KWAME NKRUMAH UNIVERSITY OF SCIENCE & TECHNOLOGY,

KUMASI

TREATMENT EFFICIENCY OF WATER PRODUCED AT THE KWANYAKU WATER TREATMENT PLANT IN THE AGONA DISTRICT OF THE CENTRAL REGION AND DISTRIBUTION LINE CONTAMINATION

A THESIS PRESENTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE

BY

CHARITY ESENAM ASSEY

B.Ed SCIENCE, UNIVERSITY OF EDUCATION, WINNEBA

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DECLARATION

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

Charity Esenam Assey (PG8283512) ……. ……..

Student Name & ID Signature Date

Mr. Alfred K. Apetorgbor ……..…….. ……

Supervisor Signature Date

Dr. Isaac K. Tetteh ……..…….. ……

Head of Department Signature Date

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DEDICATION

I dedicate this work to my husband, Mr. Gideon Asare Anor, my four lovely children, Afua Amoabea Anor, Ama Sarfoa Anor, Kwadwo Asare Anor and Kwadwo Baffour Kafui Anor

ABSTRACT

A study was conducted to assess the treatment efficiency of water produced at the Kwanyaku Water Treatment Plant and Contamination in the distribution system. The physico-chemical and bacteriological quality of water from the raw water to the final treated water and three selected locations along the distribution chain were analysed. Raw water, Settled water, Filtered water, Final water and randomly selected water in three locations along the distribution chain were sampled and examined for thermotolerant coliforms (TTC) using the most probable number method (MPN). The pH and alkalinity values for all the water samples were within the recommended limit of 6.5 -8.5 and 200 mg/l respectively. Colour and turbidity values except of that for the raw water were also within the WHO range of 0 -15 HU and ≤ 5 NTU respectively. Total Hardness, Calcium Hardness, Calcium, Magnesium Hardness, Magnesium, chloride and conductivity for raw to final water samples were all within the WHO acceptable limit of 0-500 mg/l, ≤ 200 mg/l, ≤ 80 mg/l, ≤ 30 mg/l, 50-150 mg/l, ≤ 250 mg/l and 300 µS/cm respectively. All Raw water samples were positive for TTC. The mean value of MPN per 100 ml of Raw water was 220. However, the three distribution locations sampled recorded low levels of residual chlorine, with temperature and indicator bacteria (TTC) above those of the WHO guideline. There were significant differences between residual chlorine values recorded in the Final water at the treatment plant site and those recorded for the water at the three distribution points. Residual chlorine was less than the WHO limit of 0.6 mg/l in the distribution samples making it prone to bacterial growth. Temperatures increased along the distribution chain favouring growth of biofilms in the water. Recontamination of the treated water occurred along the distribution chain and this could be as a result of bursts along the distribution chain, high temperature and low chlorine residual coupled with poor monitoring and maintenance practices. The efficiency of treatment was 100% as the quality of water produced at the Kwanyaku Water Treatment Plant met the international standard recommended by World Health Organisation (WHO). However water samples along the distribution chain revealed that the quality of the water degrades before getting to some of the consumer points, hence more work need to be done in maintaining the quality up to all the consumer points.

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ACRONYMS AND ABBREVIATIONS

ADWG	Australian Drinking Water Guidelines
ANOVA	Analysis Of Variance
ASS	Assisim
AWWA	American Water Works Association
BDH	British Drug House
EK	Ekwamkrom
GWCL	Ghana Water Company Limited
KWTP	Kwanyako Water Treatment Plant
MG	Mangoase

mg/l	milligram per litre
ml	millitres
SCADA	Supervisory Control And Data Acquisition
USEPA	United State Environmental Protection Agency
WHO	World health Organization
WRCS	Water Resources Consultancy Services
WRMS	Water Resources Management Study
WSMP	Water Safety Management Program

CHAPTER ONE INTRODUCTION

1.0 BACKGROUND

Accessibility to clean and safe water is an issue of concern to all since it is directly related to human health and welfare. The provision of safe water, sanitation and good hygiene services is vital for the protection and development of human resources (Fewtrell & Colford, 2004).

Quality drinking water may result from a combination of factors such as protection of water sources, control of water treatment processes, management of the distribution process and handling of the water. The extent of treatment provided by a water utility is dependent on the nature and degree of contamination of source water. This treatment is targeted at the removal or inactivation of bacterial pathogens from the water. Standard drinking water treatment includes impoundment, coagulation/flocculation, sedimentation, filtration, and disinfection.

The presence of pathogens in drinking water may result from source water contamination by human and animal activities followed by improper or insufficient treatment, regrowth of organisms due to insufficient disinfectant residual in the distribution system, contamination due to transient pressure drops leading to infiltration of groundwater into water pipes and contamination due to incorrect cross-connections with sewer lines. Besides the above, pathogens may also contaminate the water during transportation, distribution, or handling of the water in households or other working places. Pathogens are generally minute and easily transported in water. Additional factors that encourage the introduction of pathogens into the distribution

system include water temperature, pH, turbidity and oxygen concentration, water demand in the system, and distribution system configuration (Ailamaki *et al.*, 2003).

According to Hrudey *et al.* (2003), contamination by sewage or human excrement presents the greatest danger to public health associated with drinking water, and bacteriological testing continues to provide the most sensitive means for the detection of such pollution. Septic tanks, open dumps, improper constriction latrines and surface impoundments are the most common sources for sewage contamination. Regular examination of water quality for the presence of pathogenic organisms, chemicals and other physical contents must be conducted to provide information on the level of the safety of water.

Modern microbiological techniques have made possible the detection of pathogenic bacteria, viruses and protozoa in sewage and sewage effluents but it is not practical to attempt to isolate them as a routine procedure from samples of drinking water (Hrudey *et al*., 2003). Indicator organisms of faecal pollution include the coliform group as a whole and particularly *Escherichia coli, Streptococci faecalis* and some thermotolerant organisms such as *Clostridium perfringens* are essential parameters. Appropriate treatment and sanitary survey are also very important to protect and control the water borne diseases.

Some of the physico-chemical qualities of concern in Ghana are pH, colour, turbidity, total hardness, temperature, alkalinity and chloride while the microbial qualities of concern are total coliform and thermotolerant or *faecal* coliform. The

United States Environmental Protection Agency (USEPA) regulations require three main groups of indicator organisms to be used to monitor water quality: *total coliform* (TC), *faecal* coliform (FC) or thermotolerant coliform (TTC), and *Enterococci.* The

presence of any of the above listed indicators in water makes the water unsafe for drinking.

1.1 THE KWANYAKU WATER TREATMENT PLANT

The Kwanyaku Water Treatment Plant with the present capacity of 35,000 m^3/d (7,700,000 gals/d) is located 10km east of Agona Swedru and abstracts water from the Ayensu River with a catchment area of 884 km^2 (341 sq miles) and flows almost centrally through the supply area of the Kwanyaku water supply system. Activities along the river are mainly farming and fishing.

The Headwork has two treatment plants: the old plant with a capacity of 14,000 m^3/d was commissioned in 1964, and the new plant with a capacity of 21,000 m^3/d was commissioned in 2007. The old plant used to serve eight Districts, namely the Agona West, Agona East, Gomoa West, Gomoa East, Mfantsiman, AsikumaOdoben-Brakwa, Ajumako-Enyan-Essiam and Awutu Senya, all in the Central Region with a population of more than 5,000 and some 300 surrounding villages with pipeline estimated over 120 km (GWCL, 2007).

In 2004 the Ghana Water Company Limited representing the Government of Ghana became aware that the existing facilities at the Water Treatment Plant were insufficient to supply water to its catchment or operational area and to help alleviate the water shortage situation due to rapid population growth. The old Kwanyaku Water Treatment Plant was rehabilitated in 2007 and refurnished to a capacity of 14,000 m^3/d (4,620,000 gal/d) by Denys Engineers and Contractors B.V. of the Netherlands at a cost of €28,291,000.00 to meet the year 2020 water demand of a total population of about 750,000 persons. The Treatment Plant employs aeration,

coagulation, sedimentation, filtration, chlorination and pH adjustment processes for water purification.

1.2 PROBLEM STATEMENT

The principal aim of every conventional drinking water treatment plant should be to provide acceptable standards of service, to gain customer satisfaction, delivering to consumers water that is both aesthetically pleasing and meeting public health safety requirements (Chowdhury, 2003). In developing countries 2.2 million people, most of them children, die every year from diseases associated with lack of safe drinking water, inadequate sanitation and poor hygiene. Diarrhoeal illness remains a major killer in children and it is estimated that 80% of all illnesses in developing countries is related to water and sanitation (WHO, 2002).

For this reason both drinking water standards and technology, in recent years, have changed to help ensure safe drinking water for public consumption. As water treatment standards have become more stringent, the methods of analysis have become more sophisticated. For this reason, drinking water utilities may have to consider changing disinfectants to improve water quality and meet more stringent disinfection regulations (Volk *et al*., 2002). Water can be polluted with sewage from septic tanks, open dumps, improper constriction latrines and surface impoundments. Human activities such as mining, farming and livestock operations also account for the introduction of pollutants. Moreover, virtually anywhere a surface comes into contact with the water in a distribution system, biofilms are present. These are formed in distribution system pipelines when microbial cells attach to pipe surfaces and multiply to form a film or slime layer on the pipe.

Probably within seconds of entering the water distribution system, large particles and microorganisms absorb to the clean pipe surface.

Factors that affect bacterial growth on biofilms include water temperature, type of disinfectant and residual concentration, assimilable organic carbon level, biodegradable organic carbon level, degree of pipe corrosion, and treatment/distribution system characteristics (Hunter *et al*., 2001).

Over the years the Ghanaian populace has raised a lot of concern about the quality of water consumers are supplied by the Ghana Water Company Limited (GWCL). The issue is to find out if the quality of water produced and distributed to the consumer meets international standards.

1.3 OBJECTIVES

1.3.1 MAIN OBJECTIVE

The main objective of the study was to determine the treatment efficiency of the Kwanyaku Water Treatment Plant and the quality of the water to the consumer point.

1.3.2 SPECIFIC OBJECTIVES

The specific objectives were to:

i. Identify the treatment processes at the Kwanyaku Water Treatment Plant. ii. Analyse the physico-chemical quality (temperature, pH, turbidity, colour, alkalinity, Total Hardness, Calcium Hardness, Magnesium Hardness, Chloride and residual chlorine) of raw to final water supplied to the consumer.

iii. Analyse the bacteriological quality of drinking water being supplied from the treatment plant to the consumer.

1.4 SIGNIFICANCE OF STUDY

The study will attempt to ascertain whether or not the claims by some consumers that water supplied by GWCL is of poor quality. In light of this, the study will be significant in the following ways:

Theory development – It will serve as a source of reference for academics and researchers who want to further research on the topic under discussion.

Industry Practice – It will be of immense benefit to Ghana Water Company Limited as it aims at providing empirical data on the effectiveness of the current treatment processes at the Kwanyaku Water Treatment Plant.

National Development – It will present insights on the contribution of potable water to National Development by way of reducing water related diseases. It is expected that these knowledge will help the nation to take a critical look at ensuring the availability of potable water in order to meet some of the Millennium Development Goals.

CHAPTER TWO

LITERATURE REVIEW

2.0 CONTAMINATION OF WATER SOURCES

The main categories of raw water sources are surface and ground water.

Groundwater is water beneath the earth's surface, often between rocks, soil, springs, infiltration wells and tube-wells, whereas surface water is an open body of water, such as river, stream, lake or estuary (Ring, 2003). No water must be assumed to be safe, even if in appearance it looks clean.

Drainage from farms, streets, rooftops, driveways, feedlots and compost piles, among others pollute source water. Several types of land application is also a major concern. Many particles with domestic wastewater, livestock manure and septic tanks may also lead to contamination of water. Water percolating from these facilities contains viruses, bacteria and parasites and may contaminate water supplies (Ring, 2003).

A compilation of waterborne disease outbreak data for the years 1999 and 2000 in the United States of America indicated that 26 out of 37 infectious disease outbreaks were attributed to contamination of water sources. This is due to the presence of pit latrines close to the water sources, lack or little environmental protection and poor catchment management (Zamxaka *et al.*, 2004).

In Ghana, in spite of the fair progress made in water coverage, less than 15% of the population has access to improved sanitation (*www.wsmp.org/.../506ab2f82d648.pdf*) Indeed, it has been reported that about 20% of Ghana's population defecate in drains, fields, streams, the bush and beaches (*www.wsmp.org/.../506ab2f82d648.pdf*).

There is a growing body of evidence that the leakage of sewage is significantly degrading groundwater resources (Aidan *et al.*, 2005). In order to protect and control

the contamination of pathogenic organisms at the source of water, it is important to protect the delineated areas from sources of pollutants (Ring, 2003). Depending upon the nature of the catchment, it may be possible to protect against such events by removing grazing animals, diverting sewage overflows and discharge points (OECD/WHO, 2003) and the provision of adequate places of convenience. Despite all these protection measures, the vulnerability of untreated water supplies to microbial contamination via the rapid transport of pathogenic microorganisms, particularly bacteria and viruses should be recognized.

2.1 HEALTH HAZARDS ASSOCIATED WITH CONTAMINATED WATER

In the production of potable water, all water-borne organisms, especially water-borne pathogens are of concern. Pathogens are microorganisms that can cause disease in other organisms (humans, animals and plants). Majority of these pathogens affect the gastro-intestinal tract and can be bacteria, viruses, protozoa and sometimes fungi. Viruses, bacteria and protozoa are the three principal groups of microorganisms that can be transmitted via drinking water. They are all transmitted by the faecal-oral route, and so largely arise either directly or indirectly by contamination of water resources by sewage or possibly animal wastes (LeChevallier *et al*., 1996).

Introduction of pathogens into the distribution system can rapidly lead to an infection of thousands of people since they may depend on the same source of water and become infected with an infected person.

In addition, there are a number of newly recognized etiologic agents for which there is some evidence of an association with waterborne disease, such as enteric waterborne emerging pathogens which include *Caliciviruses, Eschericia coli*

0157:H7, *Helicobacter* sp., *Mycobacterium avium* complex and protozoa *Cryptosporidium* sp., *Cyclospora* sp. *and Taxoplasma* sp. (OECD/WHO, 2003).

Waterborne disease outbreak usually occurs due to source contamination, breakdown of the treatment barriers, contamination of the distribution system and the use of untreated water (WHO, 2004b). Faulty distribution systems are a major cause of waterborne outbreaks. For example, a review of waterborne outbreaks in the United States from 1991 shows that 38.7% of outbreaks were caused by problems within the distribution system (Smith *et al*., 2006).

The World Health Organization estimates that 80% of all illnesses in the world were attributable to insufficient water supplies or sanitation. Over 250 million new cases of waterborne diarrhoea are reported worldwide each year, which results in more than 10 million deaths. Today there are many recognized waterborne pathogens present in large numbers in human or animal waste that are resistant to environmental decomposition. Many of these pathogens are proficient in causing infections even when ingested in extremely small numbers (Skraber1 *et al*., 2005).

The major prevalent water quality problems in Ghana are those related to physical, chemical, as well as microbiological parameters, the possible causes of which are natural, anthropogenic or both. These problems are related to diseases such as cholera, typhoid, schistosomiasis, malaria, skin infection among others.

2.2 WATER QUALITY

Access to safe water is not just an issue for developing countries. Despite wealthy economies and their access to proven drinking water-treatment technologies significant outbreaks of waterborne intestinal diseases have occurred in North America and Western Europe in the past. For this reason the World Health

Organisation (WHO) has given a guideline for all drinking water irrespective of location. The WHO guidelines for drinking water are that it should be free from pathogenic organisms; low in concentration of compounds that are acutely toxic or that have serious long-term effects such as lead; clear; not saline; free from compounds that cause offensive odour or taste; and non corrosive nor should it cause encrustation of piping or staining of clothes (WHO, 2004a)

2.2.1 Bacteriological Indicators and their Significance

Indicator bacteria are types of bacteria used to detect and estimate the level of faecal contamination of water. Indicator bacteria are not themselves dangerous to health but are used to indicate the presence of a health risk. Each gramme of human faeces contains approximately 100 billion (1×10^{11}) bacteria (WHO, 2002). This may include species of pathogenic bacteria, such as *Salmonella* or *Campylobacter*, associated with gastroenteritis. In addition, faeces may contain pathogenic viruses, protozoa and parasites. The presence of these indicator organisms in water gives an evidence of faecal contamination and a risk that pathogens are present. If indicator organisms are present in large numbers, the contamination is considered to be recent and severe. Bacteria in water are, in general, present as clumps or in association with particulate matter. When enumerating bacteria in water it is not the number of individual bacteria present which are counted, but the number of clumps of bacteria or the particles and their associated bacteria. Each clump or particle may have many bacteria associated with it.

2.2.2 Types of Indicator Organisms and their Significance

Commonly used indicator bacteria include *Total coliforms,* or a subset of this group and *Faecal coliforms* which are found in the intestinal tracts of warm-blooded animals. [*Total coliforms* were used as faecal indicators by public agencies in the United States of America as early as the 1920s (USEPA, 1999)]. These organisms can be identified based on the fact that they all metabolize the sugar lactose, producing both acid and gas as byproducts.

Total Coliforms (TC)

The term "total coliforms" refers to a large group of Gram-negative, rod-shaped bacteria that share several characteristics. The group includes thermotolerant coliforms and bacteria of faecal origin, as well as some bacteria that may be isolated from environmental sources. Thus, the presence of total coliforms may or may not indicate faecal contamination. In extreme cases, a high count for the total coliform group may be associated with a low, or even zero, count for thermotolerant coliforms. Such a result would not necessarily indicate the presence of faecal contamination. It might be caused by entry of soil or organic matter into the water or by conditions suitable for the growth of other types of coliform. In the laboratory total coliforms are grown in or on a medium containing lactose, at a temperature of 35 or 37 ^{0}C. They are provisionally identified by the production of acid and gas from the fermentation of lactose (WHO, 2002).

Thermotolerant *(faecal)* Coliform (TTC)

The term "*faecal* coliform" has been used in water microbiology to denote coliform organisms which grow at 44 or 44.5 ^{0}C and ferment lactose to produce acid and gas (WHO, 2004a) In practice, some organisms with these characteristics may not be of faecal origin and the term "thermotolerant coliform" is, therefore, more correct and becoming more commonly used. Nevertheless, the presence of thermotolerant

coliforms nearly always indicates faecal contamination (Hurst *et al*., 2002). Usually, more than 95 per cent of thermotolerant coliforms isolated from water are the gut organism *Escherichia coli*, the presence of which is a definitive proof of faecal contamination (Hurst *et al*., 2002).

As a result, it is often unnecessary to undertake further testing to confirm the specific presence of *E. coli*. In the laboratory thermotolerant coliforms are grown on media containing lactose, at a temperature of 44 or 44.5°C. They are provisionally identified by the production of acid and gas from the fermentation of lactose. Nutrient-rich environments may encourage the growth or persistence of some species of thermotolerant coliforms other than *E. coli*. This possibility should be considered when, for example, an unusually high result is obtained from water that was thought to be relatively clean. In such a case, the advice of a microbiology laboratory should be sought for the determination of the more specific indicator.

Faecal streptococci (FS)

Faecal streptococci are Gram-positive, sphere-shaped bacteria that give a positive reaction with Lance field's Group D antisera. *Faecal streptococci* are associated with the faeces of warm-blooded animals (WHO, 2003). They include the genus *Enterococcus* and two species of *Streptococcus: S. bovis and S. equinus.* These organisms share certain biochemical properties and are predominantly found in animal faeces. They rarely multiply in water; they are more resistant to environmental stress and chlorination than coliforms and the intestinal *enterococci* group can be used as an index of faecal pollution.

Faecal streptococcus are excreted by all warm-blooded animals; they are widespread in the environment wherever animal life is present. *Streptococci* have an interesting

history and as a single genus of bacteria have probably caused diseases and morbidity in man over the centuries than almost any other bacteria (WSI, 2004). The fact that the *enterococci* do not multiply outside the body of intestinal tract shows a closer relationship with the pathogenic enteric bacteria *Salmonella typhosa*, which also do not multiply outside the body, and therefore suggests that *enterococci* are better indicators of recent pollution (Litsky *et al*., 2005). They are more persistent in water than *Eschericia coli*, and so may be a better mirror of the presence of certain pathogens which also die off slowly (e.g. viruses) (ADWG, 2001).

Enterococci have gained the most acceptances, particularly when used in conjunction with *Eschericia coli* (Stevens & Ashbolt, 2003). *Faecal streptococci* are a suitable specific indicator making these bacteria a better indicator for the presence of certain pathogens that die off slowly. Their main value in assessing water quality is therefore as an additional indicator of treatment efficiency.

Besides the above, the World Health Organization Guidelines for Drinking Water Quality states that as an indicator organism *E. coli* provides conclusive evidence of recent faecal pollution therefore, the presence of these organisms in the water indicates contamination of faecal matter, which could also contain pathogens such as *Salmonella* and *Shigella*. USEPA regulations also require three main groups of indicator organisms to be used to monitor water quality: total coliform (TC), *Faecal* coliform (FC) *or* thermotolerant coliform, and *Enterococcus* (USEPA, 1999).

2.2.3 Methods of Indicator Bacteria Detection

Microbial contamination is considered to be the most serious risk factor in drinking water quality because of the possible consequences of waterborne disease.

Therefore, it is important to determine the microbiological safety of these waters. The ideal manner for doing this would be to analyze the waters for the presence of specific pathogens of concern by the use of indicators (OECD/WHO, 2003). Frequent occurrences of high coliform counts signify the need for an alternative water source, or sanitary protection of the current source.

Methods of detection include Membrane filtration and culture on selective media. Indicator bacteria can be cultured on media which are specifically formulated to allow the growth of the species of interest and inhibit growth of other organisms. Typically, environmental water samples are filtered through membranes with small pore sizes and then the membrane is placed onto a selective agar. It is often necessary to vary the volume of water sample filtered in order to prevent too few or too many colonies from forming on a plate. Bacterial colonies can be counted after 24 to 48 hours depending on the type of bacteria. Counts are reported as colony forming units per 100 ml (cfu/100 ml) (Abaidoo and Obiri-Danso, 2008).

