PHYSICO-CHEMICAL ANALYSIS OF WELL WATER FROM WELLS SITED CLOSE TO ON-SITE SANITATION SYSTEMS – A CASE STUDY IN THE MFANTSEMAN WEST DISTRICT OF THE CENTRAL REGION

by

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DECLARATION

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

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ABSTRACT

Many communities in the Mfantseman Municipality of the Central Region of Ghana are increasingly dependent on hand dug wells. The aim of this study was to examine the drinking water suitability of 10 wells in the Saltpond-Ankaful-Kormantse communities in the Mfantseman municipality between June 2008 and December 2009. Total coliforms were enumerated using the standard most probable number method and membrane filtration methods. A sanitation survey was undertaken to ascertain the conditions of the wells. Also the physico-chemical properties of the water were assessed.

Overall, significantly higher bacterial counts were recorded during the wet (rainy) season compared to the dry season. A brief sanitation survey at each site indicated that the wells were frequently cited near latrines, refuse tips, as well as in the vicinity of domestic or grazing animals. In the Saltpond, Ankaful and Kormantse communities of the Central Region, the water from shallow wells upon which the local communities depend is of poor quality. This is because all the wells sampled failed to meet the zero coliform per 100 ml set by WHO (World Health Organization). The physico-chemical properties of many of the wells varied with the seasons. For instance, five of the wells indicated high nitrate levels for the dry season, and low for the wet. One well had a mean nitrate value of about 0.1 mg/l in the dry season but 0.02 in the wet season. This means for that well, the nitrate level in the wet season increased about 80% during the dry season.

CHAPTER ONE

1.0 Introduction

1.1 Background Information

Water, after air, is the most essential commodity to the survival of life. Human life depends to a large extent, on water. It is used for an array of activities; chief among these being for drinking, food preparation, as well as for sanitation purposes. Inasmuch as safe drinking water is essential to health, a community lacking a good quality of this commodity will be saddled with a lot of health problems which could otherwise be avoided (Miller, 1997).

Water is a fundamental resource, integral to all environmental and social processes. Access to adequate safe drinking water is of prime importance to many governmental and international organizations since undebatably it is the core component of primary health care and a basic component of human development as well as a precondition for man's success to deal with hunger, poverty and death (SOPAC/WHO, 2005). There is a growing concern everywhere that in the coming century, cities will suffer imbalances in quality water supply, consumption, and population. Many regions of the world are already limited by the amount and quality of available water. According to World Health Organization (WHO, 2002), in the next thirty years alone, accessible water is unlikely to increase more than ten percent (10%) but the earth's population is projected to rise by approximately one-third. Unless the efficiency of water use rises, this imbalance will reduce quality water services, reduce the conditions of health of people and deteriorate the environment and the world.

The world's population size and the rapid urbanization growth is increasingly a major issue in the world especially in developing countries. Cairncross (2002), showed that by the year 1975,

about 74% of the urban population in the developing world had access to safe water, the figure increased to about three hundred million (79%) in 1985 partly because of the International Water Decade which was an improvement, however, there were still 21% of the people who were still not having access to safe water. The rapidity with which cities are growing is frightening in the sense that human population with its associated sanitation problems will grow faster than increases in the amount of accessible quality water (Jackson *et al*, 2001). This means that per capita availability of quality water will decrease in the coming century.

Although, many international conferences as well as researches have gone on in the past, little by way of success has been chalked so far. Report from World Health Organization (2002) indicates that over 2.6 billion people were still suffering from the effect of poor water around the world. It is based on this that Heads of states and governments met and signed the Millennium Declaration at the 2000 UN Millennium summit to end the sufferings from the effects of poor water quality across the globe, as a matter of urgency (WHO, 2002).

The growing demands for adequate quality water resources create an urgent need to link research with improved water management, better monitoring, assessment, and forecasting of water resources and sanitation issues with much emphasis on the roles of stakeholders (Yamaguchi & Wesselink, 2000). It must however be emphasized that adequate water quality needs seem to have improved greatly in some regions and countries especially in the developed world but for poor nations this is still a major issue (Stockholm International Water Institute, SIWI, 2001). As observed by WHO-UNICEF (2004), while in 2002, countries like Japan, Australia, Austria, Switzerland and Sweden had achieved hundred percent, others, such as countries in sub Saharan Africa are far below 50%. For instance, Guinea 6%, Liberia 7%, Niger 4%, Togo 15%, and Ghana 46%.

According to Sarpong (2002), the main source of water in these regions includes untreated rain water from roofs, polluted rivers and streams, unprotected wells and bore holes. He went further to show that there is little to choose between sub Sahara rural and urban since the rural to some extent has only to deal with the quality while the urban has both the quantity and quality to deal with.

Water related health problems are a growing human tragedy, and according to WHO (2003), it kills more than 5 million people a year with infants being the most affected. This figure seems to be the highest as compared to wars and disasters (UNESCO, 2003). The problems also prevent millions of people from leading healthy lives, and undermine developmental efforts by burdening the society with substantial socio-economic costs for treatment of water-borne diseases. This problem is of great significance in cities in developing countries, where polluted water, water shortages, and unsanitary living conditions prevail. Information from WHO (2002), WHO/UNICEF (2004) says although access to water has improved greatly, access to safe water is still a major issue. The source quoted that about some 1.1 billion people rely on unsafe drinking water sources in developing countries and the lowest drinking water coverage rates are in sub Saharan Africa (58%) with a corresponding low sanitation coverage rates (36%) which leads to many deaths especially among children through diarrhea among other water-related diseases. To meet the 2015 target of the United Nations Millenium Development Goals (MDGs) on access to safe drinking water therefore, will require that countries create the political will and resources to manage water especially in growing urban cities in sub Saharan Africa (Bain, Gundry, Wright, Yang, Pedley & Bartram, 2011).

Sources of water available to mankind are: atmospheric water (precipitate), surface water (including rivers, streams, ponds, etc), and ground water. The potability of water from any of these sources is determined by the water quality (Miller, 1997).

With 97% of all freshwater found on the earth being stored underground, accessing ground water in the quest for potable water is a laudable venture. Groundwater is accessed by way of sinking wells and boreholes to reach the water table (Overseas Development Institute, 2009).

Water-related diseases are responsible for 80% of all illnesses/death in developing countries (UNESC0, 2007). According to Kalua and Chipeta (2005) as cited in Pritchard, Mkandawire, and O'Neill (2008), in Malawi, only 65% of the population have access to safe drinking water and 50% of all illnesses are solely due to water related diseases. Water is a medium of thousands of microorganisms, some of which are disease-causing (Schaffter & Parriaux, 2002).

A typical example can be seen in the facts of the matter as it pertains in Malawi and reported by several researchers (Chilton & Smith-Carington, 1984; Kalua, & Chipeta, 2005; Sajidu, Masamba, Henry & Kuyeli, 2007). The mortality rate in Malawi in 2002 from cholera was over 50% of the water-related deaths. During the 2001/2002 rainy season, 33,150 cholera cases and 980 deaths were recorded in Malawi (Davis, 2005). Globally, 4 billion cases of diarrhoea are reported every year causing 1.8 million deaths, out of which about 90% are children under age five (UNESCO, 2007).

Potable water is defined as water that is free from pathogens, low in compounds that are acutely toxic or that have grave long-term effects on human health (Shlutz and Okun, 1984). Potable water should be free from compounds that can cause change in the 'normal' colour, taste (e.g. high salinity) and odour. Shallow wells are normally located in valleys where the groundwater

table is relatively high (1 – 4 m below ground level) and infiltration of rain and river water plays a main part in the groundwater recharge. Boreholes however, draw water from deep (20 – 80 m or more) aquifers (Pritchard, Mkandawire & O'Neil, 2008).

1.2 Statement of the Problem

Pathogens as well as life threatening chemicals get to pollute the groundwater system through leaching. When such polluted ground water is sourced for human consumption, the health implications can be overwhelming. Poor sanitation practices, such as locating on-site sanitation systems close to these wells, are a sure contributing factor in the pollution of the ground water system (ARGOSS, 2001). It has been documented, and accepted as a standard that when on-site sanitation systems are sited less than 50 m away from wells and bore holes, the water from such wells will definitely be polluted (Obiri Danso *et al*., 2008).

Water from wells dug in close proximity to VIPs (Ventilated Improved Pits) may have health hazards. Getting safe water for human consumption is essential for good health and a basic human right. Quality of water from such wells needs to be checked periodically in order to ascertain whether they are good for human consumption and other domestic use.

The Kormantse, Saltpond and Ankaful communities in the Mfantseman District of the Central Region of the Republic of Ghana have a lot of wells to provide drinking water to curb the acute water shortages experienced by the inhabitants. Within these communities there are various improperly managed sanitation systems, including Ventilated Improved Pits (VIPs). Also the water table is quite high in the low-lying part of the area; Saltpond being a low-lying coastal community. Thus the possibility of the local ground water system being contaminated by bacteria as well as other microorganisms from the various pits cannot be overlooked.

Again, health records obtained from the Municipal Hospital showed that the communities experience periodic outbreaks of water-borne diseases like diarrhoea, cholera, dysentery, etc. This occurs virtually every year (from researcher's personal observation).

It is therefore important to investigate the possibility or otherwise of pollution of the water sourced from the wells. This will help ascertain whether or not the diseases reported at the Municipal Hospital are either directly or indirectly related to water sourced from these wells.

1.3 Objectives

The main objective of the study is to assess the quality of water from some randomly selected wells sited in close proximity (that is within a radius less than 50 m) to on-site sanitation systems within the Kormantse, Saltpond and Ankaful communities.

1.4 Specific Objectives

- To determine the level of the pH, colour, turbidity, nitrates, ammonium, chloride, and conductivity, of water samples from selected wells.
- To determine the microbial quality of water from the selected wells – faecal coliforms, *E. coli*
- To assess the perception of users about the quality of the well water by the administration of interviews.

CHAPTER TWO

2.0 Literature Review

2.1 Water Resources in Ghana

The main sources of water supply in Ghana include surface water, ground water and rain water. According to FAO (2005) as cited in Akumiah (2007), rainfall, although not reliable, has a mean ranging from 2150 mm in the south-western part to 800 mm in the south-eastern. Rainwater harvest is not so popular among urban settlers. Nevertheless, it provides a significant amount of domestic water in the southern rural areas particularly during the humid months of May, June, July and August (Akumiah, 2007). Sarpong, (2005), estimated total annual run-off as 56.4%.

In Ghana, the main surface waters is made up of the Volta river system which drains about 70% of the entire country and consists of rivers Oti, Daka, White and Black Volta, Pru, Sene and the Afram rivers. Rivers Bia, Tano, Ankobra, Pra which drain the south-western regions also cover about 22% of the country, while the coastal zone is drained by rivers Ochi-Nakwa, Ayensu, Densu and the Tordzie takes charge of about 8% of the country (FAO, 2005). Greater part of rural Ghana relies on ground water, which is often extracted from boreholes while urban Ghana gets about 95% of its waters from surface water (Akumiah, 2007). The main rock formation is the sedimentary and the non-sedimentary which provides quality ground water but there are few instances where there is localized pollution (Sarpong, 2005).

2.1.1 Groundwater

Before the 1970s, the study of life in groundwater habitats was relatively limited. In the 1970s, however, it became increasingly obvious that certain waste disposal practices were contaminating subsurface environments (Schaffter & Parriaux, 2002). There has also been an

increasing interest in demonstrating that various shallow and deep environments contain substantial numbers of viable microorganisms to degrade potential pollutants, i.e. in bioremediation. Subsurface microbiological research to study microbial community structure, microbial activities and the geochemical properties of groundwater environments has progressed with the development of aseptic sampling techniques (Obuobie, & Barry, 2010).

In a hydrogeological sense, groundwater refers to water that is easily extractable from saturated, highly permeable strata known as aquifers (Pritchard, Mkandawire & O'Neil, 2008). For saturated environments, a rigorous distinction between local, intermediate, and regional flow systems, related to the topography of recharge and discharge areas has been long recognized by hydrologists. One can thus define several underground aquifers that serve as source of potable water in the world which can be classified as shallow aquifers, intermediate and deep aquifers (Morita, 1997).

Shallow aquifers are characterized by active flow strongly influenced by local precipitation events. Intermediate aquifers within 300 m of the surface soil are separated from shallow aquifers by confining layers; they have much slower flow rates, of the order of meters per year. Deep aquifers are also confined, but more than 300 m below the subsurface soil and they are characterized by extremely slow flow rates (meters per century, Obuobie, & Barry, 2010).

Groundwater quality always has two aspects: (a) the natural quality of groundwater which is a result of the minerals the groundwater was in contact with in the saturated and unsaturated zones, the hydrochemical and biochemical conditions (pH, Eh, Temperature, pressure, presence of bacteria, etc.) and temporal aspects (flow/infiltration velocity, residence time), and (b) the anthropogenic groundwater quality influenced by human activities that add components to the groundwater or change natural equilibria (). In Benin, research has shown that it is obvious that

anthropogenic influences, in particular, contamination with pathogens play a very important role. It is however not meaningful to regionalize such local effects or relate them to natural aquifer (location) characteristics.

