more acidic (with pH of 6.37). pH for all the samples were generally within Ghana Standard Board guideline

range of 6.5 to 8.5 except W1. There were no significant differences in pH values among the individual boreholes (p =0.6634). Similarly the pH of the individual wells was also fairly similar and did not vary significantly (p =0.0828). Moreover, pH of the boreholes did not vary much from those of the wells.

4.1.2 TURBIDITY

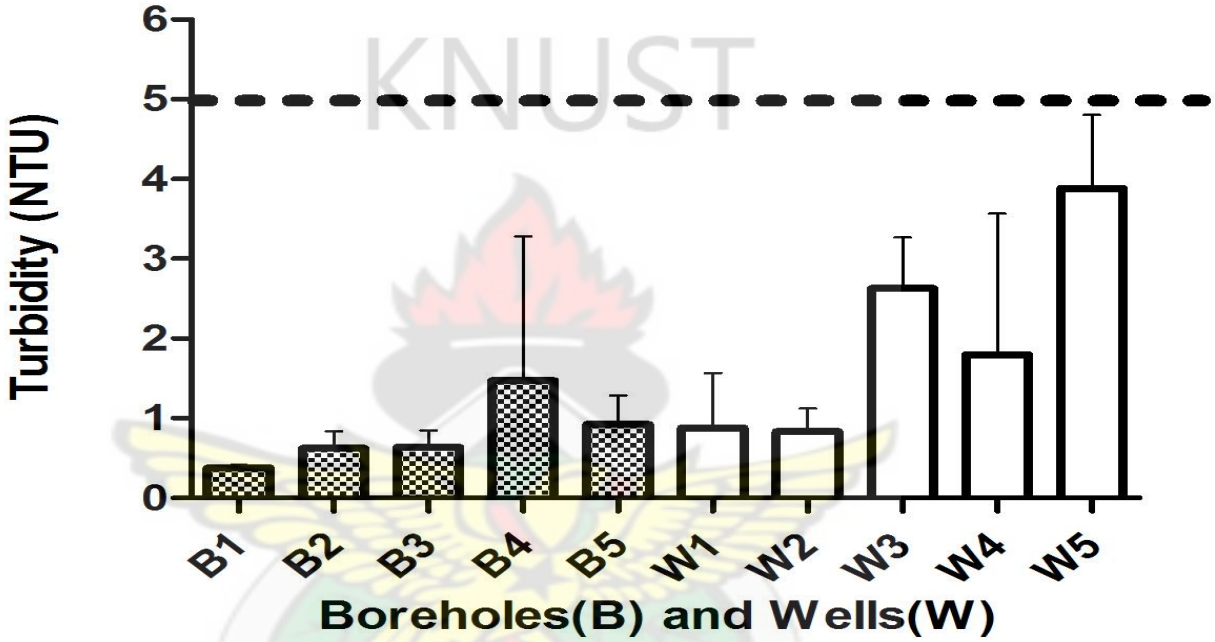

Figure 4.2: Mean Turbidity values (NTU) of water from sampled boreholes and hand dug wells as compared to GSB/WHO acceptable limit: (the dotted line shows GSB/WHO acceptable limit value).

Turbidity values for the boreholes ranged from a mean of 0.38 NTU (for B1 to 1.47 NTU. Boreholes B1 and B4 recorded the lowest (0.38 NTU) and highest (1.47 NTU) mean values respectively. Turbidity of the hand-dug wells also ranged from 0.83 NTU to 3.89 NTU with W2 and W5 recording the lowest (0.83 NTU) and highest (3.89 NTU) mean values respectively. All the samples analysed were fairly clear with turbidity values below the Ghana Standards Board limit of 5.0 NTU (figure 4.2). Turbidity values of the

individual wells recorded significant differences (p = 0.0001) but those of the boreholes showed no significant differences (p =0.0869). The hand-dug wells were generally more turbid than the boreholes.

4.1.3 COLOUR

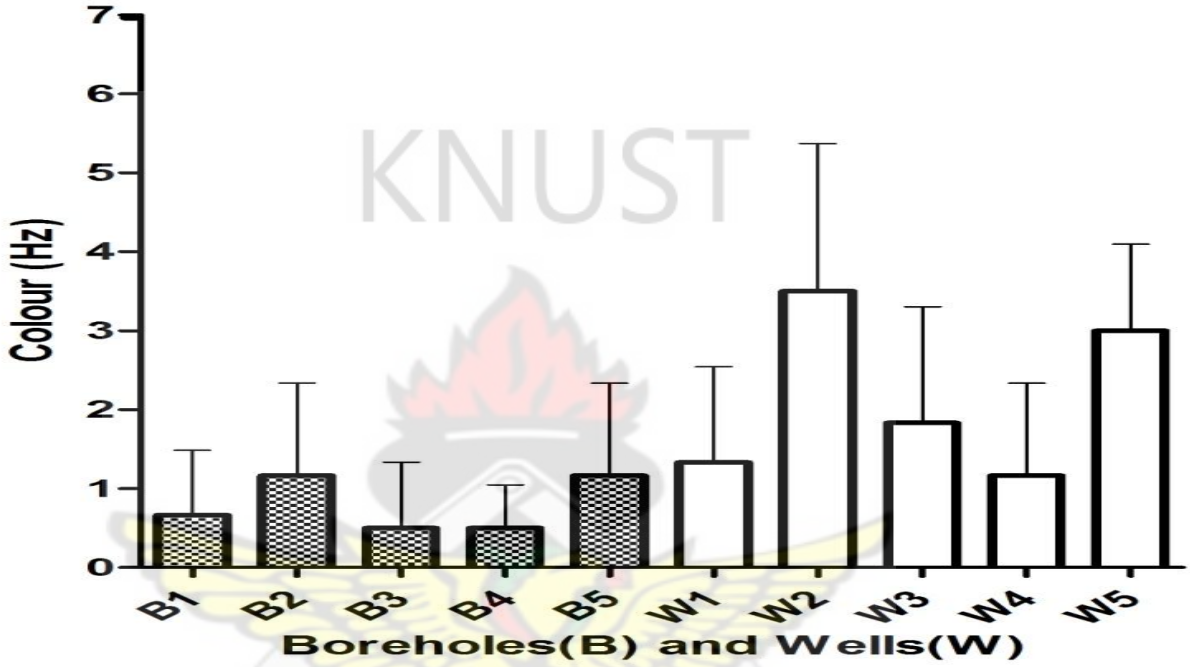

Figure 4.3: Mean colour (Hz) of water from sampled boreholes and hand dug wells.

The colour of the boreholes and wells ranged from a mean of 0.50 to 1.17 Hazen and 1.17 to 3.50 Hazen respectively. Among the boreholes, colour did not vary significantly over the study period (p=0.5394). Contrary, the wells exhibited significant differences in colour (p=0.0263). It was also observed that the hand dug wells recorded considerably higher values than the boreholes. However, measured values for both boreholes and hand dug wells were below the GSB/WHO maximum limit of 15Hazen units (figure 4.3).

4.1.4 TOTAL DISSOLVED SOLIDS (TDS)

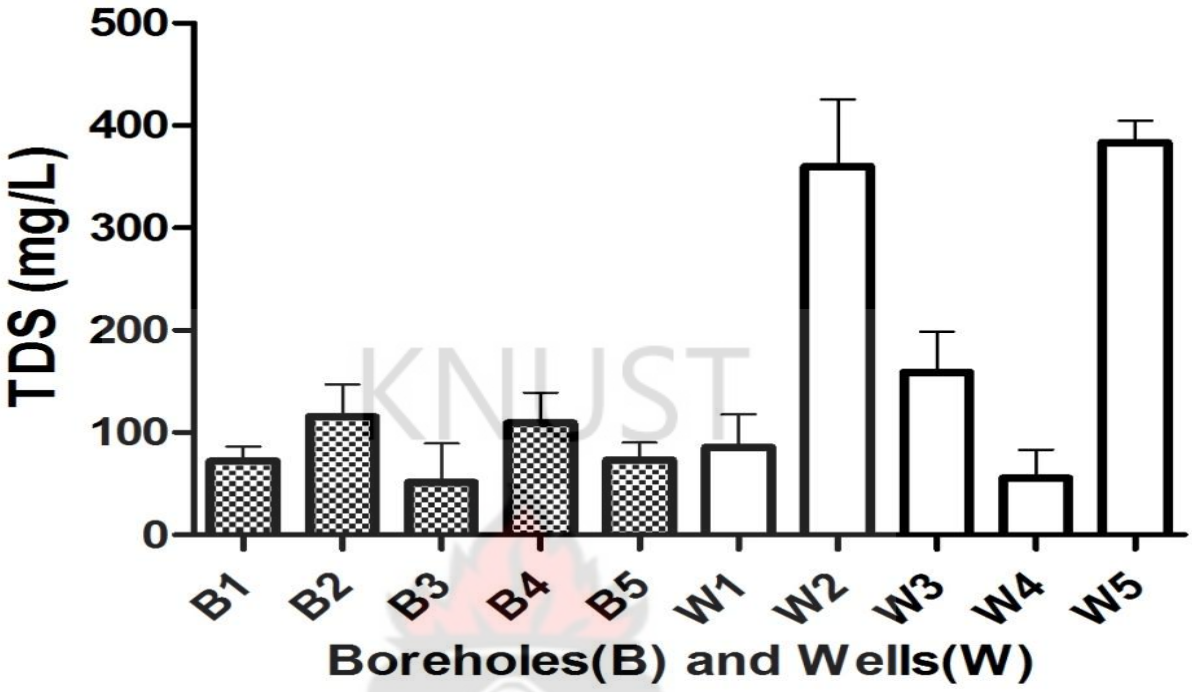

Figure 4.4: Mean concentration of Total dissolved solids (mg/L) of water from sampled boreholes and hand dug wells.

The mean values for TDS ranged from 51.53 mg/L to 116.30mg/L and 56.48mg/L and 418.20 mg/L (figure 4.4) for boreholes and wells respectively. Among the boreholes, the maximum (116.30mg/L) and minimum (51.53 mg/L) values of TDS were recorded for B2 and B3 respectively. In the case of the wells maximum (418.20mg/L) and minimum (56.48mg/L) mean values of TDS were recorded for W2 and W4 respectively. Generally the wells recorded higher concentrations of total dissolved solids than the boreholes. These values were however below the GSB/WHO maximum limit of 1000 mg/L.