The Most Probable Number (MPN) method also known as the Poisson Zeroes is a method of getting quantitative data on concentrations of discrete items from positive or negative incidence. It involves the use of statistic to determine the mean concentration of bacteria per 100 ml. The presumptive, confirmatory and completed phases are the three sequential phases involved. To recover coliform bacteria, bottles containing fermentation tubes and lactose-containing lauryptose (MacConkey or modified sodium glutamate) are both incubated for 24 to 48 hours at 35°C.

When the tubes show turbidity, acidity and gas they are considered presumptive positive for coliform bacteria. They are presumptive because false positive and false

negative reactions often occur as a result of growth and interference of non-target bacteria in the growth medium. Confirmation of subsamples from all presumptive positive tubes must be done by establishing growth target bacteria in brilliant green lactose bile broth at 35°C within 24 hours for total coliform, 44 °C within 24-48 hours for thermotolerant coliforms *and* the confirmed test for *faecal* coliform in the growth of target bacteria (*E. coli)* medium at 44.5 °C within 1-2 days (WHO, 1996). The confirmed test is reliable but not proof that the target bacteria (*E. coli)* have been detected. Hence samples of the confirmed positive reaction (about 10%) should be inoculated onto selective agar medium and the target bacterium physically recovered and gram stained. The MPN table is then used to estimate the number of the target bacterium (Abaidoo and Obiri-Danso, 2008).

Fast detections using chromogenic substance is another way of indicator bacteria detection. Chromogenic compounds are added to conventional or newly devised media used for isolation of the indicator bacteria. These chromogenic compounds are modified to change colour or fluorescence by the addition of either enzymes or specific bacterial metabolites. This enables for easy detection and avoids the need for isolation of pure cultures and confirmatory tests (Ashbolt *et al.*, 2001).

Another is the application of antibodies**.** Immunological methods using monoclonal antibodies can be used to detect indicator bacteria in water samples. Pre-cultivation in select medium must preface detection to avoid detection of dead cells. ELISA antibody technology has been developed to allow for readable detection by the naked eye for rapid identification of coliform micro colonies. Other uses of antibodies in detection use magnetic beads coated with antibodies for the concentration and separation of the oocysts and cysts as described below for Immunomagnetic Separation Methods (IMS) (Ashbolt *et al.*, 2001).

IMS culture and other rapid culture-based methods: IMS involves purified antigens biotinylated and bound to streptoavidin-coated paramagnetic particles. The raw sample is mixed with the beads, then a specific magnet is used to hold the target organisms against the vial wall and the non-bound material is poured off. This method can be used to recover specific indicator bacteria (Ashbolt *et al.*, 2001).

Gene sequence-based methods: Gene sequence-based methods depend on the recognition of exclusive gene sequences particular to specific strains of organisms. Polymerase chain reaction and fluorescence in-situ hybridization are gene sequence-based methods currently being used to detect specific strains of indicator bacteria (Ashbolt *et al.*, 2001).

2.2.4 Physico-Chemical Parameters

It is very essential and important to test water before it is used for drinking, domestic, agricultural or industrial purpose. Water must be tested for different physico-chemical parameters. Selection of parameters for testing of water quality solely depends on the purpose for which the water is to be used and the extent of its quality and purity needed. Some physical tests should be performed for testing of its physical appearance such as temperature, colour, odour, pH, turbidity and conductivity while chemical tests should be performed for its alkalinity, hardness and residual chlorine. The following different physico-chemical parameters are tested regularly for monitoring quality of water:

Temperature - Temperature is one factor that always correlates with microbial growth rates. Temperature is considered as a critical parameter since it has significant impact on many reactions, including the rate of disinfectant decay and by-product formation (Volk *et al.*, 2002). Increasing temperature influences microbial growth directly and indirectly; directly by increasing microbial metabolism, and indirectly by dissipating

disinfectant residuals and increasing corrosion rates. As the water temperature increases the disinfectant demand and by product formation, nitrification, microbial activity, algal growth, taste and odour episodes, Lead and Copper solubility increases and Calcium carbonate ($CaCO_3$) precipitation also increases. An aesthetic objective is set for maximum water temperature to aid in selection of the best water source or the best placement of dam for a water intake.

Since temperature affects water treatment, water supplies generally tend to keep the temperature as low as possible in order to minimize the bacterial growth after treatment. Keeping the temperature low reduces the risk for pathogenic proliferation and survival since the optimal temperature for most pathogens is close to the human body temperature (Boe-Hansen, 2002). In an established system the water temperature controls the rate of all chemical reactions, that is, the higher the temperature, the faster the reaction rate.

pH of water is the hydrogen ion concentration of the water. It is used in determining the corrosive nature of water, and one of the most important operational parameters for water treatment in relation to disinfection, coagulation/flocculation and pH adjustment. Dissociation is poor at pH levels below 6.0, from pH 6.0 to 8.5 a nearly complete dissociation of Hypochlorous acid (HOCl) occurs. Thus, for disinfection with chlorine control of pH is critical. As a consequence, an increasing pH of the potable water requires rising amounts of chlorine for the same disinfection efficacy (Herrmann *et al.,* 2003). The microbial activity of chlorine is greatly reduced at high pH, probably because at an alkaline pH, the predominant species of chlorine is the Hypochlorite ion (OCl^-). Equilibrium concentrations of HOCl and OCl depend on the pH of the water. If the pH of the water is high, chlorine is less effective in killing pathogens. Changes in pH can influence microbial growth, and pH can change within

a drinking water distribution system. According to Kent *et al.* (1998), pH values ranging from 3 to 10.5 could favour both indicator and pathogenic microorganism growth. The lower the pH value the higher is the corrosive nature of water. pH is positively correlated with electrical conductance and total alkalinity (Gupta *et al.*, 2009).

Electrical Conductivity (EC)

This refers to the ability of water to conduct electric current and is related to the concentration of salts dissolved into positively and negatively charged ions in water which enable it to conduct electricity. Conductivity shows significant correlation with parameters such as temperature, pH value, alkalinity, total hardness, Calcium, total solids, total dissolved solids, chemical oxygen demand, Chloride and Iron concentration of water. For temperature, the EC of water increases by 2-3% for an increase of one degree Celsius of water temperature (www.smart-fertilizer.com/articles/electrical-conductivity). EC is also a good indicator of total salinity of water. Navneet *et al.* (2010), suggest that drinking water quality of a study area can be checked effectively by controlling conductivity of the water. It is measured with the help of EC meter which measures the resistance offered by the water between two platinized electrodes. The instrument is standardized with known values of conductance observed with standard KCl solution.

Alkalinity

Alkalinity is the measure of the capacity of water to neutralize acids. It is composed primarily of Carbonate ion (CO_3^{2-}) and Bicarbonate ion (HCO_3^-). Total alkalinity is affected by environmental factors such as rain and acidic sanitizers. Most alkalinity in surface water comes from $CaCO_3$ being leached from rocks and soil

(*www.water*http://www.water-research.net/.../alkalinity.htm*research.net/.../alkalinity.htm*). Alkalinity is significant in treatment of wastewater and drinking water because it influences processes such as anaerobic digestion due to the carbonate content. Alkalinity acts as a stabilizer for pH. Alkalinity, pH and hardness affect the toxicity of many substances in the water. It is determined by simple dilute Hydrochloric acid titration in presence of phenolphthalein and methyl orange indicators.

Calcium

The presence of Calcium in water supply results from the passage of water through deposits of limestone, demolite, gypsum and gypsiferous shale. The calcium content may range from zero to several milligrams per litre, depending on the source and treatment of the water. Small concentrations of $CaCO_3$ combat corrosion of metal pipes by laying down a protective coating. Appreciable Calcium salts on the other hand, precipitate on heating to form scales in boilers, pipes and cooking utensils. Calcium contributes to the total hardness of water.

It is measured by titration with standard solution of Ethylene Diamine Tetra Acetic acid (ETDA) using indicators such as Murexide, Eriochrome Black R or Solochrome Dark Blue but the latter two are often improvement because of the colour change from pink to blue under the pH conditions of more than 12.0. These conditions are achieved by adding a fixed volume of 1N Sodium Hydroxide. The volume of titre (EDTA solution) against the known volume of sample gives the concentration of calcium in the sample.

Magnesium

Magnesium is also measured by complexometric titration with standard solution of EDTA using Eriochrome black T as indicator under the buffer conditions of pH

10.0. The buffer solution is made from Ammonium Chloride and Ammonium Hydroxide. The solution resists the pH variations during titration. It can also be determined alternatively by subtracting the value of Calcium Hardness from the value of Total Hardness which are both determined titrimetrically (GWCL, Laboratory Manual, 2009).

Total Hardness

Hardness of water is caused principally by the elements Calcium and Magnesium and sometimes by Iron and Aluminum. It must be noted that Iron and Aluminum are seldom present in sufficient amounts that can impart significantly in the hardness determination. Hence, it is mostly assumed that hardness is caused entirely by Calcium and Magnesium. Most of the Calcium and Magnesium are present in natural waters as bicarbonates, Carbonates, Sulphates and sometimes as Chlorides and Nitrates. Hardness-producing substances react with soaps forming insoluble compounds before lather is produced. They are thus a measure of the soapconsuming power of water. They also deposit scales in boilers and water-heating systems. Hardness can be classified as temporary or permanent. Temporary hardness is caused by the presence of bicarbonates of calcium and magnesium and can be removed by boiling. Permanent hardness is caused primarily by Calcium Sulphate and remains even after boiling. Compounds causing permanent hardness are often termed ***incrustants.***

Hardness can also be grouped under Carbonate or Non-carbonate hardness. Carbonate hardness is due to the presence of Calcium and Magnesium Carbonates and bicarbonates. Non-carbonate hardness includes the Calcium and Magnesium Sulphates, Chlorides and Nitrates. Sulphates are often the only non-carbonate hardness compound present.

Free Chlorine Residue

Chlorine (Cl_2) is added to drinking water supplies for the purpose of destroying or deactivating disease-producing micro-organisms. This is termed water disinfection. Cl_2 is usually added to water in liquid form or as sodium or calcium hypochlorite chemicals. Maintaining an adequate level of residual chlorine is of great importance in terms of distribution water quality management (Housseini, 2003). A contamination causing a disease outbreak in a distribution system may be prevented by a chlorine demand sufficient to destroy entirely the pathogenic organisms.

Various chemical substances, such as organic and inorganic forms of nitrogen, Hydrogen sulfide, Iron, and Manganese, react with chlorine in water, consuming the chemical and rendering it ineffective as a bactericide. If the time frame allows it, chlorine self-decomposition may take place, though at a much lower rate than the other reactions (Vieira *et al*., 2004). This creates what is called a chlorine demand in water. The effective concentration of chlorine required to disinfect water is the chlorine demand plus the necessary germicidal concentration (Volk *et al.*, 2002).

Turbidity

Turbidity in drinking water is caused by particulate matter that may be present from source water as a consequence of inadequate filtration or from re-suspension of sediment in distribution system (WHO, 2004a, 2004b). Low turbidity levels are required to minimize risk of exposure to disease-causing organisms in drinking water. Turbidity is also considered a vital microbiological parameter because it is closely linked to the microbiological safety of drinking water. Turbidity can indicate that water may be contaminated with pathogens presenting human health concerns (Olson, 2003).

High turbidity values are usually recorded in the rainy season as a result of erosion and run-off which carry deposit of sand and other particles into water bodies. One

study in the Eastern Cape Province, South Africa indicated that turbidity is typically high during a storm as a consequence of rapid erosion of surface soils into rivers (Zamxaka *et al.*, 2004). Likewise, rusted metal-piping systems probably contribute to the deterioration of the water quality by increasing turbidity at distribution. The high regrowth of heterotrophs and total *coliforms* occurring after chlorination indicates the inefficiency of the filtration and chlorination steps (Muyima and Ngcakani, 1998). This is evident when sometimes you open the tap and the water is 'coloured'.

2.3 WATER TREATMENT PROCESSES

The term water treatment is used here to mean manipulating the water to remove water-borne pathogens (e.g. those that cause diarrhoeal diseases) (AWWA, 2000). Control measures may include pretreatment or screening, coagulation/flocculation/sedimentation, filtration and disinfection.

Public Water Systems come in all shapes and sizes and no two are exactly the same. They may be publicly or privately owned and maintained. While their design may vary, they all share the same goal, which is providing safe reliable drinking water to the communities they serve. Due to the differences in water quality, the treatment efforts for water normally differ from each other. The choice of treatment processes used depends on the quality and variability of the raw water source and the treatment objectives, which may vary for industrial as opposed to municipal needs.

Normally most waters can be treated solely using conventional unit processes without the need for pre-treatment except for screening to remove fish, natural debris and litters. Pretreatment includes processes such as roughing filters, micro strainers, off-

stream storage and bank-side filtration. The unit processes that may be incorporated into a water treatment plant are discussed below as per Appendix 1 attached.

2.3.1 Preliminary Screening

The raw water is initially screened through a set of coarse screens (100 mm spacing) to remove gross solids, such as litter and branches, before being conveyed to the plant. Prior to treatment it is screened again through fine screens or, if considerable fine solids or algae are present, then micro-straining maybe used (thus a circular drum-type screen made from fine stainless steel mesh with 25,000 apertures/cm^2) before the next stage. The screenings are collected and disposed off at a landfill site.

2.3.2 Aeration

Aerators expose water to the air to remove volatile dissolved components that are in excess of their saturation concentration. Some of the toxic organics are volatile. Taste and odour-causing compounds (Iron and Magnesium) may be removed to satisfactory levels (AWWA, 2000). Addition of dissolved oxygen enhances the oxidation of iron, manganese, and other metals to higher and more soluble oxidation.

The general chemical equation that represents this reaction is as follows:

$$4Fe^{2+} + O_2 + 8OH^- + 2H_2O \leftrightarrow 4Fe(OH)_3$$

(Ferrous state) (Ferric hydroxide)

$$2Fe(OH)_2 + 1/2O_2 + H_2O \leftrightarrow 2Fe(OH)_3 \text{ OR}$$

$$4Fe(OH)_2 + O_2 + 2H_2O \leftrightarrow 4Fe(OH)_3$$

Apart from providing oxygen for purification and improving overall quality, aeration also reduces the corrosiveness of the water by eliminating Carbon dioxide (CO_2) and raising the pH. However, aeration alone cannot reduce the corrosive properties of acid

water hence neutralization using lime may also be needed. Aeration is one of the first treatment operations applied to water. It can be designed as an esthetically pleasing spray aerators open to public view (Gray, 2005).

2.3.3 Chemical Feed Mixers

Many processes rely on the addition of chemical agents. Mixers are designed to disperse the chemicals rapidly and thoroughly throughout the water and this in terms of coagulation is for all other suspended particles to form larger more readily settled particles. Coagulation reactions are fast and occur in the rapid mixing device. It is essential that the coagulant be dispersed throughout the water to contact and react with the target substances before it is consumed inside reactions with water itself (Slaats *et al*., 2002).

Common steps in coagulation and flocculation process is the addition of chemical (coagulant, Al^{3+}, Fe^{3+} products) plus rapid mixing for de-stabilisation causing collisions between the uncharged colloidal particles and removal of agglomerates from the water by sedimentation for bulk particles and filtration for smaller flocs.

2.3.4 Flocculation/Sedimentation

Flocculation refers to water treatment process that combines or coagulates small particles which settle out of the water as sediment. Aluminium and Iron salts are synthetic organic polymers used alone or combined with metal salts to promote coagulation. Some examples are hydrated Aluminium Sulphate ($Al_2(SO_4)_3 18H_2O$) , hydrated Aluminium Chloride ($AlCl_3.6H_2O$) and hydrated Ferric Sulphate ($Fe(SO_4)_3.9H_2O$). Sedimentation occurs naturally as flocculated particles settle out of the water.

Flocculators provide gentle agitation of water that has been coagulated to promote particle contact and formation of larger particles. Exposing the water to relatively quiescent conditions will allow solids that can settle to be removed by the action of the force of gravity. The sludge accumulated in these tanks may be dislodged unto sand drying beds and later disposed off in landfills or the water source downstream of the withdrawal point for the water supply (AWWA, 2000). Sedimentation proceeded without coagulation and flocculation is known as plain sedimentation. Raw waters that contain a high sediment load may be settled in a plain sedimentation basin to remove the readily settled particulates. Then a chemical assist may be provided through addition of coagulant followed by flocculation and another sedimentation basin to remove slower settling particulates. In the Kwanyaku Water Treatment Plant, aeration, coagulation, flocculation and sedimentation all take place in the Clari-flocculator. The sediments are later dislodged on to a sludge bed. The plant uses alum as the coagulant.

2.3.5 Filtration

Water treatment facilities use filtration to remove all particles from the water. These particles include clay, sand and silt, natural organic matter, precipitates from the treatment plant processes in the facility, iron, manganese and microorganisms. Filtration clarifies water and enhances the effectiveness of disinfection.

Filtration accomplishes polishing of water and follows sedimentation if it is provided. Water moves through tanks that contain sand and other types of media. Fine solids that did not settle out in a sedimentation basin will be entrapped in the filter. There will also be significant removal of bacteria in a filter but not enough are completely removed in a properly operated filter. There are two filtration alternatives in common

use. Slow sand filters have only sand media. They are cleaned by scraping off the top layer of media on a periodic basis as the filter clogs (LeChevallier *et al*., 1996).

Rapid filters which are used at the Kwanyaku Water Treatment Plant are sand filters or multimedia filters that have anthracite, sand, and possibly other media in them. Loading rates of rapid filters are much higher than slow sand filters. Flow through rapid and slow sand filters is due to gravity. Pressure filters, where water is forced through the filter by applied pressure in a completely enclosed unit are used in some smaller installations. Roughing filters that contain coarse media may be used to prefilter water with very high suspended solid content.

Rapid filters are cleaned by backwashing that is reversing the flow of the water through the media and pumping at a rate sufficient to expand the media.
Backwashing is needed regularly depending on influent water quality.

2.3.6 Disinfection

Disinfection is the removal or inactivation of pathogenic microorganisms (not necessarily sterilization). Water is often disinfected before it enters the distribution system to ensure that potentially dangerous microbes are killed. Chlorine, chloramines (Chlorine combined with Ammonia), and Chlorine dioxide are most often used because they are very effective disinfectants not only for the treatment plant but also in pipes that distribute water to the consumer. Some treatment practice advocates the addition of a small amount of chlorine (and possibly ammonia) to form chloramines, which maintain a small disinfectant residual in the distribution system when other disinfectants are used as the primary disinfectant.

2.3.7 The Reaction of Chlorine with Water

In water, chlorine hydrolyse to form hypochlorous acid (HOCl) according to the following reaction:

$Cl_2 + H_2O \rightarrow HCOl + H^+ + Cl^-$

The hypochlorous acid further dissociates into its component ions to form OCl^- (Hypochlorite ion) and H^+ (hydrogen ion):

$HOCl \rightarrow H^+ + OCl^-$

Equilibrium concentrations of HOCl and OCl^- depend on the pH of the water. Alkaline pH leads to the formation of higher concentrations of HOCl. Both HOCl and OCl^- are commonly referred to as free available Chlorine which remains available for further reaction. Available sources are Calcium Hypochlorite which is the predominant form and when it dissolves in water leads to about 70% available chlorine, Sodium Hypochlorite which is available in liquid form at concentrations of between 5 and 15%. (GWCL Laboratory Manual, 2009).

Ozone is becoming more widely used as a disinfectant. The disinfection tank or device (such as a UV chamber) maintains the water in contact with the dose of disinfectant for a time long enough to ensure the required log reductions in indicator bacteria. It is exceedingly rare to find raw water that would not require disinfection. Ultraviolet is an effective disinfectant for treatment of relatively clean source waters but not effective in controlling biological contamination in distribution pipes.

2.4 WATER DISTRIBUTION SYSTEM

The goal of a drinking water distribution system is to deliver sufficient quantities of water where and when needed at an acceptable level of quality. An underground network of pipes typically delivers drinking water to the homes and businesses served

by the water system. Small systems serving just a handful of households may be relatively simple. Large metropolitan water systems can be extremely complex, sometimes with thousands of miles of piping serving millions of people. Although water may be safe when leaving the water treatment plant, it is important to ensure that this water does not become contaminated in the distribution system because of such things as water main breaks, pressure problems, or growth of microorganisms.

Drinking water quality usually can undergo dramatic changes in distribution systems and this has made the distribution systems no longer considered as inert systems supplying drinking water to large areas (Chowdhury, 2003). With regards to this, it is important to know that in a looped pipe network, the water reaching the consumer is actually a blend of water parcels that may originate from different sources at different points in time and follow different flow paths. According to LeChevallier *et al*. (1996), distribution systems are considered as biological and chemical reactors that interact with the transported water with its quality changing with time and space. Some components of a water distribution system and their influence on water quality are described below:

2.4.1 Service Water Reservoirs

A water reservoir is normally a structure that allows a different inflow and outflow at any given time. When the inflow is lesser than the outflow, water is taken out of storage. Peak attenuation storage allows the treatment plant to produce water more consistently. Some reservoirs have a common inlet and outlet while others have them separated. Contaminant entry points to a reservoir include wildlife and human access. Reservoirs however, should be designed to keep the water fresh and to prevent the carry-over of sediment (Kawamura, 2000). Treated water from the Kwanyaku Water Treatment Plant feeds a number of service water reservoirs of which two are situated

at central points along the distribution system such as Agona Swedru (see Appendix 2), Agona Nyarkrom and Budumburam.

2.4.2 Distribution Network

Treated water has to be conveyed to consumers and this is achieved using a network of pipes known as water mains. There are two broad categories of water mains. These are Trunk mains which are the largest and used for transporting large volumes of water from the raw water source to the treatment plant, and from there to a service reservoir or tower. There are no branch or service pipe connections to trunk mains where the water often is at a very high pressure (Kawamura, 2000). The second is the distribution mains which are basically a network of pipes that bring water from the service reservoir to the consumer's property. The network is highly branched, to which connections to individual houses are made.

Distribution mains form loop systems, which equalize the pressure, and ensure that the water is used rapidly, kept and mixed thus buffering the diurnal peaks in demand from consumers (Gray, 2005). They usually have fitted fire hydrants at about 135m spacing and service connections.

2.4.3 Pump or Booster Stations

A pump station is installed where water must be lifted from a low level to a high level. The flow may be pressurized to a higher hydraulic grade instead of installing a high level reservoir. Virtually all pumps used to lift water more than a few meters are centrifugal pumps (Gray, 2005). Hence centrifugal pumps are those used at the booster stations.

