

UNIVERSITY OF MINES AND TECHNOLOGY
TARKWA

FACULTY OF MINERAL RESOURCES TECHNOLOGY
DEPARTMENT OF MINERALS ENGINEERING

A THESIS REPORT ENTITLED;

DRINKING WATER QUALITY VARIATIONS IN DISTRIBUTION NETWORKS – A
CASE STUDY AT THE KUMASI WATER SUPPLY SYSTEM (KWSS)

The logo of the University of Mines and Technology is a shield-shaped emblem. It features a blue upper section with a yellow sunburst, a green lower section with a white pickaxe and a grey gear, and a yellow banner at the bottom with the motto 'KNOWLEDGE TRUTH AND EXCELLENCE'. The text 'BY GODFRED FRIMPONG' is overlaid on the emblem.

BY
GODFRED FRIMPONG

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE
AWARD OF THE DEGREE OF MASTER OF SCIENCE IN MINERALS
ENGINEERING

THESIS SUPERVISOR

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ASSOC PROF S. A. NDUR

TARKWA, GHANA
MAY, 2019

DECLARATION

I declare that this thesis is my own work. It is being submitted for the Degree of Master of Science (MSc) in Minerals Engineering in the University of Mines and Technology (UMaT), Tarkwa. It has not been submitted for any degree or examination in any other University.

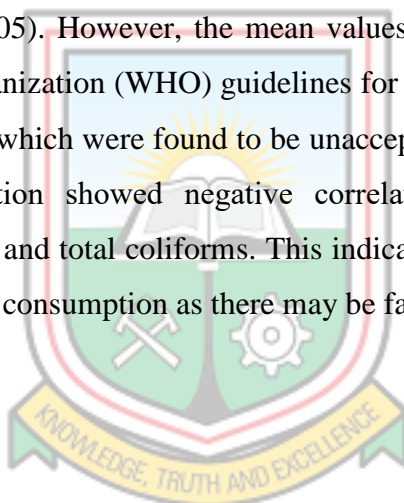
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ABSTRACT

The quality of treated drinking water at the point of use by the consumer may change after travelling through a distribution system. This study assessed changes in drinking water quality during distribution from two treatment plants at Barekese and Owabi through the Kumasi Water Supply System (KWSS). A total of 32 samples from different locations including raw and treated water from both plants, public stand-pipes, taps in homes of consumers, storage facilities, booster stations and dead-end sections of the distribution system were analysed for quality. All samples were tested using standard procedures for pH, turbidity, electrical conductivity, TDS, temperature, salinity, total hardness, calcium hardness, magnesium hardness, total alkalinity, calcium, magnesium, chloride, nitrite, residual chlorine, iron, phosphate, sulphate, manganese, ammonia, *E. coli* and total coliform. One-way ANOVA showed significant water quality variations during distribution for all parameters tested ($p < 0.05$). However, the mean values obtained for all parameters fell within World Health Organization (WHO) guidelines for drinking water quality except for *E. coli* and total coliform which were found to be unacceptable for some sample locations. Pearson's Rank Correlation showed negative correlation between residual chlorine concentration and, *E. coli* and total coliforms. This indicates that water consumed in these communities is unsafe for consumption as there may be faecal contamination.



DEDICATION

This thesis is dedicated to The Most High God, my parents Yaw Kontoh and Veronica Kontoh and my family.



ACKNOWLEDGEMENTS

I am grateful to the Almighty God for making this work a success. I also wish to express my sincere gratitude to my supervisor Assoc. Prof S. A. Ndur for his superb supervision and contribution without which this work would not have been successful.

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Finally, I say big thank you to Dr. Daniel Tutu Benefor, Principal Programmes Officer, Environmental Protection Agency (EPA), Accra, Ghana and all my friends for their immense contributions towards the success of this thesis. May God bless you all.



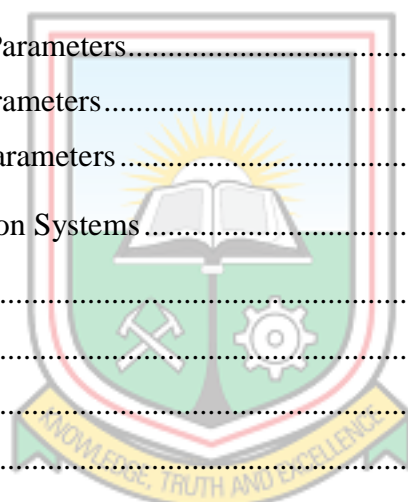
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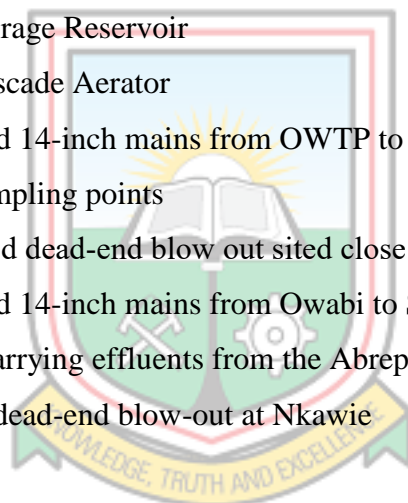
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CHAPTER 1

INTRODUCTION

1.1 Statement of Problem

Safe drinking water may be defined as one that does not present any significant risk to health over a lifetime consumption including different sensitivities that may occur between life stages (Anon, 2011a). It is estimated that 80 percent of all diseases and over one third of deaths in developing countries are caused by consuming contaminated water. On the average, as much as one tenth of each person's productive time is sacrificed to water-related diseases (Anon, 1992).

Efforts have been made by advanced economies to provide quality water to their citizenry and have put in place mechanisms to check water quality consumed by the general public. However, in developing countries, many existing water distribution systems are operating intermittently and at a fraction of their capacities (Anon, 2003). In addition, many more problems with distribution systems exist, and also occur more frequently, than in developed countries. Therefore, although presence of a public water distribution network is often an indicator of improved water supply in a developing country, it should not be assumed that the resulting water quality is always adequate for human consumption (Lee and Schwab, 2005).

The treated water may become contaminated at the source, during transport to the homes, in storage containers, or through improper handling. Statistics show that between 30-60% of water quality incidents are related to events in the water distribution network (Liu *et al.*, 2013). Insufficiently maintained pipes may contain sediments that consume chlorine residuals, rendering disinfection practices ineffective. Cracked pipes or crossed connections with sewer pipes can become entry points for contaminants into a water system, creating an efficient vehicle for transmission of pathogens (Macy and Quick, 2009). Natural ageing and corrosion of infrastructure, can create conditions favourable to bacterial growth. When power outages occur in water supply systems, or when power to systems is periodically interrupted in order to reduce costs or conserve water, the resultant negative pressure in the system can pull contaminants into the water system from outside. Clandestine connections

(holes made in existing water pipes by persons without access to a tap) create apertures in water pipes that also allow contaminants to enter into the water system (Macy and Quick, 2009).

Undoubtedly, dead-end sections of drinking water distribution networks are known to be delicate zones in terms of water quality degradation. Water stagnation due to extended residence time leads to rapid reduction of disinfectant residuals concentration allowing the regrowth of microbial pathogens (Abokifa *et al.*, 2016). Communities which fall within the dead-end zone of the distribution network are likely to consume water that may be of poor quality. Therefore, it may be difficult to ascertain the quality of water that is distributed through pipes for consumption in these communities.

Water pipes installed before and during the 19th century differed in their manufacture, materials, and life span. The oldest cast iron pipes were typically described as having an average useful lifespan of about 120 years because of the pipe wall thickness (Anon, 2006a). Over the years, pipe strength has improved from the time cast iron pipes were being used to the introduction of high-density polyethylene (HDPE) pipes. Most pipes are buried and out of sight, hence they usually draw attention only when one of them leaks, ruptures or a planned pipeline impacts a particular area (Kiefner and Rosenfeld, 2012). As the pipes in water distribution changes with respect to age, accumulation of corrosion by-products and suspended particles turn to occur within the walls of the aged pipes thereby decreasing the pipe diameter and increasing the pipe roughness (Christensen, 2009). The bursting of pipes has raised frequent alarms in many areas these days, particularly in systems coping with septuagenarian, octogenarian, and even century-old pipes (Cooper, 2009). The trends of aging pipes and increasing numbers of main pipe breakages within any distribution system are of concern because of the potential relationship between waterborne disease outbreaks and mains breakages (Anon, 2006a).

The Barekese and Owabi Water Treatment Plants were built to abstraction of raw water, production, distribution, maintenance and customer services in the Kumasi Metropolis in 1967 and 1928 respectively. However, there is little public knowledge on the quality of water consumed at the point of use. There is therefore the need to ascertain the quality of water at the production and point of use sections of the distribution network. This will help identify changes in the water quality along the distribution lines if any.