4.1.5 CONDUCTIVITY

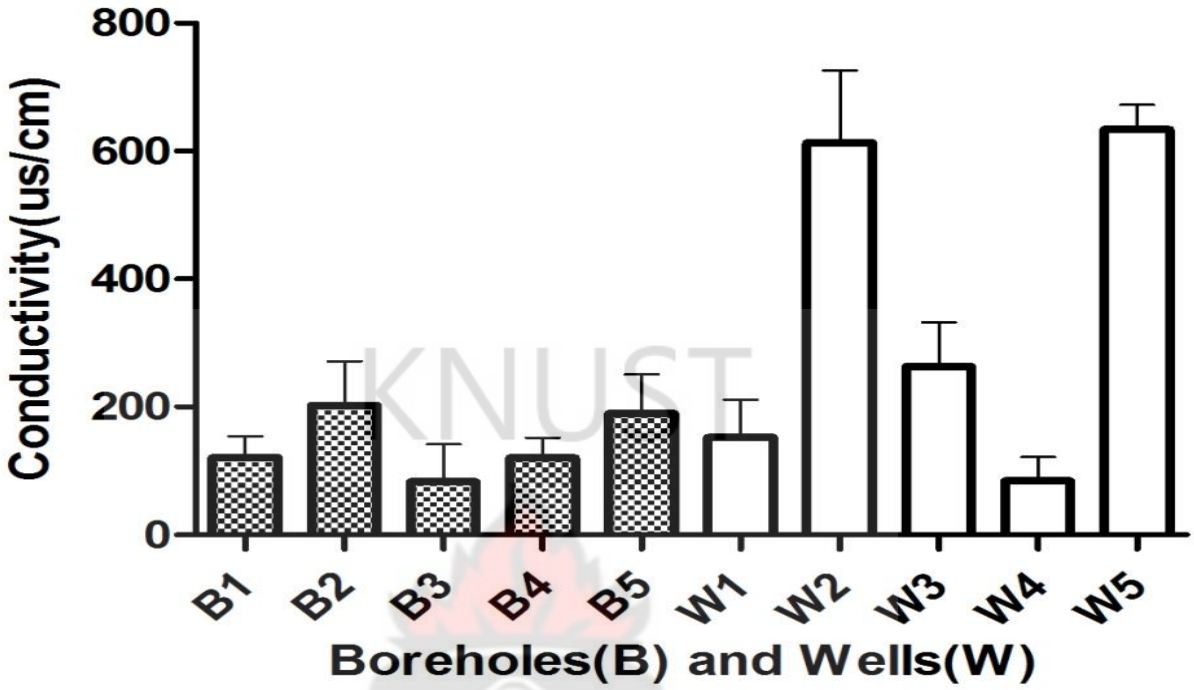

Figure 4.5: Mean Conductivity (us/cm) of water from sampled boreholes and hand dug wells.

Electrical conductivity values for the boreholes varied from a mean of 83.23 to 202.43 µs/cm with B2 recording the highest mean of 202.43 µs/cm and B3 the lowest of 83.23 µs/cm. Electrical conductivity values for the hand dug wells also varied from a mean of 84.45 to 633.50 µs/cm with W5 recording the highest mean value of 202.43 µs/cm and W4 the lowest of 83.23 µs/cm. Conductivity values obtained for the hand-dug wells were observably higher than those of the boreholes.

4.1.6 CALCIUM HARDNESS

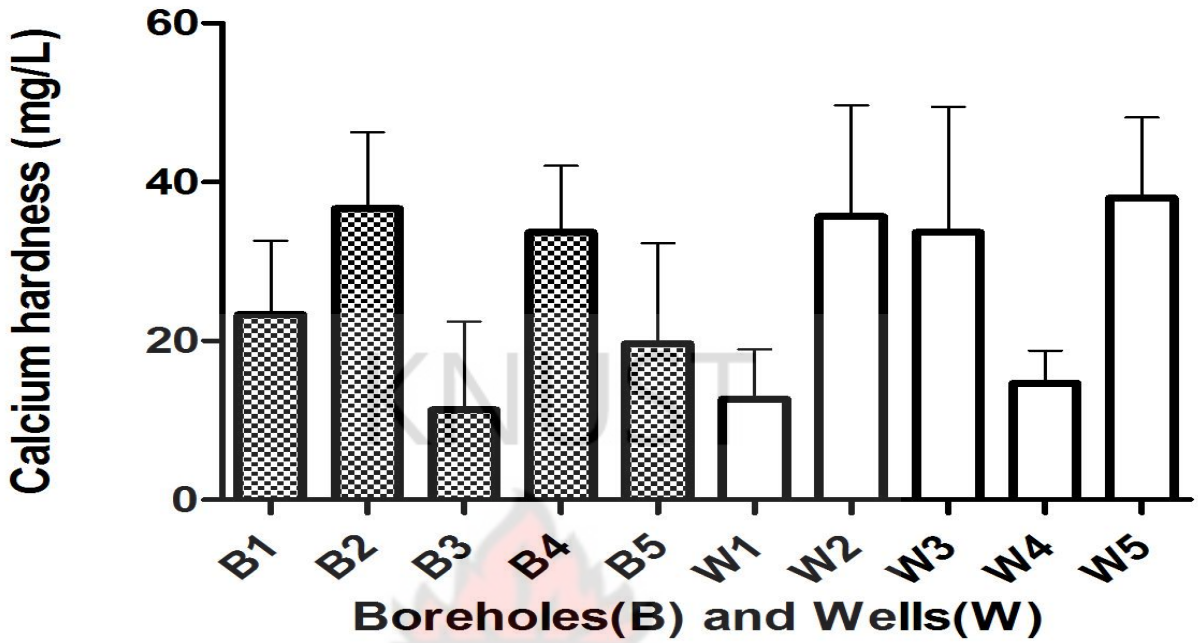

Figure 4.6: Mean Calcium hardness (mg/L) of water from sampled boreholes and hand dug wells.

Calcium hardness of the boreholes ranged from a mean value of 11.33 to 36.67 mg/L. For the hand dug wells, mean values ranged from 12.67 to 38.00 mg/L. In both cases maximum and minimum values were recorded for B2 (36.67 mg/L), W5 (38.00 mg/L) and B3 (11.33 mg/L), W1 (12.67 mg/L) respectively (figure 4.6). The mean values recorded for the boreholes did not vary much from those of the hand-dug wells.

4.1.7 MAGNESIUM HARDNESS

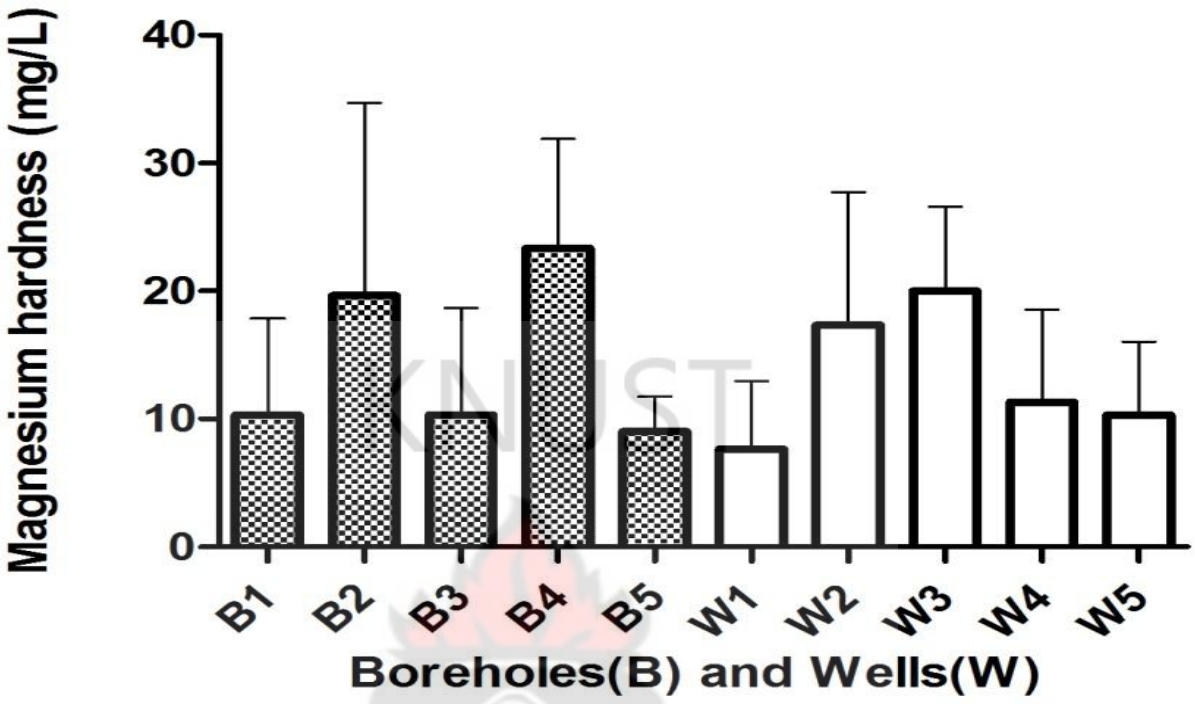

Figure 4.7: Mean Magnesium hardness of water from sampled boreholes and hand dug wells.

Magnesium hardness of the boreholes ranged from a mean value of 9.00 to 23.33 mg/L. In the case of the wells values recorded ranged from 7.67 to 20.00 mg/L. The maximum and minimum mean values were recorded for B4 (23.33 mg/L), W3 (20.00 mg/L) and B5 (9.00 mg/L), W1 (7.67 mg/L) respectively (figure 4.7). Furthermore, values obtained for the boreholes did not vary from those of the hand-dug wells.