Most pump sets usually comprise two pumps, one set to duty and the other on standby. This arrangement ensures that there is no production loss if the duty pump fails to start.

To avoid very old water in standby systems, the allocation of the duty and standby pumps should be alternated from time to time. This will also ensure that the standby pump remains functional and will spread the wear over both pump sets.

2.4.4 System Monitoring and Control

Supervisory, Control and Data Acquisition (SCADA) systems are normally installed on many distribution systems to monitor and control the operation of the system. Typical monitoring of a water reticulation system will include: Reservoir levels, pump operation, system flow at key points, system pressure and alarm systems set to warn when action is required.

SCADA provides powerful tool for checking on design information and how well a section of the system is working eg. monitoring how full a reservoir is and how often the pump starts/stops may reveal that the storage is too small or that the on/off probes are set too close together (Gray, 2005).

2.5 WATER DISTRIBUTION SYSTEM OPERATIONS

As distribution is the final stage before the water is consumed, there are no further barriers between the entry of contaminant and the consumer, thus, particular attention and care is required. Full and detailed documentation, example, the reticulation system and its components should be taken in a fully comprehensive manner by most operation authorities when asset management systems are put into operation. These can be used as a tool in identifying maintenance requirements and potential trouble spots.

2.5.1 Causes of Recontamination of Water in the Distribution System

The main causes of recontamination of water in the distribution system include poor laying of pipes, the use of inappropriate types of distribution pipe, or poorly planned and coordinated maintenance systems including a burst of a distribution line. These can, however, be overcome by good system design and a good asset management system. The most direct sources of contamination of reticulation water supplies arise from the following:

i. older style ball hydrant that will open on their own accord under loss of system pressure ii. open fire hydrants during mains repairs and iii. backflows from individual properties.

Fire hydrant contaminant entry after draining down for repair can be minimized by the use of standpipes on the hydrants. This restricts the level of the water drained from the main.

Backflows are the flow of water from consumer premises into the public supply. Its prevention is, however, very important because it results in the introduction of pathogenic organisms into the water if it is contaminated. It is necessary for the water supplier to monitor the network to ensure that there is sufficient positive flow through the pipes to prevent any backflow or inflow that could contaminate the supply. The network should also be modeled in some way to ensure that the necessary capacities and water pressure criteria are met under all conditions.

2.6 CAUSES OF WATER QUALITY DECAY IN DISTRIBUTION SYSTEMS

The abundant documentation of water quality decay in distribution systems motivates researchers to identify its causes. However, many complex, interrelated, and often competing factors influence water quality decay within drinking water distribution

systems. These factors are often difficult to correlate. Some of the factors that contribute to water quality decay in distribution systems are examined below:

2.6.1 Loss of Disinfectant Residual

Disinfection is the process of using chemical or physical means to inactivate harmful microorganisms that might be present in water and to protect distributed water from pathogen regrowth or recontamination. Majority of surface water supplies maintain some level of residual chemical disinfectant throughout the distribution system. Most commonly used disinfectants are Chlorine, chloramines (Chlorine combined with Ammonia), Ozone, and Chlorine dioxide are basically used as primary disinfection treatment step. Secondary or post-disinfection usually is done to the treated water before it is released to the distribution system to maintain a residual disinfecting capability. By their very nature, disinfectant chemicals are extremely reactive and do not persist for long periods. The loss of disinfectant residual can weaken the barrier against microbial contamination resulting from line breaks, crossconnections, or other unforeseen occurrences and can encourage the growth of pathogens (AWWA, 2000). The Kwanyaku Water Treatment Plant uses chlorine in all its form as a disinfectant and allows for a minimum of 0.5mg/l residual chlorine at the last consumer point.

Most waters exhibit a rapid consumption of chlorine when the chemical is first added during primary disinfection. Losses of 50% or more over a contact time of several hours are not uncommon. After the contact time used for primary disinfection is completed, rates of loss of chlorine are significantly lower as it reacts with the more recalcitrant organic components.

An additional loss can occur as chlorine reacts with materials on or near the pipe wall, such as iron released because of corrosion or organic slime. The rate of this reaction

can be much higher than that caused by bulk reactions, particularly in older, unlined cast iron or steel pipes (AWWA, 2000).

2.6.2 Biodegradable Organic Matter (BOM) -Growth-supporting Substrates

Another factor that controls the growth of bacterial in the distribution system is the concentration of growth-supporting substrates. A substrate is a reduced material that supports the growth of the microorganisms (Rittmann & McCarty, 2001). Many substrates that can support microbial growth can be found in finished drinking water. The major substrates are biodegradable organic matter which supports heterotrophic growth, and reduced nitrogen compounds such as Ammonia and Nitrite which support nitrifier growth. However, small amounts of microbial growth can be supported by many other substrates, such as hydrogen and ferrous iron produced in anaerobic zones on corroded pipe surfaces.

Pipe surface roughness, pipe material, and hydraulic flow patterns is one other factor that affects microbial growth in distribution systems. Rough surfaces support higher biofilm densities by providing protection from detachment resulting from hydraulic shear stress. Furthermore, pipe materials themselves can be a factor. For example, corrosion of iron pipes generates products that react with and destroy disinfectants, and some (like Fe^{2+}) can be substrates for autotrophic bacteria. Corrosion also creates tubercles that increase surface roughness, increase the hydraulic mixing and transport of materials to the surface, become points of precipitation of organic compounds, and provide cracks and crevices that protect bacteria from disinfection and shear stress (LeChevallier & Shaw, 1996).

2.6.3 Problems caused by water quality decay in Distribution Systems

Water quality can deteriorate dramatically within a distribution system, with excessive microbial growth being of primary concern. Heterotrophs and Nitrifiers are the most prevalent microbes found in drinking water distribution systems. However, several other types of organisms commonly are also found, such as anaerobic bacteria, protozoa, copepods (crustaceans), and nematodes (worms) (Geldreich, 1996). This variety of organisms demonstrates that the distribution system can be a complex ecosystem that supports life which poses a challenge to water consumers, utility operators and managers.

Problems that water consumers can notice immediately are tastes and odours. Microbial growth in distribution systems can cause offensive tastes and odours (Burlingame & Anselme, 1995). But these problems can raise a lot of health concern as discussed earlier.

For example, members of the genus *Actinomycetes* release geosmin and methylisoborneol (MIB), which cause a musty odour at very low concentrations. Also, musty taste episodes can be caused by the biotransformation of chlorophenol to chloroanisole by fungi (Piriou *et al.,* 2001). In anaerobic zones, compounds such as hydrogen sulfide and organic sulfhydryls can be produced microbially, causing swampy and rotten vegetable odours.

2.6.4 Salient points for monitoring bacteriological quality

These include:

i. Long residence time: long distance from transport line, pipes with low consumption and dead ends ii. Suspected locations for chance on contamination: hydrants, public taps, kitchen, toilets, hospitals and industries iii. Water and people:

large amount of people involved, large amount of water involved and people with weak health (Buiteman *et al*., 2008).

CHAPTER THREE

MATERIALS AND METHODS

3.0. EXPERIMENTAL DESIGN

A cross sectional study was done to examine the related physico-chemical and bacteriological quality of drinking water from the point of production to three selected points in the distribution chain.

3.1. DESCRIPTION OF THE STUDY AREA

The study was conducted in Agona Kwanyaku in the Central Region (Fig. 1) from September, 2013 to February, 2014. The Kwanyaku Water Treatment Plant abstracts water from the Ayensu River with a catchment area of 884 km^2 (341 sq miles) which flows almost centrally through Kwanyaku Supply system. The river takes its source from the Bunsu Hills, an extension of the Atiwa Range, from where it flows generally southward to the sea. The Ayensu Basin is bounded on the east by the western

boundary of the Densu Basin, on the north by the southeastern boundary of the Pra Basin, on the west by the eastern boundary of the Ochi-Nakwa Basin and on the south by the Gulf of Guinea (WRMS, 2008).

The basin has varied climatic and vegetation characteristics. The upper reaches of the Ayensu basin fall within the moist (humid) semi-deciduous rainforest zone with a two peak rainfall regime with an average annual rainfall ranging from 1,370 to 1,650 mm. The central and southern coastal areas however fall within the dry marginal Forest-Savannah Transition zone with an average annual rainfall of some 1,145 to 1,650 mm and the Sub-humid Coastal Savannah Zone with an annual average

Fig 1. Map of Ghana showing Project area and sampling Points along the water distribution network.

rainfall ranging from 750 to 1,150 mm, respectively. The original vegetation cover of the basin consisted of moist evergreen forest at the summits of the Atiwa ranges in the headwater areas, the moist and dry semi-deciduous and the marginal transition forest in the middle basin through to the coastal sub-humid savannah with shrub thicket and grasses to patches of mangrove swamps and wetlands along the coast (WRCS, 2008).

Most of the forest was opened up for cocoa cultivation which is currently replaced by intensive bush fallow food crop cultivation (cocoyam, plantains, cassava, maize, vegetables) and oil palm plantation development (WRMS, 2008). The original forest cover is almost completely eliminated. The present cover consists of small areas of secondary forest with low bush fallow re-growth in the forest areas and grasses in the coastal zone. Large numbers of cattle are known to be kept on the coastal plains while coconut plantations occur behind the beaches.

3.2 DESIGN OF STUDY

The study was carried out in two main phases. These are:

i. Physical and chemical analyses of water ii.
Bacteriological analyses of water

The categories of water samples collected are illustrated in the diagram below (Fig. 2

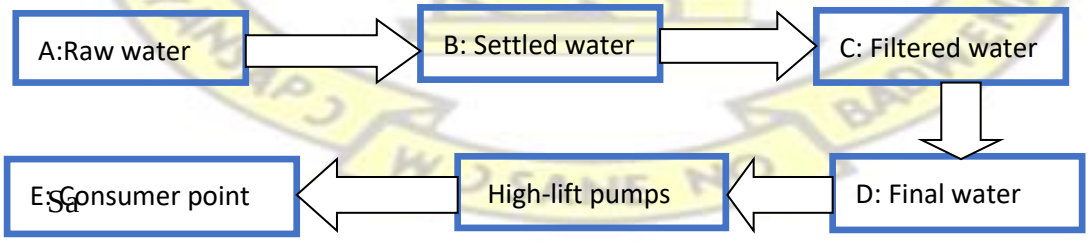

Fig. 2. A sketch of the different types of water samples collected

3.3 PRE-ANALYTICAL ACTIVITIES

Before the collection of water samples all glassware and other materials such as spatula, stirrers were washed. Racks were assembled and the benches cleaned. Bottles for collection of samples for bacteriological analyses and pipettes for inoculation were sterilised in the oven.

3.3.1 Media Preparation and Sterilisation

Media were prepared in accordance with the manufacturer's instructions, as follows:

Calculated amounts of dehydrated MacConkey Broth and Brilliant Green Lactose Bile Broth were dissolved in distilled water to obtain the media. For MacConkey Broth, double-strength and single-strength media for presumptive test were prepared. For Brilliant Green Lactose Bile Broth single-strength media were prepared for confirmatory analyses.

The requisite volumes were dispensed into culture tubes containing an inverted Durham tube and capped. The tubes were then sterilised in an autoclave at 115 ^{0}C for 30 minutes (Appendix 50 and 51). The sterilized media were stored at room temperature in the dark since several dyes are light-sensitive.

3.4 SAMPLING POINTS AND FREQUENCY

Triplicate water samples were collected from Raw, Settled, Filtered and Final water at points A, B, C, D and E respectively (Fig. 2). The consumer points comprised of three randomly selected locations along the distribution chain (Fig. 1). The water samples were examined for selected physico-chemical parameters using appropriate methods of analysis and thermotolerant coliform (TTC) using the Most Probable Number (MPN) method. 500 ml of each sample was collected in sterile

polypropylene bottles, placed in cold ice box and sent to the laboratory for analyses.

Samples at point D (Final water) were taken at the clear well tanks at the treatment station and those at point E (water at consumer point) from three locations **(**Assissim, Ekwamkrom and Mangoase) along the distribution network at a distance of 11 km, 14 km and 18 km respectively from the plant.

The method of sample collection at each source was according to the WHO Guidelines (WHO, 1994, 1995) for drinking water quality assessment. Taps from which samples were taken were first sterilized using a flame of cotton soaked in methylated spirit.

Water samples for bacteriological analysis were collected in labeled sterile glass bottles and transported to the laboratory in a cold box containing ice freezer packs. From each source, 250 ml of sample was taken. Bottles for chlorinated samples were treated with sodium thiosulphate and sterilized in an autoclave for 30 minutes at 135^0C to stop the chlorination process at the moment of taking the sample. For physico-chemical analyses 500 ml polypropylene bottles of water samples were collected, labeled and transported to the laboratory in icebox. Each sample was analyzed within four hours of collection at the treatment plant laboratory.

3.5 PHYSICAL ANALYSES

The water samples collected in the entire sampling period were analyzed for pH, turbidity, alkalinity, temperature, conductivity, colour and residual chlorine. The pH was measured using the Lovibond 2000 pH comparator. This was done by introducing ten drops of bromothymol blue into the comparator tube filled with 10 ml sample. The mixture was swirled to ensure a thorough mixing and then placed in the right hand compartment. The colour produced in the test tube was compared to the colours on the standard disc by rotating the disc until a colour match was obtained and recorded.

Turbidity measurements were made using a HACH DR 2000 spectrometer. 10 ml of each sample was poured into the tube and placed in the apparatus for the reading to be recorded.

The temperature of each water sample was determined by introducing a Celsius scale thermometer into about 200 ml of each sample in a beaker and the temperature recorded.

Conductivity measurements were made using HACH HQ40d conductivity meter. 100 ml of each sample was poured into a beaker and the electrode placed in it. The measurement was read directly in micro Siemens per centimeter (µS/cm).

Colour was measured using the B.D.H Lovibond Nessleriser. The comparator has two compartments and two tubes. One tube contains distilled water to serve as a control. Into the other tube, 50 ml of each sample was poured and compared to the control by rotating the disc to read the colour number that matched directly with the control. This was done in turns and the colour recorded.

Free chlorine residual, for each chlorinated sample was determined at site of collection with a Lovibond 2000 Comparator system, using a DPD N_o.1 chlorine tablet. One tablet was dissolved in 10 ml of each sample, placed in the comparator and compared to record the figure that matched the colour obtained when the tablet was dissolved after five minutes.

3.6 CHEMICAL ANALYSES

All chemical analyses were conducted by means of titration. In determining the alkalinity, three drops of methyl orange indicator was added to 100 ml of each sample

and titrated against 0.2 mol/dm^3 HCl. The average titre was multiplied by 10 to determine the amount of $CaCO_3$ in one litre of sample.

For measurement of calcium and calcium hardness, 1.0 ml of 1.0 M NaOH was added to 50 ml sample to produce a pH of 12-13 and then two drops of murexide indicator was added. The mixture was titrated against 0.01 M EDTA slowly with continuous swirling to the end point when the colour changed from pink to purple.

Calculations:

Calcium Hardness in mg/l $CaCO_3$ = (V* M*40.08)*1000 /ml sample where

M = molarity of EDTA,

V= titre value of EDTA.

The calcium content of the sample was determined by the formula:

molar mass of Ca divided by molecular mass of $CaCO_3$ multiplied by the value for the calcium hardness, that is

Ca^{2+} mg/l =M[Ca]/ M[$CaCO_3$] *Value of Calcium Hardness.

Total Hardness: 50 ml of sample was taken and one to two drops of buffer solution was prepared by mixing 1.179 g $Na_2EDTA.2H_2O$ and 780 mg $MgSO_4.7H_2O$ in 50 ml plus 16.9 g of Ammonium Chloride (NH_4Cl) in 143 ml concentration of Ammonium Hydroxide (NH_4OH) and diluted to 250 ml to produce a pH of 10. 2.

Two drops of Eriochrome black T indicator was added and titrated slowly with EDTA until the end point where the colour changed from pink to blue.

Calculations:

Hardness in mg/l $CaCO_3$ = (V*M*100)* 1000 /ml sample

where M = molarity of EDTA, V= titre value of EDTA.

Magnesium and Magnesium Hardness: Magnesium Hardness was determined by subtracting the value of Calcium hardness from that of Total Hardness and the magnesium content by the formula:

molar mass of Mg (23.4) divided by molecular mass of $CaCO_3$ (100) multiplied by the value of Mg Hardness.

Mg Hardness in mg/l $CaCO_3$ = [Total Hardness – Calcium Hardness].

Mg^{2+} mg/l = Value of Magnesium Hardness *M[Mg^{2+}]/ M[$CaCO_3$].

All tests except conductivity and those involving titration were done at the points sampling.

3.7 BACTERIOLOGICAL ANALYSES

3.7.1 Raw Water (Sample A)

Different test portions to provide tenfold serial dilution steps were used to analyse the raw water. The dilutions were based on the anticipated number of coliform bacteria in the water sample being tested. The following inoculations were made: 10ml sample each of five tubes containing 10 ml of double strength medium, 1.0 ml sample each of five tubes containing 10 ml of single strength medium and 0.1 ml sample each of five tubes containing 10 ml of single strength medium. The reliability of the result obtained depends on the number of tubes inoculated with each test portion. The process was as follows:

i. Three rows of five tubes each were arranged in a test-tube rack. The tubes in the first row (F1) held 10 ml of double-strength presumptive medium while the tubes in the second and third rows (F2, F3) contained 10 ml of singlestrength presumptive medium.

ii. With a sterile pipette, 10 ml of sample was added to each of the five tubes in row F1. iii. With a sterile 1ml pipette, 1 ml of sample was added to each of the five tubes in row F2.

iv. A 1:10 dilution of the sample was prepared by adding 1 ml of sample to 9 ml of dilution water (tryptone water), using a sterile 1 ml pipette. The diluted sample was shaken vigorously to ensure a thorough mixture.

v. With another sterile pipette 1ml of the 1:10 dilution was added to each of the five tubes in row F3.

vi. The tubes were shaken to mix the contents and to remove any gas collected in the inverted Durham tubes.

vii. The racks with the 15 tubes were incubated at 35^0C for 24 hours.

viii. Confirmatory test was conducted for all presumptive positive tubes as described for treated water below (Last three steps).

3.7.2 Final Water (Samples D and E)

i. The capped bottle containing the sample was shaken vigorously to achieve a homogeneous dispersion of bacteria.

ii. With a sterile 10 ml pipette, the sample was inoculated into five tubes each containing 10 ml of MacConkey Broth of double strength (Appendix 47).

50 ml of sample was also added to 50 ml double strength MacConkey Broth. The tubes were shaken gently to distribute the sample uniformly throughout the medium and also to ensure that no gas was collected in the Durham tubes

before incubation. The tubes were then incubated at a temperature of 35°C for 24 hours.

iii. At the end of the 24 hour incubation period, each tube was examined for the presence of gas. Any tube with gas in the Durham tube was labeled presumptive positive (Appendix 48). Tubes with no gas were shaken gently. Effervescence produced as a result of this also indicates a presumptive positive tube.

iv. All negative tubes were re-incubated for a further 24 hour period and the tubes checked again as above. The number of positive tubes at the end of both 24 and 48 hour periods were recorded.

v. A confirmatory test was conducted for all presumptive positive tubes by using a sterile loop to transfer one to two drops of sample from each presumptive positive tube into tubes containing Brilliant Green Lactose Bile (BGLB) Broth (Appendix 47). vi. The tubes were then incubated for 24 to 48 hours at 44^0C to confirm the presence of thermotolerant coliforms.

vii. At the end of the incubation period, the broth tubes were examined for the presence of gas in the durham tube. Growth and gas in the tubes confirmed the presence of thermotolerant coliforms. (Appendix 48).

3.8 STATISTICAL ANALYSES OF RESULTS

The One Way Analysis of Variance (ANOVA) was adopted. The means, sum of squares, mean square, F ratio and the probabilities were calculated at the 95% confidence level using the Statistical Package for the Social Sciences (SPSS). This means that the significance level was 5% or 0.05.

CHAPTER FOUR RESULTS

4.0 TREATMENT STATION SAMPLES

pH

The pH values of the Raw and Final water at the treatment station fell within the WHO guideline values (Fig. 3) while those for Settled and Filtered water had their values for the months of October and November, 2013 and February, 2014 below acceptable WHO limits (6.5-8.5). These pH values indicated slightly acidic nature of the water. The analysis of variance (ANOVA) results (Appendix 11) for the Raw and Final water showed that there is no significant difference between the average values implying that the average values are not statistically significant.

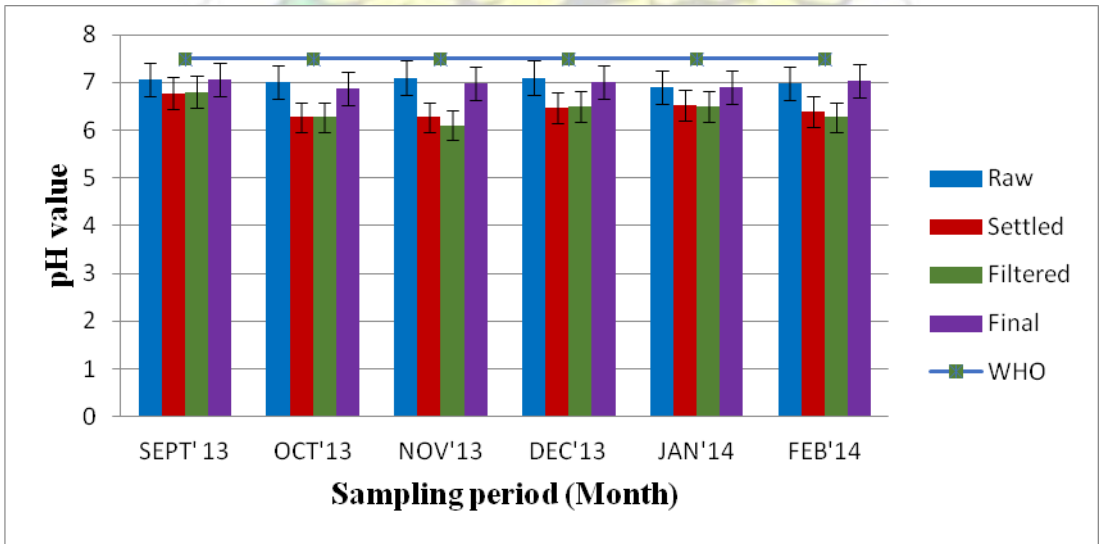

Fig. 3 pH values of water at the treatment station from September, 2013 to February, 2014 at 95% confidence level.