1.2 Objectives and Scope of the Research

The main objectives of this research are:

- to ascertain the variation in water quality produced at the Barekese and Owabi treatment plants and points of use along the distribution network
- identify the possible causes of the variation in water quality if any and
- make recommendations to management of Ghana Water Company to ensure safe distribution of water to consumers

1.3 Methods Used

- Review of relevant literature
- Sampling using GPS and laboratory analysis
- Technical advice from my supervisor and experts in the industry

1.4 Facilities and Resources Used for the Research

- Laboratory facilities Barekese Dam, Owabi Dam, Suame Booster Station, and KNUST Biology Department Laboratory.
- UMaT library, computer and the internet

1.5 Organisation of Thesis

This thesis is divided into six chapters. Chapter one is the introduction of the research work. It comprises of the statement of problem, objectives and scope of the research, methods used, facilities and resources used as well as the organisation of the thesis. Chapter two describes the background of the study area, location, the Kumasi Water Supply System and water treatment processes at Owabi and Barekese Water Treatment Plans. Chapter three contains the literature review of the nature of water, drinking water safety and human health, drinking water parameters, water distribution systems and causes of water contamination in distribution networks.

Chapter four is contains field work and laboratory analysis of the research. It focuses on water sample collection, precautions taken during the sampling process for both physico-chemical and bacteriological analyses. Chapter five presents the results obtained from the

field and laboratory for investigation and discussion of the results as well. Chapter six has the conclusions and recommendations given based on the results obtained from the study.



CHAPTER 2

BACKGROUND OF STUDY AREA

2.1 Kumasi Metropolitan Assembly (KMA)

The city of Kumasi is the capital of the Ashanti Region and it is the second largest city in Ghana after Accra and its political administration is the Kumasi Metropolitan Assembly. It lies between latitude 6° N and 7° N and longitude 1° W and 2° 30' W. It is located in the centre of the region and has major roads linking the Northern Regions, Eastern, Central, Western and Southern Regions of Ghana. It is bordered by Kwabre District to the North, Nkwabie District to the West, Ejisu District to the East and Bosumtwi-Antwima-Kwanwoma District to the South. The population of Kumasi Metropolis is 1,730,249 which represents 36.2% of the total population of Ashanti Region and covers a land area of 214.30 square kilometers (Anon, 2014). Figure 2.1 shows the Ashanti Region of Ghana.

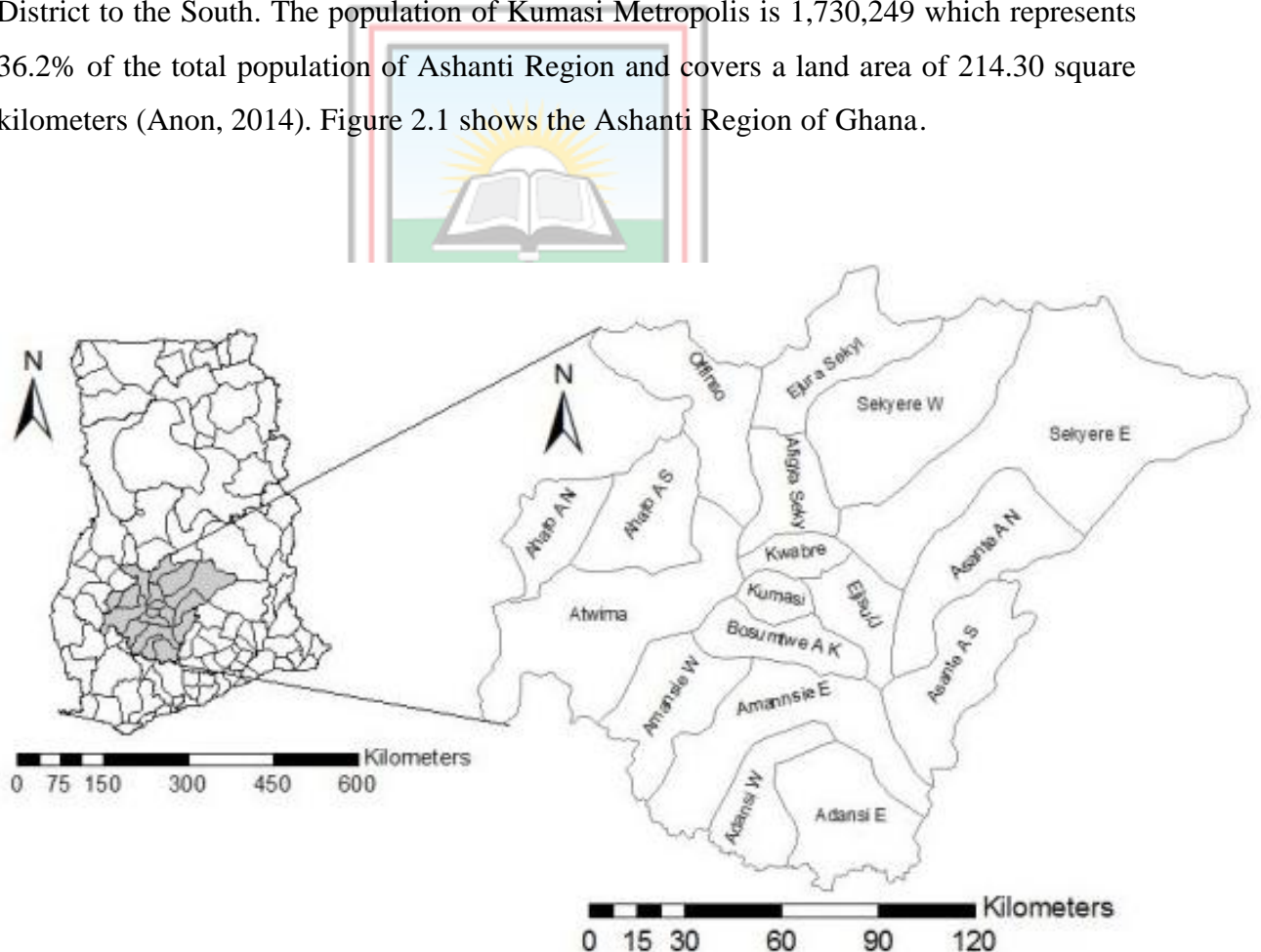


Figure 2.1 Ashanti Region of Ghana

2.2 The Kumasi Water Supply System (KWSS) of Ghana Water Company Limited – Ashanti Region

The Kumasi Water Supply System (KWSS) is managed by GWCL and it is responsible for water abstraction, production, distribution and revenue collection. The KWSS serves over 30 towns and villages in the Ashanti Region. There are twelve operational water districts within the KWSS. They are, North A, North B, North-East, North-West, East, Central, South-East, West 1, West 2, South, Offinso and Asokore Districts. Figure 2.2 shows the operational water districts within the KWSS.