4.1.8 TOTAL HARDNESS

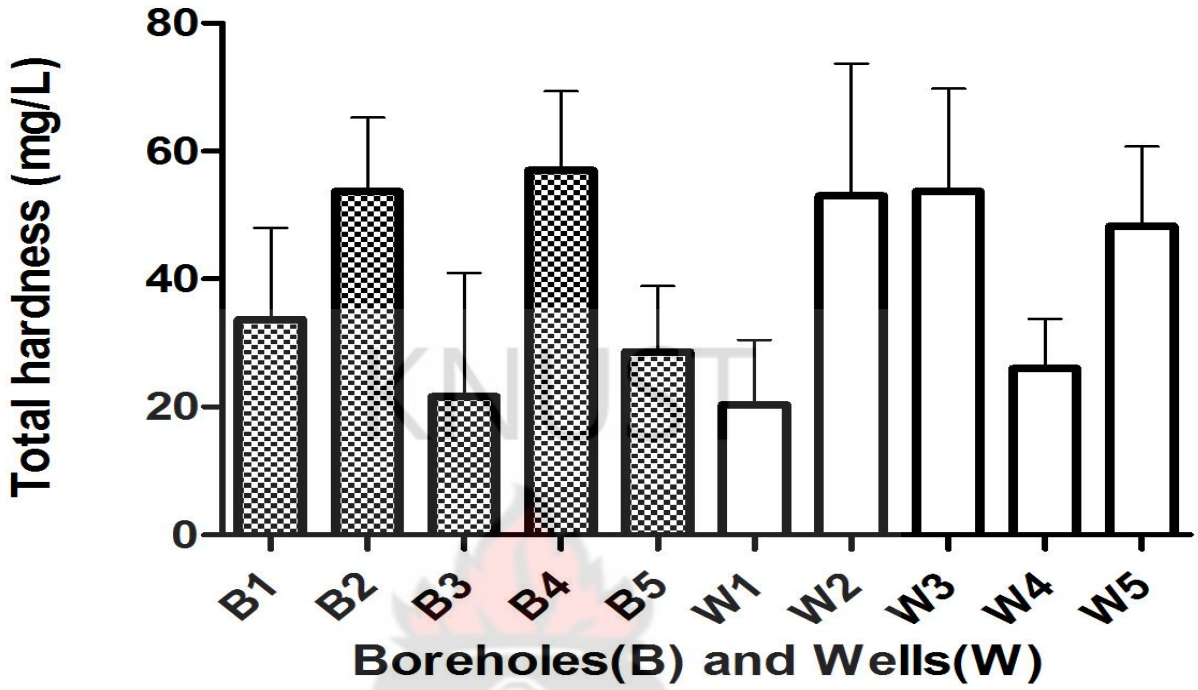

Figure 4.8: Mean Total hardness of water from sampled boreholes and hand dug wells.

Total hardness of the water samples ranged from a mean of 21.67 mg/L to 57.00 mg/L and 20.33 mg/L to 53.67mg/L for the boreholes and wells respectively (figure 4.8). Among the individual boreholes, B4 and B3 recorded the maximum (57.00 mg/L) and minimum (21.67 mg/L) mean values of total hardness. Similarly W3 and W1 also recorded the maximum (53.67mg/L) and minimum (20.33 mg/L) values for the wells (figure 4.8). Also, values obtained for the boreholes did not vary much from those of the hand-dug wells.

However, the total hardness of both borehole and well water samples were far below the GSB guideline value of 500 mg/L.

4.1.9 NITRATE

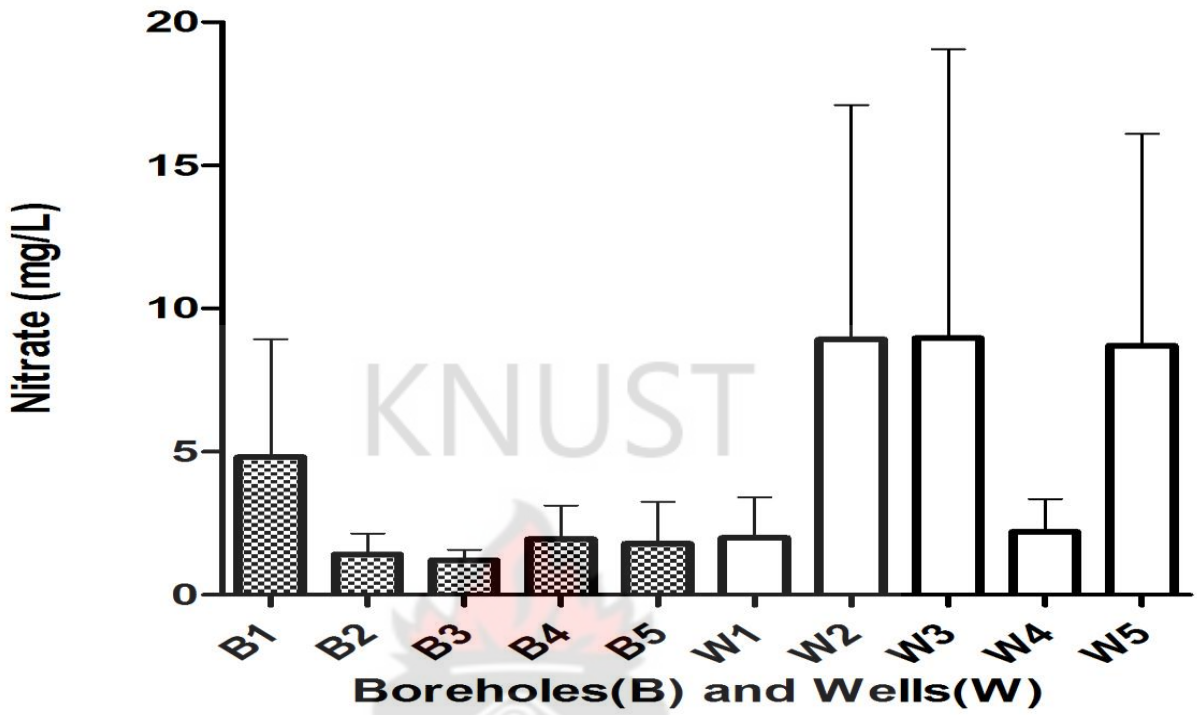

Figure 4.9: Mean Nitrate concentrations of water from sampled boreholes and hand dug wells.

The concentrations of nitrate of the boreholes ranged from a mean value of 1.21 mg/L to 4.82 mg/L. Those of the wells also ranged from 2.00 mg/L to 8.97 mg/L (figure 4.9). Among the boreholes, the highest and lowest concentrations of nitrate were recorded for B1 (4.82 mg/L) and B3 (1.21mg/L) respectively. Similarly, W1 (2.00 mg/L) and W3 (8.97 mg/L) recorded the lowest and highest concentrations of nitrate among the hand-dug wells. Again the nitrate concentration in the hand dug wells was much higher than those of the boreholes. Nitrate levels of the boreholes showed significant differences ($p = 0.0349$) but there was no significant differences in those of the wells ($p = 0.1557$).

However, nitrate concentrations for the boreholes and hand dug wells were far below GSB/WHO guideline value of 50.0 mg/L.

4.1.10 NITRITE

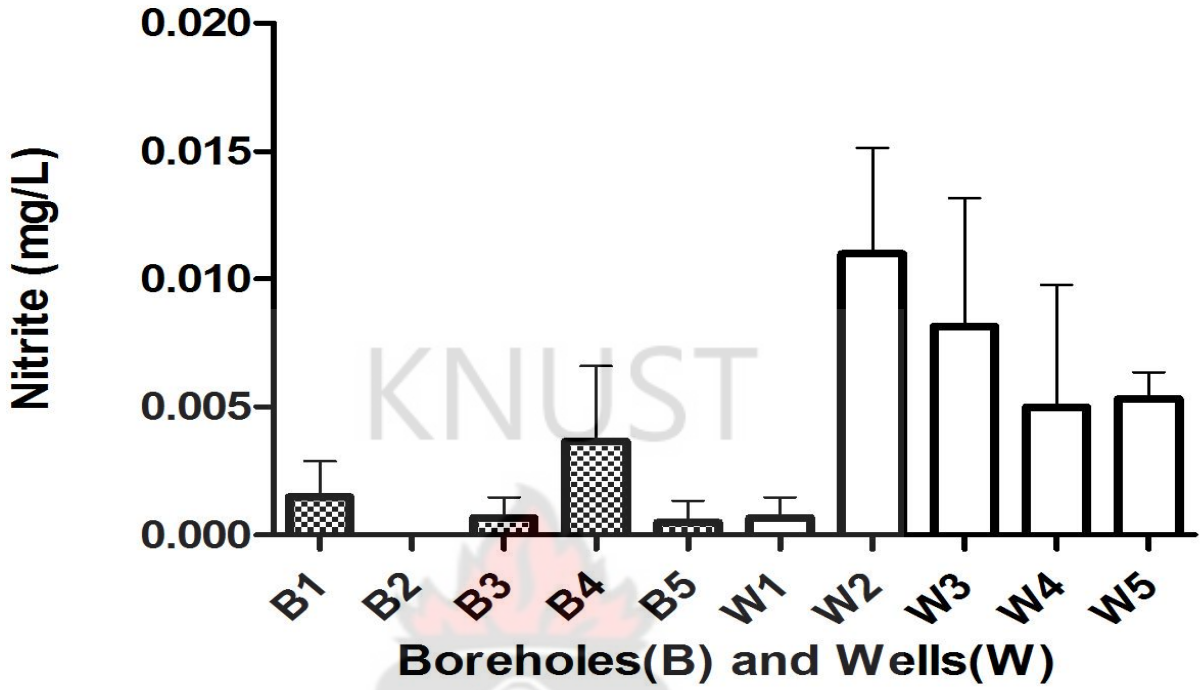

Figure 4.10: Mean Nitrite concentrations of water from sampled boreholes and hand dug wells.

In this study, the concentrations of nitrite of water from the boreholes ranged from a mean value of 0.00 mg/L to0.004mg/L. Those of the wells also ranged from 0.001 mg/L to 0.011mg/L (figure 4.10). Generally, the hand dug wells recorded higher concentrations than the boreholes.

However, mean values of nitrite obtained for the boreholes and the hand dug wells were below GSB/WHO guideline value of 3.0mg/L (figure 4.10). Significant differences were found in nitrite levels among the individual boreholes and hand dug wells ($p = 0.0033$ and $p = 0.0008$ respectively).

