KWAME NKURUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

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DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

ASSESSMENT OF WATER QUALITY OF BAREKESE DAM FROM POINT OF PRODUCTION TO SUPPLY AREAS IN KUMASI

A thesis submitted to the Department of Theoretical and Applied Biology of the Kwame Nkrumah University of Science and Technology in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science

BY

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DEDICATION

To the Almighty God, YHVH for his grace and mercy has brought me this far and to my Best Half, Minister Michael Akuamoah Boateng (M.Sc.) you are an immense blessing especially to me.

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STATEMENT OF ORIGINALITY

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

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ABSTRACT

Drinking water quality is very essential for good health. Water was sampled from four (4) booster stations namely; Achiase, Buokrom, KNUST and Tafo. Three areas each were selected from the Achiase (Asokwa, Atonsu and Asafo) and KNUST (Boadi, Kentinkrono and Oduom) booster station supply areas from December, 2011 to March, 2012. They were analysed for various physicochemical parameters and bacteriological indicators using the World Health Organisation (WHO) standard methods. Physical parameters such as pH, turbidity, colour, free and total chlorine were found to be within the WHO acceptable limits except free chlorine and temperature. All the water samples showed temperature and free chlorine above the WHO standards. The temperatures were slightly above by about 0.4^{o}C and free chlorine was below the acceptable range from 0.2 mgL^{-1} – 0.5 mgL^{-1}. The Barekese untreated water showed Temperature 26.9 ^{o}C, pH 9.1, Turbidity 31.8 FTU, colour 16.9 Hz, free and total chlorine 0.22 mg/L and 0.27 mg/L respectively, total and faecal coliforms 16 x 10^{6} MPN/100 mL and 39 x 10^{3} MPN/100 mL respectively and *E. coli* (10 MPN/100 mL), comparatively higher than the acceptable limits. The microbial quality of the untreated water is poor, rendering it unsafe for domestic purposes without prior treatment however that of the treated water samples were fairly good; the total coliforms were within the WHO limit (10 MPN/100 mL) but faecal coliforms and *E. coli* counts were slightly above the standard (0 MPN/100 mL). KNUST supply areas showed there is no significant difference but the Achiase supply areas showed a reverse because of leakages and breakages of some of the pipelines which supply various homes. This work disclosed that the level of water quality of the Barekese dam from point of production to final consumption is appreciable.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

Water is very essential for the survival of life on earth. It provides a logical link between the physical and social environments. Water is used for irrigation, in the industries, for recreation, cooking, washing, bathing and drinking (Bartram and Balance, 2001; Hayward and Oguntoyinbo, 1987). The declining availability of water supplies is one of the most important environmental issues facing various countries at the present time. Consequently, it has been estimated that nearly two-thirds of nations worldwide will experience water stress by the year 2025 (United Nations Environment Programme, 2002). The supply of safe potable drinking water in Ghana is characterized by seasonal and persistent shortages. Such shortages are widespread, often the result of poor management of water resources, irregular rainfall patterns, prolonged drought and inefficient use of available technology (Kumasi *et al*., 2007). Furthermore, on a national scale, only about 42% of Ghanaians have adequate access to safe potable drinking water, although as many as 81% of the rural population in Ghana lacks access to safe potable drinking water (GPRS, 2003). In addition, 29% of the Ghanaian rural population relies on unimproved water sources, with majority of the improved water sources in rural Ghana being boreholes and protected wells (Rossiter *et al*., 2010; JMP 2008;). Climate change, affluence and population growth have resulted in vast requirements of water for use in domestic, industrial and agricultural settings. There exists a growing demand for centralized systems of water delivery in urban locales due to the continuing trend of population migration to larger cities. In these densely populated areas, the government (or a privately contracted

company) has often installed the infrastructure necessary to deliver treated water. This type of potable piped water is necessary to ensure that all residents have convenient and continual access to a clean drinking water supply. The importance of water as a resource to improve the social well-being of a people and for national development cannot be over emphasised. That is why the quality and quantity of water supplied to a community is crucial in determining their health status, standard of living and level of development (Falkenmark *et al.*, 1990). According to Chowdhury (2003), the principal aim of every conventional drinking water treatment plant should be to provide realistic standards of service, to gain customer satisfaction, delivering to consumers' water that is both aesthetically pleasing and to meet public health safety requirements. 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 and crucial.

Appropriately, the Ghana Water Company Limited (GWCL) iterated was formed from the Ghana Water and Sewerage Corporation (GWSC) in 1999 with the responsibility to provide potable water for urban consumption. However, GWCL has been facing difficulties in fulfilling its obligations to many urban communities. Feachem *et al*. (1978) observed that in developing countries, several factors may cause these difficulties; example lack of funds for capital projects, undue political influences, mismanagement, poor designs, lack of skilled personnel, lack of appropriate technology and logistics.

Kumasi is the most populous district in the Ashanti Region and second largest city in Ghana with a current estimated population of 2,022,191 in 2010 based on a growth

rate of 5.5 % per annum and this accounts for just under a third (32.4%) of the region's population; using the 2010 Population Census (KMA, 2012; GSS, 2010). This rate is much higher than the regional and national averages of 2.8% and 2.7 % respectively.

1.2 PROBLEM STATEMENT

Water for domestic consumption must contain some residual amount of Chlorine to ensure that water remains safe from microbial attack, even after production and distribution. Total amount of chlorine added at point of final distribution is always higher and decreases with distance from point of production. Hence, the extent to which residual chlorine prevails from point of production (Barekese dam) to other parts of Kumasi needs to be investigated. Moreover, illegal pipe connections abound in society. This could act as point of entry for microbial organisms. In that the calculated amount of residual chlorine could be effectively reduced in fighting pathogens.

1.3 JUSTIFICATION OF OBJECTIVES

Knowing that Chlorine at certain levels can be harmful to humans and at lower levels in drinking water may not be able to disinfect the water when contaminated along the distribution lines, it is imperative that one ascertains the level of residual chlorine along the distribution lines from source to the final point of consumption. Since illegal connections abound in society, contamination may occur through illegal connections and delay in response to faults. There is need to determine whether or not pipe borne water reaching various homes meet water quality standards.

1.4 MAIN OBJECTIVE

To investigate the level of water quality of the Barekese dam from point of production to the final consumption.

1.5 SPECIFIC OBJECTIVES

- To determine the presence and levels of residual chlorine in the treated drinkable water along the selected major distribution lines from Barekese reservoir.
- To assess some physicochemical parameters governing water quality (Temperature, turbidity, colour, pH).
- To determine the level of the different microbial load in the drinking water (Total coliform, feacal coliform, *E. coli*)

1.6 NULL HYPOTHESIS

Ho: The levels of residual chlorine in the treated drinkable water are the same along the selected distribution lines from Barekese

Ho: The physicochemical parameters of the water for the various sample sites are the same.

Ho: The levels of microbial load in the water at the different sample sites do not differ.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 DRINKING WATER

Drinking water or potable water is water safe enough to be consumed by humans or used with low risk of immediate or long term harm. In most developed countries, the water supplied to households, commerce and industry meets drinking water standards, even though only a very small proportion is actually consumed or used in food preparation (Wiki, 2011). Typical uses (for other than potable purposes) include toilet flushing, washing and landscape irrigation. Over large parts of the world, humans have inadequate access to potable water and use sources contaminated with disease vectors, pathogens or unacceptable levels of toxins or suspended solids. Drinking or using such water in food preparation leads to widespread acute and chronic illnesses and is a major cause of death and misery in many countries. Reduction of waterborne diseases is a major public health goal in developing countries. Although covering some 70% of the Earth's surface, most water is saline. Freshwater is available in almost all populated areas of the earth, although it may be expensive and the supply may not always be sustainable (Wiki, 2011). Sources where water may be obtained include: Ground sources such as groundwater, hyporheic zones and aquifers, precipitation which includes rain, hail, snow, fog, etc, Surface water such as rivers, streams, glaciers, biological sources such as plants, the sea through desalination, Water supply network (Wiki, 2011).

2.2 DESCRIPTION OF WATER TREATMENT PLANT – OVERVIEW

Drinking water production using raw water sources may be divided into: Surface water (from rivers, lakes etc); Groundwater; and Artificially Recharged Groundwater (ARG) (Sarpong, 2007).

The last concept (ARG) combines often large volumes of the surface water with the water quality improvement often reached in the ground after infiltration. Due to the differences in water quality, the treatment efforts for groundwater and surface water normally differ from each other (Sarpong, 2007). The Barekese Headworks, (Figure 2.1) use the conventional water treatment method in their daily water treatments and the treatment from surface water that has been dammed.

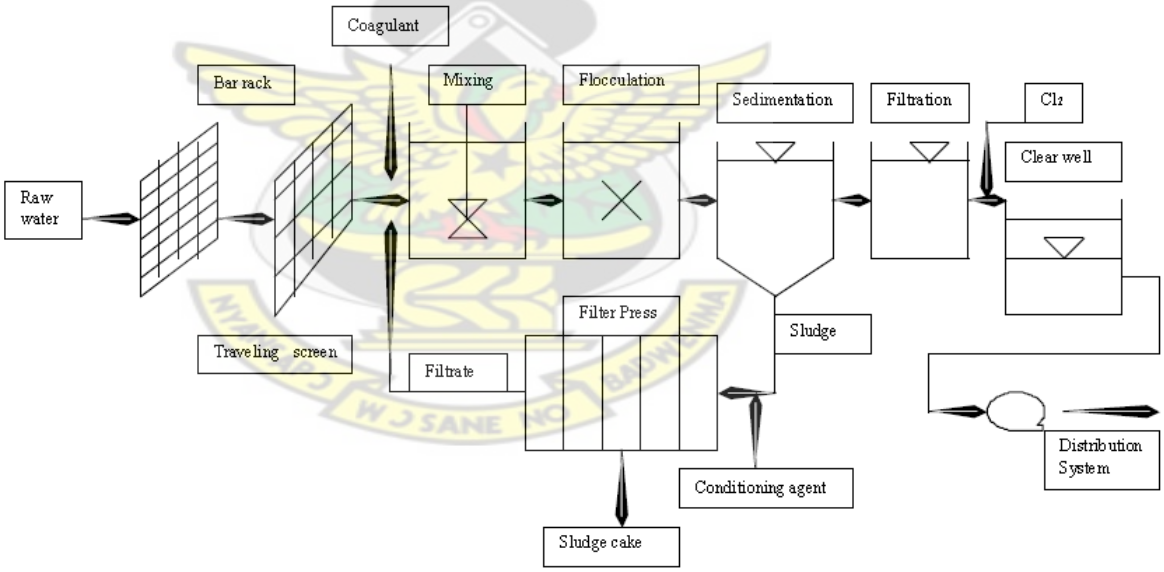

Figure 2.1: Schematic procedure for Treatment of surface water using Chemical Precipitation (Source. Barekese Head works, 2010).

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. The unit processes according to Sarpong (2007) that may be incorporated into a water treatment plant are discussed below:

2.2.1. 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 (Sarpong, 2007).

2.2.2. 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 odor-causing compounds (Fe and Mn) maybe removed to satisfactory levels (AWWA, 1999). Addition of dissolved oxygen enhances the oxidation of iron, manganese, and other metals to higher and more soluble oxidation. Apart from providing oxygen for purification and improving overall quality, aeration also reduce the corrosiveness of the water by driving CO_2 and raising the pH. However, aeration alone cannot reduce the corrosive properties of acid water; neutralization using lime may also be needed. Aeration is one of the first treatment operations applied to water. It can be designed as an aesthetically pleasing spray aerators open to public view (Gray, 2005).

2.2.3. 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. 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 the coagulant is consumed inside reactions with water itself (Slaats *et al*., 2002).

2.2.4. Flocculation

Flocculators provide gentle agitation of water that has been coagulated to promote particles contact and formation of larger particles. Hydraulic or mechanically driven flocculators may be designed. Flocculators follow the rapid mixing coagulation tank and precede sedimentation and filtration units (Kivit, 2004).

2.2.5. Sedimentation

Exposing the water to relatively quiescent conditions will allow settleable solids to be removed by the action of the force of gravity. The sludge accumulated in these tanks may be disposed in landfills or the water source downstream of the withdrawal point for the water supply (AWWA, 1999). Sedimentation proceeded without coagulation and flocculation is known as plain sedimentation. Raw waters that contain a high sediment load maybe 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. Waters, particularly groundwater's that have a low concentration of suspended solids, may not require sedimentation (Sarpong, 2007)

2.2.6. Filtration

Filtration accomplishes polishing of water. Filtration 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 are two filtration alternatives in common used; 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 are sand filters or multimedia filters that have anthracite, sand, and possibility other media in them. Loading rates of rapid filters are much higher than slow sand filters. Rapid filters are cleaned by backwashing – reversing the flow of the water through the media and pumping at a rate sufficient to expand the media; backwashing is necessary every 1-4 days depending on influent water quality (AWWA, 1999). The influent to rapid filters generally must have a coagulating agent added to it at some upstream location. 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 solids content. Raw water that is of high quality may require filtration only to remove the small quantities of suspended solids that are present. Otherwise rapid filters are preceded by coagulation, flocculation, and sedimentation (Gray, 2005).

2.2.7. Disinfection

Disinfection is the removal or inactivation of pathogenic microorganisms (not necessarily sterilization). Chemical agents, commonly chlorine or its derivatives, maybe used or the water maybe exposed ultraviolet (UV) light or radiation. 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 (Sarpong, 2007). It is exceedingly rare to find raw water that would not require disinfection. North American 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. Disinfectant is the last treatment applied to water (Boxall *et al*., 2003).

2.2.8. Fluoridation

Fluoride is added to waters to reduce the incidence of dental caries in the population. The fluoride is added by a chemical feeder. Pumping and flow through the distribution pipes will ensure that the fluoride ion is thoroughly dispersed in the water.

2.3 THE DISTRIBUTION SYSTEM – OVERVIEW

The goal of a drinking water distribution system is to deliver sufficient quantities of water where and when it is needed at an acceptable level of quality. 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. This fact can have enormous influence when trying to understand the relation between residence time and water quality. According to LeChevallier *et al*. (1996), distribution systems are considered as biological and chemical reactors that interact with the transported water, in that, water quality changes with time and space.

Many new regulations focusing on monitoring water quality within the distribution system, has caused water treatment companies to face new challenges in maintaining high quality delivered water to the consumer's tap. Water distribution systems have also been observed to have microbial instability and this has often been correlated to the consumption of dissolved organic matter by suspended and attached bacteria (Servais *et al*., 1995). Generally, the number of suspended particles in distributed water according to Brazos and O'Connor (1990) are often quite low (294 and 1117 particles larger than 3μm per mL) which in some way comparable with treated water concentrations (186-1229 particles per mL). Many of the suspended particles sediment and form, according to Sarpong (2007), loses deposits in parts of the distribution system where hydraulic conditions are favorable. E.g. low flow in the night, dead-ends, reservoirs etc. Though the composition of suspended particles is seldom detailed due to their very low concentration (e.g. 29 μg dry matter/l), however, the composition of loose deposits in the survey of several drinking water systems has been determined and shown to vary in proportions of iron and manganese oxides, sand, zinc flocs, algae siliceous skeletons, detrital organic particles and organic micro pollutants (Gauthier *et al*., 1996).

2.4 WATER QUALITY IN DISTRIBUTION SYSTEMS

Historically, the provision of piped water directly to the household has been associated with improved hygiene and reduction in disease. However, as standards of living have risen and water infrastructures have aged, there has been growing recognition that water distribution systems are vulnerable to intrusion and contamination and may contribute to endemic and epidemic waterborne disease. Analyses of the data from the waterborne disease outbreak passive surveillance system in the United States indicate that the total number of reported waterborne disease outbreaks has decreased since 1980. This may be due to improved water treatment practices and the Surface Water Treatment Rule which reduced the risk from waterborne protozoa. However, the proportion of waterborne disease outbreaks associated with problems in the distribution systems is increasing. Craun *et al*., 2002, examined causes of reported waterborne outbreaks from 1971 to 1998 and noted that, in community water systems, 30% of 294 outbreaks were associated with distribution system deficiencies, causing an average of 194 illnesses per outbreak. Distribution system contamination was the single most important cause of outbreaks in community water systems over that time period (Craun *et al*., 2002). Contamination from cross-connections and back siphonage caused 51% of the outbreaks associated with distribution systems. Contamination of water mains and household plumbing problems caused 39% of the outbreaks, and contamination of storage facilities caused the remaining 10% of outbreaks. From 1999 to 2002, there were 18 reported outbreaks in community water systems, and 9 (50%) of these were related to problems in the water distribution system.