COLOUR

Raw water values for colour were way above the WHO guideline whilst Settled, Filtered and Final water values met the WHO standard of less or equal to 15 HU (Fig.4; Appendices 3, 4 & 5). The colour of the water greatly improved at the Settled water point and further with the Filtered and Final water. Very high colour values were recorded in October, November and December, 2013 for the Raw water. The ANOVA results (Appendix 12.0) for the Raw and Final water showed that the results are statistically significant.

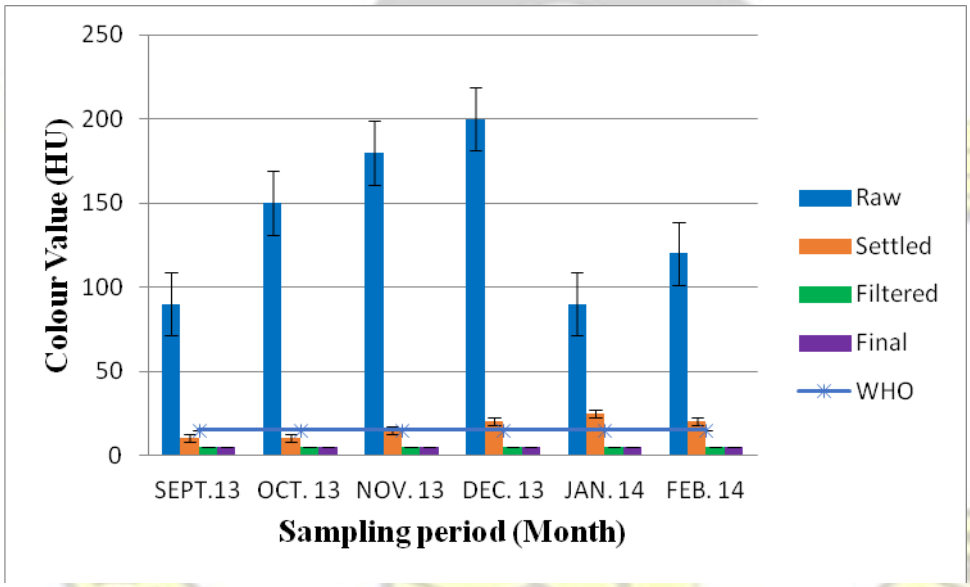

Fig. 4 Colour of water at the treatment station from September, 2013 to February, 2014 at 95% confidence level.

ALKALINITY

Alkalinity values for Raw water for the entire sampling period were higher than those for the Settled, Filtered and Final water (Fig. 5 ; Appendices 3, 4 & 5). In all cases the Alkalinity values decreased in the Settled and Filtered water but increased in the Final water. All the values recorded were within acceptable limit of WHO guideline,

which is < 200 mg/l. The ANOVA results for the Raw and Final water (Appendix13) indicated that there is no significant difference between the true average values, hence the average values are not statistically significant

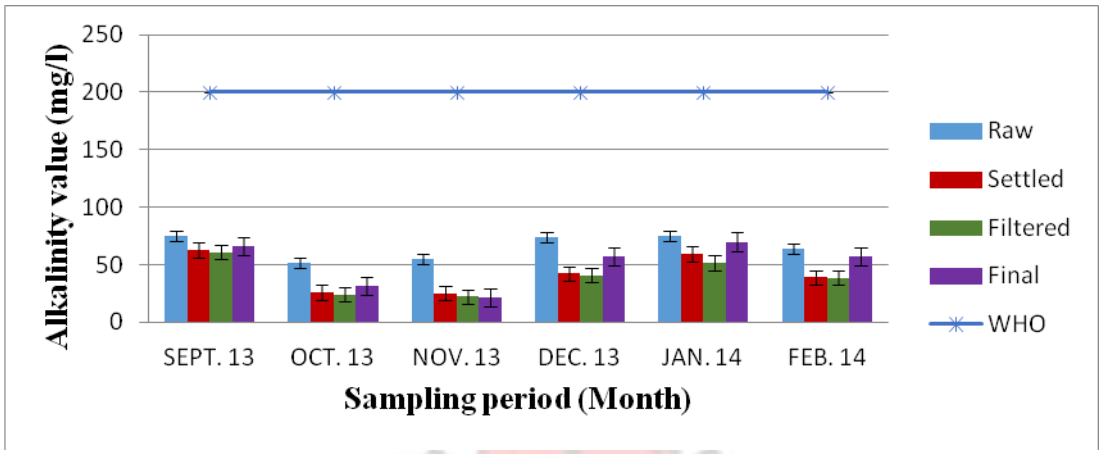

Fig. 5 Alkalinity of water at the treatment station from September, 2013 to February, 2014 at 95% confidence level.

RESIDUAL CHLORINE

Residual Chlorine was only measured for the Final water. All the values recorded were within the acceptable limit of WHO guideline of 0.6-1.00 mg/l except for the month of November which recorded a value of 1.7 mg/l (Fig. 6; Appendices 3, 4 & 5).

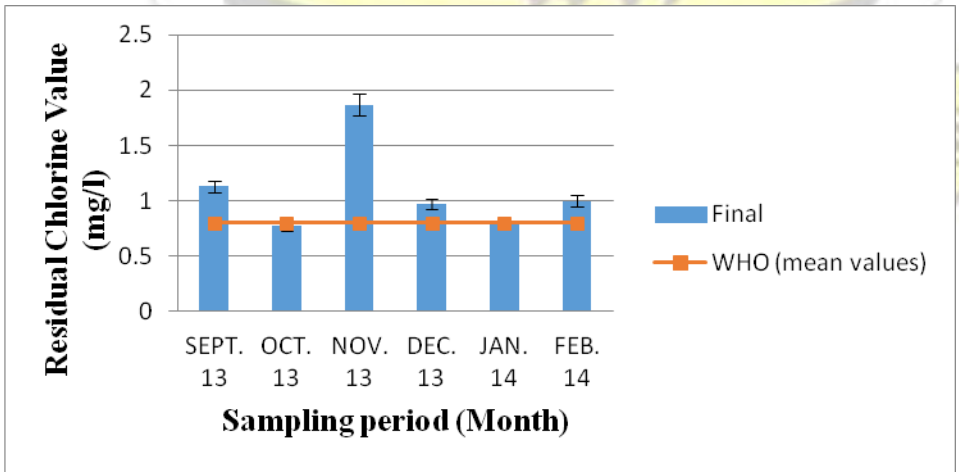

Fig. 6 Residual Chlorine of water at the treatment station from September, 2013 to February, 2014 at 95% confidence level.

TOTAL HARDNESS

All the Total Hardness values recorded for Raw, Settled, Filtered and Final water were within the acceptable range of the WHO guideline of 0 – 200 mg/l. The Total Hardness figures recorded for the Final water for the entire period were above those for Raw, Settled and Filtered water. The values were also almost stable for Raw, Settled and Filtered water (Fig. 7; Appendices 3, 4 & 5). The ANOVA results showed that there is no significant difference in the average values of the Raw and Final water.

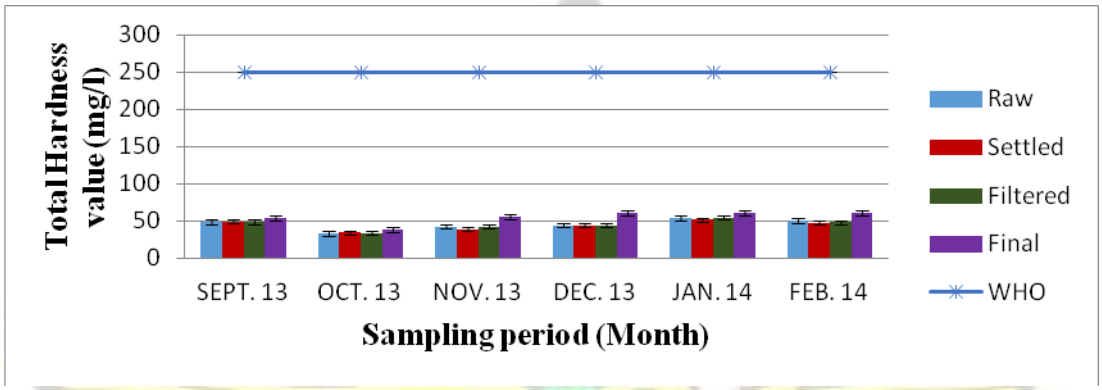

Fig. 7 Total Hardness of water at the treatment station from September, 2013 to February, 2014 at 95% confidence level.

CALCIUM HARDNESS

The values recorded for Raw, Settled, Filtered and Final water met the WHO guideline value of < 200 mg/l. The Final water values were above those of the Raw, Settled and Filtered water. The values recorded for September, October and November, 2013 were however lower than those recorded for December, 2013, January and February, 2014 (Fig. 8; Appendices 3, 4 & 5). The ANOVA results in Appendix 15 for the Raw and Final water showed that there is no significant difference between the average values; hence the average values are not statistically significant.

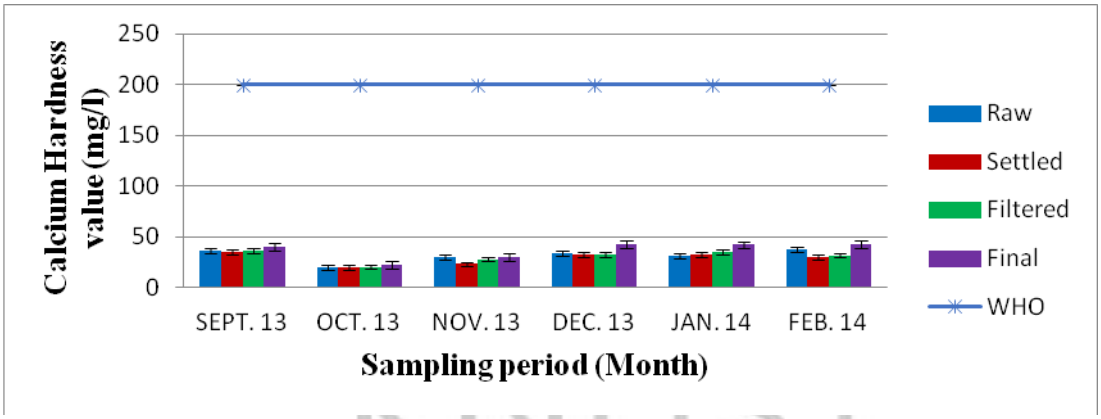

Fig. 8 Calcium Hardness of water at the treatment station from September, 2013 to February, 2014 at 95% confidence level.

CALCIUM

The Calcium ion values recorded were all within the acceptable limit of the WHO guideline value of < 80 mg/l (Fig. 9; Appendices 3, 4 & 5). However, the Calcium ion values recorded for Final water were almost in all cases above those for Raw, Settled and Filtered water, with the highest ones in the months of December, 2013, January and February, 2014. The ANOVA) results (Appendix 16) for the Raw and Final water showed that there is no significant difference between the true average values implying that the average values are not statistically significant.

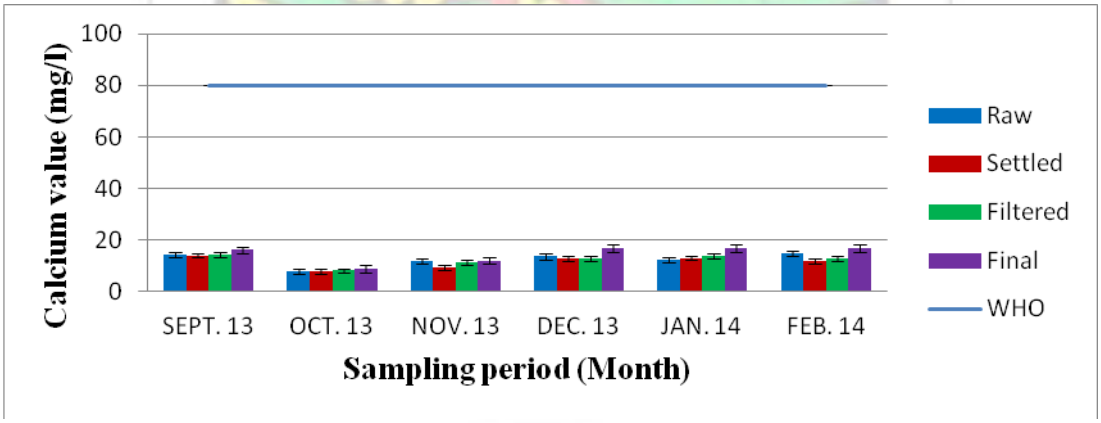

Fig. 9 Calcium of water at the treatment station from September, 2013 to February, 2014 at 95% confidence level.

MAGNESIUM HARDNESS

The recorded Magnesium values for all the water samples met the WHO guideline value of < 30 mg/l. In almost all the cases, the Final water recorded higher values than the Raw, Settled and Filtered water (Fig. 10; Appendices 3, 4 & 5). The ANOVA results (Appendix 17) indicated that there is no significant difference in the true average values of the Raw and Final water.

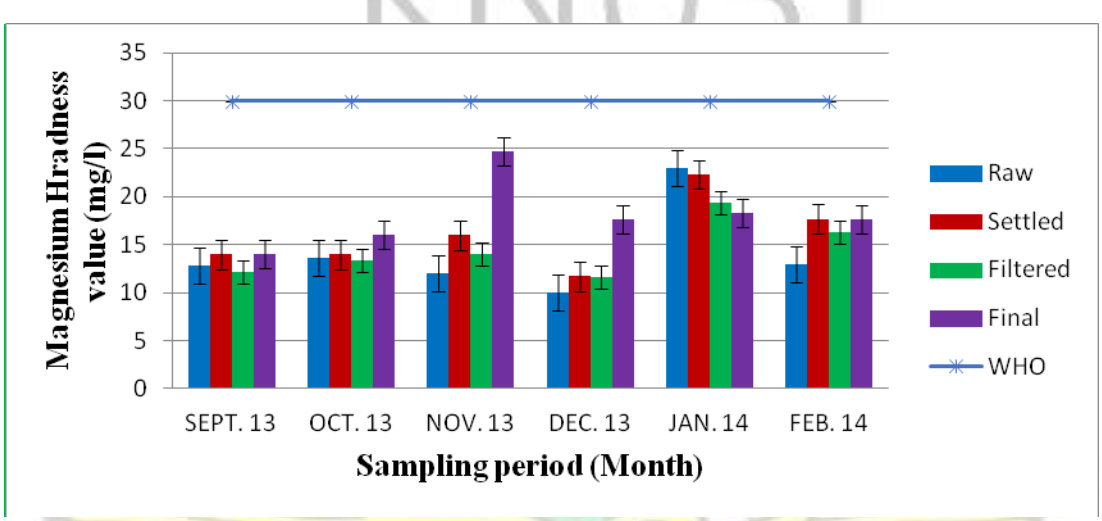

Fig. 10 Magnesium Hardness of water at the treatment station from September, 2013 to February, 2014 at 95% confidence level.

MAGNESIUM

The value recorded for all the sample types were below the acceptable limit of the WHO guideline values of 0-150 mg/l. There were only slight differences in the values recorded for each sample type in each month (Fig. 11; Appendices 3, 4 & 5). ANOVA results (Appendix 18) for the Raw and Final water revealed that there is no significant difference between the true average values of the Raw and Final water implying that the average values are not statistically significant.

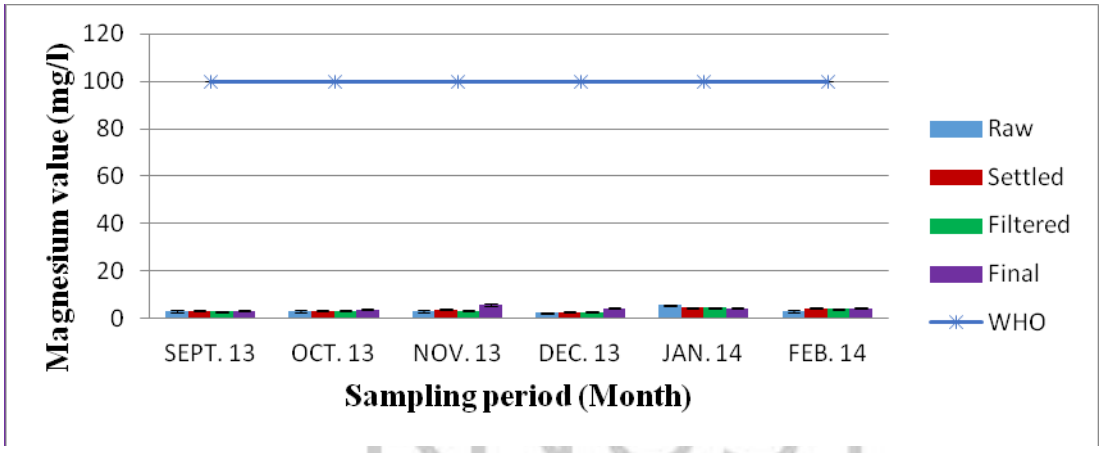

Fig. 11 Magnesium of water at the treatment station from September, 2013 to February, 2014 at 95% confidence level.

CHLORIDE

Chloride values were measured for only Raw and Final water. The highest Chloride values were recorded in November and December, 2013 as well as February, 2014. All the values recorded were however, within the acceptable limit of the WHO guideline value of < 250 mg/l (Fig. 12; Appendices 3, 4 & 5). The ANOVA results (Appendix 19) indicated that there is no significant difference in the true average values of the Raw and Final water.

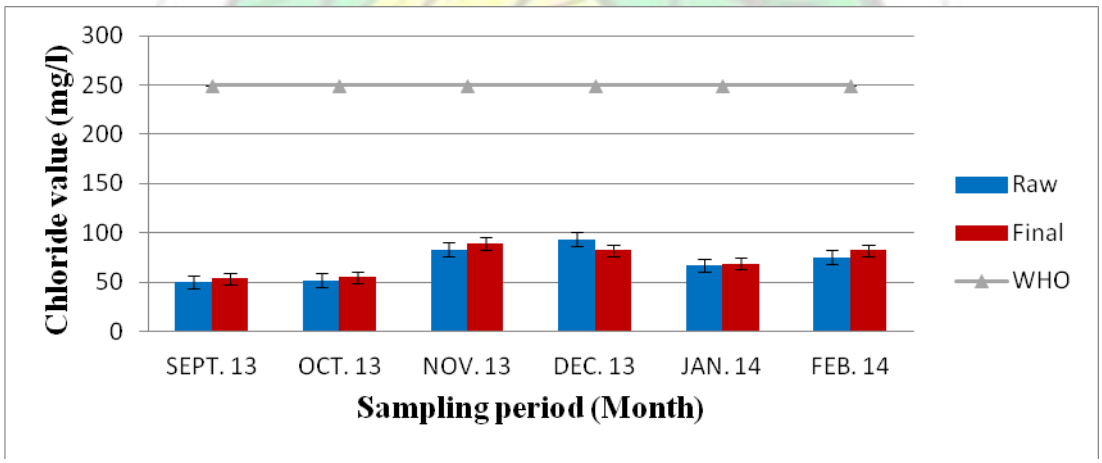

Fig. 12 Chloride of water at the treatment station from September, 2013 to February, 2014 at 95% confidence level.

TEMPERATURE

The Temperature values for all the sample types were above the acceptable limit of the WHO guideline value of 25^0C. The Temperature values for the Final water were higher than those of all the other sample types for the entire sampling period (Fig. 13; Appendices 3, 4 & 5). The ANOVA results of the Raw and Final water (Appendix 20) showed that there are significant differences in the true average values implying that the average values are statistically significant.

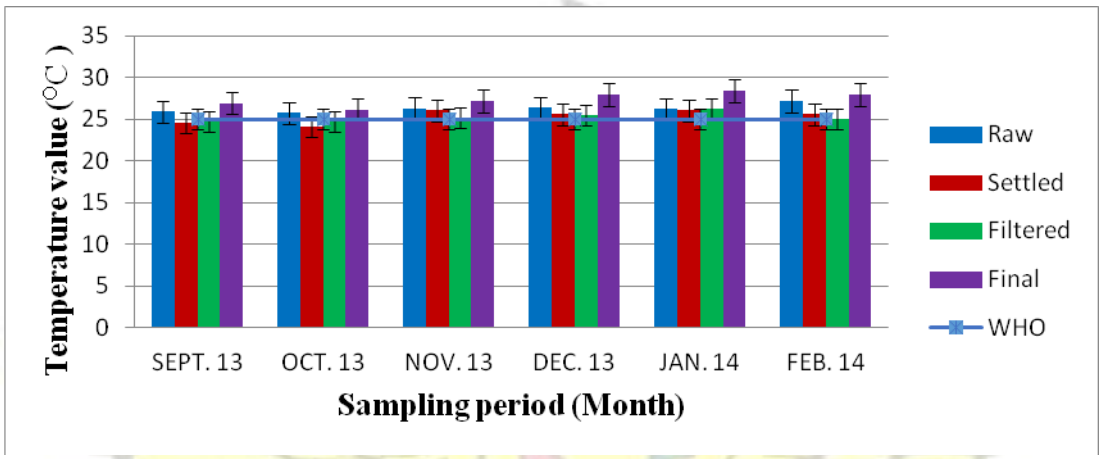

Fig. 13 Temperature of water at the treatment station from September, 2013 to February, 2014 at 95% confidence level.

CONDUCTIVITY

The Conductivity values for all the sample types were within the acceptable limit of the WHO guideline value of < 300 µS/cm. There was however no clear pattern in the conductivity values over the sampling period. The conductivity values for the Final water for the entire sampling period were above those for the Raw, Settled and Filtered water (Fig. 14; Appendices 3, 4 & 5). The ANOVA results (Appendix 21) indicated that there is no significant difference in the true average values of the Raw and Final water.

