KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

Assessment of Water Quality of the Tuse Pond in Atebubu in the Atebubu-Amantin District of Ghana

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In

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By

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CERTIFICATION

I hereby declare that this thesis is my own work towards the Master of Science (M.Sc.) degree in Environmental Science and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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Supervisor Signature Date

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Head of Department Signature Date

DEDICATION

Dedicated to my lovely daughters, Irene and Jennifer and my late mother whose memory is the driving force behind this glorious achievement.

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ABSTRACT

Access to safe water is vital in the prevention of water-borne diseases especially in less developed countries where clean water generally is unavailable for the majority of their rural population. This study was carried out to assess the suitability of the Tuse pond as a source of drinking water for the people of Atebubu. Samples were taken in duplicates from five different locations in the pond once a month for six successive months and some selected physico-chemical and bacteriological parameters were determined during the wet season (September to November) and the dry season (December to February). Analysis of samples was performed using pH meter, conductivity meter, turbidity meter and a multifunctional meter (HANNA, model HI 9032) for determining pH, conductivity, turbidity and total dissolved solids respectively. Nitrite concentration was determined by comparator method using Lovibond Nessleriser (model 2150) while argentometric method was used to determine chloride concentration. Total hardness was measured by titration using Ethylene Diamine Tetra Acetic acid. For the determination of ammonia, nitrate, sulphate, phosphate, fluoride, and iron concentrations the Palintest Photometer method was used. Total coliforms, faecal coliforms and *Escherichia coli* were identified using single strength MacConkey broth and Tryptone water by the three-tube Most Probable Number Method. To determine *Salmonella* and *Enterococci* concentrations, sterilized peptone water and Slanetz Bartley Agar respectively were used. Results from the study indicated that only turbidity, colour and iron among the selected physico-chemical parameters exceeded the World Health Organization (WHO) guideline values for drinking water. Values for colour, turbidity and iron ranged from 90 – 920 Hz; 9.3 – 220 NTU and non-detectable to 0.39 mg/L respectively for the wet season and then 62 –

670 Hz; 20.7 – 72.3 NTU; and 0.12 – 0.37 mg/L respectively for the dry season. All bacteriological parameters examined showed high values that exceeded the WHO guideline values for drinking water. The concentration of total coliforms ranged from 4.0 x 10^3 – 240 x 10^6MPN/100 mL; faecal coliforms, 4.5 x 10^2 – 240 x 10^3MPN/100 mL; *Escherichia coli*, 4.2 x 10^1 – 920 x 10^2MPN/100 mL; *Salmonella*, 2.3 x 10^1 – 92 x 10^1CFU/100 mL; and *Enterococci*, 1.0 x 10^4 – 9.4 x 10^4CFU/100 mL for the wet season. The dry season values ranged from 4.0 x 10^3 – 4.5 x 10^5MPN/100 mL for total coliform; 9.0 x 10^2 – 4.3 x 10^3MPN/100 mL for faecal coliform; 9.0 x 10^1 – 2.4 x 10^2 for *Escherichia coli*; 2.0 x 10^1 – 9.2 x 10^1 for *Salmonella*; and 2.0 x 10^3 – 3.1 x 10^4 for *Enterococci*. The high levels of faecal coliforms, *E. coli*, *Salmonella* and *Enterococci* detected in the samples especially in the wet season indicate possible faecal contamination of the Tuse pond. The study identifies that the pond becomes more contaminated during the wet season since its quality in the dry season is significantly better than that of the wet season. Consumption of water in the pond without any form of treatment could therefore give rise to disease outbreaks such as cholera, dysentery and diarrhoea.

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CHAPTER ONE

1. Introduction

Safe water and prevention of water-borne diseases are public health priorities in most developed countries and clean water generally is available for about one-third of the world's population. Global estimates of the population in developing countries that lack access to safe drinking water range from 1.1 to 1.4 billion (Water Wikipedia Encyclopedia, 2010). The consequences of lack of safe water are severe. The United Nations World Health Organization estimates that more than 3 billion cases of illnesses (Pink, 2006) and 5 million deaths, the majority children, annually can be attributed to unsafe water (Poppe and Hurst, 1997). The death rate for children alone is estimated at one every second. Water-caused intestinal infections today often are associated with impoverished regions with inadequate treatment of water and sewage. For instance more than 137,000 new cases of cholera were reported in 2000, eighty-five per cent of which were in Africa (WHO, 2004). An estimated 1.5 billion persons suffer infections with intestinal helminths each year and another billion suffer diarrhoea diseases (West, 2006). Such diseases are also linked to unsanitary excreta disposal, poor personal and domestic hygiene, and in the case of diarrhoea diseases, unsafe drinking water (Gleick, 2000).

In Ghana, the supply of pipe-borne water is inadequate in most communities. This inadequacy is both in quantity and quality of public water supply. 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 such as rivers, streams, hand-dug wells and ponds.

Water is vital to our existence and its importance in our daily lives makes it imperative that thorough physico-chemical and bacteriological examinations be conducted on drinking water. Potable water is the water that is free from disease causing organisms and chemical substances which are dangerous to health (Larikaran, 1999). The purpose of this study is to assess the physico-chemical and bacteriological quality of Tuse pond water which people in Atebubu use for drinking and to generate baseline data on the water quality of Tuse pond.

1.1 Problem Statement

The quality and safety of drinking water continues to be an important public health issue because its pollution has often been cited as being responsible for the transmission of some infectious diseases that have caused serious illness and associated deaths world-wide (Tibbetts, 1996).

Water quality is determined by its physical, chemical and biological characteristics (Diesing, 2009). According to WHO (2004), diseases contracted through drinking water kill about five million children annually and make one sixteenth of the world population sick. Contaminants that may be in untreated water include microorganisms such as viruses and bacteria; inorganic contaminants such as salts and metals; pesticides and herbicides; inorganic chemical contaminants from industrial processes and petroleum use, and radioactive contaminants (U.S. EPA, 2006).

Some common water-related diseases include diarrhoea, dysentery, cholera, hepatitis, lead poisoning and fluorosis (WHO, 2000). Amongst the poor and especially in

developing countries, diarrhoea is a major killer. In 1998, diarrhoea was estimated to have killed 2.2 million people, most of whom were under 5 years of age (WHO, 2000). In addition to the biological and chemical quality of water, the physical qualities that are likely to give rise to complaints from consumers are colour, taste and turbidity while high pH results in taste complaints. The key to increases in human productivity and long life is good quality water (Urbansky and Magnuson, 2002). Water is indispensable to human existence and that is why conscious efforts should be made to regularly assess the microbiological and physico-chemical quality of drinking water. The assessment of ponds throughout the world in developed as well as least developed countries has shown an increasing pollution brought about by man's direct or indirect influence (Poppe and Hurst, 1997). Assessment of Worthly pond in Peru revealed that development of human settlements and stormwater runoff in pond watersheds increased pollution of the pond while conservation measures minimized the extent of pollution (Scott, 2010). In Zaria, Nigeria, assessment of Lake Kubbani showed high levels of concentration of some physico-chemical parameters including manganese (Abulode, *et al.,* 2008) which may cause Parkinson-like syndrome. The assessment of Ahor lake in Ghana showed that the water met the WHO guideline values except the colour of the water which was light brownish (Amfo-Otu *et al.,* 2011).

Accessibility and availability of fresh water is key to sustainable development and an essential element of health, food production and poverty reduction (Third World Water Forum, 2003). The lack of clean drinking water and sanitation systems is a severe public health concern in Ghana contributing to seventy per cent of diseases in the country.

Consequently, households without access to clean water are forced to use less reliable and hygienic sources and often pay more (African Economic Outlook, 2007).

Atebubu is a disadvantaged community that has to rely solely on wells and ponds throughout the year owing to the absence of pipe-borne water and borehole water supply. It experiences acute water scarcity particularly during the dry season. The Tuse pond was constructed in 1964 to conserve mainly rainwater for use by the people all the year round. In recent years, the pond has been under increasing threat of pollution due to rapid demographic changes resulting in the expansion of human settlements lacking proper town planning and sanitation services. Unfortunately, this pond continues to be the main source of drinking water for the people. The Annual Performance Report (2007-2009) of Atebubu-Amantin, District Health Directorate revealed the prevalence of some infectious water-related diseases over the past three successive years with diarrhoea, dysentery, and helminthiasis being relatively high (Table 1.1).

Table 1. 1: Annual water-related diseases prevalence in Atebubu District, 2007-2009.

DISEASE	**Number of reported cases/year at Atebubu District. Hospital**		
	2007	**2008**	**2009**
Amoebiasis	14	62	8
Diarrhoea	3970	2371	4276
Dysentry	98	102	113
Guinea worm	12	1	0
Helminthiasis	2126	3363	2816
Typhoid	113	82	79

A cursory literature review has revealed that there has not been any published report on water quality assessment of the Tuse pond which is the most reliable source of water for

the people of Atebubu for over forty-six years. With several reported cases of water-borne diseases at Atebubu District Hospital (Table 1.1), it has become necessary to assess the bacteriological and physico-chemical qualities of the available source of drinking water to the people. The mechanism and extent of the pollution of the pond will be better understood when the physico-chemical and bacteriological parameters of the water are studied (Douglas and Smol, 2000). Determination of the water quality will lead to the discovery of the extent to which human and animal activities have impacted on the quality of the pond. The research will also provide baseline data and information which are essential for making and implementation of responsible water policies and regulations which will protect the health of the people.

Drinking water must meet specific criteria and standards to ensure that water supplied to the public is safe and free from pathogenic microorganisms as well as hazardous compounds. Different countries and international organizations such as World Health Organization (WHO), US EPA, Ghana Standards Authority and EPA - Ghana have therefore proposed water quality standards and guidelines to ensure safe drinking water.

1.2 General objective

The general objective for this project is to assess the suitability of Tuse pond as a source of drinking water for the people of Atebubu.

1.3 Specific Objectives

The specific objectives for this project are to:

1. Determine the concentrations of the following physicochemical and bacteriological parameters of water collected from the Tuse Pond at five specific locations where water is fetched for drinking: pH, turbidity, conductivity, colour, total dissolved solids, total hardness, iron, chloride, nitrite, nitrate, fluoride, sulphates, phosphates ammonia, total coliform, faecal coliform, *Escherichia coli, Salmonella*, and *Enterococci*.

2. Determine any seasonal differences in physicochemical and bacteriological parameters of the water in the Tuse pond.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Global Water Resources

The World's total water resource is estimated at 1.36 x10^8 M ha-m. Of these global water resources, about 97.2 % is salt water mainly in the oceans, and only 2.8% is available as fresh water at any time on the planet earth (Raghunath, 2006). Out of this 2.8 % of fresh water, about 2.2% is available as surface water and 0.6% as ground water. Even out of this 2.2% of surface water, 2.15 % is fresh water in glaciers and icecaps and only 0.01% is available in lakes and streams, the remaining 0.04% being in other forms (Raghunath, 2006). Although water covers 70% of the earth's surface, only 1% of the earth's water is available as the source of drinking water.

Water availability is one of the important issues with health implications that confront Africa in particular and the world in general. The fourth assessment report of the Intergovernmental Panel on Climate (IPCC) states that twelve countries would be limited to 1,000 to 1,700 m^3/person/year, and the population at risk could be up to 460 million mainly in West Africa. The estimate was based only on population growth rates and did not take into account the variation in water resources due to climate change and other human activities including mining.

2.2 Ghana's Water Resources

Ghana is well endowed with water resource. The Volta river system basin, consisting of the Oti, Daka, Pru, Sene and Afram rivers as well as the White and Black Volta rivers

covers 70% of the country area. (Water Resources Commission of Ghana, 2012). Another 22% of Ghana is covered by the Southwestern river system watershed, comprising the Bia, Tano, Ankobra and Pra rivers. The coastal river system watershed, comprising the Ochi-Nawuku, Ochi-Amissah, Ayensu, Densu, and Tordzie rivers, covers the remaining 8% of the country.

Furthermore, groundwater is available in Mesozoic and Cenozoic sedimentary rocks and in sedimentary formations underlying the Volta basin. The Volta Lake, with a surface of 8,500 km^2, is one of the world's largest artificial lakes. In all, the total actual renewable water resources is 53.2 billion m^3 per year The Ghana Standard Statistical Survey indicated that more than 40% of Ghanaians in rural, urban and peri urban centres especially children die each year from diseases associated with unsafe water, inadequate sanitation and poor hygiene. According to the Ghana Standard Statistical Survey 2008 report, on the average, women and children walk a distance of six kilometers each day carrying 20 litres of water. The Environmental Protection Agency (EPA) of Ghana estimated that fresh water resource in Ghana amounted to 40 million acres from rainfall, rivers, streams, spring and creeks, natural lakes impoundments and ground water from various aquifers.

The water supply and sanitation sector in Ghana faces severe problems, partly due to a neglect of the sector. Tarrrifs are kept at a low level which is far from reflecting the real cost of service. Economic efficiency still remains below the regional average, resulting in lack of financial resources to maintain and extend infrastructure (UNICEF, 2006). The

lack of clean drinking water and sanitation systems is a severe public health concern in Ghana, contributing to 70% of disease in the country. Consequently house holds without access to clean water are forced to use less reliable and hygienic sources and often pay more. (African Economic Outlook 2007).

2.3 Surface Water Pollution

Water pollution is a major problem in the global context. It has been suggested that it is the leading worldwide cause of deaths and diseases (Pink, 2006) and that it accounts for the deaths of more than 14,000 people daily (West, 2006).

Drinking water is derived from either surface water or ground water. Industrialization and urbanization together with intensified agricultural activity have led to increased demands for water on one hand but to the potential for large scale release of contaminants on the other. McGraw Hill Science and Technology Encyclopedia defines water pollution as a change in the chemical, physical, biological and radiological quality of water that is injurious to its existing, intended or potential uses. It continued to state that water pollution generally refers to human induced (anthropogenic) changes to water quality. This implies that the release of toxic chemicals and organic waste such as livestock and human wastes is considered pollution.

2.3.1 Sources of surface water pollution:

Sources of water pollution are generally divided into two categories, point source pollution and non-point source pollution.

Point source pollution: In this category, contaminants are discharged from a discreet location directly into a water body. Sewage outfalls, oil spills and confined industrial stormwater are examples of point source pollution (Hogan, 2010).

Non-point source pollution: This refers to all discharges that deliver contaminants indirectly into water bodies. These contaminants do not originate from a single discrete source. Acid rain and unconfined runoff from agricultural or urban areas are examples of non point source pollution. Bacterial and viral pathogens can pose public health risk for those who drink contaminated water.

Rain drainage is another major polluting agent. It carries such substances as highway debris (including oil and chemicals from automobile exhaust), sediments from highway and building construction and acids and radioactive wastes from mining operations into fresh water systems. Also transported by runoff and by irrigation return flow are animal wastes from farms and feedlots: pesticides and fertilizer residues from farms also contribute to water pollution via rain drainage. Antibiotics, hormones and other animals used to raise livestock are components of such animal wastes. Other natural and anthropogenic activities may cause turbidity.

2.3.2 Dangers of water pollution

All water pollutants are hazardous to humans as well as lesser species; sodium is implicated in cardiovascular disease, nitrates in blood disorders. Mercury and lead can cause nervous disorders. Some contaminants are carcinogenic. DDT can alter chromosomes; PBCs cause liver and nerve damage, skin eruptions, vomiting, fever,

diarrhoea and foetal abnormalities. Pathogens can produce water-borne diseases in either human or animal hosts (Hogan, 2010). Diarrhoea, dysentery, salmonellosis, cryptosporidium and hepatitis are some of the maladies transmitted by sewage in drinking and bathing water.

Pollution alters water's physical chemistry for instance acidity, electrical conductivity temperature and eutrophication. Eutrophication is an increase in the concentration of chemical nutrients (nitrogen and phosphorus) in a water body to the extent that they increase the primary productivity of the water body. Depending on the degree of eutrophication, subsequent environmental effects such as anoxia (oxygen depletion) and reduction in water quality may occur, affecting fish and other animal population.

2.4 Physico-chemical Pollutants

2.4.1 Turbidity

The American Public Health Association (APHA) defines turbidity as "the optical property of water sample that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample". Turbidity is a measure of the degree to which water loses transparency or brilliance due to either a single foreign substance or a mixture of several substances. The most frequent causes of turbidity in water bodies are planktons and soil erosion from logging, construction, mining and dredging operations. High sediment levels enter water bodies during rain storms due to storm water run-off and create turbid condition. Urbanized areas contribute large amounts of turbidity to

nearby waters through stormwater pollution from paved surfaces such as roads, bridges and parking lots.

According to Michaud (1991) the major effect turbidity has on humans might be simply aesthetic - people do not like the look of dirty water. High turbidity adds extra cost to treatment of surface water supplies. Suspended particles also help the attachment of heavy metals and many other toxic organic compounds and pesticides. In water bodies such as lakes and reservoirs, high turbidity can reduce the amount of light reaching lower depths which can inhibit growth of emerged aquatic plants and consequently affect species which are dependent on them, such as fish and shellfish. Large suspended matter may clog the gills of fish and shellfish and kill them directly. Suspended particles may provide a place for harmful microorganisms to lodge and some suspended particles may provide a breeding ground for bacteria (Mitchell, and Stapp (2005).

