KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF SCIENCE

DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

WATER QUALITY ASSESSMENT AND CONSUMERS' PERCEPTION IN APP1ADU, KUMASI, ASHANTI REGION OF GHANA

BY

MARVIN OSEI BOSOMPEM

FEBRUARY, 2014

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Thesis submitted to the College of Science in partial fulfillment of the requirement for the award of MSc. degree in Environmental Science

FEBRUARY, 2014

DECLARATION

I certify that this thesis does not contain any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

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ABSTRACT

The provision of quality water supply to communities is critical in enhancing their health status. This study assessed the quality of water supplied to inhabitants of Appiadu in the Kumasi Metropolis of the Republic of Ghana, by the Appiadu Community Water Supply System. Water samples from the main reservoir and selected household taps were analysed for some physico-chemical and microbiological parameters using standard methods. A survey was also conducted to assess consumers' perception of the quality of their water supply. Results of the study showed that mean levels of total coliform, faecal coliform, total viable count and faecal enterococci in all the water samples far exceeded the WHO and Ghana Standard Authority (GSA) permissible limits for drinking water. *Escherichia coli* and *Salmonella* were, however absent in all the samples. It was also revealed that the mean concentrations of all of the investigated physico-chemical parameters (pH, temperature, electrical conductivity, total dissolved solids, turbidity and total hardness) were within the respective WHO / GSA permissible limits. Analysis of the survey results also revealed that majority of inhabitants at Appiadu had no concern about the physical properties (that is taste, smell and colour) of their water, and were satisfied with its quality, even though the microbiological analysis indicates a poor quality, and may pose a health risk to consumers. This study has help highlight the incident of coliform bacteria in the Appiadu Water System.

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AMCOW:	African Ministers' Council on Water
CWSA:	Community Water and Sanitation Agency
CWSD:	Community Water and Sanitation Department
DFID:	Department for International Development
EDTA:	Ethylenediaminetetra-acetic acid
EPA:	Environmental Protection Agency
GSA:	Ghana Standard Authority
GWSC:	Ghana Water and Sewerage Corporation
GWCL:	Ghana Water Company Limited
GOG:	Government of Ghana
MDGs:	Millennium Development Goals
NTU:	Nephelometric Turbidity Units
PURC:	Public Utilities Regulatory Commission
RWD:	Rural Water Department
SIWI:	Stockholm International Water Institute
TCU:	True Colour Units
UNCED:	United Nations Conference on Environment and Development
WRC:	Water Resources Commission
WUP:	Water Utility Partnership
WHO:	World Health Organisation

CHAPTER ONE

INTRODUCTION

1.1. Background

Water has always been an important and life-sustaining drink to humans, and is essential to the existence and survival of all known organisms (Greenhalgh, 2001). About 75% of the Earth's surface is covered by water, but only 1% of that is drinkable (Romanowski, 2011). The human body is made up of 60% of water (USGS, 2009) and therefore our basic existence as humans is largely dependent on safe drinking water. Apart from drinking, water also serve useful purposes such as agriculture, washing, transportation, recreation, industrial application and other uses (Doe, 2007). Access to safe drinking is a major challenge affecting many countries in the world especially developing countries (WHO/UNICEF, 2010), and the provision of quality water supply to communities is critical in enhancing the health status to promoting human development (DFID, 1998).

Africa has the lowest water supply and sanitation coverage of any region in the world. More than 30% of Africans residing in urban areas currently lack access to adequate water services and facilities. In the year 2000, World Health Organisation (WHO) estimated that Africa contains 28% of the world's population without water access to improved water supplies, and 13% of the world's population that have no access to improved sanitation. With this, only 62% of the people in African countries have access to improved water supplies, and only 60% have access to improved sanitation (Doe, 2007). The situation is clearly appreciated worldwide and therefore the Millennium Development Goal 7 of ensuring environmental sustainability, has a target of significantly reducing by halve, by 2015, the proportion of population in developing countries without access to safe drinking water and basic sanitation (MDG, 2000). Although water remains a renewable resource that is replenished by precipitation, the quality of water that is available for human use has significantly been affected by human activities (Herman and Zaslow, 1996). It is estimated that 80 per cent of all diseases and over one third of deaths in developing countries are caused by the consumption of contaminated water (UNCED, 1992). In Ghana, more than nine million people have no access to safe drinking water and 80% of all diseases are caused by unsafe water and poor sanitation (WaterAid Ghana, 2013).

Water supply is basically the provision of water by public utilities, commercial organisations, community endeavors or by individuals, usually via a system of pumps and pipes. The Ghana Water Company Limited (GWCL) is responsible for the provision, distribution, conservation and supply of potable water to the urban population in Ghana. The Community Water and Sanitation Department (CWSD) on the other hand is responsible for the provision of safe drinking water and sanitation services to rural and small towns. Community Water and Sanitation Agency (CWSA) facilitates the development, operations and maintenance of the community water supply systems. The main source of water supply to many rural and peri-urban communities is groundwater. Although groundwater has excellent natural quality which often times requires little or no treatment as compared to surface water, poor distribution systems make the groundwater become susceptible to contamination. Most community drinking water distribution system involves a complex net-work of pipes, tanks and reservoirs that delivers finished water to consumers. As water travels through the distribution system, a variety of physical, chemical and biological transformations can cause an adverse change in the water quality (Umar, 2012). The purpose of a water supply distribution system is to deliver to each consumer safe drinking water that is also adequate in quantity and acceptable in terms of taste, odour and appearance (Karikari and Ampofo, 2013). Microorganisms such as viruses, protozoan, bacteria etc. can cause undesirable water quality changes such as taste and odour problem. The integrity of the reservoirs and mains in the distribution network is critical for the safety of drinking water (Van Lieverloo *et al.*, 2006). Lack of maintenance of pipelines and other distribution infrastructure causes leaks and breaks which may serve as entry point for the intrusion of microorganisms. The complicated nature of the distribution system; pipelines, storage reservoir and standpipes may serve as suitable habitat for certain microorganisms which cause contamination of water supply. Hunter (1997) reported that 15 out of 57 outbreaks in public water supplies in the UK between 1911 and 1995 were associated with contamination within the distribution system. Many waterborne outbreaks are as a result of contamination of drinking water in the distribution system.

In the USA, 18% of 619 outbreaks reported in public water systems from 1971 to 1998 were caused by chemical or microbial contaminants entering the distribution system or water that was corrosive to plumbing systems within premises (Craun and Calderon, 2001).

1.2 Problem statement

The Appiadu Community Water System draws groundwater from borehole which is pumped to a series of overhead tanks. The water is later distributed through a network of pipelines to individual homes. Most of these pipelines run through the main drainage system, and since the distributed water undergoes no treatment process, there is an increasing chance of contamination from the waste water in the drains. Microbial contamination has the potential to cause large outbreaks of waterborne diseases especially within community drinking-water supplies than in larger drinking-water supplies (WHO, 2008). Due to the health risk that a potential contamination may pose, it is important to investigate the microbial and physico-chemical quality of water reaching the tap at homes and water in the storage tank. It is also important to investigate the inhabitants' perception and opinions regarding the quality of their water supply. This study therefore sought to monitor water quality as water flows from the tank to the tap at individual homes.

1.3 Justification of study

Water remains the major source of transmission of enteric pathogens in developing countries (Egwari and Aboaba, 2002). From 1990–2004, 86 waterborne outbreaks were reported in Europe with a total of 72,546 cases, of which 341 were hospitalized and 1 died. In 33% of these outbreaks, contamination during distribution was the dominant cause of the outbreak (Van Lieverloo *et al*., 2006). There are so many water and sanitation diseases prevalent in Ghana and the country ranks second worldwide in guinea worm cases. Other water and sanitation related diseases include diarrhea, trachoma, cholera, hepatitis A, bilharzias, typhoid fever, malaria, polio, hookworm and tapeworm (WaterAid Ghana, 2013). According to WHO (2007), 88% of diarrheal diseases is attributed to unsafe water supply, inadequate sanitation and hygiene resulting in 1.8 million deaths, of which 1.5 million are children under the age of 5. It also estimates that 133 million people worldwide suffer from high intensity intestinal helminth infections, which causes around 9400 deaths every year. Access to safe drinking water will eliminate vast part of water-borne disease cases (Bartram and Cairncross, 2010). Due to the health impact of reported waterborne outbreaks, there has been an increasing public concern on the quality of drinking water delivered to households. It is expected that the quality of water supply reaching taps in households should meet acceptable standards. Results from this study will help guide managers of the Appiadu Community Water System to adopt effective and efficient methods in managing the water system.

1.4 Study objectives

The main objective of this study was to assess the quality of water supplied by the Appiadu Community Water System and consumers' perception on the quality of the water.

The specific objectives were to:

- ✓ determine the physico-chemical (pH, temperature, electrical conductivity, total dissolved solids, turbidity and total hardness) quality of water in the main reservoir and some selected household taps in the study area.
- ✓ determine the microbiological (total coliform, faecal coliform, total viable count and faecal enterococci) quality of water in the main reservoir and some selected household taps in the study area.
- ✓ To assess consumers' perception on the quality of water supplied to their homes.

CHAPTER TWO

LITERATURE REVIEW

2.1 The hydrological cycle

Water is a renewable resource which is unevenly distributed across the length and breadth of the earth. Water occurs as atmospheric water (precipitation), surface water (rivers, lakes and seas) and groundwater (soil moisture). It moves continually on the earth through the hydrological cycle which is a continuous exchange of water within the various components of the earth driven by the sun's energy. The hydrological cycle involves processes such as evaporation and transpiration (evapotranspiration), condensation, precipitation, and runoff. In this cycle, water evaporates from oceans and other water bodies and transpiration from land plants and animals into the atmosphere. The water vapour condenses in the air and falls to earth or ocean as precipitation, which runoff from the land usually reaching the sea. A significant amount of precipitation infiltrates and percolates the soil as a result of gravity to form groundwater, which usually occurs in the pores within the soil (USGS, 2013).