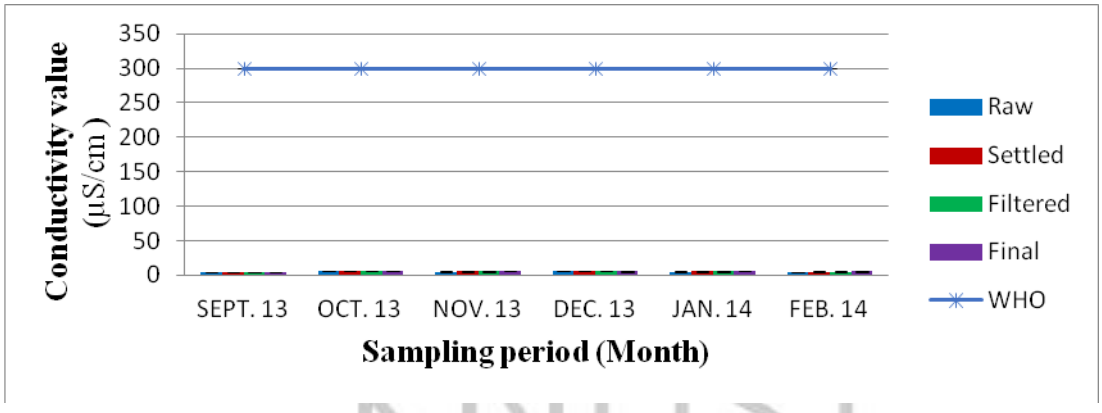

Fig. 14 Conductivity of water at the treatment station from September, 2013 to February, 2014 at 95% confidence level.

TURBIDITY

Except for the Raw water which recorded high Turbidity values above the WHO guideline values of ≤ 5 NTU. Settled, Filtered and Final water had values within the acceptable limit (Fig. 15; Appendices 3, 4 & 5). The Turbidity values decreased from the Raw to the Filtered water then slightly increased from the Filtered to the Final water. High Turbidity values were recorded in October and December, 2013. The ANOVA results (Appendix 22) showed that there is significant difference in the true average values of the Raw and Final water.

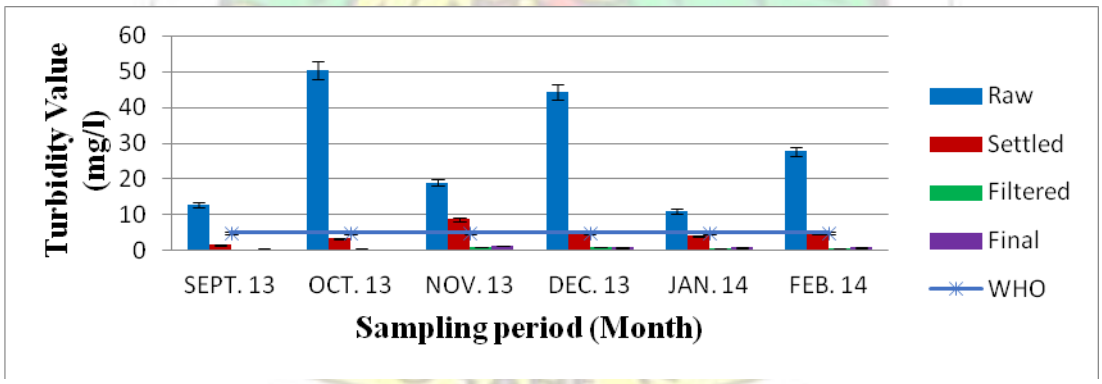

Fig. 15 Turbidity of water at the treatment station from September, 2013 to February, 2014 at 95% confidence level.

4.1 WATER DISTRIBUTION POINT SAMPLES pH

The pH values of water for the three distribution sampling points or locations decreased slightly from those of the Final water from the treatment plant (Fig. 16; Appendices 6 & 7). There was however no clear pattern between the values at the three locations. The ANOVA results for the pH at each location and the Final water (Appendices 23, 30 & 37) showed that there is no significant difference in the true average values.

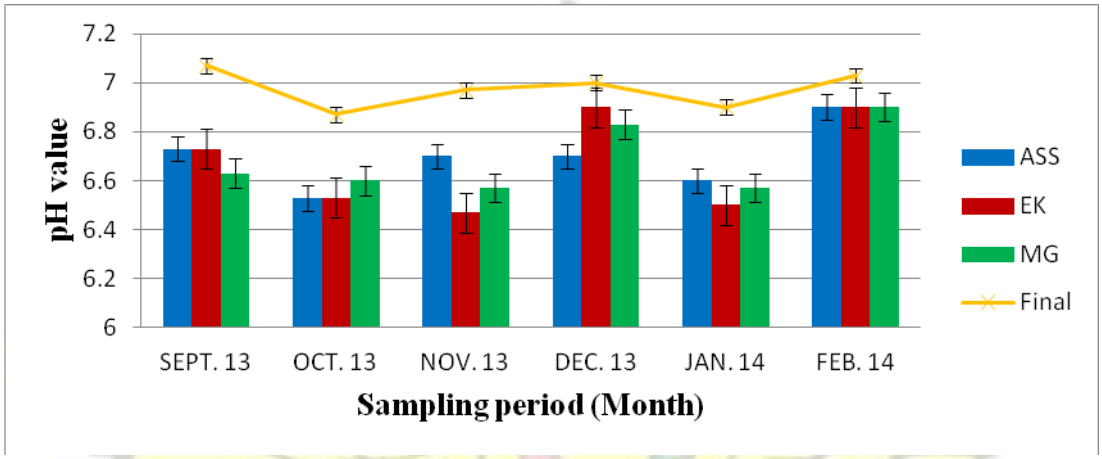

Fig. 16 pH values of water at distribution points recorded from September, 2013 to February, 2014 at 95% confidence level.

COLOUR

The Colour values for all the three points were the same as the Final water leaving the treatment plant (Fig. 17; Appendices 6 & 7).

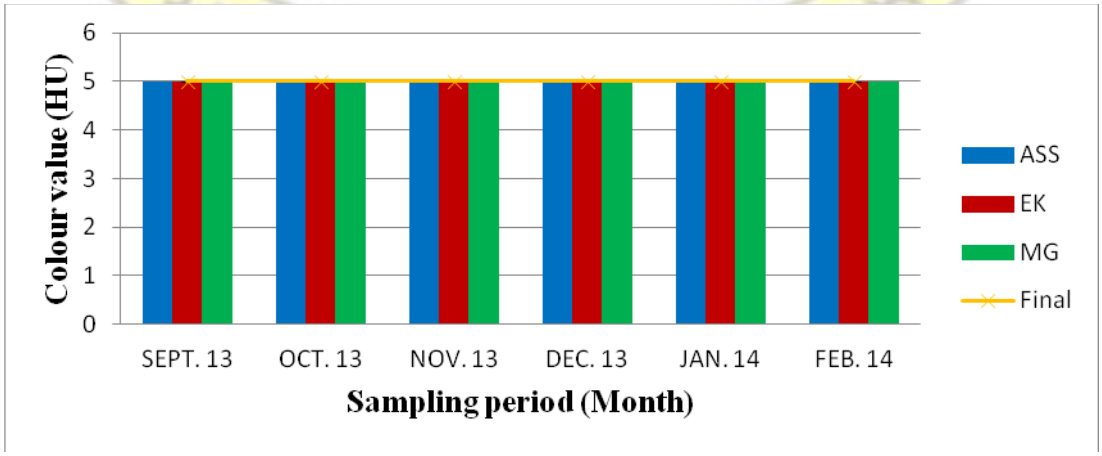

Fig. 17 Colour of water at distribution points recorded from September, 2013 to February, 2014 at 95% confidence level.

ALKALINITY

Generally there was a decrease in Alkalinity values at the three locations compared to those of the Final water. As the distance from the treatment plant to the sampling point increases, the Alkalinity decreases (Fig. 18; Appendices 6 & 7). The ANOVA results for the alkalinity of each location and the Final water (Appendices 25, 32 & 39) indicated that there is no significant difference in the average values, implying that the average values are not statistically significant.

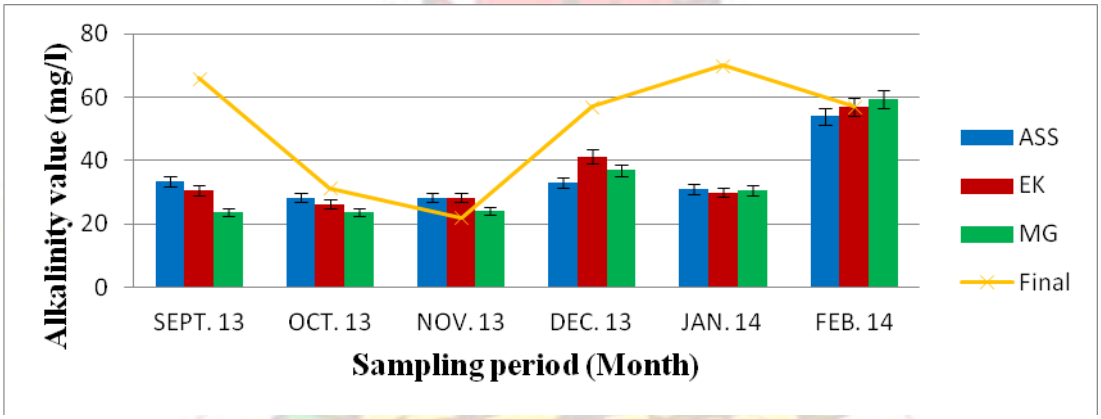

Fig. 18 Alkalinity of water at distribution points recorded from September, 2013 to February, 2014 at 95% confidence level.

RESIDUAL CHLORINE

The three sampling points recorded lower Residual Chlorine values than that of the Final water leaving the plant for the entire sampling period (Fig. 19; Appendices 6 & 7). The ANOVA results for the residual chlorine of all the three locations sampled revealed that there is significant difference in the true average values for each location and that of the Final water (Appendices 26, 33 & 40).

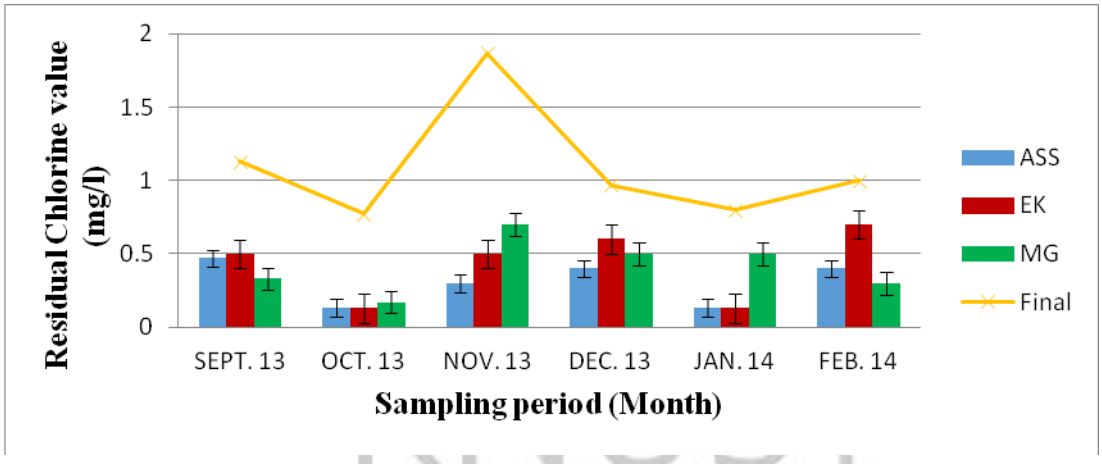

Fig. 19 Residual Chlorine of water at distribution points recorded from September, 2013 to February, 2014 at 95% confidence level.

TEMPERATURE

Temperature values recorded for the three sampling points were generally higher than the temperature of the Final water (Fig. 20; Appendices 6 & 7). The ANOVA results for all the three locations sampled revealed that there is significant difference in the true average values of the temperature of each location and the Final water (Appendices 27, 34 & 41).

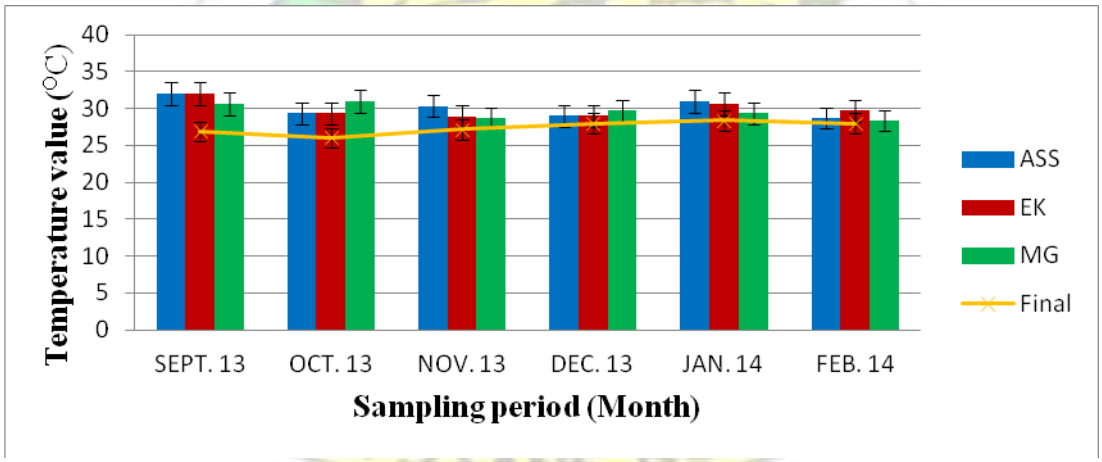

Fig. 20 Temperature of water at distribution points recorded from September, 2013 to February, 2014 at 95% confidence level.

CONDUCTIVITY

The conductivity measured for the sampled locations reflected a slight general decrease in value compared to that of the Final water (Fig. 21; Appendices 6 & 7). The ANOVA results (Appendices 28, 35 & 42) showed that there is no significant difference in the average values of the conductivity of each location and the Final water.

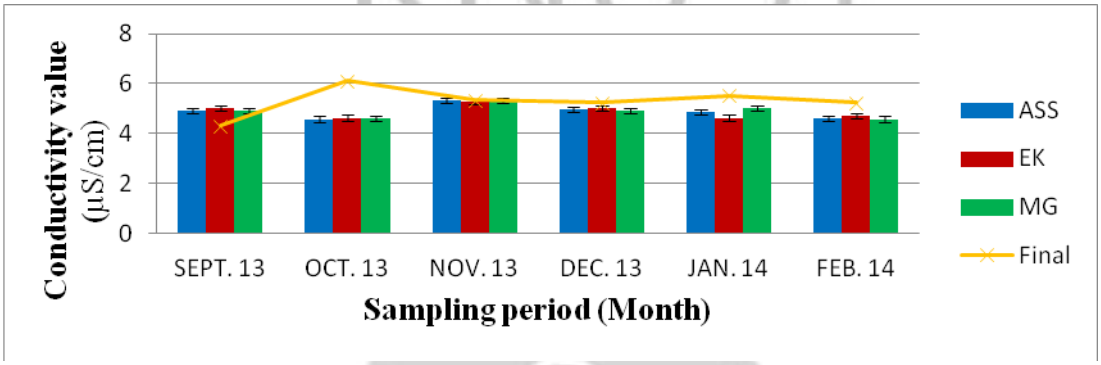

Fig. 21 Conductivity of water at distribution points recorded from September, 2013 to February, 2014 at 95% confidence level.

TURBIDITY

The turbidity values for the months of September and October, 2013 for the distribution samples were higher than that of the Final water. The months of November and December, 2013 recorded lower turbidity values, with January and February, 2014 values being averagely the same (Fig. 22; Appendices 6 & 7). The ANOVA results of the turbidity of the water sampled at the three locations and that of the Final water revealed that there is no significant difference in the true average values (Appendices 29, 36 & 43).

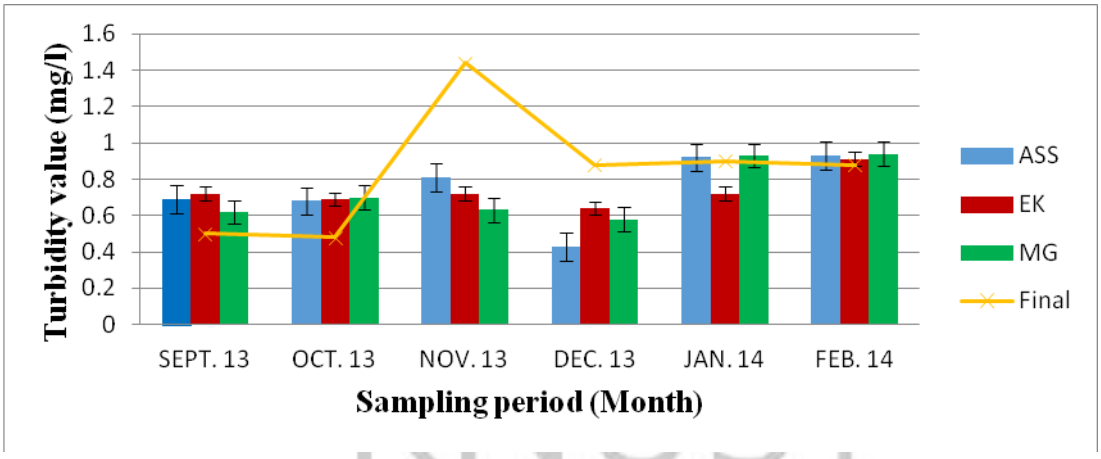

Fig. 22 Turbidity of water at distribution points recorded from September, 2013 to February, 2014 at 95% confidence level.

4.2 BACTERIOLOGICAL ANALYSES

RAW WATER

The Bacteriological analyses of the Raw water revealed a high MPN value for TTC with the highest values recorded in September, 2013 and January, 2014 (Table 1). The resulting mean gave coded results of 5, 4, 2 which implies that the mean concentration of Thermotolerant Coliform (TTC) or Faecal Coliform (FC) per 100 ml is 220 (Table 1). This is above the WHO Guideline value which is nil, an indication that the water is polluted and unsafe for drinking.

Table 1: Results of Bacteriological Analyses for Raw Water

SAMPLING PERIOD/ MONTH	SAMPLE VOLUME INNOCULATED (ml)	NO. OF POSITIVE TUBES IN CONFIRMATORY TEST AT 44^{O}C				MPN
		S1	S2	S3	MEAN	TTC
SEPTEMBER, 2013	10	5.00	5.00	5.00	5.00	540.00
	1	5.00	4.00	5.00	5.00	
	0.1	2.00	2.00	3.00	2.00	
OCTOBER, 2013	10	5.00	5.00	5.00	5.00	220.00

	1	4.00	5.00	4.00	4.00	
	0.1	2.00	2.00	1.00	2.00	
NOVEMBER, 2013	10	5.00	5.00	5.00	5.00	
	1	4.00	5.00	3.00	4.00	220.00
	0.1	2.00	2.00	1.00	2.00	
DECEMBER, 2013	10	5.00	5.00	5.00	5.00	
	1	5.00	4.00	4.00	4.00	
	0.1	2.00	1.00	1.00	1.00	170.00
JANUARY, 2014	10	5.00	5.00	5.00	5.00	
	1	5.00	5.00	5.00	5.00	
	0.1	3.00	3.00	2.00	3.00	920.00
FEBRUARY, 2014	10	5.00	5.00	5.00	5.00	
	1	4.00	4.00	5.00	4.00	
	0.1	2.00	1.00	2.00	2.00	220.00

Source: Filed data

Keys: S1- Sample 1
S2- Sample 2
S3- Sample 3

Coded results of resulting means

1ml = 5

0.1ml = 4

10ml = 2

4.3 BACTERIOLOGICAL ANALYSES OF FINAL WATER AND WATER AT DISTRIBUTION POINTS

The result of all the bacteriological analyses conducted on the Final water was negative. However the distribution samples recorded low to high levels of thermotolerant coliforms (Fig. 23; Appendices 8, 9 & 10). The months of October, 2013 and January, 2014 recorded the highest values. The ANOVA results for the bacteria analyses conducted on the Final water and on the distributed water to Assissim

and Mangoase showed that there is significant difference in the true average values, whereas for Ekwamkrom, the average values are not statistically significant (Appendices 44 ,45 & 46).

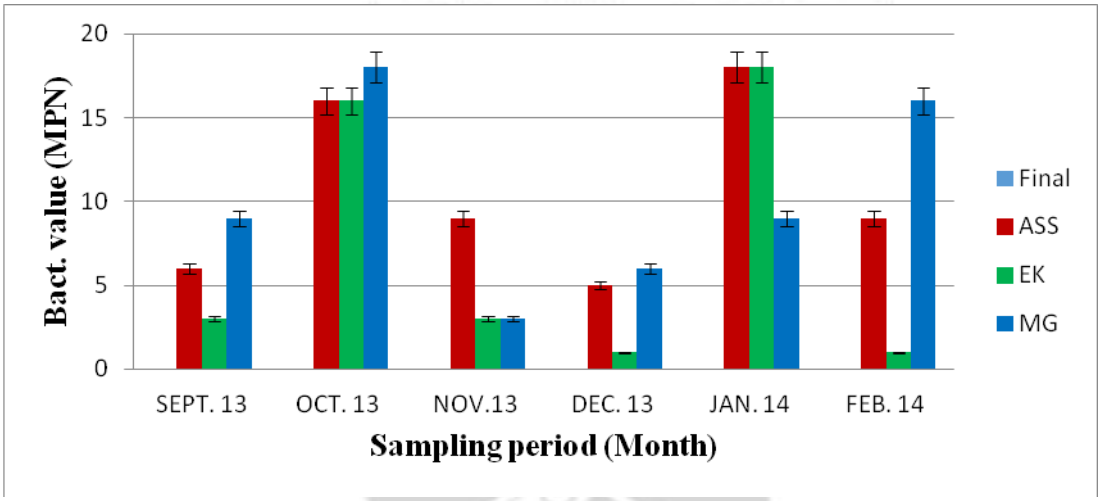

Fig. 23 MPN values of water at Distribution points recorded from September, 2013 to February, 2014 at 95% confidence level.

CHAPTER FIVE

DISCUSSIONS

5.0 TREATMENT PLANT SAMPLES

pH

The Raw water recorded almost neutral pH. Acidic rain might have entered the alkaline rocks underneath the source river. The dissociation of the alkaline

components in these rock reacted with the acidic water to give a neutral pH of the Raw water r (*www.water-research.net/.../alkalinity.htm*).