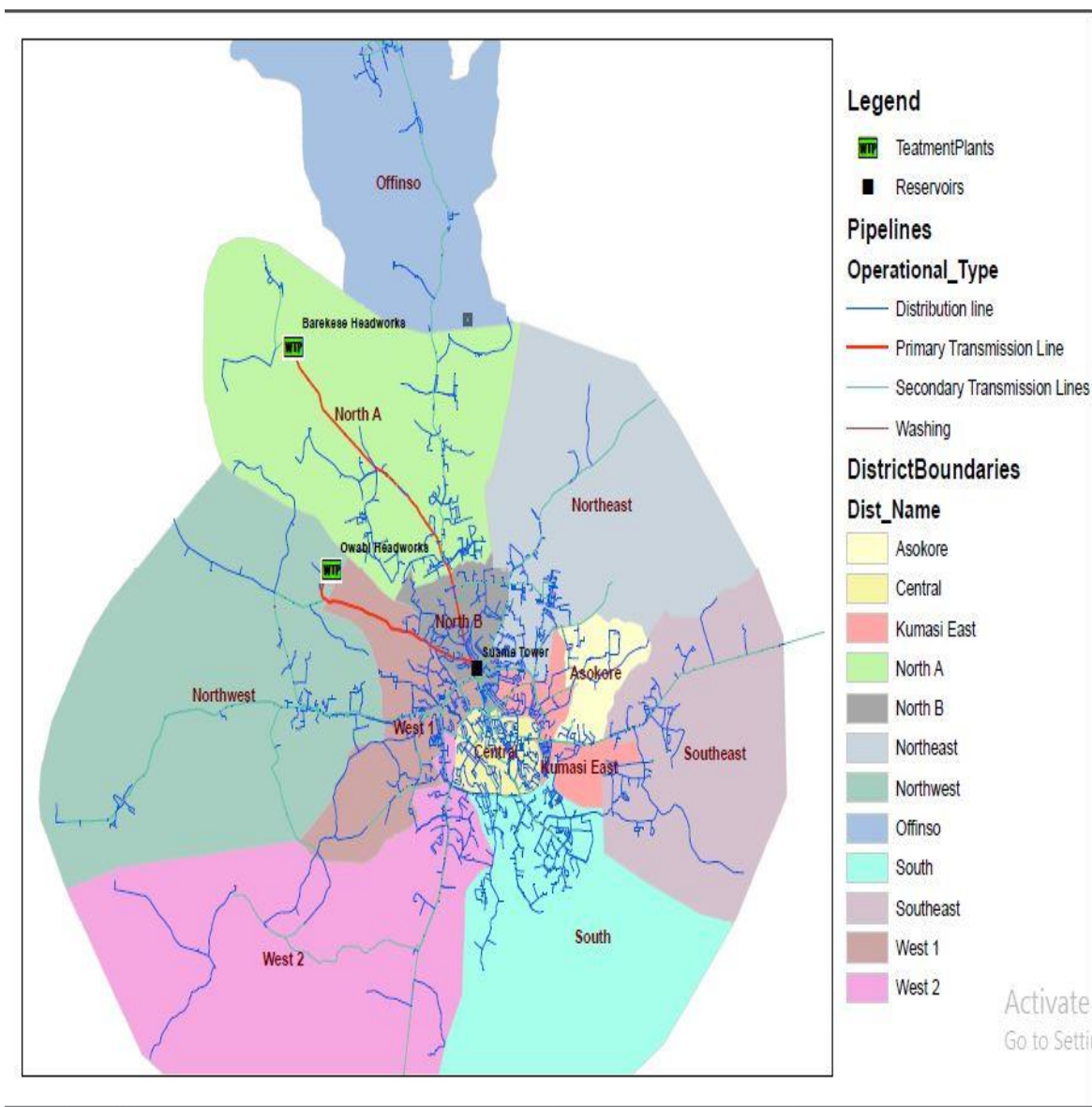


Figure 2.2 Operational Districts of KWSS (Source: Ghana Water GIS Department, Ashanti)

The percentages of water distributed to each of these water districts by the KWSS are influenced by the following factors.

- The availability of water at good pressure in the water district
- The size of the water district
- The average monthly bulk meters reading to Offinso and South East districts
- The average monthly unaccounted-for water as compared with the production
- The production figures from Barekese and Owabi Water Treatment Plants and
- The metering ratio

The KWSS was built in the late 1920's with the Owabi Dam as its only water source. This has now been expanded over the years with growth of the city and population. At present the supply of water to the metropolis is from two surface water treatment plants, The Owabi and Barekese Water Treatment Plants. Currently, the KWSS serves over one million consumers in the Metropolis and its environs.

Treated water from both dams are pumped to Suame Water Reservoir (SWR) before they are re-chlorinated and redistributed by gravity to other communities in the metropolis through pipelines with reducing diameters as water moves further away from the booster station. This is done to maintain adequate pressures in the pipelines which supplies water to communities which are far from the SWR. However, other communities along the mains from both treatment plants and those which are close to the dams are served with water before treated water gets to the SWR while the rest of Metropolis is served by the SWR. This is illustrated in Figure 2.3. O1, O2 and O3 represents communities which receives water directly from the OWTP mains while B1, B2 and B3 represents communities which receives water directly from the BWTP mains and S1, S2, S3, S4 and S5 represents communities which receives water directly from the SWR. There are three underground reservoirs located at the SWR and one overhead tank. The three underground reservoirs have a combined capacity of four million gallons. There are two 1-million-gallon capacity reservoirs and one 2-million-gallon capacity reservoir. The overhead tank has a capacity of 67000 gallons and 100 feet tall.

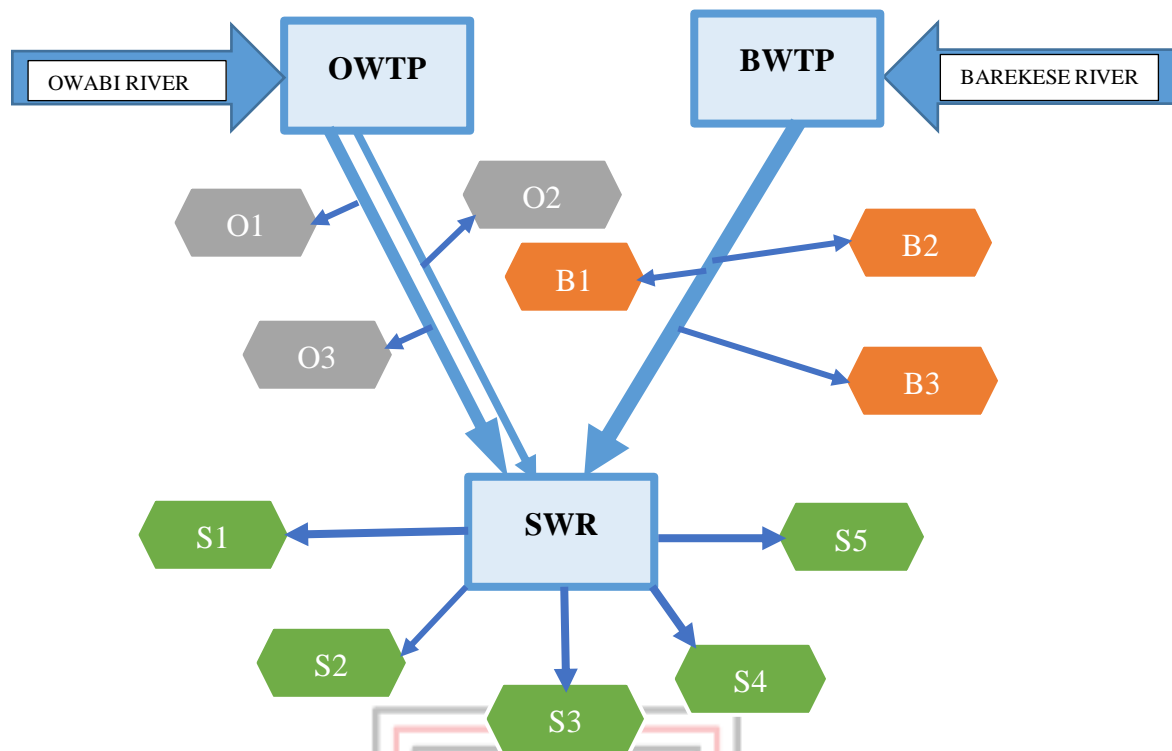


Figure 2.3 Flow Chart of Kumasi Water Supply System

2.3 The Barekese Water Treatment Plant (BWTP)

The Barekese Dam was built on the River Offin at the end of the 1960's. It is an earth fill dam with rock protection on the upstream slope. The dam is about 600 m long and has a maximum height of approximately 15 m. In the middle, the dam is provided with a 77 m wide concrete spillway with a crest elevation of +220.98 m. A raw water intake tower is situated in the impoundment just east from the spillway. The intake tower consists of a dry and a wet well. Raw water can be abstracted at 3 different levels (+218.85 m, +217.02 m and +213.07 m). Each abstraction point is fitted with screens and a penstock gate.

2.3.1 The Water Treatment Processes at BWTP

Raw water received at the BWTP goes through several unit processes in order to produce a wholesome or potable drinking water for human and industrial consumption and commercial purposes. The process flow chart of BWTP is as shown in Figure 2.4.