Groundwater and surface water (including rivers, lakes and streams) are the main sources of water for most of the world's inhabitants. As a result of human activities, the quality of most surface water sources has been compromised through pollution. Groundwater has excellent natural quality and is much less vulnerable to contamination than surface water due to the protective cover provided by the soil. Over 1.5 billion people worldwide depend on groundwater as their source of drinking water and many more will in the future (UNEP, 2002).

2.2 Access and challenges of water supply in Africa

Access to safe water supply is a basic right that every human should be entitled to, regardless of his economic situation. For developing countries, however, access to safe water remains a major challenge. The United Nations Millennium Development Goals (MDGs) number seven, target ten, aims to halve, by 2015 the proportion of the population without sustainable access to safe drinking water and sanitation. In order to achieve the MDG target 10 in Africa, the number of people served with safe drinking water will need to double. An estimated 350 million more people, half-rural and half-urban, will need to be served by 2015. A least cost estimate of the investment required to achieve the 2015 MDG for water is $20 billion ($1.5 billion per year), (WUP, 2000). Africa lurks behind other continents in terms of water supply and sanitation coverage.

More than 30% of Africans residing in urban areas currently lack access to adequate water services and facilities. In the year 2000, World Health Organisation (WHO) estimated that Africa contains 28% of the world's population without access to improved water supply and only 62% of the people in African countries have access to improved water supply (WHO, 2000).

The continuing increase in population growth and the lack of its corresponding increase in water infrastructure leads to increasing number of Africans without access to water supply. Inadequate government commitment in terms of the policies and funding as well as the weak economic situation hinders the development of the water supply sector (Nyarko, 2007).

The Water Utility partnership (WUP), for capacity building in Africa estimates that the absolute number of people without access to water services will double between

2001 and the year 2020 from 200 million to 400 million if drastic measures are not taken (WUP, 2001).

The constraints in addressing these challenges include political and financial factors. Inadequate political will to expand water supply coverage is one of the political challenges. It refers to the absence of political leadership to undertake reforms necessary to improve performance and attract investment and government commitment to allocate sufficient national resources to the sector (SIWI, 2005).

2.3 Access and challenges of water supply in Ghana

Although Ghana is naturally endowed with many water resources, the situation of access to safe drinking water supply by the populace is still a gloomy one. Ghana's water resources are primarily groundwater and surface water (including rivers, lakes and streams). Access to improved and safe drinking water source has improved considerably within the last decade for both rural and urban population, from 60.2 % and 88.2 % in 2001 to 80 % and 92.1 % in 2011, respectively (World Bank, 2013). This represents a major improvement in ensuring that a greater percentage of Ghanaians have access to safe drinking water. This achievement will also help prevent the incidences of water related diseases like guinea worm. In Ghana the main sources of water for households are pipe borne supply from treated water sources, untreated pipe borne water from groundwater sources, rivers, boreholes, wells and ponds, lakes and stream. One major challenge facing the water supply sector in Ghana is the inadequate investment in the sector by various governments over the years, which has led to dilapidated infrastructure. The World Bank estimates that half a billion dollars would be needed to resolve water supply problems in Accra alone; with another half a billion at least for the rest of the country (Hooker, 2008).

Increased population growth coupled with rapid urbanization has also resulted in widening of the demand and supply gap.

2.4 Components of water supply system

Drinking water supply systems usually comprise of a source of water, transmission or transportation of the potable water to community, a network of pipes and appurtenances (valves, bends, meters, reservoirs) known as the distribution systems that convey potable water to the consumers or customers. The source of water is either from a well field of boreholes or from surface water sources based on conventional treatment methods (Nyarko, 2007).

The water transmission system is made up of large diameter pipes that convey water from the treatment work or headwork to the community for distribution. The distribution network consists of small to medium sized pipes usually laid along the sides of the streets to allow households to tap using their service lines. The engineering aspects (hydraulic and engineering design) of water supply aim at the following:

- Water production of acceptable quantity and quality to meet the population needs.
- Adequate pressures, velocity and acceptable head loss within the network
- Engineering design to ensure that the potable water is transported efficiently to the community by selected appropriate pipe sizes (diameters) and appropriate pipe materials.
- Location and design of storage facilities to ensure that there will be adequate water supply during emergency situation break pressure tank in some case depending on the topography

- Reliable distribution system that ensure good quality of service. Criteria usually include adequate pressures, water quality and reliability of the services.

The exact nature of the water supply system may vary depending on a number of factors such as topography, availability of water resource and its quality. The nature of the water supply system gives rise to peculiar characteristics, which influence how the water system and the sector is organized (Nyarko, 2007).

2.5 Community water supply system

The CWSA policy defines a small town water system as a piped system serving communities of between 2,000 and 50,000 inhabitants who are prepared to manage their water supply systems in an efficient and sustainable manner (CWSA, 2003).

The major components of a typical small towns' water system comprises the source of water; which is usually a mechanized borehole with a submersible pump, a reservoir to hold the pumped water and a series of transmission and distribution pipelines to carry water to intended locations (Jonah, 2003).

2.6 Factors contributing to microbial quality deterioration in distribution system

Deterioration of drinking-water quality during storage or in distribution systems remains one of the major difficulties experienced by potable water suppliers. It is an established fact that the distribution system is often vital in determining the final quality of potable water. Pathogenic microbiological agents in drinking water have long been known to cause disease and death in consumers (Craun, 1986).

Factors contributing to deterioration of microbial quality may be associated with source water quality, biofilm formation, treatment processes, or distribution network operation and maintenance (Geldreich and LeChevallier, 1999).

2.6.1 Source Water Quality

Bacteria in distributed water may originate from the source water. High-quality groundwater can be characterized as containing less than 1 coliform per 100 mL and a heterotrophic bacterial population that is often very sparse (less than 10 organisms per mL), even in waters that reach the growth stimulating temperature of 15°C or more (Olson, 1982).

These microbial qualities show little fluctuation, because the groundwater aquifer is protected from surface contamination. Some groundwater, however, are not insulated from surface contamination (Allen and Geldreich, 1975). Agricultural fertilizer runoff can contribute nitrates, and improperly isolated landfills may introduce a variety of organics, many of which are biodegradable. In such situations, bacterial populations in the groundwater become excessive, resulting in 1000 to 10,000 heterotrophic bacteria per ml. Groundwater containing a high concentration of iron or sulfur compounds provides nutrients for a variety of nuisance bacteria that may become numerous and restrict water flow from a well. Where groundwater is poorly protected from contamination by stormwater runoff and wastewater effluents, coliforms and pathogens (bacterial, viral, protozoan) may be introduced into the distributed water unless a treatment barrier is provided (Craun, 1985).

Surface water sources are subject to a variety of microbial contaminants introduced by stormwater runoff over the watershed and the upstream discharges of domestic and industrial wastes. While impoundments and lakes provide water volume and buffering capacity to dilute bacterial contamination, counterproductive factors must be considered. Stratification/ destratification of lake waters, decaying algal blooms, and bacterial nutrient buildup contribute to deteriorating water quality that may interfere with treatment effectiveness (Geldreich and LeChevallier, 1999).

2.6.2 Treatment Processes

Water supplies using a single barrier (disinfection) for surface water treatment will not prevent a variety of organisms (algae, protozoa, and multicellular worms and insect larvae) from entering the distribution system (Allen *et al.*, 1980). While many of these organisms are not immediately killed by disinfectant concentrations and contact times (C·T values) that control coliforms and viruses (Hoff, 1986), they eventually die because of lack of sunlight (algae) or adverse habitat (multicellular worms and insect larvae). Disinfection is also less effective on a variety of environmental organisms that include spore-forming organisms (Clostridia), acid-fast bacteria, gram-positive organisms, pigmented bacteria, fungi, yeast, and protozoan cysts. All of these more resistant organisms can be found in the pipe environment (Haas *et al.*, 1983). Improperly operated filtration systems have been responsible for releasing concentrated numbers of entrapped cysts (Giardia and Cryptosporidium) as a result of improper filter backwashing procedures or filter bypasses and channelization within the filter bed (Amirtharajah and Wetgstein, 1980). Properly operated water treatment processes are effective in providing a barrier to coliforms and pathogenic microorganisms reaching the distribution system. This does not, however, preclude the passage of all nonpathogenic organisms through the treatment train. Microorganisms upon entering the pipe network, persistence and growth of these organisms will be influenced by the same factors that also affect disinfectant effectiveness: habitat locations, water temperature, pH etc. (Haas *et al.*, 1983).

2.6.3 Distribution Network Operation and Maintenance

Because the public health concern for the microbial quality of drinking water has until recently been based solely on limiting total coliform occurrence (EPA, 1976), the acceptance of new or repaired mains has depended only on a laboratory report that no coliforms are detected in water held in the new pipe sections. A more rigorous check on installed pipe cleanliness would include examination of water in the pipe section for elevated heterotrophic bacterial densities in addition to total coliforms (Geldreich *et al*., 1972). Soil deposits in new pipe sections may not only introduce a variety of heterotrophic bacteria to the distribution network but also provide some measure of protection to associated bacteria from disinfection exposure. In Halifax, Nova Scotia, a new supply line was found to contain pieces of wood used during construction work embedded in some pipe sections (Martin *et al.*, 1982).