Microbial contamination in parts of the distribution system may also play a role in risks of endemic illness. Studies by Payment *et al*. (1991, 1997) suggest that the distribution system may have contributed to gastrointestinal illness rates observed in study households which drank tap water compared to study households which drank tap water, with additional treatment, or bottled water. A recent study conducted in Wales and northwest England between 2001 and 2002 found a very strong association (p,0.001) between self-reported diarrhoea and reported low water pressure at the home tap based on a postal survey of 423 subjects (Hunter *et al*., 2005). Although there has been concern about possible health risks from pressure loss and pathogen intrusion in water distribution systems (LeChevallier *et al*., 2003), this is the first study to provide solid evidence of that risk.

Biofilms in distribution systems may provide a favorable environment for some bacterial pathogens – especially opportunistic pathogens which cause disease primarily in people with weak or immature immune systems. These pathogens can enter the distribution system from faecal contamination and then replicate and colonize parts of the distribution system. Non-enteric pathogens, such as *Legionella, Pseudomonas aeruginosa* and *Mycobacterium avium-intracellulari*, can also colonize parts of the distribution system and plumbing systems in buildings and may play a role in waterborne disease. Biofilm in the distribution system may also protect viral and protozoan pathogens from disinfection and allow them to survive longer. Storey and Ashbolt (2003), recently demonstrated the accumulation and persistence of model enteric virions in potable water biofilms. Aging distribution systems may be particularly vulnerable to contamination problems. A recent report by the American Water Works Association (AWWA 2001) and a white paper by the American Water

Works Service Company, Inc. (AWWSC 2002) point out that the majority of water distribution system pipes in the United States are reaching the end of their expected lifespan in the next 30years. Analysis of main breaks at one large mid-western water utility which kept careful records of their management of the distribution system documented a sharp increase in the annual number of main breaks from 1970 (approximately 250 breaks/year) until 1989 (approximately 2200 breaks/year) (AWWSC, 2002). There is increasing recognition that the water industry is beginning a new era where it must make substantial investments in pipe repair and pipe replacement. A USEPA report on water infrastructure needs (2002) predicted that transmission and distribution pipe replacement rates need to be around 0.3% per year in 2005 and will rise to 2.0% per year by 2040 in order to adequately maintain the water infrastructure.

Cost estimates for drinking water infrastructure replacement range from $4.2 to $6.3 billion per year (AWWSC, 2002). Recent investment in water infrastructure in the United States has not been adequate to meet current water demands. It will be an even greater challenge for public and private water utilities to generate the necessary excess revenue to implement these critical pipe replacement programs. Problems with water quality in the distribution system are especially serious in middle income and developing countries where there are inadequate resources to maintain the distribution system infrastructure and disinfectant residual. Moe and Rheingans (2006) says Rapid urbanization in developing countries is often accompanied by overwhelming demands on existing water systems and illegal connections to distribution systems in poor neighborhoods. Many systems have cracks and high leakage. In 1991, an international survey of water loss as a percentage of water supplied reported that in industrialized countries water loss ranged from 8% to 24%.

However, in middle income or newly industrialized countries, water loss ranged from 15% to 24%, and in developing countries, water loss was estimated at between 25% and 45% (WHO 2001). Frequent power outages contribute to low or negative pressure in the pipes which allows contaminated water or wastewater surrounding the pipes to be drawn in through any cracks. Many of the largest documented waterborne outbreaks in the last two decades have been associated with cross-contamination in the distribution system (e.g. typhoid in Dushanbe, Tajikistan, 1997, cholera in Cape Verde, 1994–1997, Guinea Bissau, 1996 and Trajillo, Peru, 1990) (Renkevich *et al*., 1998).

2.6 WATER QUALITY

To be able to control the processes and to locate the points to improve, it is important to have a good knowledge about the quality of the water in different sections of the plant and in the distribution systems.

2.6.1 Physicochemical Parameters

Temperature

One of the most common physical parameters of water quality is the measurement of temperature (APHA, 1992). Temperature of a waterway is significant because it affects the amount of dissolved oxygen in the water. The amount of oxygen that will dissolve in water increases as temperature decreases. The temperature of source water can fluctuate seasonally and depends upon the type of source.

pH

The most commonly measured chemical attribute of water is acidity or pH. pH value is the logarithm of reciprocal of hydrogen ion activity in moles per liter. In water

solution, variations in pH value from 7 are mainly due to hydrolysis of salts of strong bases and weak acids or vice versa. The overall pH range of natural water is generally between 6 and 8. Industrial wastes may be strongly acidic or basic and their effect on pH value of receiving water depends on the buffering capacity of water. According to WHO, 2004, pH lower than 4 will produce sour taste that is very acidic and higher value above 8.5 bitter taste too basic. Higher value of pH hastens the scale formation in water heating apparatus and reduces the germicidal potential of chlorine. pH below 6.5 starts corrosion in pipes, thereby releasing toxic metals such as Zn, Pb, Cd, Cu etc.

Colour

Colour in water may be due to the inorganic ions, such as iron and manganese, humus and peat materials, plankton, weeds and industrial wastes. The term colour is used to mean the true colour of water from which turbidity has been removed. The term apparent colour includes not only the colour due to substances in solution but also that due to suspended matter. Apparent colour is determined on the original sample without filtration or centrifugation (APHA, 1992).

Turbidity

Turbidity is a measure of the ability of light to pass through water, that is, a measure of the water's murkiness. Turbidity is caused by suspended materials which absorb and scatter light. These colloidal and finely dispersed turbidity-causing materials do not settle under quiescent conditions and are difficult to remove by sedimentation. Turbidity is a key parameter in water supply engineering, because turbidity will both cause water to be aesthetically unpleasant and cause problems in water treatment processes, such as filtration and disinfection. Turbidity is also often used as indicative

evidence of the possibility of bacteria being present. Turbidity is measured in Nephelometric Turbidity Units (NTU's). Turbid water is associated with the mobilization of accumulated particles from within distribution networks. Different particles have significantly different effects on perceived turbidity. The particulate matter suspended making drinking water turbid could either be organic or inorganic, or both (Boxall *et al*., 2003).

Discrete instruments, turbidity meters, have been available as proven and reliable instrumentation for some time, while treatment work control has driven the development of continuous, low range instruments for processes control. However, more robust instrumentation, with greater dynamic range and improved logging and communications technology are now available suitable for deployment on distribution systems. Such equipment allows continuous monitoring at several locations at the same time, making it possible to record the changes in turbidity and hence to identify casual factors (Slaats *et al*., 2002). Data obtained from such turbidity meters have been used to develop techniques to aid water companies to identify and quantify discolouration risks within the distribution networks.

Free Chlorine and Total chlorine

Chloride is one of the major inorganic anion in water. In potable water, the salty taste is produced by the chloride concentrations is variable and dependent on the chemical composition. When chlorine is added to water, some of the chlorine reacts first with organic materials and metals in the water and is not available for disinfection (this is called the chlorine demand of the water). The remaining chlorine concentration after the chlorine demand is accounted for is called total chlorine. Total chlorine is further

divided into: 1) the amount of chlorine that has reacted with nitrates and is unavailable for disinfection which is called combined chlorine and, 2) the free chlorine, which is the chlorine available to inactivate disease-causing organisms, and thus a measure to determine the portability of water. Chlorine is a disinfectant added to drinking water to reduce or eliminate microorganisms, such as bacteria and viruses, which can be present in water supplies. The addition of chlorine to our drinking water has greatly reduced the risk of waterborne diseases. A major advantage of chlorine is that it has a residual disinfection effect, and it can ensure disinfection right up to the tap. In fact, the residual ability to destroy and inhibit the activity of pathogenic agents is a specific characteristic of chlorine. Modern treatment processes not only use free chlorine as a disinfectant but also bound species such as chloramines, which are longer lasting in distribution systems. Chlorine is highly soluble and is easily applied to water in controlled amounts, either as chlorine gas (Cl_2), which readily dissolve in water at room temperature, or as a slat of hypochlorite (OCl^-). The basic form of chlorine is Cl_2 (g). When Cl_2 (g) is added into water, the following reactions occur.

$$Cl_2 + H_2O \longrightarrow HOCl + H^+ + Cl^-$$

$$HOCl + H_2O \longrightarrow 3H^+ + OCl^-$$

The concentrations of free chlorine, according to Frederick and Pontius (1997), the hypochlorous acid (HOCl) and hypochlorite ions (OCl^-), are determined by pH. HOCl is more germicidal than OCl^-, and dissociates into OCl^- between a pH of 7.0 and 8.0. However, the concentration of HOCl and OCl^- is the same at a pH of 7.53. According to Rice and Gomez-Taylor (1986), monochloramine is produced by adding chlorine to a solution containing ammonia, by adding ammonia to a solution containing free residual chlorine or by adding premixed solution of ammonia and chlorine to water. The production of NH_2Cl, $NHCl_2$, and NCl_3 with respect to Wolfe *et al*. (1984) and

Kirmeyer, *et al.* (1993), is highly dependent upon pH, the ration of chlorine to ammonia-nitrogen and temperature and contact time.

$Cl_2 + H_2O \longrightarrow HOCl + HCl$

$HOCl + NH_3 \longrightarrow H_2O + NH_2Cl$ (monochloramine): between pH 7.5 and 9.0 (ideal pH is 8.3)

$HOCl + NH_2Cl \longrightarrow H_2O + NHCl_2$ (dichloramine): between pH 4.5 and 4.6

$HOCl + NHCl_2 \longrightarrow H_2O + NCl_3$ (trichloramine): under lower than pH 4.4

Source: Kirmeyer *et al.* (1993) and White (1992)

The formation of chloramines can continue to prevent microbial growth in the water distribution system. Organic matter is oxidized and HOCl participates in substitution reactions yielding organic chlorine compounds such as trihalomethanes, which can cause cancers. However it is still possible to form trihalomethanes if chlorine is added too much in the water treatment system, which means that residual chlorine is high. This study was conducted to verify whether the drinking water in Bloomington has proper residual chlorine.

2.6.2 Bacteriological Indicators

Faecal Coliform

Faecal coliforms are bacteria that occur in the digestive tracks of warm-blooded animals which aids in the process of digestion. Faecal coliforms can enter water bodies by direct discharge from mammals and birds, from Agricultural runoff, or from open or broken sewers. Faecal coliform is itself non-pathogenic. However, studies have shown that faecal wastes may also contain some pathogenic microbes. High levels of faecal coliform – greater than 200 colonies per 100 mL of water are good indicator of the presence of pathogenic microorganisms. Health risks include

induction of illness through exposure of recreational swimmers and boaters to pathogens and consumption of undercooked or raw food that have accumulated pathogens. They can result in health problems ranging from common diarrhea and ear infections to deadly disease such as hepatitis, cholera and typhoid fever. Therefore, it is suggested that one does not have total body contact with water containing levels of faecal coliform greater that 200colonies per 100 mL of water (WHO, 2004).

Escherichia coli

Escherichia coli is used as an indicative of the unsuitability of water bodies for recreational activities according to Indiana's surface water quality standards. It occurs only in the faecal of warm blooded animals. *E. coli* is a type of fecal coliform bacteria commonly found in the intestines of animals and humans. E. coli is short for Escherichia coli. The presence of *E. coli* in water is a strong indication of recent sewage or animal waste contamination. Sewage may contain many types of disease-causing organisms. *E. coli* comes from human and animal waste. During rainfalls, snow melts, or other types of precipitation, *E. coli* may be washed into creeks, rivers, streams, lakes, or groundwater. When these waters are used as sources of drinking water and the water is not treated or inadequately treated, *E. coli* may end up in the drinking water (Bruce, 2008). According to USEPA, 2000, the presence of *E. coli* in fresh water has a much higher correlation with the presence of human pathogens (0.8), whereas no correlation for faecal coliform (-0.08).

Studies have shown that disinfectant residuals can be used to inactivate microorganisms in the distribution system. In a study by Snead *et al*. (1980), researchers showed that a 0.70 mg/L free chlorine residual could effectively inactivate

coliform bacteria (3-log inactivation within 30 minutes) when 1% seeded, autoclaved, raw sewage was introduced to tap water. Additionally, more than 1.5-log inactivation of poliovirus 1 was observed after 120 minutes. The initial free chlorine residual lost its effectiveness when challenged with 5% sewage. LeChevallier (1999) states that in cases of massive contamination, the residual chlorine may be overwhelmed. Proponents of maintaining a disinfectant residual point to situations where residuals were not maintained and preventable waterborne disease outbreaks occurred. Haas (1999) argues that both a 1993 *Salmonella* outbreak caused by animal waste introduced to a distribution system reservoir and a 1989 *E. coli* O157:H7 outbreak could have been forestalled if distribution system chlorination had been in effect. Both of these outbreaks were due to bacterial pathogens that are sensitive to chlorine and could have been at least partially inactivated. Whether the extent of inactivation would have been great enough to prevent the outbreak is unknown. Propato and Uber (2004) determined that disinfection practices may provide some public health protection. However, other factors, such as distribution system dynamics and the presence of storage tanks, can affect the vulnerability of consumers to pathogens. This section focuses on routes by which bacteria enter the distribution system and pathogen inactivation in distribution systems. Estimates of the possible extent of inactivation provided by secondary disinfection and the factors that might influence inactivation are also presented. As with primary disinfection, secondary disinfection effectiveness at pathogen inactivation depends on several factors. For example, turbidity, pH, and chlorine demand of the water containing the pathogens will affect inactivation rates. Pathogen dose and condition will dictate how likely the contamination is to cause waterborne disease. Disinfectant concentration and contact time will impact how strong a treatment barrier the secondary disinfection provides.

2.7 BAREKESE RESERVOIR

This is an earth filled dam with rock protection constructed between 1967 and 1971. The reservoir is 15 m high and 600 m long with a 77 m wide concrete spillway that has a crest elevation of +220.98 m. The original storage capacity of the Barekese reservoir is 35.3 Mm^3 with an ultimate design capacity of 218 400 m^3/day but is considered to be heavily silted (Blokhuis *et al.*, 2005). Major expansion and rehabilitation works were undertaken in 1998 with an expected daily production capacity of 81 830 m^3/day. However, the average daily output is 59 392 m^3/day.

2.7.1 Water Production at Barekese Reservoir

Data obtained from GWCL, Kumasi is plotted in Figure 2.2 and shows the Production Target (PT) set for Barekese and Owabi headworks, the Water Produced (WP) their totals including the percent of the PT produced. It is observed that the total PT for KWSS increased from 24.6 mm^3 in 1996 to 31.1 mm^3 in 1998 as a result of major rehabilitation and expansion works undertaken at the Barekese headworks. From 2000, to date, the production target stabilised around 32 mm^3 a year because the production limit of the treatment equipment has been attained. It is also observed that water produced for KWSS has not increased since 2003 but has rather decreased gradually. The percentage of total WP compared to the total PT varies between 78% in 2008 to 93% in 1996. Variations in rainfall in the catchment area of the two rivers do not seem to have any effect on the production target (Figure 2.2).