The pH values were low for the Settled and Filtered water. This was due to the addition of Aluminium and Potassium Bis tetraoxosulphate(VI) dodecahydrate (alum), an acidic salt which made these samples slightly acidic. For the Final water, the addition of chlorine for the purpose of disinfection made the water more acidic but in order to achieve the WHO guideline value and make the water potable for consumption, Calcium Hydroxide [$Ca(OH)_2$] was added to the water for pH adjustment or correction hence the almost neutral values recorded.

COLOUR

The colour of the Raw water was caused by the amount of humic acid resulting from organic soils such as peat and decayed vegetation (Breach, 2011). It was also affected by silt or clay as a result of rain water from upstream. The high colour values recorded for the Raw water was due to the presence of the above mentioned factors. The reduction in the colour values for the Filtered and Settled water was a result of the reduction in the organic matter content of the water since the water was strained to remove plant debris which could have decayed to give more colour to the water. The addition of alum also cleared the water by causing most of the particles in the water to coagulate and settle beneath the chamber. For the Final water, the addition of the Calcium hypochlorite bleached its colour and made it colourless.

ALKALINITY

Alkalinity of the Raw water was affected by the types of rocks that form the 'bed' of the water. The main sources of natural alkalinity are rocks which contain carbonate, bicarbonate and hydroxide compounds. Limestone ($CaCO_3$) is rich in carbonates as

such water flowing through limestone regions or bedrock containing carbonate generally have high alkalinity, hence a good buffering capacity (*www.water*http://www.water-research.net/.../alkalinity.htm*research.net/.../alkalinity.htm*). This might have accounted for the high alkalinity values for the Raw water. The alkalinity values reduced further for the Settled and Filtered water due to the addition of the alum (acidic salt) to act as a coagulant. The alkalinity values increased in the Final water because of the addition of the $Ca(OH)_{2aq}$ to adjust the pH.

RESIDUAL CHLORINE

The Residual Chlorine was measured only for the Final water because the Calcium hypochlorite [$Ca(OCl)_2$)] or Chlorine gas (Cl_2) was only added after the water has been Filtered to destroy the harmful microorganisms that survived all the previous stages of treatment. The month of November recorded a very high chlorine value because the Calcium Hypochlorite might not have reacted completely with the water before the sample was taken, since the duration for complete reaction between chlorine upon addition to water for purification is after 30 minutes (*www.safewater@cdc.gov*).

TOTAL HARDNESS

The total hardness of the water might have resulted from the presence of Ca^{2+} and Mg^{2+} in large concentrations. These are from $CaCO_3$ and $MgCO_3$ rocks underneath the river, affecting the total hardness values for the Raw, Settled and Filtered water which were about the same (*www.water-research.net/.../alkalinity.htm*).

The water containing these ions Ca^{2+} and Mg^{2+} was again dosed with $Ca(OH)_2$ to adjust the pH after the addition of Chlorine which further increased the Ca^{2+} ion

concentration. This accounted for the slightly higher Total Alkalinity values for the Final water as compared to the rest of the samples.

CALCIUM HARDNESS

The calcium hardness resulted from the dissociation of rocks containing calcium in the water. The high values recorded in the months of December, 2013 and February, 2014 could be attributed to the usual acidic rain which caused the dissociation of the rocks containing Ca^{2+} (*https://sciencepolicy.colorado.edu/.../pub034.pdf,*). Or due to the dosage of a high amount of lime $Ca(OH)_2$ at the Final water point as a result of colour problems encountered in the dry season (GWCL Kwanyaku Laboratory Records, 2012)

CALCIUM

Calcium ion content in water is dependent on the calcium hardness content. The higher the calcium hardness of the water, the higher the calcium ion concentration. The higher Calcium ion values recorded for the Final water was as a result of the high Calcium Hardness recorded. Calcium Hardness values were also high in the months of December, 2013, January and February, 2014, hence the high Calcium ion values for the Final water in those months.

MAGNESIUM HARDNESS

Magnesium Hardness is also dependent on the Total Hardness and Calcium Hardness. The higher the Total Hardness, the higher the Magnesium Hardness. The Total Hardness values for all the Final water were above those of the rest of the samples and hence the Magnesium Hardness as well. The low Magnesium Hardness values were as a result of the high Calcium Hardness values.

MAGNESIUM

Magnesium ion concentration is directly proportional to the measure of Magnesium Hardness, hence months with high Magnesium Hardness had high Magnesium ion (Mg^{2+}) values recorded.

CHLORIDE

The reagent $AgNO_3$ for the analysis of Chloride was very expensive and therefore was used to conduct analysis for only the Raw and Final water. Further analysis was needed only if the ion was suspected to be of unusually high concentration in the water. Chloride ion could result from the dissociation of rocks containing Chloride such as $CaCl_2$. The high values in November and December, 2013 and February, 2014 could be an indication of an increased dissociation of these rocks as a result of acidic rain (*https://sciencepolicy.colorado.edu/.../pub034.pdf,*).

TEMPERATURE

The high Temperature values recorded for the water samples were as a result of the high ambient temperatures (Agona Kwanyako Pocket Register for Meteorological Observation, Form met 105RVD) (Appendix 49.0). The temperature values of the Final water were above those of the other samples because of the absorption of heat at the Final water storage point. The Raw, Settled and Filtered water were constantly moving which allowed more aeration to take place and allow heat to pass into the atmosphere.

CONDUCTIVITY

Electrical Conductivity of water was based on the dissolved ions in the water. It estimates the total amount of solids dissolved in water. Electrical Conductivity depends on temperature. The higher the temperature, the higher the conductivity value.

Electrical Conductivity of water increases by 2-3% of an increase in one Degree Celsius of water (www.smart-fertilizer.com/articles/electrical-conductivity). The high Conductivity values recorded for the Final water for the entire sampling period was as a result of the higher temperatures of the Final water than all of the other samples.

TURBIDITY

The high turbidity of the Raw water was caused by growth of phytoplankton. Human activities such as construction and agriculture around the catchment area led to high sediment levels entering the water body during rain storms and water runoff.

This explains why the Raw water samples recorded high turbidity values as compared to the Settled, Filtered and Final water.

In the Clari-floculator, the large and heavy particles settled at the bottom (the very small particles due to constant agitation were prevented from settling). This accounted for the reduction in the Turbidity values at the settled stage. The Settled water was passed through sand filter bed to remove all other particles that were not removed at the sedimentation stage, hence the lower values recorded at the filtered stage. The Turbidity of the Final water increased slightly due to the addition of lime which made the water a bit turbid before its complete reaction with the chlorinated water.

5. 2 DISTRIBUTION SAMPLES pH

and ALKALINITY

The pH and Alkalinity of the distributed water was dependent on the Calcium hypochlorite used for the disinfection. For the disinfection to be efficient a large amount of Hypochlorous acid (HOCl) which is the most effective form of free Chlorine residual is needed to be present in the water to kill any microorganisms present (GWCL Laboratory Manual, 2009), (Herrmann *et al.*, 2003) Hence in the distribution mains, the large quantities of the hypochlorous acid available reduced the pH of the water a little more slightly than that of the Final water.

The sipping of acidic waste water into the water mains due to bursts of pipelines which might not have been attended to promptly and the relatively high temperatures recorded for the distribution samples could favour the growth and activities of biofilms which respired to give out carbon dioxide which reacts with the water to produce carbonic acid could also result in lowering the pH and alkalinity. The alkalinity of the Final water was also higher than that of the distribution samples because of the addition of lime after chlorination to adjust the pH of the Final water.

RESIDUAL CHLORINE

The WHO guideline which requires a residual chlorine level of 0.6-1mg/l to prevent microbial regrowth and protect the water through the distribution system was ensured by the treatment plant. Chlorine self decomposition, (Vieira *et al*., 2004). reaction with impurities along the distribution chain and possible contamination by pathogens might have reduced the residual chlorine level at the three locations.

TEMPERATURE

The increase in the temperature values of the water at the locations sampled was as a result of the absorption of heat from the environment as the water was being transported to the consumer.

CONDUCTIVITY

The conductivity of the distributed water was expected to increase as there was an increase in temperature but the values rather reduced. The reason was that other factors such as the Total hardness and alkalinity also affects conductivity. The Final water recorded higher alkalinity values than the distributed water, hence the higher conductivity values recorded over the distributed water.

TURBIDITY

The turbidity values of the water was almost the same for the months of January and February, 2014, decreased in the months of November and December, 2013 but increased in the months of September and October, 2013 for the distribution samples. This was because the dosage of lime at the Final water point increased the turbidity. Complete reaction of the lime with the water results in a clearer water thereby reducing the turbidity as the water is stored and transported. The lower values recorded in November and December, 2013 might be due to the time the lime was dosed and the time Final water sample was taken. The increase in the turbidity values for the months of September and October, 2013 might be as a result of intrusion of particles resulting from broken water mains.

5.3 BACTERIOLOGICAL ANALYSIS OF RAW WATER

The high TTC values recorded in the Raw water was an indication that it was polluted with microbes. The possible sources of the pollution could be drainage from farms, streets, rooftops, driveways, feedlots, compost piles. Water percolating from domestic

wastewater, livestock manure and septic tanks (Ring, 2003) may contain viruses, bacteria and parasites and may contaminate water supplies.

5.4 BACTERIOLOGICAL ANALYSES OF WATER AT DISTRIBUTION POINT

The negative results for TTC recorded for the Final water is an indication that the water produced at the Kwanyaku Water Treatment Plant is efficiently treated and safe for consumption. The low to high levels of TTC recorded in the three distribution samples indicate the possible occurrence of pollution along the distribution chain. The ANOVA results (Appendices 44.0, 45.0 & 46.0) also revealed that there is significant difference in the true average values of two out of the three locations sampled, meaning that the average values are statistically significant and hence the water at those points could pose some health threats to consumers. One of the locations however had its average values being statistically insignificant and hence safe for consumption.

The implication of the above discussion is that the water is efficiently treated before being distributed to the populace but recontamination may occur at some points along the distribution chain which makes it unsafe for consumption at those collection points.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The water treatment processes conducted at the Kwanyaku Water Treatment Plant include screening, sedimentation, filtration, chlorination and pH adjustment. Results obtained from both physico-chemical and bacteriological analyses of the Final water produced at the Kwanyaku Water Treatment Plant revealed that all the parameters were within the WHO guideline values. No faecal contamination was recorded. The quality of water produced by the GWCL at the Kwanyaku Water Treatment Plant is within the acceptable limit of WHO and poses no health threat to consumers.

However, the water sampled at the three distribution locations recorded low levels of residual chlorine, with temperature and indicator bacteria (TTC) above those of the WHO guideline. There were significant differences between residual chlorine values

recorded in the Final water at the treatment plant site and those recorded for the water at the three distribution points. Residual chlorine levels less than 0.6 mg/l which is the limit given by WHO in drinking water were recorded at the three distribution points making the water prone to bacterial growth.

Temperatures increased along the distribution chain favouring growth of biofilms in the water. Recontamination of the treated water occurred along the distribution chain which could be as a result of burst which allow seepage of environmental water into the distributed water, high temperature and low chlorine residual coupled with poor monitoring and maintenance practices.

6.2 RECOMMENDATIONS

Based on the research findings, the following recommendations are being forwarded:

i. A more effective disinfectant such as chloramines and chlorine dioxide which gives a more efficient disinfection not only at the treatment plant but also in the distribution pipelines should be used.

ii. Pipelines in water logged areas should be redirected iii. Distribution pipelines should be routinely checked at least every six months to prevent issues such as seepage of contaminants into the distributed water. iv. A well planned and coordinated maintenance system should be instituted which should include selected members of each zone or locality to be responsible for reporting burst of pipelines to the GWCL district or local stations near them for prompt action.

v. Water storage sites should be disinfected regularly.

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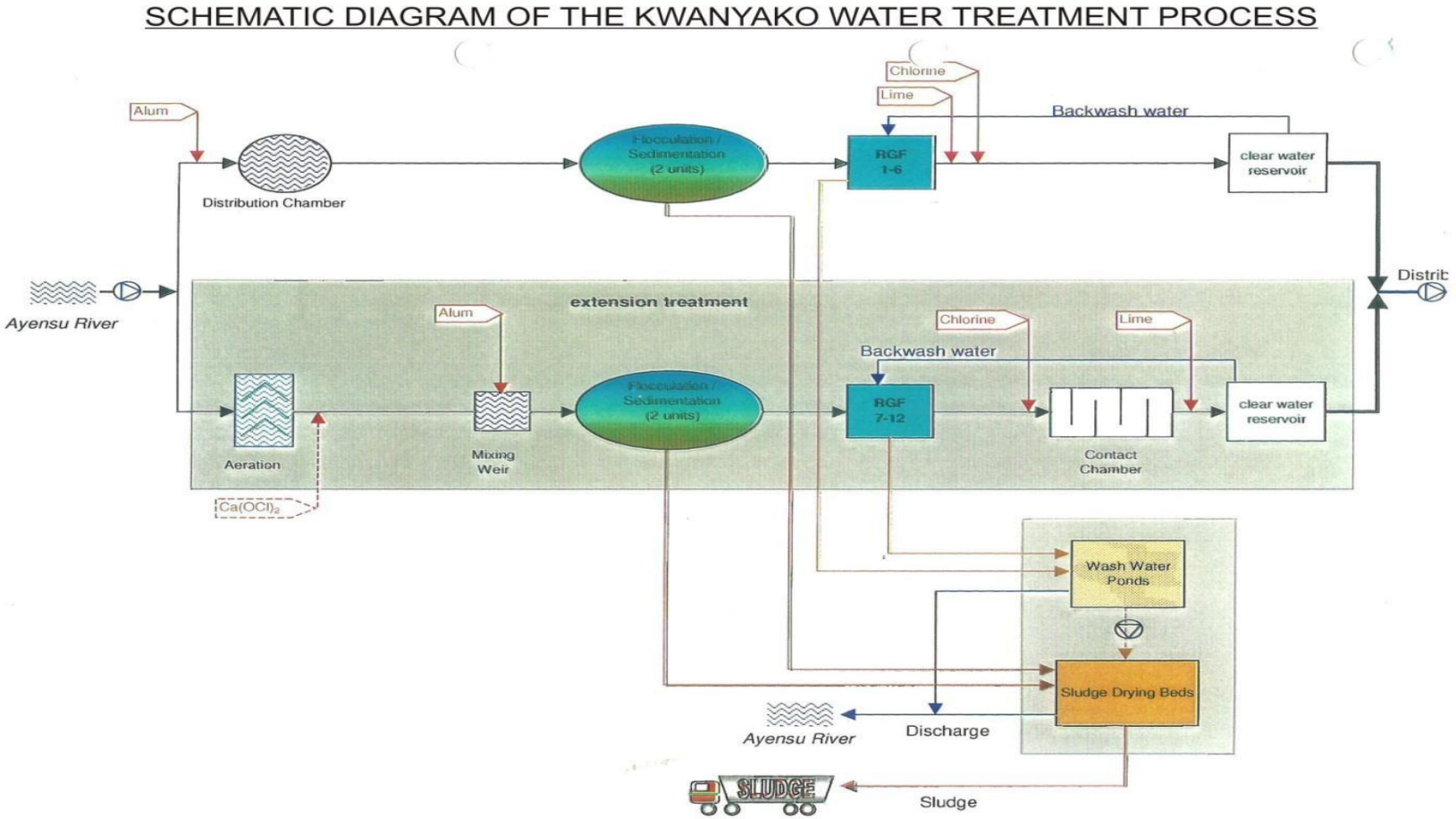
APPENDIX 1: SCHEMATIC DIAGRAM OF THE KWANYAKU WATER TREATMENT PROCESS



APPENDIX 2 : Plate of the Agona Swedru Water Reservoir

PHYSICO – CHEMICAL ANALYSIS AT VARIOUS STAGES

OF THE TREATMENT PROCESS

APPENDIX 3 TABLE1

MONTH SEPTEMBER, 2013

PARAMETER	UNIT	RAW WATER			MEAN	SETTLED WATER			MEAN	FILTERED WATER			MEAN	FINAL WATER			MEAN
pH		7.10	7.10	7.00	**7.07 ± 0.06**	6.90	6.70	6.70	**6.77 ± 0.21**	6.90	6.70	6.80	**6.80 ± 0.10**	7.00	7.10	7.10	**7.07 ± 0.06**
colour	H.U	90.00	90.00	90.00	**90.0±.0.00**	12.00	10.00	10.00	**10.67±.1.15**	5.00	5.00	5.00	**5.00±.0.00**	5.00	5.00	5.00	**5.00±.0.00**
Alkalinity	mg/l	74.00	76.00	76.00	**75.33±1.15**	60.00	66.00	62.00	**62.67±3.06**	60.00	60.00	62.00	**60.67±1.15**	64.00	68.00	66.00	**66.00±2.00**
Res Chlorine	mg/l													1.20	1.20	1.00	**1.13±0.12**
Total Hardness	mg/l	48.00	50.00	48.00	**48.67±1.15**	48.00	50.00	50.00	**49.33±1.15**	48.00	48.20	49.00	**48.40±0.53**	54.00	55.00	54.00	**54.33±0.58**
Ca Hardness		36.00	35.40	36.00	**35.80±0.35**	36.00	34.00	34.00	**34.67±1.15**	36.00	36.24	36.43	**36.22±0.22**	40.00	41.00	40.00	**40.33±0.58**
Calcium	mg/l	14.40	14.16	14.40	**14.32±0.14**	14.40	14.20	13.60	**14.07±0.42**	14.40	14.50	14.60	**14.50±0.10**	16.00	16.40	16.00	**16.13±0.23**
Mg Hardness		12.00	14.60	12.00	**12.87±1.50**	12.00	16.00	14.00	**14.00±2.00**	12.00	11.97	12.57	**12.18±0.34**	14.00	14.00	14.00	**14.00±0.00**
Magnesium	mg/l	2.92	3.55	2.92	**3.13±0.36**	2.92	3.89	3.40	**3.40±0.49**	2.92	2.91	3.05	**2.96±0.08**	3.40	3.40	3.40	**3.40±0.00**
Chloride	mg/l	50.00	49.00	51.00	**50.00±1.00**									53.00	54.00	54.00	**53.67±0.58**

Temperature	^{o}C	26.00	25.80	26.00	**25.93±0.12**	24.80	24.60	24.40	**24.60±0.20**	24.50	25.00	24.60	**24.70±0.26**	26.90	26.90	26.70	**26.83±0.12**
Conductivity	µS/cm	3.90	4.10	3.90	**3.97±0.12**	3.98	3.98	3.96	**3.97±0.01**	4.10	4.05	4.02	**4.06±0.04**	4.31	4.30	4.33	**4.31±0.02**
Turbidity	NTU	12.90	12.90	12.90	**12.90±0.00**	1.64	1.64	1.64	**1.64±0.00**	0.47	0.47	0.47	**0.47±0.00**	0.50	0.50	0.50	**0.50±0.00**

APPENDIX 3 TABLE 2

MONTH OCTOBER, 2013

PARAMETER	UNIT	RAW WATER				SETTLED WATER				FILTERED WATER				FINAL WATER			
					MEAN				MEAN				MEAN				MEAN
pH		7.00	7.00	7.00	**7.00 ± 0.00**	6.30	6.30	6.20	**6.27 ± 0.06**	6.30	6.30	6.20	**6.27 ± 0.06**	6.90	6.80	6.90	**6.87± 0.06**
colour	H.U	150.00	150.00	150.00	**150.00±.0.00**	10.00	10.00	12.00	**10.67±.1.15**	5.00	5.00	5.00	**5.00±.0.00**	5.00	5.00	5.00	**5.00±.0.00**
Alkalinity	mg/l	51.00	52.00	51.00	**51.33±0.58**	26.00	25.00	27.00	**26.00±1.00**	24.00	24.00	24.00	**24.00±0.00**	30.00	32.00	32.00	**31.33±1.15**
Res Chlorine	mg/l													0.80	0.70	0.80	**0.77±0.06**
Total Hardness	mg/l	32.00	33.00	34.00	**33.00±1.00**	34.00	34.00	34.00	**34.00±0.00**	34.00	34.00	33.00	**33.67±0.58**	38.00	38.00	39.00	**38.33±0.58**
Ca Hardness		18.00	20.00	20.00	**19.33±1.15**	20.00	20.00	20.00	**20.00±0.00**	20.00	21.00	20.00	**20.33±0.58**	22.00	22.00	22.00	**22.00±0.00**
Calcium	mg/l	7.20	8.00	8.00	**7.73±0.46**	8.00	8.00	8.00	**8.00±0.00**	8.00	8.40	8.00	**8.13±0.23**	8.80	8.80	8.80	**8.80±0.00**
Mg Hardness		14.00	13.00	14.00	**13.67±0.58**	14.00	14.00	14.00	**14.00±0.00**	14.00	13.00	13.00	**13.33±0.58**	16.00	16.00	16.00	**16.00±0.00**

Magnesium	mg/l	3.40	3.16	3.40	**3.32±0.14**	3.40	3.40	3.40	**3.40±0.00**	3.40	3.16	3.16	**3.16±0.14**	3.89	3.89	3.89	**3.89±0.00**
Chloride	mg/l	52.00	52.00	51.00	**51.67±0.58**									55.00	54.00	56.00	**55.00±1.00**
Temperatur e	^{O}C	25.8 0	25.8 0	25.6 0	**25.73±0.12**	24. 30	24. 00	24. 00	**24.10±0. 17**	24. 70	24. 70	24. 60	**24.67±0. 06**	26. 20	26. 10	26. 00	**26.10±0. 01**
Conductivit y	µS/c m	5.82	5.83	5.82	**5.82±0.01**	5.88	5.86	5.84	**5.86±0.02**	5.96	5.94	5.93	**5.94±0.02**	6.12	6.10	6.12	**6.11±0.01**
Turbidity	NTU	50.60	50.50	50.50	**50.53±0.06**	3.42	3.42	3.43	**3.42±0.01**	0.52	0.51	0.50	**0.51±0.01**	0.49	0.49	0.47	**0.48±0.01**