2.6.4 Biofilm formation

The term "biofilm" is used to describe a layer of microorganisms in an aquatic environment held together in a polymetric matrix attached to a substratum such as pipes, tubercules or sediment deposits (Escher and Characklis, 1988). Biofilm development is a result of successful attachment and subsequent growth of micro-organisms on a surface. Under suitable conditions a biofilm develops, initially through the accumulation of organic matter on the metal surface, which is then colonised by bacteria (Wolfaardt and Archibald, 1990).

The small number of bacteria which can survive the water treatment process or bacteria already present in the distribution system provides a seed which will multiply in the distribution system given the right conditions for growth. The conditions which will enhance growth include factors such as the disinfectants used and the maintenance of a residual concentration in the system, the resistance of micro-organisms to disinfectants, the nature and concentration of biodegradable compounds in the treated drinking water, the kind of piping material used in the system as well as the water temperature (Momba *et al.*, 2000).

The microbial composition of potable water reflects the microflora characteristics of the raw water source. These may be broadly classified into four groups: bacteria, viruses, protozoa and fungi. Biofilm serves as a focal point where bacteria and other microorganisms interact (Colbourne *et al.*, 1988).

Several investigators have shown that the multiplication of micro-organisms in biofilms along the distribution systems results in the deterioration of the bacteriological quality of drinking water, the development of odour or colour as well as the acceleration of the phenomenon of corrosion within the pipework (Nagy and Olson, 1985).

Plate 1: Biofilm growth inside a pipe (Source: Raju *et al.*, 2010)

2.7 Water Quality Indicators

Water quality indicators include physical, chemical, and biological measurements that are used to describe the condition of a water source. Water quality determines the suitability and 'goodness' of water for particular purposes. Parameters that may be tested for drinking water include temperature, pH, turbidity, salinity, conductivity, total hardness, concentration of organic and inorganic compounds, total coliform and faecal coliform (McCaffrey, 2010).

2.7.1 Turbidity

Turbidity is an expression of the scattering and absorption of light through water. The presence of clay, silt, fine organic and inorganic matter, soluble colored organic compounds, and plankton and other microscopic organisms' increases turbidity. High turbidity can increase the cost of water treatment for drinking water. Turbidity is affected by several factors in water: presences of dissolved and suspended solids, size and shape of particles and composition of the particles. Though high turbidity is often a sign of poor water quality and land management, crystal clear water does not always guarantee healthy water. Extremely clear water can signify very acidic conditions or high levels of salinity. Turbidity is measured with an instrument call turbidimeter, and the readings are expressed as nephelometric turbidity units (NTU). A turbidity value of 10 is generally accepted for drinking water (MPCA, 2008).

2.7.2 pH

pH is a measure of the hydrogen ion concentration of water, and is used to indicate degree of acidity or alkalinity of water. The pH scale ranges from 0 to 14 standard units (SU). A pH of 7 is considered neutral, with values less than 7 being acidic, and values greater than 7 being basic (Shelton and Scibilia, 2005). The pH is of major importance in determining the corrosivity of water (Nordberg *et al.*, 1985) and can be used as a proxy of water quality conditions.

Careful attention to pH control is necessary at all stages of water treatment to ensure satisfactory water clarification and disinfection. For effective disinfection with chlorine, the pH should preferably be less than 8. The pH of the water entering the distribution system must be controlled to minimize the corrosion of water mains and pipes in household water systems. Failure to do so can result in the contamination of drinking-water and in adverse effects on its taste, odour, and appearance. The optimum pH will vary in different supplies according to the composition of the water and the nature of the construction materials used in the distribution system, but is often in the range 6.5 to 8.5 (WHO, 2011).

2.7.3 Colour

Ideally, drinking water should be clear and colourless. A change in colour in drinking water may be the first indication of a water quality problem. The presence of colour in drinking water may be indirectly linked to health, although its primary importance in drinking water is aesthetic. Colour in water may indicate natural substances in the water supply, including; dissolved organic matter such as humic substances, tannin, lignin, or coal and inorganic materials such as iron, manganese, copper, or zinc. Colour in drinking water may also indicate inadequate water treatment or the presence of surface or subsurface contaminants in the water supply. Relative colour intensity in water samples is measured using an arbitrary scale and the units are called true colour units (TCU) (www.gov.ns.ca). Most people can detect colour above 15 TCU in a glass of water. Levels of colour below 15 TCU are often acceptable to consumers. High colour from natural organic carbon (e.g. humics) could also indicate a high propensity to produce by-products from disinfection processes. No health-based guideline value is proposed for colour in drinking-water (WHO, 2011).

Table 1: Colour in drinking water and its indication

Colour	Indication
Red-brown	Red, brown, or rusty coloured staining may indicate iron in well water. Adverse health effects are not expected at levels normally found in drinking water.
Black	Brownish-black stains might be due to manganese in drinking water. Adverse health effects are not expected at levels normally found in drinking water.
Yellow-brown	Humic substances, tannin, and lignin can impart a yellowish to brownish colour in water. Humic substances, tannin, and lignin are not believed to be harmful to human health. However, their presence in drinking water may mean other surface contaminants are also present.
Green or blue	A green or blue colour is generally the result of water coming in contact with copper, often in the plumbing system. Very high concentrations of copper can cause nausea and other gastrointestinal discomforts.
White	Water with a high concentration of zinc tends to have an opalescent (milky) appearance. Short-term exposure (over days or weeks) to very high levels of zinc can result in nausea and diarrhea.

Source: www.gov.ns.ca

2.7.4 Electric Conductivity

The ability of water to conduct electric current is a measure of its conductivity. Conductivity is directly related to the total dissolved salt content of the water. This is so because the salts dissolve into positive and negative ions and can conduct electric current proportional to their concentration. It is reported in microsiemens per centimetre (μS/cm) using a conductivity meter.

2.7.5 Temperature

The importance of temperature as a determinant of water quality is derived mainly from its relationship with other water quality parameters. Most of these relationships have a bearing on the aesthetic aspects of water quality; some are indirectly related to health (www.hc-sc.gc.ca). Cool water is generally more palatable than warm water, and temperature will have an impact on the acceptability of a number of other inorganic constituents and chemical contaminants that may affect taste. High water temperature enhances the growth of microorganisms and may increase problems related to taste, odour, colour and corrosion (WHO, 1996).

2.7.6 Total dissolved solids

The palatability of water with a total dissolved solids (TDS) level of less than about 600 mg/l is generally considered to be good; drinking water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000 mg/l. The presence of high levels of TDS may also be objectionable to consumers, owing to excessive scaling in water pipes, heaters, boilers and household appliances. No health-based guideline value for TDS has been proposed (WHO, 2011).

2.7.7 Hardness

Hardness caused by calcium and magnesium is usually indicated by precipitation of soap scum and the need for excess use of soap to achieve cleaning. Consumers are likely to notice changes in hardness. Public acceptability of the degree of hardness of water may vary considerably from one community to another. The taste threshold for the calcium ion is in the range of 100–300 mg/l, depending on the associated anion, and the taste threshold for magnesium is probably lower than that for calcium. In some instances, consumers tolerate water hardness in excess of 500 mg/l. Depending on the interaction of other factors, such as pH and alkalinity, water with hardness above approximately 200 mg/l may cause scale deposition in the treatment works, distribution system and pipework and tanks within buildings. It will also result in high soap consumption and subsequent "scum" formation. On heating, hard waters form deposits of calcium carbonate scale. Soft water, but not necessarily cation exchange softened water, with a hardness of less than 100 mg/l may, in contrast, have a low buffering capacity and so be more corrosive for water pipes. No health-based guideline value is proposed for hardness in drinking-water (WHO, 2011).

2.7.8 Faecal Coliform

Coliform bacteria are present in the digestive tract and faeces of all warm-blooded animals, including humans, poultry, livestock, and wild animal species. Faecal coliform bacteria are themselves generally not harmful, but their presence indicates that the water source may be contaminated with faecal matter. Fecal coliforms are a good indicator of contamination from human or other animal waste products and they indicate greater risk of exposure to pathogenic organisms than total coliforms. *Escherichia coli* is considered the most suitable index of fecal contamination. *E. coli* are the first organism of choice in monitoring programs for verification, including surveillance of drinking-water quality. Water temperatures and nutrient concentrations are not generally elevated enough within the distribution system to support the growth of *E.coli* (or enteric pathogenic bacteria) in biofilms. Thus, the presence of *E.coli* should be considered as evidence of recent fecal contamination. Detection of *E.coli* should lead to consideration of further action, which could include further sampling and investigation of potential sources such as inadequate treatment or breaches in distribution system integrity (WHO, 1996). The fecal *streptococci* is another indicator microorganism that is also used in detecting fecal contamination. *Streptococci* has a greater survival rate in water than other fecal coliforms.

2.7.9 Total Coliform

The total coliform group is an amalgamation of different kinds of bacteria which are the standard by which microbial contamination is measured. Coliforms are usually one of the first bacteria present in water should contamination occur and therefore coliforms act as indicators of possible contamination. Coliform bacteria detect both non-pathogenic and disease-producing bacteria. Since the identification of specific disease-producing micro-organisms is difficult, total coliform is often used as an indicator of the water possibly containing disease-producing organisms that normally live in the intestinal tracts of man and warm-blooded animals (Driscoll, 1986).

2.8 Some important pathogens in water system

The four major types of pathogenic organisms that can affect the safety of drinking water are bacteria, viruses, protozoa and occasionally worm infections. These pathogenic agents are directly transmitted to people when the infected water is used for drinking and other purposes. Typhoid, cholera and dysentery are caused by bacteria and protozoa. Diseases caused by viruses include infectious hepatitis and polio.