4.1.11 FLUORIDE

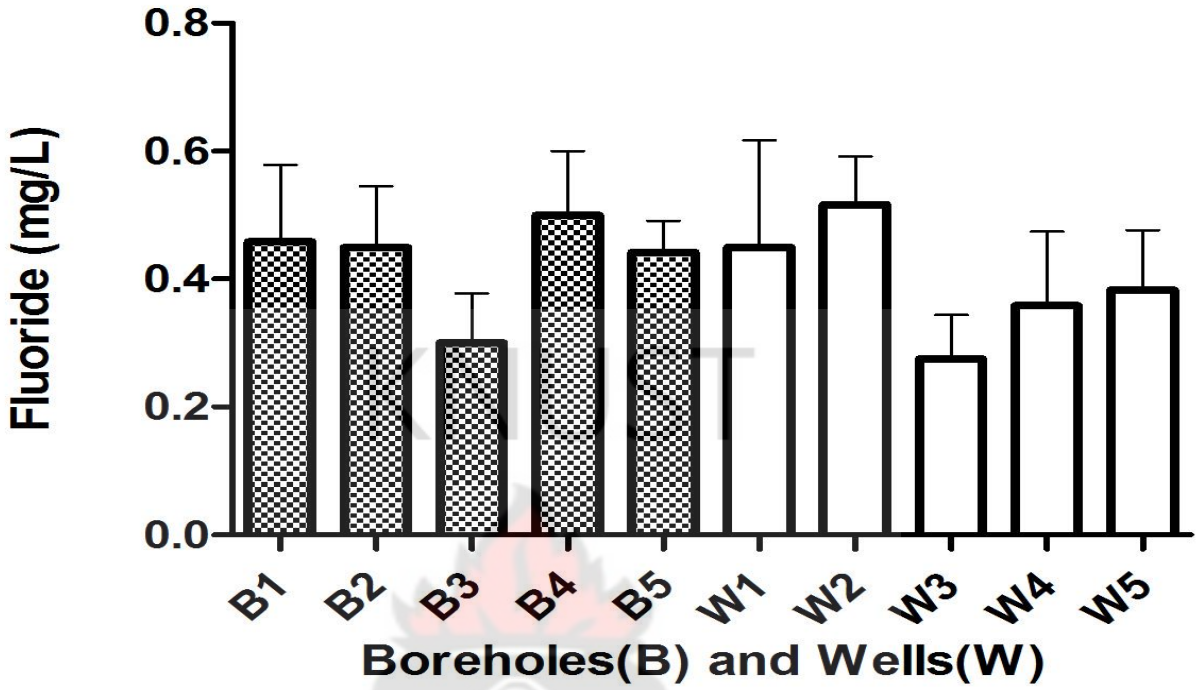

Figure 4.11: Mean Fluoride concentrations of water from sampled boreholes and hand dug wells.

Mean fluoride concentrations for the boreholes and wells ranged from 0.30 mg/L to 0.50 mg/L and 0.28 mg/L to 0.52mg/L respectively (figure 4.11). Among the boreholes, the maximum and minimum mean concentrations of fluoride were recorded for B4 (0.50 mg/L) and B3 (0.30 mg/L) respectively. Similarly, wells W2 and W3 also recorded the maximum (0.52mg/L) and minimum (0.28 mg/L) mean concentrations of fluoride. Fluoride concentrations in the individual borehole and well samples showed statistically significant differences ($p = 0.0103$ and $p = 0.0100$ respectively).

On the average, the boreholes recorded higher concentrations of fluoride than the hand-dug well. However, values obtained were below the GSB/WHO guideline value of 1.5mg/L.

4.1.12 PHOSPHATE

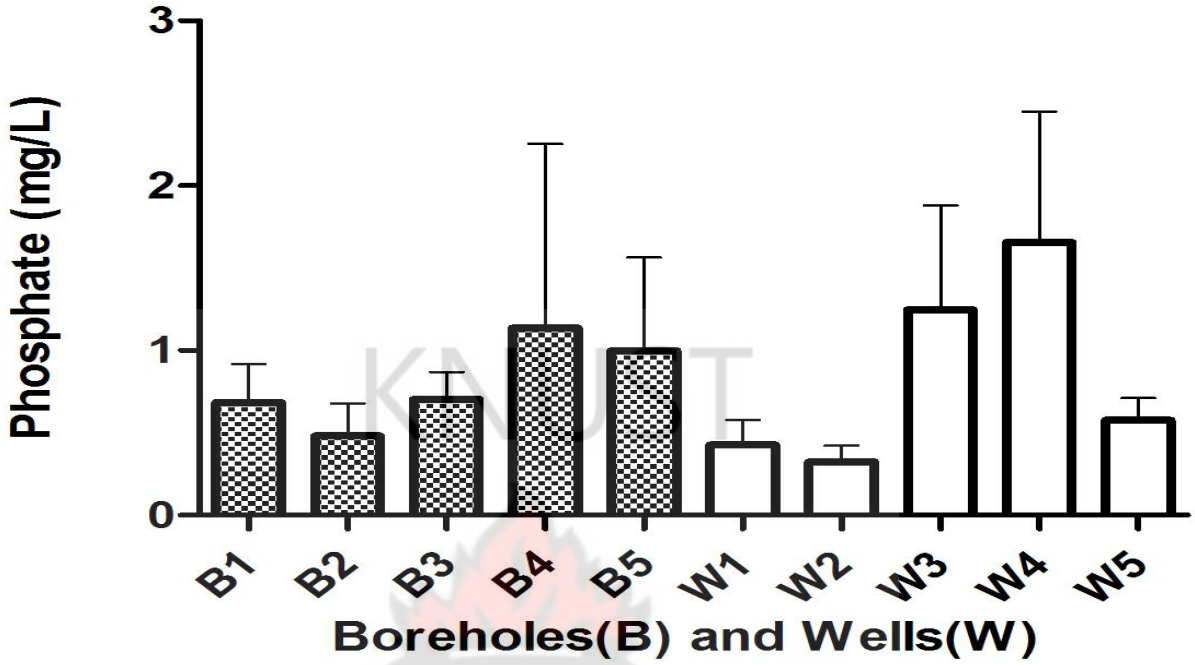

Figure 4.12: Mean Phosphate concentrations of water from sampled boreholes and hand dug wells.

Generally, phosphate levels in sampled boreholes and wells ranged from a mean of 0.48 mg/L to 1.14 mg/L and 0.33 mg/L to 1.66mg/L for boreholes and hand dug wells respectively (figure 4.12). Among the boreholes the maximum (1.14 mg/L) and minimum (0.48 mg/L) mean phosphate concentrations were recorded by B4 and B2 respectively. Also W4 and W2 recorded the maximum (1.66mg/L) and minimum (0.33 mg/L) phosphate concentrations among the sampled hand dug wells. Phosphate levels in the boreholes showed no significant differences ($p = 0.3223$) but those of the wells were significantly different from each other ($p = 0.0001$).

The concentration of phosphate in the sampled boreholes did not vary much from that of the hand dug wells. However, mean values obtained were below the GSB/WHO maximum guideline of 400mg/L.

4.1.13 SULPHATE

Figure 4.13: Mean Sulphate concentrations of water from sampled boreholes and hand dug wells.

Mean values of sulphate of sampled boreholes and wells in this research ranged from 3.67 mg/L to 12.33 mg/L and 5.00 to 40mg/L (figure 4.13). Between the boreholes the highest (12.33 mg/L) and lowest (3.67 mg/L) sulphate concentrations were recorded by B2 and B5 respectively. In the same way, W2 and W3 also recorded the highest (40mg/L) and minimum (5.00 mg/L) sulphate levels for the wells. The hand dug wells showed apparently higher levels of sulphate than the boreholes Again sulphate levels in this research were below the GSB/WHO guideline value of 400mg/L.

4.1.14 CHLORIDE

Figure 4.14: Mean Chloride concentrations of water from sampled boreholes and hand dug wells.

The mean concentration of chloride in the boreholes ranged from 13.83 to 20.83mg/L. Those of the wells also ranged from 13.50 to 42.33mg/L (figure 4.14). The maximum and minimum mean concentrations of chloride in the boreholes and hand dug wells were observed in B3 (20.83mg/L), W2 (42.33mg/L) and B4 (13.83mg/L), W3 and W5 (13.50mg/L) respectively. Though the levels of chloride were all below the GSB/WHO maximum limit of 250mg/L but those of the wells were a little higher than the boreholes. Chloride levels in this research showed significant differences in both boreholes and wells ($p = 0.0110$ and $p = 0.0001$ respectively).

4.2 BACTERIOLOGICAL PARAMETERS

4.2.1 TOTAL COLIFORMS

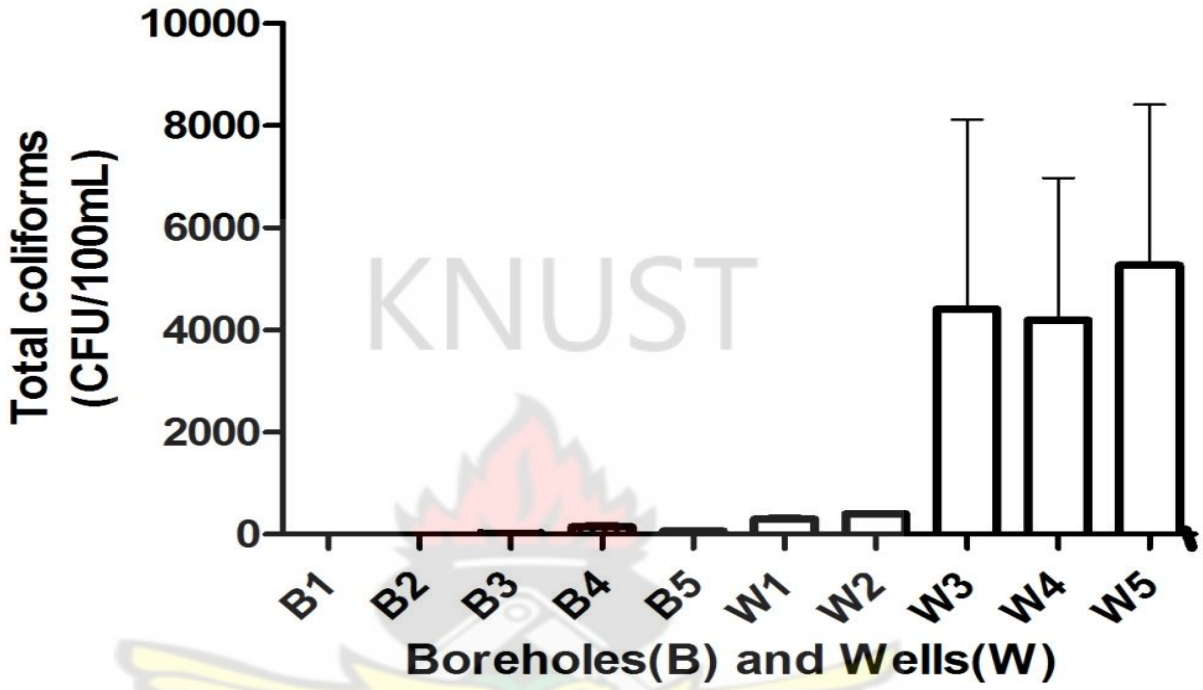

Figure 4.15: Mean Total coliform counts of water samples collected from borehole and hand dug wells.