APPENDIX 4 TABLE 3

MONTH NOVEMBER, 2013

PARAMETER	UNIT	RAW WATER			MEAN	SETTLED WATER			MEAN	FILTERED WATER			MEAN	FINAL WATER			MEAN
pH		7.10	7.10	7.10	**7.10 ± 0.10**	6.20	6.30	6.30	**6.27 ± 0.06**	6.10	6.10	6.10	**6.10 ± 0.00**	7.00	7.00	6.90	**6.97± 0.06**
colour	H.U	180.00	180.00	180.00	**180.00±.0.00**	15.00	15.00	15.00	**15.00±.0.00**	5.00	5.00	5.00	**5.00±.0.00**	5.00	5.00	5.00	**5.00±.0.00**
Alkalinity	mg/l	56.00	55.00	54.00	**55.00±1.00**	26.00	24.00	26.00	**25.33±1.15**	22.00	22.00	23.00	**23.33±0.58**	22.00	22.00	22.00	**22.00±0.00**
Res Chlorine	mg/l													2.00	1.80	1.80	**1.87±0.12**
Total Hardness	mg/l	42.00	43.00	42.00	**42.33±0.58**	38.00	40.00	39.00	**39.00±1.00**	42.00	42.00	42.00	**42.00±0.00**	54.00	55.00	55.00	**54.67±0.58**

Ca Hardness		30.00	30.00	30.00	**30.00±0.00**	24.00	23.00	22.00	**23.00±1.00**	28.00	28.00	28.00	**28.00±0.00**	30.00	30.00	30.00	**30.00±0.00**
Calcium	mg/l	12.00	12.00	12.00	**12.00±0.00**	9.60	9.20	8.80	**9.20±0.40**	11.20	11.20	11.20	**11.2±0.00**	12.00	12.00	12.00	**12.00±0.00**
Mg Hardness		12.00	13.00	12.00	**12.33±0.58**	14.00	17.00	17.00	**16.00±1.73**	14.00	14.00	14.00	**14.00±0.00**	24.00	25.00	25.00	**24.67±0.58**
Magnesium	mg/l	2.92	3.16	2.92	**3.00±0.14**	3.40	4.13	4.13	**3.89±0.42**	3.40	3.40	3.40	**3.40±0.00**	5.83	5.83	5.83	**5.83±0.00**
Chloride	mg/l	83.00	83.00	83.50	**83.17±0.29**									89.00	89.00	89.00	**89.00±0.00**
Temperature	^{o}C	26.30	26.30	26.20	**26.27±0.06**	26.10	26.10	26.00	**26.07±0.06**	25.20	25.10	25.20	**25.17±0.06**	27.20	27.20	27.20	**27.20±0.00**
Conductivity	µS/c m	5.11	5.08	5.10	**5.10±0.02**	5.19	5.16	5.16	**5.17±0.02**	5.24	5.24	5.24	**5.24±0.00**	5.36	5.35	5.35	**5.35±0.01**
Turbidity	NTU	19.00	19.00	19.00	**19.00±0.00**	8.81	8.81	8.81	**8.81±0.00**	1.15	1.14	1.15	**1.15±0.01**	1.45	1.44	1.44	**1.44±0.01**

APPENDIX 4 TABLE 4

MONTH DECEMBER, 2013

PARAMETER	**UNIT**	**RAW WATER**			MEAN	**SETTLED WATER**			MEAN	**FILTERED WATER**			MEAN	**FINAL WATER**			MEAN
pH		7.20	7.10	7.00	**7.10 ± 0.10**	6.50	6.50	6.40	**6.47 ± 0.06**	6.50	6.50	6.50	**6.50 ± 0.00**	7.00	7.00	7.00	**7.00± 0.00**
colour	H.U	200.00	200.00	200.00	**200.00±.0.00**	20.00	20.00	20.00	**20.00±.0.00**	5.00	5.00	5.00	**5.00±.0.00**	5.00	5.00	5.00	**5.00±.0.00**

Alkalinity	mg/l	74.00	73.00	74.00	**73.67±0.58**	42.00	42.00	43.00	**42.33±0.58**	40.00	42.00	40.00	**40.67±1.15**	58.00	56.00	57.00	**57.00±1.00**
Res Chlorine	mg/l													1.00	0.90	1.00	**0.97±0.06**
Total Hardness	mg/l	44.10	44.00	44.00	**44.03±0.06**	44.00	43.20	44.00	**43.73±0.46**	44.00	44.00	44.00	**44.00±0.00**	60.00	60.00	60.00	**60.00±0.00**
Ca Hardness		34.00	34.20	34.00	**34.07±0.12**	32.00	32.00	32.00	**32.00±0.00**	32.00	33.00	32.20	**32.40±0.53**	42.00	43.00	42.00	**42.33±0.58**
Calcium	mg/l	13.60	13.68	13.60	**13.63±0.12**	12.80	12.80	12.80	**12.80±0.00**	12.80	13.20	12.88	**12.96±0.21**	16.80	16.80	16.80	**16.80±0.00**
Mg Hardness		10.10	9.80	10.00	**9.97±0.15**	12.00	11.20	12.00	**11.73±0.46**	12.00	11.00	11.80	**11.60±0.53**	18.00	17.00	18.00	**17.67±0.58**
Magnesium	mg/l	2.45	2.38	2.43	**2.42±0.04**	2.9	2.7	2.9	**2.85±0.1**	2.9	2.6	2.8	**2.82±0.1**	4.3	4.1	4.3	**4.29±0.1**
						2	2	2	**2**	2	7	6	**3**	7	3	7	**4**
Chloride	mg/l	94.00	94.00	93.00	**93.67±0.58**									82.00	82.00	82.00	**82.00±0.00**
Temperature	^{o}C	26.40	26.30	26.40	**26.37±0.06**	25.70	25.60	25.50	**25.60±0.10**	25.50	25.50	25.50	**25.50±0.00**	28.00	28.00	28.00	**28.00±0.00**
Conductivity	µS/cm	5.31	5.45	5.45	**5.40±0.08**	5.38	5.37	5.38	**5.38±0.01**	5.42	5.42	5.41	**5.42±0.00**	5.22	5.23	5.24	**5.23±0.01**
Turbidity	NTU	44.30	44.20	44.30	**44.27±0.06**	5.55	5.55	5.53	**5.54±0.01**	0.97	0.98	0.97	**0.97±0.01**	0.88	0.88	0.88	**0.88±0.00**

APPENDIX 5 TABLE 5

MONTH JANUARY, 2014

PARAMETER	**UNIT**	**RAW WATER**	**SETTLED WATER**	**FILTERED WATER**	**FINAL WATER**

					MEAN				MEAN				MEAN				MEAN
pH		6.90	6.90	6.90	**6.90 ± 0.00**	6.60	6.50	6.50	**6.53 ± 0.06**	6.50	6.50	6.50	**6.50 ± 0.00**	6.90	6.90	6.90	**6.90± 0.00**
colour	H.U	90.00	90.00	90.00	**90.00±.0.00**	25.00	20.00	20.00	**21.67±.2.89**	5.00	5.00	5.00	**5.00±.0.00**	5.00	5.00	5.00	**5.00±.0.00**
Alkalinity	mg/l	76.00	75.00	75.00	**75.33±0.58**	60.00	58.00	60.00	**59.33±1.15**	52.00	52.00	51.00	**51.67±0.58**	70.00	70.00	70.00	**70.00±0.00**
Res Chlorine	mg/l													0.80	0.80	0.80	**0.80±0.00**
Total Hardness	mg/l	54.00	53.00	54.00	**53.67±0.58**	52.00	52.00	51.00	**51.67±0.58**	54.00	54.00	54.00	**54.00±0.00**	60.00	60.00	61.00	**60.33±0.58**
Ca Hardness		30.00	30.00	32.00	**30.67±1.15**	32.00	33.00	33.00	**32.67±0.58**	34.00	35.00	35.00	**34.67±0.58**	42.00	42.00	42.00	**42.00±0.00**
Calcium	mg/l	12.00	12.00	12.80	**12.27±0.46**	12.80	13.20	13.20	**13.07±0.23**	13.60	14.00	14.00	**13.87±0.23**	16.80	16.80	16.80	**16.80±0.00**
Mg Hardness		24.00	23.00	22.00	**23.00±1.00**	20.00	29.00	18.00	**22.33±5.86**	20.00	19.00	19.00	**19.33±0.58**	18.00	18.00	19.00	**18.33±0.58**
Magnesium	mg/l	5.83	5.59	5.35	**5.59±0.24**	4.86	4.62	4.37	**4.62±0.25**	4.86	4.62	4.62	**4.70±0.14**	4.37	4.37	4.62	**4.45±0.14**
Chloride	mg/l	67.00	67.10	67.10	**67.07±0.06**									69.00	69.00	68.00	**68.67±0.58**
Temperature	^{o}C	26.30	26.20	26.20	**26.23±0.06**	26.00	26.00	26.20	**26.07±0.12**	26.20	26.20	26.30	**26.23±0.06**	28.40	28.30	28.40	**28.37±0.06**
Conductivity	µS/cm	5.04	5.04	5.03	**5.04±0.01**	5.20	5.21	5.20	**5.20±0.01**	5.25	5.25	5.26	**5.25±0.01**	5.52	5.54	5.52	**5.53±0.01**
Turbidity	NTU	11.10	11.00	11.10	**11.07±0.06**	4.10	4.10	4.10	**4.10±0.00**	0.69	0.69	0.69	**0.69±0.00**	0.90	0.90	0.91	**0.90±0.01**

APPENDIX 5 TABLE 6

MONTH FEBRUARY, 2014

PARAMETER	UNIT	RAW WATER			MEAN	SETTLED WATER			MEAN	FILTERED WATER			MEAN	FINAL WATER			MEAN
pH		6.90	6.90	7.10	**6.97 ± 0.09**	6.40	6.40	6.40	**6.40 ± 0.09**	6.20	6.30	6.30	**6.27± 0.06**	7.00	7.10	7.00	**6.73± 0.06**
colour	H.U	120.00	120.00	120.00	**120.00±.0.00**	20.00	20.00	20.00	**20.00±.0.00**	5.00	5.00	5.00	**5.00±.0.00**	5.00	5.00	5.00	**5.00±.0.00**
Alkalinity	mg/l	64.00	64.00	63.00	**63.67±0.47**	40.00	38.00	39.00	**39.00±1.00**	38.00	38.00	39.00	**38.33±0.58**	58.00	56.00	57.00	**57.00±1.00**
Res Chlorine	mg/l													1.00	0.90	1.10	**1.00±0.10**
Total Hardness	mg/l	50.00	51.00	50.00	**50.33±0.47**	48.00	48.00	47.00	**47.67±0.58**	48.00	48.00	48.00	**48.00±0.00**	60.00	60.00	60.00	**60.00±0.00**
Ca Hardness		38.00	36.00	38.00	**37.33±0.94**	30.00	30.00	30.00	**30.00±0.00**	32.00	31.00	32.00	**31.67±0.58**	42.00	43.00	42.00	**42.33±0.58**
Calcium	mg/l	15.20	14.40	15.20	**14.93±0.38**	12.00	12.00	12.00	**12.00±0.00**	12.80	12.40	12.80	**12.67±0.23**	16.80	16.80	16.80	**16.80±0.00**
Mg Hardness		12.00	15.00	12.00	**13.00±1.41**	18.00	18.00	17.00	**17.67±0.58**	16.00	17.00	16.00	**16.33±0.58**	18.00	17.00	18.00	**17.67±0.58**
Magnesium	mg/l	2.92	3.65	2.92	**3.16±0.34**	4.37	4.37	4.13	**4.29±0.14**	3.89	4.13	3.89	**3.97±0.14**	4.37	4.13	4.37	**4.29±0.14**
Chloride	mg/l	75.00	75.00	75.00	**75.00±0.00**									82.00	82.00	82.00	**82.00±0.00**

Temperature	^{o}C	27.00	27.50	27.00	**27.17±0.24**	25.70	25.50	25.60	**25.60±0.10**	25.00	25.10	25.00	**25.03±0.06**	28.00	28.00	28.00	**28.00±0.00**
Conductivity	µS/cm	4.73	4.73	4.72	**4.73±0.00**	4.99	5.00	4.98	**4.99±0.01**	5.06	5.03	5.05	**5.05±0.02**	5.22	5.23	5.24	**5.23±0.01**
Turbidity	NTU	27.70	27.70	27.70	**27.70±0.00**	4.89	4.89	4.89	**4.89±0.00**	0.66	0.66	0.66	**0.66±0.00**	0.88	0.88	0.88	**0.88±0.00**

PHYSICO-CHEMICAL ANALYSIS OF THE DISTRIBUTION SAMPLES APPENDIX

6 TABLE 7

MONTH SEPTEMBER, 2013

PARAMETER	**UNIT**	**MANGOASE**			**MEAN**	**EKWAMKROM**			**MEAN**	**ASSISSIM**			**MEAN**
pH		6.60	6.60	6.70	**6.63±0.06**	6.70	6.70	6.80	**6.73±0.06**	6.70	6.60	6.90	**6.73±0.15**

colour	H.U	5.00	5.00	5.00	**5.00±0.00**	5.00	5.00	5.00	**5.00±0.00**	5.00	5.00	5.00	**5.00±0.00**
Alkalinity	mg/l	24.00	24.00	23.00	**23.67±0.58**	31.00	31.00	30.00	**30.67±0.58**	34.00	34.00	32.00	**33.33±1.15**
Res Chlorine	mg/l	0.30	0.30	0.40	**0.33±0.06**	0.50	0.50	0.50	**0.50±0.00**	0.40	0.50	0.50	**0.47±0.06**
Temperature	^{O}C	31.00	30.00	31.00	**30.67±0.58**	33.00	32.00	31.00	**32.00±1.00**	31.00	32.00	32.00	**31.67±0.58**
Conductivity	µS/cm	4.93	4.93	4.93	**4.93±0.00**	5.02	5.02	4.99	**5.01±0.02**	4.91	4.92	4.93	**4.92±0.01**
Turbidity	NTU	0.63	0.62	0.62	**0.62±0.01**	0.72	0.72	0.72	**0.72±0.00**	0.69	0.69	0.69	**0.69±0.00**

APPENDIX 6 TABLE 8

MONTH OCTOBER, 2013

PARAMETER	**UNIT**	**MANGOASE**			**MEAN**	**EKWAMKROM**			**MEAN**	**ASSISSIM**			**MEAN**
pH		6.60	6.60	6.60	**6.60±0.00**	6.50	6.60	6.50	**6.53±0.06**	6.50	6.60	6.50	**6.53±0.06**
colour	H.U	5.00	5.00	5.00	**5.00±0.00**	5.00	5.00	5.00	**5.00±0.00**	5.00	5.00	5.00	**5.00±0.00**
Alkalinity	mg/l	24.00	23.00	24.00	**23.67±0.58**	27.00	26.00	26.00	**26.33±0.58**	29.00	28.00	28.00	**28.33±0.58**
Res Chlorine	mg/l	0.20	0.10	0.20	**0.17±0.06**	0.10	0.10	0.20	**0.13±0.06**	0.10	0.20	0.10	**0.13±0.06**
Temperature	^{O}C	31.00	31.00	31.00	**31.00±0.00**	29.00	30.00	29.00	**29.33±0.58**	30.00	29.00	29.00	**29.33±0.58**
Conductivity	µS/cm	4.61	4.61	4.61	**4.61±0.00**	4.63	4.63	4.63	**4.63±0.00**	4.58	4.59	4.58	**4.58±0.01**
Turbidity	NTU	0.69	0.71	0.70	**0.70±0.01**	0.69	0.70	0.69	**0.69±0.01**	0.68	0.68	0.69	**0.68±0.01**

APPENDIX 6 TABLE 9

MONTH NOVEMBER, 2013

PARAMETER	**UNIT**	**MANGOASE**	**MEAN**	**EKWAMKROM**	**MEAN**	**ASSISSIM**	**MEAN**

pH		6.60	6.60	6.50	**6.57±0.06**	6.40	6.50	6.50	**6.47±0.06**	6.70	6.70	6.70	**6.70±0.00**
colour	H.U	5.00	5.00	5.00	**5.00±0.00**	5.00	5.00	5.00	**5.00±0.00**	5.00	5.00	5.00	**5.00±0.00**
Alkalinity	mg/l	24.00	24.00	25.00	**24.33±0.58**	28.00	28.00	29.00	**28.33±0.58**	29.00	28.00	28.00	**28.33±0.58**
Res Chlorine	mg/l	0.70	0.70	0.70	**0.70±0.00**	0.50	0.50	0.50	**0.50±0.00**	0.30	0.30	0.30	**0.30±0.00**
Temperature	^{O}C	28.00	29.00	29.00	**28.67±0.58**	29.00	28.80	29.00	**28.93±0.12**	31.00	30.00	30.00	**30.33±0.58**
Conductivity	µS/cm	5.32	5.32	5.32	**5.32±0.00**	5.29	5.29	5.27	**5.28±0.01**	5.33	5.34	5.34	**5.34±0.01**
Turbidity	NTU	0.63	0.63	0.63	**0.63±0.00**	0.72	0.71	0.72	**0.72±0.01**	0.81	0.80	0.81	**0.81±0.01**

APPENDIX7TABLE10

MONTH DECEMBER, 2013

PARAMETER	**UNIT**	**MANGOASE**			**MEAN**	**EKWAMKROM**			**MEAN**	**ASSISSIM**			**MEAN**
pH		6.80	6.80	6.90	**6.83±0.06**	6.90	6.90	6.90	**6.90±0.00**	6.70	6.70	6.70	**6.70±0.00**
colour	H.U	5.00	5.00	5.00	**5.00±0.00**	5.00	5.00	5.00	**5.00±0.00**	5.00	5.00	5.00	**5.00±0.00**
Alkalinity	mg/l	36.00	38.00	37.00	**37.00±1.00**	42.00	41.00	41.00	**41.33±0.58**	33.00	34.00	32.00	**33.00±1.00**
Res Chlorine	mg/l	0.50	0.50	0.50	**0.50±0.00**	0.60	0.60	0.60	**0.60±0.00**	0.40	0.40	0.40	**0.40±0.00**
Temperature	^{O}C	30.00	29.00	30.00	**29.67±0.58**	29.00	29.00	29.00	**29.00±0.00**	29.00	29.00	29.00	**29.00±0.00**
Conductivity	µS/cm	4.93	4.93	4.92	**4.93±0.01**	5.03	5.03	5.02	**5.03±0.01**	4.96	4.96	4.97	**4.96±0.01**
Turbidity	NTU	0.57	0.59	0.57	**0.58±0.01**	0.64	0.64	0.64	**0.64±0.00**	0.43	0.43	0.43	**0.43±0.00**

APPENDIX7 TABLE11

MONTH JANUARY,2014

PARAMETER	UNIT	MANGOASE			MEAN	EKWAMKROM			MEAN	ASSISSIM			MEAN
pH		6.50	6.60	6.60	**6.57±0.06**	6.50	6.50	6.50	**6.50±0.00**	6.60	6.60	6.60	**6.60±0.00**
colour	H.U	5.00	5.00	5.00	**5.00±0.00**	5.00	5.00	5.00	**5.00±0.00**	5.00	5.00	5.00	**5.00±0.00**
Alkalinity	mg/l	31.00	30.00	31.00	**30.67±0.58**	33.00	28.00	29.00	**30.00±2.65**	30.00	31.00	32.00	**31.00±1.00**
Res Chlorine	mg/l	0.10	0.20	0.40	**0.23±0.15**	0.10	0.10	0.20	**0.20±0.13**	0.10	0.20	0.10	**0.13±0.06**
Temperature	^{O}C	29.00	30.00	29.00	**29.33±0.58**	31.00	30.00	31.00	**30.67±0.58**	31.00	31.00	31.00	**31.00±0.00**
Conductivity	µS/cm	5.01	5.01	5.00	**5.01±0.01**	4.63	4.62	4.64	**4.63±0.01**	4.86	4.85	4.85	**4.85±0.01**
Turbidity	NTU	0.93	0.93	0.92	**0.93±0.01**	0.72	0.71	0.72	**0.72±0.01**	0.93	0.93	0.91	**0.92±0.01**

APPENDIX 7 TABLE 12

MONTH FEBRUARY, 2014

PARAMETER	UNIT	MANGOASE			MEAN	EKWAMKROM			MEAN	ASSISSIM			MEAN
pH		6.90	6.90	6.90	**6.90±0.00**	6.90	6.90	6.90	**6.90±0.00**	6.90	6.90	6.90	**6.90±0.00**
colour	H.U	5.00	5.00	5.00	**5.00±0.00**	5.00	5.00	5.00	**5.00±0.00**	5.00	5.00	5.00	**5.00±0.00**
Alkalinity	mg/l	60.00	60.00	58.00	**59.33±1.15**	57.00	56.00	58.00	**57.00±1.00**	56.00	55.00	54.00	**55.00±1.00**
Res Chlorine	mg/l	0.30	0.30	0.30	**0.30±0.00**	0.70	0.70	0.70	**0.70±0.00**	0.40	0.40	0.40	**0.40±0.0**
Temperature	^{O}C	29.00	28.00	28.00	**28.33±0.58**	30.00	30.00	29.00	**29.67±0.58**	28.00	29.00	29.00	**28.67±0.58**
Conductivity	µS/cm	4.59	4.58	4.58	**4.58±0.01**	4.71	4.72	4.73	**4.72±0.01**	4.62	4.61	4.62	**4.62±0.01**
Turbidity	NTU	0.90	1.00	0.93	**0.94±0.05**	0.92	0.91	0.90	**0.91±0.01**	0.94	0.93	0.92	**0.93±0.01**

APPENDIX 8 TABLE 13 RESULTS OF BACTERIOLOGICAL ANALYSIS FOR DISTRIBUTION SAMPLES (ASSISIM)

SAMPLING PERIOD / MONTH	SAMPLE VOLUME INNOCULATED (ml)	NO. OF POSITIVE TUBES IN CONFIRMATORY TEST AT 44^{O}C				MPN
		S1	S2	S3	Mean	TTC
SEPTEMBER, 2013	50	1	1	0	1	6
	10	2	3	2	6	
OCTOBER, 2013	50	1	1	1	1	16
	10	4	4	4	4	
NOVEMBER, 2013	50	1	1	1	1	9
	10	4	3	3	3	
DECEMBER, 2013	50	0	0	1	0	5
	10	4	4	3	4	
JANUARY, 2014	50	1	1	1	1	>18
	10	5	4	5	5	
FEBRUARY, 2014	50	1	1	1	1	9

	10	3	4	3	3	

Source: Field Data

Keys: S1- Sample 1
S2- Sample 2
S3-Sample 3

APPENDIX 9 TABLE 14 RESULTS OF BACTERIOLOGICAL ANALYSIS FOR DISTRIBUTION SAMPLES (EKWAMKROM)

SAMPLING PERIOD / MONTH	SAMPLE VOLUME INNOCULATED (ml)	NO. OF POSITIVE TUBES IN CONFIRMATORY TEST AT 44^{O}C				MPN TTC
		S1	S2	S3	Mean	
SEPTEMBER, 2013	50	1	1	1	1	3
	10	0	1	2	1	
OCTOBER, 2013	50	1	1	1	1	16
	10	4	4	5	4	
NOVEMBER, 2013	50	1	1	1	1	3
	10	2	1	1	2	
DECEMBER, 2013	50	0	0	1	0	1

	10	0	1	1	1	
JANUARY, 2014	50	1	1	1	1	>18
	10	5	5	4	5	
FEBRUARY, 2014	50	0	0	0	0	<1
	10	1	0	0	0	

Source: Field Data

Keys: S1- Sample 1
S2- Sample 2
S3-Sample 3

APPENDIX 10 TABLE 15 RESULTS OF BACTERIOLOGICAL ANALYSIS FOR DISTRIBUTION SAMPLES (MANGOASE)

SAMPLING PERIOD / MONTH	SAMPLE VOLUME INNOCULATED (ml)	NO. OF POSITIVE TUBES IN CONFIRMATORY TEST AT $44^{O}C$				MPN TTC
		S1	S2	S3	Mean	
SEPTEMBER, 2013	50	1	1	1	1	9
	10	3	3	4	3	
OCTOBER, 2013	50	1	1	1	1	>18
	10	5	5	5	5	
NOVEMBER, 2013	50	1	1	0	1	3

	10	1	2	1	1	
DECEMBER, 2013	50	1	1	1	1	6
	10	2	3	2	2	
JANUARY, 2014	50	1	1	1	1	9
	10	3	4	3	3	
FEBRUARY, 2014	50	1	1	1	1	16
	10	4	4	5	4	

Source: Field Data

Keys: S1- Sample 1
S2- Sample 2
S3-Sample 3

Appendix 11.0: Table 16.0 Summary of ANOVA Single factor for pH of Raw water compared to Final water.