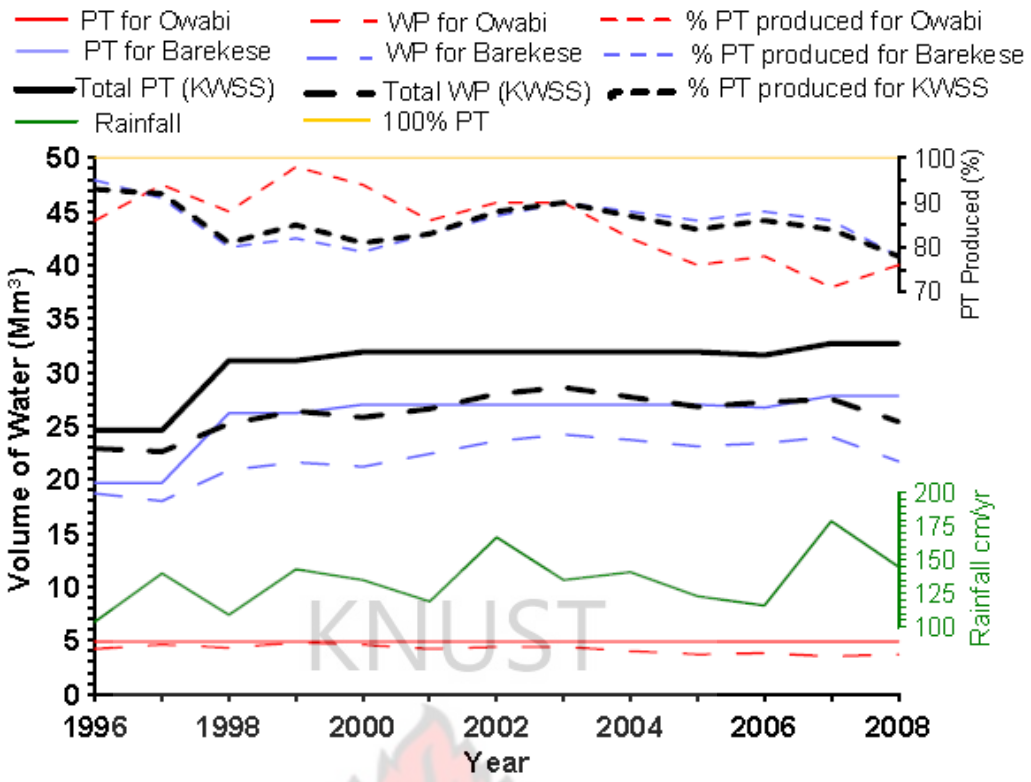

Figure 2.2: Annual water production data for Owabi and Barekese headworks.

Source: Kuma *et al*., 2010

2.7.2 Storage and Distribution System

Treated water is pumped from Barekese Headworks through steel and iron mains for 22 km to Suame where it is centrally monitored. Two ground and one elevated reservoirs with a total capacity of 13 800 m^3 store water at Suame. Calcium hypochlorite is used to "refresh" the water received from the water treatment plants (Blokhuis *et al*., 2005). Approximately 580 km of pipelines with diametres ranging between 13 mm and 600 mm distribute water within the KWSS. About 37 km of grey cast iron pipes which are 60 years or more are located mostly in the city centre and are inaccessible. In other parts of the city transmission and distribution mains are exposed resulting in frequent leaks and bursts. The quality of water is monitored in a central laboratory at Suame and at 150 other points in the distribution system (Blokhuis *et al*., 2005).

2.7.3 Water Used For Treatment (WFT)

WFT with reference to Kuma *et al* (2010) is the difference between the volumes of water abstracted and treated and is dependent on the quality of the raw water. WFT comprises three components namely; proportion lost through sludge, wash water and filters wash and is expressed either in cubic metres or percentage. According to Hammer (2007), the three components respectively should not exceed 5 %, 3 % and 3 % (totaling 11 %). Yearly WFT values for Owabi vary between 3 and 7% while those of Barekese are between 6 and 12% with the total (KWSS) values ranging from 6 to the maximum allowable limit of 11%. The lower WFT values recorded for Owabi is because a large portion of its catchment area is occupied by the Owabi Forest Reserve which is restricted from human activities. However, the catchment area of Barekese has been under intense human pressure such as construction, farming, sand winning and logging leading to high sediment levels entering the dam during runoff, hence the high WFT (Kuma *et al*., 2010). WFT trend for Barekese generally began to reduce (improve) from 2002 due to education and more stringent restrictions on human activities.

2.7.4 Water Consumption and Unaccounted For Water (UFW)

Water consumed is the metered water sold out while UFW is 'the difference between the amount of water a utility purchases or produces and the amount of water that it can account for in sales and other known uses for a given period' (Yepes and Dianderas, 1996). Thus, UFW is that water which cannot be accounted for by a utility or the water lost when it is being transported from the headworks to the consumer. It includes unmetered water put to beneficial use as well as water losses from the

system; that is leaks, bursts, illegal connections and under invoicing. Thackery (1992) suggests that UFW should not exceed 25% for other utility companies.

2.7.5 Pipe Breaks

An inventory of pipe breaks within the Kumasi North Water District has been conducted in a bid to estimate the effect of pipe breaks on KWSS. The Kumasi North Water District receives 15.52% of water produced by KWSS and most households receive water 5 days a week. Both distribution (diameters greater than 7.6 cm) and service (diameters less than 7.6 cm) network pipe breaks are respectively called bursts and leaks (Kuma *et al*., 2010). The frequency of pipe breaks in the Kumasi North Water District from 2003-2007 is shown in table 2.7.5a where it is observed that there are bursts every two and one half days and leaks occur every other day: a rather worrying event in the district. The mean figures in Table 2.7.5a suggest that annual bursts and leaks within KWSS are respectively 954 and 1276. That is, 2 to 3 bursts and 3 to 4 leaks daily within the KWSS. Table 2.7.5a depicts classification of the pipe breaks according pipe diameters (Kuma *et al*., 2010). The high frequency of breaks in the 10.2 cm pipes (table 2.7.5b) may be due to the fact that these are take-off points and are therefore likely to break. The service lines have higher frequency breaks compared to the larger diameter distribution lines because they are buried nearer the surface and are therefore easily ruptured. The KWSS is phasing out the 1.3 cm, 1.9 cm and 3.2 cm pipes and these are being replaced with 2.5 cm pipes (Kuma *et al*., 2010).

Table 2.1: Frequency of pipe breaks from 2003 to 2007 in the Kumasi North Water District

Year	Distribution network breaks (bursts)	Monthly Rate	Service network breaks (leaks)	Monthly Rate
2003	191	16	142	12
2004	148	12	288	24
2005	123	10	199	17
2006	147	12	155	13
2007	132	11	207	17
MEAN	148	12	198	17

Source: Kuma *et al* (2010)

Table 2.2: Pipe Diametre and Breaks in the Kumasi North Water District from 2003 to 2007

Service Network		Distribution Network	
Diametre (cm)	**Pipe Breaks**	**Diametre (cm)**	**Pipe Breaks**
1.3	2	7.6	120
1.9	174	10.2	426
2.5	309	15.2	137
3.2	66	20.3	19
3.8	179	25.4	3
5.1	261	30.5	36

Source: Kuma *et al* (2010)

2.8 POPULATION GROWTH AND WATER DEMAND

Kumasi is strategically located in Ghana and is the largest city that links the north of the country to the south. Population growth rate and the proportion of immigrants in Kumasi from 1948 are shown in Table 2.3 (Anon., 2004). The source of urban growth in Ghana is attributed to natural increase. The growth rate per annum recorded between 1984 and 2000 is used to project the population in Kumasi by employing the exponential growth model at an annual rate of 5.5 %(Kuma *et al.*, 2010)

Table 2.3: Population Growth Rate and the proportion of migrants in Kumasi from 1948

Period Population	Growth Rate (%)	Proportion of Immigrants	% of population
1948-1960	100,584	4.1	26.5
1960-1970	254,930	9.3	60.8
1970-1984	485,408	4.6	53.1
1984-2000	1,170,270	5.5	48.6

Source: Kuma *et al* (2010)

Future water demand projections in Kumasi were undertaken by considering three categories of water users; namely: Domestic, Commercial and public, and Institutional and industrial. With domestic demand, the average daily per capita water consumed by inhabitants of Kumasi using four major suburbs; Manhyia, Subin, Asokwa and Bantama was estimated at 0.094 m^3 (Adusei, 2003). KWSS estimates that commercial and public demand is 10 % of domestic demand while institutional and industrial demand in the metropolis is 12 % of same. The Projected Water Demand (PWD) for the metropolis is the sum of the three categories of demand. Figure 2.3 shows the yearly population, projected target, water produced, PWD and the shortfall in water production for Kumasi between 1996 and 2008.

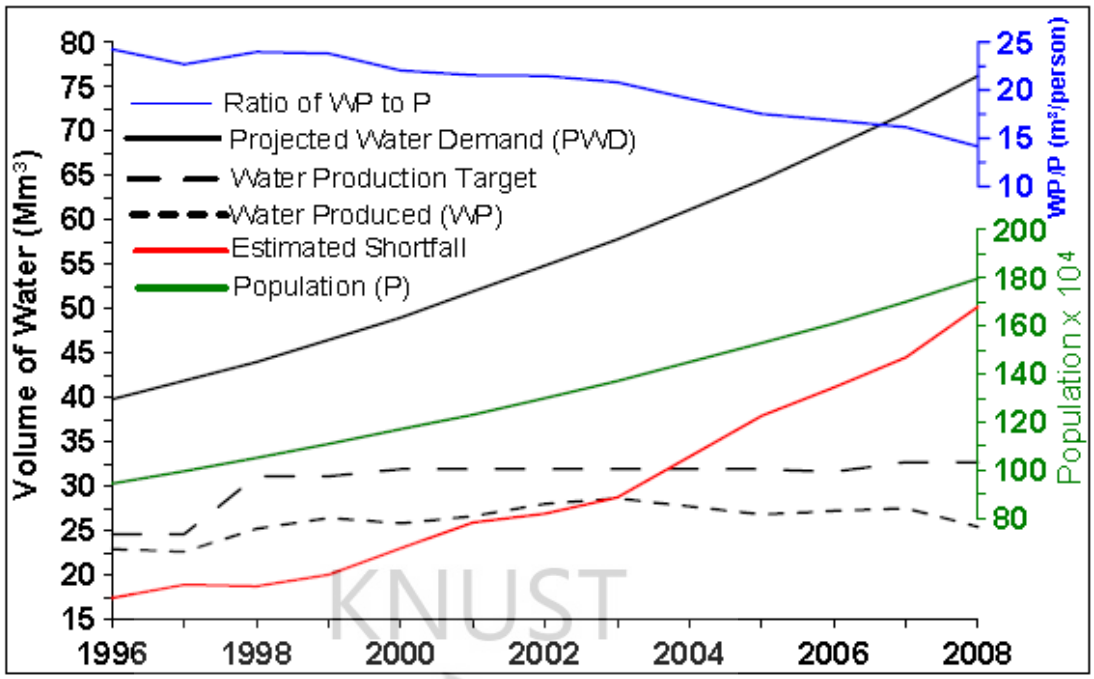

Figure 2.3: Projected water demand and other water indices for KWSS from 1996 to 2008. Source: Kuma *et al.*, 2010

It is observed that PT is more or less constant with a lower WP. However, a steadily increasing annual population growth of 5.5 % has resulted in a PWD of 76 mm^3 in 2008. Consequently, a shortfall of 17 mm^3 of water in 1996 to the metropolis is observed to reach 50 mm^3 in 2008. When the ratio of the population to WP is annually computed, it is observed that each person had 24.2 m^3/yr (66 litres/day) of water in 1996 and this figure steadily decreased to 14.1 m^3/yr per person (39 litres/day) (Kuma *et al.*, 2010). This calculation is based on the assumption that all the water produced is available for use and only to the population. When compared to the required 94 litres/day, it is noted that much less than 41% of the water required is available to the people in Kumasi. Current water supply to Kumasi metropolis is therefore inadequate. With current projects, the population of Kumasi in 2020 would be 3,510,000 and the corresponding water demand would be 132 mm^3 (Kuma *et al.*, 2010).

2.8.1 Water Pollution Causes

Most drinking water contamination can be attributed to human activities. Controlling contaminants in our drinking water is a delicate balance between regulating the source, determining safe levels, and choosing the best treatment. Listed below are some typical sources of contaminants in drinking water. According to Fei-Baffoe (2009), there are many specific causes of water pollution, but before we list the toppers, it's important to understand two broad categories of water pollution: “Point source” — occurs when harmful substances are emitted directly into a body of water. “Nonpoint source” — delivers pollutants indirectly through transport or environmental change.

An example of a point source of water pollution is a pipe from an industrial facility discharging effluent directly into a river. An example of a nonpoint-source of water pollution is when fertilizer from a farm field is carried into a leaking pipe line or stream by rain (i.e. run-off). Point-source pollution is usually monitored and regulated, at least in Western countries, though political factors may complicate how successful efforts are at true pollution control. Nonpoint sources are much more difficult to monitor and control, and today they account for the majority of contaminants in streams and lakes with reference to Fei-Baffoe (2009).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 DESCRIPTION OF THE STUDY AREA

3.1.1 Location, Drainage and Geology of the Catchment Area

Kumasi is the capital of Ashanti region with a metropolis covering an area of about 245 km^2. It is located in the central portion of the Region and lies between Latitudes 6^o 37'N and 6^o 46'N and Longitudes 1^o 31'W and 1^o 40' W (Anon, 2004). Ashanti Region lies within the wet semi-equatorial zone marked by double maximum rainfall ranging between 1150 mm and 1750 mm per annum. The major rainfall season is from April to July and minor season is between September and Mid- November. Offin and Owabi are two rivers dammed to supply water to Kumasi City and are respectively called Barekese and Owabi reservoirs. These two rivers are however fed by several tributary streams and their catchment areas lie within the Birimian meta-sediments and associated Dixcove granitoids which intrude the Birimian. Typical lithologies of the Birimian metasediments are tuffaceous phyllite, schist and meta-greywacke (Kuma *et al.*, 2010). These meta-sediments are generally strongly foliated and jointed with weathering profiles reaching 100 m in depth. Therefore, moderate quantities of water are expected under suitable conditions in regolith aquifers. The Dixcove granite which is typically dioritic in composition dominates the catchment area and may possess minor secondary porosity (Eisenlohr and Hirdes, 1992).

3.1.2 Sampling Site

Twenty-four sampling sites located at different communities were selected for this study as shown in Figure 3.1

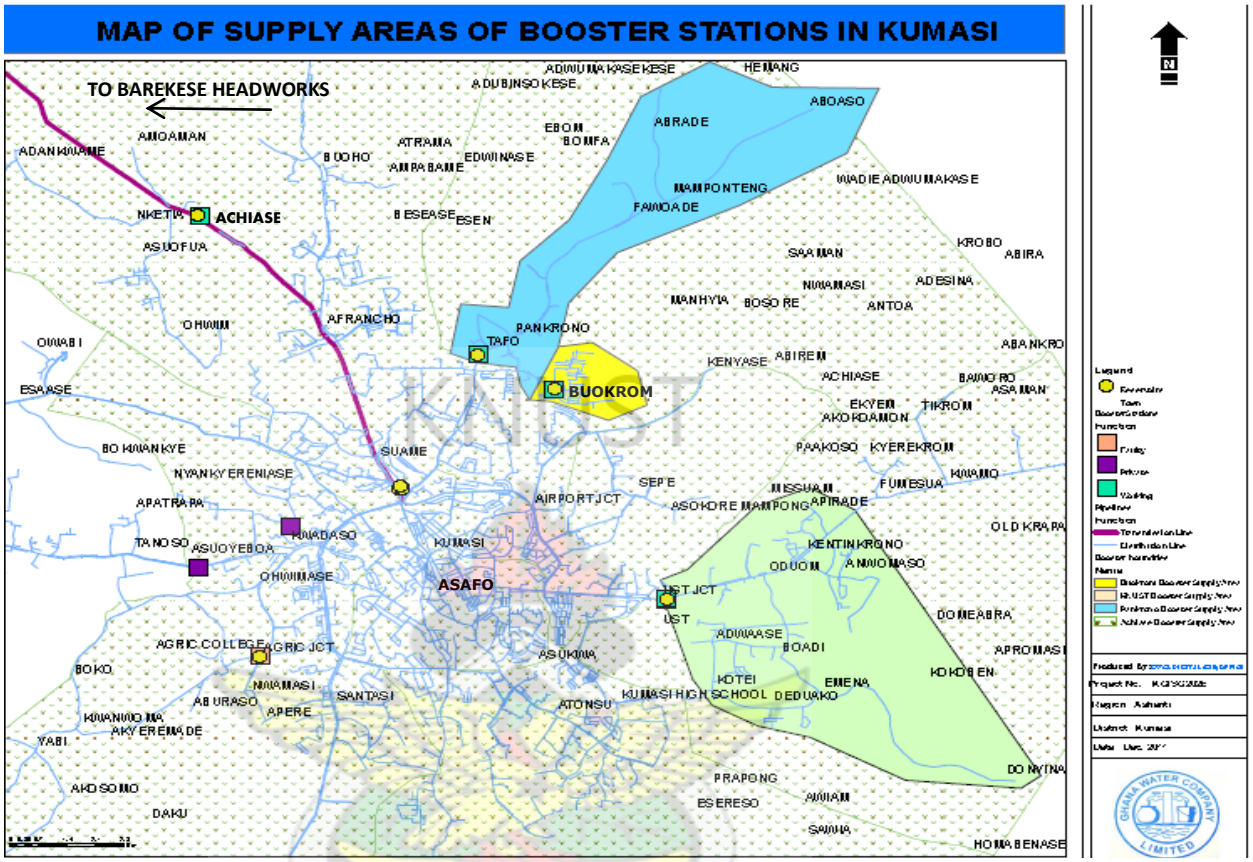

Figure 3.1: Map of supply areas of Booster stations in Kumasi

Source: Ghana Water Company, 2011.