There are significant fluctuations in the amount of turbidity in water at different times in a year. Heavy rainfalls, strong winds and convection currents can greatly increase the turbid state of lakes, ponds and rivers. Warm weather and increases in temperature cause microorganisms and aquatic plants to renew their activity in water. As they grow and later decay, these plant and animal forms substantially add to the turbid state of water and frequently cause an increase in odour and colour problems. Increase in turbidity and nitrate concentrations present potential threats to the quality of drinking water in rural areas. Nebbache *et al.,* (2001) suggested that turbidity or nitrate concentrations peak during heavy rain episodes and are short-term events. In terms of management this

implies that the solution to water pollution caused by such events is also short-term and can therefore, be addressed at a local scale.

In 1999, Power and Nagy determined the relationships between bacterial regrowth and some physical and chemical parameters within Sydney's drinking water distribution system. Morris *et al.,* (1996) compared daily counts of diagnosed gastroenteritis (gastrointestinal events) in Milwaukee County, Wisconsin, from January 1992 through April 1993 with reported daily turbidity from two drinking water treatment plants. Turbidity in both plants was associated an increased number of gastrointestinal events.

According to World Health Organization, the maximum permissible level of turbidity is 5 NTU (Nephelometric Turbidity Unit).

2.4.2 Colour

Colour is common in surface water supplies, while it is virtually non-existent in spring water and deep wells. A yellow-tint indicates that humic acids are present and a reddish brown colour if ferric hydroxide precipitates in the presence of air. Dark brown stains are created by manganese. Excess copper can create blue stains. True colour of water is the colour due to natural minerals such as ferric hydroxide and dissolved organic substances such as humic or fulvic acids. Colour measured in water containing suspended matter is defined as apparent colour (APHA, 1992).

Colour in natural waters is due mainly to organic matter which originated from soil, peat, and decaying vegetation. In addition, organic iron and manganese are present in some ground waters and surface waters and may impart a red and black hue respectively. Discoloration of potable water may arise from the dissolution of iron (red) or copper (blue) in distribution pipes which can enhance or be enhanced by bacteriological processes. Microbiological action can also produce "red water" resulting from oxidation of iron (II) to iron (III) by "iron bacteria". Similarly, black discoloration may result from the action of bacteria capable of oxidizing dissolved manganese to give insoluble forms. The colour of natural water range from 5 mg/L PtCo in very clear waters to 1,200 mg/L PtCo in dark peaty waters.

2.4.3 Conductivity

Conductivity is a measure of the ability of water to pass an electrical current. Absolutely, pure water is a poor conductor of electricity. Water shows significant conductivity when dissolved salts are present. The amount of mineral and salt impurities in the water is called "total dissolved solids (TDS)". Total dissolved solids is measured in parts per million. Drinking water should be less than 500ppm. There are several factors that determine the degree to which water will carry an electrical current. These include: the concentration or number of ions: mobility of the ion; oxidation state (valency) and temperature of the water, the presence of inorganic dissolved solids such as chloride, nitrate, sulphate and phosphate anions or sodium, magnesium, calcium, iron and aluminium cations. Organic compounds like oil, phenol, alcohol and sugar do not conduct electrical current very well and therefore have low conductivity in water. (Wu *et*

al., 1987). Conductivity in water bodies is affected primarily by the geology of the area through which the water flows. Streams that run through areas with granite bedrock tend to have lower conductivity because granite is composed of more inert materials that do not ionize when washed into water. On the other hand, streams that run through areas with clay soils tend to have higher conductivity because of the presence of materials that ionize when washed into the water. Discharges to streams and other water bodies can change the conductivity depending on their make-up.

Conductivity is useful as a general measure of water quality. Significant changes in conductivity of water could be an indication that a discharge or some other source of pollution has entered the water body.

2.4.4 Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) is the term used to describe the inorganic salts and small amounts of organic matter present in solution in water. The principal constituents are usually calcium, magnesium, sodium, and potassium cations and carbonate, hydrogen carbonate, chloride, sulphate, and nitrate anions. The presence of dissolved solids in water may affect its taste (Bruvold and Ongerth, 1969). The palatability of drinking water has been rated by panels of tasters in relation to its TDS levels as follows: Excellent, less than 300 mg/litre; good, between 300 and 600 mg/litre; fair, between 600 and 900 mg/litre; poor, between 900 and 1200 mg/litre; and unacceptable, greater than 1200 mg/litre (Bruvold and Ongerth, 1969). Water with extremely low concentrations of TDS may also be unacceptable because of its flat insipid taste.

TDS in water supplies originate from natural sources, sewage, urban and agricultural run-off, and industrial waste water. Salts used for road de-icing can also contribute to the TDS of water supplies. Concentrations of TDS from natural sources have been found to vary from less than 30 mg/litre to as much as 6000 mg/litre (WHO/UNEP, GEMS, 1989), depending on the solubilities of minerals in different geographical regions.

Inverse relationships were reported between TDS concentrations in drinking water and the incidence of cancer (Burton and Cornhill, 1977), coronary hearth disease, (Schroeder, 1960), atherosclerotic heart disease and cardiovascular disease (Sauer, 1974; Craun and McGabe, 1975).

It was reported in a summary of a study in Australia that mortality from all categories of ischemic heart disease and acute myocardial infarction increased in a community with high levels of soluble solids, calcium, magnesium, sulphate, chloride, fluoride, alkalinity, total hardness and pH of water when compared with one in which levels were lower.(WHO, 1996).

2.4.5 Nitrate and Nitrite

Nitrogen in aquatic environments occurs in four forms: Ammonia (NH_3), Nitrate (NO_3), Nitrite (NO_2^-) and Ammonium (NH_4). The most toxic nitrogen to biota such as fish and amphibians is ammonia followed by nitrite and nitrate (Rouse *et al.,* 1999). Nitrates are very soluble and can move easily through the soil. Nitrate is the final oxidation product of Nitrogen cycle in natural water and is considered the only thermodynamically stable

nitrogen compound in aerobic waters. Following pesticides, nitrate is listed as the second greatest chemical threat to surface and groundwater in the world.

Sources of nitrate contaminations of drinking water include application of nitrogen based mineral fertilizers, manure and their subsequent run-off. High concentrations may also be due to on-site waste water disposal systems (Jenkins, 1999).

Ammonia can indicate faecal contamination, compromise disinfection efficiency, causes taste and odour problems, result in nitrite formation in distribution systems, and cause the failure of filters for the removal of manganese (WHO, 1996).

Contamination of drinking water by nitrate is an evolving public health concern since nitrate can undergo endogenous reduction to nitrite, and nitrosation of nitrite can form N-nitroso compounds which are potent carcinogens. Nitrate pollution of drinking water can be potentially hazardous with health risks for considerable groups of people (Volokita *et al.,* 1996; Terblanche, 1991). In human infants who drink water containing nitrogen in excess could develop blue-baby syndrome (methaemoglobinaemia) (Spalding and Exner, 1993).

High levels of nitrate in drinking water can also cause cancer when it reacts with protein compounds in the body to form nitrosomine; a well documented cancer causing agent (Tricker and Preussman, 1991). It causes algae to bloom resulting in eutrophication in surface water. No cases of methaemoglobinaemia have been proved conclusive to be caused by the consumption of water containing less than 10 mg of nitrate-N per litre, and

there are many examples where nitrate concentrations up to 20 mg/litre have not produced any clinical effects in infants. Although the clinical manifestations of infantile methaemoglobinaemia may not be apparent at these levels, undesirable increases in methaemoglobin in blood do occur. For this reason, a guideline value of 10 mg of nitrate-N per litre is recommended (WHO, 1984).

Akoto and Adiya (2008) studied dissolved nitrogen in drinking water resources of farming communities in Brong Ahafo Region of Ghana. Results indicated that the annual mean concentration of nitrate, nitrite and ammonia varied from 0.09-1.06 mg/L, 0.006-0.36 mg/L and 0.008-0.179 mg/L respectively. It was observed that in general, higher nitrate and nitrite concentrations were found during the raining season compared to the dry season. However, concentrations were below WHO acceptable limits for surface and ground waters.

Elevated levels of nitrate is not necessarily a health hazard for most adults however, nitrate concentrations above 50 mg/L can cause adverse health effects in infants under three months of age, and nitrate concentrations above 100 mg/L can affect pregnant women and those adults with a rare metabolic condition called congenital glucose-6-phosphate dehydrogenase deficiency (an inability to metabolize sugar) (Scragg, 1982). Methaemoglobinaemia occurs when nitrate is consumed and converted to nitrite. The affected blood carries less oxygen than it should, turning the baby's skin blue (cyanosis) particularly around the eyes and mouth and depriving the body of the oxygen it needs. Infants in the first three months of life are particularly susceptible to nitrite induced

methaemoglobinaemia because their stomach acid is not strong enough to stop the growth of bacteria that convert nitrate to nitrite.

A nitrate content of more than 100 mg/L impact bitter taste to water and may cause psychological problem (Adeyeye and Abulude, 2004).

2.4.6 Total hardness

Hardness is a measure of polyvalent cations (ions with a charge greater than +1) in water. Hardness generally represents the concentration of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, because these are most common polyvalent cations. Other ions such as iron (Fe^{2+}) and manganese (Mn^{2+}) may also contribute to the hardness of water, but are generally present in much lower concentrations. Waters with high hardness values are referred to as "hard" while those with low hardness values are "soft". Soft waters are generally derived from the drainage of igneous rocks because these rocks don't weather very easily and so don't release many cations. Hard water is often derived from the drainage of calcareous (calcite rich) sediments, because calcite ($CaCO_3$) dissolves, releasing the calcium. Calcium, magnesium and other polyvalent cations such as iron and manganese may be added to a natural water system as it passes through soil and rock containing large amounts of these elements in mineral deposit.

Drainage from operating and abandoned mine sites can contribute calcium, magnesium, iron, manganese and other ions if minerals containing these constituents are present and are exposed to air and water. This can increase the hardness of water. Some industrial processes may also produce significant amount of calcium and manganese that are later

discharged into streams. The effluent from waste water treatment plants can add hardness to water bodies. The waste water from our houses contain calcium, magnesium and other cations from cleaning agents, food residue, and human waste that we put down our drains.

Hard water is not a health hazard. Hard water interferes with almost every cleaning task from laundering and dishwashing to bathing and personal grooming. Hair washed in hard water may feel sticky and look dull. Water flow may be reduced by deposits in pipes. Bathing with soap with hard water leaves a film of sticky soap curd on the skin and may prevent removal of soil and bacteria. Soap curd interferes with the return of skin to its normal, slightly acid condition, and may lead to irritation. It has been suggested that intake of very soft waters may have an adverse effect of mineral balance and cause cardiovascular diseases, rectal and oesophageal cancer and even mortalities. (Sauvant and Pepsin, 2000; WHO, 1996; Yang *et al.*, 1999).

Sauvant and Pepsin (2000) also observed a statistically significant negative relationship between the hardness of the drinking water supplies in Puy de Dome (France) and cardiovascular disease mortality data (i.e. the lower the hardness of drinking water, the higher the mortality).

2.4.7 Phosphate

Phosphorus is a nutrient used by organisms for growth. It occurs in natural water bound to oxygen to form phosphates (PO_4^{-3}). Phosphates are classified as orthophosphate,

polyphosphates and organically bound phosphate. Orthophosphates are produced by natural processes and are found in waste water. Polyphosphates are used for treating boiler waters and in detergents. Organic phosphate may result from breakdown of pesticides which contain phosphates. Phosphate deposits and phosphate-rich rocks release phosphorus during weathering, erosion and leaching. Phosphates may be released from lakes and reservoir bottom sediments during seasonal overturns. Manmade sources of phosphate include human sewage, agricultural runoff from farms, sewage from animal feedlots, pulp and paper industry, vegetable and fruit processing, chemical and fertilizer manufacturing and detergent (Chester, 1989).

Phosphates are not toxic to people or animals unless they are present in very high levels. Digestive problems could occur from extremely high levels of phosphate. In water, phosphorus behaves as fertilizer accelerating plant and algae growth enhancing eutrophication. When plants and algae die, bacteria consume oxygen that is dissolved in water decreasing levels of oxygen in water (Murphy, 2007).This can lead to fish kills and degradation of habitats with loss of species.

In 2002, a Dane county teen died from ingesting algae-produced toxins while swimming in an area lake (William *et al.*, 2004). Algal blooms caused by excess phosphate also impact fisheries. They impact water quality by affecting the odour and taste of drinking water (Jeer and Sanjay, 1997).

2.4.8 Sulphate

Sulphate is a naturally occurring substance that contains sulphur and oxygen. Sulphates occur naturally in numerous minerals including barite ($BaSO_4$), epsomite ($MgSO_4.7H_2O$) and gypsum ($CaSO_4.2H_2O$) (Greenwood and Eanshaw, 1984). These dissolved minerals contribute to the mineral content of many drinking-waters.

Reported threshold concentrations in drinking water are 250-500 mg/l (median 350 mg/l) for sodium sulphate, 250-1000 mg/l (median 525 mg/l) for calcium sulphate and 400-600 mg/l (median 525 mg/l) for magnesium sulphate (Morris and Levy, 1983). In a survey of 10-20 people, the median concentrations that could be detected by taste were 237, 370 and 419 mg/l, for the sodium, calcium and magnesium salts respectively (Whipple, 1907). Concentrations of sulphates at which 50% of panel members considered the water to have an "offensive taste" were approximately 1000 and 850 mg/l for calcium and magnesium sulphate, respectively (Zoeteman, 1980). Aluminum sulphate (alum) is used as a sedimentation agent in the treatment of drinking water. Copper sulphate has been used for the control of algae in raw and public water supplies (McGuire, 1984).

Sulphates are discharged into water from mines and swelter and from Kraft pulps and paper mills, textile mills and tanneris. Sodium, potassium and magnesium sulphate are all highly soluble in water, whereas calcium and barium sulphates and many heavy metal sulphates are less soluble. Atmospheric sulphur dioxide, formed by combustion of fossil fuels and in metallurgical wasting processes, may contribute to the sulphate content of surface waters. Sulphurtrioxide, produced by the protolytic or catalytic oxidation of

sulphur dioxide, combines with water vapour to form dilute sulphuric acid, which falls as "acid rain" (Dellisle and Schmidt, 1977).

Ingestion of 8 g of sodium sulphate and 7 g of magnesium sulphate caused catharsis in adult males (Coccheto and Levy, 1981, Morris and Levy, 1983). Cathartic effects are commonly reported to be experienced by people consuming drinking water containing sulphate in concentrations 600 mg/l (US Department of Health, Education and Welfare, 1962), although it is also reported that humans can adapt to higher concentrations with time (U.S. EPA, 1985). Dehydration has also been reported as a common effect following the ingestion of large amounts of magnesium or sodium sulphate (Fingl, 1980). There are subpopulations that may be more sensitive to the cathartic effects of exposure to high concentrations of sulphate. Children, transients and the elderly are such populations because of the potentially high risk of dehydration from diarrhoea that may be caused by high levels of sulphate in drinking water. There have been a number of studies conducted to determine the toxicity of sulphate in humans. Case reports of diarrhoea in three infants exposed to water containing sulphate at concentrations ranging from 630 to 1150 mg/L have been presented (Chien, 1968). However, the diarrhoea could not be explained as being solely due to exposure to high sulphate levels, other factors may have played a role(e.g. consumption of infants formula with high osmolarity or the presence of microbial pathogens). These other potential causes were not addressed by the authors.

A survey in North Dakota, U.S.A observed a slight increase in the percentage of people who reported a laxative effect when the drinking water contained 500 -1000 mg of

sulphate per litre (28% versus 21%). Sixty –eight percent of people consuming water with levels of sulphate between 1000 and 1500 mg/litre reported laxative effects.

It was concluded that drinking water containing ≥750 mg of sulphate per litre was associated with a self-reported laxative effect, whereas water containing<600 mg/litre was not (Esteban, 1997).

2.4.9 Chloride

Chloride compounds include those containing a chlorine atom as a negatively charged anion (Cl^-) such as sodium chloride (NaCl). Chlorine is a halogen (salt-forming) element with a boiling point of -33.9^{0}C. Chlorine is never found in free form in nature and occurs most commonly as sodium chloride. Chloride compounds are highly soluble in water in which they persist in dissociated form as chloride anions with their corresponding positively charged cations (e.g. sodium).

Chloride is widely distributed in nature, generally in the form of sodium chloride (NaCl) and potassium chloride (KCl) salts. It constitutes about 0.05% of earths outer crust. By far, the greatest amount of chloride found in the environment is in the oceans. Finding the source of elevated sodium and chloride levels in drinking water is particularly important since sodium and chloride may indicate the nearby disposal of human wastewater or solid waste. The presence of elevated sodium and chloride must initially be considered an indication of increased risk of more serious bacterial or chemical pollution until a more

detailed analysis of the water supply source identifies the origin of sodium and chloride (WHO, 1991).

The taste threshold for chloride varies depending on the associated cation that is present (e.g. sodium, potassium, etc.) and is generally in the range of 200 to 300 mg/L (Health Canada, 1996). Chloride concentrations detected by taste in drinking water by panels of 18 or more people were 210, 310 and 222 mg/L for sodium, potassium and calcium salts respectively. The taste of coffee was affected when brewed with water containing chloride concentrations of 400, 450 and 530 mg/L from sodium chloride, potassium chloride, and calcium chloride respectively. Chloride concentrations in excess of 250 mg /litre can give a detectable taste to water (WHO, 1996).Taste thresholds for chloride (as sodium, potassium or calcium chloride) are in the range of chloride ion concentrations of 200-300 mg/litre.

Chloride increases the electrical conductivity of water and thus increases its corrosivity. High chloride concentrations are corrosive to metals in the distribution system, particularly in waters of low alkalinity, and conventional water treatment does not remove chloride from the water.