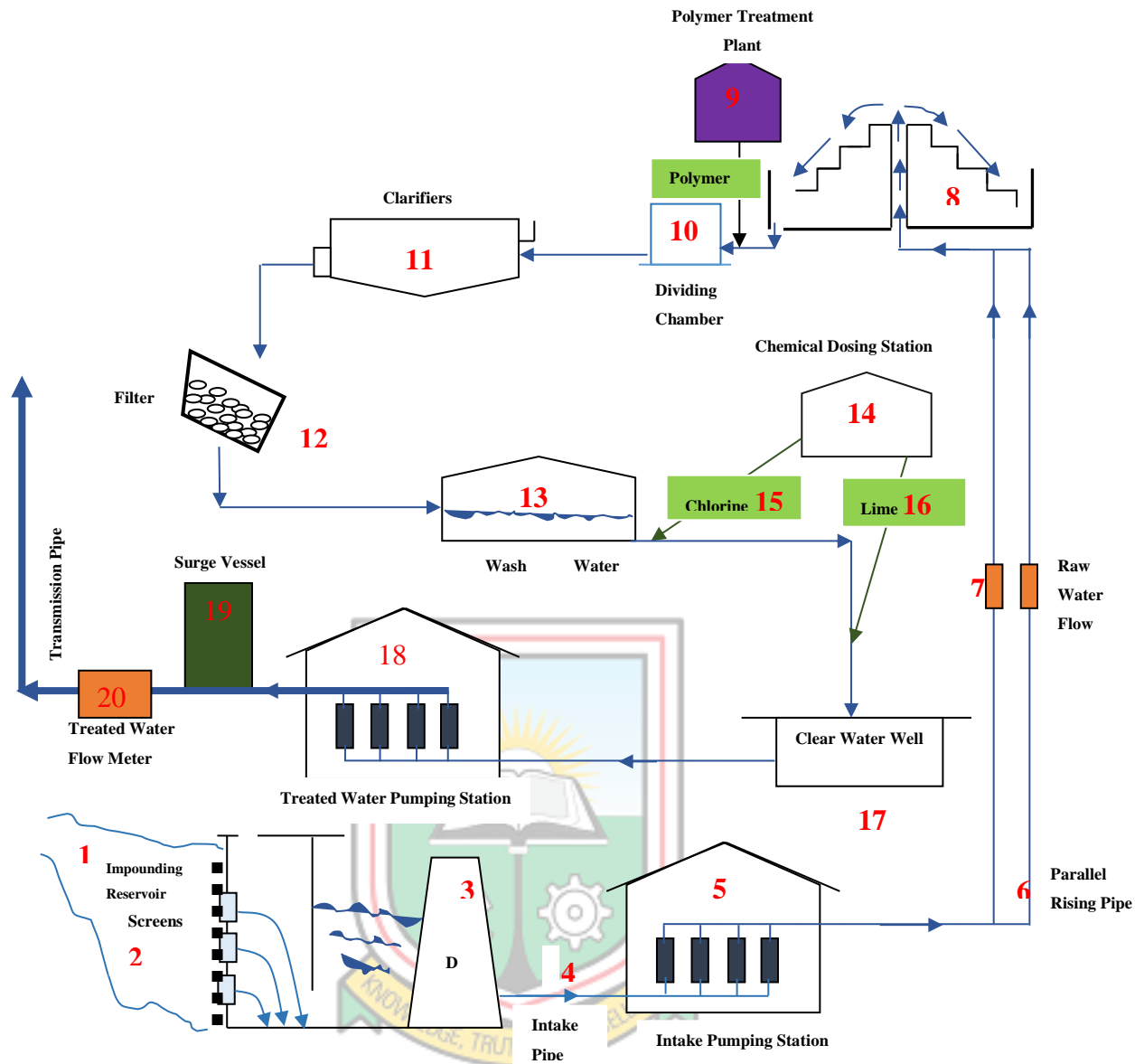


Figure 2.4 Flow chart of Barekese Water Treatment Plant

2.3.2 Impounding Reservoir and Screening

Raw water from source is impounded in a dam. In the dam particles that are heavy enough settle freely thereby enhancing the colour. The raw water is allowed to flow by gravity through screens which eliminates sticks, dead plants, weeds, debris, other organic matter, etc. These materials are removed in order to protect the intake pumps from damage and prevent them from interfering with the subsequent water treatment processes. The water is then transported to the treatment plant through the Intake Tower. The Intake Tower consists of pumps which pumps water to the aerators. The Pump Station consists of an approximately 5 m deep basement and an upper room roughly at ground level.

2.3.3 Aeration

Water from the intake tower is pumped to a double cascade aerator (Figure 2.5) where it mixes the water with atmospheric oxygen. This is done to remove odour arising from high levels of H_2S and CO_2 from decomposing plants and other organic matter. The double cascading aerator is an inclined stepped structure built with concrete where turbulence is induced to the cascading water from the top of the aerator. The thin film of water is allowed to flow at a relatively high velocity through small baffles to divert the flow in a criss-crossing manner. Water samples are taken on an hourly basis by the water quality assurance technicians at the plant for analysis. The parameters accessed are pH, turbidity, dissolved oxygen and colour. This is repeated at each stage of the treatment process.



Figure 2.5 Double Cascade Aerator at BWTP

2.3.4 Water Clarification

The BWTP has been using alum in its clarification processes until January, 2017 when the use of organic polymer was introduced. This is because the polyelectrolyte is more effective than alum. Moreover, its effectiveness is not much affected by the pH of water.

Raw water from the aerator flows through a dividing (or distribution) chamber where it is vigorously mixed with the organic polymer (polyelectrolyte) to obtain a homogenous mixture and sent to the clarifiers (Figure 2.7) for clarification to begin.

The purpose of water clarification at the plant is to remove the suspended or colloidal particles which are not heavy enough to settle freely unless settling is aided or induced. The colloidal particles mainly consist of clay and silt, precipitated iron or manganese oxides, and even bacteria and algae.



Figure 2.6 Hanisa Polymer Treatment Plant at BWTP

Most colloidal particles in natural water supplies carry a net negative electrical charge. Because all the particles carry the same charge, they repel each other. They will not come together to form particles which are large enough to precipitate unless a coagulant and flocculant is applied. The process of neutralization of particle charges and the initial collision and coalescence of two or more particles to form “micro-flocs” due to natural Brownian movement in the body of the water is called Coagulation. So coagulation is the first step of the clarification process at the plant.

The micro-flocs that are formed are still virtually not visible to the eye and too small to settle in a sedimentation tank. Gentle stirring of the water is then applied to cause further collisions

of the micro-flocs so that further growth occurs into particles of sufficient size that are heavy enough to settle rapidly. This growth in size of the micro-flocs due to externally applied movement is called flocculation.

The coarse particles formed are allowed to settle and deposited as sludge in the clarifier so as to reduce the concentration of suspended particles at the filtration tanks. This process is known as sedimentation. The clear water is then received through decanting troughs and sent to the filtration tanks.

The organic polyelectrolyte polymer that is being used at the plant now greatly helps in this flocculation process because they possess numerous sites on the same polymer chain which can absorb additional colloidal particles so that a bridging action occurs and thus precipitation is enhanced. This polymer is pumped from a treatment plant (Figure 2.6) to mix with the raw water in the mixing chamber.



Figure 2.7 BWTP Clarifier

2.3.5 Filtration

Clear water from the clarifiers is received at the filters. The filters are made of layers of sand and gravel. The Barekese Dam uses Rapid Sand Filters (Figure 2.8). They collect the suspended particles such as dust and flocs that were unable to settle at the clarification stage, bacteria, viruses and other micro-organisms. Their removal enhances the effectiveness of

disinfection which is next stage in the water purification process. This is because it is expected to reduce turbidity to less than 0.5NTU and remove about 99.5% of flocs, suspended particles, pathogens and other micro-organisms.



Figure 2.8 BWTP Sand Filters

2.3.6 Disinfection or Chlorination

Chlorine is a strong oxidant commonly used in water treatment for oxidation and disinfection purposes. Chlorination is the process of adding chlorine to drinking water to disinfect it. Chlorine kills and inactivates viruses, bacteria, and other pathogens. It is available as compressed elemental gas, sodium hypochlorite solution (NaOCl) or solid calcium hypochlorite ($\text{Ca}(\text{OCl})_2$).

The filtered water from the filters is received at the wash water sump where it mixes with NaOCl and in some cases hydrogen gas. The accepted chlorine concentration at the plant 4 mg/L. The concentration of chlorine depletes along the distribution network so the chlorine concentration is tested at the SWR and appropriate doses applied to achieve an acceptable concentration as re-distributed water flows through the network.

2.3.7 pH Adjustment

Lime is added to the filtered water from the wash water sump to adjust to between 6.5 and 7 to stabilise the treated water in order to minimise corrosion within the distribution system, and the plumbing of consumers. Corrosive water contains excessive amounts of carbon dioxide. Lime precipitates the CO₂ to form calcium carbonate, which provides a protective coating on the inside of water mains.

The water is then received into the clear water well which has a capacity to store two million gallons of water. It is then pumped through a 36-inch diameter pipe to the Suame central storage where it is re-chlorinated and re-distributed to other communities in the metropolis. Some communities along the mains such as Offinso, Okess, UGC and Breman are also served through pipes with varying diameters. Offinso is served with a 12-inch pipe while Breman, UGC and Okess receive water from an 8-inch pipe connected to the mains. The 36-inch pipe from the treatment plant ends at the Suame roundabout where it is connected to an 18-inch diameter pipe which feeds the new 1 million capacity reservoir and a 24-inch pipe to the 2-million-gallon capacity reservoir.