The sampling sites were the main Barekese dam untreated water from the dam and the treated water from the laboratory. Samples were also taken from all the four booster stations that were supplied with water from the Barekese headworks. Also the other samples were collected from the closest and the farthest booster station supply areas (Achiase booster station closest to the headworks and KNUST farthest). All samples were fetched directly from the tap except the raw water from the dam which was fetched directly from the dam. When the water has been treated, it is first pumped into a reservoir at the Barekese head works then pumped to the Achaise booster station,

from thence it is further pumped to the Tafo, Buokrom and KNUST booster stations uninterrupted. The Achiase booster station, it supplies the greatest portion of the Kumasi metropolis with treated water whiles the KNUST booster has the smallest supply area. The Tafo and Buokrom booster stations supply its environs as indicated in the map in Figure 3.1

3.2 METHODOLOGY

The procedures that were used in the study are outlined below;

3.2.1 Treatment of sample container

- Sampling was done with glass containers. The glass containers were thoroughly washed with detergent and tap water. The bottles and the tops were autoclaved at 120^{o}C for 15 minutes.

3.2.2 Sampling frequency

Water samples were collected from selected sites of all the booster stations and randomly at the Achiase and KNUST booster station supply areas at monthly intervals for a period of four months from December 2011 to March 2012. Triplicate samples were taken for each at every sampling period. A total of twenty-four (24) samples were taken each month and altogether a total of one hundred and four samples were taken for analysis in this study. Water samples were collected in the morning between the hours of 8:00 GMT and 11:00 GMT.

3.2.3 Sample collection

Samples for microbial analysis were collected into sterile bottles. All samples containers and lids were first rinsed three times with some of the sampled water except for microbial analysis. All the Physico-chemical parametres were determined on site; temperature, pH, Turbidity, colour, free Chlorine and total Chlorine. Samples were collected in prewashed glass bottles and kept in an ice box and sent to the Microbiological laboratory in Theological and applied Biology Department of KNUST, Kumasi.

3.2.4 Temperature Determination

The temperatures of the samples were determined on site. A thermometer was used to measure the temperature. An aliquot of 100 mL was measured into a 500 mL beaker and the thermometer probe was immersed into the water and the temperature was recorded (Bruce, 2008).

3.2.5 pH Determination

The pH was also determined on site with the – pH meter. The pH meter was calibrated by immersing the electrode in two buffer solutions of pH 4.01 and 7.00 prepared from capsules of BDH buffer. The pH meter was adjusted to correspond to the standard buffers (4.01 and 7.0). The water sample was placed in a beaker and the electrode was rinsed with distilled water and lowered into the sample in the beaker. The pH meter was allowed to stabilize and the pH of the samples read (APHA, 1998).

3.2.6 Colour, Chlorine and Turbidity Determination

The Colour, chlorine and Turbidity of the samples were determined on site using the Wagtech 7100 photometer. The cuvette was rinsed three times in the sample to be tested, the sample was fetched up to the 10 mL mark, the light shield cap replaced and the outside surfaces were cleaned and made dry with a soft tissue paper. Tests were done at the treatment plant and also at the points of consumption in selected areas in the Kumasi metropolis; locations throughout the distribution system to determine an upgraded chlorine dosing regimen. Beside chlorine dosing at the water treatment plant(s) there may be the need for intermediate chlorine dosing treatment. Then the colour and the turbidity were determined. The most common test for total and residual / free chlorine is the DPD (diethyl paraphenylene diamine) indicator test. This test is the quickest and simplest method for testing chlorine residual. With this test, a tablet reagent was added to a sample of water, colouring it red. The stronger the colour of the water, the higher the concentration of chlorine in it. After the DPD 1 tablet placed into it dissolved completely. It was then topped up to the 10 mL mark with the same sample then the outside surfaces was cleaned and inserted into the optical well for the free chlorine reading. The reading was measured by pressing the button to read. After the DPD no. 3 tablet was crushed and added to the same tested sample; the colour deepened indicating high level of chlorine, it was push into the optical well and the total chlorine was then read (WHO, 2004)

3.2.7 Enumeration of Faecal Coliform and *Escherichia coli*

Faecal Coliforms were estimated using three-tube most probable number method (MPN) according to standard methods (1992). Dilution of 10^{-1} to 10^{-3} were prepared in 0.1% buffered peptone water (BPW) (Oxiod CM 509) and 1 mL of each dilution

inoculated into three tubes containing 5 mL of minerals modified glutamate medium (Oxiod CM 607). The three test tubes from the dilution were inoculated at 44^{o}C. Tubes showing acid and gas after 24 hours were confirmed as faecal coliforms by plating on MacConkey No. 3 agar (Oxiod CM 115) and examine for typical colonies. Counts per 100 mL were calculated from most probable number tables. *E. coli* was confirmed by further inoculating tubes showing acid and gas in tryptone broth and inoculated for 24 hours at 35 ^{o}C. 0.3 mL Kovac's reagent was added to test for indole ring. Appearance of distinct red colour in upper layer is positive test. Counts per 100 mL were calculated from MPN tables (Feng *et al.*, 2002).

3.7 QUALITY CONTROL

Samples were taken in triplicates and the averages of each result were taken for the analysis. All instruments used in this study were calibrated with standard known concentrations. Average values of three replicates were taken for each determination. Water samples were fetched directly from the taps and all the physico-chemical parametres were determined on site. All water droplets on the cuvette were cleaned with tissue paper before the readings were taken. Gloves were used to prevent finger prints on the cuvette. Each sample was blanked before the readings were taken.

3.8 STATISTICAL ANALYSIS

All statistical analysis was carried out using both Microsoft Excel 2010. Analysis of variance, ANOVA was used to determine the level of significance at $p < 0.05$.

CHAPTER FOUR

4.0 RESULTS

4.1 PHYSICOCHEMICAL PARAMETERS ASSESSED FOR THE BOOSTER STATIONS UNDER STUDY

The physicochemical parameters of water reviewed for the booster stations under investigation included temperature, pH, turbidity, colour, residual chlorine and total chlorine. See table 4.1 for details.

Table 4.1: Physicochemical parameters assessed for the booster stations under study in the Kumasi Metropolis, 2012

	PHYSICOCHEMICAL					
LOCATIONS	**Temperature / ^{o}C**	**pH**	**Turbidity / FTU**	**Colour / Hz**	**Free chlorine / mg/L**	**Total chlorine / mg/L**
Barekese (untreated)	29.2±0.62	9.1±0.03	31.8±11.57	16.9±20.2	0.222±0.012	0.27±0.008
Barekese (treated)	25.3±0.34	6.9±0.06	0±0	1.5±0.9	0.05±0.002	0.265±0.008
Achiase	25.5±0.37	6.9±0.04	0±0	0±0	0.048±0.003	0.246±0.005
Buokrom	25.5±0.40	6.9±0.03	2.4±1.78	5.1±6.3	0.045±0.004	0.235±0.07
Tafo	25.2±0.25	6.8±0.06	3.8±3.39	7.4±6.9	0.048±0.001	0.252±0.01
KNUST	25.6±0.43	6.9±0.03	5.1±3.48	9.9±8.5	0.043±0.004	0.258±0.008
WHO Standards	**15.0-25.0**	**6.5-8.5**	**≤5.0**	**≤15.0**	**0.2-0.5**	**≤0.5**

4.1.1 Temperature of water assessed for the booster stations under study

Temperature determined for the water from the respective booster stations proved that the Barekese untreated water recorded the highest (29.2°C), followed by KNUST (25.6°C), Achiase, Buokrom (25.5°C), Barekese treated water (25.3°C) and Tafo booster water respectively (Table 4.1). There was significant difference ($p < 0.05$) between at least two treatments means within the data. However, the differences existed between mean temperature for Barekese untreated water and the rest of the mean temperatures at $p < 0.05$. Differences among the rest of the data were not significant ($p > 0.05$).

4.1.2 pH of water assessed for the booster stations under study

pH for the water from the respective booster stations, proved that the Barekese untreated water recorded the highest (9.1), followed by KNUST, Achiase, Buokrom and Barekese treated water (6.9 each) and Tafo booster water recorded the least (6.8) (Table 4.1). Significant differences ($p < 0.05$) between at least two treatments means existed within the data. The differences existed between mean pH for Barekese untreated water and the rest of the mean pH at $p < 0.05$. Among the rest of the data the differences were not significant ($p > 0.05$).

4.1.3 Turbidity of water assessed for the booster stations under study

Turbidity determined for the water from the respective booster stations proved that the Barekese untreated water recorded the highest (31.8 FTU), followed by KNUST (5.1 FTU), Tafo booster water (3.8 FTU), Buokrom Booster water (2.4 FTU), Achiase and Barekese treated water both did not give the record of the presence of turbid particles (0 FTU) (Table 4.1). There was significant differences ($p < 0.05$) between at least two

treatments mean within the data. The variations existed between mean turbidity for Barekese untreated water and the rest of the mean turbidity at $p < 0.05$. The differences among the rest of the data were significant ($p < 0.05$).

4.1.4 Colour of water assessed for the booster stations under study

The colour determined for the water from the respective booster stations proved that the Barekese untreated water recorded the highest (16.9 E+1), followed by KNUST (9.9), Tafo booster water (7.4), Buokrom (5.1), Barekese treated water (1.5) and Achiase Booster water recorded (0) (Table. 4.1). There was substantial variance ($p < 0.05$) between at least two treatments means within the data. These differences existed between mean colour for Barekese untreated water and the rest of the mean colour at $p < 0.05$. Significant differences existed among the rest of the data were ($p < 0.05$).

4.1.5 Residual chlorine of water assessed for the booster stations under study

For the residual/ free chlorine determination, the water from the respective booster stations proved that the Barekese untreated water recorded the highest (0.222 mgL^{-1}) > Barekese treated water (0.05 mgL^{-1})> Achiase and Tafo booster water both (0.048 mgL^{-1}) > Buokrom Booster water (0.045 mgL^{-1}) > KNUST (0.043 mgL^{-1}), (Table 4.1). Significant variances ($p < 0.05$) between at least two treatments mean existed within the data. Besides, the disparity existed ($p < 0.05$) between mean residual chlorine levels for Barekese untreated water and the rest of the mean residual chlorine levels.

4.1.6 Total chlorine of water assessed for the booster stations under study

In the determination of total chlorine, the water from the respective booster stations proved that the Barekese untreated water recorded the highest (0.270 mgL^{-1}) followed by Barekese treated water (0.265 mgL^{-1}), KNUST (0.258 mgL^{-1}) then Tafo booster water (0.252 mgL^{-1}) through Achiase booster water (0.246 mgL^{-1}) and finally Buokrom Booster water (0.235 mgL^{-1}) (Table 4.1). Substantial differences ($p < 0.05$) were between at least two treatments mean existed within the data. There were differences ($p < 0.05$) between mean residual chlorine levels for Barekese untreated water and the rest of the mean residual chlorine levels. The differences among the rest of the data were significant ($p < 0.05$).

4.1.7 Microbial Parameters Assessed for the Booster Stations under Study

The microbial parameters of water reviewed for the booster stations under investigation included Total coliforms, faecal coliforms and *E. coli.*

Table 4.2: Microbial parameters assessed for the booster stations under study in the Kumasi Metropolis, 2012

LOCATIONS	MICROBIAL		
	Total coliforms MPN/100 mL	**Faecal coliforms MPN/100 mL**	**E. coli MPN/100 mL**
Barekese (untreated)	$16x10^{6}±2.7x10^{7}$	$39.5x10^{3}±1.5x10^{4}$	10±1.95
Barekese (treated)	0±0	0±0	0±0
Achiase	8.1±0.9	8.1±0.9	0±0
Buokrom	7.4±3.9	7.4±3.9	0±0
Tafo	7.8±3.6	7.8±3.6	0.1±0.02
KNUST	0±0	0±0	0±0
WHO Standards	**10.0**	**0**	**0**

4.1.8 Total coliforms in water assessed for the booster stations under study

The Total coliforms determined for the water from the respective booster stations proved that the Barekese untreated water recorded the highest number of total coliforms; (16 x 10^{6} MPN 100/mL), followed by Achiase (8.1 MPN 100/mL), then Tafo (7.8 MPN 100/mL), Buokrom (7.4 MPN 100/mL) and finally Barekese treated water and KNUST both recorded no coliforms that is (0 MPN 100/mL) (Table 4.1). There were significant differences ($p < 0.05$) between at least two treatments mean within the data. These differences existed between mean Total coliforms for Barekese untreated water and the rest of the mean Total coliforms at $p < 0.05$. Significant the differences existed among the rest of the data ($p < 0.05$).

4.1.9 Faecal coliforms in water assessed for the booster stations under study

Faecal coliforms determined for the water from the respective booster stations proved that the Barekese untreated water recorded the highest number of total coliforms; (39.5 MPN 100/mL), followed by Achiase (8.1 MPN 100/mL), then Tafo (7.8 MPN 100/mL), Buokrom (7.4 MPN 100/mL) and finally Barekese treated water and KNUST both recorded no coliforms that is (0 MPN 100/mL) (Table. 4.1). Significant differences ($p < 0.05$) between at least two treatments mean existed within the data. Differences existed between mean Total coliforms for Barekese untreated water and the rest of the mean Total coliforms at $p < 0.05$. The differences among the rest of the data were significant ($p < 0.05$).

4.1.10 *E. coli* of water assessed for the booster stations under study

E. coli determined for the water from the respective booster stations proved that the Barekese untreated water recorded the highest number of *E. coli*; (10 MPN 100/mL), 0.1 MPN 100/mL for Tafo and for Achiase, Buokrom, Barekese treated water and KNUST there were no *E. coli* present that is (0 MPN 100/mL) (Table. 4.1). The data had significant differences ($p < 0.05$) between at least two treatments mean. These differences existed between mean *E. coli* for Barekese untreated water and the rest of the mean *E. coli* at $p < 0.05$. Variations among the rest of the data were significant ($p < 0.05$).

4.2. WATER QUALITY ASSESSMENT FOR SUPPLY AREAS

4.2.1 Water Quality Assessment for Supply Areas of Achiase Booster Station

Water quality assessed for the Achiase Booster station supply areas included physicochemical and microbial parameters that characterize drinking water.

4.2.1.1 Physicochemical parameters of water assessed for the selected Achiase Booster station supply areas

The physicochemical parameters of water reviewed for the Achiase Booster station supply areas under investigation included temperature, pH, turbidity, colour, residual chlorine and total chlorine.

Table 4.3: Mean physicochemical parameters assessed for the Achiase booster stations supply areas under study, 2012

LOCATIONS	PHYSICOCHEMICAL					
	Temperature (^oC)	pH	Turbidity (FTU)	Colour (Hz)	Residual chlorine (mL/L)	Total chlorine (mg/L)
Asokwa	25.6±0.42	6.8±0.05	4.9±7.9	14.2±24.77	0.070±0.04	0.260±0.02
Atonsu	25.6±0.42	6.9±0.04	8.6±10.3	24.9±30.62	0.040±0.01	0.260±0.04
Asafo	25.9±0.69	6.9±0.05	4.2±6.8	12.5±21.55	0.050±0.01	0.250±0.01
WHO Standards	**15.0-25.0**	**6.5-8.5**	**≤5.0**	**≤15.0**	**0.2-0.5**	**≤0.5**

Temperature of water assessed for the selected Achiase Booster station supply areas

Temperature determined for the water from the respective supply areas proved that the Asafo 1 water recorded the highest (26.4°C) whiles Asafo 3 recorded the lowest at 25.1°C. See Appendix 45 for details. Within the data, notable difference ($p < 0.05$) was observed between at least two treatments means. Differences existed between mean temperature for Achiase supply areas water and the rest of the mean

temperatures at $p < 0.05$. The rest of the data had no significant difference among them ($p > 0.05$).