Groundwater is a key water resource in much of the world. Many major cities and small towns in the world depend on groundwater for their water supplies, mainly because of its abundance, stable quality and also because it is inexpensive to exploit (Morris *et al.,* 2003). In developing countries, use of shallow groundwater sources for drinking and other domestic purposes is a common feature of many low-income communities (Howard *et al.,* 1999). The communities relying on such sources tend to be poor and live in polluted environments with associated high health risks (WHO and UNICEF, 2000). Such communities occur in most cities in developing countries, for example in Asia, Africa, Latin America and the Caribbean. Their occurrence is attributed to rapid urbanization where urban growth is associated with rapid expansion of small, unplanned urban centres and peri-urban settlements (Vernon, 2002; Hardroy *et al.*, 2001).

2.1.1.1 Sources of Contamination of Groundwater

Groundwater is an important source of drinking water in many nations and may be heavily contaminated in many industrialized nations by industrial waste pits, septic tanks, oil wells, landfills, etc. Aquifers supply drinking water for about 120 million Americans (Lawson, 1982) and supply a quarter of the annual water demands in the United States. They are also a major supplier of water in many other countries. United States groundwater, scientists are now reporting, is increasingly threatened by pollution. Many pollutants are present at much higher concentrations in groundwater than they are in most contaminated surface supplies (Moyer, & Morita, 2000). Also, many contaminants are tasteless and odourless at concentrations thought to be threatening human health.

According to Miller (1997), about 4500 billion litres of contaminated water seeps into the ground in the United States every day from septic tanks, cesspools, oil wells, landfills, agriculture, and ponds holding hazardous wastes. Unfortunately, very little is known about the extent of groundwater contamination. The Environmental Protection Agency of the United States of America (USEPA) estimates one percent (1%) of the drinking water wells in the United States has contaminants that exceed the standard designed to protect human health. Although that may seem small, 1% of hundreds of thousands of wells is a large number. In fact, one study reported that at least 8000 private, public and industrial wells in the U.S are contaminated (Miller, 1997).

2.1.1.2 Survival of Microorganisms in Groundwater

Due to the long time the indigenous bacteria have had to degrade the organic matter originally present, subsurface environments contain little organic matter. Furthermore, when percolating through the porous media, water containing organic matter encounters attached bacteria which remove most of this organic matter. Thus, subsurface systems are oligotrophic and the intermediate aquifer flow systems are among the most oligotrophic microbial environments that have ever been described (Morita, 1997). The average concentration of Dissolved Organic Carbon (DOC) for various types of consolidated rock aquifers ranges from 0.1 to 0.7 mg/l. Chemical analysis of the organic carbon in any environmental sample certainly does not determine what portion is available for use by the autochthonous bacteria. Most of the organic matter in subsurface environments, other than the readily labile compounds such as free amino acids, free carbohydrates, and free fatty acids, is humic, polymeric material high in molecular mass and refractory, i.e. resistant to breakdown. Humic substances have extremely complex structures, and can be divided into three major fractions defined in terms of their solubility in water: humic acid, fulvic acid and humin. In the subsurface environments, it can be supposed

that the unavailable humic and fulvic acids make up more than 50% of the total organic carbon (Morita, 1997).

Microbes have evolved longer than any other living organism, so in all probability, the non-spore-forming heterotrophic bacteria must have developed mechanisms to survive long periods when no energy or nutrients were available. Thus, the concept of starvation – survival is fundamental for the evolutionary point of view. In order to provide a pragmatic approach to this concept, a definition has been provided by Morita (*op cit.*): 'starvation - survival is a physiological state resulting from an insufficient amount of nutrients, especially energy, to permit growth (cell size increase) and/or reproduction'. There are various degrees of starvation, starting with cells that just utilized the last amount of nutrients for growth, to cells that have been deprived of nutrients for long periods of time (Morita, *op cit.*).

To confront nutrient limitation, bacteria may develop defence mechanisms to enhance their ability to survive periods of starvation. Some differentiating bacteria respond to starvation by marked alteration in their ultrastructure, producing spores or cysts. Spores are essentially dormant, waiting out lean periods to germinate as nutrients become available. Non-differentiating bacteria respond more by an alteration of their physiology rather than developing resistant structural modifications (Szewzyk, Szewzyk, Manz and Schleifer, 2000).

According to Morita (1997), when bacteria are grown under conditions of nutrient excess, they accumulate reserve carbon polymers, such as glycogen and poly-L-hydroxybutyric acid, RNA, protein, etc. The utilization of these cellular constituents during starvation is manifested by a basal level of endogenous metabolism which can be measured by oxygen consumption, CO_2

production or other tests. Thus bacteria that are more able to utilize endogenous macromolecules at a slow rate appear to have a specific advantage over other bacteria (Morita, *op cit.*).

Bacteria respond to specific nutrient limitation by two mechanisms: first, they produce transport systems with increased affinities for the nutrient most easily exploited; secondly, they express transport and metabolic systems for alternative nutrients. Thus, these bacteria may be able to escape starvation by more efficient scavenging of a preferred nutrient or by using another, relatively more abundant, source (Moyer, & Morita, *op cit.*). The physiological and genetic basis of enhanced assimilation capacity for nitrogen, phosphorus, iron and carbon has been largely developed in many reviews. These studies have revealed a large number of proteins that are induced by carbon starvation and require cyclic AMP for this induction. These proteins, termed the C_{st} (Carbon starvation) proteins, are believed to be primarily concerned with escape from carbon starvation (Moyer, & Morita, *op cit.*).

Again, there is evidence that bacteria subjected to nutrient starvation become more resistant to various environmental stresses (Morita, *op cit.*). It is clear that the stress responses discussed above, involving enhanced scavenging capacity, are insufficient to ensure survival. It has been shown that, upon exposure to nutrient limitation, bacteria synthesized new proteins that increased their resistance to a number of stresses including shifts in temperature, acid, oxidative and osmotic shock. This resistance failed to develop if synthesis of starvation proteins was prevented, and increased the longer the culture was allowed to synthesize the starvation proteins. These additional proteins are often referred to as stress proteins (Morita, *op cit*).

Four patterns of starvation - survival have been described. The most frequent pattern noted which might be representative for most environmental bacteria shows an initial increase in cell

number due to fragmentation (reductive division) followed by a decline (Morita, *op cit*). The starvation pattern with time occurs in three stages, as that has been demonstrated by Moyer and Morita (2000) in the marine bacteria Ant-300. During the first stage lasting 14 days, large fluctuations in plate counts were noted. In the second stage (14 – 70 days), the colony count decreased by 99.7%. The third stage was marked by a stabilization of viable cells (0.3% of the total count numbers). Cells in this stage of metabolic arrest have been termed 'shut down' cells by Dow, Whittenbury and Carr (1983). Cells resulting from nutrient starvation are mainly microcells defined as being 0.3 Wm or smaller (also termed ultramicrocells or ultramicrobacteria). As a consequence of forming ultramicrocells, the surface – volume ratio becomes larger and leads to sequester nutrients more efficiently in low-nutrient environments. This is listed as a paramount characteristic of the model oligotrophs. The presence of ultramicrocells in natural mineral water, capable of passing through a 0.2 Wm filter, has been demonstrated (Morita, *op cit*).

2.2 Drinking Water Standard

Metals such as Lead, Selenium, Arsenic, Chromium, Cyanide, Cadmium and Barium present in water beyond some specific maximum allowable concentrations are considered toxic for human consumption. Table 2.1 gives the maximum allowable concentrations for some of these elements (WHO, 1996).

Table 2.1 Maximum allowable concentrations of some toxic substances in potable water

Toxic Substance	**Maximum allowable concentration, mg/l**
Lead (Pb)	0.05
Selenium (Se)	0.01
Arsenic (As)	0.05

Chromium (Cr hexavalent)	0.05
Cyanide (CN)	0.2
Cadmium (Cd)	0.01
Barium (Ba)	1.0

Additionally, there are other substances that may be injurious to health under certain conditions if present in high concentrations. Some of these substances are regarded as essential constituents of drinking water, and when present in too low concentrations may have adverse effects on health. Two of these substances are fluorides and nitrates (Pritchard, Mkandawire, O'Neil, *op cit.*).

Fluorides, although beneficial when present in concentrations of 0.8 ppm -1.0 ppm, cause mottled enamel of the teeth when present in potable waters in concentrations in excess of 1.0 – 1.5 ppm. Also nitrates, which may be present naturally in potable waters or may result from seepage from cesspools, sewers, etc, or from the use of fertilizer, are harmful to some infants but do not affect growing children or adults (Jackson, *et al*, 2001). Nitrates present in water consumed directly or indirectly in prepared food, by infants may be reduced to nitrites in the intestinal tract, leading to infantile methaemoglobinaemia (Jackson *et al*, *op cit.*). This may occur when the nitrate content exceeds 45 mg/l. High concentrations of nitrates occur in some ground waters which are subjected to seepage from near-by-sources of pollution. The content of many chemical substances in potable waters varies widely in different parts of the world, making the establishment of rigid water standards virtually impossible (Morita, *op cit.*). Table 2.2 gives the acceptable concentration of chemicals that can be found in potable or drinking water. It gives maximum concentrations generally acceptable to consumers, and also maximum allowable concentrations beyond which potability is considered to be seriously impaired.

Table 2.2: Acceptable and allowable concentrations of some chemical substances and properties affecting potability

Substance or property	Maximum acceptable	Maximum allowable
Colour	5 units[a]	50 units[a]
Turbidity	5 units[b]	25 units[b]
Taste	Unobjectionable	-
Odour	Unobjectionable	-
Calcium (Ca)	75 mg/l	200 mg/l
Chloride (Cl)	200 mg/l	600 mg/l
pH range	7.0 – 8.5	6.5 or greater than 9.2

[a] Platinum-cobalt scale [b] Turbidity units Source: WHO (1996)

2.3 Microbiological Quality of Drinking Water

2.3.1 Identifying microbial hazards in drinking water

A large variety of bacterial, viral and protozoan pathogens are capable of initiating waterborne infections. Some are primarily the enteric bacterial pathogens including classic agents such as *Vibrio cholerae, Salmonella* spp., *Shigella* spp., and newly recognized pathogens from faecal sources like *Campylobacter jejuni* and enterohemorrhagic *E. coli*. The survival potential of these bacteria increases in biofilms and due to their stages as VBNC (viable but non-culturable) cells (Wilson *et al*, 1983).

Several new bacterial pathogens such as *Legionella* spp., *Aeromonas* spp., P. *aeruginosa* and *Mycobacterium avium* have a natural reservoir in the aquatic environment and soil. These organisms are introduced from the surface water into the drinking water system usually in low

numbers. They may survive and grow within the distribution system biofilm (Wilson *et al, op cit.*).

Again, more than 15 different groups of viruses, encompassing more than 140 distinct types, can be found in the human gut. These enteric viruses are excreted by patients and find their way into sewage. Hepatitis A and E viruses cause illness (hepatitis) unrelated with gut epithelium. Another specific group of viruses has been incriminated as a cause of acute gastroenteritis in humans; it includes rotavirus, calicivirus, the most notorious being Norwalk virus, astrovirus and some enteric adenovirus. These viruses cannot grow in the receiving water and may only remain in small number or die off (Szyweck *et al*, 2000).

The most prevalent enteric protozoa, associated with water-borne disease, include *Giardia lamblia* and *Cryptosporidium parvum*. In addition, protozoa like Cyclospora, Isospora and many microsporidian species are emerging as opportunist pathogens and may have waterborne routes of transmission (Szyweck *et al, op cit.*). Like viruses, protozoa cannot multiply in the receiving waters. With the exception of *Salmonella, Shigella* and hepatitis A virus, all the other organisms can be so-called 'new or emerging pathogens'. There are a number of reasons for the emergence of these new pathogens. These have been analyzed in every detail by Szewzyck *et al* (*op cit*). They include high resistance of viruses and protozoan cysts, a lack of identification methods for viruses, change in habit of water use (*Legionella*) and subpopulations at risk. Another striking epidemiological feature is the low number of bacteria that can trigger disease. The infectious dose of *Salmonella* is in the range of 107 – 108 cells while only around 100 cells are required to cause clinical illness with *E. coli* 0157:H7 and *Campylobacter*. The infective dose of enteric viruses is low, typically in the range of 1 – 10 infectious units; it is about 10 – 100 oocysts for *Cryptosporidium* (Szewzyck et al, 2000).

2.4 Assessment of Microbial Risks

The view on the microbiological safety of drinking water is changing. The demand for the total absence of any pathogenic organism is no longer significant in light of the new pathogens, some of which are capable of growing in drinking water systems. According to the new European Union Council directive 98/83/EC, water for human consumption must be free from any microorganisms and parasites and from any substances which, in numbers or concentrations, constitute a potential danger to human health (European Union Council, 1998). To deal with this issue, the U.S. Environmental Protection Agency for the first time used a microbial risk assessment approach. It has been defined that an annual risk of 1, 034 (one infection per 10 000 consumers per year) should be acceptable for diseases acquired through potable water, this value being close to the annual risk of infection from waterborne disease outbreaks in the United States (i.e. 4×10^{-3}) (U.S. EPA, 2006).