2.4 The Owabi Water Treatment Plant (OWTP)

The Owabi Water Treatment Plant (OWTP) is situated on latitude 06-43°N and longitude 01-36°N with altitude 287 m. It is located at Owabi near Akropong Esaase in the Atwima Mponua district of the Ashanti region. It was constructed in 1928. It is a stone masonry gravity dam with a spillway crest at 227.5 m. It is about 135 m long and 11 m high. The main river is the Owabi River with six tributaries coming together to form the reservoir. They are Mpopunase, Akuasu, Acheampong, Ntikyir, Sikabrei and Anyanasu. The average area of the entire reservoir is 3.5 km² with average depth of 6.86 m when spilling. It has a capacity of 13.7 billion gallons of water. The Owabi reservoir is designed to produce 20% of the total potable water requirement in the Kumasi metropolis and nearby townships (Akoto *et al.*, 2014). The main purpose of preserving the Owabi catchment includes maintenance of water quality, water storage, water recharge, and reproduction area for fish and other aquatic organisms (Okurut *et al.*, 2000).

The OWTP is built near the reservoir which provides about 3 million gallons of potable water to the Kumasi Metropolis daily. The land surrounding the dam is used for agriculture

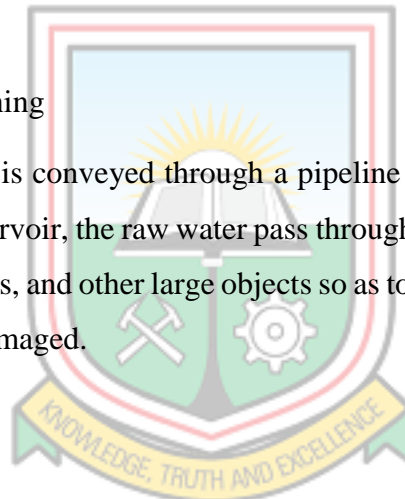
and human settlements. The remainder is made up a vegetation cover and water bodies. The catchment area is densely populated because of rapid urbanization and increased agricultural activities in the past few decades. The river and its tributaries within the catchment run through some communities within the Kumasi Metropolis. The main sources of water pollution include municipal waste from suburbs like Kronum, Bremang and Abrepo that are situated within the catchment as well as industrial effluents from small-scale industries dotted along the tributaries (Akoto *et al.*, 2014).

2.4.1 The Water Treatment Processes at OWTP

The raw water from the dam as in the OWTP goes through several unit processes to render it wholesome for human and industrial consumption. The process flow chart of OWTP is shown in Figure 2.9.

2.4.2 Preliminary screening

Raw water from the dam is conveyed through a pipeline to the reservoir for treatment. At the intake point in the reservoir, the raw water pass through a set of coarse screens to remove solids such as debris, sticks, and other large objects so as to protect pipes from being blocked and pumps from being damaged.



2.4.3 Storage Reservoir

Raw water flows by gravity or sometimes pumped from the intake to a storage reservoir (Figure 2.10) before it is treated at the plant. The storage reservoir ensures that water is continually supplied even during periods of drought or at peak demands. It also improves the quality of raw water because fine particles settle. Some pathogens are also destroyed by ultraviolet radiation from the sun.

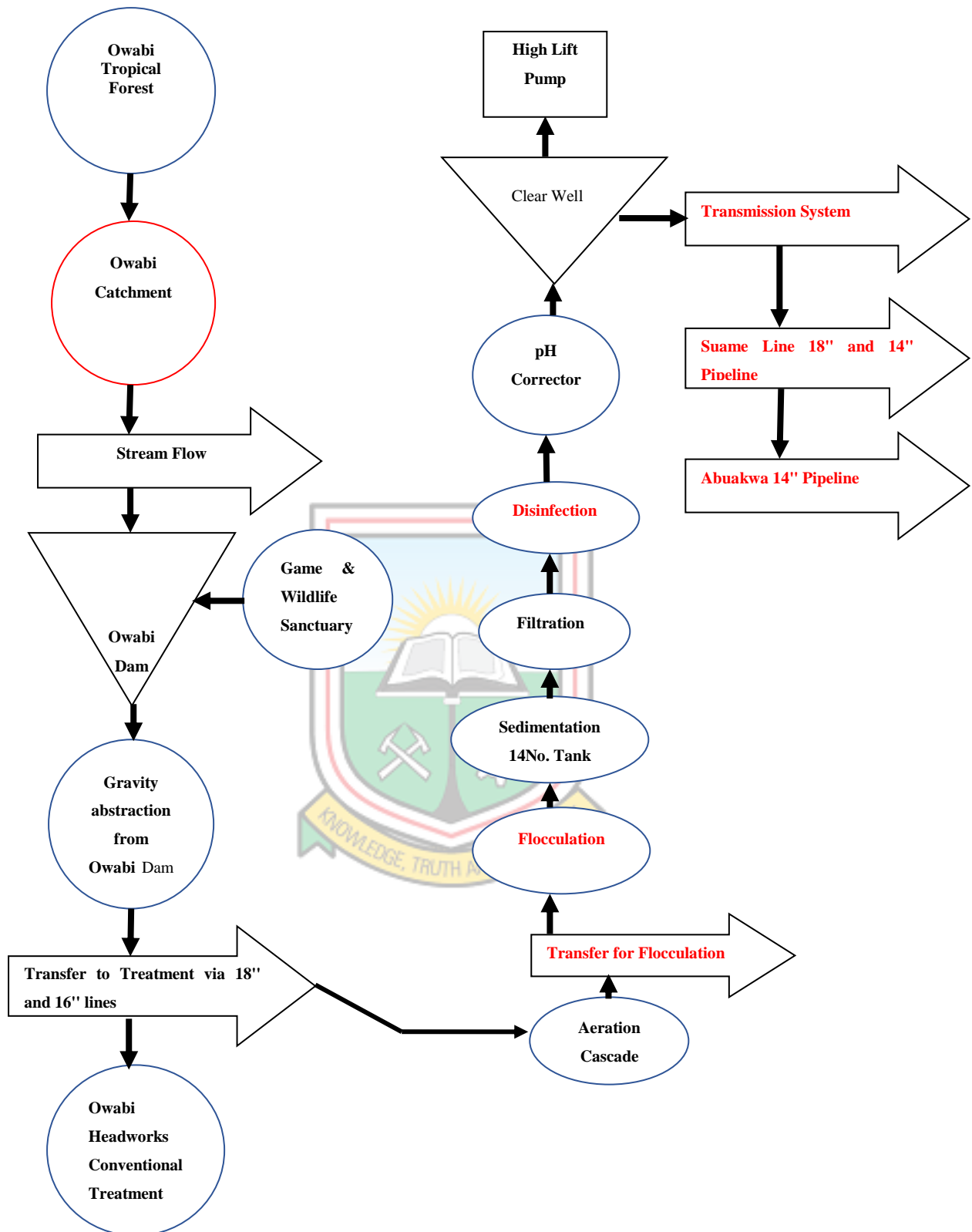


Figure 2.9 Flow Chart of OWTP - Source Owabi Headworks - Ashanti Region



Figure 2.10 OWTP Storage Reservoir

2.4.4 Screening and micro-straining

At the treatment plant, the raw water is screened again to remove fine solids particularly algae. Micro-strainers consist of fine stainless-steel mesh drums with up to 25000 apertures per sq. cm. The apertures are between 25 – 35 μm .

2.4.5 Aeration

Water from the screen and micro-strainers is sent to the cascade aerator (Figure 2.11) where it mixes with atmospheric oxygen to increase dissolved oxygen content and also to reduce objectionable odour. Aeration also reduces corrosiveness of water by reducing carbon dioxide due to the rise in pH. Some amount of iron and manganese are also removed in the process.



Figure 2.11 OWTP Cascade Aerator

2.4.6 Coagulation

The remaining suspended solids after fine screening are small (less than 10 μm) and hence are unable to settle on their own. These are particles of clay, metal oxides, and microorganisms which normally are negatively charged. Coagulants (polyelectrolyte) is added to destabilise these particles to form flocs which can then settle on their own. The process of increasing the chance of particle collisions is known as coagulation. This is achieved by slow mixing of the coagulant with water. After thorough mixing, the coagulated raw water then flows by gravity through water flumes to the sedimentation tanks where sedimentation and clarification takes place. The type of chemical coagulant used is a polymer (SUDFLOC 3870/Poly aluminium chloride).

2.4.7 Clarification and Sedimentation

The flocs formed after flocculation is collected as sludge after settling in sedimentation tanks. As the flocs settle, the clear water is decanted into the filtration units.