The total coliforms count in the borehole samples ranged from a mean of 7 CFU/100mL to 142 CFU/100mL with B1 and B4 recording the lowest and highest counts respectively (figure 4.15). Average total coliforms of the wells also ranged from 293CFU/100mL to 5267CFU/100mL with W1 and W5 recording the lowest and highest respectively. Statistical analysis on borehole samples showed significant differences in total coliform ($p = 0.0001$).

Similarly, statistical analysis on well samples also showed significant differences in total coliform ($p = 0.0029$). Levels of total coliform recorded in this work highly exceeded GSB/WHO guideline value for drinking water (zero count per100mL).

4.2.2 FAECAL COLIFORM

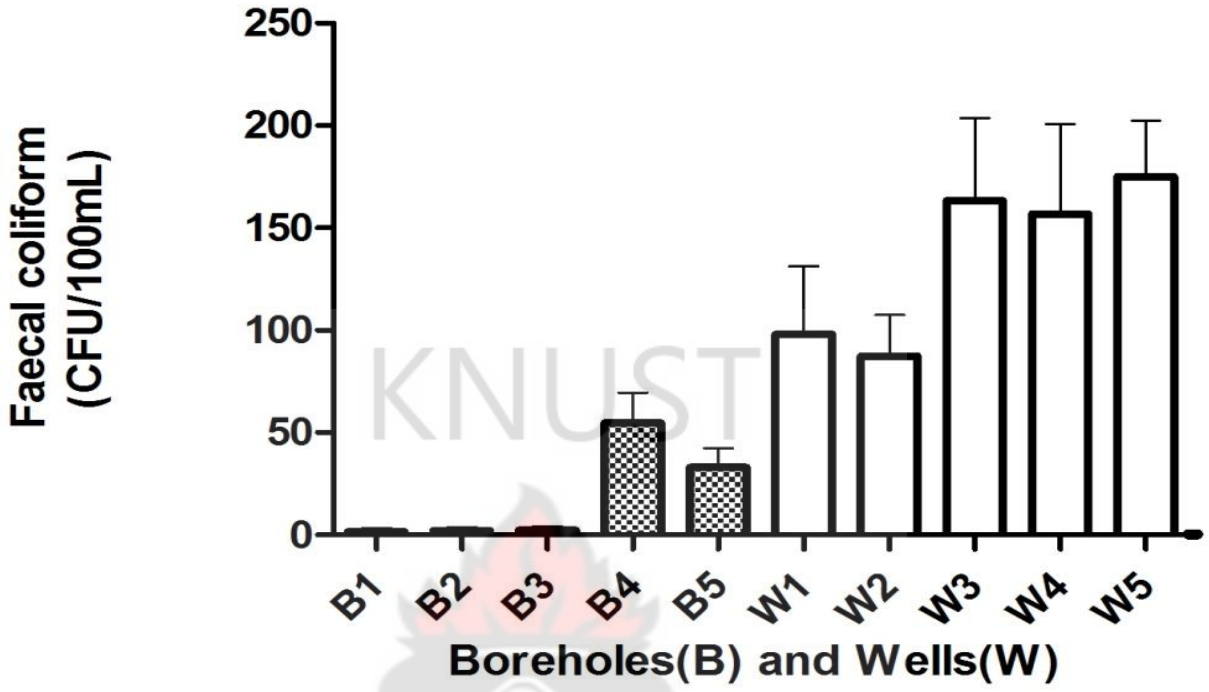

Figure 4.16: Mean Faecal coliform counts of water samples collected from borehole and hand dug wells.

All the boreholes contained some amount of faecal coliform. However, among the boreholes, B4 and B5 recorded higher mean counts of faecal coliform; 55 and 33CFU/100 mL respectively (figure 4.16). Well W5 recorded the highest mean count of faecal coliform (175CFU/100ml) followed by W2 recorded the lowest count among the wells. Faecal coliform in borehole and well samples showed statistically significant differences ($p = 0.0001$ and $p = 0.0002$ respectively).

Generally, the wells recorded higher mean counts of faecal coliform than the boreholes.

4.2.3 SALMONELLA

The analysis carried on the water samples did not record any count for Salmonella.

4.2.4 Enterococci

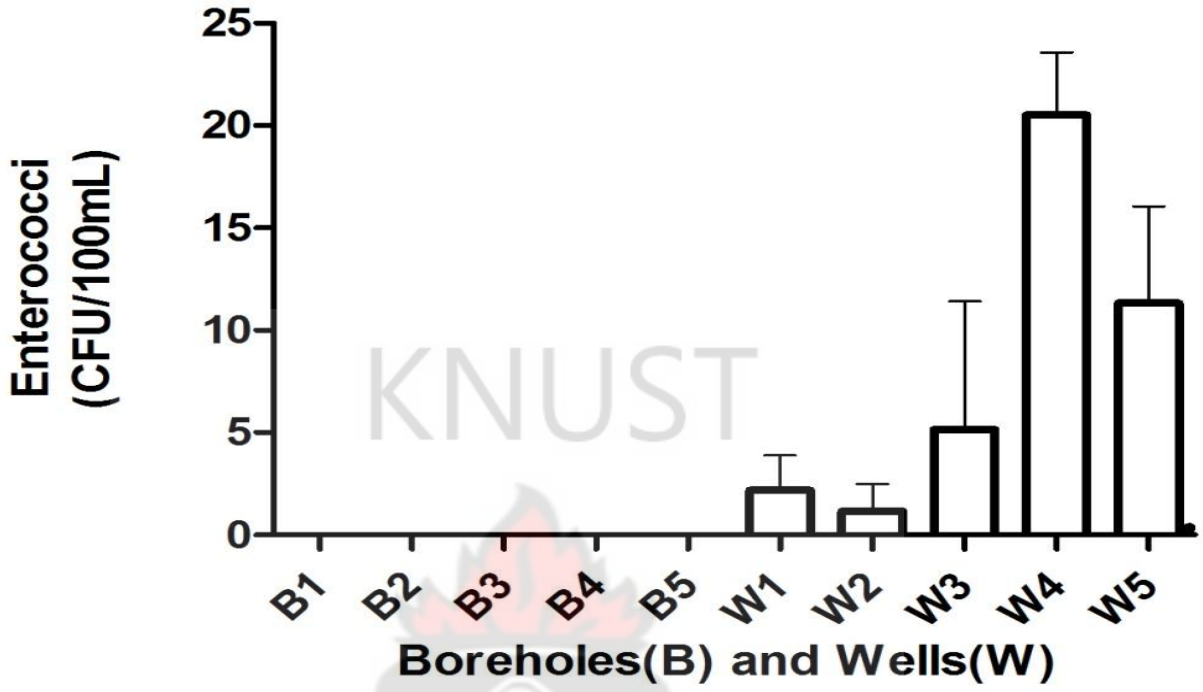

Figure 4.17: Mean Enterococci counts of water samples collected from borehole and hand dug wells.

The mean count of enterococci in the wells range from 1 to 21CFU/100ml. Wells W3, W4 and W5 recorded higher counts of 5, 21 and 11CFU/100ml respectively (figure 4.17). The lowest mean count was recorded for W2. However, none of the boreholes recorded any amount of enterococci.

CHAPTER FIVE

DISCUSSION

5.1 PHYSICOCHEMICAL PARAMETERS

5.1.1 pH

The mean pH of the ground water samples taken from the area were all within the normal GSB/WHO range (6.5 – 8.5) except W1 with mean pH of 6.37. This finding could be attributed to the rock/soil type at the location. Water with pH lower than 6.5 is considered too acidic for human consumption and can cause health problems such as acidosis. Acidic water has 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). However, the mean pH of all the water samples did not vary much from each other. The pH values recorded in this research were in conformity with those observed by other authors (Shittu *et al.*, 2008; Nkansah *et al.*, 2010).

5.1.2 TURBIDITY

Though all the samples analysed were fairly clear with turbidity values below the GSB/WHO limit of 5.0 NTU. It was also observed that the hand dug wells recorded relatively higher turbid values. This may be attributed to the open nature of the wells and hence the possibility of algae growth, entry of phytoplankton and sediments from erosion, etc. High turbidity may also increase the possibility of microbiological contamination (DWAF, 1998). The turbidity values recorded in this research were in agreement with those reported by Amankona (2010) and Tekpor (2012) but were significantly lower.

5.1.3 COLOUR

The average colour of the hand dug wells far exceeded those of the boreholes. This may be attributed to the fact that the wells are somehow exposed to the immediate environment and matter (both organic and inorganic matter) in the air as well as in receptacles for drawing water finally end up in them.

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 above the ranges obtained in this research.

5.1.4 TOTAL DISSOLVED SOLIDS (TDS)

Higher suspended solids and total dissolved solids (TDS) are indicators of water pollution.

The concentration of total dissolved solids recorded for the boreholes were far below those of the hand-dug wells. The sources of TDS are geology and soils which release ions very easily, urban and fertilizer run- off and decaying organisms. Again, since the wells are an opened source of water there is easy entry of soil particles (dust in the air) as well as dead organic matter (insects and plants). McCutheon *et al.*(1983) stated that the palatability of water with TDS level less than 600 mg/L is generally considered to be good whereas water with TDS greater than 1200 mg/L becomes increasingly unpalatable. High TDS gives unobjectionable odour or offensive taste (Aydin, 2007). The concentration of total dissolved solids in this research were below the GSB/WHO acceptable limit of 1000mg/L and hence do not pose any health threat to consumers. This also explains the reason why the water were odourless.

The range of TDS obtained in this research was relatively higher than those reported by Olobaniyi (2007) in well water samples.

5.1.5 CONDUCTIVITY

The mean conductivity values recorded for the water sampled from boreholes and wells were all within the acceptable limit of 1000 µs/cm prescribed by GSB/WHO and therefore do not pose any potential health risk to consumers.

However, it was observed that conductivity of the hand dug wells far exceeded those of the boreholes. People draw well water with receptacles with varying degree of hygiene in the absence of permanent ones. Since some of the wells are poorly covered, solid particles floating in the air enter into the wells and end up dissolved in them. All these may contribute to the high values of conductivity in the hand dug wells.