The mean temperature determined for the water from the respective supply areas proved that the Asafo water recorded the highest (25.9°C), followed by both Atonsu and Asokwa at 25.6°C (Table 4.3). Significant difference ($p < 0.05$) occurred between at least two treatments means within the data. There were differences existed between mean temperature for Achiase supply area water and the rest of the mean temperatures at $p < 0.05$. The differences among the rest of the data were not significant ($p > 0.05$).

pH of water assessed for the selected Achiase Booster station supply areas

The pH determined for the water from the respective supply areas proved that the Asokwa 1, Asokwa 2, Atonsu 1, Atonsu 2, Asafo 1 and Asafo 2 tap waters recorded the highest pH at 6.9 and the rest at 6.8. The dada recorded significant difference ($p < 0.05$) between at least two treatments means within the data. The differences existed between mean pH for Achiase supply area water and the rest of the mean pH at $p < 0.05$. The variances among the rest of the data were not significant ($p > 0.05$).

The mean pH determined for the water from the respective supply areas proved that both Atonsu and Asafo water recorded the highest at (6.9), followed by Asokwa at 6.8 (Table 4.3). Noteworthy difference ($p < 0.05$) was between at least two treatments means within the data. The differences existed between mean pH for Barekese untreated water and the rest of the mean pH at $p < 0.05$. No significant changes were among the rest of the data that is ($p > 0.05$).

Turbidity of water assessed for the selected Achiase Booster station supply areas

Turbidity determined for the water from the respective supply areas proved that the Atonsu 2 water recorded the highest (15.8 FTU) whiles Asokwa recorded the lowest at (1.3 FTU). Significant difference ($p < 0.05$) was between at least two treatments means within the data. However, the differences existed between mean turbidity for Achiase supply areas water and the rest of the Mean turbidity recorded notable differences ($p < 0.05$). Among the rest of the data, the differences were not significant ($p > 0.05$).

The mean turbidity determined for the water from the respective supply areas proved that the Atonsu water recorded the highest (8.6 FTU), followed by Asokwa (4.9 FTU) and Asafo at 4.2 FTU (Table 4.3). There was significant difference ($p < 0.05$) between at least two treatments means within the data. Nevertheless, the differences existed between mean turbidity for Achiase supply areas water and the rest of the mean turbidities at $p < 0.05$. No significant differences occurred among the rest of the data ($p > 0.05$).

Colour of water assessed for the selected Achiase Booster station supply areas

The determination of colour of the water from the respective supply areas proved that the Atonsu 2 water recorded the highest (44.9 Hz), Asokwa 1 recorded the lowest at (3.4Hz). See Appendix 45 for details. There was significant difference ($p < 0.05$) between at least two treatments means within the data. Still, the differences existed between mean colour for Achiase supply areas water and the rest of the mean colour at $p < 0.05$. The differences among the rest of the data were not significant ($p > 0.05$).

The mean colour determined for the water from the respective supply areas proved that the Atonsu water recorded the highest (24.9Hz), followed by Asokwa (14.2Hz) and Asafo at 12.5Hz (Table 4.3). Significant difference ($p < 0.05$) between at least

two treatments means existed within the data. Nonetheless, the differences existed between mean colour for Achiase supply areas water and the rest of the mean colour at $p < 0.05$. Differences among the rest of the data were not noteworthy ($p > 0.05$).

Residual chlorine of water assessed for the selected Achiase Booster station supply areas

Residual chlorine determination of the water from the respective supply areas proved that the Asokwa 1 water recorded the highest (0.105mg/L) Atonsu 3 and Asafo 1, both recorded the lowest at (0.041 mg/L) (Appendix 45). Significant difference ($p < 0.05$) between at least two treatments means existed within the data. Nonetheless, the differences were between mean Residual chlorine for Achiase supply areas water and the rest of the mean Residual chlorine at $p < 0.05$. The differences among the rest of the data were not significant ($p > 0.05$).

The mean residual chlorine determined for the water from the respective supply areas proved that the Asokwa water recorded the highest (0.07mg/L), followed by Asafo (0.05 mg/L) and Atonsu at 0.04mg/L (Table 4.3). Noteworthy difference ($p < 0.05$) between at least two treatments means existed within the data. Mean Residual chlorine for Achiase supply areas water and the rest of the mean Residual chlorine at $p < 0.05$ were not significant ($p > 0.05$).

Total chlorine of water assessed for the selected Achiase Booster station supply areas

Total chlorine determination of the water from the respective supply areas proved that the highest was Atonsu 1 (0.267 mg/L), whiles Asafo 3 recorded the lowest at (0.244 mg/L) (See Appendix 45). There were significant differences ($p < 0.05$) between at least two treatments means within the data. The differences occurred between mean Total chlorine for Achiase supply areas water and the rest of the mean total chlorine at $p < 0.05$. There were no differences among the rest of the data ($p > 0.05$).

The mean total chlorine determined for the water from the respective supply areas proved that both Asokwa and Atonsu water recorded the highest (0.26mg/L), followed by Asafo (0.25 mg/L) (Table 4.3). Significant difference ($p < 0.05$) between at least two treatments means exist within the data. Mean Total chlorine for Achiase supply areas water and the rest of the mean Total chlorine showed significant difference at $p < 0.05$. No substantial differences existed among the rest of the data.

4.2.1.2 Microbial parameters of water assessed for the selected Achiase Booster station supply areas

Table 4.4: Mean Microbial parameters assessed for the Achiase booster stations supply areas under study, 2012

LOCATIONS	MICROBIAL		
	Total coliforms (MPN / 100mL)	Faecal coliforms (MPN / 100mL)	E. coli (MPN / 100mL)
Asokwa	5.3±0.90	5.3±0.90	0±0
Atonsu	3.2×10^4±9.10	3.2×10^4±9.10	1.3±2.07
Asafo	3.6×10^5±1.2×10^6	3.6×10^5±1.2×10^6	1.7±2.80
WHO Standards	**10.0**	**0**	**0**

Total coliforms in water assessed for the selected Achiase Booster station supply areas

Total coliforms determination of the water from the respective supply areas showed the highest at Asafo 2 (10.8E+6 MPN/100mL) and Asafo 3 recorded the lowest at (4.4 MPN/100mL), See Appendix 46 for details. There was significant difference ($p < 0.05$) between at least two treatments means within the data. Still, the differences existed between mean Total coliforms for Achiase supply areas water and the rest of the mean total coliforms at $p < 0.05$. The differences among the rest of the data were not significant ($p > 0.05$).

The mean total coliforms determined for the water from the respective supply areas proved that Asafo water recorded the highest (3.6E+5 MPN/100mL), followed by Atonsu (3.2E+4 MPN/100mL) and the lowest Asokwa (5.3 MPN/100mL) (Table 4.4). At least two treatments means within the data indicated significant dissimilarity. Such differences existed between mean Total coliforms for Achiase supply areas water and the rest of the mean Total coliforms at $p < 0.05$. The rest of the data recorded no significant differences ($p > 0.05$).

Faecal coliforms in water assessed for the selected Achiase Booster station supply areas

Faecal coliforms determination of the water from the respective supply areas verified that the Asafo 2 water recorded the highest (10.8E+6 MPN/100mL), Asafo 3 recorded the lowest at (4.4 MPN/100mL). Within the data, there was substantial difference ($p < 0.05$) between at least two treatments means. These differences existed between mean faecal coliforms for Achiase supply areas water and the rest of the mean faecal coliforms) $p < 0.05$). The differences among the remaining data were not significant ($p > 0.05$).

The mean faecal coliforms determined for the water from the respective supply areas proved that Asafo water recorded the highest (3.6E+5 MPN/100mL), followed by Atonsu (3.2E+4 MPN/100mL) and the lowest Asokwa (5.3 MPN/100mL) (Table 4.4). Notable difference ($p < 0.05$) between at least two treatments means within the data. Between mean Total coliforms for Achiase supply areas water and the rest of the mean Faecal coloforms significant differences were present at $p < 0.05$. The rest of the data showed no notable differences among them ($p > 0.05$).

***E. coli* of water assessed for the selected Achiase Booster station supply areas**

The determination of *E. coli* the water from the respective supply areas proved that the Asafo 2 water recorded the highest (3.9 MPN/100mL), followed by Atonsu 2 (3.9 MPN/100mL), the rest of the study areas recorded 0 MPN/100mL for the *E. coli* (Appendix 46). There was significant difference ($p < 0.05$) between at least two treatments means within the data. The differences were between mean *E. coli* for Achiase supply areas water and the rest of the mean total coliforms at $p < 0.05$. The variances among the rest of the data were not significant ($p > 0.05$).

The mean *E. coli* determined for the water from the respective supply areas proved that Asafo water recorded the highest (1.7 MPN/100mL), followed by Atonsu (1.3 MPN/100mL) and the lowest Asokwa (0 MPN/100mL) (Table 4.4). There was substantial difference ($p < 0.05$) between at least two treatments means within the data. However, the differences existed between mean Total coliforms for Achiase supply areas water and the rest of the mean *E. coli* ($p < 0.05$). There were no significant changes ($p > 0.05$), among the rest of the data.

4.2.2 Water Quality Assessment for Supply Areas of KNUST Booster Station Selected for Study in the Kumasi Metropolis

Water quality assessed for the booster stations included physicochemical and microbial parameters that characterize drinking water

4.2.2.1 Physicochemical parameters of water assessed for the selected KNUST Booster station supply areas

The physicochemical parameters of water reviewed for the KNUST stations under investigation included temperature, pH, turbidity, colour, residual chlorine and total chlorine.

Table 4.5: Mean physicochemical parameters assessed for the KNUST supply areas under study, 2012

LOCATIONS	PHYSICOCHEMICAL					
	Temperature (^{o}C)	pH	Turbidity (FTU)	Colour (Hz)	Residual chlorine (mL/L)	Total chlorine (mg/L)
Kentinkrono	25.6±0.45	6.9±0.05	0.8±1.48	4.1±9.10	0.05±0.0	0.24±0.02
Oduom	25.8±1.13	6.9±0.05	1.3±1.95	3.4±5.72	0.04±0.01	0.23±0.03
Boadi	25.8±0.51	6.9±0.02	1.1±1.53	3.2±4.63	0.04±0.01	0.22±0.08
WHO Standards	**15.0-25.0**	**6.5-8.5**	**≤5.0**	**≤15.0**	**0.2-0.5**	**≤0.5**

Temperature of water assessed for the selected KNUST Booster station supply areas

Temperature determined for the water from the respective supply areas ascertained that the water at Oduom 3 recorded the highest (27.2 °C), Oduom 1 recorded the lowest at 25.1 °C (See Appendix 47 for details). There was significant difference ($p < 0.05$) between at least two treatments means within the data. Differences were found

between mean temperature for KNUST supply areas water and the rest of the mean temperatures at $p < 0.05$. Variations among the rest of the data were not significant ($p > 0.05$).

The mean temperature determined for the water from the respective supply areas proved that the Oduom and Boadi water recorded the highest (25.8 °C), followed by Kentikrono at 25.6 °C (Table 4.5). There was significant difference ($p < 0.05$) between at least two treatments means within the data. Differences existed between mean temperature for KNUST supply area water and the rest of the mean temperatures at $p < 0.05$. The differences among the rest of the data were not significant ($p > 0.05$).

pH of water assessed for the selected KNUST Booster station supply areas

The pH determined for the water from the respective supply areas proved that the Kentikrono 3, Oduom 1, Oduom 2, Oduom 3, and Boadi 3 tap waters recorded the highest pH at 6.9, followed by Kentikrono 1, Kentikrono 2, Boadi 1 and Boadi 2 all at 6.8. There was significant difference ($p < 0.05$) between at least two treatments means exist within the data. The differences existed between mean pH for KNUST supply area water and the rest of the mean pH at $p < 0.05$ and significant differences ($p > 0.05$) were not among the rest of the data.

The mean pH determined for the water from the respective supply areas proved that Kentikrono, Oduom and Boadi water all recorded the pH at (6.9) (Table 4.5). There was significant difference ($p < 0.05$) between at least two treatments means within the data. There existed disparity between mean pH for Barekese untreated water and the

rest of the mean pH ($p < 0.05$). There was differences among the rest of the data were not significant ($p > 0.05$).

Turbidity of water assessed for the selected KNUST Booster station supply areas

Turbidity determined for the water from the respective supply areas proved that the Oduom 3 water recorded the highest (3.8 FTU), followed by Boadi 3 (3.2 FTU), and Kentikrono 2 (2.5 FTU). The rest of the areas under review gave no readings for the turbidity, that is recorded 0 FTU. There was significant difference ($p < 0.05$) between at least two treatments means within the data. Mean turbidity for KNUST supply areas water and the rest of the mean turbidities at $p < 0.05$ had differences existing between them. Differences among the rest of the data were not significant ($p > 0.05$).

The mean turbidity determined for the water from the respective supply areas proved that the Oduom water recorded the highest (1.3 FTU), followed by Boadi (1.1 FTU) and Kentikrono the lowest at 0.8 FTU (Table 4.7). There was significant difference ($p < 0.05$) between at least two treatments means within the data. However, the differences existed between mean turbidity for KNUST supply areas water and the rest of the mean turbidities at $p < 0.05$. There were no significant changes among the rest of the data. ($p > 0.05$).

Colour of water assessed for the selected KNUST Booster station supply areas

The determination of colour of the water from the respective supply areas proved that the Oduom 3 water recorded the highest (10.3 Hz), followed by Kentikrono 2 (9.7 Hz), Boadi 3 (9.5 Hz), then Kentikrono 3 (2.8 Hz). The rest of the area under review showed no reading for colour that is at 0 Hz. There was significant difference ($p < 0.05$) between at least two treatments means within the data. The data showed

differences between mean colour for KNUST supply areas water and the rest of the mean colour at $p < 0.05$. There were no significant differences among the rest of the data. ($p > 0.05$).

The mean colour determined for the water from the respective supply areas proved that the Kentikrono water recorded the highest (4.1 Hz), followed by Oduom (3.4 Hz) and finally Boadi at 3.2 Hz. (Table 4.5). There was significant difference ($p < 0.05$) between at least two treatments means within the data. Differences existed between mean colour for KNUST supply areas water and the rest of the mean colour at $p < 0.05$. The rest of the data had differences which were not significant ($p > 0.05$).

Reisdual chlorine of water assessed for the selected KNUST Booster station supply areas

Residual chlorine determination of the water from the respective supply areas proved that the Kentikrono 1 water recorded the highest (0.048mg/L), and Boadi 3, the lowest at (0.037 mg/L) (See Appendix 47 for details). Significant difference ($p < 0.05$) was between at least two treatments means within the data. There were variations between mean Residual chlorine for KNUST supply areas water and the rest of the mean Residual chlorine at $p < 0.05$ and no significant disparities were observed among the rest of the data ($p > 0.05$).

The mean residual chlorine determined for the water from the respective supply areas proved that the Boadi and Oduom water recorded the lowest (0.04 mg/L), and the highest at 0.05 mg/L. (Table 4.5). Significant differences ($p < 0.05$) were between at least two treatments means within the data. Differences existed between mean

Residual chlorine for KNUST supply areas water and the rest of the mean Residual chlorine at $p < 0.05$. Among the rest of the data differences were not significant ($p > 0.05$).

Total chlorine of water assessed for the selected KNUST Booster station supply areas

Total chlorine determination of the water from the respective supply areas attested that the Boadi 1 water recorded the highest (0.253 mg/L), Boadi 3 recorded the lowest at (0.201 mg/L) (See Appendix 47 for details). At least two treatments means within the data had significant difference ($p < 0.05$) between them. Moreso, there was the existence of differences between mean Total chlorine for KNUST supply areas water and the rest of the mean total chlorine ($p < 0.05$). The differences among the rest of the data were not significant ($p > 0.05$).