2.4.8 Filtration

After sedimentation, the remaining impurities in water are very fine solids. Some of these impurities are originally in the raw water, but some are formed during the coagulation

process. The residual materials are removed in the filtration process where water moves through layers of fine sand and gravels.

2.4.9 pH adjustment

The pH of the treated water is adjusted to between 6.5 and 7 to prevent it from being corrosive to the metallic portions of the distribution network and household plumbing if it is acidic, or form scales in the pipes if it is alkaline in nature. Lime is added to adjust pH at the plant.

2.4.10 Disinfection

Although the coagulation and filtration processes can remove some viruses and bacteria, the filtered water may still contain some pathogens, viruses and bacteria which have to be destroyed to make it safe for human and industrial consumption. Disinfection methods include chlorination with calcium hypochlorite and ozonation. The treated water is then pumped to the clear well reservoir and distributed to communities close to the dam for consumption and also to the Suame central storage for re-chlorination and re-distribution.

Treated water is distributed through three main pipelines. They are two 14-inch and one 18-inch diameter pipelines. One 14-inch diameter pipeline supplies Abuakwa and surrounding communities. The other-14inch diameter pipeline is laid parallel to the 18-inch diameter pipeline to the Suame central storage facility (Figure 2.12). However, the 14-inch pipeline to Suame is fitted with a centre valve at Kropo to maintain adequate pressures for water distribution to adjoining communities.



Figure 2.12 18-inch and 14-inch mains from OWTP to Suame Water Reservoir



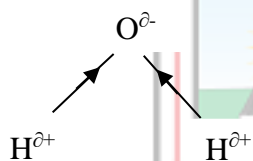
CHAPTER 3

LITERATURE REVIEW

3.1 Overview of Water

Water is an essential resource in the production of most types of goods and services including food, energy and manufacturing. Water supply (quantity and quality) at the place where the user needs it must be reliable and predictable to support financially sustainable investments in economic activities (Anon, 2015).

Water is a transparent and nearly colourless chemical substance. It is the main constituent of Earth's streams, rivers, lakes, and oceans, and the fluids of most living organisms. Its chemical formula is H_2O . That is, one molecule of water contains one oxygen and two hydrogen atoms, that are connected by covalent bonds (Anon, 2015).



The angle between the two hydrogen-oxygen bonds is about 105° . The water molecule is polar and hence can form hydrogen bonds with many polar molecules. It is usually referred to as a universal solvent. The liquid state of the substance is normally referred to as water but it's also referred to as ice in its solid state as ice or as steam or water vapour in its gaseous state. It also occurs in nature as snow, glaciers, icebergs and ice packs, dew, fog, clouds, aquifers, and atmospheric humidity.

3.2 Drinking Water Safety and Human Health

The quality of drinking-water is a powerful environmental determinant of health. Drinking-water quality management has been a key pillar of primary prevention for over one-and-a-half centuries now. It also continues to be the foundation for the prevention and control of waterborne diseases. Water is essential for life, but it can and does transmit disease in countries in all continents – from the poorest to the wealthiest. Diarrhoea is the most predominant waterborne disease and has an estimated annual incidence of 4.6 billion cases and causes 2.2 million deaths every year (Awopetu *et al.*, 2013).

There are several variants of the faecal-oral pathway of water-borne disease transmission. These include contamination of drinking-water catchments by faecal matter from human or animals, water within the distribution system (e.g. through leaky pipes or obsolete infrastructure) or of stored household water as a result of unhygienic handling.

Millions of people worldwide are exposed to unsafe levels of chemical contaminants in the water they drink. This may be linked to a lack of proper management of urban and industrial wastewater or agricultural run-off water. Chemical contamination can also be linked to naturally-occurring fluoride and arsenic, which can cause tooth/skeletal and cancer damage respectively, when exposed to it for a long time (Anon, 2010). The Millennium Development Goal target 7c calls for reducing by half the proportion of people without sustainable access to safe drinking-water and basic sanitation by 2015. Reaching this target implies among other things, tackling both the quantity (access and scarcity) and quality (safety) dimensions of drinking-water provision (Anon, 2010).

3.3 Drinking Water Quality

Drinking water does not need to be absolutely pure to be safe. Since water is such a good solvent, pure water containing nothing else is almost impossible to attain. What is required is that drinking water be safe to drink for people in most stages of normal life, including children over six months of age and the very old. It should contain no harmful concentrations of chemicals or pathogenic microorganisms, and ideally it should be aesthetically pleasing with regards to appearance, taste and odour (Anon, 2011b). To achieve this, the Biological, Physical and Chemical parameters are assessed to see if they fall within acceptable limits.

3.3.1 Biological Parameters

The greatest risk to public health from microbes in water is associated with consumption of drinking-water that is contaminated with human and animal excreta, although other sources and routes of exposure may also be significant (Anon, 2004). It is a very significant feature because most infections and diseases like cholera, typhoid fever, dysentery and hepatitis A and other gastrointestinal diseases which are prevalent in our society can be transmitted to humans through an unsafe drinking water source. Drinking such contaminated water or using it in food preparation may cause new cases of infection. Those at greatest risk of

infection are infants and young children, people whose immune system is suppressed, the sick, and the elderly. Drinking water pathogens may be divided into three general categories: bacteria, parasitic protozoa and viruses (Anon, 2003).

The use of indicator organisms, in particular the coliform group, as a means of assessing the potential presence of water-borne pathogens has been paramount to protecting public health. These are based upon the principle of the detection of selected bacteria that are indicative of either contamination or deterioration of water quality through the use of simple bacteriological tests. This has been the foundation upon which protection of public health from water-borne disease has been developed (Anon, 2002).

Bacterial Pathogens

Bacterial pathogens may be excreted pathogens from humans and animals or pathogens growing in water supplies. The human bacterial pathogens that can be transmitted by consuming contaminated drinking water, and that present a serious risk of disease, include *Salmonella spp*, *Shigella spp*, enterovirulent *E. coli*, *Vibrio cholera*, *Yersinia enterocolitica*, *Campylobacter jejuni* and *C. coli* (Anon., 2011b).

After being excreted in faeces from the body of their host, bacterial pathogens gradually lose viability and the ability to cause infection. The rate of decay varies with different bacteria; it is usually exponential, and after a certain period a pathogen will become undetectable. The most common waterborne pathogens are those that are highly infectious or highly resistant to decay outside the body. Pathogens with a low persistence (i.e. those that do not survive long outside the host) must rapidly find a new host and are more likely to be spread by person-to-person contact or by poor personal or food hygiene than by drinking water. If drinking water is faecally contaminated, bacterial pathogens are likely to be widely and rapidly dispersed. Outbreaks of waterborne disease are therefore frequently characterised by infection across a whole community (Anon, 2011b).

Total coliform bacteria are a collection of relatively harmless microorganisms that live in large numbers in the intestines of man, warm-blooded and cold-blooded animals. They aid in the digestion of food. A specific subgroup of this collection is the faecal coliform bacteria, the most common member being *Escherichia coli* (*E. coli*). These organisms may be separated from the total coliform group by their ability to grow at elevated temperatures and

are associated only with the faecal material of warm-blooded animals. *Escherichia coli* is a gram negative rod of the family *Enterobacteriaceae*, lactose-fermenting in 24 hours at 44.5 ° C, and which can grow with or without oxygen. Faecal coliform by themselves are usually not pathogenic; they are indicator organisms, which means they may indicate the presence of other pathogenic bacteria. Faecal Coliform bacteria indicate the presence of sewage contamination of a waterway and the possible presence of other pathogenic organisms. Most strains of *E. coli* do not produce debilitating toxins but there are a few strains that are; one of them is the *E. coli* O157:H7 strain. It is found in the digestive tract of cattle. The primary sources of faecal coliform bacteria to fresh water are wastewater treatment plant discharges, failing septic systems, and animal waste (Oram, 2014). Drinking-water may be only one vehicle of transmission for pathogens by the faecal–oral route. Contamination of food, hands, utensils and clothing can also play a role, particularly when domestic sanitation and hygiene are poor.

Drinking water safety is not related only to faecal contamination. Some organisms grow in piped water distribution systems (e.g. *Legionella*), whereas others occur in source waters guinea worm (*Dracunculus medinensis*) and may cause outbreaks and individual cases (Anon., 2006a; Anon, 2014b).

Protozoa

The great majority of protozoa in freshwater are natural aquatic organisms of no significance to health. They generally feed on other microorganisms such as bacteria, cyanobacteria or algae. The greatest diversity of protozoa is found in open surface waters, including water supply sources, but some species can colonise piped water supplies; the extent to which this occurs depends on bacterial activity in these supplies.