2.8.1 Salmonella

Salmonella are the most predominant pathogenic bacteria (about 200 serotypes) in wastewater; they cause typhoid and paratyphoid fever, and gastroenteritis. About 0.1% of the human population excretes *Salmonella* at any given time, and the disease is usually contracted through food contamination but its transmission by drinking water remains a great concern. According to Abantanga *et al*. (2009), typhoid fever was identified as the most frequent cause of abdominal surgery in children, responsible for 68% of all acute surgical abdomens in children between 1 and 15 years of age in Ghana. Municipal sewage, agriculture pollution remains the main sources of these pathogens in natural waters (Cabral, 2010) and the organism are normally found at highest concentrations in drinking water sources in Africa at the onset of the wet season (Morpeth *et al*.,2009). An outbreak of 42,564 cases of typhoid fever was reported in the Democratic Republic of Congo, between September 2004 and early January 2005 (Cabral, 2010). A study conducted by Shrestha *et al*. (2009), reported the occurrence of Salmonella in drinking water samples of urban water supply system of Kathmandu, Nepal. The presence of the organism can be controlled through adequate water treatment process (eg. chlorination, filtration).

2.8.2 Shigella

Shigella causes bacillary dysentery, a diarrhea disease that produces bloody stools as a result of inflammation and ulceration of the intestinal mucosa. Four pathogenic examples are *S. flexneri, S. dysenteriae, S. boydii* and *S. sonnei*. The disease is contracted by contact with an individual, who might excrete 10^9 cells per gram wet of faeces, but food borne and waterborne transmission have also been documented; no quantitative data are available on its occurrence and removal in water and waste water treatment plants because the organism is difficult to cultivate.

2.8.3 Escherichia coli (E. coli)

Escherichia coli (E. coli) bacteria normally live in the intestines of people and animals. Most *E. coli* are harmless and actually are an important part of a healthy human intestinal tract. However, some *E. coli* are pathogenic, meaning they can cause illness, either diarrhea or illness outside of the intestinal tract. The types of *E. coli* that can cause diarrhea can be transmitted through contaminated water or food, or through contact with animals or persons. *E. coli* consists of a diverse group of bacteria. Pathogenic *E. coli* strains include; Enterotoxigenic *E. coli* (ETEC), Enteropathogenic *E. coli* (EPEC), Enteroaggregative *E. coli* (EAEC), Enteroinvasive *E. coli* (EIEC) and Diffusely adherent *E. coli* (DAEC) (www.cdc.gov).

2.8.4 Vibrio cholera

Vibrio cholera is almost exclusively transmitted by water .It releases an enterotoxin that causes mild to profuse diarrhea, vomiting and a very rapid loss of fluid, and may result in death a relative short period of time. It may be found in waste water at levels of 103 – 104 cells per 100 ml of the waste water during a cholera epidemic. The bacterium is also naturally present in the environment and attaches to solids, including zooplankton (copepods) and phytoplankton.

Between January and March 2012, a total of 15,270 cases of cholera and 268 deaths were reported from 15 African countries including Ghana. Ghana recorded 375 cases and 7 deaths (WHO, 2012).

2.8.5 Helminths

Helminths are parasitic worms that grow and multiply in sewage and wet soil. They enter the body by burrowing through the skin, or by ingestion of the worm in one of its many lifecycle phases. The eggs as well as the adult and larval forms of the worms are large enough to be trapped during conventional water treatments, so they tend not be a problem in water systems (DeZyane, 1990). In addition, most of these helminths are not waterborne, so chances of infection are minimized. Drinking water is usually not tested for these, as they are not considered to be much of an issue in the United States; they are more prevalent in developing countries (WHO, 1996).

2.8.6 Hepatitis A

Hepatitis A is an enteric virus that is very small. It can be transferred through contaminated water, causing outbreaks (DeZyane, 1990). The virus is excreted by a person carrying it, and if the sewage contaminates the water supply, then the virus is carried in the water until it is consumed by a host. Symptoms such as an inflamed liver, accompanied by lassitude, anorexia, weakness, nausea, fever and jaundice are common. A mild case may only require a week or two of rest, while a severe case can result in liver damage and possible death (WHO, 1996). Generally, water systems utilize chlorination, preceded by coagulation, flocculation, settling and filtration to remove the virus (DeZyane, 1990).

2.8.7 Giardia Lamblia

Giardia is a microscopic parasite that causes the diarrheal illness known as giardiasis. *Giardia* is found on surfaces or in soil, food, or water that has been contaminated with feces from infected humans or animals. *Giardia* enters the water supply via contamination by fecal material (www.cdc.gov). The disease is characterized by symptoms such as diarrhea, abdominal cramps, nausea, weight loss, and general gastrointestinal distress. *Giardia* is protected by an outer shell that allows it to survive outside the body for long periods of time. While the parasite can be spread in different ways, water (drinking water and recreational water) is the most common method of transmission. It has been suggested that 40-45% of *giardia* cases are associated with exposure to unfiltered water (WHO, 1996).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location

This study was conducted at Appiadu a peri-urban area and the control community used for the survey section of this study was Asafo, an urban area. Both areas are located within Kumasi, the capital of Ashanti Region of Ghana (Figure 1). Kumasi covers an area of about 245 km^2 and is located in the transitional forest zone and is about 270 km north of the national capital, Accra. It is between latitude 6.35° and 6.40°and longitude 1.30° and 1.35° and lies within the wet semi-equatorial zone marked by double maximum rainfall ranging between 1150 mm and 11750 mm per annum. The major rainfall season is from April to July and the minor season is between September and Mid-November.

Ghana Urban Water Limited (GUWL) is responsible for supplying pipe borne water to the numerous urban and peri-urban areas within Kumasi but the rapid expansion of the city coupled with other infrastructure deficiencies of GUWL have led to intermittent and irregular supplies and in many cases a total lack of water in the communities. This situation has resulted in many communities resorting to streams, rivers and groundwater as sources of potable / domestic water.