The mean total chlorine determined for the water from the respective supply areas proved that Kentikrono water recorded the highest (0.24 mg/L), followed by Oduom (0.23 mg/L) and the least is Boadi (0.22 mg/L) (Table 4.5). There happened to be significant difference ($p < 0.05$) between at least two treatments means within the data. Differences existed between mean Total chlorine for KNUST supply areas water and the rest of the mean Total chlorine at $p < 0.05$. Differences among the rest of the data were not significant ($p > 0.05$)

4.2.2.2 Microbial parameters of water assessed for the selected KNUST Booster station supply areas

Table 4.6: Mean microbial parameters assessed for the KNUST booster stations supply areas under study, 2012

	MICROBIAL		
LOCATIONS	**Total coliforms (MPN 100/mL)**	**Faecal coliforms (MPN 100/mL)**	**E. coli (MPN 100/mL)**
Kentinkrono	5.0±1.49	5.0±1.49	0
Oduom	6.1±1.32	6.1±1.32	0
Boadi	7.0±1.20	7.0±1.20	0
WHO Standards	**10.0**	**0**	**0**

Total coliforms in water assessed for the selected KNUST Booster station supply areas

Total coliforms determination of the water from the respective supply areas proved that the Boadi 3 water recorded the highest (7.8 MPN/100mL) whiles Boadi 3 recorded the lowest at (3.7 MPN/100mL). (See Appendix 48 for details). The significant differences between at least two treatments means within the data were significant. However, differences existed between mean Total coliforms for KNUST supply areas water and the rest of the mean total coliforms ($p < 0.05$). Among the rest of the data were no significant differences ($p > 0.05$).

The mean total coliforms determined for the water from the respective supply areas proved that Boadi water recorded the highest (7.0 MPN/100mL), followed by Oduom (6.1 MPN/100mL) and the lowest Kentikrono (5.0 MPN/100mL) (Table 4.6). Noteworthy difference at $p < 0.05$ happened between at least two treatments means within the data. Besides, the differences existed between mean Total coliforms for KNUST supply areas water and the rest of the mean Total chlorine at $p < 0.05$. The variations among the rest of the data were not significant ($p > 0.05$).

Faecal coliforms in water assessed for the selected KNUST Booster station supply areas

Faecal coliforms determination of the water from the respective supply areas proved that the Boadi 3 water recorded the highest (7.8 MPN/100mL) and Boadi 3 recorded the lowest at (3.7 MPN/100mL) (Appendix 48). Significant differences at $p < 0.05$ were between at least two treatments means within the data. However, the differences were between mean Total coliforms for KNUST supply areas water and the rest of the mean Faecal coliforms at $p < 0.05$. The differences among the rest of the data were not significant ($p > 0.05$).

The mean faecal coliforms determined for the water from the respective supply areas proved that Boadi water recorded the highest (7.0 MPN/100mL), followed by Oduom (6.1 MPN/100mL) and the lowest Kentikrono (5.0 MPN/100mL) (Table 4.6). There was significant difference ($p < 0.05$) between at least two treatments means within the data. Moreso, the differences occurred between mean Faecal coliforms for KNUST supply areas water and the rest of the mean Faecal chlorine at $p < 0.05$. Among the rest of the data the differences were not significant ($p > 0.05$).

***E. coli* of water assessed for the selected KNUST Booster station supply areas**

The determination of *E. coli* the water from the respective supply areas proved that there was no *E. coli* present in any of the water samples that is the study areas recorded zero MPN/100mL for the *E. coli* for all the samples. There was substantial variance ($p < 0.05$) between at least two treatments means within the data. The differences existed between mean *E. coli* for KNUST supply areas water and the rest of the mean total coliforms at $p < 0.05$. The differences among the rest of the data were not significant ($p > 0.05$).

CHAPTER FIVE

5.0 DISCUSSION

5.1 WATER QUALITY ASSESSMENT FOR BOOSTER STATIONS UNDER STUDY IN THE KUMASI METROPOLIS

5.1.1 Physicochemical Parameters of Water Assessed For the Booster Stations under Study

The Physico-chemical parameters of the booster stations have been given in Table 4.1. Temperature is one of the important factors in environment since it regulates the various Physico-chemical as well as biological activities (Kumar *et al*., 1996). The water temperature follows a diurnal variation, increases in day time and decreases during night. The temperature of the booster stations were in the range of 25.2 – 25.5 °C. The Barekese dam from which the treated water is sourced recorded an average mean temperature of 29.2±0.62. Increase in temperature accelerates the chemical reactions in dam water and thereby reduces the solubility of gases and imparts taste and odour to the water. This indicates that the immediate treated water and those at the booster stations mean temperatures fall above the WHO and Ghana EPA recommended standard (15 – 25°C) for drinking water. This could result because at the sampling times the sun was high up, so it could have caused the slight average increase in temperature of 0.5°C above the recommended range. There is no set temperature standard for water as far as the WHO and EPA guidelines for surface water are concerned. The temperature range is a reflection of its tropical statues. The natural background level for temperature is 22 – 29.5 °C. No significant difference was noted in the observed temperature ranges at each site

but the variation in temperature due to change in sampling location was significant at $p < 0.05$ confidence level. The water temperature was influenced by the atmospheric or ambient temperature at the time of sampling. The high temperature recorded for the Barekese dam may be due to high turbidity and conductivity value (suspended materials) in the stream (DWAF, 1998).

According to (Bankar *et al.*, 2010), the pH values of lake body is in the range of 7.4 - 7.8. The pH values of the booster stations in the study ranged 6.8 – 6.9. The untreated water recorded 9.1. These values are within prescribed limit given by W.H.O. concerning the drinking water pH, the WHO (2010) standard is 6.5 – 8.5. It means that the drinking water for the entire booster stations under study were within the WHO range that is 6.8 – 6.9. pH is lowest in the summer and highest in the monsoon (Bruce, 2008). As usual the Barekese dam recorded the highest pH at 9.1, which is slightly higher than the standard of WHO and also not consistent with Bankar *et al.* (2010). This range of pH is best for the growth of algae and in fact is the required range for the better production of fish (Huet, 1961), aquatic life (Kakavipure and Yeragi, 2005; USEPA, 1975, Bell, 1971). The usual range of pH in inland water is 6.0-9.0 (Zafar, 1984). The water pH gets drastically changed due to biological activities and variations in temperature. Significant change in pH is due to discharge of agricultural waste and surface runoff from the farms around the dam.

The mean turbidity values ranged from 31.80±11.57 FTU at the Barekese dam (untreated water) to 0±0 FTU at both Achiase booster station and Barekese treated water. The

background limit for turbidity is 5 FTU (WRC, 2003). These values recorded shows that they grossly exceeded this background level. High turbidity levels in water causes problems with water purification processes such as flocculation and filtration, which may increase treatment cost (DWAF, 1998). High turbidity also has the capacity to significantly increase water temperature. Though high turbidity is often a sign of poor water quality and land management, crystal clear water does not always guarantee healthy water. Extremely clear water can signify very acidic conditions or high levels of salinity (DWAF, 1998). Elevated turbid water, according to DWAF (1998), is often associated with the possibility of microbiological pollution as high turbidity makes it difficult to disinfect water properly. The high level of turbidity recorded in this study for the Barekese dam water may have been strongly influenced by soil erosion and decay of organic matter from improper disposal of domestic waste within the catchment. The treated water as well, had varying turbidity which averagely was 3.77 FTU, close to the recommended limit. The rest of the booster stations showed turbidity values within the WHO standard for drinking water range of 0 – 5 FTU (WHO, 2010).

Colour of the treated water samples was clear, slightly turbid and odour was unobjectionable. The mean colour ranged from a minimum of 0±0 (Achiase booster water) to a maximum of 16.9±20.2. The value for the untreated water was above 15 Hz limit recommended by the WHO. This goes to indicate that the dam water was not aesthetically satisfactory. Colour is an important physical property of water because of its implications for water supply and the need to reduce it to acceptable levels by water treatment is highly recommended. According to Karikari and Ansa-Asare (2006),

increase in the colour of water in reservoirs results in increases in treatment cost. Colour in natural water, according to Karikari and Ansa-Asare (2006), usually results from the leaching of organic materials and is primarily the result of dissolved and colloidal humic substances, primarily humic and fulvicacids. Colour is also strongly influenced by the presence of iron and other metals, either as natural impurities or as corrosion products. Highly coloured water may be due to decaying vegetation. No significant difference was noted in the observed colour ranges at each site but the dam and variation in colour was due to change in sampling location ($P<0.05$).

The residual/free chlorine is the chlorine available to inactivate disease-causing organisms, and thus a measure to determine the portability of water. Natural free chlorine determined for the dam water was 0.222±0.012 mg/L while the residual chlorine for the treated water at the booster stations ranged from 0.005±0.002 mg/L to 0.043±0.004 mg/L. Maintenance of a disinfectant residual throughout the distribution system may help to maintain the integrity of the distribution system in the following ways: Inactivating microorganisms in the distribution system. Free chlorine is also currently the most widely used secondary disinfectant in medium systems (USEPA, 2002a; AWWA, 2000). The 24 samples tested for chlorine residual for the four months in Kumasi showed very poor compliance with the WHO's mandated range for free chlorine residual in the distribution system. According to the WHO, after at least 30 minutes of contact time, "the minimum residual concentration of free chlorine at the point of use should be 0.2 mg/L" (WHO, 2008). The Philippines DOH requires free chlorine residual concentrations for Level 2 and Level 3 water supplies to ensure that the water remains disinfected. According to the

Department of Health (DOH, 1995), the free chlorine residual at any point that reaches the consumer as well as any point in the distribution system must also be between 0.2 mg/L (DOH Min) and 0.5 mg/L (DOH Max). The water discharged from the water treatment plant(s) and booster station should be disinfected to ensure that the WHO and DOH standard of 0.2 mg/L to 0.5 mg/L of free chlorine can be found at all points in the distribution system. Values as high as 1.0 mg/L have been reported by Ormeci and Linden (2002). These results could be due to low chlorine dose administered to the effluent drinking water at the water treatment plant, and inadequate testing of chlorine residual at the treatment plants and throughout the distribution system to ensure that it meets WHO/DOH standards.

The remaining chlorine concentration after the chlorine demand is accounted for is called total chlorine. Total chlorine determined for the dam water was 0.27±0.008 mg/L while the total chlorine for the treated water at the booster stations ranged from 0.265±0.008 mg/L to 0.235±0.007 mg/L. The city of Bloomington utilities' water quality report of 2002 detected highest levels of total chlorine residual at 3.5 mg/L for drinking water which is far higher than that recorded for Kumasi tap water. With reference to the WHO standard for total chlorine in drinking water which is 0.5 mg/L, none of the results met this standard. This could be due to decrease in temperature because chlorination is less effective as the temperature decreases and when the water is more turbid (Safe drinking water, 2010). The chlorine will decrease in concentration with distance from the source, until it reaches the point where the chlorine level can become ineffective as a disinfectant (Safe drinking water, 2010). While LeChevallier (1999) contends that disinfectant

residuals may be overwhelmed by large backflow episodes, maintaining a disinfectant residual throughout the distribution system may be effective at providing a barrier to illness in instances of smaller contamination episodes. Payment *et al*. (1991) studied waterborne endemic gastrointestinal illness in a Canadian system that experienced many pipe breaks and low disinfectant residuals throughout the distribution system network, especially at the ends of the system. LeChevallier *et al*. (2002) report that analysis of Payment's data shows that people who lived in zones far away from the treatment plant had the highest risk of gastroenteritis.

5.1.2 Microbial Parameters of Water Assessed for the Booster Stations

The total coliforms of drinking water tested showed appreciable numbers of coliforms. Only the KNUST and the Barekese treated water did not record any coliforms present (0MPN/100mL). These two met the WHO standard of 0MPN/100mL for total coliforms in drinking water. The rest of the samples at the booster stations showed significant amounts of Total coliforms present. With the exception of the Barekese dam (untreated water) which gave total coliforms number as 16E+6±2.7E+7 MPN/100mL, this value conforms with that of Kumasi *et al*. (2010) that is 1.65E+6 – 2.18E+7 MPN/100mL. For the remaining samples, the total coliforms were equal to the faecal coliforms that mean the coliforms that were present in the treated water were only faecal coliforms. In contrast, according to Quist (1999), treated pipe water received in consumer homes within the Kumasi metropolis sometimes contain coliform bacteria varying from 30 - 78 MPN 100/ mL total coliforms. This is so because with time and increase in research and technology, the GWC has adapted proper ways of treating and disinfecting water which

has led to the drastic decrease in total number of coliforms in the drinking water currently.

For water to be considered no risk to human health, the faecal coliform count in the water sample should be zero (WHO, 1987, 2004). The Barekese dam; untreated water, recorded the highest faecal coliform with a mean 39.5E+3±1.5E+4 MPN/100mL and the lowest was the Barekese treated water and KNUST booster station water at 0±0 MPN/100mL as shown in Table 4.1.

This indicated that people from these areas might be prone to water-borne diseases and suitable disinfection units must be established. There were significant differences ($P<0.05$) in all the sampling sites. The presence of high faecal coliform counts is a sign of the extent of contamination of the streams that feed the dam by pathogens or disease causing organisms. The quality of drinking water is of vital concern to mankind, since it is directly associated with human life. Faecal pollution of drinking water causes water-borne diseases, which could wipe out entire population of cities (Farah *et al*., 2002). The faecal coliform level observed at this point of pollution of the lake make it unsuitable for both primary contacts such as swimming and secondary contact i.e. for boating and fishing (WHO, 2004; Millipore, 1991). This value follows that of Kumasi *et al* (2010) that is between 1.73E+4 and 1.84E+5 MPN/100mL. In contrast, according to Quist (1999), treated pipe water received in consumer homes within the Kumasi metropolis sometimes contain coliform bacteria varying from 0 -18 MPN/100mL faecal coliforms. Relating the presence of the faecal coliforms to the amount of residual chlorine, it could be inferred that in the water sample where the residual chlorine was low, there were

faecal coliforms in those water samples i.e. Buokrom, Tafo and KNUST booster water. This could be due to the fact that the amounts of chlorine redose at the booster stations were low or had all been used for disinfection.

Escherichia coli counts which were determined in the water samples from the dam and the booster stations indicated significantly very low or negligible *E. coli* counts except the Barekese dam (untreated water) which showed *E. coli* counts of 10±1.95 MPN/100mL. Kumasi *et al* (2010), recorded values from 2.00E+2 – 2.85E+2 MPN/100mL. The Barekese treated water, Achiase, Buokrom and KNUST booster stations water did not record any *E. coli*. The Tafo booster station water had quite low counts for *E. coli*, 0.1±0.02 MPN/100mL and hence it will not be suitable for drinking since the presence of the *E. coli* has a high risk to human health. Therefore the chlorination of drinking water must be considered and monitored more carefully. Chlorination is considered to be highly effective for virus inactivation if the water has turbidity (FTU < 1; free chlorine residual of 1 mg L^{-1} or greater for at least 30 minutes) and pH < 8 (Dufour *et al*., 2003). The WHO (2004) standard stipulates that *E. coli* should be absent from all domestic and drinking water. The coliform groups of bacteria principally infect water used for domestic, industrial or other purposes (Zamaxaka *et al*., 2004). High levels of coliform counts indicate a contaminated source, inadequate treatment or post treatment deficiencies.

5.2 WATER QUALITY ASSESSMENT FOR SUPPLY AREAS UNDER STUDY

5.2.1 Physicochemical Parameters Assessed for Achiase and KNUST supply areas

The Physico-chemical parameters of both the Achiase supply areas have been given in Table 4.3 and that of KNUST supply areas in Table 4.5. Temperature is one of the important factors in environment since it regulates the various Physico-chemical as well as biological activities (Kumar *et al*., 1996). The temperature of water ranged from 25.6 – 25.9 °C and 25.6 – 25.8 °C for the Achiase supply areas and KNUST supply areas respectively. Increase in temperature accelerates the chemical reactions in dam water and thereby reduces the solubility of gases and imparts taste and odour to the water. The lowest temperatures recorded for Achiase supply areas were at Asokwa and Atonsu at 25.6°C each and that of KNUST supply areas was at Kentinkrono (25.6°C). The highest temperatures recorded for Achiase supply areas was at Asafo (25.9°C) and that of KNUT supply areas were at Oduom and Boadi at 25.8°C each. This indicates that immediately treated water is distributed from the booster stations, the mean temperatures go above the WHO and EPA – Ghana recommended standard of 15 – 25°C of drinking water. This is because at the sampling times the sun was high up, so it could have caused the slight average increase in temperature of 0.6 - 0.9°C above the recommended range. The Kentinkrono samples gave an average of 25.6°C which equals to that of the booster station, the reason may be because Kentinkrono is the closest supply area to the KNUST booster station.