Groups	Count	Sum	Average	Variance
Raw water	6	42.14	7.023333	0.006507
Final Water	6	41.84	6.973333	0.005867

Source: Field Study

Appendix 11.1: Table 16.1 ANOVA single factor for pH of Raw water compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	0.0075	1	0.0075	1.212284	0.29667611	4.9646033
Within Groups	0.061867	10	0.006187			
Total	0.069367	11				

p> .05 Source: Field Study

Appendix 12.0: Table 17.0 Summary of ANOVA Single factor for Colour of Raw water compared to Final water.

Groups	Count	Sum	Average	Variance
Raw water	6	830	138.333	2136.667
Final Water	6	30	5	0

Source: Field Study

Appendix 12.1: Table 17.1 ANOVA single factor for Colour of Raw water compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	53333.33	1	53333.33	49.922	0.000034	4.964603
Within Groups	10683.33	10	1068.333			
Total	64016.67	11				

p< .05 Source: Field Study

Appendix 13.0: Table 18.0 Summary of ANOVA Single factor for Alkalinity of Raw water compared to Final water.

Groups	Count	Sum	Average	Variance
Raw water	6	394.33	65.72167	114.8199
Final Water	6	303.33	50.555	376.9442

Source: Field Study

Appendix 13.1: Table 18.1 ANOVA single factor for Alkalinity of Raw water compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	690.0833	1	690.0833	2.806563	0.124817208	4.9646033
Within Groups	2458.82	10	245.882			
Total	3148.904	11				

p> .05 Source: Field Study

Appendix 14.0: Table 19.0 Summary of ANOVA Single factor for Total Hardness of Raw water compared to Final water.

Groups	Count	Sum	Average	Variance
Raw water	6	272.03	45.33833	53.68594

Final Water	6	327.66	54.61	71.1886

Source: Field Study

Appendix 14.1: Table 19.1 ANOVA single factor for Total Hardness of Raw water compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	257.8914	1	257.8914	4.130408	0.069532093	4.964603
Within Groups	624.3727	10	62.43727			
Total	882.2641	11				

p> .05 Source: Field Study

Appendix 15.0: Table 20.0 Summary of ANOVA Single factor for Calcium Hardness of Raw water compared to Final water.

Groups	Count	Sum	Average	Variance
Raw water	6	187.2	31.2	41.91832
Final Water	6	218.99	36.49833	73.07934

Source: Field Study

Appendix 15.1: Table 20.1 ANOVA single factor for Calcium Hardness of Raw water compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	84.21701	1	184.2170 1	1.464673	0.25401744 7	4.9646033
Within Groups	574.9883	10	57.49883			
Total	659.2053	11				

p> .05 Source: Field Study

Appendix 16.0: Table 21.0 Summary of ANOVA Single factor for Calcium of Raw water compared to Final water.

Groups	Count	Sum	Average	Variance
Raw water	6	74.88	12.48	6.70952
Final Water	6	87.33	14.555	11.44975

Source: Field Study

Appendix 16.1: Table 21.1 ANOVA single factor for Calcium of Raw water compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	12.91688	1	12.91688	1.422621	0.260504733	4.964603
Within Groups	90.79635	10	9.079635			
Total	103.7132	11				

p> .05 Source: Field Study

Appendix 17.0: Table 22.0 Summary of ANOVA Single factor for Magnesium Hardness of Raw water compared to Final water.

Groups	Count	Sum	Average	Variance
Raw water	6	84.543	14.0905	20.68933
Final Water	6	108.34	18.05667	12.95927

Source: Field Study

Appendix 17.1: Table 22.1 ANOVA single factor for Magnesium Hardness of Raw water compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit

Between Groups	47.19143	1	47.19143	2.804957	0.124912908	4.9646033
Within Groups	168.243	10	16.8243			
Total	215.4344	11				

p> .05 Source: Field Study

Appendix 18.0: Table 23.0 Summary of ANOVA Single factor for Magnesium of Raw water compared to Final water.

Groups	Count	Sum	Average	Variance
Raw water	6	20.62	3.436667	1.209067
Final Water	6	26.15	4.358333	0.664257

Source: Field Study

Appendix 18.1: Table 23.1 ANOVA single factor for Magnesium of Raw water compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	2.548408	1	2.548408	2.720735	0.130067173	4.964603
Within Groups	9.366617	10	0.936662			
Total	11.91503	11				

p> .05 Source: Field Study

Appendix 19.0: Table 24.0 Summary of ANOVA Single factor for Chloride of Raw water compared to Final water.

Groups	Count	Sum	Average	Variance

Raw water	6	420.58	70.09667	300.461
Final Water	6	430.34	71.72333	224.9237

Source: Field Study

Appendix 19.1: Table 24.1 ANOVA single factor for Chloride of Raw water compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	7.938133	1	7.938133	0.030208	0.865487858	4.9646033
Within Groups	2627.854	10	262.7854			
Total	2635.792	11				

p> .05 Source: Field Study

Appendix 20.0: Table 25.0 Summary of ANOVA Single factor for Temperature of Raw water compared to Final water.

Groups	Count	Sum	Average	Variance
Raw water	6	157.7	26.28333	0.245547
Final Water	6	164.6	27.43333	0.721027

Source: Field Study

Appendix 20.1: Table 25.1 ANOVA single factor for Temperature of water compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	3.9675	1	3.9675	8.209413	0.016806221	4.964603
Within Groups	4.832867	10	0.483287			
Total	8.800367	11				

p< .05 Source: Field Study

Appendix 21.0: Table 26.0 Summary of ANOVA Single factor for Conductivity of Raw water compared to Final water.

Groups	Count	Sum	Average	Variance
Raw water	6	30.06	5.01	0.39544
Final Water	6	31.76	5.293333	0.340227

Source: Field Study

Appendix 21.1: Table 26.1 ANOVA single factor for Conductivity of Raw water compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	0.240833	1	0.240833	0.654735	0.437253546	4.9646033
Within Groups	3.678333	10	0.367833			
Total	3.919167	11				

p> .05 Source: Field Study

Appendix 22.0: Table 27.0 Summary of ANOVA Single factor for Turbidity of Raw water compared to Final water.

Groups	Count	Sum	Average	Variance
Raw water	6	165.47	27.57833	273.3944
Final Water	6	5.08	0.846667	0.122347

Source: Field Study

Appendix 22.1: Table 27.1 ANOVA single factor for Turbidity of Raw water compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	2143.746	1	2143.746	15.67543	0.002689835	4.964603
Within Groups	1367.584	10	136.7584			
Total	3511.33	11				

p< .05 Source: Field Study

Appendix 23.0: Table 28.0 Summary of ANOVA Single factor for pH of Distribution sample (ASS) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	40.16	6.693333	0.015907
Final Water	6	41.84	6.973333	0.005867

Source: Field Study

Appendix 23.1: Table 28.1 ANOVA single factor for pH of Distribution sample (ASS) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	0.2352	1	0.2352	21.60441	0.000911	4.9646033
Within Groups	0.108867	10	0.010887			
Total		11				

p< .05 Source: Field Study

Appendix 24.0: Table 29.0 Summary of ANOVA Single factor for Colour of Distribution sample (ASS) compared to Final water.

Groups	Count	Sum	Average	Variance

Distribution Sample	6	30	5	0
Final Water	6	30	5	0

Source: Field Study

Appendix 24.1: Table 29.1 ANOVA single factor for Colour of Distribution sample (ASS) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	0	1	0	65635	0.0000	4.964603
Within Groups	0	10	0			
Total	0	11				

p< .05 Source: Field Study

Appendix 25.0: Table 30.0 Summary of ANOVA Single factor for Alkalinity of Distribution sample (ASS) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	207.99	34.665	94.41867
Final Water	6	303.33	50.555	376.9442

Source: Field Study

Appendix 25.1: Table 30.1 ANOVA single factor for Alkalinity of Distribution sample (ASS) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	757.4763	1	757.4763	3.213984	0.103263	4.9646033
Within Groups	2356.814	10	235.6814			

Total	3114.29	11				

p >05 Source: Field Study

Appendix 26.0: Table 31.0 Summary of ANOVA Single factor for Residual Chlorine of Distribution sample (ASS) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	1.83	0.305	0.02131
Final Water	6	6.54	1.09	0.1638

Source: Field Study

Appendix 26.1: Table 31.1 ANOVA single factor for Residual Chlorine of Distribution sample (ASS) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	1.848675	1	1.848675	19.9738	0.001199	4.964603
Within Groups	0.92555	10	0.092555			
Total	2.774225	11				

p< 5 Source: Field Study

Appendix 27.0: Table 32.0 Summary of ANOVA Single factor for Temperature of Distribution sample (ASS) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	180.33	30.055	1.66171
Final Water	6	164.6	27.43333	0.721027

Source: Field Study

Appendix 27.1: Table 32.1 ANOVA single factor for Temperature of Distribution sample (ASS) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	20.61941	1	20.61941	17.30733	0.001948	4.9646033
Within Groups	11.91368	10	1.191368			
Total	32.53309	11				

p< .05 Source: Field Study

Appendix 28.0: Table 33.0 Summary of ANOVA Single factor Conductivity of Distribution sample (ASS) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	29.27	4.878333	0.075617
Final Water	6	31.76	5.293333	0.340227

Source: Field Study

Appendix 28.1: Table 33.1 ANOVA single factor for Conductivity of Distribution sample (ASS) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	0.516675	1	0.516675	2.48495	0.146018	4.964603
Within Groups	2.079217	10	0.207922			
Total	2.595892	11				

p> .05 Source: Field Study

Appendix 29.0: Table 34.0 Summary of ANOVA Single factor for Turbidity of Distribution sample (ASS) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	4.46	0.743333	0.035107

Final Water	6	5.08	0.846667	0.122347

Source: Field Study

Appendix 29.1: Table 34.1 ANOVA single factor for Turbidity of Distribution sample (ASS) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	0.032033	1	0.032033	0.406893	0.537882	4.9646033
Within Groups	0.787267	10	0.078727			
Total	0.8193	11				

p> .05 Source: Field Study

Appendix 30.0: Table 35.0 Summary of ANOVA Single factor for pH of Distribution sample (EK) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	40.03	6.671667	0.039577
Final Water	6	41.84	6.973333	0.005867

Source: Field Study

Appendix 30.1: Table 35.1 ANOVA single factor for pH of Distribution sample (EK) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	0.273008	1	0.273008	12.01533	0.006058	4.964603
Within Groups	0.227217	10	0.0227			
Total	0.500225	11				

p< .05 Source: Field Study

Appendix 31.0: Table 36.0 Summary of ANOVA Single factor for Colour of Distribution sample (EK) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	30	5	0
Final Water	6	30	5	0

Source: Field Study

Appendix 31.1: Table 36.1 ANOVA single factor for Colour of Distribution sample (EK) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	0	1	0	0	0	4.9646033
Within Groups	0	10	0			
Total	0	11				

Appendix 32.0: Table 37.0 Summary of ANOVA Single factor for Alkalinity of Distribution sample (EK) compared to Final water.

Groups	Count	Sum	Average	Variance

Distribution Sample	6	213.66	35.61	137.0486
Final Water	6	303.33	50.555	376.9442

Source: Field Study

Appendix 32.1: Table 37.1 ANOVA single factor for Alkalinity of Distribution sample (EK) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	670.0591	1	670.0591	2.607271	0.137449	4.964603
Within Groups	2569.964	10	256.9964			
Total	3240.023	11				

p> .05 Source: Field Study

Appendix 33.0: Table 38.0 Summary of ANOVA Single factor for Residual Chlorine of Distribution sample (EK) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	2.56	0.426667	0.058307
Final Water	6	6.54	1.09	0.1638

Source: Field Study

Appendix 33.1: Table 38.1 ANOVA single factor for Residual Chlorine of Distribution sample (EK) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	1.320033	1	1.320033	11.88648	0.00625	4.9646033

p< .05 Source: Field Study

Within Groups	1.110533	10	0.111053			
Total	2.430567	11				

p< .05 Source: Field Study

Appendix 34.0: Table 39.0 Summary of ANOVA Single factor for Temperature of Distribution sample (EK) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	179.6	29.93333	1.424987
Final Water	6	164.6	27.43333	0.721027

Source: Field Study

Appendix 34.1: Table 39.1 ANOVA single factor for Temperature of Distribution sample (EK) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	18.75	1	18.75	17.47426	0.001887	4.964603
Within Groups	10.73	10	1.07307			
Total	29.48007	11				

Appendix 35.0: Table 40.0 Summary of ANOVA Single factor for Conductivity of Distribution sample (EK) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	29.3	4.883333	0.068787
Final Water	6	31.76	5.293333	0.340227

Source: Field Study

Appendix 35.1: Table 40.1 ANOVA single factor for Conductivity of Distribution sample (EK) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	0.5043	1	0.5043	2.465934	0.147412	4.9646033
Within Groups	2.045067	10	0.204507			
Total	2.549367	11				

p>.05 Source: Field Study

Appendix 36.0: Table 41.0 Summary of ANOVA Single factor for Turbidity of Distribution sample (EK) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	4.4	0.733333	0.008467
Final Water	6	5.08	0.846667	0.122347

Source: Field Study

Appendix 36.1: Table 41.1 ANOVA single factor for Turbidity of Distribution sample (EK) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	0.038533	1	0.038533	0.589135	0.460493	4.964603
Within Groups	0.654067	10	0.065407			
Total	0.6926	11				

p> .05 Source: Field Study

p< .05 Source: Field Study

Appendix 37.0: Table 42.0 Summary of ANOVA Single factor for pH of Distribution sample (MG) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	40.1	6.683333	0.020787
Final Water	6	41.84	6.973333	0.005867

Source: Field Study

Appendix 37.1: Table 42.1 ANOVA single factor for pH of Distribution sample (MG) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	0.2523	1	0.2523	18.93197	0.001441	4.9646033
Within Groups	0.133267	10	0.013327			
Total	0.385567	11				

Appendix 38.0: Table 43.0 Summary of ANOVA Single factor for Colour of Distribution sample (MG) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	30	5	0
Final Water	6	30	5	0

Source: Field Study

Appendix 38.1: Table 43.1 ANOVA single factor for Colour of Distribution sample (MG) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit

Between Groups	0	1	65535	65535	0.00	4.964603
Within Groups	0	10				
Total	0	11				

p> .05 Source: Field Study

Appendix 39.0: Table 44.0 Summary of ANOVA Single factor for Alkalinity of Distribution sample (MG) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	198.67	33.11167	192.7779
Final Water	6	303.33	50.55	376.9442

Source: Field Study

p< .05 Source: Field Study

Appendix 39.1: Table 44.1 ANOVA single factor for Alkalinity of Distribution sample (MG) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	912.8096	1	912.8096	3.204403	0.103713	4.9646033
Within Groups	284861	10	284.861			
Total	3761.42	11				

p< .05 Source: Field Study

Appendix 40.0: Table 45.0 Summary of ANOVA Single factor for Residual Chlorine of distribution sample (MG) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	2.5	0.4166667	0.035227
Final Water	6	6.54	1.09	0.1638

Source: Field

Appendix 40.1: Table 45 .1 ANOVA single factor for Residual Chlorine of Distribution sample (MG) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	1.360133	1	1.360133	13.66785	0.004129	4.964603
Within Groups	0.995133	10	0.099513			
Total	2.355267	11				

p< .05 Source: Field Study

Appendix 41.0: Table 46.0 Summary of ANOVA Single factor for Temperature of Distribution sample (MG) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	177.67	29.61167	1.131937
Final Water	6	164.6	27.43333	0.721027

Source: Field Study

Appendix 41.1: Table 46.1 ANOVA single factor for Temperature of Distribution sample (MG) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	14.23541	1	14.23541	15.36502	0.002867	4.9646033
Within Groups	9.264817	10	0.926482			
Total	23.50023	11				

p< .05 Source: Field Study

Appendix 42.0: Table 47.0 Summary of ANOVA Single factor for Conductivity of Distribution sample (MG) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	29.38	4.896667	0.075347
Final Water	6	31.76	5.293333	0.340227

Source: Field Study

Appendix 42.1: Table 47.1 ANOVA single factor for Conductivity of Distribution sample (MG) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	0.472033	1	0.472033	2.271721	0.162675	4.964603

Within Groups	2.077867	10	0.207787			
Total	2.5499	11				

p> .05 Source: Field Study

Appendix 43.0: Table 48.0 Summary of ANOVA Single factor for Turbidity of Distribution sample (MG) compared to Final water.

Groups	Count	Sum	Average	Variance
Distribution Sample	6	4.4	0.733333	0.025907
Final Water	6	5.08	0.846667	0.122347

Source: Field Study

Appendix 43.1: Table 48.1 ANOVA single factor for Turbidity of Distribution sample (MG) compared to Final water.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	0.038533	1	0.038533	0.519831	0.487427	4.9646033
Within Groups	0.741267	10	0.074127			
Total	0.7798	11				

p> .05 Source: Field Study

Appendix 44.0: Table 49.0 Summary of ANOVA Single factor for bacteriological analysis of water in the distribution network (Assism) and final water

Groups	Count	Sum	Average	Variance
ASS	5.0	57.0	11.4	29.3
FINAL WATER	5.0	0.0	0.0	0.0

Source: Field Study

Appendix 44.1: Table 49.1 Analysis of variance (ANOVA) for bacteriological analysis of water in the distribution network (Assism) and final water values.

Source of variation	Sum of Squares	df	Mean Square	F	P value	Fcrit
Between Groups	324.9	1	324.9			
Within Groups	117.2	8	14.65	22.17747	0.001523	5.317655
Total	442.1	9				

p<.05 Source: Field Study

Appendix 45.0: Table 50.0 Summary of ANOVA Single factor for bacteriological analysis of water in the distribution network (Ekwamkrom) and final water

Groups	Count	Sum	Average	Variance
EK	5.0	39.0	7.8	71.7
FINAL WATER	5.0	0.0	0.0	0.0

Source: Field Study

Appendix 45.1: Table 50.1 Analysis of variance (ANOVA) for bacteriological analysis of water in the distribution network (Ekwamkrom) and final water values.

Source of variation	Sum of Squares	df	Mean Square	F	P value	Fcrit
Between Groups	152.1	1	152.1			
Within Groups	286.8	8	35.85	4.242678	0.073386	5.317655
Total	438.9	9				

p>.05 Source: Field Study

Appendix 46.0: Table 51.0 Summary of ANOVA Single factor for bacteriological analysis of water in the distribution network (Mangoase) and final water

Groups	Count	Sum	Average	Variance
MG	5.0	52.0	10.4	41.3
FINAL WATER	5.0	0.0	0.0	0.0

Source: Field Study

Appendix 46.1: Table 51.1 Analysis of variance (ANOVA) for bacteriological analysis of water in the distribution network (Mangoase) and final water values.

Source of variation	Sum of Squares	Df	Mean Square	F	P value	Fcrit
Between Groups	270.4	1	270.4			
Within Groups	165.2	8	20.65	13.09443	0.006796	5.317655
Total	435.6	9				

p<.05 Source: Field Study

APPENDIX 47: Plates of tubes containing MacConkey broth media (A) and Brilliant Green Lactose bile broth media (B) before inoculation

A

B

APPENDIX 48: Plates of tubes containing inoculated samples for presumptive test (A), tubes showing positive results after presumptive test (B) and tubes showing positive results after confirmatory test (C).

A **B**

C

APPENDIX 49.0: Temperature figures for the duration of the project.

MONTH	TEMPERATURE ^{O}C	
	MIN	MAX
SEPT. 2013	20.1	30.2
OCT. 2013	22.4	32.1
NOV. 2013	22.0	32.5
DEC. 2013	20.8	34.8
JAN. 2014	21.7	34.4
FEB. 2014	22.2	34.6

Source: Local Meteorological Station, Form met 105 RVD)

Appendix 50.0: WHO guideline values

PARAMETERS	UNIT	WHO GUIDELINE
pH	-	6.5-8.5
Colour	HU	0.0-15
Alkalinity	mg/l	200

Residual Chlorine	mg/l	-
Total hardness	mg/l	0-500
Calcium Hardness		<or=200
Calcium	mg/l	<or=80
Magnesium Hardness		<or=30
Magnesium	mg/l	50-150
Chloride	mg/l	<or=250
Temperature	^{O}C	25
Conductivity	µS/cm	300
Turbidity	NTU	<or=5