2.4.10 Fluoride

Fluorine is the lightest member of the halogen group and is one of the most reactive of all chemical elements. It is not therefore, found as fluorine in the environment. It is the most electronegative of all the elements (Hem, 1989) which means that it has a strong tendency to acquire a negative charge, and in solution form F^- ions. Fluoride ions have the same charge and nearly the same radius as hydroxide ions and may replace each other in mineral structures (Hem, 1989). Fluorine in the environment is therefore found as fluorides which together represent about 0.06-0.09 percent of the earth's crust. Fluoride has beneficial effects on the teeth at low concentrations in drinking water but excessive exposure to fluoride in drinking water, or in combination with exposure to fluoride from other sources, can give rise to a number of adverse effects. These range from mild dental fluorosis to crippling skeletal fluorosis as the level and period of exposure increases. Crippling skeletal fluorosis is a significant cause of morbidity in a number of regions of the world.

High levels of fluoride in drinking water at concentrations up to10 mg/L were associated with dental fluorosis (yellowish or brownish striations or mottling of the enamel) while low levels of fluoride less than 0.1 mg/L were associated with high levels of dental decay (Edmunds and Smedely, 1996), although poor nutritional status is also an important contributory factor. Concentrations in drinking water of about 1m g/litre are associated with a lower incidence of dental caries, particularly in children whereas excess intake of fluoride can result in dental fluorosis. In severe cases this can result in erosion of enamel.

Dental chlorosis is a cosmetic effect that ranges in appearance from scarcely discernible to a marked staining or pitting of the teeth in severe forms. It is caused by an elevated fluoride level in, or adjacent to, the developing enamel. Thus it follows that the dental fluorosis can develop in children but not in adults (Whitford, 1997). Dental fluorosis in an adult is a result of high fluoride exposure when the adult was a child or adolescent.

Endemic fluorosis is known to be global in scope. For example in China some 38 million people are reported to suffer from dental fluorosis and 1.7 million from the more severe skeletal fluorosis. In India and China alone over 60 million people may be affected and when other populations in Africa and eastern Mediterranean in particular are taken into account, the global total may exceed 70 million. (Schivashankara, 2000). Endemic skeletal fluorosis is prevalent in several parts of the world including India, China and Africa. It is primarily associated with the consumption of drinking water containing elevated levels of fluoride.

The regions of Ghana most vulnerable to high fluoride concentrations and associated dental fluorosis are the arid zones of the north and areas where bedrock geology is dominated by granite. The upper regions of Ghana are therefore considered the most likely areas to experience potential problems. Concentrations of fluoride in excess of 1.5 mg/L up to 3.8 mg/L have been observed in Bolgatanga and Sekoti, Upper East Region is in close association with granite rock types (Smedley, 1995). Occurrence of dental fluorosis is common in these areas.

A study was conducted by Xiang (2003) in China on the effect of fluoride in drinking water on children's intelligence. The result showed that in endemic fluorosis areas, drinking water fluoride levels greater than 1.0 mg/litre adversely affected the development of children's intelligence. In similar studies done by Lu (2000), he concluded that the IQ of 60 children in the high fluoride area was significantly lower, mean 92.27 ± 20.45, than that of 58 children in low fluoride area, mean 103.05 ± 13.86. More children in high fluoride area, 21.6% are in the retardation (< 70) or borderline (70-79) categories of IQ than children in the high fluoride area, 3.4%.

2.4.11 Ammonia

Ammonia in water (NH_3) is a gas usually expressed as nitrogen and is extremely soluble in water supplies. Ammonia is a colourless, gaseous compound with a sharp distinctive odour. Ammonia is the natural product of decay of organic nitrogen compounds. Surface waters may contain up to 12 mg/L (WHO, 1986). Ammonia levels in drinking water are not usually found in well water supplies because bacteria in the soil convert it to nitrate. Ammonia concentrations in water vary seasonally and regionally, and are also affected by surrounding land use, temperature and pH. The average human intake from drinking water is about 1 mg/day in cities and less than 0.4 mg/day in rural areas. On dissolution in water, ammonia forms the ammonium cation; hydroxyl ions are formed at the same time. The degree of ionization depends on the temperature, the pH, and the concentration of dissolved salts in the water. The ammonium cation is less mobile in soil and water than ammonia and is in the biological processes of nitrogen fixation, mineralization, and nitrification. Ammonia has a toxic effect on healthy humans only if the intake becomes

higher than the capacity to detoxify. The threshold odour concentration of ammonia in water is approximately 1.5 mg/litre. A taste threshold of 35 mg/litre has been proposed for ammonium cation (WHO, 1986). The reason for not establishing a guideline value for ammonia is that it occurs in drinking water at concentrations well below those at which toxic effects may occur.

2.4.12 Iron

Iron is the second most abundant metal in the earth's crust, of which it accounts for 5%. Elemental iron is rarely found in nature as the iron ions, Fe^{2+} and Fe^{3+} readily combine with oxygen and sulphur –containing compounds to form oxides, hydroxides, carbonates and sulphides. Iron is the most commonly found in nature in the form of its oxides (Elinder, 1986; Knepper, 1981). In drinking water, iron (II) salts are unstable and are precipitated as insoluble iron (III) hydroxide, which settles out as a rust – coloured silt. Staining of laundry and plumbing may occur at concentrations above 0.3mg/litre (Department of National Health and Welfare, Canada, 1990). Iron also promotes undesirable bacterial growth (iron bacteria) within waterworks and distribution systems resulting in the deposition of shiny coating in the piping. (Department of National Health and Welfare, 1990).

In surface waters iron is generally present as salts containing iron (III) when the pH is above 7. Most of these salts are insoluble and settle out or absorbed on to surfaces, hence the concentration of well aerated waters is seldom high. Under reducing conditions which may exist in some groundwaters, lakes or reservoirs and in the absence of sulphides and

carbonates, high concentrations soluble iron (II) may be found (Hem, 1972) The presence of irons in natural waters can be attributed to the weathering of rocks and minerals, acidic mine water drainage (Bell, 1976), landfill leachates (James, 1977), sewage effluents and iron related industries (Great Lakes Water Quantity Board, 1976). If excessive iron is found in water, the water will contain a reddish tint indicating that the iron is not dissolved. Excessive amounts of iron in water (more than 10 ppm) will give food and drink unpleasant metallic flavour .Additionally, water with too much iron could stain clothing and appliances if spilled.

The average lethal dose of iron is 200-250 mg/kg of body weight, but death has occurred following ingestion of doses as low as 40 mg/kg of body weight (National Research Council, 1979). Chronic iron overload results primarily from a genetic disorder (haemochromatosis) characterized by increased iron absorption and from diseases that require frequent transfusions (Bothwell, 1998) Attempts to derive a taste threshold for iron in drinking water have produced somewhat inconsistent results owing to the subjective native of human perception. However, in a frequently cited study, Cohen *et al* reported that 5% of a 15-20 member taste panel were able to detect ferrous sulphate in distilled water at concentrations of 0.04 mg/L. Approximately 20% detected a concentration of 0.3 mg/L and 50% detected a concentration of 3.4 mg/L (Mahmond *et al.*, 2001). High amounts of iron can cause the water to smell like rotten eggs or taste metallic. When iron is well over 0.5 ppm, then the taste of food that the water is cooked in is also affected according to Minnesota Department of Health.

2.4.13 pH

pH stands for "potential of hydrogen" referring to the amount of hydrogen found in a substance (in this case, water). The indicator for acidity or alkalinity, or basicity is known as pH value. A lower pH value indicates acidity and a higher value is a sign of alkalinity. pH value is the logarithm of reciprocal of hydrogen ion activity in moles per litre. In water solution, variations in pH value from 7 are mainly due to hydrolysis of salts of strong bases and weak acids or vice versa. Dissolved gases such as carbon dioxide, hydrogen sulphides and ammonia also affect the pH of water. The overall pH range of natural water is generally between 6 and 8. Industrial waste may be strongly acidic or basic and their effect on pH value of receiving water depends on the buffering capacity of water. pH lower than 4 will produce sour taste and higher value above 8.5 bitter taste. Higher value of pH hastens the scale formation in water heating apparatus and reduces the germicidal potential of chlorine. pH below 6.5 starts corrosion in pipes, thereby releasing toxic metals such as Zn, Pb, Cd, Cu, etc. Water with low pH can be acidic, and corrosive. Acidic water can leach metals such as copper, zinc and lead from pipes and fixtures. It can also damage metal pipes and cause aesthetic problems such as a metallic or sour taste, laundry staining or blue green stains in sinks and drains. (Stone, 1987).

Drinking-water with a pH level above 8.5 indicates that a high level of alkaline minerals is present. High alkalinity does not pose a health risk but can cause aesthetic problems such as an alkali taste to the water that makes coffee taste bitter, scale built-up in plumbing, and lowered efficiency of electric water heaters (McClanaham and Mancy, 1974).

In most natural waters, the pH is controlled by the carbon dioxide – bicarbonate-carbonate equilibrium systems. An increased carbon dioxide will therefore lower pH, whereas a decrease will cause it to rise. Temperature also affects the equilibrium and pH. In pure water, a decrease in pH of about 0.45 occurs as the temperature is raised by 25^0 C. In water with buffering capacity imparted by bicarbonate, carbonate and hydroxyl ions, this temperature effect is modified. The pH of most water lies within the range (6.5-8.5) (APHA, 1989). The pH is of major importance in determining the corrosivity of water. In general, the lower the pH, the higher the level of corrosion. However, pH is only one of a variety of factors affecting corrosion. (Nordberg, *et al.* 1985).

Human exposure to extreme pH values results in irritation to the eyes, skin and mucous membranes. Eye irritation and exacerbation of skin disorders have been associated with pH values greater than 11. In addition, solutions of pH 10 -12.5 have been reported to cause hair fibres to swell (WHO 1986). In sensitive individuals, gastrointestinal irritation may also occur. Exposure to low pH values can also result in similar effects. Below pH of 4, redness and irritation of the eyes have been reported, the severity of which increases with decreasing pH. Below pH 2.5, damage to the epithelium is irreversible and extensive (WHO, 1986).

Lower pH values are indicative of high acidity, which can be caused by the deposition of acid forming substances in precipitation. A high organic content will tend to decrease the pH because of the carbonate chemistry. As microorganism break down organic material

the by-product will be CO_2 that will dissolve and equilibrate with the water forming carbonic acid (H_2CO_3). Other organic acids such as humic and fulvic acid can also result from organic decomposition.

2.5 Bacteriological Pollutants

2.5.1 Coliform Bacteria

Coliform bacteria are not a single species of bacteria rather a group of bacteria.

They make up around 10 per cent of the intestinal microflora of humans and animal intestine. Coliforms are defined as any bacteria capable of fermenting lactose (milk sugar) with the production of acid and gas in 48 hours at 35^0C under aerobic conditions.

The presence of coliforms in water is designed to indicate the possible presence of faecal contamination and therefore the presence of pathogens. Since coliforms were adopted as indicators of faecal contamination in water in 1914, their use has been questioned. That is because, while they are found naturally in the intestines of warm – blooded animals including humans, they may also be found naturally in other sources that are not associated with faecal contamination. However, high levels of coliforms in drinking water supply may indicate contamination from surface or shallow subsurface sources such as soil, septic or cesspool leakage, animal feedlot runoff, treatment failures, etc.

2.5.2 Total coliform bacteria

Total coliform bacteria include a wide range of aerobic and facultative anaerobic, Gram negative, non- spore forming bacilli capable of growing in the presence of relatively high

concentration bile salts with the fermentation of lactose and production of acid or aldehyde within 24 hr at 35-37^{0}C.

Escherichia coli and thermotolerant coliforms are a subset of the total coliform group that can ferment lactose at higher temperatures. As part of lactose fermentation, total coliform produce the enzyme 3- Galactosidase. The total coliform group includes both faecal and environmental species. (Ashbolt *et al.,* 2001).

Total coliforms include organism that can survive and grow in water. Hence they are not useful as an index of faecal pathogens, but can be useful as an indicator of treatment effectiveness and to assess the cleanliness and integrity of distribution systems and the potential presence of biofilms. Total coliform bacteria (excluding *E.coli*) occur in both sewage and natural waters. Some of these bacteria are excreted in the faeces of humans and animals, but many coliforms are heterotrophic and are able to multiply in water and soil environments (Grabow, 1996).

Traditionally, total coliforms were regarded as belonging to the genera. *Escherichia, Citrobacter, Enterobacter* and *Klebsiela.* However, regardless of the definition adopted, the group is heterogeneous. It includes many lactose-fermenting bacteria, such as *Enterobacter cloacae* and *Citrobacter freundii* which can be found in both faeces and environment (nutrient rich waters, soil, decaying plant material) as well as in drinking water containing relatively high concentration of nutrients. It also includes members of genera such as *Budvicia* and *Rahnella,* which are never found in mammalian faeces.

2.5.3 Faecal Coliforms

The term 'faecal coliform' although frequently employed is not correct: the correct terminology for these organisms is thermotolerant coliforms. Thermotolerant coliforms are defined as the group of total coliforms that are able to ferment lactose at 44-45^{0}C. They comprise the genus *Escherichia* and to a lesser extent, species of *Klebseilla, Enterobacter* and *Citrobacter*. Of these organisms, only *Escherichia coli* is considered to be specifically of faecal origin being always present in faeces of humans, other mammals, and birds in large numbers and rarely if ever, found in water or soil in temperate climates that has not been subject to faecal pollution (although there is the possibility of regrowth in hot environments. (Richards and Batram, 1993).

Thermotolerant coliforms other than E. coli may originate from organically enriched water such as industrial effluent or from decaying plant materials and soils. In tropical and subtropical waters, thermotolerant coliform bacteria may occur without any obvious relation to human pollution and have been found on vegetation in the tropical rainforest). Thermotolerant coliforms are less reliable index of faecal contamination than E.coli although under most circumstances and especially in temperate areas, in surface water their concentration are directly related to E. coli concentration.

2.5.4 *Escherichia coli*

Escherichia coli, originally known as *Bacterium coli commune* was identified in 1885 by the German pediatrician, Theodore Escherich (Escherich, 1885). *E. coli* is widely distributed in the intestine of humans and warm-blooded animals and is the predominant

facultative anaerobe in the bowel and part of the essential intestinal flora that maintains the physiology of the healthy host. (Conway, 1995). *E. coli* is a member of the family *Enterobacteriaceae* (Ewing, 1986). Although most strains of *E. coli* are not regarded as pathogens, they can be opportunistic pathogens that cause infections in immunocompromised hosts. There are also pathogenic stains that when ingested, causes gastrointestinal illness in humans.

Escherichia coli are present in large numbers in the normal intestinal flora of humans and animals, where it generally causes no harm. However, in other parts of the body, *E. coli* can cause serious disease such as urinary tract infections, bacteraemia and meningitis. A limited number of entreopathogenic strains can cause acute diarrhoea. Several classes of enteropathogenic *E. coli* have been identified on the basis of different virulence factors including enterohaemorrhagic E. coli (EAEC) and diffusely adherent *E. coli* (DAEC). The pathogenicity and prevalence of EAEC and DAEC strains are less well established.

EHEC serotypes, such as *E. coli* 0157:H7 and *E. coli* 0111, cause diarrhoea that ranges from mild and non-bloody to highly bloody, which is indistinguishable from haemorrhagic colitis. Between 2% and 7% of cases can develop potentially fatal haemolytic uraemic syndrome (HUS), which is characterized by acute renal failure and haemolytic anaemia. Children under five years of age are at most risk of developing HUS. (Roels, *et al*., 1998)) The infectivity of EHEC is substantially higher than that of other strains. As few as 100 EHEC organisms can cause infection.

ETEC produces heat-labile or heat-stable *E. coli* enterotoxin or both toxins simultaneously and is an important cause of diarrhoea in developing countries especially in young children. Symptoms of ETEC infection include mild watery diarrhoea, abdominal cramps, nausea and headache.

EPEC infections are rare in developed countries, but occur commonly in developing countries, with infants presenting with malnutrition, weight loss and growth retardation.

EIEC causes watery and occasionally bloody diarrhoea where strains invade colon cells by a pathogenic mechanism similar to that of *Shigella.* (Ephros *et al.,* 1996). Waterborne transmission of pathogenic E. coli has been well documented for recreational waters and contaminated drinking water.

A well publicized waterborne outbreak illness caused by *E. coli* 0157:H7 (and *Campylobacter*) occurred in the farming community of Walkerton in Ontario, Canada. The outbreak took place in May, 2000 and led to 7 deaths and more than 2300 illness (O'Connor, 2002). The drinking water supply was contaminated by rainwater runoff containing cattle excreta. Enteropathogenic *E. coli* are enteric organisms and humans are the major reservoir, particularly of EPEC, ETEC and EIEC strains. Livestock such as cattle and sheep and to a lesser extent, goats, pigs and chickens are a major source of EHEC strains. The latter have also been detected in a variety of water environments. Clark, (2010) indicated that people who contract gastroenteritis from drinking water contaminated with *E. coli* are at increased risk of developing high blood pressure , kidney

problems and heart disease in later life . It is also estimated that E. coli 0157:H7 infections cause up to 120,000 gastro-enteric illnesses annually in the US alone resulting in over 2,000 hospitalizations and 60 deaths.

2.5.5 *Salmonella*

The causative organism of enteric fever or typhoid fever is *Salmonella typhi*. *S. typhi* is an obligate parasite that has no known natural reservoir outside of humans. Originally isolated in 1880 by Karl J. Eberth, S. *typhi* is a multi-organ pathogen that inhabits the lymphatic tissues of the small intestine, liver, spleen and blood stream of infected humans.