MAP OF ASHANTI REGION

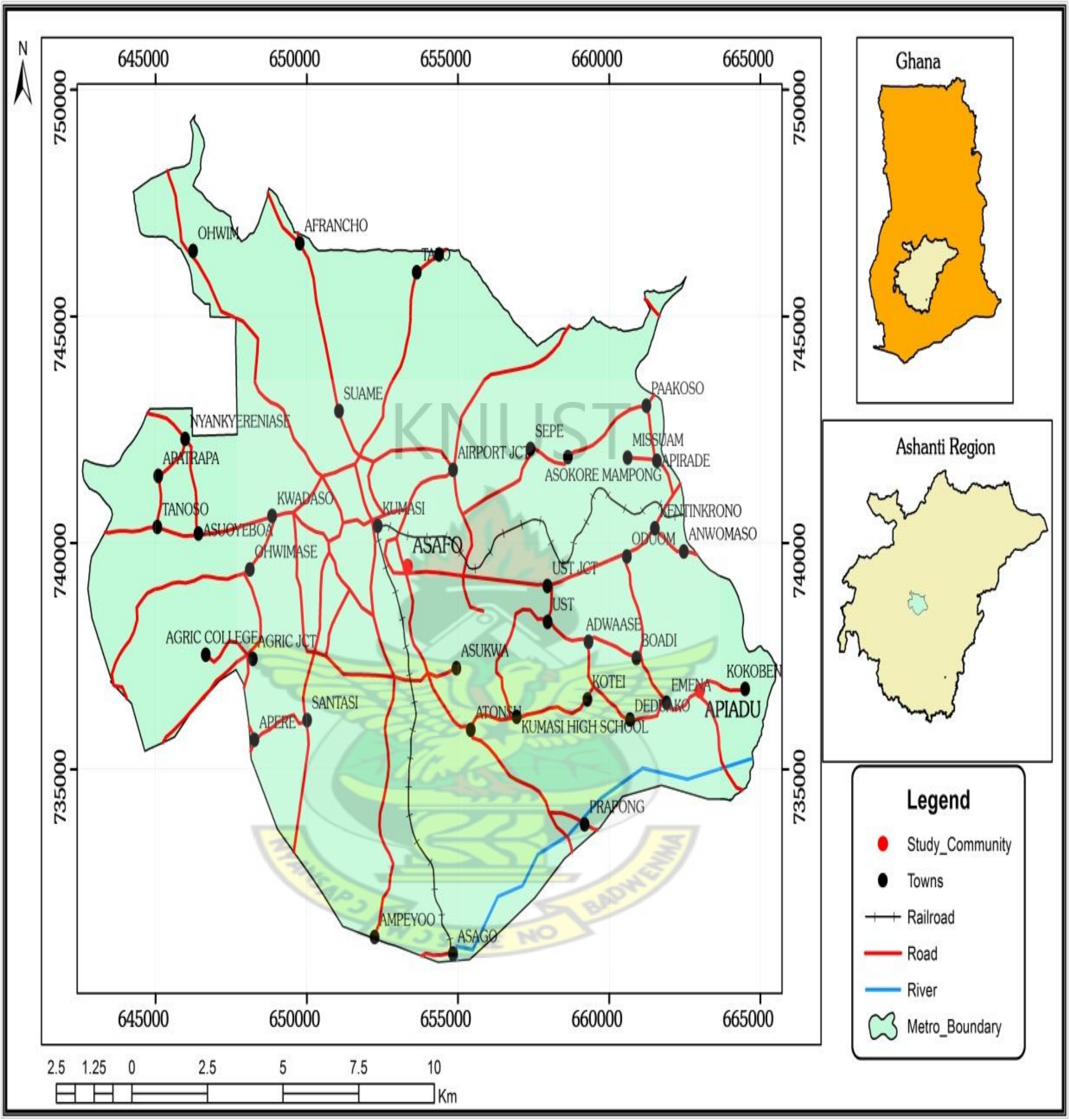

Figure 1: Map of Ashanti Region showing the study areas

3.1.2 Historical background of Appiadu Community Water System

Before the year 2009, Appiadu was prone to guinea worm infection, a water-borne disease, which had tremendous adverse effect on the health of the inhabitants. Consequently in 2009, through the community's own efforts and in partnership with the erstwhile Ghana Water Company Limited (GWCL), pipe borne water was extended to the area. However, this supply of water to the area was irregular and, coupled with lack of maintenance of the pipelines, resulted in the community reverting to the guinea worm-infested streams and, hence the return of the disease (Akrofi and Whittal, 2011). Later the community sought technical assistance from GWCL to sink a borehole to supply water. Electricity was extended to the borehole site and a reservoir was later installed to store the pumped water. Distribution pipelines were also laid and connected to the already existing GWCL pipelines to supply water from the reservoir to individual homes in the community. In 2005, two new additional boreholes were constructed to complement the existing one. The community currently has three (3) boreholes, with 2 in operation and 1 serving as a backup in case of any eventuality. Plate 2 shows one of the boreholes used to draw groundwater in Appiadu. The community has also procured a diesel power plant to power the pumps in case of power outage. The community's water system is solely the initiative of the community, and not under the Community Water and Sanitation Department (CWSD) of GWCL. Households that are connected to the water system pay a fixed monthly charge for this service.

The supply lines which carry water to connected households and the community standpipes are opened early in the morning at 5 am and closed at 10 am. Pumping subsequently follows till 2 pm to allow for refill of the reservoir. The supply lines are once again opened till 7 pm when it is closed for refill to meet the next day's supply.

Plate 2: Borehole with pump used to draw groundwater in Appiadu

3.2 Data collection

3.2.1 Selection of sampling points

A total of 30 water samples were collected from the main reservoir (tank) and 5 households' taps in Appiadu from April to June, 2013. Microbiological and physico-chemical analysis were conducted on the samples from each of the sampling points and repeated five times. Table 2 below shows the frequency of sampling and sampling points.

Table 2: Water sampling points for microbiological and physico-chemical analysis

Sampling point	Code	Frequency of sampling		Total number of sample
		Microbiological Analysis	Physico-chemical Analysis	
Tank	APT	5	5	5
Household 1	AP1	5	5	5
Household 2	AP2	5	5	5
Household 3	AP3	5	5	5
Household 4	AP4	5	5	5
Household 5	AP5	5	5	5

Sampling was conducted at two weeks interval. The five households were selected using judgmental sampling from seven households that had their pipelines running through the main drainage system in Appiadu. These distribution mains are exposed resulting in frequent leaks and bursts and therefore making them possible points of contamination. Plate 3 shows a series of distribution pipelines running through the main drains in the sample area.

Plate 3: Series of distribution pipelines running through the main drains in Appiadu.

3.2.2 Collection of water samples for physico-chemical analysis

Samples for physico-chemical analysis were stored in clean 500 ml plastic bottles. The PC 300 Waterproof Handheld pH/Conductivity/TDS/Temperature meter used on-site was calibrated before use. On-site analyses were carried out for parameters like pH, temperature, TDS and electric conductivity (EC) whilst total dissolved solids, turbidity and total hardness were analyzed at the Civil Engineering Laboratory of the Kwame Nkrumah University of Science and Technology (KNUST).

3.2.3 Collection of water samples for microbiological analysis

Samples for microbiological analysis were also collected in sterilised 500 ml plastic bottles. Extra care was taken when sampling water supplies for the microbial analysis because of the risk of contaminating the sample from hands and other surfaces during collection and subsequent handling. Prior to filling, the sample bottles were rinsed two to three times with the water to be collected. The spout of the taps was cleaned with methanol for 30-60 seconds before sampling. Samples were taken after allowing the tap to flow for about 1 minute to avoid the use of stagnant water in the pipes. Collected samples for microbial analysis were preserved in an ice chest at 4°C and taken to the Department of Theoretical and Applied Biology of KNUST laboratory for immediate analysis.

3.3 Inhabitants or Consumer Perception Survey

3.3.1 Purpose of survey

The purpose of this survey was to assess the perception of local residents of Appiadu on the quality of their water supply. Asafo, a suburb in Kumasi was subsequently selected as a case-control urban community. A comparative study based on perceptions of the peri-urban and urban areas on their water quality was carried out and information from the two areas was analysed.

3.3.2 Survey Design and Sampling

Structured questionnaires designed for households included both open-ended and closed questions. A total of 200 questionnaires were administered to people in both peri-urban (100 questionnaires) and urban (100 questionnaires) communities to assess information on consumer response to water quality and the perception of water management. These numbers were thought to offer a good representation of the population of households and a tolerable level of accuracy. Households were selected at random and interviewed. The questions included basic socio-demographic questions (including sex, age, marital status, educational level and reported monthly household income). The questions also aimed at seeking information regarding household water usage patterns and households hygiene behaviour as perceived by respondents in the study areas.

3.3.3 Survey Data Analysis

The study was based on qualitative and quantitative methods of data analysis. Chi-square test was used to test for significance between categorical variables. Questionnaires were entered manually into Microsoft Excel 2010 and analysed using the GraphPad Prism®. Chi-square test was used to examine associations between dichotomous variables from respondents in peri-urban compared to the control. Two-tailed tests were used with $p < 0.05$ considered significant.

3.4 Physico-chemical Analysis of water sample

The physico-chemical parameters that were determined were pH, Temperature, Conductivity. Total dissolved solids, Turbidity and Total hardness.

3.4.1 Temperature, pH, TDS and EC

The PC 300 Waterproof Handheld pH/Conductivity/TDS/Temperature meter was used in measuring the above parameters. A digital reading appears upon inserting the probes into the sample indicating first the values of pH and temperature. The sample was stirred and the digital reading allowed to stabilise before recording. The "MODE" button which allows switching to other parameters was then used to read the values of TDS and EC.

3.4.2 Total Hardness

100 ml of the sample was pipetted into a 500 ml Erlenmeyer flask. With a dispenser, 1.0 ml of NH_4CL-NH_4OH buffer mixture of pH 10 containing Mg- EDTA was added

to the sample. 5 drops of eriochrome black T indicator was also added to sample. The solution was titrated immediately but slowly with EDTA and stirred continuously until the colour changed from wine-red to blue. The total hardness was calculated as mg $CaCO_3$/L.

$$\text{Total harness (mg/l)} = (\text{V x M x 100}) \text{ x } \frac{1000}{\text{ml sample}}, \quad \text{where}$$

V = ml EDTA titrated

M = molarity of EDTA

100 = molecular mass of calcium carbonate

1000 = factor

3.4.3 Turbidity

The Hanna turbidity meter (HI 93414 model) was used for turbidity measurement. Formazine standard solution made up of hydrazine sulphate ((NH)2.H2SO4) and hexamethylenetetramine (C6H12N4) was used to calibrate the meter. A clean, dry glass cuvet was filled with 10 ml of the sample. Silicone oil was applied on the cuvet and wiped with a lint-free cloth to obtain an even film over the entire surface of the cuvet. The cuvet was placed into its holder in the Hanna HI 93414 turbidity and free/total chlorine meter with its mark aligned with that of the instrument. The turbidity range was selected. When READ/ENTER was pressed, the display showed blinking dashes, after which the result in NTU was displayed and recorded accordingly.

3.5 Microbial Analysis of water sample

3.5.1 Total and Faecal coliforms

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

3.5.2 E. coli

From each of the positive tubes identified for total and faecal coliforms, a drop was transferred into a 5 ml test tube of trypton water and incubated at 44°C for 24 hours. A drop of Kovacs' reagent was then added to the tube of trypton water. All tubes showing a red ring colour development after gentle agitation denoted the presence of indole and recorded as presumptive for *E.coli*. Counts per 100 ml were calculated from the MPN table.

3.5.3 Total Viable Count

Viable counts were isolated and enumerated by pour plate method and growth on plate count agar (PCA). Serial dilutions of 10^{-1} to 10^{-4} were prepared by diluting 1 g of the caecum into 10 ml of sterilized distilled water. One millilitre aliquots from each of the dilutions were inoculated into petri dishes with already prepared PCA. The plates were then incubated at 35°C for 24 hours. After incubation all white spot or spread were counted and recorded as total viable counts using the colony counter.

3.5.4 Faecal enterococci

Serial dilutions of 10^{-1} to 10^{-4} were prepared by picking 1 ml of the sample into 9 ml sterile distilled water. One millilitre aliquots from each of the dilutions were inoculated on a Slanetz and Barltey Agar prepared on sterile Petri dishes. The Petri dishes were pre-incubated at a temperature of 37°C for 4 hours to aid bacterial resuscitation. The plates were then incubated at 44°C for a further 44 hours. After incubation, all red, maroon and pink colonies that were smooth and convex were counted and recorded as *faecal enterococci*.

3.5.5 Salmonella

10 ml of manufactured formula of Buffered peptone water (BPW) was prepared in a universal bottle and serial dilution of samples was added to it. It was then incubated at 37°C for 24 hours. 0.1 ml of the sample from the BPW was placed in a 10 ml of selenite broth in universal bottle and incubated at 44°C for 48 hours. Swaps from the bottle was transferred onto SS agar and incubated at 37°C for 48 hours. Black colonies on the SS agar would have indicated the presence of *salmonella*.