Conductivity is affected by the presence of dissolved inorganic solids (APHA/AWWA/WEF, 2003 and Spellman, 2003). Generally, conductivity of clean water is lower but as it moves down the earth it leaches and dissolves ions from the soil and also picks up organic matter from biota and detritus (Ferrar, 1989). Oludare and Sikuru (2012) as well as Tekpor (2012), have reported conductivity values in borehole and well water samples which are below those obtained in this study.

5.1.6 CALCIUM, MAGNESIUM AND TOTAL HARDNESS

Hardness (calcium, magnesium and total) of the boreholes did not vary much from those of the hand-dug wells. 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. Hardness may also affect the taste of water but may not have any health implications. The total hardness of water in all the boreholes and wells

were below 150mg/L and thus could be classified as soft to moderately hard with regards to classification of water hardness by Spellman (2003).

Although hardness of (Calcium, Magnesium and Total) the sampled boreholes and hand-dug wells were all below their respective recommended guideline values by GSB; low hardness as per Spellman (2003; 2008) contributes to corrosive tendencies of water

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. On the contrary, they are below the levels reported by Ifayibi (2009) for hand dug wells in Nigeria. Also, levels of total hardness recorded in this study were below the reported range by Shittu *et al*. (2008) and Fasunwon *et al*. (2008).

5.1.7 NITRATE AND NITRITE

The mean concentrations of nitrate and nitrite in this research were appreciably below the GSB/WHO guideline values and therefore pose no health threat to their consumers. However, the hand dug wells recorded distinctly higher values than the boreholes.

Metcalf and Eddy (2003) stated 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). Many nitrogenous fertilizers are converted into mobile nitrates by natural processes which contaminate the nearby water bodies more profusely (Freeze and Cherry 1979, Walter *et al*., 1975).

Therefore, levels of nitrate could be as a result of use of fertilizer or sewage disposal systems.

New Edubiase is basically a farming community and the lands at most of these sites (sampling sites) were agricultural lands and people still cultivate lands in the vicinity.

Moreover, since most of the wells have poor lids, droppings of animals (birds especially) which perch on them as well as those that roam could finally end up in the water. This may be a major reason why the wells recorded higher levels of nitrate.

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. Nitrate levels in this study were within the reported range by Nyarko (2008) and Nkansah *et al.* (2010).

5.1.8 FLUORIDE

The concentration of fluoride determined for the boreholes did not vary much from that of the hand-dug wells.

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. Levels of fluoride in this research will have no health effect on consumers of the water as they were below the GSB/WHO guideline value of 1.5mg/L. In groundwater, fluoride occurs as a natural constituent ranging from trace to 5mg/L. Fluoride concentration in the water samples were in conformity with those reported by Nyarko (2008) in borehole water but were however lower.

5.1.9 PHOSPHATE

Phosphate levels in sampled boreholes and wells were below the GSB/WHO guideline of 400 mg/L. However, the hand-dug wells recorded slightly higher concentrations than the boreholes.

According to Salvato *et al.* (2003), phosphate is usually associated with plant remains, animal wastes or fertilizer. Other potential sources of phosphates include cleaning products, cosmetics, medicated shampoos, food products, faeces and urine (Tjandraatmadja *et al.*, 2010). Hence high levels of phosphate in groundwater could indicate the possible pollution from faecal origin or agro products. Some people draw well water by standing on the concrete lids with their footwear. As a result spilled water wash whatever is underneath their feet back into the water. Fetching receptacles which are often left on the ground may also carry many contaminants into the water. These factors may contribute immensely to the increased phosphate levels in the wells.

The mean concentrations of phosphate in the sampled boreholes and hand dug wells pose no health threat to their users. Phosphate levels obtained in this study were in conformity with results obtained by Abila *et al.* (2012). Phosphate levels obtained in this study pose no health threat to their consumers.

5.1.10 SULPHATE

The hand dug wells showed apparently higher levels of sulphate than the boreholes. The sources of sulphate into water are; leaching from soils, decaying plant and animal matter, human activities such as the combustion of fossil fuels and sour gas processing release sulphur oxides into the atmosphere, some of which is converted to sulphate (http://www.health.gov.sk.ca/environmental-health). Wells are more vulnerable to the entry of contaminants (both organic and inorganic) due to their opened nature.

Corbit (2004) stated that, 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. According to WHO (2004), this effect is mostly manifested at concentrations between 1000 mg/L and 1200mg/L. Sulphate

concentrations recorded in this research were far below this range as well as the GSB/WHO limit and hence pose no health threat to consumers.

Increased sulphate levels can cause deficiencies in trace minerals which can contribute to a depressed growth rate and infertility in herd. The most serious is thiamine deficiency. The major physiological effect resulting from the ingestion of large quantities of sulphate leads to catharsis, dehydration, and gastrointestinal irritation. The presence of sulphate in drinking water can also result in a noticeable taste, the lowest taste threshold concentration for sulphate.

The levels of sulphate recorded in this research were within the range reported by Nyarko(2008) in borehole water but were greater than that reported by Nkansah *et al.* (2010)

5.1.11 CHLORIDE

Higher concentrations of chloride were observed in the hand-dug wells than the boreholes. This could be attributed to the occasional chlorine disinfection by the owners. Chloride in surface and groundwater spring 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). Since sodium chloride has a salty taste, it can be deduced that Chloride in water impacts a salty taste in the water. However the salty taste may be absent in water containing as high as 1000 mg/L chlorine when the predominant cations are calcium and magnesium. That is to say that too much of chlorine in water makes the water esthetically undesirable for drinking purposes.

Although there is no health-based guideline value for chloride, WHO (2004) also stress that, chloride concentrations in excess of 250mg/L can result in detectable taste in water. All the water samples were within the GSB/WHO acceptable limit. Chloride

concentrations in this research conforms to but were greater than those obtained by Amankona (2010) in borehole water samples but were however less than those reported by Abila *et al.* (2012).

5.2 BACTERIOLOGICAL PARAMETERS

5.2.1 TOTAL COLIFORMS

The mean count of total coliforms in the hand-dug wells was sixty-three times higher compared to the boreholes. This may be due to the fact that boreholes were fitted with hand pumps, thus preventing any human and animal contact with the water body.

The presence of total coliforms in water supplies can reveal re-growth and possible biofilm formation or contamination through entrance of foreign material, including soil or plants. This therefore poses health threats to consumers of these water supplies. The levels of total coliforms recorded in this research were in conformity and below those reported by other authors (Tekpor, 2012; Nyarko, 2008; Obiri-Danso *et al.*,2010) but were far greater than as reported by Agbabiaka and Sule (2010).

5.2.2 FAECAL COLIFORM

The mean count faecal coliform in the hand-dug wells was seven times higher compared to the boreholes. Boreholes had aprons that carried wastewater away from their immediate vicinity into a seepage area downhill thus reducing the amount of contamination.

The unfastened condition of hand pump on borehole B4 to its concrete platform may have contributed to its highest count among the boreholes since there is the likelihood of dirty water flowing back. Animals come to graze on the vegetation near B4 and defecate in the process. 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. It has been shown by Adekunle *et al.,* (2007) that feacal and total coliform decrease with increasing distance from pollution source irrespective of the season. Borehole B4 is located downhill and very close to an uncemented gutter, its immediate surrounding gets flooded during heavy down pour.

Wells W3, W4 and W5 which are within the immediate vicinity of septic tanks, pit latrines and other social amenities also recorded high mean values of faecal coliform. Cairncross and Cliff (1987) have shown that soakage pits and pit latrines can extend their influence on groundwater quality up to 10 m or more as groundwater flow is either lateral or vertical.

The construction and depth of the wells could further explain contamination levels. Most of the wells have poor concrete lining allowing easy seepage. Well water was drawn normally using various receptacles (plastic or aluminium buckets) with varying degrees of hygiene. This could also be a contributing factor.

The range of faecal coliforms recorded in this research was below the reported levels by Olowe *et al*. (2005) in hand dug well water.

5.2.3 SALMONELLA

The result obtained for the microbial analysis indicated that all the water samples were free from salmonella. Therefore it may be said that faecal matter that contaminated the wells and some of the boreholes contained no *Salmonella*.

5.2.4 ENTEROCOCCI

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. In this research, high levels of enterococci were recorded in the wells while the boreholes had

none. This may indicate possible pollution by sewage and/or wastes from humans and animals and therefore pose a health threat to users.

All the communities in this study raised their domestic animals (sheep, goat,cattle and poultry) through the free-range system. These animals roam the community in search of food and water and in the process indiscriminately contaminate the wells with their faeces.

Obiri-Danso *et al.* (2010) did a similar work on hand dug well and borehole water samples and reported enterococci counts higher than in this research.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSIONS

The water samples analyzed in study are suitable for consumption in terms of physico-chemical quality since the tested parameters were below GSB/WHO guideline values for drinking water. On the other hand, there were high bacteriological indicator counts in them which were extremely above GSB/WHO recommended guideline values for drinking water. Thus the boreholes and hand dug wells analysed may not be wholesome for drinking with respect to bacteriological quality. This could be the cause of some water borne infections in the area.

6.2 RECOMMENDATIONS

From the outcome of the research, the following measures are recommended:

Water quality analysis be carried out on all the boreholes and hand dug wells in the district on regular basis. This will ensure that incidences of contamination are noticed earlier for remedial action to be taken. People in the community should observe basic hygiene around the immediate environs of these all important sources of water. Dwellers should be educated on the dangers of constructing boreholes and wells downhill and near places of questionable sanitation. There should be regular maintenance and rehabilitation of hand pumps on boreholes. Disinfection of wells with hypochlorite by their owners. Receptacles for drawing water from the wells should be kept clean and permanently attached to a windlass when not in use. Well lids must be kept dry and clean and should be constructed as a single unit and not in pieces with openings at the joints to allow water through.

Wells must be well lined with concrete rings instead of cementing the upper 1 - 2 m as this would prevent the development of fissures within wells. Wells and boreholes aprons should be well reinforced with steel wire to avoid cracking and; access to wells and boreholes by domestic and grazing animals should be restricted by fencing.

6.3 SUGGESTIONS FOR FURTHER RESEARCH

The research has generally revealed that the quality of water from the boreholes and hand dug wells is of questionable quality. However, the research was carried within a period of erratic rain pattern. Further research can be carried out to investigate the effect of seasonal variation on the level of contamination in these major sources of water in the New Edubiase township.