Salmonella spp. belongs to the family *Enterobacteriaceae.* They are motile, Gram-negative bacilli that do not ferment lactose, but most produce hydrogen sulphide or gas from carbohydrate fermentation. *Salmonella* species are widely distributed in the environment but some species or serovars show host specificity. Notably, *S. typhi* and generally *S. paratyph*i are restricted to humans, although livestock can occasionally be a source of *S. paratyphi*. A large number of serovars including *S. typhimurium* and *S. enteritidis* infect humans and also a wide range of animals including poultry, cattle, pigs, sheep, birds and even reptiles. The pathogens typically gain entry into water systems through faecal contamination from sewage discharges, livestock and wild animals. Contamination has been detected in a wide variety of foods and milk.

Enteric fever or typhoid fever is among the most common water borne diseases. In natural waters at a temperature above 15^0C, *salmonella* has a short survival period. At the maximum they can survive for 7days. Drinking water contaminated with faeces or urine containing the pathogen may be the potential source of outbreaks. Infection by typhoid species is associated with consumption contaminated water or food (Escartin, 2002 and Angulo *et al.,* 1997). Water borne typhoid fever outbreaks and transmission are commonly caused by *S. typhimurium* and has been associated with the consumption of contaminated groundwater and surface water supplies. In an outbreak of illness associated with a communal rainwater supply, bird faeces were implicated as a source of contamination (Koplan, 1978).

Salmonella bacteria are a major health hazard in many developing countries. More than two million people suffer from typhoid each year, 90 per cent in Asia. It takes just 15 bacteria to cause illness and people reliant on natural water sources which can contain bacteria from untreated sewage are particularly vulnerable (Science and Development Network, 2010)

2.5.6 *Enterococci*

Enterococci are a subgroup of the larger group of organisms defined as faecal streptococci; comprising species of Gram-positive and relatively tolerant of sodium chloride and alkaline pH levels. They are facultatively anaerobic. Faecal streptococci (not coliform bacteria) including intestinal streptococci have been isolated from faeces of warm blooded animals. The subgroup intestinal enterococci consist of the species

Enterococcus faecalis, *E. faecium*, *E. durans and E. hirae* (Pinto, 1999).This group was separated from the rest of faecal streptococci because they are relatively specific for faecal pollution. However, some intestinal enterococci isolated from water may occasionally also originate from other habitats, including soil, in the absence of faecal pollution.

The enterococci group can be used as an index of faecal pollution. The numbers of intestinal enterococci in human faeces are generally lower than those of *E. coli*. Important characteristic of this group is that they tend to survive longer in water environments than *E. coli* (or thermotolerant coliforms) and are more resistant to chlorination (Ashbolt *et al.,* 2001).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of sampling sites

The Tuse pond popularly called 'Tuse Dam' by the local people is found in Atebubu, the capital of Atebubu-Amantin district in the Brong Ahafo region of Ghana. Atebubu-Amantin district lies approximately between latitudes 0^0 23^0 and longitudes 0^0 30^0 W and 1^0 26^0 W (Fig.3.1). It shares boundaries with Pru district to the North and the south with Ejura-Sekyeredumasi district of Ashanti Region, to the east with Sene district and west with Kintampo and Nkoranza districts all in the Brong Ahafo region. There are about 196 settlements including Atebubu. The district lies within the transitional zone (i.e. between the forest and savanna) and experiences sunny condition during most of the year usually from November to May while the wet season usually begins from the end of May to October.

The pond is located at a low-lying area to the northern outskirt of Atebubu between the Zongo community in the south and Ahontor, a suburb north of Atebubu. Tuse pond is about 100 metres away from the Kumasi-Yeji highway and occupies a land area of approximately 7 acres (Atebubu Town and Country Planning Department Annual Report, 2010). Tuse pond has five main locations from which people fetch water for use. These are labeled T1, T2, T3, T4 and T5 (Fig. 3.2). Fig.3.3 to Fig.3.5 indicates the state of Tuse pond and some activities by the inhabitants that go on in its surroundings.

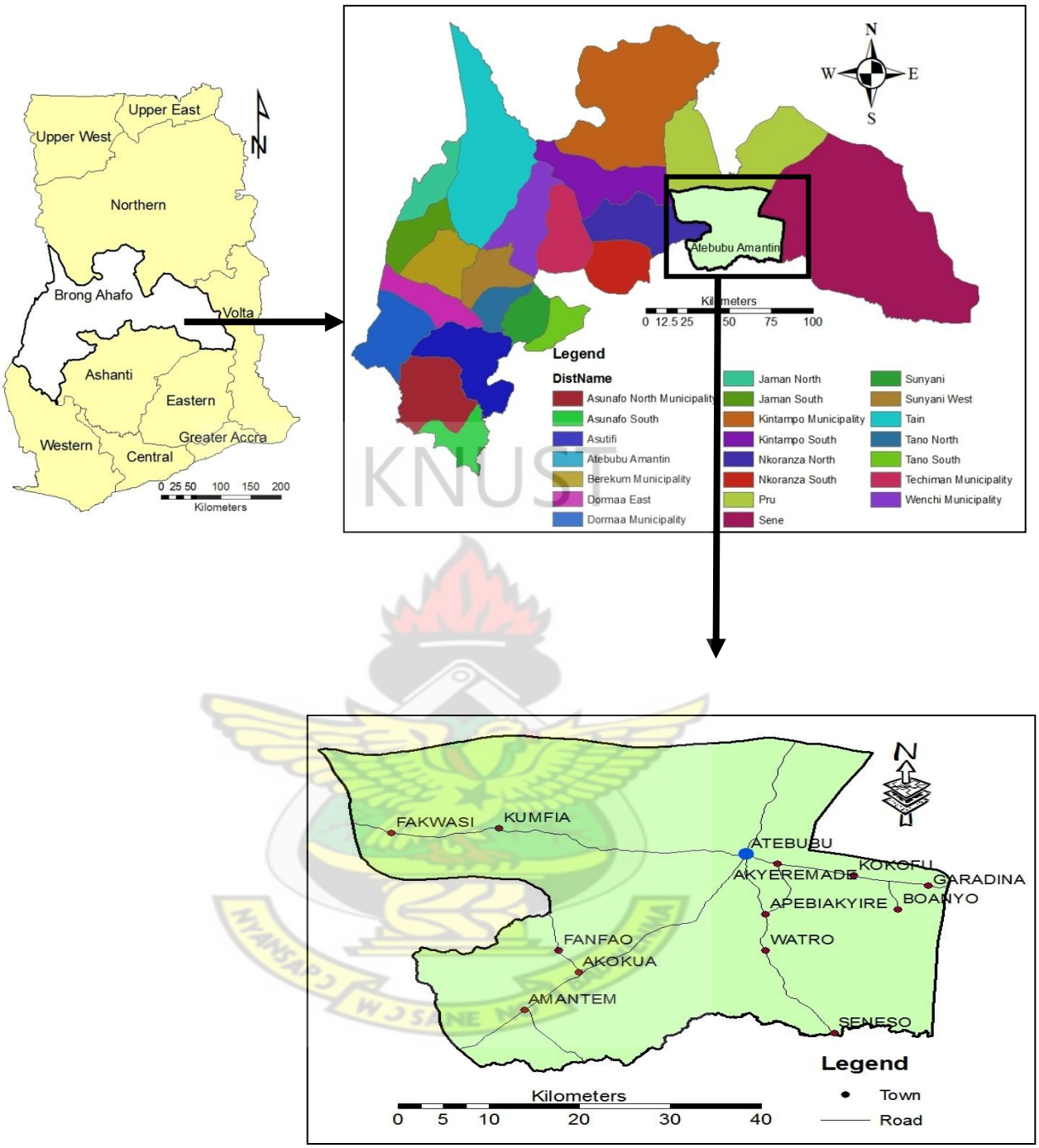

Fig 3. 1 Location of Atebubu in Ghana (**www.ghana@aglance.com**) **Retrieved 21-10-2010**

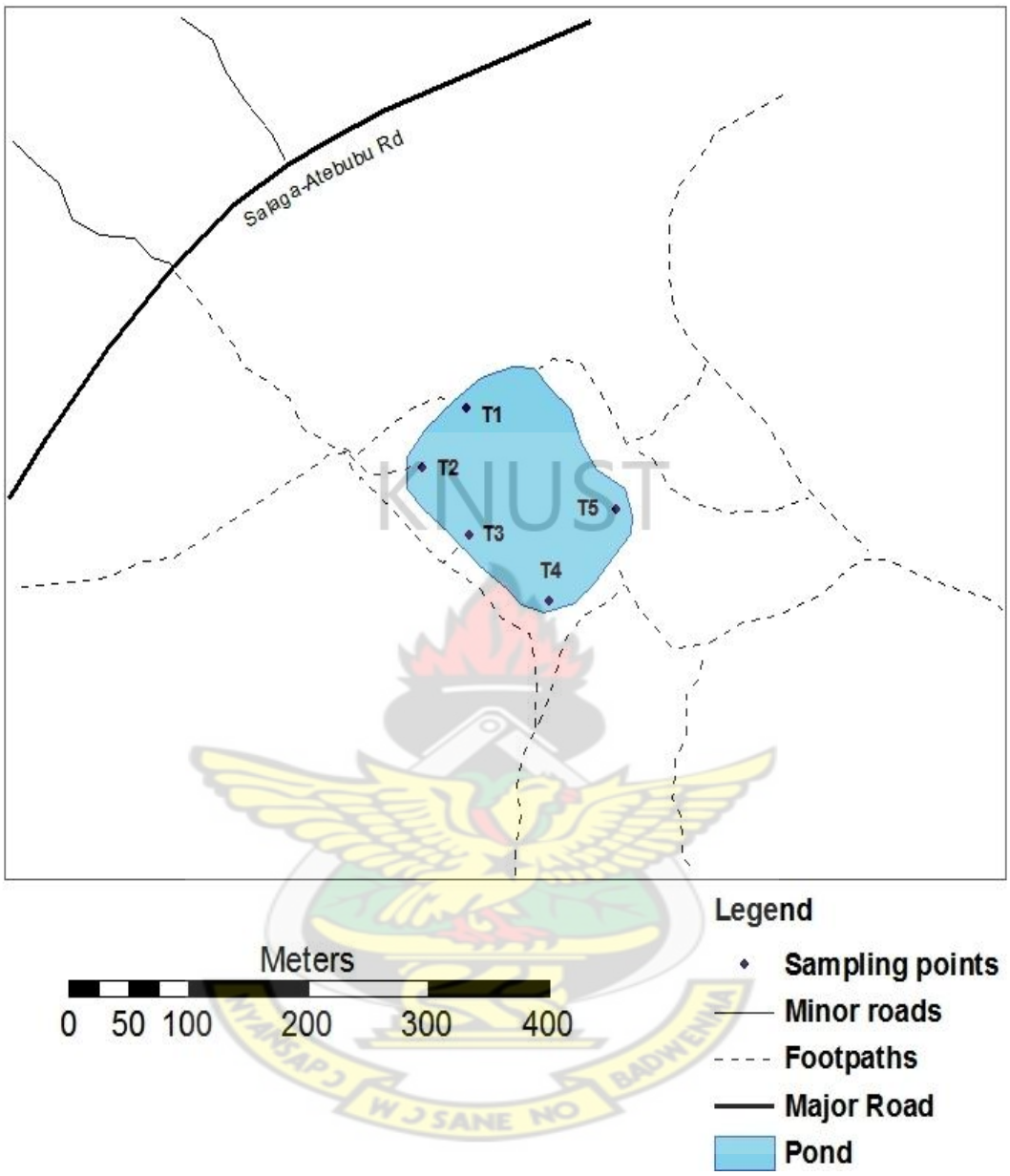

Fig. 3.2 Atebubu map showing Tuse pond and sampling points.

(**www.ghana@aglance.com)** Retrieved 21-10-2011

Fig 3.3 Examples of deep gullies that transport pollutants into Tuse pond during heavy rain.

Fig. 3. 4 Some human activities (bathing, washing of clothes and motorbikes) on the bank of Tuse pond

Fig 3.5 People wading into Tuse pond water to draw water using dirty containers

3.2 Sample collection

Water samples were collected in duplicates once a month from the five locations labeled T1, T2, T3, T4 and T5 for six successive months (i.e. from September, 2010 to February, 2011). By virtue of the rainfall pattern in Atebubu district in 2010, wet season samples were collected from September to November while dry season samples were collected from December, 2010 to February, 2011. Water samples were collected using sterile 1000 ml plastic bottles and transported in an ice box to Ghana Water Company Limited Laboratory at Kumasi for examination of some of their physical and chemical properties within 14 days. Tests on samples for bacteria were conducted at the microbiology laboratory of the Department of Biological Science, Kwame Nkrumah University of Science and Technology in Kumasi within 8 to 48 hours using standard methods for the determination of total coliform, faecal coliform, *Escherichia coli*, *Salmonella and Enterococci*. (Brenner *et al.,* 1993; APHA, AWWA, WEF, 1998).

3.3 Sample Analysis

The water samples were analyzed to determine pH, turbidity, conductivity, colour, total dissolved solids, total alkalinity, total hardness, iron, chloride, nitrite, nitrate, fluoride, sulphate, phosphate, ammonia, total coliform, faecal coliform, *Escherichia coli*, *Salmonella*, and *Enterococci.* To determine pH, turbidity, colour, conductivity and Total Dissolved Solids (TDS), their respective calibrated meters were used. Bacteriological analysis was conducted using the Most Probable Number (MPN) method. In determining the concentration of the chemical parameters, the Palintest Photometer model 5000 (Transmittance – Display Photometer) was used.

3.3.1 Physico - chemical Analysis

3.3.2 Determination of pH

In the laboratory, pH meter (HANNA model 209) was used to determine the pH of water samples. Buffer solutions of pH 4.0, 7.0 and 9.0 prepared from tablets of BDH buffer were used to calibrate the pH meter. About 50ml of water sample was poured into a clean glass beaker and the electrode inserted into it. The button selector of the pH meter was turned and the pH was read and recorded. This was repeated for all other water samples.

3.3.3 Determination of Apparent Colour

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

3.3.4 Determination of Conductivity

Conductivity meter (HANNA model HI 9032) was used to determine the conductivity of water samples in the laboratory. It was calibrated by using sodium chloride standard solution of 12880µs/cm. The conductivity meter was then returned to the operation mode to facilitate measurement.

About 50ml of water sample was poured into a clean glass beaker and the conductivity meter electrode was then inserted into the water. The value was read and recorded after five (5) minutes, in µS/cm. The same procedure was repeated for all other water samples.

3.3.5 Determination of Turbidity

Turbidity of water samples was determined with HACH turbidity meter (model number CO 150). The turbidity meter was first calibrated with Formazin standard solutions of 0.2 NTU, 10 NTU, 100 NTU and 1000 NTU by filling consecutively a clean dry cuvette with the well mixed standard solutions. It was then returned to the measurement mode and used. A clean dry cuvette was rinsed three times with the water sample to be tested. The cuvette was filled with the water sample to be analyzed and the light shield cap was replaced. The outer surface of the cuvette was wiped dry with a clean tissue paper. It was then pushed firmly into the optical well and the lid closed. The NTU values were measured by pressing and releasing the arrow and the value was recorded after the display has stopped flashing.

3.3.6 Determination of Total Dissolved Solids

A multifunctional HANNA meter (model HI 9032) was used to determine the total dissolved solids of water samples in the laboratory after calibration. About 50ml of water sample was poured into a clean glass beaker. The electrode was then immersed into the sample and stirred to ensure uniformity. After the reading stabilized the value was read and recorded in mg/L.

3.3.7 Determination of Ammonia

Palintest Photometer (model 5000) was used to determine the concentration of ammonia in the water samples after calibration. Using pipette, a clean test tube was filled to the 10ml mark with the water sample. One tablet each of Ammonia No. 1 and No. 2 were added, crushed and mixed to dissolve. The mixture was allowed to stand for 10 minutes for colour development. The transmittance (%T) of the mixture was taken at wavelength of 640nm. Ammonia (Indophenol) calibration chart was used for obtaining the ammonia concentration in mg/L.

3.3.8 Determination of Nitrite-Nitrogen

The Lovibond Nessleriser (model 2150) was used to measure nitrite-nitrogen by comparator method after the instrument was calibrated. Using a clean pipette, 50ml of the water sample was poured into a clean Erlenmeyer flask and 2ml each of Griess-Ilosvays No. 1 and 2 were added, swirled and allowed to stand for fifteen (15) minutes. If colour changed to pink, a nesseler's tube was filled with the mixture and then inserted into the chamber. The value was read by matching colour using the nitrite disc and comparator.

NB. The markings on the disc represent the actual amount of nitrogen (N) present as nitrite.

Calculation:

$$N\ (mg/L) = \frac{\text{Disc Reading} \times 0.5}{\text{Sample Volume}}$$

$$NO_2\ (mg/L) = N\ (mg/L) \times 3.284$$

3.3.9 Determination of Nitrate-Nitrogen

Palintest photometer (model 5000) was used to determine nitrate-nitrogen after the meter was calibrated. A clean nitratest tube was filled with 20ml of water sample. One level spoonful of nitratest powder and one tablet of nitratest were added, capped and the tube shaken well for a minute and then allowed to stand for another one minute. It was again inverted several times to allow flocculation and then allowed to stand for extra two minutes to enable complete settlement. The clear solution was then decanted into a clean test tube to 10ml mark. One tablet of nitricol was added, crushed and mixed to dissolve and allowed to stand for an extra 10 minutes for colour development. A wavelength of 570nm was selected on the Photometer and the tube was inserted into the chamber and reading was then taken. The nitratest calibration chart was used to determine the nitrate-nitrogen and the nitrate concentration was multiplied by 4.4 to obtain mg/L of NO_3.