CHAPTER FOUR

RESULTS

4.1 Physico-chemical parameters of the water samples

The mean pH values of the water samples ranged from 5.166±0.37 to 5.618±0.56. Water samples from the tank (APT) recorded the lowest mean pH level whilst AP1 recorded the highest mean. The pH levels were below the WHO/GSA optimum limits of between 6.5 and 8.5.

Mean temperature of the water samples also ranged from 28.60±0.94 to 30.78±4.35°C as shown in Table 3. AP3 recorded the lowest mean temperature whilst AP5 recorded the highest. There is no guideline value for temperature set by WHO and GSA.

The mean conductivity values ranged from 304.4±7.96 to 308.8±4.15 µS/cm. The highest mean conductivity was recorded at AP5 with AP2 recording the lowest. The observed values for conductivity were within the WHO/GSA permissible limits.

For TDS, mean concentrations of the water samples ranged from 152.6±3.85 to 154.4±2.07 mg/l as illustrated in Table 3. AP2 recorded the lowest mean concentration of TDS with AP5 recording the highest.

Also, mean turbidity was within a range of 0.370±0.21 to 0.694±0.43 NTU which were within the WHO/GSA permissible limits. The lowest mean level was observed at AP3 with AP1 recording the highest mean level.

With respect to total hardness, mean levels for the samples ranged from 81.6±9.21 to 88.8±8.56/4.60 mg/l which was below the WHO/GSA guideline value. The lowest mean level was recorded at AP1 whilst samples from APT and AP3 recorded the highest mean levels.

Table 3: Mean levels of physico-chemical parameters of the water samples from Appiadu

Parameter	APT		AP1		AP2		WHO (2011)/ GSA
	Mean	SD	Mean	SD	Mean	SD	
Ph	5.1	0.369	5.6	0.5639	5.4	0.1508	6.5-8.5
Temperature(°C)	28.7	0.965	28.7	0.8503	28.7	0.9138	-
Conductivity (µS/cm)	306.8	5.450	306.0	4.416	304.4	7.925	1000
TDS (mg/l)	153.6	2.702	153.2	2.168	152.6	3.847	1000
Turbidity (NTU)	0.616	0.715	0.694	0.4318	0.588	0.4012	5.0
T. Hardness (mg/l)	88.8	8.556	81.6	9.206	86.8	8.319	500
Parameter	**AP3**		**AP4**		**AP5**		**WHO (2011) GSA**
	Mean	SD	Mean	SD	Mean	SD	
pH	5.3	0.387	5.2	0.4237	5.3	0.3493	6.5-8.5
Temperature(°C)	28.6	0.943	28.6	0.8849	30.7	4.3490	-
Conductivity (µS/cm)	304.8	4.494	307.4	1.817	308.8	4.147	1000
TDS (mg/l)	152.8	2.280	154.0	0.707	154.4	2.074	1000
Turbidity (NTU)	0.370	0.213	0.380	0.1606	0.426	0.2392	5.0
T. Hardness (mg/l)	88.8	4.604	83.2	6.261	87.2	8.672	500

SD: Standard Deviation

4.2 Total / faecal coliform, total viable count and faecal enterococci in the water samples

The mean total coliform, faecal coliform, faecal enterococci and total viable count numbers present in the water samples at the various sampling points ranged from

$1.29 \times 10^5 – 1.95 \times 10^6$ cfu/100 ml, $1.60 \times 10^4 – 1.29 \times 10^5$ cfu/100 ml, 0 – 1.28×10^2 cfu/100 ml and $1.65 \times 10^3 – 4.87 \times 10^4$ cfu/100 ml respectively as shown in Table 4. Water samples from APT recorded the lowest mean level of total coliform and total viable count whilst AP1 recorded the highest level of total coliform and total viable count. With respect to faecal coliform, AP2 had the lowest number, with AP1 recording the highest coliform number. Subsequently, the presence of faecal enterococci was higher at AP4 whilst the water samples from APT, AP1 and AP5 recorded no incidences of faecal enterococci.

Table 4: Mean values of total/faecal coliform, total viable count and faecal enterococci in the water samples

Parameter	APT		AP1		AP2		WHO(2011)/ GSA
	Mean	Log of mean	Mean	Log of mean	Mean	Log of mean	
Total coliform	1.29×10^5	5.11	1.95×10^6	6.29	1.01×10^5	5.00	0
Faecal coliform	1.60×10^4	4.20	1.29×10^5	5.11	1.80×10^4	4.26	0
Total viable count	1.65×10^3	3.22	4.87×10^4	4.69	4.48×10^3	3.65	0
Faecal enterococci	0	0.00	0	0.00	2×10^1	1.30	0

Parameter	AP3		AP4		AP5		WHO(2011)/ GSA
	Mean	Log of mean	Mean	Log of mean	Mean	Log of mean	
Total coliform	1.45×10^5	5.16	5.29×10^5	5.72	2.75×10^5	5.44	0
Faecal coliform	1.80×10^4	4.26	4.60×10^4	4.66	1.80×10^4	4.26	0
Total viable count	1.44×10^4	4.16	4.31×10^4	4.63	2.25×10^4	4.35	0
Faecal enterococci	5.20×10^1	1.72	1.28×10^2	2.11	0	0.00	0

All values in cfu/100 ml

4.3 Perception Survey

4.3.1 Survey Population Demographic

In this study, participants who responded to structured questions consisted of males and females aged 6 years and older shown in Table 5. Fewer proportions of peri-urban dwellers were single and educated to levels as high as tertiary. Majority of the peri-urban respondents (24%) had at least primary education compared to the control (6%) and this was statistically significant as shown in Table 5. Majority of these peri-urban respondents were farmers with fewer proportion employed as civil servants. Analysis of respondents questionnaire of demographic data based on age with respect to the type of settlement showed, there were about 2 times more study subjects in the peri-urban localities (14%) with ages ranging between 16-20 years compared to their urban counterpart (7%) (OR = 2.163). This was, however, not significant ($p = 1.064$) as shown in Table 5. This was also seen with the older population (i.e. age >50 years). The study also showed that lesser proportions of the peri-urban settlements were single (31%) compared to their urban counterparts and this was significant ($p < 0.0001$). The marital population within the peri-urban settings were, however greater (42%) compared to their urban counterpart (31%) but this was not significant as shown in Table 5 ($p = 1.612$).

Educational level stratification based on settlement types during the study showed that greater proportion of peri-urban dwellers (9%) had never been to school compared to their control (2%). This was, however, not statistically significant ($p = 0.0299$) (Table 5). When the occupational status of the respondents were compared, the study showed that majority of peri-urban subjects who responded to the questionnaires were farmers (19%) compared to their urban counterparts (control) (0%) and this was significant ($p < 0.0001$) as shown in Table 5 below.

Table 5: Stratification of Respondents' Demographic Data among Peri-urban and unban Inhabitants

Variable	% Peri-urban (100)	% Urban (100)	p-value	Odds ratio (OR)
Age				
6 to 15	0 (0)	1 (1)	0.3161	0.33
16 to 20	14 (14)	7 (7)	0.1064	2.163
21 to 50	64 (64)	83 (83)	0.0023	0.3641
Above 50	22 (22)	9 (9)	0.0248	1.444
Sex				
Male	43 (43)	48 (48)	0.4777	0.8173
Female	57 (57)	52 (52)	0.4777	1.224
Marital Status				
Married	42 (42)	31 (31)	0.1062	1.612
Single	31 (31)	59 (59)	< 0.0001	0.3122
Divorced	18 (18)	6 (6)	0.009	3.439
Widowed	9 (9)	3 (3)	0.074	3.198
Separated	0 (0)	1 (1)	0.3161	0.33
Educational level				
Primary	24 (24)	6 (6)	0.0004	4.947
JHS/MSLC	47 (47)	28 (28)	0.0055	2.28
Tertiary	4 (4)	32 (32)	< 0.0001	0.08854
SHS	13 (13)	31 (31)	0.0021	0.3326
Never Been To Sch.	9 (9)	2 (2)	0.0299	4.846
Tech/Comm/Voc	3 (3)	1 (1)	0.3124	3.062
Occupation				
Farmer	19 (19)	0 (0)	< 0.0001	48.09
Trader	11 (11)	11 (11)	1	1
Unemployed	28 (28)	26 (26)	0.7501	1.107
Gov't Worker	2 (2)	14 (14)	0.0018	0.1254
Self-Employed	40 (40)	41 (41)	0.8855	0.9593
None Of The Above	0 (0)	8 (8)	0.0039	0.05414

4.3.2 Consumers' perception on water quality and satisfaction

The study also sought to compare the water usage behaviour of the respondent population based on whether a subject lived in a peri-urban or an urban area. Analysis of the results after the interview showed that, with respect to water treatment, fewer proportions of peri-urban dwellers (5%) subject their water for drinking and for domestic purposes to some form of treatment (filtration) before use compared to their urban control (18%). This was statistically significant ($p = 0.004$) as shown in Table 6 below. The storage of domestic water in plastic containers before usage was however evenly distributed among both peri-urban and their urban control ($p = 0.0093$) (Table 6).

Fewer proportions of peri-urban settlers (50%) perceived debris settled at the bottom of their storage container when kept for some time before use compared to their peri-urban counterpart (77%) and this was significant ($p < 0.0001$). These fewer proportions of peri-urban dwellers (7%) however, did not have any concerns with the taste of the water during drinking or usage for cooking and other domestic purposes compared to the urban dwellers (35%) ($p < 0.0001$). Greater proportions of the peri-urban consumers (93%) and (97%) did not object negatively with respect to the taste and smell, respectively of their drinking water compared to the urban ($p < 0.0001$) ($p < 0.0001$) as shown in Table 6 below.