Microbiological risk assessment is a major tool for decision making in the regulatory area. The problem is, however, that the key data to perform this assessment are mostly missing. Few epidemiological studies associating the incidence of disease to the pathogen densities have been reported. Several outcomes, from asymptomatic infection to death, are possible through exposure to microbes (Szyweck *et al*, *op cit.*). The issue of dose-response relationships is particularly striking: these relationships are only available for a few pathogens; when infectious doses are low as is the case for some viruses and protozoan cysts, the calculated tolerable concentrations are also low and monitoring of these pathogens in drinking water becomes impracticable (Miller, 1997).

2.4.1 Faecal Coliform Organisms

Faecal coliforms are one of the most important parameters to consider when assessing the suitability of drinking water because of the infectious disease risk (WHO, 1997). Faecal coliforms indicate contamination by mammals and birds' waste (faeces) and signify the possible presence of pathogenic bacteria and viruses which are responsible for water-related diseases such as cholera, typhoid and other diarrhoeal-related illnesses. One gram of faeces is reported to contain 10,000,000 viruses; 1,000,000 bacteria; 1000 parasite cysts; and 100 parasite eggs (UNESCO, 2007). Zero faecal cfu/100 ml is considered uncontaminated (WHO, 2006; MBS, 2005); 50 faecal cfu/100 ml is regarded suitable by MoWD (2003) for untreated waters.

2.4.2 Total Coliforms

The most commonly measured indicators of water quality are the coliform organisms. Gram negative bacteria are cytochrome oxidate negative, non-spore forming, and ferment lactose at 35 ^{o}C – 37 ^{o}C, within 24 – 48 hours (Morita, *op cit.*). This defines total coliforms. The group is as diversified as their habits from which they originate. Thus the total coliform group should not be regarded as an indicator of organisms exclusively from faecal origins especially in hot countries where coliforms of non-faecal origins are common. In the presence of organic material and under suitable conditions, coliforms multiply. Measurement of faecal coliforms is a better indicator of general contamination of faecal origin. Faecal coliforms differ from the other members of the total coliform groups on the grounds that they tolerate and grow at higher temperatures of 44 -45 ^{o}C. Presumptive *Escherichia coli* convert tryptophan to indole. They are permanent species among the faecal coliforms (Szyweck *et al*, *op cit.*).

2.4.3 Presence of Bacteria

The presence of bacteria is of great importance in the water industry with regards to water-borne diseases. Some of such diseases are dysentery, typhoid fever, paratyphoid fever, cholera,

infantile paralysis, poliomyelitis, infectious hepatitis, guinea worm, amoebic dysentery, etc (Szyweck *et al, op cit.*). Transmission of the causative micro-pathogenic organism is through direct or indirect contamination of water source by human excreta. Since it is extremely difficult to isolate and identify different forms of pathogens, the microorganisms which are of significance to water quality are those of enteric pathogenic origin (Szyweck *et al, op cit*).

2.5 Water-borne Diseases

Water-borne diseases are diseases contracted through the ingestion of contaminated water. Table 2.3 present some of such diseases and their causative agents (Mills, 2000).

Table 2.3 Some Water-borne diseases and their Causative agents

Disease	**Causative Organism**
Bacterial Dysentery	*Shigella dysentera*
Typhoid Fever	*Salmonella typhii*
Para Typhoid Fever	*Salmonella paratyphii*
Cholera	*Vibrio cholera*
Amoebic Dysentery	*Entamoeba histolytic*
Infantile Paralysis (Poliomyelitis)	*Poliomyelitis* virus
Infectious Hepatitis	*Hepatitis* virus
Guinea Worm	*Dracunculus mendenensis*

2.6 The health dimension of poor sanitation

Despite the fact that access to an adequate water supply and sanitation is a fundamental need (and, indeed, arguably a right) for all people, a recent survey shows that almost two and a half billion people do not have access to improved sanitation (WHO, 2000a). In the Global Burden of Disease (GBD) study, disability adjusted life years (DALYs) were ascribed to 10 selected risk factors. Water, sanitation (i.e. excreta disposal) and hygiene accounted for the second biggest

percentage of DALYs behind malnutrition (WHO, 2001). Worldwide, it is estimated that there are approximately 4 billion cases of diarrhea per year (resulting in 2.2 million deaths), 200 million people with schistosomiasis and as many as 400 million people infected with intestinal worms (Murray and Lopez, 1996; UN, 1998; WHO, 2000). All of these diseases are largely excreta-related. In less developed countries, poor nutritional status and poverty exacerbate morbidity and mortality associated with excreta-related diseases. For example, most deaths attributed to diarrhea occur in children below the age of five (WHO, 2000). Rice *et al*., (2000) reviewed 21 studies on infant mortality associated with diarrhea and found that children with low weight for their age had a much higher risk of mortality.

Two literature reviews assessing the health impact of water and sanitation interventions have been published (Esrey *et al*., 1985, 1991). The first review focused on water and sanitation interventions with one of three outcomes (diarrhea or a specific pathogen e.g. *Shigella* spp., nutritional status and mortality). The second study expanded the literature on diarrhea or similar outcomes to include: ascariasis, dracunculiasis, hookworm, schistosomiasis and trachoma as well as diarrhea. Median values, rather than means, were used to summarise the findings. It is important that all members of a community, particularly the children, make use of improved sanitation installations. Children are frequently the victims of diarrheal disease and other faecally/orally transmitted illnesses, and thus may act as sources of pathogens (WHO, 2001). Getting children to use sanitation facilities (or designing child friendly toilets) and implementing school sanitation programmes are important interventions for reducing the spread of disease associated with waste and excreta (WHO, 1993).

Results of the many studies and reviews conducted indicate that improvements in excreta management, hygiene and water supply may reduce diarrheal morbidity, diarrhea mortality and

child mortality by significant amounts (WHO, 1993). For example, Esrey *et al*. (1991) found reductions in diarrhea mortality and overall child mortality of 65% and 55% respectively when improved water and sanitation were introduced. However, the size of the impact is likely to vary according to a wide range of factors, including current sanitary conditions, food supply, breast-feeding habits, education level and uptake of new facilities and behaviors. Clearly, tackling the problem at source assists in reducing transmission via all routes (WHO, 2001).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The selected points for sampling in the Kormantse, Saltpond and Ankaful communities were approximately within a 7 km radius of the Saltpond municipal hospital. They lie between 0^{o} $50^{'}$ and 1^{o} $10^{'}$ N and 5^{o} 10’ and 1^{o} 20’ W in a coastal belt (Figure 3.1). The soils of these areas are sandy, well drained and formed in sandy loam (). The communities are characterized by poor housing and sanitation, inadequate water and overcrowding. The population in each of these communities ranges between 200 and 500 and many are mainly engaged in fishing, farming and petty trading (Ghana Statistical Service, 2000).

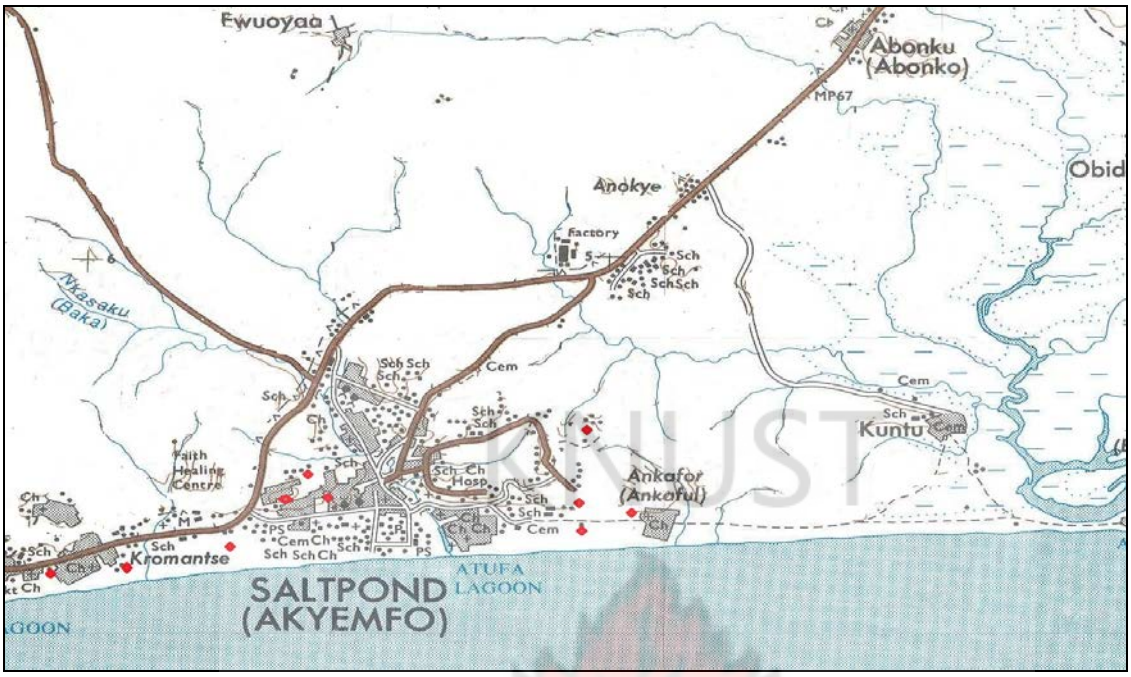

Fig. 3.1 Map of Mfantseman District showing the location of sampling point (shown in red)

3.2 Observational study

A direct observation of conditions of individual wells was made to ascertain any possible sources of contamination of the water other than contamination from on-site sanitation systems. Factors like the major uses of the water, the depth, water levels, nearness to a possible source of contamination like septic tanks, public toilets, private toilet pits and gutters were looked out for.

3.3 Sanitation Survey

At each site a sanitary inspection was made during the sampling period. The sanitary inspections involved the use of unstructured questionnaire based on the individual state of the wells.

3.4 Interviews

At each well, ten regular users of the well waters were interviewed. Interviewees were asked about the uses they put the water fetched from the wells to. They were asked about their

perception on the quality of the water, as well as whether they had experienced any illness they could link to the use of the water in their various activities.

3.5 Sampling Sites

A total of 10 wells were selected for sampling in the study. Three wells were selected from Saltpond Low Cost area (i.e. SW1, SW2 and SW3), four from Ankaful (i.e. AW1, AW2, AW3 and AW4), and three from Kormantse (i.e. KW1, KW 2 and KW3) as shown in Fig. 3.1.

3.6 Water Sampling

Monthly water samples were collected from all sites for four months from June to September, 2008, and December, 2009. Sampling covered both the major wet/rainy (April – June) and minor rainy (July – September) seasons. Triplicate water samples were collected in sterile 500 ml Duran Schott glass bottles from each of the wells from the three locations using a sterile stainless steel cup with a 30 ft rope. Samples were kept in a cool box (8 – 10 ^{0}C) during transportation to the laboratory and analysed within 6 hours.

3.7 Procedure for Physico-chemical Analyses

3.7.1 pH

A Horiba Compact B-212 pH meter was used to determine the pH of samples after calibrating with two different buffer solutions (4.0 and 7.0 pH values).

3.7.2 Conductivity

A Hatch conductivity meter 4600 was used to determine the conductivity of the samples. An electrode connected to a meter was immersed into the sample of water so that the water covered a sensitized electrode. Values on the display kept varying until a stabilized value was obtained and recorded.

3.7.3 Turbidity

A DR/2000 was used with its electrode immersed in a sample of water, then switched on and the values read on display. First, the stored program number for turbidity (i.e. 750) was entered. Then the wavelength dial was rotated until the small display showed 450 nm. Afterwards the 'READ/ENTER' was pressed. The display showed 'FTU TURBIDITY'. Then 25 ml of demineralized water (the blank) was poured into a sample cell. The blank was then placed into the cell holder, and the light shield closed. Then 'ZERO' was pressed. The display showed 'WAIT' then '0.FTU TURBIDITY'. At this point, 25 ml of the water sample was poured into another sample cell. Immediately after placing the sample cell into the cell holder, the light shield was closed. 'READ/ENTER' was then pressed. The display showed 'WAIT', then the result in Formazin Turbidity Units (FTU) was displayed.

3.7.4 Nitrates

The D – R 2000, Direct Reading Spectrophotometer was used. The stored program number for high range nitrate nitrogen (NO_3^--N) - (that is 355) - powder pillows was entered. The display showed: 'DIAL nm TO 500'. Then the wavelength dial was rotated until the small display showed '500 nm'. The 'READ/ENTER' button was then pressed. The display showed : 'mg/l N NO_3^- H. Afterwards, a sample cell with 25 ml of sample was filled. The content of one Nitra Ver 5 Nitrate Reagent Powder Pillow was then added to the cell (i.e. the prepared sample). It was then stoppered. The 'SHIFT TIMER' was pressed. The cell was shaken vigorously until the time beeped in one minute. When the timer beeped, the 'SHIFT TIMER' was pressed. Five minutes was allowed to elapse for the reaction to take place if nitrate nitrogen was present. An amber color developed indicating the presence of nitrate nitrogen. Another sample cell was then filled with 25 ml of the blank sample.