3.3.10 Determination of Sulphate

Palintest photometer (model 5000) was used to measure sulphate by colorimetric method. The Palintest Sulphate test is based on a single tablet reagent containing barium chloride in a slightly acidic formulation. Using pipette, a clean test tube was filled with water sample to the 10ml mark. One tablet of Sulphate Turb was added to the water in the test

tube, crushed and mixed to dissolve. A cloudy solution formed is an indication of the presence of sulphate and the mixture was allowed to stand for five minutes and remixed to ensure uniformity. A wavelength of 520nm was selected and the cell was inserted into the chamber and the transmittance (%T) read. The sulphate calibration chart was used to determine its corresponding concentration in mg/L.

3.3.11 Determination of Chloride

Argentometric method was used to determine chloride concentrations in water samples. Potassium chromate indicator solution was prepared by dissolving 50g of K_2CrO_4 in a little distilled water and 1M $AgNO_3$ solution was added until a definite precipitate was formed. The solution was allowed to stand for twelve hours, after which it was filtered and diluted to 1000ml. The silver nitrate titrant solution (0.0141M) was prepared by dissolving 2.395g $AgNO_3$ in distilled water and diluted to 1000ml.

Using pipette, 50ml of water sample was poured into a clean conical flask. Then 1ml of 5% Potassium chromate (K_2CrO_4) indicator was added. This was titrated against 0.0141M $AgNO_3$ solution, with gentle swirling until the colour changed from yellow to brick red. The titre was read and recorded in millimeters. The concentration of chloride was calculated as:

$$Cl^- \text{ (mg/L)} = \frac{(A\text{-}0.2) \times 0.5 \times 1000}{\text{Sample Volume (ml)}}$$

Where A = Titre value

3.3.12 Determination of Phosphate

Palintest photometer (model 5000) was used to determine phosphate after the meter was calibrated. A clean test tube was filled with water sample to the 10ml mark. One tablet each of phosphate No.1 LR and No. 2LR were added, crushed and dissolved. The mixture was allowed to stand for ten minutes for full colour development. The test tube was inserted into the chamber and a wavelength of 640nm was selected and the sample transmittance (%T) read. The corresponding concentration on the phosphate LR calibration chart was read and recorded in mg/L.

3.3.13 Determination of Total Hardness

Using a pipette, 50ml of water sample was poured into a clean conical flask and 1.0ml of 0.5M Ammonium buffer solution (pH= 10.0) and 2ml of Eriochrome Black T indicator were added. The content in the conical flask was titrated with 0.01M EDTA solution (Ethylene Diamine Tetra Acetic acid), mixed gently until the colour changed from red to blue. Titration was repeated until a consistent titre was obtained. The average titre value was recorded and total hardness was calculated:

$$\text{Total Hardness (mg/L)} = \frac{\text{Average titre} \times 1000}{\text{Volume of water sample}}$$

3.3.14 Determination of fluoride

Palintest Photometer (Model 5000) was used to determine fluoride concentration after the meter was calibrated. A test tube was filled with a sample to the 10 ml mark. One

fluoride No.1 tablet was added, crushed and mixed to dissolve. After that one fluoride No.2 tablet was added, crushed and mixed to dissolve. The solution was allowed to stand for five minutes to allow full colour development. The test tube was inserted into the chamber, a wavelength of 570 nm selected and the sample transmittance (% T) read. The corresponding concentration on the fluoride calibration chart was read and recorded in mg/L.

3.3.15 Determination of iron

Palintest Photometer (Model 5000) was used to determine iron concentration after calibrating the meter. A test tube was filled with sample to the 10 ml mark. One tablet of iron LR was added and crushed to mix and dissolve. The solution was left to stand for a minute to allow full colour development. The test tube was inserted into the chamber, a wavelength of 520 nm selected and the sample transmittance (% T) read. The corresponding concentration on the iron calibration chart was read and recorded in mg/L.

3.4 Bacteriological Quality Analysis

The bacteriological quality of the drinking water samples were assessed by using the total coliforms, faecal coliforms and *Escherichia coli* as indicators (APHA, AWWA, WEF, 1998). Total coliforms, faecal coliforms and *Escherichia coli* were identified using single strength MacConkey broth and Tryptone water by the three tube Most Probable Number method.

3.4.1 Preparation of Media

MacConkey broth preparation

Purple MacConkey broth was prepared by dissolving 35g of the powder in 1.0 litre of distilled water. It was mixed well and dispensed into fermentation tubes with inverted Durham tubes. The bottles with their contents were autoclaved for 15 minutes at 121^{o}C. (APHA, AWWA, WEF, 1998).

Tryptone water preparation

Tryptone water (Buffered) was also prepared by dissolving 15g of the powder in 1.0 litre of distilled water and mixed well. The mixture was distributed into test tubes and sterilized by autoclaving for 15 minutes at 121^{o}C.

Kovac's reagent preparation

Kovac's reagent was prepared by dissolving 5g of p-dimethylaminobenzaidehyde in 25ml of alcohol and 25ml of 1.0 M HCl was added slowly and finally stored at 4^{o}C in the dark.

3.4.2 Identification and Enumeration of total and faecal coliform bacteria

Serial dilutions of 10^{-1}, 10^{-2}, 10^{-3} and 10^{-4} were prepared for each water sample using distilled water. One milliliter aliquots from the raw water sample and each set of the dilutions were inoculated into three fermentation tubes containing 5ml of MacConkey broth with inverted Durham tubes. The tubes were closed firmly, agitated to distribute the sample evenly and inverted gently to expel air from the Durham tubes. They were then incubated at 35^{o}C for 48 hours to determine total coliforms growth and at 44^{o}C for 24 hours to determine faecal coliforms growth. The tubes that showed colour change, from purple to yellow with gas collected in the Durham tubes after 24 and 48 hours were

identified as positive for faecal and total coliforms respectively and quantified from the MPN tables as MPN per 100ml.

3.4.3 Identification and Enumeration of *Escherichia coli*

From each of the positive tubes identified, 1ml was transferred into 5ml Trypton water in a fermentation tube and incubated at 44^{o}C for 24 hours. A drop of Kovac's reagent was then added to the tube of Trypton water. All the tubes showing a red ring colour development after gentle agitation indicated the presence of indole and recorded as confirmed for *Escherichia coli* count. Counts of bacteria per 100ml were calculated from the Most Probable Number (MPN) table.

3.4.4 Identification and Enumeration of *Salmonella*

1 ml each of the samples was poured into 10 ml sterilized peptone water and incubated at 37 ^{0}C for 24 hours. After 24 hours 1 ml of each incubated sample was transferred to a Selenite broth and again incubated at 37 ^{0}C for 48 hrs after which streaking was done onto solidified Salmonella Shigella Agar (SSA). Final incubation at 37 ^{0}C for 48 hrs was done. After 48 hrs cream colonies with black centres which show the presence of *Salmonella* were counted.

3.4.4 Identification and Enumeration of *Enterococci*

Serial dilutions of 10^{-1} to 10^{-6} were prepared by picking 1ml of the sample into 9 ml sterile distilled water. One millilitre aliquots from each of the dilutions were inoculated on a Slanetz Bartley Agar prepared on sterile Petri dishes. The Petri dishes were

preincubated at a temperature of 37^0C for 4 hours to aid bacterial resuscitation. The plates were then incubated at 44^0C for a further 44 hours. After incubation, all red, maroon and pink colonies that were smooth and convex are counted and recorded as faecal *Enterococci.*

3.5 Statistical Analysis

The results from the study were subjected to the student's t-test using SPSS and Microsoft Office Excel 2007 to determine any significant difference for each parameter between the wet and dry seasons. This was carried out at a significance level of 5%.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Physico-chemical parameters

4.1.1 pH

pH levels recorded for the dry and wet seasons had ranges of 7.2 – 7.9 and 7.0 – 8.3 respectively, indicating relatively higher levels of pH in the wet season. For the whole sampling period, sampling point T5 recorded the highest pH of 8.30 with T1 recording the lowest pH of 7.03. The pH values were within the "no effect" range of 6.5–8.5 for drinking water use (Figure 4.1). There was no significant difference ($p = 0.13$) at 5%between wet and dry season for pH. Drinking water with a pH level above 8.5 indicates that a high level of alkaline minerals is present. Human exposure to extreme pH values above 11 may result in irritation of the eyes, skin and mucous membranes (WHO, 1986).

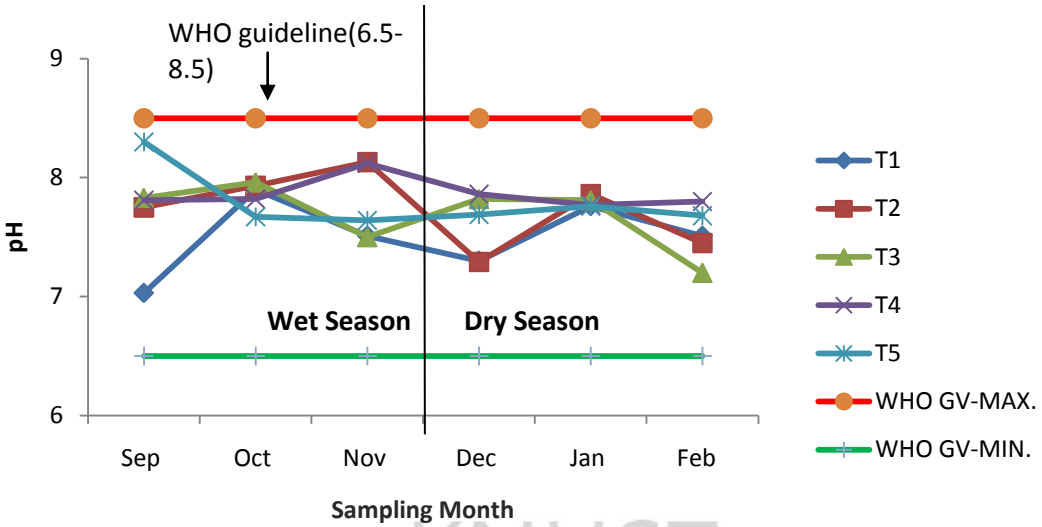

Figure 4. 1 pH of water from the Tuse pond Sept.2010 – Feb.2011

4.1.2 Turbidity

Turbidity of water in the pond showed a decreasing trend at all the sampling points in the wet season (i.e. from September to November). High variation occurred during the dry season with lower values than the wet season (Figure 4.2). The turbidity level decreased during the wet season (9.3 - 220NTU) through the dry season (20.7 – 72.3NTU). The relatively higher level of turbidity in the pond during the wet season is expected since runoff from its catchment discharges soil particles into it and also displaces sediments at the bottom (Gliwicz, 1999). Lower turbidity in the dry season may be due to settling of the particles at the bottom of the pond. Turbidity values for all the points during the two seasons were generally above the WHO recommended limit of 5 NTU (Figure 4.2) and showed a statistically significant difference between the wet and dry seasons ($p = 0.01$). High turbidity reduces the amount of light reaching lower depths which can affect species which depend on them such as fish. Suspended particles may serve as a breeding

substrate for bacteria (Mitchel and Stapp 2005). This may pose health risk of disease transmission due to infectious disease agents and chemicals adsorbed onto particulate matter especially in the wet season. Turbidity had aesthetic effects on appearance.

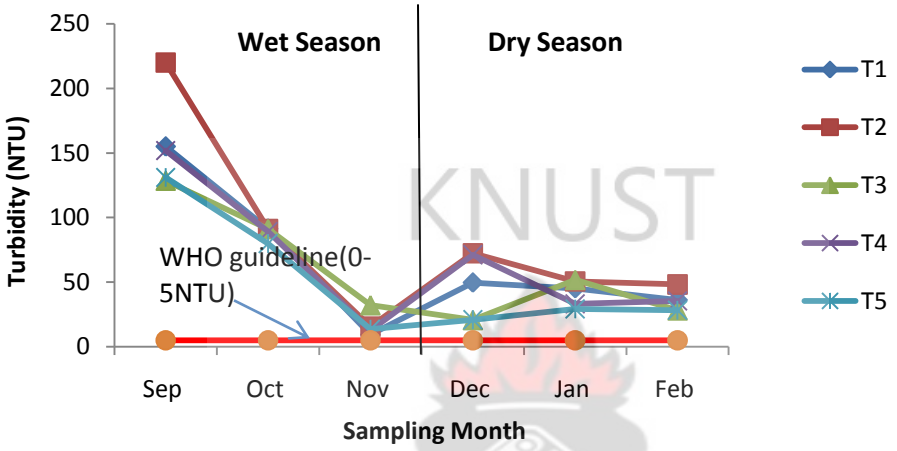

Figure 4. 2 Turbidity of water from the Tuse pond Sept.2010 –Feb.2011

4.1.3 Colour

The range of colour of the water in the dry and wet seasons was 90 – 920 Hazen and 62 – 670 Hazen respectively indicating relatively higher values in the wet season as compared to the dry season (Figure 4.3). Generally, the colour of water was very high throughout the sampling period and all values recorded were above the WHO recommended limit of 15Hazen. There was a high colour content of the pond during the early part of the wet season (September and October) but deceased in November. It however, increased in January (Figure 4.3). According to WHO (2004), colour in water is due to the presence of coloured organic matter (primarily humic and fulvic acids) associated with the humus fraction of soil. The difference in colour between dry and wet season was statistically

significant (p = 0.02) and shows the impact of rainfall and runoff on the colour of water in the Tuse pond. In the wet season the inflow of dissolved organic matter and suspended colloidal particles into the pond resulting from heavy rainfall and surface runoff were likely to have increased the colour and turbidity of the pond water. Relatively lower levels of colour and turbidity in the dry season could have been due to cessation of heavy inflow and mixing and apparent stagnation of the pond water. However, human activities such as stepping into the water and fishing as well as herds of cattle and swine wading into the pond to drink during the dry season might have caused agitation and muddying of the water hence increased the turbidity and colour above acceptable limits.

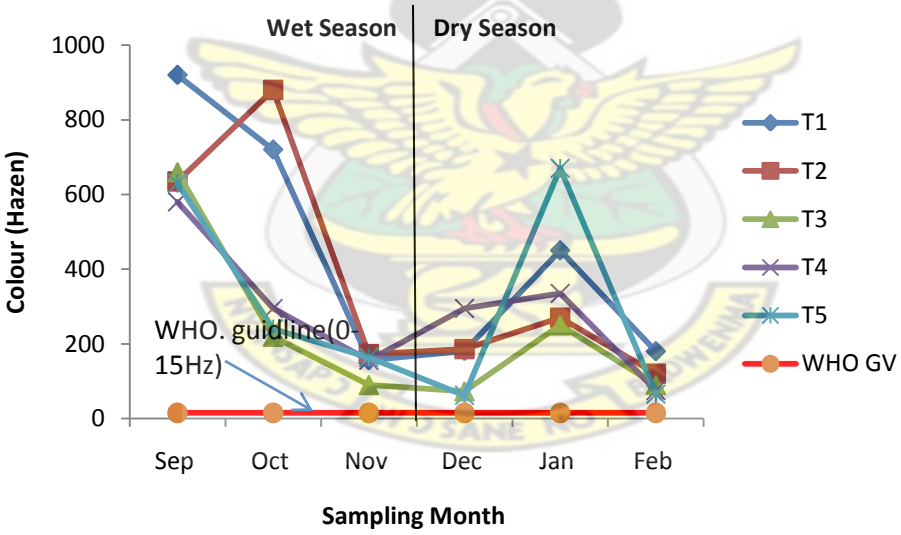

Figure 4. 3 Colour of water from the Tuse pond Sept.2010- Feb.2011

4.1.4 Conductivity

Conductivity of water in the Tuse pond during the sampling period ranged from 133 µS/cm to 550 µS/cm for the dry season and from 130 µS/cm to 500 µS/cm for the wet season. The values recorded generally showed an increasing trend from the wet season to the dry season (Figure 4.5). For the whole sampling period, sampling location T5 recorded the highest value of 550µS/cm in the dry season with location T2 recording the lowest value of 130µS/cm in the wet season. The relatively lower values of conductivity during the wet season could be explained by dilution from rainfall. All values recorded for both seasons fell below the WHO recommended guideline value of 1000µS/cm (Figure 4.5). The difference in conductivity between the wet and dry seasons was not significantly ($p = 0.5$) and shows that the influx of surface runoff from rainfall does not appreciably change its conductivity.