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APPENDICE

APPENDIX 1: RESULTS

PHYSICO-CHEMICAL PARAMETERS

Table 1.1: MONTHLY pH**VALUES**

MONTH	**B1**	**B2**	**B3**	**B4**	**B5**	**W1**	**W2**	**W3**	**W4**	**W5**
NOV	7.28	7.36	7.28	7.35	7.24	7.12	7.21	7.25	7.29	7.2
DEC	7.02	6.54	6.45	7.25	6.74	6.13	6.98	7.18	6.82	7.15
JAN	6.35	6.97	6.15	6.78	6.53	5.23	6.43	6.63	6.31	6.5
FEB	7.09	7.16	7.35	7.3	6.99	7.1	7	7.42	7.23	6.95
MAR	7	6.64	7.45	7.2	6.89	6.43	7.11	7.88	6.96	7.35
APR	6.65	6.88	6.8	7.01	6.92	6.23	6.93	6.42	6.42	7
MEAN	6.898	6.925	6.913	7.148	6.885	6.373	6.943	7.130	6.838	7.025
S.D	0.3376	0.3092	0.5335	0.2152	0.2389	0.7037	0.2710	0.5325	0.4066	0.2945

Table 1.2: MONTHLY TURBIDITY (NTU) VALUES

MONTH	B1	B2	B3	B4	B5	W1	W2	W3	W4	W5
NOV	0.34	0.95	0.87	0.31	0.94	1.60	0.91	2.12	3.80	4.32
DEC	0.37	0.65	0.65	0.29	0.40	0.52	0.52	3.49	0.48	3.53
JAN	0.32	0.34	0.62	4.27	1.37	0.31	0.89	2.89	1.02	4.99
FEB	0.42	0.45	0.88	0.41	1.02	1.90	0.71	1.82	4.30	3.75
MAR	0.39	0.65	0.42	0.29	0.60	0.42	0.62	3.12	0.28	2.33
APR	0.42	0.70	0.38	3.27	1.20	0.53	1.34	2.32	0.89	4.39
MEAN	0.3767	0.6233	0.6367	1.473	0.9217	0.8800	0.8317	2.627	1.795	3.885
S.D	0.04131	0.2118	0.2130	1.807	0.3644	0.6852	0.2914	0.6418	1.774	0.9195

Table 1.3: MONTHLY CONDUCTIVITY (µS/cm) VALUES

MONTH	B1	B2	B3	B4	B5	W1	W2	W3	W4	W5
NOV	146	306	149.6	116.3	287	206	727	338	124.6	664
DEC	83	149.4	39.6	123	162.2	75.8	515	167.3	38.1	640
JAN	126.2	158.7	48	93.9	155.7	194.8	587	293	88.2	677
FEB	156	276	166.9	165.3	245	178.2	778	306	121.6	592
MAR	78	159.4	42.3	143	136	78.8	505	185.3	42	580
APR	136.2	165.1	53	79.9	150.7	181.8	568	288	92.2	648
MEAN	120.9	202.4	83.23	120.2	189.4	152.6	613.3	262.9	84.45	633.5
S.D	32.87	69.44	58.55	31.28	61.39	59.14	113.3	69.56	37.46	39.14

Table 1.4: MONTHLY VALUES OF COLOUR (Hz)

MONTH	**B1**	**B2**	**B3**	**B4**	**B5**	**W1**	**W2**	**W3**	**W4**	**W5**
NOV	2	3	1	1	3	3	6	3	2	5

DEC	0	0	0	0	0	0	4	1	1	3
JAN	0	2	0	0	1	1	2	2	1	2
FEB	1	1	2	1	2	2	5	4	3	3
MAR	1	0	0	0	0	0	1	0	0	2
APR	0	1	0	1	1	2	3	1	0	3
MEAN	0.667	1.167	0.500	0.500	1.167	1.333	3.500	1.833	1.167	3.000

Table 1.5: MONTHLY CHLORIDE (Mg/l) CONCENTRATIONS

MONTH	B1	B2	B3	B4	B5	**W1**	**W2**	**W3**	**W4**	**W5**
NOV	20	15	20	8	20	27	48	13	15	13
DEC	13	13	23	13	18	31	62	13	20	14
JAN	21	17	20	16	17	24	26	12	15	12
FEB	18	18	24	10	13	20	36	15	18	14
MAR	16	16	20	18	17	23	60	12	24	13
APR	21	21	18	18	20	32	22	16	16	15
MEAN	18.17	16.67	20.83	13.83	17.50	26.17	42.33	13.50	18.00	13.50
S.D	3.189	2.733	2.229	4.215	2.588	4.708	17.04	1.643	3.521	1.049

Table 1.6: MONTHLY FLUORIDE (Mg/l) CONCENTRATIONS

MONTH	B1	B2	B3	B4	B5	**W1**	**W2**	**W3**	**W4**	**W5**
NOV	0.6	0.55	0.25	0.6	0.4	0.55	0.5	0.2	0.25	0.35
DEC	0.3	0.5	0.45	0.55	0.45	0.45	0.5	0.25	0.3	0.3

JAN	0.4	0.35	0.3	0.45	0.5	0.25	0.6	0.35	0.4	0.5
FEB	0.6	0.55	0.25	0.6	0.4	0.55	0.5	0.2	0.25	0.35
MAR	0.45	0.4	0.25	0.35	0.4	0.65	0.4	0.3	0.55	0.3
APR	0.4	0.35	0.3	0.45	0.5	0.25	0.6	0.35	0.4	0.5
MEAN	0.458	0.450	0.300	0.500	0.442	0.450	0.517	0.275	0.358	0.383
S.D	0.120	0.0949	0.0775	0.100	0.0492	0.167	0.0753	0.0689	0.116	0.0931

Table 1.7: MONTHLY NITRATE (Mg/l) CONCENTRATIONS

MONTH	**B1**	**B2**	**B3**	**B4**	**B5**	**W1**	**W2**	**W3**	**W4**	**W5**
NOV	0.97	0.66	0.86	0.54	0.48	0.72	0.79	1.06	1.57	0.88
DEC	3.69	1.48	1.06	2.18	1.34	1.56	7.45	4.08	1.31	8.36
JAN	10.56	2.4	1.67	3.2	3.75	3.96	18.92	23.32	3.74	18.92
FEB	0.97	0.66	0.86	0.54	0.48	0.72	0.79	1.06	1.57	0.88
MAR	3.48	1.22	1.18	2.16	1.28	1.45	6.89	4.01	1.41	7.78
APR	9.22	2.1	1.64	3.08	3.45	3.56	18.72	20.3	3.61	15.45
MEAN	4.815	1.420	1.212	1.950	1.797	1.995	8.927	8.972	2.202	8.712
S.D	4.124	0.7241	0.3647	1.176	1.449	1.418	8.179	10.08	1.146	7.393

Table 1.8: MONTHLY NITRITE (Mg/l) CONCENTRATIONS

MONTH	B1	B2	B3	B4	B5	**W1**	**W2**	**W3**	**W4**	**W5**
NOV	0.001	0	0	0.004	0	0.001	0.012	0.008	0.01	0.006
DEC	0.003	0	0.002	0	0.001	0.001	0.004	0.004	0.001	0.006
JAN	0	0	0	0.006	0	0	0.014	0.014	0.003	0.006
FEB	0.002	0	0.001	0.006	0	0.002	0.014	0.007	0.012	0.004
MAR	0.003	0	0.001	0	0.002	0	0.008	0.002	0.001	0.004

APR	0	0	0	0.006	0	0	0.014	0.014	0.003	0.006
MEAN	0.0015	0.0	0.000667	0.00367	0.0005	0.000667	0.011	0.00817	0.005	0.00533
S.D	0.00138	0.0	0.000816	0.00294	0.000837	0.000816	0.00415	0.00500	0.00477	0.00103

Table 1.9: MONTHLY SULPHATE (Mg/l) CONCENTRATIONS

MONTH	B1	B2	B3	B4	B5	**W1**	**W2**	**W3**	**W4**	**W5**
NOV	0	7	7	5	5	38	46	3	3	3
DEC	8	16	7	3	3	32	42	7	12	7
JAN	7	14	9	5	3	25	32	5	7	5
FEB	0	7	7	5	5	38	46	3	3	3
MAR	8	16	7	3	3	32	42	7	12	7
APR	7	14	9	5	3	25	32	5	7	5
MEAN	5.000	12.33	7.667	4.333	3.667	31.67	40.00	5.000	7.333	5.000
S.D	3.899	4.227	1.033	1.033	1.033	5.820	6.450	1.789	4.033	1.789

Table 1.10: MONTHLY PHOSPHATE (Mg/l) CONCENTRATIONS

MONTH	B1	B2	B3	B4	B5	**W1**	**W2**	**W3**	**W4**	**W5**
NOV	0.91	0.72	0.78	2.58	0.38	0.54	0.3	2.06	0.72	0.51
DEC	0.44	0.36	0.56	0.42	1.88	0.24	0.22	0.88	2.20	0.48
JAN	0.56	0.36	0.78	0.42	1.09	0.30	0.30	0.89	2.60	0.54
FEB	0.91	0.72	0.78	2.58	0.38	0.54	0.30	2.06	0.72	0.51
MAR	0.42	0.26	0.44	0.38	1.06	0.34	0.32	0.79	2.10	0.58

APR	0.86	0.46	0.88	0.44	1.20	0.60	0.51	0.79	1.60	0.84
MEAN	0.683	0.480	0.703	1.14	0.998	0.427	0.325	1.25	1.66	0.577
S.D	0.236	0.196	0.167	1.12	0.565	0.151	0.0971	0.633	0.792	0.133

Table 1.11: MONTHLY TOTAL SOLIDS (Mg/l) CONCENTRATION

MONTH	**B1**	**B2**	**B3**	**B4**	**B5**	**W1**	**W2**	**W3**	**W4**	**W5**
NOV	90.8	148	89.8	68.9	156.5	112.8	436	204	86.8	399
DEC	51.9	89.7	24.3	73.3	93.7	45.4	313	100.5	21.8	386
JAN	75.7	97	29.1	60.5	93.9	108.9	354	178.6	53.7	402
FEB	90	163	109.8	94.3	136.5	92.4	782	188	92.8	395
MAR	58.4	102.7	26.8	92	83.7	45.1	282	124.5	31.8	345
APR	75.3	97.4	29.4	56.5	92	108.9	342	158.6	52	381
MEAN	73.68	116.30	51.53	74.25	109.38	85.58	418.17	159.03	56.48	384.67
S.D	15.96	31.01	37.96	15.82	29.67	32.03	185.59	39.66	28.56	20.98