3.7.5 Ammonia

The procedure was same as for nitrates. The only difference being the stored program number that was pressed to begin the test for ammonia.

3.7.6 Chloride

Method: Silver Sulphate method (i.e. from colourless to white precipitate) was used.

Procedure: The scale was inserted in distilled water and the filter ring set to zero. 25 mls of sample water was put in the cell bottle and into the cell box and zero adjustment set. The content of one chloride reagent pack was added and the bottle swirled to mix. The swirling continued for three minutes and the cell bottle and its content was put in the cell box and the concentration read from the meter in mg/l.

3.7.7 Colour

This was measured using the Platinum-cobalt Standard Method. The DR/2000 instrument was used. The stored program number for colour (455) was enterd. The display showed: 'DIAL nm TO 455'. The wavelength dial was rotated until the small display showed '455 nm'. The 'READ/ENTER' was then pressed. The display showed: 'UNITS PtCo COLOR'. 50 ml of sample was poured through the filter. A second sample cell (the prepared sample) was filled with 25 ml of the sample. The blank was placed into the cell holder. The lights shield was closed. 'ZERO' was pressed. The display showed: 'WAIT', then '0. UNITS PtCo COLOR'. The prepared sample was placed into the cell holder, and the light shiel closed. 'READ/ENTER' was pressed. The display showed 'WAIT' and then the result in platinum-cobalt units was displayed.

3.8 Most probable number (MPN)

The isolation and enumeration of total coliform bacteria was carried out using the *Most Probable Number* (MPN) method. The MPN method is the most commonly used method in determining

the approximate number of coliforms in a water sample (Nester *et al*., 2004). The presence or absence of total coliform bacteria was observed as characteristic visible change such as gas production after a 48 hour incubation period. The result was then compared against an MPN table.

3.8.1 Presumptive Tests

To determine the MPN, three sets of five tubes containing the same growth media (MacConkey broth) and Durham tubes were prepared. Each set received a measured amount of water sample such as water and food. What was important was that, the second set received 10-fold less than the first and the third set 100-fold less. Thus, each set was inoculated with an amount 10-fold less than the previous set and incubated for 48 hours. Tubes showing color change from purple to yellow and gas collected in the Durham tubes after 24 hours were identified as positive. Counts per 100 ml were calculated from Most Probable Number Tables.

3.8.2 Differential Tests

To isolate the organisms detected in the presumptive tests, differential tests were carried out. Fermentation of lactose after incubation at 44^{o}C showing the presence of any amount of gas in the inverted inner tube after 24 hours indicated a positive reaction. Absence of gas production in 24 hours incubation even though growth of acid production is present was regarded as a negative reaction.

Indole test: After incubation of peptone water culture at 44^{o}C for 24 hours, 0.2 – 0.3ml of Kovac's reagent was added and the tube gently shaken. When the test was positive, a deep red colour appeared in the upper layer almost immediately.

3.9 Data Analysis

Results were analyzed using Microsoft Excel 2007 version.

CHAPTER FOUR

Results

4.1 Sanitation survey

The sanitation survey revealed that eight of the wells did not have cover slabs. Well water was drawn normally using various receptacles (plastic or aluminium buckets) with varying degrees of hygiene (that is some appeared very dirty, others looked relatively clean). These receptacles were also used for other purposes at home including bathing and washing of clothing and utensils. Similarly, there were no windlass on these wells and all users had to use one rope for drawing water which was often left in water that had been spilt around the well head.

All the 10 wells studied were shallow, approximately ranging between 1.5 - 3.5 m in depth. The linings of all the wells were defective as they were fissured. Ideally, wells should be constructed with concrete ring pipes but due to financial constraints, six of the wells have only the upper 2 m portion cemented thus allowing easy seepage.

The area of study is low lying and one needs not dig deep to reach the water table. Hence filtration, adsorption and trapping of bacteria by fine sandy materials, clays and organic matter may not be effective (Wilson *et al.*, 1983).

Lastly, all the studied wells were sited within the communities' utility area. They were all approximately within a 10 m or less radius from pit latrines and refuse tips.

4.2 Characteristics of wells

A detailed description and conditions around the wells are presented in Tables 4.1 to 4.3 (see Appendix A). The depths of the wells, water levels, population served, major uses and whether the wells are well protected from possible contamination sources, have all been documented. The conditions of the wells and the surrounding areas have also been described. Observational study

results showed clearly that majority of the wells and their surroundings are in unhygienic conditions, serve a large population and are never covered. For instance, for the three wells in Saltpond (SW1, SW2 and SW3) one was found without any form of covering. In two of the three cases different containers are used for fetching water from the wells as indicated in table 4.1.

From Table 4.1, it can be seen that depths of the Saltpond wells ranged between 1.5 m and 3.5 m. The water levels also are between 1.0 m and 1.2 m. Water from SW2 can be said to be contaminated with elements from the immediate surroundings. For instance dirty polythene bags, sticks, corn cobs, etc., were found in the well (see Plates 4.1 and 4.2 at Appendix C).

From Table 4.2, it was obvious that all the four wells in Ankaful are practically not covered even though AW3 has a cover which was never in use any time samples were taken. In all cases, different users used different containers for fetching the water paving the way for contamination of all sorts from various sources.

Finally, wells from Kormantse were assessed to ascertain their characteristics. The results are tabulated in Table 4.3. From Table 4.3, it can be said that all the wells from Kormantse do not have any covering. Therefore they can be contaminated with elements of the weather and any contaminant from the immediate surroundings.

KW3, one of the wells which the people sourced drinking water from is in a deplorable condition. An old metal barrel was used as the lining. It is rusted and torn in many places as shown in Plates 4.5 and 4.6 in Appendix A.

4.3 Physico-chemical Characteristics of Well Water

The well waters sampled displayed wide variations in physical quality (i.e. pH, colour, turbidity, and conductivity). The pH levels of the various well waters ranged between 6.63 ± 0.12 and 8.10 ± 0.17, with site AW2 recording the highest level (Table 4.1 Appendix B), and the least value being recorded at site AW1. The variations are significant at $P<0.05$. Furthermore, these levels are within the acceptable WHO guideline level of 6.5 - ≥ 9.2.

The mean values of colour for the sites ranged between 1.67 Pt.Co and 80.00 Pt.Co with KW2 having the least and SW1 recording the highest. Turbidity values ranged between 0.33 NTU and 14.00 NTU. With sites KW2 and KW3 recording the least value, 0.33 NTU, and SW1 the highest of 14.00 NTU. Conductivity values ranged between 610.00 µS/cm and 1700 µS/cm.

The mean pH values were generally almost the same for both seasons, except for AW1, AW2, SW1, and KW3 which indicated high during the wet season and relatively lower during the dry season. Also AW4, SW3, KW1 and KW2 indicated a high pH level during the dry season and a low during the wet season, whereas AW3 and SW2 showed no variation in pH with the seasons (Fig. 4.1).

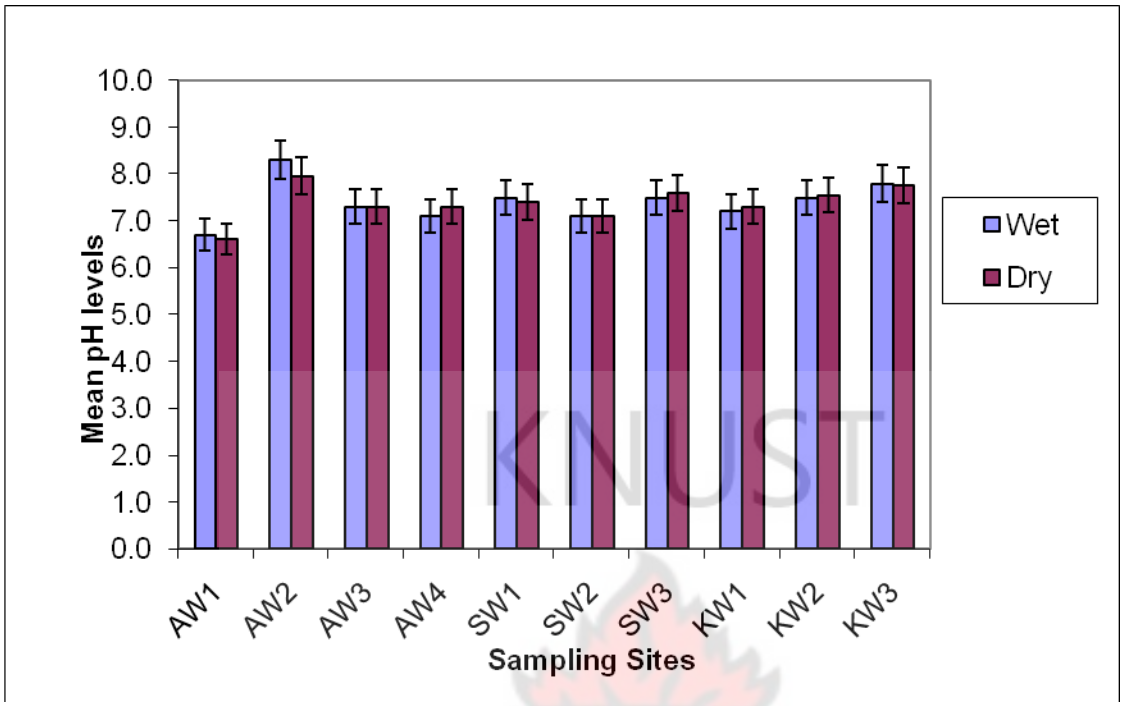

Fig 4.1: Seasonal variation in pH levels in well waters

The variations in colour with the seasons were as follows: AW1, AW2 and SW1 registered high colour levels during the dry season. But during the wet/rainy season, AW2, AW4, SW3, KW1, KW2 and KW3, all recorded high colour levels; but AW3 and SW2 registered no colour change with the seasons.

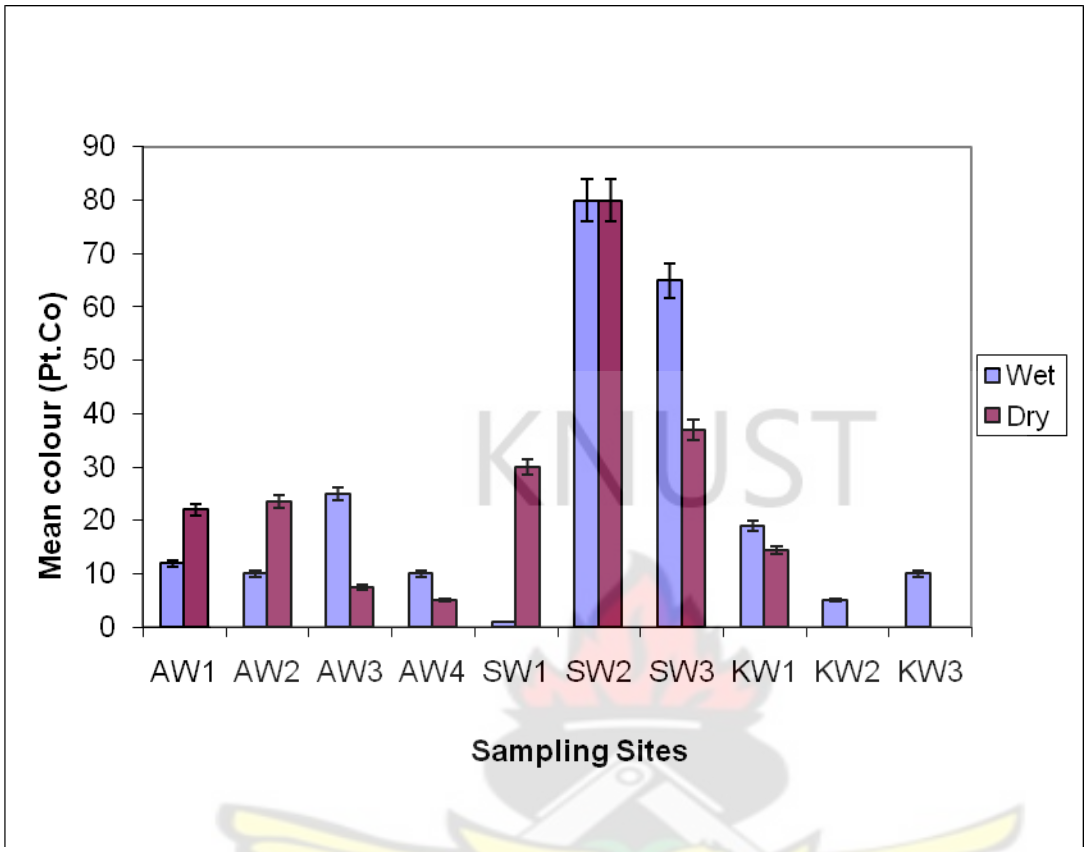

Fig 4.2: Variations in colour of the well waters with seasons

The turbidity values also varied with the seasons. While AW1, AW2, SW1 and KW1 had high turbidity values during the dry season, AW4, SW3, KW2 and KW3 had high turbidity values during the rainy season. Indeed, KW2 and KW3 registered no turbidity values during the dry season. And AW3 and SW2 showed no variation in turbidity with the seasons (Fig. 4.3).