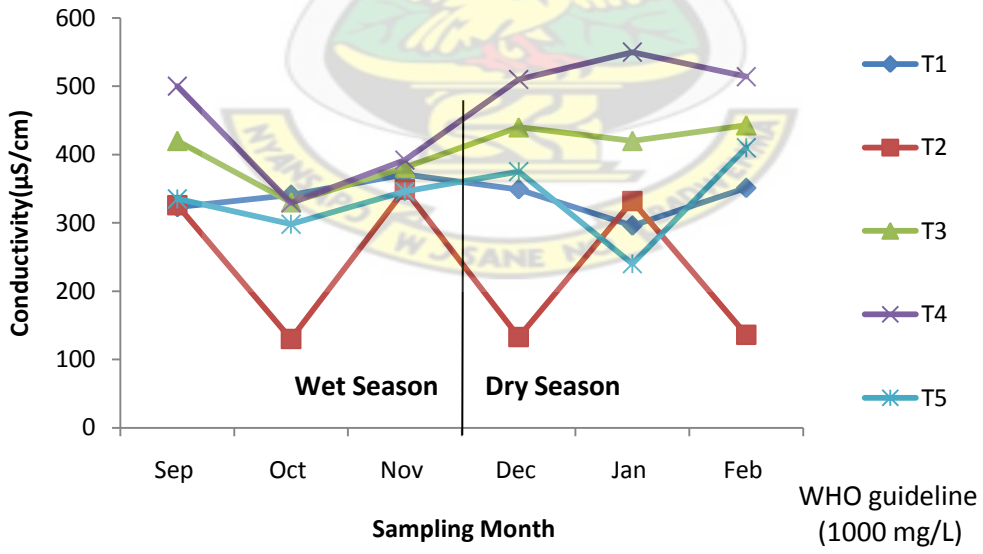

Figure 4. 4 Conductivity of water from the Tuse pond Sept.2010 – Feb.2011

4.1.5 Total dissolved solids

Total Dissolved Solids (TDS) in the Tuse pond was below the WHO recommended guideline value of 1000 mg/L for all the samples throughout the study period (Figure 4.6). The TDS level for the dry season was between 112mg/L and 243mg/L while that of the wet season was between 148mg/L and 250mg/L (Figure 4.6). The highest value of 250 mg/L was recorded in the wet season at sampling point T4 and the lowest value of 112 mg/L was recorded in the dry season at sampling point T2. Surface runoff introduces various sizes of soil particles that can either dissolve or remain suspended in the pond and explains the maximum level of TDS recorded in the wet season. The difference in TDS between the wet and dry season was statistically insignificant ($p = 0.6$) and shows the unappreciable effect of rainfall runoff on the TDS of the pond.

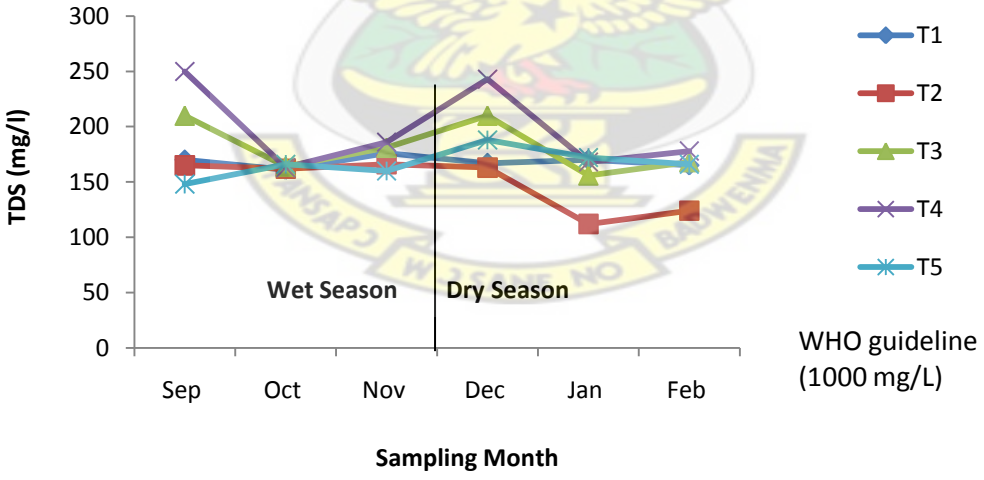

Figure 4. 5 TDS of water from the Tuse pond Sept.2010- Feb.2011.

4.1.6 Total hardness

The ranges of total hardness of water in the Tuse pond during the dry and wet seasons were 98 - 128mg/L and 90 - 132mg/L. There was a slight difference between values recorded for both seasons although that of the dry season was relatively higher (Figure 4.8). All values recorded were below the WHO recommended limit of 500 mg/L for all the sampling points throughout the study period (Figure 4.8). The highest value being 132 mg/L was recorded at sampling point T4 and the lowest value being 90mg/L was recorded at sampling point T1. Both values were recorded in the wet season. With reference to the classification of water hardness by Spellman (2008), water in the Tuse pond can be described as moderately hard since its hardness was within 75 – 150 mg/L and may thus lather moderately well with soap. Sauvant and Pepsin ((2000) suggested that the intake of very soft water may have an adverse effect on mineral balance and cause cardiovascular diseases, rectal and oesophagal cancer and even mortalities. Dry and wet season variation of total hardness in the pond was not statistically significant ($p = 0.4$) and shows the consistency of hardness of water in the pond. .

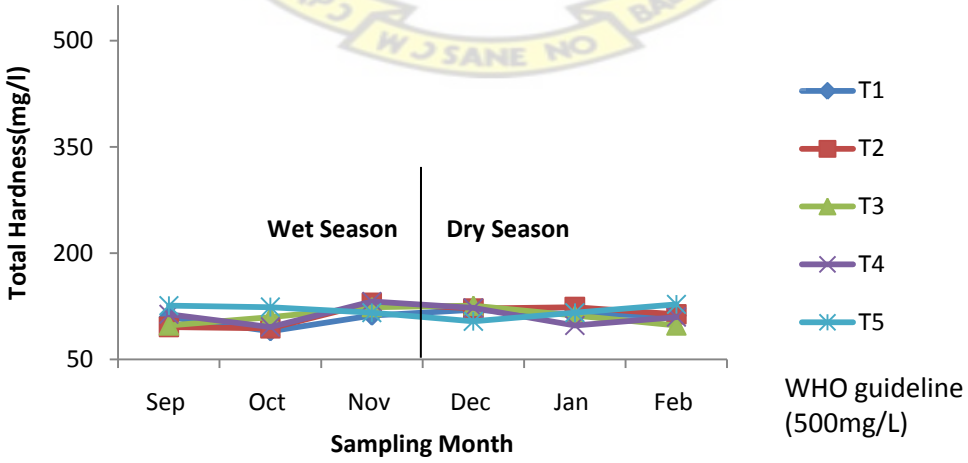

Figure 4.6 Total hardness of water from the Tuse pond Sept.2010- Feb.2011

4.1.7 Iron

The concentrations of iron in the pond during the dry and wet season had ranges of 0.12 – 0.37 mg/L and 0 – 0.39mg/L respectively. Levels of iron in the pond were consistently higher in the dry season although it reduced drastically at all sampling points in November (Figure 4.9). In the months of September, October and February, almost all sampling locations recorded values relatively higher than the WHO recommended limit of 0.3 mg/L (Figure 4.9). The highest value of 0.39 mg/L was recorded at T1 while the value at T5 was below detection. Both values were recorded in the wet season. This might have been due to runoff or the dissolution of rocks and soils. The presence of iron in natural water can be attributed to the weathering of minerals (Bell, 1976); landfill leachates (James, 1977), sewage effluents and iron-related industries.

According to Minnesota Department of Health when iron is well over 0.5 ppm it may affect the taste of the food that is cooked in it. High amounts of iron can cause the water to smell like rotten eggs or taste metallic. Excessive amounts of iron in water (more than 10 ppm) will give food unpleasant metallic flavour. Additionally, water with too much iron could stain clothing and appliances if spilled. The variation of iron in the pond between the wet and dry seasons was not statistically significant ($p = 0.15$). This implies that, rainfall runoff has little effect in changing the levels of iron in the pond.

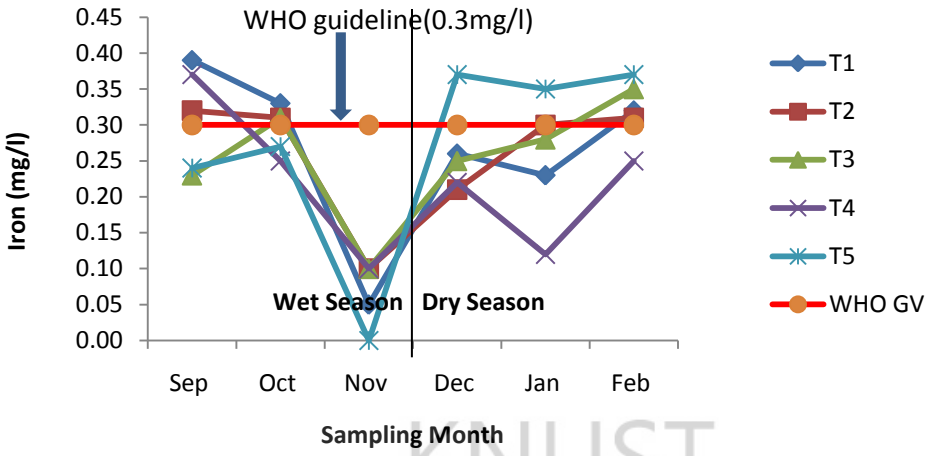

Figure 4. 7 Iron in water from Tuse pond Sept.2010 – Feb.2011

4.1.8 Chloride

The concentration of chloride in the pond ranged from 46mg/L to 96mg/L in the wet season and from 60mg/L to 100mg/L in the dry season. From September, chloride levels reduced in October and generally increased during the dry season (Figure 4.10). The chloride concentrations at all the sampling points for the whole period were below the WHO acceptable limit of 250 mg/L (Figure 4.10). The highest value of 100 mg/L was recorded at sampling point T4 in dry season while the lowest value of 46 mg/L was recorded at all the samplings in the wet season. Chloride in surface and groundwater, according to WHO (2004), results from both natural and anthropogenic sources, such as run-off containing, inorganic fertilizers, landfill leachates, septic tank effluents, animal feeds, industrial effluents, irrigation drainage, and seawater intrusion in coastal areas. The variation of chloride levels between the wet and dry seasons in the pond was not

statistically significant (p = 0.07) and could possibly be due to the influx of rainfall runoff in the wet season which accumulates in the pond even after the wet season.

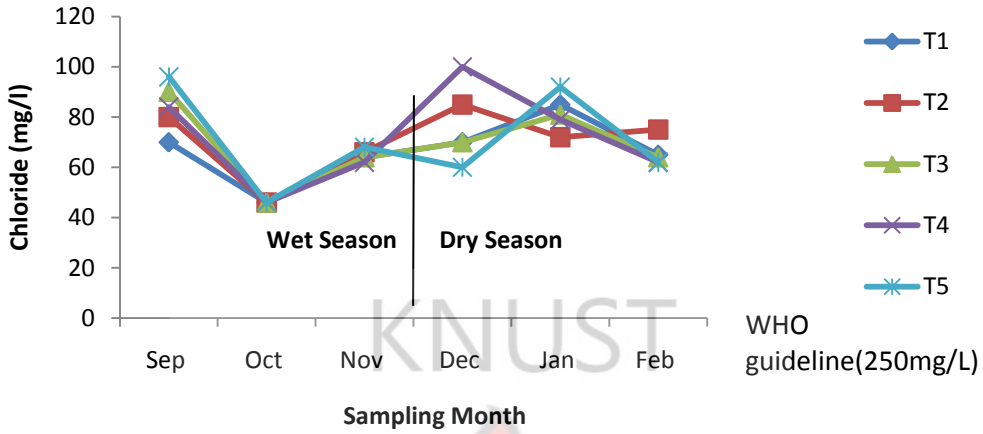

Figure 4. 8 Chloride in water from Tuse pond Sept.2010- Feb.2011

4.1.9 Nitrogen-nitrite

Nitrogen-nitrite concentration in the wet season ranged from below detection to 0.4 mg/L and from below detection to 0.05mg/L in the dry season (Figure 4.11). The higher level of nitrite concentration during the wet season was also observed by Adiyah and Akoto (2008) in the study of dissolved nitrogen in drinking water resources of some farming communities in Brong Ahafo Region of Ghana. Nitrite concentration in samples collected in the wet season, compared to those in the dry season did not however show a statistically significant variation (p = 0.05). Nitrite concentrations at all sampling points were below the WHO maximum permissible limit of 3.0 mg/L (Figure 4.11). Nitrite concentration was below detection at all sampling locations in September, December and February. Nitrite concentration in the pond water therefore does not pose any health hazard to consumers.

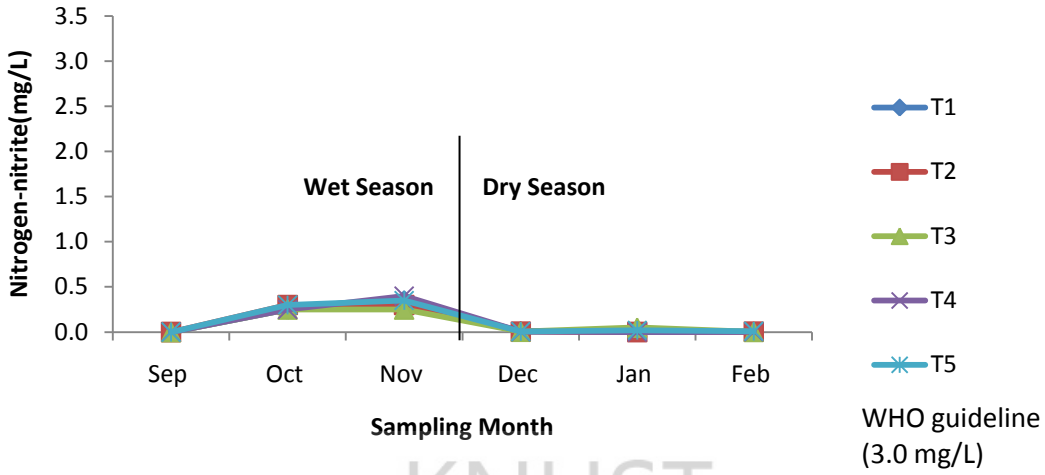

Figure 4. 9 Nitrogen-nitrite in water from Tuse pond Sept.2010- Feb.2011

4.1.10 Nitrogen-nitrate

The concentration of nitrogen-nitrate was far below the WHO guideline value of 50 mg/L at all sampling locations during the study period (Figure 4.12). Levels of nitrate ranged between 0.01 and 1.30 mg/L and showed a statistically significant variation between the wet and dry seasons ($p = 0.02$). Nitrate in drinking water can undergo endogenous reduction to nitrite, and nitrosation of nitrite can form N-nitroso compounds which are potent carcinogens. High levels of nitrate in drinking water can also cause cancer when it reacts with protein compounds in the body to form nitrosomine, a well documented cancer causing agent (Tricker and Preussman, 1991).

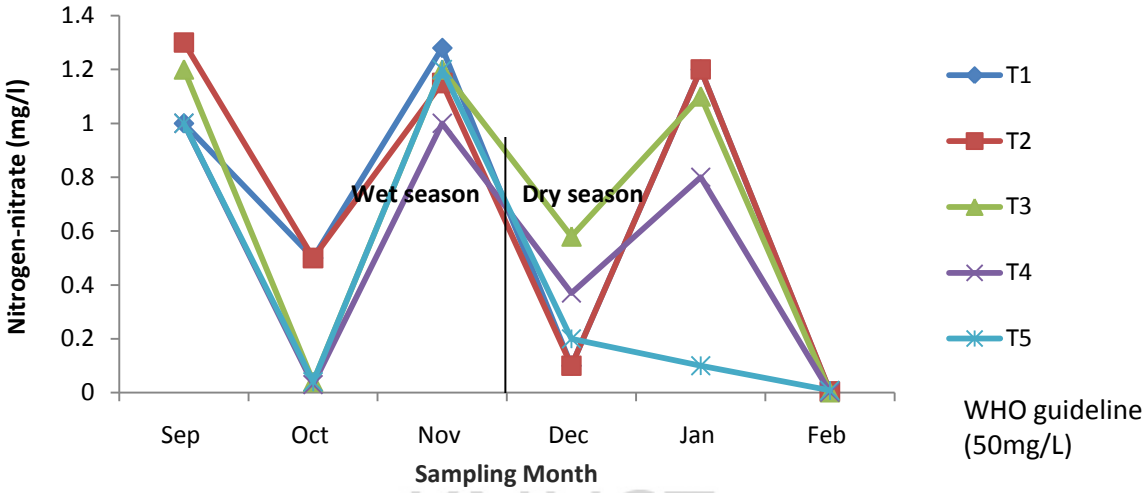

Figure 4. 10 Nitrogen-nitrate in water from Tuse pond Sept.2010- Feb.2011

4.1.11 Nitrogen-ammonia

The concentration of ammonia at all the sampling locations was found to be less than the maximum permissible limit of 1.5 mg/L. Values ranged from non- detectable to 0.03 mg/L for both seasons. Ammonia concentration was non-detectable in September and October at all the sampling locations. Ammonia concentration increased from non-detectable in October to 0.09 mg/L in November, declined to 0.06 mg/L and then to below detection at sampling point T1 (Figure 4.13). Dry and wet season variation of ammonia was statistically significant ($p = 0.01$).

Ammonia, according to Liu (1999), is usually released upon decomposition of proteinaceous matter and can be released into the atmosphere, used directly by microorganisms or converted into nitrite and nitrate. Thus, the low level of ammonia explains the low levels of nitrate and nitrite present in the pond. In surface waters, presence of the ammonia can indicate faecal contamination which poses diverse health risks to consumers if the water is not disinfected (WHO, 1966).