The protozoa that may occur in drinking water and cause adverse health effects fall into two functional groups:

- enteric protozoa that occur widely as parasites in the gut of humans and other mammals (e.g. *Cryptosporidium*, *Giardia* and *Entamoeba histolytica*);
- Free-living organisms that are opportunistic pathogens in humans and are responsible for serious cerebral and eye diseases (there are very few such organisms), e.g. *Naegleria* and *Acanthamoeba*.

Both *Acanthamoeba* and *Naegleria* species are known to support symbiotic growth of *Legionella* species within the cell, and the presence of these amoebae in cooling-tower water can indicate conditions that favour *Legionella* (Anon, 2011b).

Viruses

Viruses are among the smallest of all infectious agents. In essence they are molecules of nucleic acid that can enter cells and replicate in them. The virus particle consists of a genome, either ribonucleic acid (RNA) or deoxyribonucleic acid (DNA), surrounded by a protective protein shell, the capsid. Frequently this shell is itself enclosed within an envelope that contains both protein and lipid. Viruses replicate only inside specific host cells, and they are absolutely dependent on the host cell's synthetic and energy-yielding apparatus for producing new viral particles. The viruses of most significance for drinking water are those that multiply in the human intestine and are excreted in large numbers in the faeces of infected individuals. Although they cannot multiply outside the tissues of infected hosts, some enteric viruses can survive in the environment and remain infective for long periods. Human enteric viruses occur in water largely as a result of contamination with sewage and human excreta (Anon, 2011b). Other known bacteria, viruses, protozoa and helminths that are found to contaminate water are presented in Table 3.1.

Table 3.1 Common bacteria, viruses, protozoa and helminths (Anon, 2011b)

| Viruses | Bacteria | Protozoa and Helminths |
|-------------------|---------------------------|-------------------------------|
| Adenovirus | <i>Campylobacter spp.</i> | <i>Cryptosporidium parvum</i> |
| Astrovirus | <i>E. Coli</i> | <i>Dracunculus medinensis</i> |
| Enteroviruses | <i>Salmonella spp.</i> | <i>Entamoeba histolytica</i> |
| Hepatitis A virus | <i>Shigella spp.</i> | <i>Giardia intestinalis</i> |
| Hepatitis E virus | <i>Vibrio cholera</i> | <i>Toxoplasma gondii</i> |

In 2008, Ghana reported 3,357 cases of water related diseases (mainly diarrhoea and cholera) and 107 deaths, resulting in a fatality rate of 3.19% (Opintan *et al.*, 2008). Between January and April 2009 there were 5,000 cases of cholera with 60 deaths. In the year 2010, there was a total number of 9,548 cases of cholera and 100 deaths were reported in Ghana (Anon., 2014a).

3.3.2 Physical Parameters

Physical parameters of water are colour, taste, odour, turbidity, temperature, total dissolved solids (TDS), dissolved oxygen, hardness and pH. Even though these characteristics may not in themselves be of direct consequence to health but they may lead to the water being rejected by consumers. These consumers may seek other water sources that may not be safe.

Colour

Colour in water is primarily a concern of water quality for aesthetic reason. Ideally, drinking water should not have any visible colour. Coloured water gives the appearance of being unfit to drink, even though the water may be perfectly safe for public use. Colour in drinking water may also indicate the presence of organic substances, such as algae or humic compounds, dissolved iron and other metal impurities. Colour is measured in standard Platinum-Cobalt Units (PCU) or APHA (Anon, 2011b).

Taste and Odour

Taste and odour are human perceptions of water quality. Human perception of taste includes sour, salty, sweet and bitter. Relatively simple compounds produce sour and salty tastes. However sweet and bitter tastes are produced by more complex organic compounds. Organic materials discharged directly to water, such as falling leaves, runoff, etc., are sources of tastes and odour-producing compounds released during biodegradation. Objectionable tastes and odours can result from compounds produced by certain types of algae, cyanobacteria (blue-green algae), bacteria and sometimes protozoa (Anon, 2011b)

Turbidity

Turbidity is a measure of clarity or transparency of water. Cloudy water is caused by the presence of suspended particles scattering and absorbing light. The more the total suspended solids there is, the higher the turbidity. It is important for health and aesthetic reasons. Turbidity is measured in Nephelometric Turbidity Units (NTU). Then parametric turbidity value of drinking water according to the Environmental Protection Agency is 1 NTU and measures are put in place to make sure that the necessary agencies responsible for water are dealt with in the event of non-compliance.

Temperature

Cool water is generally more palatable than warm water, and temperature will have an impact on the acceptability of a number of other inorganic constituents and chemical contaminants that may affect taste. High water temperature enhances the growth of microorganisms and may increase problems related to taste, odour, colour and corrosion (Anon, 2011). Temperature of water is significant because it affects the amount of dissolved oxygen in the water. The amount of oxygen that will dissolve in water decreases as temperature increases. This is as a result of the low solubility levels of O₂ when temperature increases (Matear *et al*, 2000). It is measured in *degree Celsius*.

Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) consists of inorganic salts and small amounts of organic matter that are dissolved in water. Clay particles, colloidal iron and manganese oxides and silica, fine enough to pass through a 0.45-micron filter membrane can also contribute to TDS (Anon, 2011a). The palatability of water with TDS level of less than about 600 mg/L is generally considered to be good; drinking-water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000 mg/L. The presence of high levels of TDS may also be objectionable to consumers, owing to excessive scaling in water pipes, heaters, boilers and household appliances. Water with very high or low TDS may also be corrosive.

Dissolved Oxygen

Drinking water will generally contain an adequate concentration of dissolved oxygen; however, under some circumstances the oxygen concentration may be reduced. This may occur, for instance, where water has been drawn from deep storages, where there is considerable growth of microorganisms in a distribution system, or following prolonged periods of high water temperature (Anon, 2011b).

Low oxygen concentrations enable nuisance anaerobic microorganisms to grow, producing by-products that affect the aesthetic quality of the water and increase corrosion of pipes and fittings. There are a number of such nuisance microorganisms. Manganese-reducing bacteria produce black manganese deposits which can slough off pipes and soil laundry. Sulphate-reducing bacteria can produce hydrogen sulphide, giving drinking water a 'rotten egg' smell. Nitrate-reducing bacteria can produce nitrite. Iron-reducing bacteria can increase the concentration of ferrous ion in solution which will lead to the deposition of insoluble ferric

salts when aeration is increased. Localised pH changes associated with the growth of nuisance microorganisms can also cause rapid corrosion in metal pipes.

There have been no direct health effects caused by low oxygen concentrations in drinking water. Indirect effects may result from the corrosion of fittings, which can give rise to higher concentrations of heavy metals such as lead, copper and cadmium, and by the anaerobic generation of hydrogen sulphide and nitrite. It is desirable that the dissolved oxygen concentration in drinking water be greater than 85% saturation.

Hardness

Hardness is caused primarily by the presence of calcium and magnesium ions, although other cations such as strontium, iron, manganese and barium can also contribute to hardness. Hard water requires more soap than soft water to obtain a lather. It can also cause scale to form on hot water pipes and fittings. Public acceptance of hardness can vary considerably among communities and is generally related to the hardness that the consumer has come to expect, which in turn is due to the source of the water (Anon., 2013a).

Power of Hydrogen (pH)

Power of hydrogen (pH) is a measure of the hydrogen ion concentration of water. It is measured on a logarithmic scale from 0 to 14. A pH of 7 is neutral, greater than 7 is alkaline, and less than 7 is acidic. When pH is below 6.5 or above 11, the water may corrode plumbing fittings and pipes. This, however, will depend on other factors such as the material used, the concentration and type of ions in solution, the availability of oxygen, and the water temperature. Under some conditions, particularly in the presence of strong oxidising agents such as chlorine, water with a pH between 6.5 and 7 can be quite corrosive. The release of hazardous chemicals from materials and fittings can be influenced by pH, the change in pH values can either lead to an increase or decreased of metals released (Anon., 2014c). Corrosion of iron pipes can increase as pH increases, but iron concentrations in drinking water decrease due to the lower solubility of iron at higher pH (Karalekas *et al*, 1983).

3.3.3 Chemical Parameters

The chemical parameters include most of the metals on the periodic table. In different concentrations they tend to pose serious health problems to humans, plants and animals.

Some of these metals are Arsenic, cadmium, chromium, lead, manganese, nickel, copper, iron and zinc.

Arsenic

The concentration of arsenic in natural waters, including open ocean seawater, generally ranges between 1 and 2 µg/l. In areas with volcanic rock and sulphide mineral deposits, concentrations may be elevated. However, mean arsenic concentrations in sediment range from 5 to 3000 mg/kg; the higher levels occur in areas of contamination but are generally unrelated to arsenic concentrations in water (arsenic). Very toxic to humans, some arsenical compounds are carcinogens, hence much of the concern regarding them, but there are a variety of other effects on health. The World Health Organisation (WHO) states that inorganic arsenic is a documented human carcinogen, and that a relatively high incidence of skin and possibly other cancers that increase with dose and age has been observed in populations ingesting water containing high concentrations of arsenic (Anon, 2001).