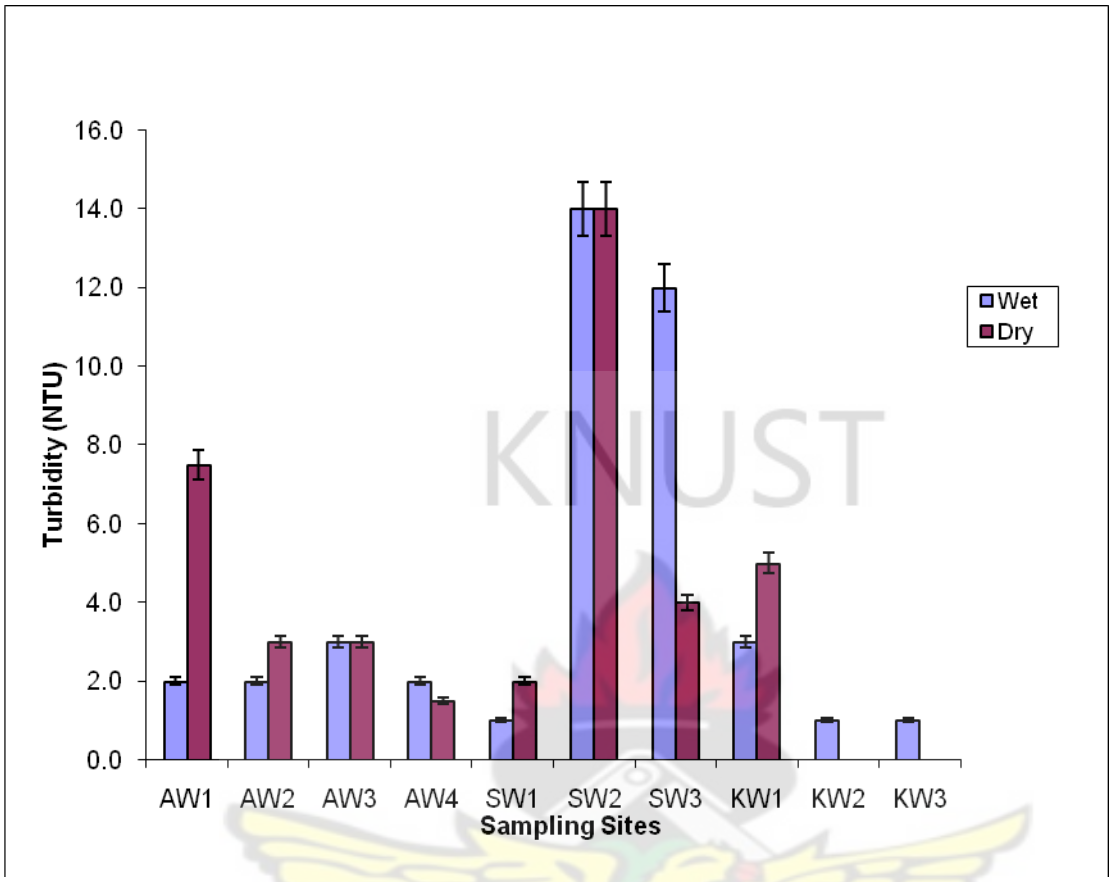

Fig 4.3: Seasonal variations in turbidity levels of well water samples

Water from AW1, AW2, AW4 and KW2 were found to have high conductivities during the dry season but recorded low during the wet/rainy season. But those for SW1, SW3, KW1 and KW3 had high conductivity values during the wet season. However, water samples from AW3 and SW2, showed no variation in conductivity with the seasons (Fig. 4.4).

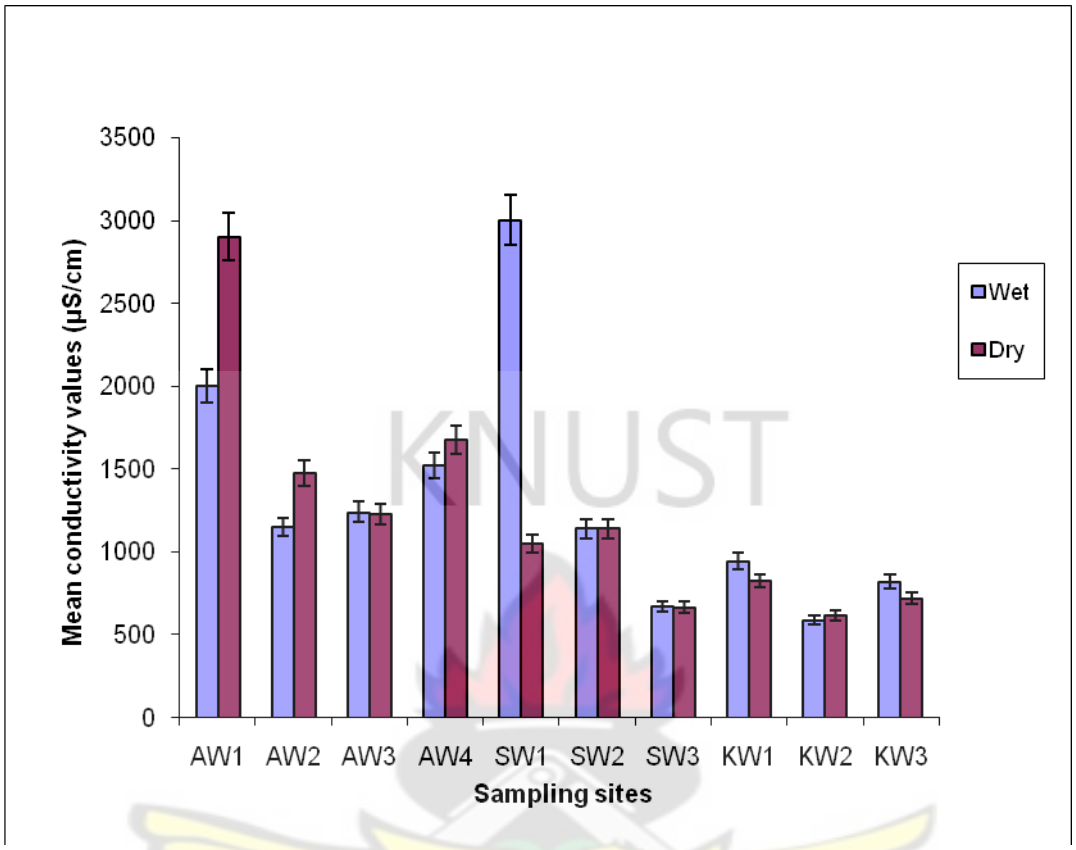

Fig 4.4: Seasonal variations in electrical conductivity in well water samples

The mean nitrate levels at various points varied with the seasons as well. AW1, AW3, KW1, KW2 and KW3 all recorded high nitrate levels in the dry season and low in the wet season. KW1 had a mean nitrate value of about 0.1 mg/l in the dry season but 0.02 mg/l in the wet season indicating an increase of about 80% during the dry season. AW4 and SW1 had high nitrate levels during the wet season, and low during the dry season. But AW2 and SW2 showed no variation in nitrate levels with the seasons (Fig. 4.5).

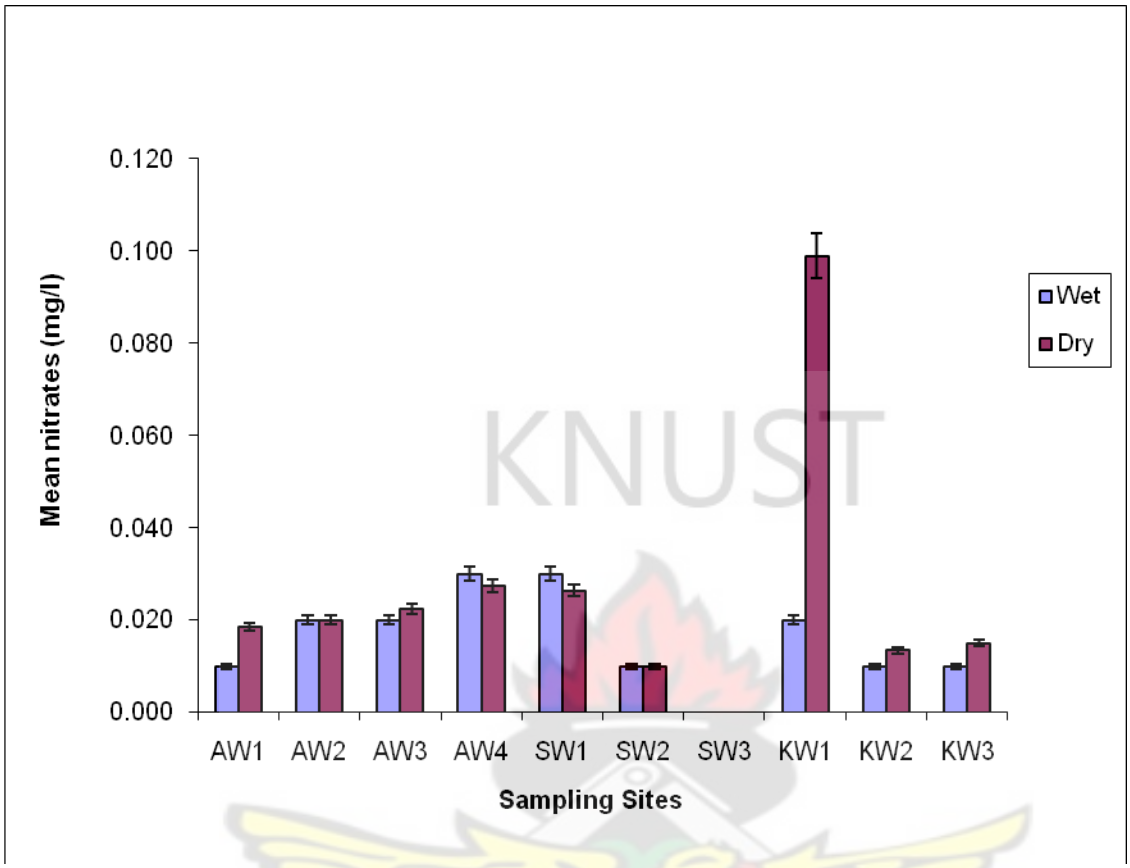

Fig 4.5: Seasonal changes in nitrate levels in well water samples

The mean ammonia levels were high at SW1, SW3 and KW2 during the dry season, but were high during the wet season at AW1, AW2, AW3, AW4, KW1 and KW3. SW2 registered no seasonal variation in the mean ammonia levels (Fig. 4.6).

The mean nitrate levels ranged from that below detection limit and 0.07 mg/l; with SW2 recording values below detection limit and KW1 the highest value of 0.07 mg/l. SW1 had the lowest mean ammonia level, while AW1 had the highest from a range of 0.120 mg/l to 0.256 mg/l as shown in Appendix C.

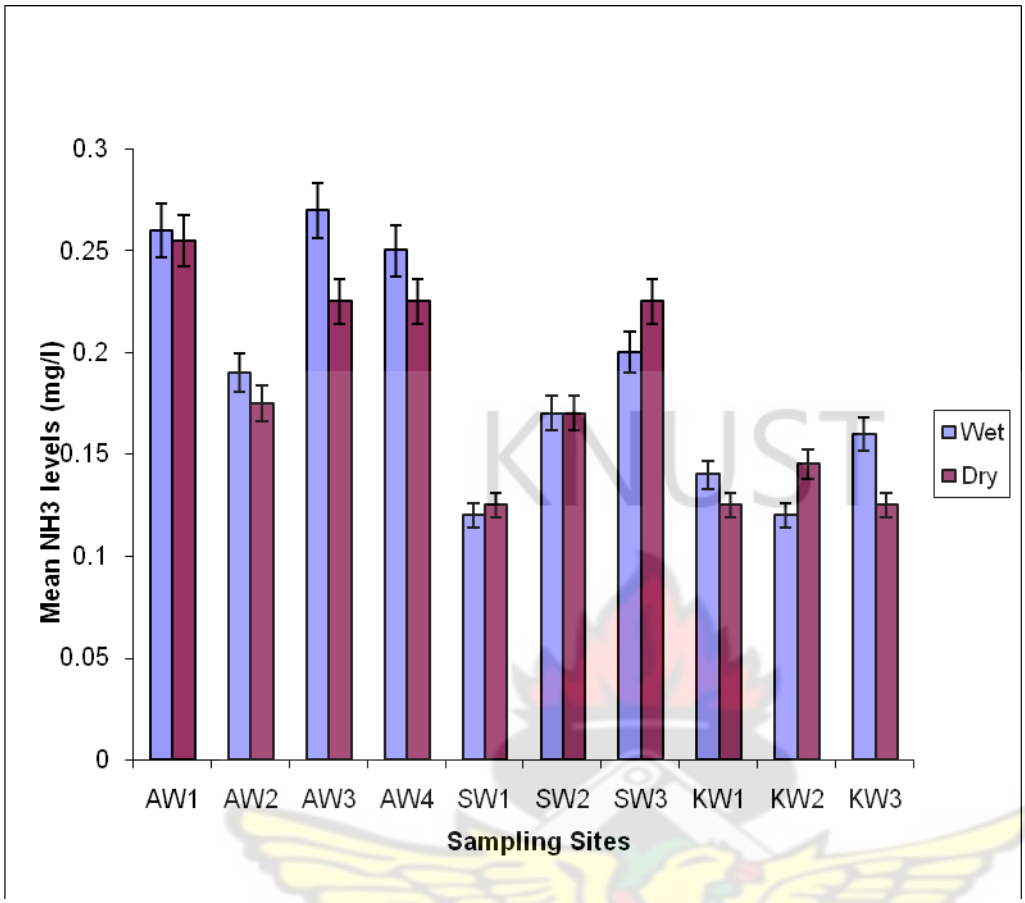

Fig 4.6: Seasonal changes in ammonia level in well waters

At AW1, AW2 and AW4, the mean chloride levels were high during the dry season but low during the wet season. However, for AW3, SW1, SW3 and KW2 the mean chloride levels were low in the dry season and high in the wet season, though the difference in the values between the wet and dry seasons for SW3 and KW2 were not significant. SW2, KW1 and KW3 showed no seasonal variations in chloride levels (Fig. 4.7).