Table 1.12: MONTHLY CONCENTRATIONS OF TOTAL DISSOLVED SOLIDS (Mg/l)

MONTH	**B1**	**B2**	**B3**	**B4**	**B5**	**W1**	**W2**	**W3**	**W4**	**W5**
NOV	90.8	148	89.8	68.9	156.5	112.8	436	204	86.8	399
DEC	51.9	89.7	24.3	73.3	93.7	45.4	313	100.5	21.8	386
JAN	75.7	97	29.1	60.5	93.9	108.9	354	178.6	53.7	402
FEB	90	163	109.8	94.3	136.5	92.4	782	188	92.8	395
MAR	58.4	102.7	26.8	92	83.7	45.1	282	124.5	31.8	345
APR	75.3	97.4	29.4	56.5	92	108.9	342	158.6	52	381

MEAN	73.68	116.3	51.53	74.25	109.4	85.58	418.2	159.0	56.48	384.7
S.D	15.96	31.01	37.96	15.82	29.67	32.03	185.6	39.66	28.56	20.98

Table 1.13: MONTHLY CONCENTRATIONS OF TOTAL HARDNESS (Mg/L)

MONTH	B1	B2	B3	B4	B5	**W1**	**W2**	**W3**	**W4**	**W5**
NOV	34.00	56.00	10.00	70.00	20.00	28	76	62	30	60
DEC	40.00	50.00	40.00	58.00	36.00	20	40	50	30	38
JAN	20.00	42.00	8.00	42.00	22.00	8	36	40	16	46
FEB	30.00	72.00	12.00	68.00	26.00	30	82	82	32	66
MAR	58.00	60.00	52.00	62.00	46.00	28	48	48	32	34
APR	20.00	42.00	8.00	42.00	22.00	8	36	40	16	46
MEAN	33.67	53.67	21.67	57.00	28.67	20.33	53.00	53.67	26.00	48.33
S.D	14.28	11.55	19.28	12.38	10.25	10.15	20.70	16.07	7.797	12.42

Table 1.14: MONTHLY CONCENTRATIONS OF MAGNESIUM HARDNESS (Mg/L)

MONTH	B1	B2	B3	B4	B5	**W1**	**W2**	**W3**	**W4**	**W5**
NOV	14.00	12.00	6.00	30.00	10.00	16.00	16.00	16.00	10.00	6.00
DEC	20.00	6.00	20.00	28.00	6.00	8.00	10.00	10.00	10.00	4.00
JAN	2.00	14.00	4.00	14.00	12.00	2.00	12.00	20.00	4.00	12.00
FEB	8.00	24.00	6.00	20.00	8.00	10.00	38.00	26.00	20.00	20.00
MAR	16.00	48.00	22.00	34.00	6.00	8.00	16.00	28.00	20.00	8.00
APR	2.00	14.00	4.00	14.00	12.00	2.00	12.00	20.00	4.00	12.00
MEAN	10.33	19.67	10.33	23.33	9.000	7.667	17.33	20.00	11.33	10.33
S.D	2.251	15.04	8.335	8.548	2.757	5.279	10.41	6.573	7.230	5.715

Table 1.15: MONTHLY CONCENTRATIONS OF CALCIUM HARDNESS (Mg/L)

MONTHS	B1	B2	B3	B4	B5	**W1**	**W2**	**W3**	**W4**	**W5**
NOV	20.00	44.00	4.00	40.00	10.00	12.00	60.00	46.00	20.00	54.00
DEC	20.00	44.00	20.00	30.00	30.00	12.00	30.00	40.00	20.00	34.00
JAN	18.00	28.00	4.00	28.00	10.00	6.00	24.00	20.00	12.00	34.00
FEB	22.00	48.00	6.00	48.00	18.00	20.00	44.00	56.00	12.00	46.00
MAR	42.00	28.00	30.00	28.00	40.00	20.00	32.00	20.00	12.00	26.00
APR	18.00	28.00	4.00	28.00	10.00	6.00	24.00	20.00	12.00	34.00
MEAN	23.33	36.67	11.33	33.67	19.67	12.67	35.67	33.67	14.67	38.00
S.D	9.27	9.61	11.08	8.43	12.68	6.28	14.00	15.82	4.13	10.12

BACTERIOLOGICAL PARAMETERS

Table 1.16: MONTHLY VALUES OF TOTAL COLIFORM (CFU/100ML) COUNT

MONTH	**B1**	**B2**	**B3**	**B4**	**B5**	**W1**	**W2**	**W3**	**W4**	**W5**
NOV	9	9	11	240	75	230	430	9000	4300	9300
DEC	12	9	7	230	95	240	400	2300	4000	9000
JAN	6	12	9	64	35	270	350	2400	9300	2400
FEB	7	6	9	95	42	340	390	1100	2400	4300
MAR	6	7	12	75	36	420	420	2300	1100	2300
APR	3	6	6	150	93	260	390	9300	4000	4300
MEAN	7.167	8.167	9.000	142.3	62.67	293.3	396.7	4400	4183	5267
S.D	3.061	2.317	2.280	77.71	28.36	73.12	28.05	3712	2791	3133

Table 1.17: MONTHLY VALUES OF FAECAL COLIFORM (CFU / 100ML) COUNT

MONTH	**B1**	**B2**	**B3**	**B4**	**B5**	**W1**	**W2**	**W3**	**W4**	**W5**
NOV	3	3	4	75	44	95	120	210	150	210
DEC	4	3	3	64	36	64	95	160	120	210
JAN	0	4	3	42	20	95	95	160	240	160
FEB	0	0	4	44	27	120	64	120	160	160
MAR	3	0	0	39	29	150	75	120	120	150
APR	0	3	0	64	42	64	75	210	150	160
MEAN	1.667	2.167	2.333	54.67	33.00	98.00	87.33	163.3	156.7	175.0
S.D	1.862	1.722	1.862	14.88	9.295	33.22	20.17	40.33	44.12	27.39

Table 1.18: MONTHLY VALUES OF SALMONELLA (CFU/100ML) COUNT

MONTH	**B1**	**B2**	**B3**	**B4**	**B5**	**W1**	**W2**	**W3**	**W4**	**W5**
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	0
MAR	0	0	0	0	0	0	0	0	0	0
APR	0	0	0	0	0	0	0	0	0	0
MEAN	0	0	0	0	0	0	0	0	0	0
S.D	0	0	0	0	0	0	0	0	0	0

Table 1.19: MONTHLY COUNTS OF ENTEROCOCCI (CFU/100ML)

MONTH	**B1**	**B2**	**B3**	**B4**	**B5**	**W1**	**W2**	**W3**	**W4**	**W5**
NOV	0	0	0	0	0	3	3	16	20	6
DEC	0	0	0	0	0	0	0	3	24	12
JAN	0	0	0	0	0	3	2	0	16	20
FEB	0	0	0	0	0	4	2	0	20	10
MAR	0	0	0	0	0	0	0	3	19	9
APR	0	0	0	0	0	3	0	9	24	11
MEAN	0.0	0.0	0.0	0.0	0.0	2.167	1.167	5.167	20.50	11.33
S.D	0.0	0.0	0.0	0.0	0.0	1.722	1.329	6.242	3.082	4.719

APPENDIX 2: Ghana Standard Board (GSB) Guideline Values of some Physico

Table 2.1: Chemical and Bacteriological Parameters for drinking water

PHYSICO – CHEMICAL PARAMETERS	**GSB 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
Salmonella	0.0
Enterococci	0.0

APPENDIX 3: Results of Statistical Analysis

Table 3.1: ANOVA of Borehole and Well parameters

Physico-chemical Parameters	**BOREHOLES p-value**	**HAND-DUG WELLS p-value**
pH	0.6634*	0.0828*
Turbidity	0.0869*	< 0.0001
Colour	0.5394*	0.0263
Conductivity	0.0026	< 0.0001
Total Dissolved Solids	0.0018	< 0.0001
Total Solids	0.0019	< 0.0001
Calcium Hardness	0.0015	0.0004
Magnesium Hardness	0.0404	0.0378
Total Hardness	0.0004	0.0004
Nitrogen-nitrate	0.0349	0.1557
Nitrogen-nitrite	0.0033	0.0008
Fluoride	0.0103	0.0100
Phosphate	0.3223*	< 0.0001
Sulphate	< 0.0001	< 0.0001
Chloride	0.0110	< 0.0001
Bacteriological Parameters	**p-value**	
Salmonella	-	-
Enterococci	-	< 0.0001
Faecal coliforms	< 0.0001	0.0002
Total coliforms	< 0.0001	0.0029

*p-value > 0.05; differences not statistically significant

APPENDIX 4: Relationship between bacteriological parameters and distance from sanitary facilities.

Table 4.1: Relationship between Total coliform and distance from sanitary facilities.

Borehole/Well	Count	Distance
B4	293	4.5
B5	397	14.3
W3	4400	7.5
W4	4183	6.8
W5	5267	8
Correlation coefficient, r	-0.3	

Table 4.2: Relationship between Faecal coliform and distance from sanitary facilities

Borehole/Well	Count	Distance
B4	55	4.5
B5	33	14.3
W3	163	7.5
W4	157	6.8
W5	175	8
Correlation coefficient, r	-0.4	

Table 4.3: Relationship between Enterococci and distance from sanitary facilities

Borehole/Well	Count	Distance
B4	0	4.5
B5	0	14.3
W3	5.17	7.5
W4	20.5	6.8
W5	11.33	8
Correlation coefficient, r	-0.3	

APPENDIX 5 : Relationship between bacteriological parameters and depth of sampled wells

Table 5.1: Relationship between Total coliform depth of sampled wells

Well	Count	Depth
W1	293	4.5
W2	397	6
W3	4400	3.8
W4	4183	5
W5	5267	4.5
Correlation coefficient, r	-0.5	

T

able 5.2: Relationship between Faecal coliform and depth of sampled wells

Well	Count	Depth
W1	98	4.5
W2	87	6
W3	163	3.8
W4	157	5
W5	175	4.5
Correlation coefficient, r	-0.6	

Table 5.3: Relationship between Enterococci and depth of sampled wells

Well	Count	Depth
W1	2.17	4.5
W2	1.17	6
W3	5.17	3.8
W4	20.50	5
W5	11.33	4.5
Correlation coefficient, r	-0.1	