Fewer proportions of the peri-urban population (0%) answered in the affirmative to questions relating to concerns of the colour of their drinking water compared to the urban settlement as shown ($p < 0.0001$) (Table 6).

Table 6: Respondents perception on satisfaction of water stratified by location

Variable	% Peri-urban (100)	% Urban (100)	p-value	Odds ratio(OR)
Is your water treated before drinking?				
Yes	5 (5)	18 (18)	0.004	0.2398
No	95 (95)	80 (80)	0.0013	4.75
Don't know	0 (0)	2 (2)	0.1552	0.196
Do you store water in a container before use?				
Yes	97 (97)	86 (86)	0.0093	5.264
No	3 (3)	14 (14)	0.0447	0.2784
If yes, do you see sediments at the bottom of the container?				
Yes	50 (50)	77 (77)	< 0.0001	0.2987
No	47 (47)	6 (6)	< 0.0001	13.89
Don't know	0 (0)	3 (3)	0.081	0.1386
Do you have any concern about the taste of the water?				
Yes	7 (7)	35 (35)	< 0.0001	0.1398
No	93 (93)	60 (60)	< 0.0001	8.857
Don't know	0 (0)	5 (5)	0.0235	0.08639
Do you have any concern about the smell of the water?				
Yes	3 (3)	37 (37)	< 0.0001	0.05266
No	97 (97)	63 (63)	< 0.0001	18.99
Do you have any concern about the colour of the water?				
Yes	0 (0)	65 (65)	< 0.0001	0.002696
No	100 (100)	35 (35)	< 0.0001	0.002696
Do you drink any other water source?				
Yes	37 (37)	73 (73)	< 0.0001	0.2172
No	63 (63)	27 (27)	0.0002	2.899
If yes, specify				
Sachet	34 (34)	50 (50)	0.0219	0.5152
Bottled	2 (2)	23 (23)	< 0.0001	0.0683
Do you have regular water supply?				
Yes	67 (67)	43 (43)	0.0006	2.691
No	33 (33)	57 (57)	0.0006	0.3716

Suspected leakage of environmental water into the main distribution lines?				
Yes	55 (55)	54 (54)	0.8871	1.041
No	45 (45)	43 (43)	0.7757	1.085
Don't know	0 (0)	3 (3)	0.081	0.1386
Preferred an alternative source of water supply?				
Yes	33 (33)	73 (73)	< 0.0001	0.1822
No	66 (66)	27 (27)	< 0.0001	5.248
Don't know	1 (1)	0 (0)	0.3161	3.03

With regards to the regularity of water supply, the results revealed that majority of the peri-urban population (67%) were satisfied with their water supply as compared to the urban populace (43%) ($p = 0.0006$). A higher proportion of the peri-urban respondents (66%) answered negatively to preference for an alternative source of water supply as compared to their urban counterpart (27%), and this was significant as shown above (Table 6). Fewer proportions of peri-urban inhabitants (37%) drink other water source at home as compared to the urban inhabitants (73%) and this was statistically significant ($p < 0.0001$) as shown in Table 6.

CHAPTER FIVE

DISCUSSION

5.1 Levels of physico-chemical parameters

Although the water samples at APT, AP1, AP2, AP3, AP4 and AP5 were from a single common source, there was an observed difference in the levels of physico-chemical parameter recorded at the different sampling sites. The difference in physico-chemical levels at AP1, AP2, AP3, AP4 and AP5 may be attributed to the nature and extent of leakage of waste water from the drainage system into the distribution pipelines serving the particular household. The introduction of environmental water with its own unique physico-chemical character can alter the physico-chemical composition of the water in the pipelines.

5.1.1 pH

The pH levels observed for the water samples were below the WHO/GSA optimum limits of between 6.5 and 8.5. This gives the indication that the water from the various sampling points was mildly acidic. The slightly acidic nature of the water can be attributed to the source water; which is groundwater. Groundwater quality is largely determined by the geology of the area and as the country is dominated by crystalline silicate rocks and weathered derivatives (regolith), groundwater is mainly of low salinity and commonly acidic (pH < 6.5) in composition (www.wateraid.org/~/media/Publications/groundwater-quality-information-ghana.pdf). The acidity may be due to the presence of carbon dioxide (CO_2) within the soil zone and other natural biogeochemical processes (Yankey *et al*., 2011). Amfo-Otu *et al*. (2012), in assessing the physico-chemical quality of groundwater sources in Ga East Municipality of Ghana observed that the pH (5.2±0.5, 5.3±0.4 and

5.1±0.2) of all the three boreholes sampled were below WHO recommended levels which made the water acidic and aggressive. Acidity in water is not in itself harmful to health. Many popular beverages have considerable acidity or alkalinity. The concern for acidity in drinking water is that even mildly acidic water can dissolve metals, such as copper and lead from pipes, solder or fixtures, from the plumbing system (American GroundWater Trust, 2003).

5.1.2 Temperature

Cold water is generally preferred to hot water. A drinking water industry research indicated that temperature influenced how much consumers liked their drinking water found that temperature affected taste intensities, and also concluded that chilling it increased consumer palatability and acceptance of drinking water (Pangborn and Bertolero, 1972).

High water temperature enhances the growth of microorganisms and may increase taste, odour, colour and corrosion problems (WHO, 2008). Temperature also affects dissolved oxygen concentration in water. Cold water tends to hold more dissolved oxygen than hot water because as temperature increases, water releases some oxygen (Addy and Green, 1997). The temperatures observed for the water samples could be attributed to the high daily temperatures averaging during the sampling periods.

5.1.3 Electrical Conductivity

Electrical Conductivity is affected by the presence of inorganic dissolved salts in water and therefore water with a higher conductivity indicates a higher salt concentration of the water (Hach, 2000), which may cause water to taste salty. The observed conductivity levels of the water samples were within the WHO/GSA permissible limit, which suggests that, the supplied water was good in terms of conductivity.

5.1.4 Total Dissolved Solids

The palatability of water with a TDS level of less than 600 mg/l is generally considered to be good; drinking-water becomes significantly and increasingly unpalatable and aesthetic problems such as a bitter or salty taste occurs at TDS levels greater than about 1000 mg/l. Water with extremely low concentrations of TDS may also be unacceptable because of its tasteless and flavourless taste (WHO, 2008). The TDS values obtained for the water samples at the various points indicates that the water may be excellent according to the WHO guidelines for TDS.

5.1.5 Turbidity

High levels of turbidity can protect microorganisms from the effects of disinfection and can stimulate the growth of bacteria, and therefore the appearance of water with a turbidity of more than 5 NTU is usually unacceptable to consumers (WHO, 2008). The lower turbidity levels observed for the samples were expected, considering the fact that the source of water supply is groundwater. Groundwater is not under the direct influence of surface water, thus is considered less vulnerable to contamination and therefore turbidity should generally be below 1.0 NTU (www.hc-sc.gc.ca/ewh-semt/consult/_2011/turbidit/draft-ebauche-eng.php#a3.1.3). The observed result for turbidity in this study is in accordance with a study conducted by Chan *et al.* (2007), in which turbidity levels measured for drinking water samples from different houses were less than 1 NTU. The supplied water in terms of its turbidity level can be considered safe for domestic use and does not pose any health problems to the consumers.

5.1.6 Total Hardness

Hardness of water is mainly due to the presence of salts of calcium and magnesium and this reduces lather formation and also increases boiling point of water (Murhekar, 2011). Although no health-based guideline value is proposed for hardness, the degree of hardness in water may affect its acceptability to consumers in terms of taste (WHO, 2008) and users of hard water tend to use a lot of soap for washing. The values obtained for the water samples indicate that the water supply is moderately hard and can be considered to be safe.

5.2 Microbial Contamination

The mean figures observed for total coliform, faecal coliform and faecal enterococci in this study far exceeded the WHO and GSA recommended guideline for drinking water. Ideally, indicator organisms should not be detectable in any 100 ml sample for drinking water (WHO, 1996), and therefore the presence of indicator organisms in drinking water is a very powerful indication of faecal contamination which poses a public health risk (Van Lieverloo *et al*., 2006).

The occurrence of indicator organisms in drinking water is a common phenomenon all over the world. From this study, the presence of total coliform, faecal coliform, faecal enterococci and total viable count in the water samples collected at the 5 households could be attributed to leaks in the distribution pipelines, causing a breach in the distribution system's integrity by allowing leakage of contaminated environmental water into the distribution lines carrying water to the houses. Waste water from the drains in the study community could be the primary possible source of contamination.

The observed trend of total coliform, faecal coliform, faecal enterococci and total viable count presence in the water samples was lower at APT as compared to the households (AP1, AP2, AP3, AP4 and AP5). It can there be deduced from this observation that the microbial load increased as water travelled from the APT through the distribution system to the individual households. A number of studies have reported a statistically significant deterioration in the microbiological quality of water between the source and point of use in the home (Simango *et al*., 1992).

The observations made in this study is consistent with a study conducted by Umar (2012), who observed that microbial quality of water sampled deteriorated as water travelled through the distribution network to homes. An earlier work in environmental impact on the bacteriological quality of domestic water supplies in Lagos, Nigeria (Egwari and Aboaba, 2002) concluded that leakages in pipelines increases the rate of contamination and wastewater from drains was the main source of contamination of pipe-borne water.