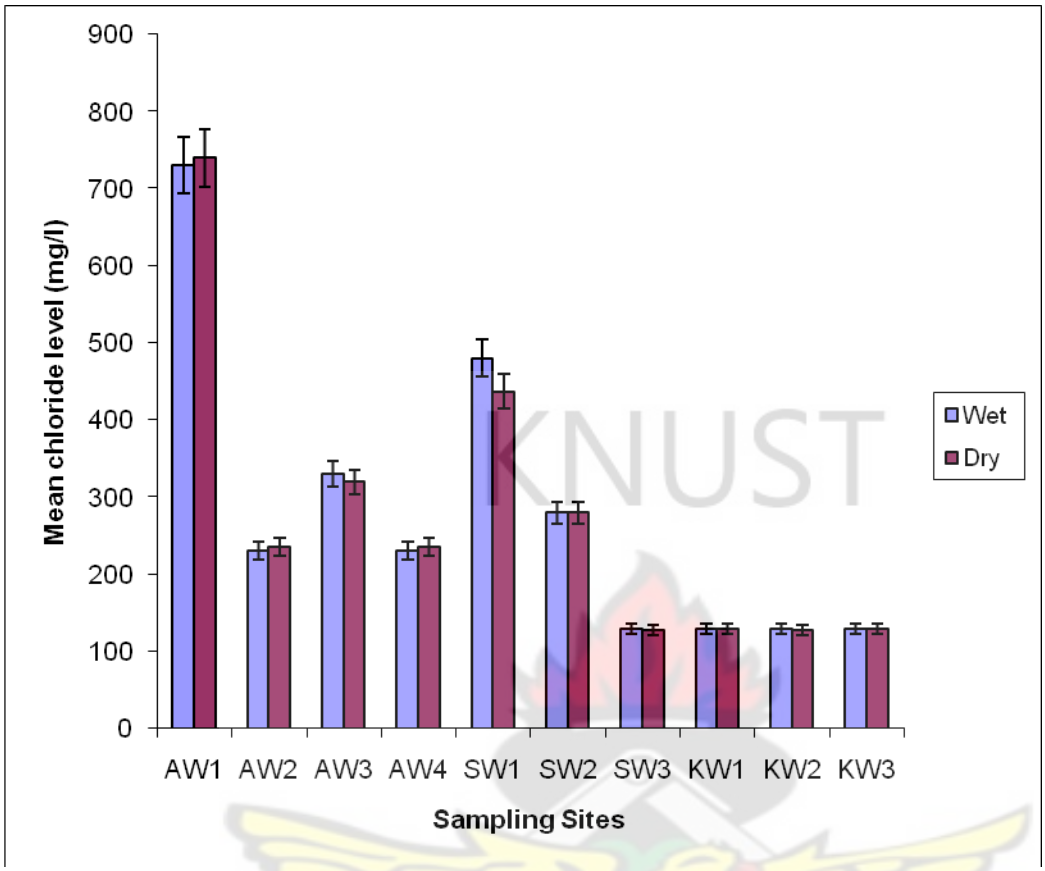

Fig 4.7: Seasonal changes in chloride level in well waters

The mean chloride levels ranged between128.33 mg/l and 736.67 mg/l inclusive. Both SW2 and KW2 had the same value (i.e. the lowest) whereas AW1 registered the highest level.

4.4 Microbiological Characteristics of Wells

To ascertain the microbiological characteristics of the wells under study, both presumptive and differential tests were conducted. The presumptive tests gave the Most Probable Numbers (MPN) per 100 ml of samples. And the differential tests indicated the actual microorganisms present in the individual wells. Table 4.4 below gives the MPN values of the various wells.

Table 4.4: Levels of total coliforms in the water samples

Source	Total Coliforms per 100 ml/MPN
SW1	918
SW2	1609
SW3	918
AW1	278
AW2	345
AW3	2400
AW4	221
KW1	1609
KW2	345
KW3	1609

Table 4.4 shows that the total coliforms per 100 ml of sample from the various sampling points ranged between 221 to 1609 MPN, with AW4 registering the lowest MPN (of 221 coliforms per 100 ml) and SW2, KW1 and KW3 registering the highest value (of 1609 MPN).

Results of the Differential Tests

All the organisms that were capable of producing acid and gas from lactose peptone water in 48 hours at 37^{o}C went through the differential test and results obtained are as shown in Table 4.5.

Table 4.5: Results of the differential tests

Sampling Site	Type of Organism	Normally Found in
AW1	E-Coli type 1	Sewage

AW2	Intermediate type 1	Soil
AW3	Intermediate type 1	Soil
AW4	Intermediate type 1	Soil
SW1	Intermediate type 1	Soil
SW2	Intermediate type 1	Soil
SW3	Intermediate type 1	Soil
KW3	Intermediate type 1	Soil
KW2	Intermediate type 1	Soil
KW1	Intermediate type 1	Soil

4.4.1 Users' Perception of the Quality of the Well Waters

The third specific objective was to assess users of the wells' perception of the quality of the water from the wells. A section of the users were interviewed on the uses they put the water to and how 'good' they considered the water was for those purposes. Table 4.5 is a thematic presentation of the findings from the various interviews.

Table 4.6 Thematic presentation of users' perception of the well water quality

Well	What the Water is used for	The Results of the Usage	Conclusions

SW1	Laundry, bathing, flushing water closet toilet	Water lathers well with soap, but forms plaque in toilet bowl	Water good for laundry and bathing
SW2	Laundry, bathing, cooking	Water lathers with soap. However, it wastes soap, usually powdered soap.	Not too good for laundry and bathing, but okay for cooking purposes
SW3	Laundry, bathing, cooking	Lathers well with soap.	It's okay for laundry and bathing. Good for cooking too.
AW1	Laundry, bathing, cooking, drinking, etc	Lathers very well with soap. Tastes like normal/tap water	Nothing wrong with using it for bathing, drinking, cooking, etc.
AW2	Laundry, bathing, cooking	Wastes soap; occasional itchiness after bathing	Not too bad for laundry and bathing, and alright for cooking
AW3	Laundry, bathing, cooking	Wastes a lot of soap	Not very good for laundry and bathing.
AW4	Laundry, bathing, cooking	Wastes soap, usually powdered soap	It is not very good for bathing, but is good for cooking.
KW1	Laundry, bathing, cooking, drinking, etc	Lathers well with soap. Tastes like tap water, but few report stomach upset after drinking for the first time	Quite good, except that for drinking purposes first timers need to be wary
KW2	Laundry, bathing, cooking	Wastes soap, sometimes one gets rashes after bathing	Not good for laundry and bathing.
KW3	Laundry, bathing, cooking	Wastes soap, leaves holes in saucepans used often	Not good for laundry and cooking.

From Table 4.5 it is clear that from the standpoint of users, the water from the wells is of good quality if it lathers well with soap. It is however not too good when it wastes soap. From the results of the various interviews it can be said that ninety percent (90%) of users access the well waters for laundry, cooking and bathing purposes. Only two of the wells (that is, AW1 and

KW1) are deemed fit for drinking by users. Yet in both cases users report some form of stomach upset for the first time of drinking from them. Also users of two of the wells report some form of skin problems after bathing with the water. This was the case with wells AW2 and KW2.

CHAPTER FIVE

5.0 Discussion

5.1 Seasonal Quality of well water

The quality of the well water from the sampling various points varied with the seasons, (i.e. the wet and dry seasons) as indicated in chapter four. It was found that the mean pH values were generally almost the same for both seasons, except for wells AW1, AW2, SW1, and KW3 which recorded high pH values during the wet season and relatively lower during the dry season. Wells AW4, SW3, KW1 and KW2 indicated a high pH level during the dry season and a low during the wet season, whereas AW3 and SW2 showed no variation in pH with the seasons.

This trend may be due to the contamination of the groundwater by leachates of acidic origin during the dry season. During the wet season, however, more water is available to dilute the leachates. As a result the pH of the water will be low (meaning that the water tends to be slightly acidic) in the dry and high (slightly alkaline) in the wet season.

The variations in colour with the seasons where high colour levels were registered during the dry season and low in the wet season could have been due to contamination from users of the wells. In this case during the wet or rainy season, since more water is available to dilute the contamination effect, the colour levels were relatively low. However, in the case of the wells where the opposite of the foregoing was true, it could have been that more contamination occurred during the wet season than it was during the dry season.

With the variation of turbidity levels with the seasons, it is obvious that during the wet season, due to surface runoff of rainwater into some of the wells which had no protection against the phenomenon, turbidity levels tended to be high during the wet and low during the dry season as it was the case with AW4, SW3, KW2 and KW3. With wells where turbidity was low during the dry season and high during the dry season (wells AW4 and SW3) it was because during the dry season the water levels tend to be generally low such that when users fetch from them the agitation results in mud particle clouding the water, thus resulting in high turbidity levels in the dry seasons.

Water from AW1, AW2, AW4 and KW2 were found to have high conductivity values during the dry season and low during the wet/rainy season this may be due to the fact that dissolved salts tend to be more concentrations were high during the dry season and were reduced during the wet season, as more water is available during the wet season to dilute the salts concentration. But samples from for SW1, SW3, KW1 and KW3 had high conductivity values during the wet season, and low conductivity values during the dry. This could have been the result of more dissolved salts leaching into or otherwise finding their way into the wells. However, water from AW3 and SW2, showed no variation in conductivity with the seasons.

The mean nitrate levels at various points varied with the seasons as well. AW1, AW3, KW1, KW2 and KW3 all indicated high nitrate levels for the dry season, and low for the wet. In fact, KW1 had a mean nitrate value of about 0.1 mg/l in the dry season but 0.02 in the wet season. This means the nitrate level in the wet season increased about 80% during the dry season. This is the result of pollution from animal sources occurring more during the dry season than in the wet season (ref). AW4 and SW1 had high nitrate levels during the wet season, and low during the dry season; an indication of more contamination from animal sources during the wet season

than during the dry season. But AW2 and SW2 showed no variation in nitrate levels with the seasons. This indicates no change in the amount of contaminants during the seasons.

The mean ammonia levels were high at SW1, SW3 and KW2 during the dry season, but were high during the wet season at AW1, AW2, AW3, AW4, KW1 and KW3. SW2 registered no seasonal variation in the mean ammonia levels (Fig. 4.6).

At wells AW1, AW2 and AW4, the mean chloride levels were high during the dry season but low during the wet. The opposite was observed for AW3, SW1, SW3 and KW2, though the difference between the wet and dry seasonal levels for SW3 and KW2 were insignificant. SW2, KW1 and KW3 showed no seasonal variations in terms of the chloride levels (Fig. 4.7).

The wells analysed in the study contained high microbial indicator counts which were considerably in excess of WHO recommended guidelines for drinking water (WHO, 2006). WHO guidelines stipulate that drinking water should have zero microbial indicator counts.

CHAPTER SIX

Conclusion and Recommendations

6.1 Conclusion

The results showed that shallow wells yield water of very poor quality microbiologically. All of the wells sampled failed to meet the zero coliform per 100 ml set by WHO (2006). Water quality was inferior when it rained as compared to the dry season.

The results from this study clearly demonstrate that the water quality obtained from shallow wells are unfit for human consumption. Certain wells have microbiological contamination with the potential for fatal consequences if consumed untreated by humans. Relying on the natural filtration characteristics of the local soil alone to filter the water as it percolates through the surrounding ground, is clearly insufficient to provide safe potable water for the majority of shallow wells which have been documented in this research study. The location and construction play a large part in reducing the contaminations in these wells, but do not guarantee that the water obtained from shallow well will be safe to drink.