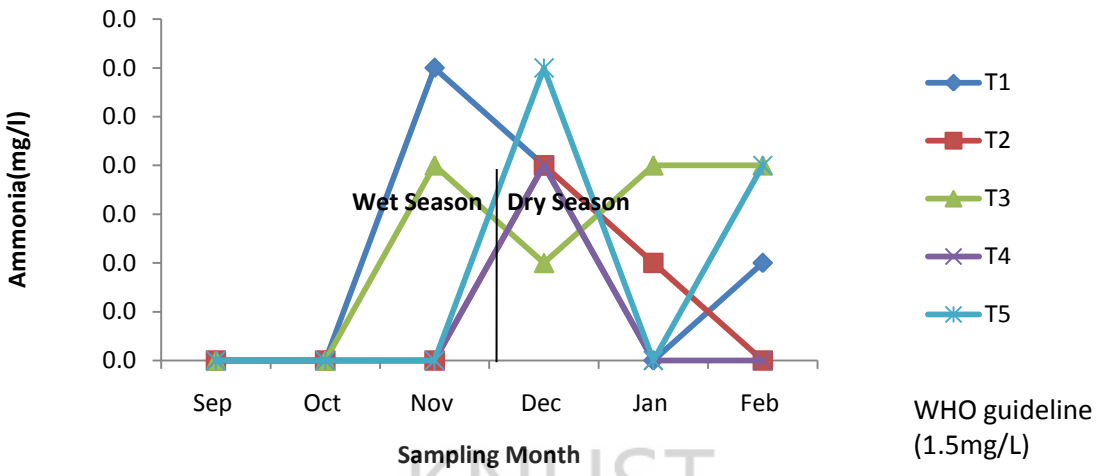

Figure 4. 11: Ammonia in water from Tuse pond Sept.2010- Feb.2011

4.1.12 Phosphate

Phosphate levels in the pond were less than the maximum permissible limit of 5 mg/L at all sampling locations throughout the study period. Values ranged between 0.3 and 2.5 mg/L and generally, it showed a decreasing trend in the wet season but increased in the dry season (Figure 4.14). The highest values were recorded in January and September at sampling point T3. Statistically, the levels of phosphate in the dry and wet seasons did not vary significantly ($p = 0.45$). In surface water bodies, phosphorus is usually associated with plant remains, animal wastes, fertilizer and detergents. It facilitates plant and algae growth and thus promotes eutrophication (Salvato *et al*., 2003).

Phosphate is not harmful to humans unless consumed at very high levels. It however impacts on water quality by affecting the odour and taste of drinking water (Jeer and Sanjay, 1997).

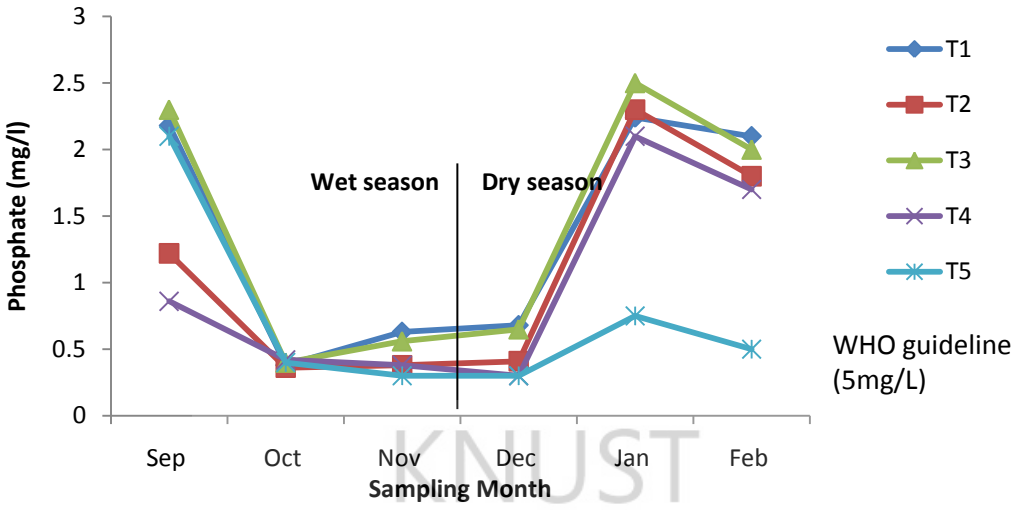

Figure 4. 12 Phosphate in water from Tuse pond Sept.2010- Feb.2011

4.1.13 Fluoride

Concentration of fluoride in the pond ranged from 0.18mg/L to 1.35mg/L in the dry season and from 0.1mg/L to 1.5mg/L in the wet season. Levels of fluoride in the Tuse pond did not show any definite pattern during the wet and dry seasons (Figure 4.15). The maximum fluoride level of 1.5 mg/L was recorded in October during the wet season while the minimum of 0.1 mg/L was recorded in September and November. Fluoride levels were predominantly below the WHO guideline value of 1.5 mg/L (Figure 4.15). Dry and wet season variation of fluoride in the pond was not statistically significant ($p = 0.38$) although that of the dry season was relatively higher than the wet season. WHO (2004) asserts that, fluoride in drinking water occurs naturally and can be released from phosphate-containing rocks which contains 4% fluorine. In drinking water, high levels of fluoride (up to 10 mg/L) results in dental fluorosis while concentrations below 0.1mg/L leads to dental decay (Edmunds and Smedely, 1996)

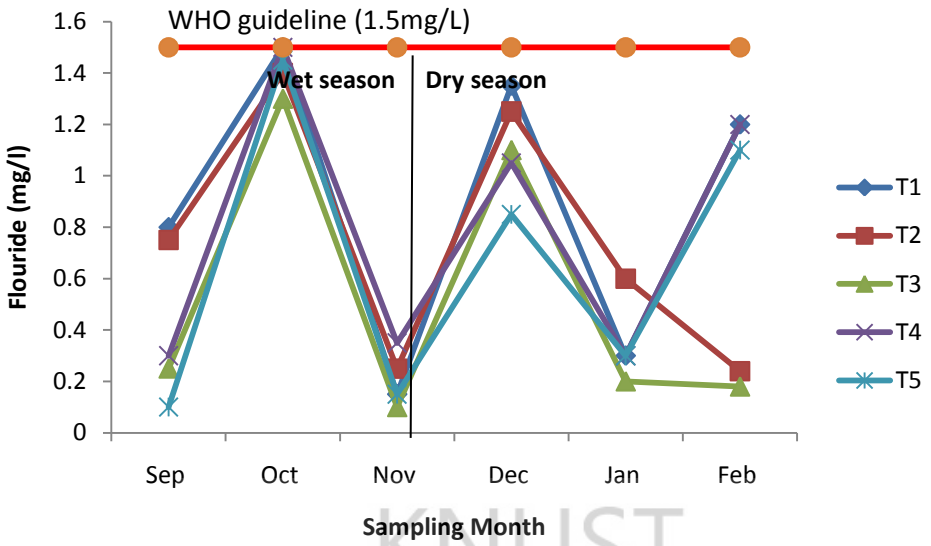

Figure 4.13 Fluoride levels in water from the Tuse pond Sept.2011 – Feb.2011

4.1.14 Sulphate

The range of values for sulphate levels were 9 – 14mg/L in the dry season and 7 – 43mg/L in the wet season. Sulphate concentrations in the Tuse pond showed a decreasing pattern from the wet season to the dry season (Figure 4.16). At all sampling locations levels of sulphate were below the maximum permissible limit of 250 mg/L during the study period with a minimum of 7 mg/L and a maximum of 43 mg/L (Figure 4.15). Sulphate ion occurs naturally in most water supplies and is reduced biologically to sulphide, which in turn can combine with hydrogen to form Hydrogen sulphide which has a characteristic rotten-egg odour (Spellman, 2003; Liu, 1999). According to WHO (2004), sulphate in drinking water has a laxative effect which is mostly manifested at concentrations between 1000 and 1200 mg/L. However, this effect is not expected to manifest in the pond since it has extremely low sulphate levels (7 – 43 mg/L). Variation

of sulphate levels between the dry and wet seasons was not statistically significant (p = 0.14).

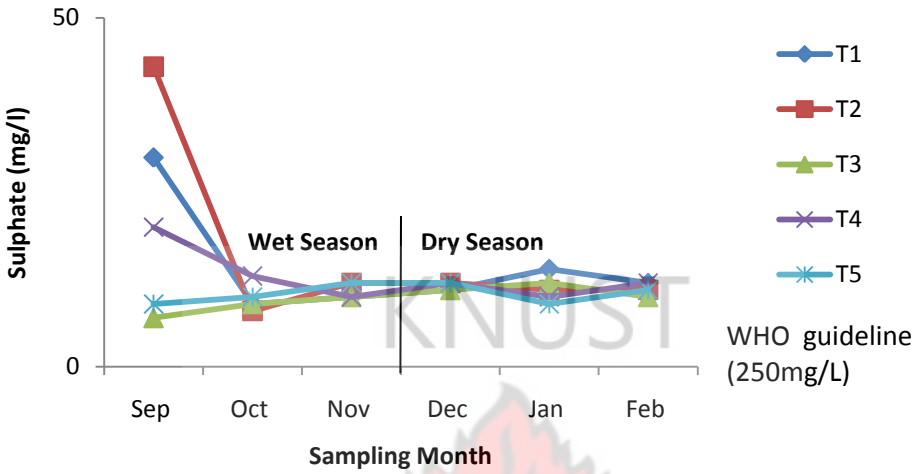

Figure 4. 14 Sulphate in water from the Tuse pond Sept.2010- Feb.2011

4.2 Bacteriological parameters

The bacteriological parameters measured were Total Coliform, Faecal coliform, *Escherichia coli*, *Salmonella* and *Enterococci*. For health reasons, the WHO recommends that there should be no form of bacteriological organisms in drinking water.

4.2.1 Total coliforms

The ranges of total coliforms in the pond for the dry and wet seasons were 4000 – 4500MPN/100mL and 5000 – 240000000MPN/100mL respectively. Total coliform bacteria levels showed a decreasing pattern throughout the wet season but increased in January during the dry season (Figure 4.16). Variation of total coliforms between the dry and wet seasons was statistically significant (p = 0.01). The relatively high levels of total

coliforms in the wet season could be attributed to the influx of rainfall runoff into the pond. Some of these bacteria are excreted in the faeces of humans and animals, but many coliforms are heterotrophic and able to multiply in water and soil environments (WHO, 2004; Grabow, 1996). This presence of total coliform bacteria indicates the capacity of the pond to transmit various diseases related with water including cholera and dysentery.

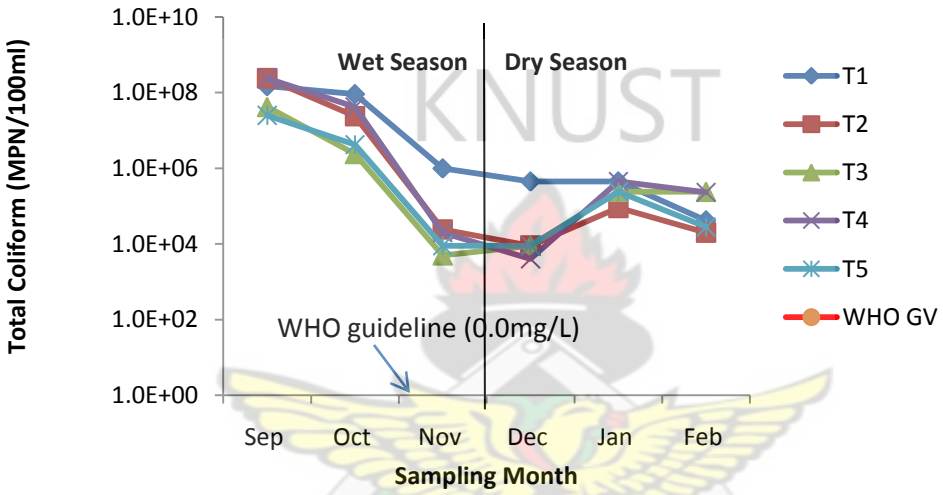

Figure 4. 15 Total coliform in water from Tuse pond Sept.2010- Feb.2011

4.2.2 Faecal coliforms

Faecal coliform counts were relatively higher in the wet season (450 - 240000MPN/100 mL) as compared to the dry season (90 – 4300MPN/100 mL) as shown in Figure 4.17. Between the wet and dry seasons, the levels of faecal coliforms differed significantly ($p = 0.01$) and shows the impact of rainfall runoff on the pond during the wet season. Richards and Batram (1993) reported that faecal coliforms (FC) are the most commonly used indicator bacteria for faecal contamination, since their excreted load is similar or larger

than that of pathogenic organisms, and their survival time in the environment longer than that of excreted bacteria and viruses.

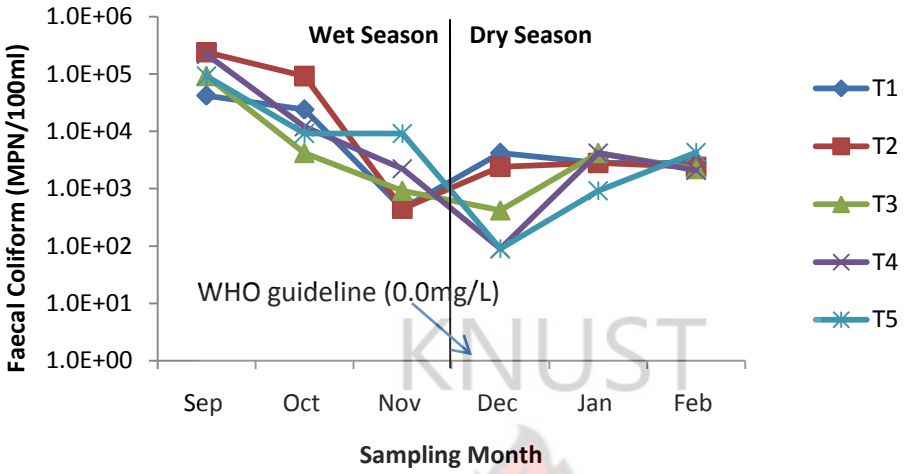

Figure 4. 16 Faecal coliform in water from Tuse pond Sept.2010- Feb.2011

4.2.3 *Escherichia coli* (*E. coli*)

E. coli concentration ranged from 9 to 240MPN/100mL in the dry season and from 42 to 92000MPN/100mL for the wet season. Its concentration was relatively higher during the wet season compared to the dry season (Figure 4.18). The presence of *E. coli* in the pond provides conclusive evidence of faecal pollution which should not occur in drinking water (WHO, 2004). Its concentration did not differ significantly between the dry and wet seasons ($p = 0.11$)

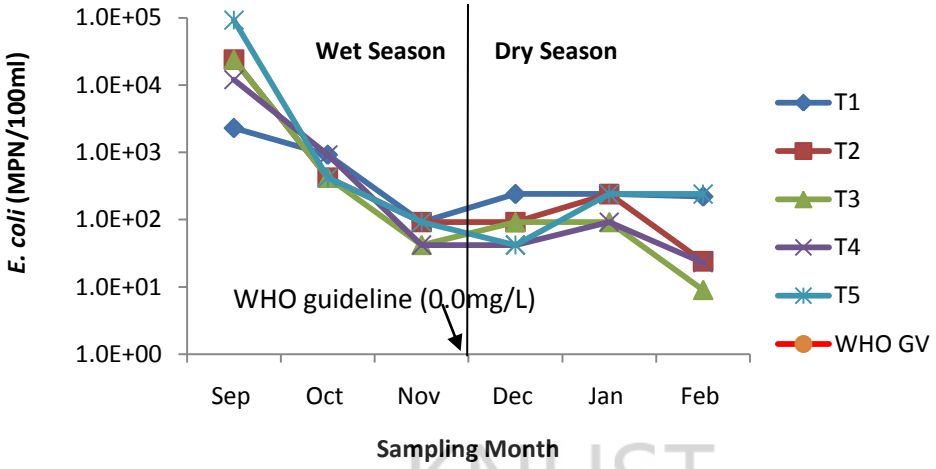

Figure 4.17 *E. coli* in water from the Tuse pond Sept.2010 – Feb.2011

4.2.4 *Salmonella*

Salmonella concentration was highest in September at all sampling locations and reduced gradually from October to February (Figure 4.19). In the dry season, *Salmonella* counts ranged from 20 – 92cfu/100 mL while ranging from 23 – 920cfu/100 mL in the wet season. Dry and wet season variation of *Salmonella* was statistically significant ($p = 0.01$). *Salmonella* are widely distributed in the environment and typically gain entry into water systems through faecal contamination from sewage discharges, livestock and wild animals (WHO, 2004). *Salmonella* infections typically cause four clinical manifestations: gastroenteritis (ranging from mild to serious diarrhoea, nausea and vomiting), bacteraemia or septicaemia (high spiking fever with positive blood cultures), typhoid fever / enteric fever (sustained fever with or without diarrhoea) and a carrier state in persons with previous infections. According to the Science and Development Network (2010), it takes just fifteen *Salmonella* bacteria to cause illness. Therefore the likelihood of the Tuse pond water to cause infections to those who drink it is very high.