The incidents of indicator organisms in the tank could also be due to biofilm formation and build-up in the tank. This assertion was consistent with a study by Batinas (2012), where the results of indicators of faecal contamination and opportunistic pathogenic bacteria monitored in biofilms associated with drinking water indicated that coliform populations prevailed in surface attached consortia. Biofilms can serve as a hosting platform for bacteria and other microbes and can allow the growth of bacteria to reach a level that interferes with total coliform compliance testing or support the growth of coliform organisms to a level that jeopardizes the microbial quality of drinking water (Seo, 2010).

Water leaving the tank was relative lower in microbial load and the upsurge in microbial loads in the 5 houses occurred as water travelled through the pipelines; which served as a source of further microbial contamination. The data clearly shows that the levels of total coliform, faecal coliform, faecal enterococci and total viable count in the water samples far exceeded the recommended WHO/GSA permissible levels. Presence of faecal coliforms in water may not necessarily indicate the presence of faeces; however it does indicate an increased likelihood of harmful pathogens in the water supply (www.freedrinkingwater.com). This situation represents a major health concern and the continuous consumption of the water supply by the community could increase the risks of water-related diseases especially in children.

5.2.1 Absence of *E. coli* and *Salmonella*

All samples showed negative results for the presence of *E. coli* and *Salmonella*. The presence of *E. coli* and *Salmonella* in the water samples would have been a strong indication of recent sewage or animal waste contamination. *E. coli* has been credited to be a more specific indicator of faecal contamination than the more general test for faecal-coliform bacteria (Dufour, 1984).

5.3 Peri-urban perception on water quality

The objective of this survey study was to investigate the perception of inhabitants of Appiadu, a peri-urban community, on the quality and satisfaction of their water supply using Asafo (an urban community) as a control (both in the Ashanti Region, Ghana). Perceptive survey has been employed in past studies to investigate water quality issues (Kite-Powell, 2003). Data from the perception survey shows that age, sex, marital status, education level and occupation of the respondents had no effect on their perception with respect to concerns of water quality. Results of the study showed that a significantly high number of inhabitants in the peri-urban area did not treat their water before drinking and this phenomenon was probably due to the fact that inhabitants in the peri-urban area had advanced perception of the source of their water supply to be of doubtless quality. In addition to this, would be the proximity of the water supply site to the community members.

Gyau-Boakye and Dapaah-Siakwan (2000) in assessing groundwater as a source of rural water supply in Ghana stated that, groundwater has excellent microbiological and chemical quality due to adequate aquifer protection and therefore requires minimum or no treatment. This perception among the peri-urban community may also be due to the fact that no previous history of health complaint or complication associated with usage of their water has been reported or observed. This awareness may have been the reason why greater proportion of these respondents did not drink water from any other sources at home, neither sachet water nor bottled water. This was consistent with a study carried out in the Upper Region Region of Ghana (Apambire *et al*., 1997).

The observation that 2 times more respondents in the peri-urban area did not drink water from any other source at home apart from the main community water source was expected. In addition, it was also established that, majority of respondents from the peri-urban area were satisfied with the physical properties (i.e, taste, smell and colour) of their drinking water was also anticipated. In a study conducted by a group of researchers in Tarkwah, Ghana, on the contamination status of drinking water in the region, results of the study showed that, people would always accept drinking water whose quality was not doubtful (Asante *et al.*, 2007). Majority of respondents from the peri-urban area had no concern at all about the taste and smell, respectively, of their water. In the case of colour, none of the inhabitants from the peri-urban area expressed concern. This was consistent with earlier study conducted in India (Brindha and Elango, 2011)

5.4 Response to the quality of water supply

The greater proportion of both peri-urban and urban inhabitants storing drinking water and water for domestic purposes in containers in times of draught was expected. However, fewer proportions of peri-urban settlers complained sediments were seen at the bottom of the containers after few days of storage. This assertion could be understood because data collected during the study showed that, a significantly higher number of peri-urban settlers were satisfied with the regular flow of their water supply. This was consistent with earlier study by Subramani *et al.* (2010). Once it has been perceived that water may not flow regularly, there was the propensity water would be kept in reservoirs for longer periods. However, the longer water stays in a container the higher the probability of sediment build up. The presence of sediments in water is generally undesirable and may be an indication of poor or compromised quality (Yidana and Koffie, 2013).

The perception that water flows regularly among peri-urban settlers did not come as a surprise and this could be attributed to the presence of adequate infrastructure and management support at the community level. Research has shown that, settlements where infrastructure is well established often do not have water shortage challenges (Bakker, 2003). Within this peri-urban settlement, a community stand pipe has been installed to provide inhabitants whose homes are not connected to the distribution pipelines access. Subjects' satisfaction with the physical properties of their water for drinking and domestic purposes (taste, smell and colour) in the peri-urban community was consistent with answers to question posed relative to an alternative source of water supply. The data also shows that significantly higher numbers of peri-urban settlers were satisfied with their water source. Consistent with other studies, Umar (2012), in investigating customer perception on the quality of water at Adum a suburb in Kumasi, Ghana, established that, respondents' perception of the water taste, smell and colour affected their choice of the water for drinking. Respondent's satisfaction with taste, smell and colour among the peri-urban settlers alone could not account for reasons why majority of this group did not prefer an alternative to their water supply. The community's previous bad experience with supply from Ghana Water Company (The Government owned water Distribution Company) may have influenced their perceived reaction to their water. It must be emphasized that, with the benefit of hindsight, they would have preferred their current water source for drinking and for domestic purposes to no other. This was consistent with an earlier research (Yidana and Koffie, 2013).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

From the results obtained and analysis made, it can be concluded that the mean total coliform, faecal coliform and faecal enterococci detected in the water samples at all the sample points far exceeded the WHO and GSA recommended guideline for drinking water. The presence of coliform bacteria in the water samples from the tank and the households is a very powerful indication of faecal contamination which poses a health risk to consumers. All the water samples however showed negative results for the presence of *E. coli* and *Salmonella*. The mean concentrations of the physico-chemical parameters assayed for in the tank and the households were within the permissible limits of World Health Organisation (WHO) and Ghana Standard Authority (GSA)

Analysis of the perception survey data also concluded that majority of inhabitants in Appiadu had no concern about the physical properties (that is taste, smell and colour) of their water. A highly significant number of inhabitants 93%, 97% and 100% were satisfied with the taste, smell and colour respectively, and they could therefore attest to the quality of water supplied. Fifty percent (50%) of inhabitant however complained of sediments at the bottom of the containers upon storing water. Results from this study also concluded that satisfaction with water supply among peri-urban inhabitants is high and a greater proportion of these settlers (67%) perceived their water supply as regular and therefore had no preference for an alternative. The age, sex, marital status, education level and occupation of inhabitants had no effect on their perception on quality and satisfaction of their water.

6.2 Recommendation

The incident of coliform bacteria should be addressed urgently to avoid incidences of water related diseases. Considering the fact that a higher number (55%) of settlers in the study area suspected leakage of environmental water into the main distribution lines, although statistically not significant, it will be prudent for managers of the water system to adopt effective and efficient ways to compact this perception and also to construct water tight covert to place the distribution pipes inside to avoid contaminated water from reaching the potable water. An urgent and prompt response should also be employed in identifying and repairing leaked or busted pipelines.

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APPENDIX – QUESTIONAIRE

WATER QUALITY PERCEPTION SURVEY

The information you provide will be treated as confidential and will be used only for academic purposes. Thank you for your time and cooperation.

Community Name:……………………. House Number:…………………………….

Study Code:……………………… …… Name of respondent:………………………

SECTION A: SOCIAL DEMOGRAPHIC DATA

1. Age 6-15 [1] 16-20 [2] 21-50 [3] 50 upwards [4]

2. Sex Male [1] Female [2]

3. Marital Status: Married [1] Divorced [3]

   Separated [5] Single [2] Widowed [4]

4. What is your highest educational level?

   Primary [1] Tertiary [3] Never been to school [5]

   JSS/MSLC [2] SSS [4] Tech/Comm/Voc [6]

5. What is your main occupation?

   Farmer [1] Unemployed [3] Self-employed [5]

   Trader [2] Gov't Worker [4] None of the above [6]

SECTION B: COMSUMER PERCEPTION

6. What is your source of water?

   Pipe borne water from Appiadu community water system [1]

   GUWL [2]

7. Is this your major source of domestic/potable water?

   Yes [1] No [2] Don't know [3]

8. Do you drink any other water source?

   Yes [1] No [2] Don't know [3]

9. If yes, specify Sachet [1] Bottled [2] others (specify)……………

10. Is your water treated before drinking?

Yes [1] No [2] Don't know [3]

11. Do you store water in a container before use?

Yes [1] No [2] Don't know [3]

12. If yes, do you see sediments at the bottom of the container?

Yes [1] No [2] Don't know [3]

13. Do you have any concern about the taste of the water?

Yes [1] No [2] Don't know [3]

14. Do you have any concern about the smell of the water?

Yes [1] No [2] Don't know [3]

15. Do you have any concern about the colour of the water?

Yes [1] No [2] Don't know [3]

16. What health complaint do children in your house often experience?

Diarrhea [1] Abdominal pain [3]

Headache [2] None of the above [4]

17. Do your water easily foam lather with soap?

Yes [1] No [2] Don't know [3]

18. Do you have regular water supply?

Yes [1] No [2] Don't know [3]

19. Have you ever suspected leakage of environmental water into the main distribution lines?

Yes [1] No [2] Don't know [3]

20. In your opinion, would you prefer an alternative source of water supply?

Yes [1] No [2] Don't know [3]