There is an urgent need to develop some form of local treatment to purify shallow well waters for people in the Mfantseman Municipality and other similar places in Ghana. This will help go a long way to ensure that the Millennium Development Goals (MDGs) are achieved by 2015.

6.2 Recommendations

Groundwater contamination often correlates with areas of poor hygienic standards and sanitation. Minimizing faecal pollution of wells within communities must be an integrated approach. Developing sound water resource management programmes will be crucial to Ghana's poverty reduction, economic growth, food security and maintenance of natural systems. There is the need for greater community participation in water management in the three communities (Saltpond, Kormantse and Ankaful) where the study was conducted.

The following recommendations are made:

1. More surveys of water quality analysis should be carried out in other communities in the municipality.

2. A fitting water purification method for purifying water from shallow wells needs to be developed for the area of study as soon as possible.

3. Household treatment such as boiling should be encouraged before water from these wells is used for drinking purposes.

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APPENDICES

APPENDIX A

Some of the sampled wells in pictures

Plate 4.1: AW2 (State of inner-lining)

Plate 4.2: AW3 (Surroundings)

Plate 4.3: SW3 (Surroundings)

Plate 4.4: SW3 (Close-up of bottom)

Plate 4.5: KW3 (Surroundings)

Plate 4.6: KW1 (Inner-lining)

Plate 4.7: KW3 (Close-up)

Plate 4.8: KW1 (Close-up)

APPENDIX B

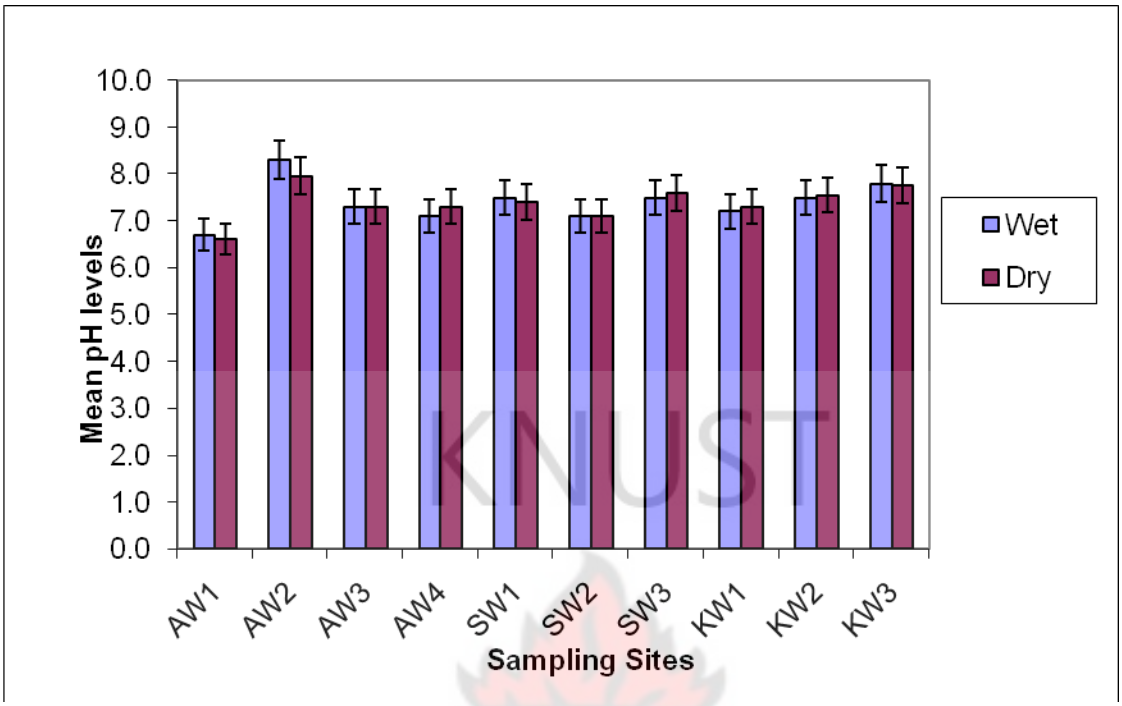
Mean and standard deviation of physical parameters measured in well water from the selected sites

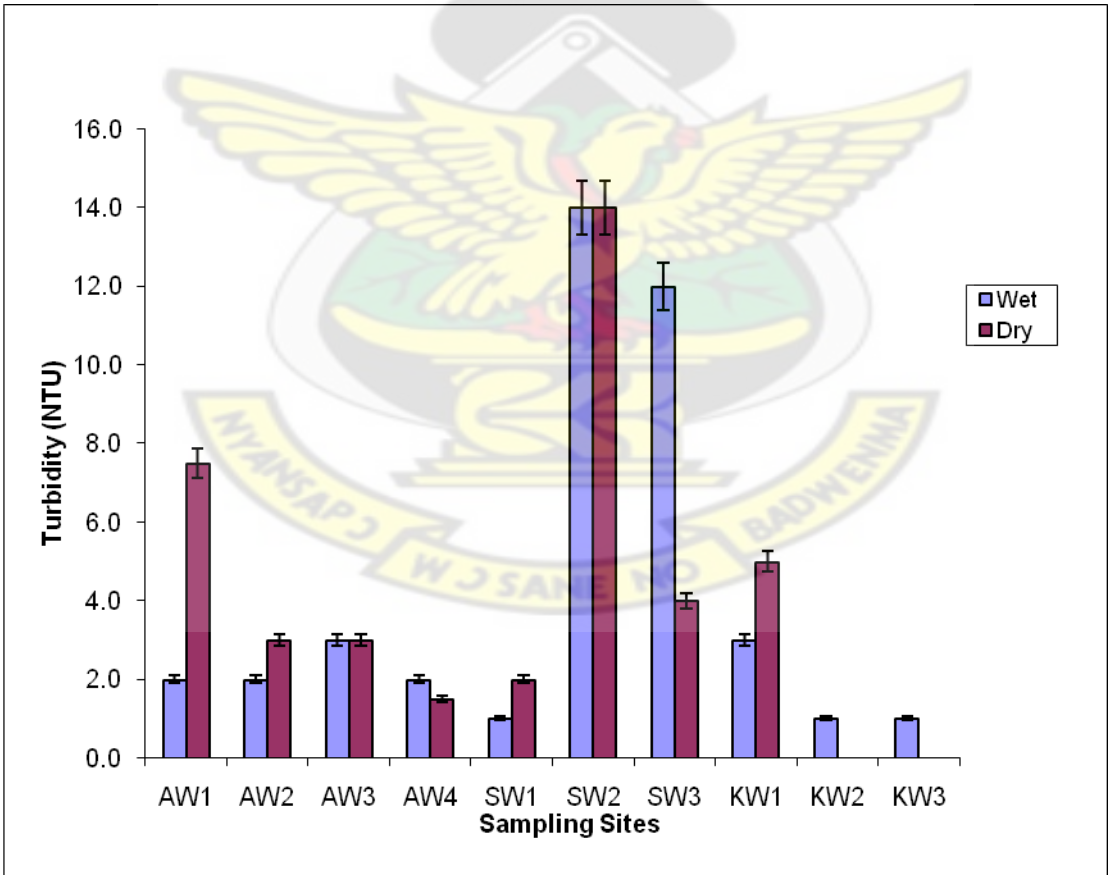
Sampling Site	pH	Colour (Pt.Co)	Turbidity (NTU)	Conductivity (µS/cm)
SW 1	7.10 ±0.06	80.00 ±17.47	14 ±0.58	1140 ±1126.94
SW2	7.57 ±0.06	46.33 ±20.74	6.67 ±5.03	666.67 ±15.28
SW3	7.43 ±0.06	20.33 ±17.47	1.67 ±0.58	1700 ±1126.94
AW1	6.63 ±0.12	18.67 ±9.87	5.67 ±0.12	2600 ±529.15
AW2	8.10 ±0.17	19.00 ±9.00	2.67 ±2.08	1366.67±189.30
AW3	7.30 ±0.20	13.33 ±0.69	3.00 ±1.00	1233.33 ±70.24
AW4	7.30 ±0.00	5.00 ±7.70	1.50 ±2.12	1675.00 ±35.36
KW1	7.27 ±0.12	16.00 ±9.85	4.33 ±3.21	867.00 ±70.89
KW2	7.53 ±0.06	1.67 ±2.89	0.33 ±0.58	610.00 ±20.00
KW3	7.77 ±0.06	3.33 ±5.77	0.33 ±0.58	753.33 ±90.74

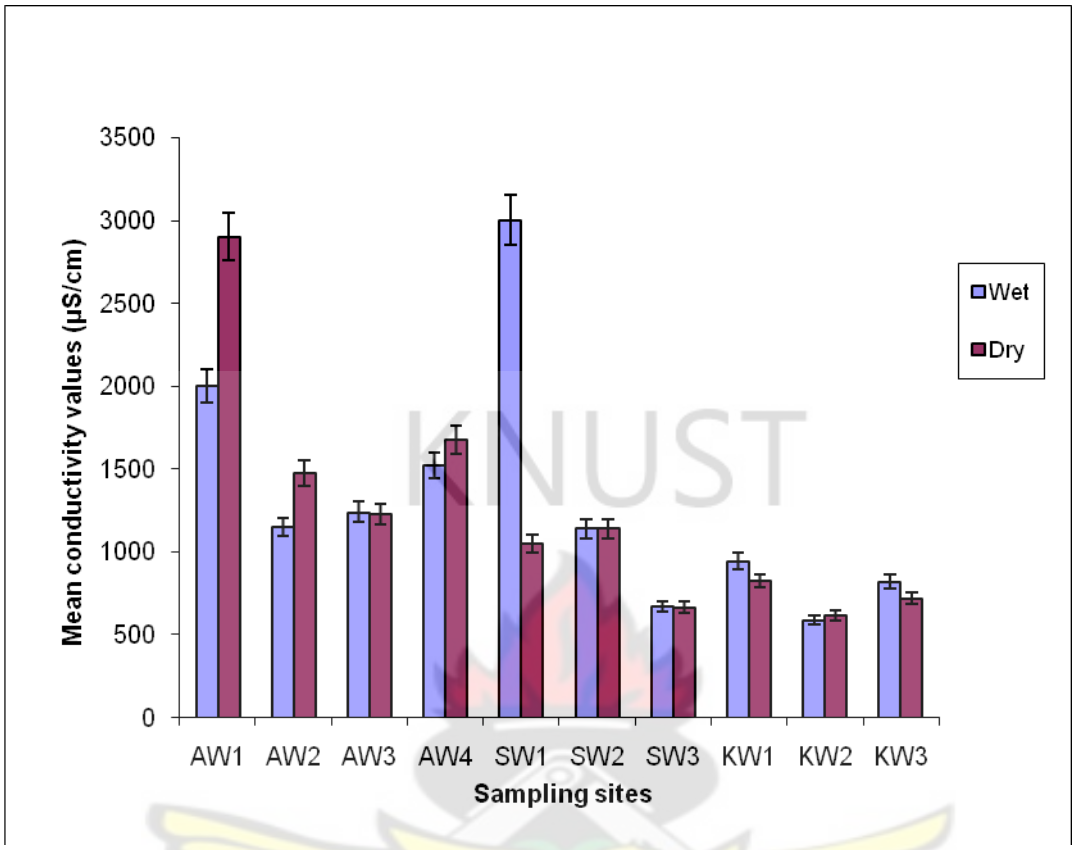
APPENDIX C

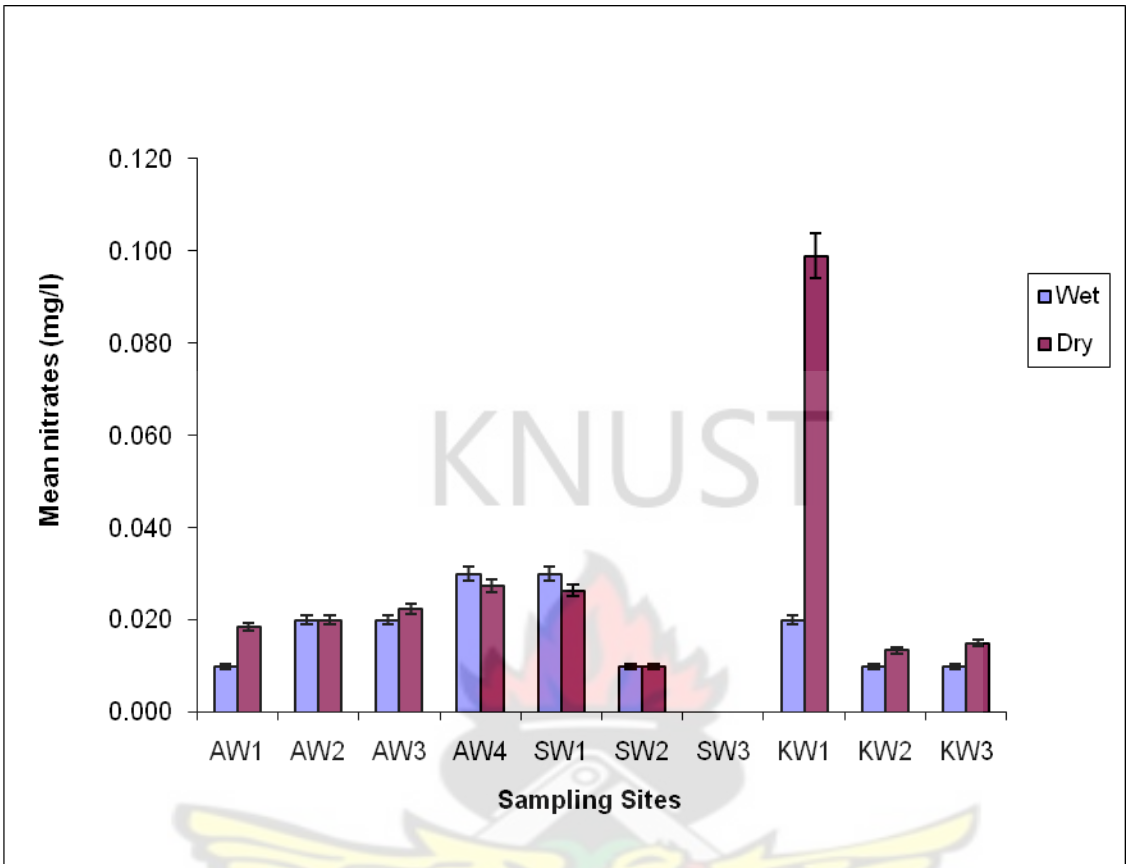
Nutrient levels in well water from selected sites