The pH values of water at Achiase supply areas ranged from 6.8 - 6.9 and that of KNUST supply areas was 6.9 for all the supply areas. These values are within the prescribed limit given by WHO. Concerning pH of drinking water, the WHO (2010) standard is 6.5 – 8.5.

It means that the drinking water for the entire booster stations under study were within the WHO range. According to Dufour *et al*., (2003), treated water have a pH less than 8.0 and it agrees with the results gotten from this research work.

The mean turbidity values ranged from 8.6±10.3 FTU (Atonsu) to 4.2±6.4 FTU (Asafo) for Achiase supply areas and 0.8±1.48 FTU (Kentinkrono) to 1.3±1.95 FTU (Oduom) for KNUST supply areas. The background limit for turbidity is 5FTU (WRC, 2003). Some of the turbidity values recorded in Tables 4.3 and 4.5 met the WRC and the WHO (2010) standard (5FTU). The values were significantly different ($P<0.05$) in all the sampling sites. High turbidity levels in water causes problems with water purification processes such as flocculation and filtration, which may increase treatment cost (DWAF, 1998). Though high turbidity is often a sign of poor water quality and land management, crystal clear water does not always guarantee healthy water. Elevated turbid water, according to DWAF (1998), is often associated with the possibility of microbiological pollution as high turbidity makes it difficult to disinfect water properly. The high level of turbidity recorded in this study for the Barekese dam water may have been strongly influenced by soil erosion and decay of organic matter from improper disposal of domestic waste within the catchment. The high turbidity could be due to the increased amount of precipitates in the water from corrosion, the amount of particulate matter (and thus turbidity) increases (Juhna and Klavins, 2001). As a result, microbes may attach and aggregate onto these particles and be protected from disinfection (Besner *et al*., 2002), rendering a disinfection residual less effective. The KNUST supply areas showed a lower level of turbidity i.e. below even the standard, meaning the water is very portable for drinking. Hence, no

microbes may attach and aggregate onto these particles and be protected from disinfection rendering a disinfection residual less effective. The water at the supply areas; Oduom, Kentikrono and Boadi had low turbidity than at the booster station, this can be as a result of settled particles in the pipe along the distribution routes.

Colour of the water samples was clear, slightly turbid and odour was unobjectionable. The mean colour ranged from a minimum of 12.5±21.6 Hz to a maximum of 24.9±30.6 Hz for Achiase supply areas and a minimum of 3.2±4.6 Hz to a maximum of 4.1±9.2 Hz for KNUST. The values of the drinking water for Achiase supply areas were above <15 Hz which is WHO recommended limit for no risk except for Asafo (12.5±21.6). This goes to indicate that the rest of the drinking water is not very suitable for drinking. The values for KNUST supply areas fell within the WHO recommended limit for no risk indicating that all the drinking water for KNUST supply areas were very suitable for drinking. Colour is an important physical property of water because of its implications for water supply and the need to reduce it to acceptable levels by water treatment is highly recommended. According to Karikari *et al.* (2006), Increase in the colour of water in reservoirs results in increases in treatment cost. Highly coloured water may be due to decaying vegetation. The high colour for Achiase supply areas could be due to possible leakages or pipe breaks along the main route from booster station to point of supply since the values at the booster station meet the WHO standards (<15). The low colour for KNUST supply areas could be due the absence of leakages or pipe breaks along the main route from booster station to point of supply and also good disinfection at the booster station.

The amount of chlorine available to inactivate disease-causing organisms, and thus a measure to determine the portability of water is called residual/free chlorine. Maintenance of a disinfectant residual throughout the distribution system may help to maintain the integrity of the distribution system in the following ways: Inactivating microorganisms in the distribution system; indicating distribution system upset; and controlling biofilm growth. Currently, free chlorine is also the most widely used secondary disinfectant in medium systems (USEPA, 2002a; AWWA, 2000). The samples tested for chlorine residual for the four months in both Achiase and KNUST supply areas showed very poor compliance with the WHO's mandated range for free chlorine residual in the distribution system. According to the WHO, after at least 30 minutes of contact time, "the minimum residual concentration of free chlorine at the point of use should be 0.2 mg/L" (WHO, 2008) but the opposite was found that all the drinking water tested at all the homes showed residual chlorine level less than 0.2 mg/L. According to the Department of Health (DOH, 1995), the free chlorine residual at any point that reaches the consumer as well as the any point in the distribution system must also be between 0.2 mg/L (DOH Min) and 0.5 mg/L (DOH Max). The water discharged from the water treatment plant(s) and booster station should be disinfected to ensure that the WHO and DOH standard of 0.2 mg/L to 0.5 mg/L of free chlorine can be found at all points in the distribution system. Ormeci and Linden (2002) reported that the residual chlorine for drinking water tested was 1.0 mg/L, the values for the tested samples contradicts with this. These results could be due to low chlorine dose administered to the effluent drinking

water at the booster station and inadequate testing of chlorine residual, or it has been used for disinfection along the distribution lines.

The remaining chlorine concentration after the chlorine demand is accounted for is called total chlorine. Total chlorine determined for the Achiase supply areas were between 0.26 – 0.25 mg/L and that of KNUST supply areas were between 0.24 – 0.22 mg/mL. The city of Bloomington utilities' water quality report 2002 indicated highest levels detected of total chlorine residual was 3.5 mg/L for drinking water which is far higher than that recorded for Kumasi tap water. With reference to the WHO standard for total chlorine in drinking water which is 0.5 mg/L, none of the results for total chlorine met this standard. This could be due to decrease in temperature because chlorination is less effective as the temperature decreases and when the water is more turbid (Safe drinking water, 2010). The chlorine will decrease in concentration with distance from the source, until it reaches the point where the chlorine level can become ineffective as a disinfectant. (Safe drinking water, 2010). The KNUST booster station water had high level of total chlorine than those at the supply areas. This may be because with distance the level of chlorine reduces because it may cater for the reinfection that occurs along the lines. While LeChevallier (1999) contends that disinfectant residuals may be overwhelmed by large backflow episodes, maintaining a disinfectant residual throughout the distribution system may be effective at providing a barrier to illness in instances of smaller contamination episodes. Payment *et al*. (1991) studied waterborne endemic gastrointestinal illness in a Canadian system that experienced many pipe breaks and low disinfectant residuals throughout the distribution system network, especially at the ends of the system. LeChevallier *et al*.,

(2002) report that analysis of Payment's data shows that people who lived in zones far away from the treatment plant had the highest risk of gastroenteritis.

In comparison, the KNUST booster supply area of water is more convenient for drinking than the Achiase water, which has high levels of all the physicochemical parameters determined. As seen from the map of the supply areas (Figure 3.2.1) earlier, it could be clearly seen that the KNUST supply areas is smaller than that of Achiase (Almost 8 times as big as KNUST supply areas). This could be true if the water must travel great distances to reach the end consumer, since generally, residual chlorine levels decline as the distances from the plant increase (Egorov *et al*., 2002). For example, it was observed in Dushanbe, Tajikistan, that a longer length of pipe increased the chances of contamination, especially in the event of low pressure as discovered by Mermin *et al*. (1999). In Pietermaritzburg, South Africa, coliforms were found to be associated with low chlorine residual; as distance from the water plant increased, the level of free chlorine decreased with resulting coliform increase (Bailey and Thompson 1995). In addition to distance travelled according to Egorov *et al*. (2002) other factors that affect the rate of depletion of a residual are: water flow velocity, residence time, age and material of pipes, and water pressure

5.2.2 Microbial Parameters Assessed For both Achiase and KNUST supply areas

For the Achiase supply areas, the total coliforms of drinking water tested revealed palpable numbers of coliforms present. All the water sampled from the areas under review recorded some coliforms present i.e. between 5.3±0.9 to 3.6 E+5 ± 1.2 E+6 MPN/100mL which is equal to faecal coliforms. Some of these do not meet the WHO

standard 10 MPN/100mL total coliforms in drinking water. Treated pipe water received in consumer homes according to Quist (1999), within the Kumasi metropolis sometimes contain coliform bacteria varying from 30 - 78 MPN 100/ mL total coliforms, in contrast the results from the Achiase supply areas were higher than that of Quist (1999). Water from Asokwa showed a lesser count of total and faecal coliforms that is 5.3 MPN/100mL than that of Quist (1999). This could be especially true if the water must travel great distances to reach the end consumer, since generally, residual chlorine levels decline as the distances from the plant increase (Egorov *et al*., 2002). For example, it was observed in Dushanbe, Tajikistan, that a longer length of pipe increased the chances of contamination, especially in the event of low pressure (Mermin *et al*., 1999). In Pietermaritzburg, South Africa, coliforms were found to be associated with low chlorine residual; as distance from the water plant increased, the level of free chlorine decreased with resulting coliform increase (Bailey and Thompson 1995). In addition to distance travelled, other factors that affect the rate of depletion of a residual are: water flow velocity, residence time, age and material of pipes, and water pressure (Egorov *et al*., 2002).

For water to be considered no risk to human health, the faecal coliform count in the water sample should be zero (WHO, 1987; 2004). The high levels of faecal coliform counts indicated that people from these areas might be prone to water-borne diseases and suitable disinfection units must be established. There were significant differences ($P<0.05$) in all the sampling sites. The presence of high faecal coliform counts is a sign of the extent of contamination of the streams by pathogens or disease causing organisms.

The quality of drinking water is of vital concern to mankind, since it is directly associated with human life. Faecal pollution of drinking water causes water-borne diseases, which wiped out entire population of cities (Farah *et al*., 2002). The faecal coliform level observed at this point of pollution of the lake make it unsuitable for both primary contacts such as swimming and secondary contact i.e. for boating and fishing (WHO, 2004; Millipore, 1991). In contrast, according to Quist (1999), treated pipe water received in consumer homes within the Kumasi metropolis sometimes contain coliform bacteria varying from 0 -18 MPN 100 mL^{-1} faecal coliforms. Relating the presence of the faecal coliforms to the amount of residual chlorine, it could be interfered that in the water sample where the residual chlorine was low, there were faecal coliforms in those water samples i.e. Asokwa, Atonsu and Asafo supply areas water. This could be due to the fact that the amounts of chlorine redose at the booster stations were low or had all been used for disinfection, possible leakages and breaks and distance from the Achiase booster. It supplies water to a very large area compared to the other booster stations and the presence of particles and reinfection could have reduced drastically the level of chlorine which led to the increase in the faecal coliforms. Also, the existence of breakages close to places of convenience or where people defecate can be washed into the pipe by rain water.

Escherichia coli counts which were determined in the water samples from Achiase supply areas indicated significantly very low or negligible. According to Bailey and Thompson (1995), coliforms, in Pietermaritzburg, South Africa, were found to be associated with low chlorine residual. The least counts for *E. coli* were recorded 0±0

MPN/100mL for Asokwa water. The rest had some amount of *E. coli*, and hence it will not be suitable for drinking since the presence of the *E. coli* has a high risk to human health. Therefore the chlorination of drinking water must be considered and monitored more carefully. Chlorination is considered to be highly effective for virus inactivation if the water has turbidity (FTU < 1; free chlorine residual of 1 mg L^{-1} or greater for at least 30 minutes) and pH < 8 (Dufour *et al*., 2003). The WHO (2004) standard stipulates that *E. coli* should be absent from all domestic and drinking water.

For the KNUST supply areas, the total coliforms of drinking water tested revealed that the numbers of coliforms present were not so profound. All the water sampled from the areas under review recorded small amounts of coliforms present i.e. between 7.0±1.19 to 5.0 ± 1.49 MPN/100mL which is equal to faecal coliforms. These do meet the WHO standard of 10 MPN/100mL total coliforms in drinking water. Treated pipe water received in consumer homes according to Quist (1999), within the Kumasi metropolis sometimes contain coliform bacteria varying from 30 - 78 MPN 100/ mL total coliforms, in contrast the results from all the KNUST supply areas were higher than that of Quist (1999). Water from Kentkrono, Oduom and Boadi supply areas showed a lesser count of total and faecal coliforms that is 5.3 MPN/100mL than that of Quist (1999) and WHO. This could be especially true if the water must travel great distances to reach the end consumer, since generally, residual chlorine levels decline as the distances from the plant increase (Egorov *et al*., 2002) but this is not true because this thesis indicated that the KNUST booster station is really re-dosed with residual chlorine and that has resulted in the low levels of total coliforms.

For water to be considered no risk to human health, the faecal coliform count in the water sample should be zero (WHO, 1987; 2004). The low levels of faecal coliform counts indicated that people from these areas might not be prone to water-borne diseases and suitable disinfection units must not need to be established. There were not significant differences ($P<0.05$) in all the sampling sites. The presence of low faecal coliform counts is a sign of the low extent of contamination of the streams by pathogens or disease causing organisms. The quality of drinking water is of vital concern to mankind, since it is directly associated with human life. Faecal pollution of drinking water causes water-borne diseases, which wiped out entire population of cities (Farah *et al*., 2002). In similarity, according to Quist (1999), treated pipe water received in consumer homes within the Kumasi metropolis sometimes contain coliform bacteria varying from 0 -18 MPN 100/mL faecal coliforms and this thesis fall within this range with respect to the KNUST supply areas.

Escherichia coli counts which were determined in the water samples from KNUST supply areas indicated significantly very low or negligible. Coliforms were found to be associated with low chlorine residual with reference to Bailey and Thompson (1995). Null counts for *E. coli* were recorded for all the water supplied by the KNUST booster, it is suitable for drinking since the presence of the *E. coli* may have a high risk to human health. Therefore, the chlorination of drinking water is being considered and monitored more carefully. Chlorination is considered to be highly effective for virus inactivation if the water has turbidity (FTU < 1; free chlorine residual of 1 mg L^{-1} or greater for at least 30 minutes) and pH < 8 (Dufour *et al.*, 2003). The WHO (2004) standard stipulates that *E. coli* should be absent from all domestic and drinking water.

In distinction, the Achiase supply areas showed very large counts of coliforms in the tested drinking water as high as 3.6 E+5 ± 1.2 E+6 MPN/100mL meaning is has high risk of infection, as compared to KNUST supply areas which recorded as high as 7.0 ± 1.19 MPN/100mL which is even within the WHO, (2010), standard hence suitable for consumption. Only the Asokwa drinking water samples under the Achiase supply area showed a level that is suitable for drinking i.e. below 10 MPN/100mL.

5.3 SUMMARY DISCUSSION

In summary, it can be inferred from these results that the KNUST water supply is highly portable and it conforms to the WHO standard but the Achiase water is really not and had some coliform counts within them. It also looks like that KNUST booster water and its supply areas receive high attention from the GWC more than that of Achiase supply areas. The distance travelled by the water in the distribution system could also lead to decrease in the level of chlorine which will lead to increase in Microorganisms. The presence of residual chlorine with reference to Stewart, *et al.,* (2001) is to inactivate microorganisms in the distribution system, serve as indicators of distribution system upset, and control biofilms formation. Reduced amount of chlorine residual in the water at Achiase led to increase in the microorganisms.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

From the results and discussions, the following deductions are made;

1. All Physico-chemical paremeters of the Barekese dam water (untreated) did not meet the WHO standards and this pollution may be attributed to contamination from domestic wastes and human and animal faeces whiles that of the booster stations among all the selected samples, almost all of them were within the WHO standards with exception of the residual and total chlorine which may be because it catered for reinfection.
2. The Microbial indicators showed that the Barekese dam is heavily polluted with faecal coliforms, total coliforms and some amount of *E. coli.* None of the booster stations were polluted with *E. coli* but Tafo booster station.
3. The supply areas showed appreciably different values from their respective booster stations; for instance, the Achiase booster and its supply areas but the KNUST booster and its supply areas gave very similar results which were not significant ($P<0.05$). Almost all the physicochemical parametres were within the WHO standards except for the residual and total chlorine and this is due to the fact that it was used up to handle infections that may have occurred along the distribution lines.
4. The microbial water quality of the supply areas were within the WHO standards, with the exception of that of Atonsu and Asafo; this is because along the lines the

samples were picked, there were leakages and also broken pipes, by those paths the microbes entered the water flowing through the pipe of that supply area. This could cause infection to communities that drink that water.