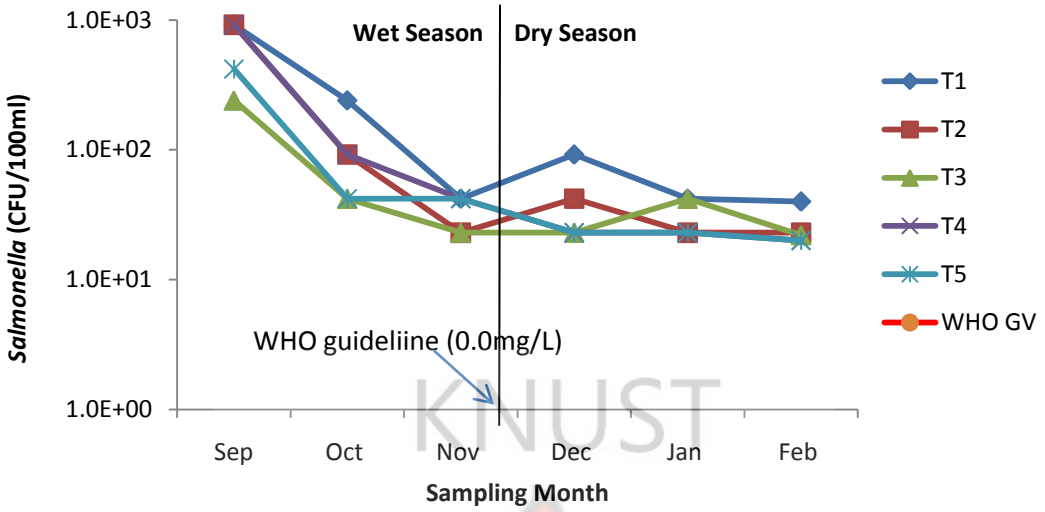

Figure 4.18: *Salmonella* in water from the Tuse pond Sept.2010 – Feb.2011

4.2.5 *Enterococci*

Enterococci concentrations were highest in September as compared with the other sampling months and were relatively steady during the dry season (Figure 4.20). In the dry season, a range of 2000 – 31000cfu/100 mL was obtained while that of the wet season was 8000 – 94000cfu/100 mL showing relatively higher levels in the wet season. Dry and wet season variation was statistically significant ($p = 0.01$) and depicts the impact of surface runoff in increasing the levels of *Enterococci* in the pond. *Enterococci*, according to WHO (2004), are typically excreted in the faeces of humans and other warm-blooded animals but have also been detected in soil in the absence of faecal contamination. Its presence in the pond is an indication of faecal contamination. Ashbolt *et al*. (2001) asserted that *enterococci* tend to survive longer in water environments than *E. coli* (or thermotolerant coliforms) and are more resistant to chlorination.

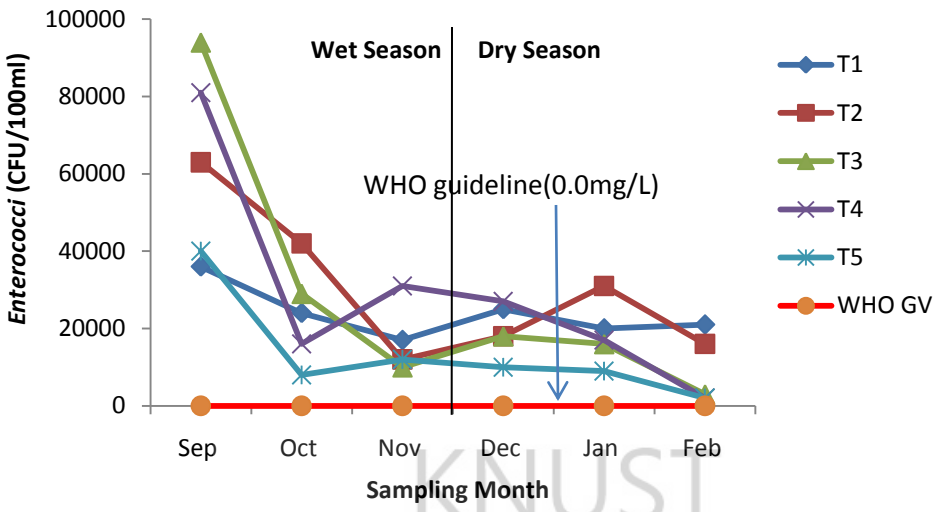

Figure 4.19: *Enterococci* in water from the Tuse pond Sept.2010 – Feb.2011

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study concludes that the Tuse pond which serves as the source of drinking water for residents of Atebubu has a fairly good physico-chemical characteristics since most of them were below the WHO recommended guideline values. Only turbidity, colour and iron showed levels that were higher than their respective guideline values.

The presence of high levels of bacteriological contaminants in the pond; faecal coliforms, *Salmonella*, *Enterococci, Escherichia coli* and total coliforms indicates faecal contamination of the Tuse pond. Consumption of water in the pond without any form of treatment could therefore give rise to disease outbreaks such as cholera, dysentery and diarrhoea. Water in the pond becomes more contaminated in the wet season as shown by the statistically significant higher levels of most parameters.

5.2 Recommendations

With regard to the numerous health risks that the Tuse pond poses to consumers as seen from this study, it is recommended that:

- An alternate source of drinking water should be provided to enable those who cannot afford bottled and sachet water have access to good drinking water.
- Approved treatment processes of the pond water should be instituted by the District Assembly to ensure good quality drinking water for the people.

- Further work should be done on the pond water to ascertain the concentrations of other physico-chemical and bacteriological parameters that have not been captured in this work.

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APPENDICES

Appendix 1: Results of analysis of Physico-chemical parameters

pH (pH units)

Month	T1	T2	T3	T4	T5
Sep	7.03	7.75	7.83	7.81	8.30
Oct	7.90	7.93	7.96	7.82	7.67
Nov	7.51	8.13	7.50	8.12	7.64
Dec	7.3	7.29	7.82	7.86	7.69
Jan	7.76	7.86	7.81	7.77	7.76
Feb	7.51	7.45	7.2	7.8	7.68

Turbidity (NTU)

Month	T1	T2	T3	T4	T5
Sep	155	220	128.6	151.9	131.1
Oct	91.3	91.2	91.2	89.2	79.9
Nov	9.34	15.5	32.2	12.6	13.5
Dec	49.6	72.3	20.7	71.2	20.9
Jan	45.2	50.6	51.8	33.2	29.2
Feb	36.1	48.2	28.2	35.5	28.2

Conductivity (µs/cm)

Month	T1	T2	T3	T4	T5
Sep	323	326	420	500	335
Oct	341	130	330	329	298
Nov	371	349	381	392	346
Dec	349	133	440	510	375
Jan	296	332	420	550	240
Feb	351	136	443	514	410

Colour (Hz)

Month	T1	T2	T3	T4	T5
Sep	920	635	660	580	630
Oct	720	880	219	295	240
Nov	156	172	90	156	164
Dec	181	186	73	295	62
Jan	450	270	250	335	670
Feb	180	120	90	75	65

Total Dissolved Solids (mg/L)

Month	T1	T2	T3	T4	T5
Sep	170	165	210	250	148
Oct	161	162	164	163	166
Nov	176	166	181	186	160
Dec	167	163	210	243	188
Jan	170	112	156	168	172
Feb	165	124	168	178	166

Total hardness (mg/L)

Month	T1	T2	T3	T4	T5
Sep	110	96	98	114	126
Oct	90	94	110	96	124
Nov	112	130	124	132	116
Dec	120	122	126	123	104
Jan	114	124	112	98	116
Feb	112	114	98	110	128

Iron (mg/L)

Month	T1	T2	T3	T4	T5
Sep	0.39	0.32	0.23	0.37	0.24
Oct	0.33	0.31	0.31	0.25	0.27
Nov	0.05	0.1	0.1	0.1	0.0
Dec	0.26	0.21	0.25	0.22	0.37
Jan	0.23	0.3	0.28	0.12	0.35
Feb	0.32	0.31	0.35	0.25	0.37

Chloride (mg/L)

Month	T1	T2	T3	T4	T5
Sep	70	80	90	84	96
Oct	46	46	46	46	46
Nov	64	66	64	62	68
Dec	70	85	70	100	60
Jan	85	72	81	79	92
Feb	65	75	64	62	62

Nitrite (mg/L)

Month	T1	T2	T3	T4	T5
Sep	0	0	0	0	0
Oct	0.25	0.3	0.25	0.25	0.3
Nov	0.35	0.3	0.25	0.4	0.35
Dec	0.008	0.006	0.004	0.004	0.005
Jan	0.01	0	0.05	0	0.02
Feb	0.003	0.005	0.002	0.001	0.008

Nitrate (mg/L)

Month	T1	T2	T3	T4	T5
Sep	1.0	1.3	1.2	1.0	1.0
Oct	0.5	0.5	0.04	0.03	0.04
Nov	1.28	1.15	1.2	1.0	1.2
Dec	0.1	0.1	0.58	0.37	0.2
Jan	1.2	1.2	1.1	0.8	0.1
Feb	0.0	0.0	0.0	0.0	0.0

Fluoride (mg/L)

Month	T1	T2	T3	T4	T5
Sep	0.8	0.75	0.25	0.3	0.1
Oct	1.5	1.4	1.3	1.5	1.45
Nov	0.15	0.25	0.1	0.35	0.15
Dec	1.35	1.25	1.1	1.05	0.85
Jan	0.3	0.6	0.2	0.3	0.3
Feb	1.2	0.24	0.18	1.2	1.1

Sulphates (mg/L)

Month	T1	T2	T3	T4	T5
Sep	30	43	7	20	9
Oct	9	8	9	13	10
Nov	10	12	10	10	12
Dec	11	12	11	12	12
Jan	14	11	12	10	9
Feb	12	11	10	12	11

Phosphates (mg/L)

Month	T1	T2	T3	T4	T5
Sep	2.18	1.22	2.3	0.86	2.1
Oct	0.38	0.36	0.4	0.42	0.4
Nov	0.63	0.38	0.56	0.38	0.3
Dec	0.68	0.41	0.65	0.3	0.3
Jan	2.24	2.3	2.5	2.1	0.75
Feb	2.10	1.8	2.0	1.7	0.5

Ammonia (mg/L)

Month	T1	T2	T3	T4	T5
Sep	0	0	0	0	0
Oct	0	0	0	0	0
Nov	0.03	0	0.02	0	0
Dec	0.02	0.02	0.01	0.02	0.03
Jan	0	0.01	0.02	0	0
Feb	0.01	0	0.02	0	0.02

Appendix 2A: Results of bacteriological analysis

Total coliform (MPN/100 mL)

Month	T1	T2	T3	T4	T5
Sep	150×10^6	240×10^6	42×10^6	240×10^6	25×10^6
Oct	92×10^6	24×10^6	2.4×10^6	42×10^6	4.2×10^6
Nov	1.0×10^6	0.024×10^6	0.005×10^6	0.02×10^6	0.009×0^6
Dec	0.45×10^6	0.009×10^6	0.009×10^6	0.004×10^6	0.009×10^6
Jan	0.45×10^6	0.09×10^6	0.24×10^6	0.45×10^6	0.24×10^6
Feb	0.042×10^6	0.02×10^6	0.24×10^6	$0.2\ 3 \times 10^6$	0.028×10^6

Faecal coliform (MPN/100 mL)

Month	T1	T2	T3	T4	T5
Sep	42×10^3	240×10^3	92×10^3	220×10^3	92×10^3
Oct	24×10^3	92×10^3	4.2×10^3	12×10^3	9.2×10^3
Nov	0.45×10^3	0.45×10^3	0.92×10^3	2.24×10^3	9.2×10^3
Dec	4.2×10^3	2.4×10^3	0.42×10^3	0.09×10^3	0.09×10^3
Jan	2.8×10^3	2.8×10^3	4.2×10^3	4.2×10^3	0.92×10^3
Feb	2.8×10^3	2.4×10^3	2.2×10^3	2.1×10^3	4.3×10^3

***Escherichia coli* (MPN/100 mL)**

Month	T1	T2	T3	T4	T5
Sep	23 $x10^2$	240 $x10^2$	240 $x10^2$	120 $x10^2$	920 $x10^2$
Oct	9.2 $x10^2$	4.2 $x10^2$	4.2 $x10^2$	9.2 $x10^2$	4.2 $x10^2$
Nov	0.92$x10^2$	0.92 $x10^2$	0.42 $x10^2$	0.42 $x10^2$	0.92 $x10^2$
Dec	2.4 $x10^2$	0.92 $x10^2$	0.92 $x10^2$	0.42 $x10^2$	0.42 $x10^2$
Jan	2.4 $x10^2$	2.4 $x10^2$	0.92 $x10^2$	0.92 $x10^2$	2.4 $x10^2$
Feb	2.2 $x10^2$	0.24 $x10^2$	0.09 $x10^2$	0.23 $x10^2$	2.4 $x10^2$

***Salmonella* (cfu/100 mL)**

Month	T1	T2	T3	T4	T5
Sep	92$x10^1$	92 $x10^1$	24 $x10^1$	92 $x10^1$	42 $x10^1$
Oct	24 $x10^1$	9.2 $x10^1$	4.2 $x10^1$	9.2 $x10^1$	4.2 $x10^1$
Nov	4.2 $x10^1$	2.3 $x10^1$	2.3 $x10^1$	4.2 $x10^1$	4.2 $x10^1$
Dec	9.2 $x10^1$	4.2 $x10^1$	2.3 $x10^1$	2.3 $x10^1$	2.3 $x10^1$
Jan	4.2 $x10^1$	2.3 $x10^1$	4.2 $x10^1$	2.3 $x10^1$	2.3 $x10^1$
Feb	4.0 $x10^1$	2.3 $x10^1$	2.2 $x10^1$	2.0 $x10^1$	2.0 $x10^1$

***Enterococci* (cfu/100 mL)**

Month	T1	T2	T3	T4	T5
Sep	$3.6x10^4$	$6.3 x10^4$	$9.4 x10^4$	$8.1 x10^4$	$4.0 x10^4$
Oct	$2.4 x10^4$	$4.2 x10^4$	$2.9 x10^4$	$1.6 x10^4$	$0.8 x10^4$
Nov	$1.7 x10^4$	$1.2 x10^4$	$1.0 x10^4$	$3.1 x10^4$	$1.2 x10^4$
Dec	$2.5 x10^4$	$1.8 x10^4$	$1.8 x10^4$	$2.7 x10^4$	$1.0 x10^4$
Jan	$2.0 x10^4$	$3.1 x10^4$	$1.6 x10^4$	$1.7 x10^4$	$0.9 x10^4$
Feb	$2.1 x10^4$	$1.6 x10^4$	$0.3 x10^4$	$0.2 x10^4$	$0.2 x10^4$

Appendix 2B: Log concentration of bacteriological parameters

Total coliform (MPN/100 mL)

Month	T1	T2	T3	T4	T5
Sep	8.18	8.38	7.62	8.38	7.40
Oct	7.96	7.38	6.38	7.62	6.62
Nov	6.0	4.38	3.70	4.30	3.95
Dec	5.65	3.95	3.95	3.60	3.95
Jan	5.65	4.95	4.38	5.65	5.38
Feb	4.62	4.30	4.38	5.30	4.45

Faecal coliform (MPN/100 mL)

Month	T1	T2	T3	T4	T5
Sep	4.62	5.38	4.96	5.32	4.96
Oct	4.38	4.96	3.62	4.08	3.96
Nov	2.65	2.65	2.95	3.35	3.96
Dec	3.62	3.38	2.60	1.95	1.95
Jan	3.45	3.45	3.62	3.62	2.96
Feb	3.45	3.38	3.34	3.32	3.63

***Escherichia coli* (MPN/100 mL)**

Month	T1	T2	T3	T4	T5
Sep	3.36	4.38	4.38	4.08	4.96
Oct	2.96	2.62	2.62	2.96	2.62
Nov	1.95	1.96	1.62	1.62	1.96
Dec	2.38	1.96	1.96	1.62	1.62
Jan	2.38	2.38	1.96	1.96	2.38
Feb	2.34	1.38	0.95	1.36	2.38

***Salmonella* (cfu/100 mL)**

Month	T1	T2	T3	T4	T5
Sep	2.96	2.96	2.38	2.96	1.62
Oct	2.38	1.96	1.62	1.96	1.62
Nov	1.62	1.36	2.36	1.62	1.62
Dec	1.96	1.62	2.36	1.36	1.36
Jan	1.62	1.36	1.62	1.36	1.36
Feb	1.60	1.36	1.34	1.30	1.30

***Enterococci* (cfu/100 mL)**

Month	T1	T2	T3	T4	T5
Sep	4.56	4.80	4.97	4.91	4.60
Oct	4.38	4.62	4.46	4.20	3.90
Nov	4.23	4.10	4.0	4.49	4.10
Dec	4.40	4.26	4.26	4.43	4.0
Jan	4.30	4.49	4.20	4.23	3.95
Feb	4.32	4.20	3.48	3.30	3.30

APPENDIX 3: Statistical analysis

PARAMETERS	**Wet season**	**Dry season**	***T - test (P – value at α = 0.05)***
Physico-chemical parameters			
pH	7.79	7.64	0.13*
Turbidity (NTU)	80.84	41.39	0.01
Conductivity (µs/cm)	344.47	366.6	0.50*
Colour (Hz)	434.47	220.13	0.02
Total Dissolved Solids (mg/L)	175.20	170.0	0.60*
Total Hardness (mg/L)	111.47	114.73	0.40*
Iron (mg/L)	0.22	0.28	0.15*
Chloride (mg/L)	64.93	74.8	0.07
Nitrite (mg/L)	0.3	0.008	0.05
Nitrate (mg/L)	0.83	0.45	0.02
Fluoride (mg/L)	0.69	0.87	0.38*
Sulphate (mg/L)	14.13	11.33	0.14*
Phosphate (mg/L)	0.86	0.97	0.45*
Ammonia (mg/L)	0.007	0.015	0.01
Bacteriological parameters			
Total coliform (MPN/100mL)	57510533	167400	0.01
Faecal coliform (MPN/100mL)	56044	2395	0.01
Escherichia coli (MPN/100mL)	10517	129	0.11*
Salmonella (MPN/100mL)	273	32	0.01
Enterococci (MPN/100mL)	34333	15667	0.01

***Seasonal variation is not statistically significant for *P (T < = t)* two-tail.**