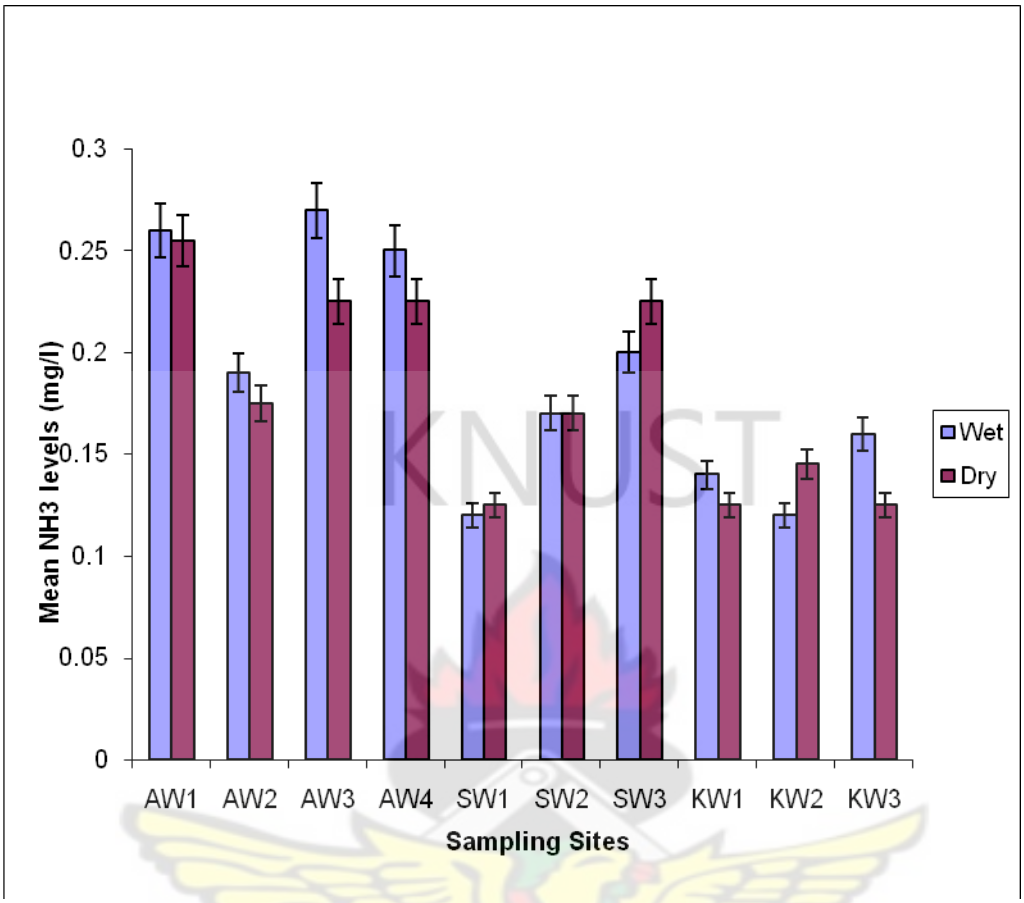
Sampling sites	Nitrate	Ammonia	Chloride
	Mean levels (mg/l)		
SW1	0.01 ±0.00	0.170 ±0.040	280.00 ±7.07
SW2	0.00 ±0.00	0.220 ±0.040	128.33 ±7.07
SW3	0.03 ±0.00	0.120 ±0.030	451.67 ±44.81
AW1	0.016 ±0.05	0.256 ±0.006	736.67 ±11.55
AW2	0.020 ±0.00	0.180 ±0.020	233.33 ±2.89
AW3	0.020 ±0.00	0.240 ±0.040	323.33 ±11.55
AW4	0.030 ±0.00	0.230 ±0.040	235.00 ±7.07
KW1	0.070 ±0.09	0.130 ±0.030	130.00 ±5.00
KW2	0.010 ±0.00	0.140 ±0.020	128.33 ±7.07
KW3	0.010 ±0.00	0.140 ±0.030	130.00 ±0.00

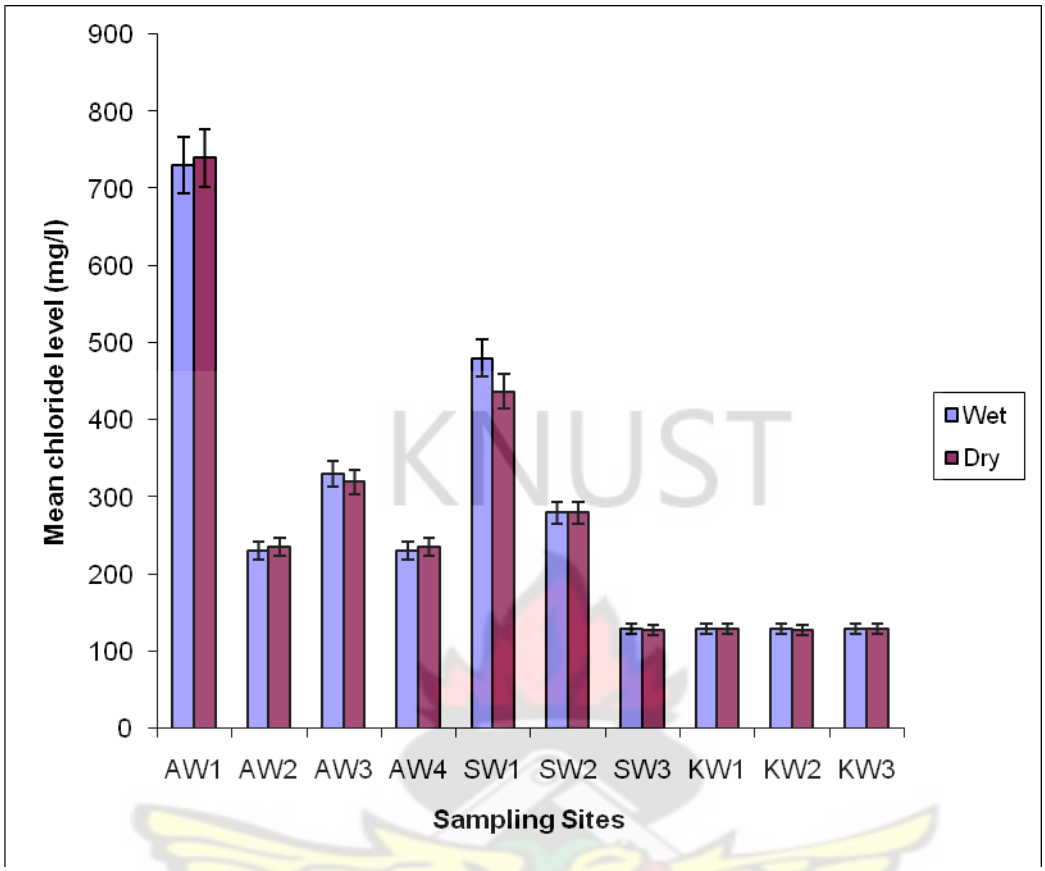

10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Mean pH levels
AW1
AW2
AW3
AW4
SW1
SW2
SW3
KW1
KW2
KW3
Sampling Sites
Wet
Dry

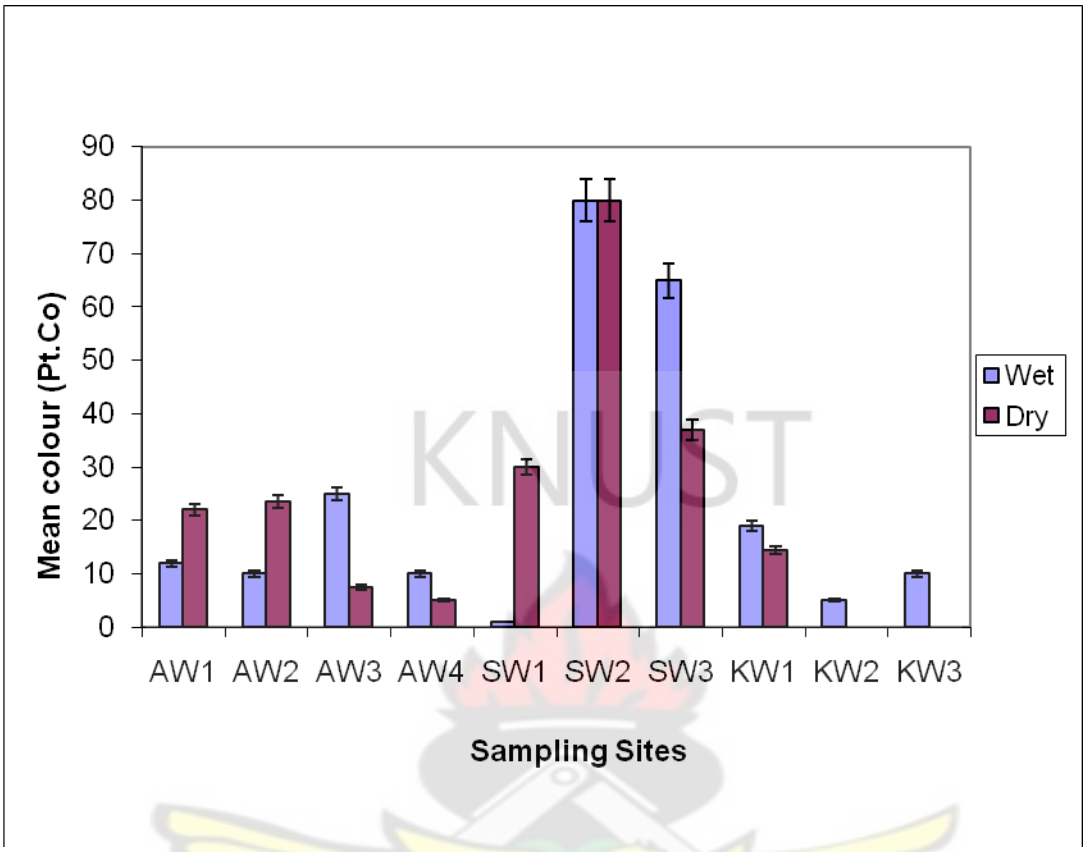

16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Turbidity (NTU)
AW1
AW2
AW3
AW4
SW1
SW2
SW3
KW1
KW2
KW3
Sampling Sites
Wet
Dry


3500
3000
2500
2000
1500
1000
500
0
Mean conductivity values (µS/cm)
AW1
AW2
AW3
AW4
SW1
SW2
SW3
KW1
KW2
KW3
Sampling sites
Wet
Dry


0.120
0.100
0.080
0.060
0.040
0.020
0.000
Mean nitrates (mg/l)
AW1
AW2
AW3
AW4
SW1
SW2
SW3
KW1
KW2
KW3
Sampling Sites
Wet
Dry


0.3
0.25
0.2
0.15
0.1
0.05
0
Mean NH3 levels (mg/l)
AW1
AW2
AW3
AW4
SW1
SW2
SW3
KW1
KW2
KW3
Sampling Sites
Wet
Dry


900
800
700
600
500
400
300
200
100
0
Mean chloride level (mg/l)
AW1
AW2
AW3
AW4
SW1
SW2
SW3
KW1
KW2
KW3
Sampling Sites
Wet
Dry


90
80
70
60
50
40
30
20
10
0
Mean colour (Pt.Co)
AW1
AW2
AW3
AW4
SW1
SW2
SW3
KW1
KW2
KW3
Sampling Sites
Wet
Dry