5. Generally, the level of the water quality of the Barekese dam with distance from point of production to final consumption is appreciable; from this research KNUST supply areas under study showed that there is no significant difference in the water quality of the Barekese dam with distance from point of supply. The Achiase water supply areas showed a reverse because of leakages and breakages of some of the pipelines which supply various homes hence its level of quality is questionable. It is anticipated that quality drinking water will ultimately facilitate the achievement of the Millennium Development Goals target of halving the proportion of people without sustainable access to safe water by the year 2015.

6.2 RECOMMENDATIONS

From the studies, the following recommendations are made:

- In municipal water systems, the drinking water is chlorinated prior to being distributed and chlorine totals should be measured at the far end of the distribution line. This would ensure that the house located furthest from the plant still receives water that is adequately disinfected. It should also be redosed at the booster station to cater for reinfection.
- There should be routine testing of water quality level, checks of breakages and leakages of pipes in the metropolis, especially the Achiase supply area as has been concluded from this thesis. This will reduce infection and diseases which will be introduced to the body of users.

- The general public should be educated on the possible effect of pipes leakages and breakages; introduction of disease causing microorganisms, the amount of water loss when there is a pipe break and also to be quick and prompt to report all pipe leakages, breakages and illegal connections that abound in the society which may lead to introduction of some of these disease causing microorganisms in the environment into the drinking water.
- There is very little work that has been done on the quality of the treated drinking water in the Kumasi metropolis. Hence, it is recommended that lots of research should go into this kind of research to check the water quality level. The test could centre on the effect of the iron pipes and rust in the drinking water.
- It is also recommended that another take up this same task and analyse the Tafo and Buokrom booster stations then compare all the four booster stations water quality. From that the general level of the water quality in the metropolis would be known.

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APPENDIX

1. ANOVA for Temperature of water at booster stations.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	145.6424	5	29.12847	168.0856	3.83E-36	2.353809
Within Groups	11.4375	66	0.173295			
Total	157.0799	71				

2. ANOVA for pH of water at booster stations

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	47.71519	5	9.543038	4979.961	1.29E-83	2.353809
Within Groups	0.126475	66	0.001916			
Total	47.84167	71				

3. ANOVA for Turbidity of water at booster stations

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	8947.667	5	1789.533	66.86688	1.7E-24	2.353809
Within Groups	1766.333	66	26.76263			
Total	10714	71				

4. ANOVA for Colour of water at booster stations

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	269108.8	5	53821.77	569.9385	7.45E-53	2.353809
Within Groups	6232.667	66	94.43434			
Total	275341.5	71				

5. ANOVA for Residual Chlorine of water at booster stations

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.306926	5	0.061385	1947.52	3.19E-70	2.353809
Within Groups	0.00208	66	3.15E-05			
Total	0.309007	71				

6. ANOVA for Total Chlorine of water at booster stations

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.009655	5	0.001931	2.4332	0.043764	2.353809
Within Groups	0.052376	66	0.000794			
Total	0.06203	71				

7. ANOVA for Total Coliforms of water at booster stations

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	8.61E+14	5	1.72E+14	1.26176217	0.3226732	2.772853
Within Groups	2.46E+15	18	1.37E+14			
Total	3.32E+15	23				

8. ANOVA for Faecal coliforms of water at booster stations

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5.2E+09	5	1.04E+09	26.47607	1.05E-07	2.772853
Within Groups	7.07E+08	18	39277783			
Total	5.91E+09	23				

9. ANOVA for *E. coli* of water at booster stations

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	331.5345	5	66.3069	104.5166	1.19E-12	2.772853
Within Groups	11.41948	18	0.634415			
Total	342.954	23				

10. ANOVA for Temperature of water at Achiase supply area

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	12.59240741	8	1.574051	8.157981	2.04E-08	2.03329
Within Groups	19.10166667	99	0.192946			
Total	31.69407407	107				

11. ANOVA for Temperature of water at Achiase supply area

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.480741	2	0.74037	2.572999	0.081111	3.082852
Within Groups	30.21333	105	0.287746			
Total	31.69407	107				

12. ANOVA for pH of water at Achiase supply area

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.12408	8	0.01551	14.0978	1.63E-13	2.033295
Within Groups	0.108917	99	0.0011			
Total	0.232996	107				

13. ANOVA for pH of water at Achiase supply area

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.018363	2	0.009181	4.491639	0.013436	3.082852
Within Groups	0.214633	105	0.002044			
Total	0.232996	107				

14. ANOVA for Turbidity of water for Achiase Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1799.333	8	224.9167	3.636377	0.00095	2.033295
Within Groups	6123.333	99	61.85185			
Total	7922.667	107				

15. ANOVA for Turbidity of water for Achiase Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	392	2	196	2.732826	0.069664	3.082852
Within Groups	7530.667	105	71.72063			
Total	7922.667	107				

16. ANOVA for Colour of water for Achiase Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	13630.13	8	1703.766	2.804289	0.007646	2.033295
Within Groups	60148.17	99	607.5572			
Total	73778.3	107				

17. ANOVA for Colour of water for Achiase Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3236.796	2	1618.398	2.408962	0.094862	3.082852
Within Groups	70541.5	105	671.8238			
Total	73778.3	107				

18. ANOVA for Residual Chlorine of water for Achiase Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.039631	8	0.004954	27.50341	5.36E-22	2.033295
Within Groups	0.017832	99	0.00018			
Total	0.057463	107				

19. ANOVA for Residual Chlorine of water for Achiase Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.010838	2	0.005419	12.20419	1.72E-05	3.082852
Within Groups	0.046624	105	0.000444			
Total	0.057463	107				

20. ANOVA for Total Chlorine of water for Achiase Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.004691	8	0.000586	0.698671	0.691943	2.033295
Within Groups	0.083083	99	0.000839			
Total	0.087774	107				

21. ANOVA for Total Chlorine of water for Achiase Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.003502	2	0.001751	2.181587	0.117952	3.082852
Within Groups	0.084272	105	0.000803			
Total	0.087774	107				

22. ANOVA for Total Coliforms of water for Achiase Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	4.11E+12	8	5.14E+11	1.050053	0.42833	2.355081
Columns	1.7E+12	3	5.68E+11	1.161323	0.345002	3.008787
Error	1.17E+13	24	4.89E+11			
Total	1.76E+13	35				

23. ANOVA for Total Coliforms of water for Achiase Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	9.58E+11	2	4.79E+11	0.95266	0.396066	3.284918
Within Groups	1.66E+13	33	5.03E+11			
Total	1.76E+13	35				

24. ANOVA for Faecal coliforms of water for Achiase Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	4.11E+12	8	5.14E+11	1.050053	0.42833	2.355081
Columns	1.7E+12	3	5.68E+11	1.161323	0.345002	3.008787
Error	1.17E+13	24	4.89E+11			
Total	1.76E+13	35				

25. ANOVA for Faecal coliforms of water for Achiase Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	9.58E+11	2	4.79E+11	0.95266	0.396066	3.284918
Within Groups	1.66E+13	33	5.03E+11			
Total	1.76E+13	35				

26. ANOVA for *E. coli* of water for Achiase Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	19.61507	2	9.807536	2.41936	0.104599	3.284918
Within Groups	133.7745	33	4.053773			
Total	153.3896	35				

27. ANOVA for *E. coli* of water for Achiase Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	19.61507	2	9.807536	2.41936	0.104599	3.284918
Within Groups	133.7745	33	4.053773			
Total	153.3896	35				

28. ANOVA for Temperature of water for KNUST Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	35.16666667	8	4.39583	16.08083	5.41E-15	2.033295
Within Groups	27.0625	99	0.27336			
Total	62.22916667	107				

29. ANOVA for Temperature of water for KNUST Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.347222	2	0.673611	1.161743	0.31693	3.082852
Within Groups	60.88194	105	0.579828			
Total	62.22917	107				

30. ANOVA for pH of water for KNUST Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.081466667	8	0.010183	8.143376	2.1E-08	2.033295
Within Groups	0.1238	99	0.001251			
Total	0.205266667	107				

31. ANOVA for pH of water for KNUST Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.033239	2	0.016619	10.14395	9.38E-05	3.082852
Within Groups	0.172028	105	0.001638			
Total	0.205267	107				

32. ANOVA for Turbidity of water for KNUST Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	245.8518519	8	30.73148	62.19591	3.27E-35	2.033295
Within Groups	48.91666667	99	0.494108			
Total	294.7685185	107				

33. ANOVA for Turbidity of water for KNUST Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3.12963	2	1.564815	0.563387	0.570989	3.082852
Within Groups	291.6389	105	2.777513			
Total	294.7685	107				

34. ANOVA for Colour of water for KNUST Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2189.666667	8	273.7083	10.17701	2.82E-10	2.033295
Within Groups	2662.583333	99	26.89478			
Total	4852.25	107				

35. ANOVA for Colour of water for KNUST Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	18.05556	2	9.027778	0.196086	0.822242	3.082852
Within Groups	4834.194	105	46.03995			
Total	4852.25	107				

36. ANOVA for Free Chlorine of water for KNUST Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.0015195	8	0.00019	5.50275	9.39E-06	2.033295
Within Groups	0.003417167	99	3.45E-05			
Total	0.004936667	107				

37. ANOVA for Free Chlorine of water for KNUST Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.001184	2	0.000592	16.56524	5.59E-07	3.082852
Within Groups	0.003753	105	3.57E-05			
Total	0.004937	107				

38. ANOVA for Total Chlorine of water for KNUST Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.032040741	8	0.004005	1.568915	0.143833	2.033295
Within Groups	0.252725	99	0.002553			
Total	0.284765741	107				

39. ANOVA for Total Chlorine of water for KNUST Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.00928	2	0.00464	1.76844	0.175642	3.082852
Within Groups	0.275486	105	0.002624			
Total	0.284766	107				

40. ANOVA for Total coliforms water for KNUST Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	52.125	8	6.515625	5.601493	0.000461	2.355081
Columns	3.895833	3	1.298611	1.116418	0.361986	3.008787
Error	27.91667	24	1.163194			
Total	83.9375	35				

41. ANOVA for Total coliforms water for KNUST Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	24.69792	2	12.34896	6.87911	0.003183	3.284918
Within Groups	59.23958	33	1.795139			
Total	83.9375	35				

42. ANOVA for Faecal coliforms water for KNUST Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	52.125	8	6.515625	5.601493	0.000461	2.355081
Columns	3.895833	3	1.298611	1.116418	0.361986	3.008787
Error	27.91667	24	1.163194			
Total	83.9375	35				

43. ANOVA for Faecal coliforms water for KNUST Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	24.69792	2	12.34896	6.87911	0.003183	3.284918
Within Groups	59.23958	33	1.795139			
Total	83.9375	35				

44. ANOVA for *E. coli* water for KNUST Booster station supply areas

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0	8	0	65535	#NUM!	2.355081
Columns	0	3	0	65535	#NUM!	3.008787
Error	0	24	0			
Total	0	35				

APPENDIX 45

Physicochemical parameters assessed for the Achiase booster stations supply areas under study

LOCATIONS	PHYSICOCHEMICAL					
	Temperature (°C)	**pH**	**Turbidity (FTU)**	**Colour (Hz)**	**Residual chlorine (mL/L)**	**Total chlorine (mg/L)**
Asokwa 1	25.6±0.48	6.9±0.01	1.3±2.46	3.4±6.50	0.105±0.04	0.255±0.03
Asokwa 2	25.5±0.45	6.8±0.05	5.0±9.09	19.4±35.31	0.048±0.01	0.258±0.02
Asokwa 3	25.8±0.34	6.9±0.02	8.3±9.11	19.8±21.70	0.044±0.0	0.263±0.01
Atonsu 1	25.5±0.40	6.9±0.02	3.6±6.54	12.6±23.0	0.043±0.01	0.267±0.01
Atonsu 2	25.7±0.49	6.9±0.03	15.8±14.24	44.9±42.01	0.044±0.01	0.264±0.07
Atonsu 3	25.6±0.48	6.8±0.05	6.3±0.87	17.1±4.40	0.041±0.0	0.262±0.04
Asafo 1	26.4±0.51	6.9±0.04	2.0±3.93	6.5±11.88	0.041±0.01	0.254±0.02
Asafo 2	26.1±0.49	6.9±0.03	6.4±10.42	18.9±32.16	0.050±0.0	0.253±0.01
Asafo 3	25.1±0.23	6.8±0.03	4.3±3.82	12.0±14.78	0.048±0.0	0.244±0.01

APPENDIX 46

Microbial parameters assessed for the Achiase booster stations supply areas under study

LOCATIONS	MICROBIAL		
	Total coliforms (MPN 100/mL)	**Faecal coliforms (MPN 100/mL)**	**E. coli (MPN 100/mL)**
Asokwa 1	5.8±1.26	5.8±1.26	0±0
Asokwa 2	4.9±0.54	4.9±0.54	0±0
Asokwa 3	5.3±0.74	5.3±0.74	0±0
Atonsu 1	4.5±1.32	4.5±1.32	0±0
Atonsu 2	$9.6 \times 10^4 \pm 1.5 \times 10^4$	$9.6 \times 10^4 \pm 1.5 \times 10^4$	3.9±1.56
Atonsu 3	6.7±1.16	6.7±1.16	0±0
Asafo 1	5.0±0.94	5.0±0.94	0±0
Asafo 2	$10.8 \times 10^6 \pm 2.1 \times 10^6$	$10.8 \times 10^6 \pm 2.1 \times 10^6$	5.2±2.14
Asafo 3	4.4±1.20	4.4±1.20	0±0

APPENDIX 47

Physicochemical parameters assessed for the KNUST booster stations supply areas under study

LOCATIONS	PHYSICOCHEMICAL					
	Temperature (^{o}C)	**pH**	**Turbidity (FTU)**	**Colour (Hz)**	**Residual chlorine (mL/L)**	**Total chlorine (mg/L)**
Kentinkrono 1	25.5±0.45	6.8±0.03	0±0	0±0	0.048±0.01	0.251±0.01
Kentinkrono 2	25.7±0.45	6.8±0.04	2.5±1.57	9.7±14.58	0.047±0.01	0.243±0.01
Kentinkrono 3	25.6±0.46	6.9±0.06	0±0	2.8±0.45	0.045±0.00	0.238±0.0
Oduom 1	25.1±0.73	6.9±0.02	0±0	0±0	0.044±0.0	0.236±0.0
Oduom 2	25.3±0.75	6.9±0.01	0±0	0±0	0.040±0.0	0.237±0.01
Oduom 3	27.2±0.23	6.9±0.06	3.8±1.36	10.3±5.16	0.040±0.01	0.218±0.01
Boadi 1	26.1±0.36	6.8±0.02	0±0	0±0	0.042±0.01	0.253±0.10
Boadi 2	25.5±0.40	6.8±0.02	0±0	0±0	0.038±0.0	0.210±0.07
Boadi 3	25.7±0.62	6.9±0.02	3.2±0.39	9.5±1.62	0.037±0.01	0.201±0.06

APPENDIX 48

Microbial parameters assessed for the KNUST booster stations supply areas under study

LOCATIONS	MICROBIAL		
	Total coliforms (MPN 100/mL)	**Faecal coliforms (MPN 100/mL)**	**E. coli (MPN 100/mL)**
Kentinkrono 1	5.8±1.33	5.8±1.33	0±0
Kentinkrono 2	3.7±0.60	3.7±0.60	0±0
Kentinkrono 3	5.4±1.61	5.4±1.61	0±0
Oduom 1	5.1±0.90	5.1±0.90	0±0
Oduom 2	7.6±0.75	7.6±0.75	0±0
Oduom 3	5.8±0.80	5.8±0.80	0±0
Boadi 1	6.6±1.84	6.6±1.84	0±0
Boadi 2	6.6±0.63	6.6±0.63	0±0
Boadi 3	7.8±0.60	7.8±0.31	0±0