Cadmium

Cadmium is highly toxic, its concentrations in waters must be highly limited and controlled. With it being very strongly adsorbed on muds, humus and organic matter, leading to the possibility of entry to the food chain via fish and fish food, and subsequent accumulation in tissue (Anon, 2004). Usually cadmium concentrations in unpolluted natural waters are below 1 µg/l. The average levels of cadmium open waters may range between 0.1 µg/l and 0.025 µg/l. In the sediments, levels in mud can range from 1 to 10 mg/kg dry weight and sometimes from 5–19 mg/kg dry weight. Levels of cadmium could be higher in areas supplied with soft water of low pH, as this would tend to be more corrosive in plumbing systems containing cadmium (Anon, 2011b).

Chromium

The most common forms of chromium that occur in natural waters in the environment are trivalent chromium (chromium-3) and Hexavalent chromium (chromium-6). The current federal drinking water standard for total chromium is 0.1 mg/L or 100 ppb. Chromium-6 and chromium-3 are covered under the total chromium drinking water standard because these forms of chromium can convert back and forth in water and in the human body, depending on environmental conditions. Measuring just one form may not capture all of the chromium that is present. In order to ensure that the greatest potential risk is addressed,

EPA's regulation assumes that a measurement of total chromium is 100 % chromium-6, the more toxic form (Anon, 2004).

Lead

Lead levels in the water will increase as it sits, or stagnates, in the pipes when the water is not used for several hours, such as overnight or during working hours. Taps that are used frequently will be less likely to contain lead in the water (Anon., 2011b). Like arsenic, lead is also a natural element to be found in the environment, e.g. in form of lead sulphide (galena). However, its solubility in water is limited. The natural background concentrations of lead in groundwater – in relation to the 90 percentile – are between 0.07 µg/l in vulcanite and 8.5 µg/l in sand and gravel of Northern Germany. Taking all key hydro-geological units together, this produces a “cross-unit background value” of approximately 3.9 µg/l Pb. However, significantly high natural lead concentrations may occur locally in individual cases (Anon., 2013a).

Manganese

Manganese is a mineral that naturally occurs in rocks and soil and is a normal constituent of the human diet. It exists in well water as a naturally occurring groundwater mineral, but may also be present due to underground pollution sources. Manganese may become noticeable in tap water at concentrations greater than 0.05 milligrams per litre of water (mg/L) by imparting a colour, odour, or taste to the water. However, health effects from manganese are not serious concern until concentrations are approximately 10 times higher. This action level is consistent with the World Health Organization guidance level for manganese in drinking water. (Anon, 2011b).

Copper

Copper is a reddish metal that occurs naturally in rock, soil, water, sediment, and air. It is an essential element for living organisms, including humans, and in small amounts necessary in our diet to ensure good health. However, too much copper can cause adverse health effects, including vomiting, diarrhoea, stomach cramps, and nausea. It has also been associated with liver damage and kidney disease. Water is one of the ways that copper may enter our bodies. The Environmental Protection Agency (EPA) has established an “action level” for copper in drinking water. This action level is exceeded if the level of copper in

more than 10 percent of the tap water samples collected by a water system is greater than 1,300 micrograms per litre (Anon, 2011b).

Nickel

Nickel occurs in water as Ni^{2+} and sometimes as NiCO_3 . It may be either dissolved, or made to form complexes with inorganic ligands. This is another metallic element which is of moderate concern because of possible carcinogenicity as far as humans are concerned; it also has variable harmful effects on aquatic life. It is toxic to plant life, too, and is a hazard to fish (generally in the mg/L concentration range). Nickel may also be bound to particles. Seawater contains approximately 0.5-2 ppb of nickel, and rivers contain approximately 0.3 ppb. Under normal conditions nickel does not react with water Iron (Anon, 2004).

Mercury

Mercury is very toxic which can normally be found in industrial waste. Normally from industrial waste discharges. Very toxic, especially in organo-mercury compounds (e.g. methyl-mercury). This is a very toxic element, the hazards of which are magnified by the accumulation of organo-mercury compounds in fish. It is generally industrial in origin (dental amalgams, anti-fouling paints, plastics manufacture, battery-making, paper-making and so on) though some come from the natural environment. There have been some major pollution incidents (notably in Japan) where both death and severe damage to health has been caused to many people consuming fish and shellfish contaminated by heavy industrial discharges of mercury (Anon, 2004).

Iron

Although the WHO does not have a suggested guideline for iron in drinking water, it does not have any adverse health effects. Concentrations between 1.0 – 3.0 mg/L can be acceptable for people drinking anaerobic well water. Iron levels above 0.3 mg/L can stain water pipes and clothes during washing. Dissolved iron is mainly present as $\text{Fe}(\text{OH})^{2+}$ under acidic and neutral, oxygen-rich conditions. Under oxygen-poor conditions it mainly occurs as binary iron. Iron is part of many organic and inorganic chelation complexes that are generally water soluble. Drinking water may not contain more than 200 ppb of iron.

Zinc

Zinc is naturally present in water. The average zinc concentration in seawater is 0.6-5 ppb. Rivers generally contain between 5 and 10 ppb zinc. The World Health Organization stated a legal limit of 5 mg Zn^{2+} mg/L. Inhalation of zinc-containing fumes can cause a variety of physiological effects, but principal significance of excessive amounts in water can induce vomiting (Anon, 2001). Since the solubility of zinc dependant on temperature and pH, it becomes water insoluble at pH of 7. Even though zinc in a large quantity has an emetic effect, it still remains one of the important element to mankind. However, the concern in water supply arises in regard to taste not toxicity, and quite high levels are permissible. The toxic action is much more important and very much lower limits have been imposed. The toxicity of zinc to aquatic life is (as with copper) dependent on the hardness of the water: it decreases with rising hardness while the solubility increases with increasing acidity. Above pH of 11, solubility also increases making zinc to dissolve in water as ZnOH^+ (aq) or Zn^{2+} . ZnCO_3 has a solubility of 0.21 g/L (Anon, 2006).

3.4 Water Distribution Systems

Water distribution systems carry drinking water from a centralized treatment plant or well supplies to consumers' taps. These systems consist of pipes, pumps, valves, storage tanks, reservoirs, meters, fittings, and other hydraulic appurtenances (Anon, 2006). The American Water Works Association defines the water distribution system as including all water utility components for the distribution of finished or potable water by means of gravity storage feed or pumps through distribution pumping networks to customers or other users, including distribution equalizing storage. These systems must also be able to provide water for non-potable uses, such as fire suppression and irrigation of landscaping (Anon, 2006).

The function of a water distribution system is to deliver water to all customers of the system in sufficient quantity for potable drinking water and fire protection purposes, at the appropriate pressure, with minimal loss, of safe and acceptable quality, and as economically as possible. To convey water, pumps must provide working pressures, pipes must carry sufficient water, storage facilities must hold the water, and valves must open and close properly. Indeed, the carrying capacity of a water distribution system is defined as its ability to supply adequate water quantity and maintain adequate pressure (Male and Walski, 1991).

The distribution system is therefore the final barrier before delivery to the consumer's tap. Even when the water leaving the treatment plant is of the highest quality, if precautions are not taken its quality can seriously deteriorate. In extreme cases, dangerous contamination can occur. Because distribution systems represent the vast majority of physical infrastructure for water supplies, they constitute the primary management challenge from both an operational and public health standpoint. Furthermore, their repair and replacement represent an enormous financial liability (Anon, 2006).

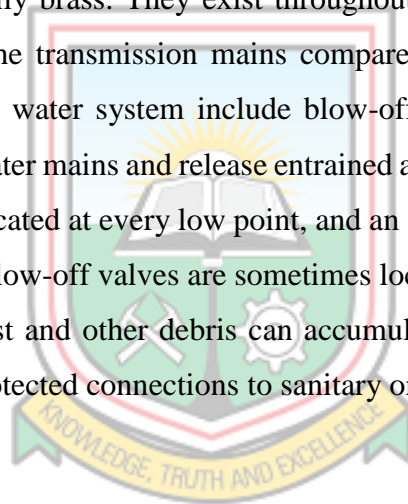
3.4.1 Pipes

The systems of pipes that transport water from the treatment plant to the consumer are often categorized from largest to smallest as transmission or trunk mains, distribution mains, service lines, and premise plumbing. Transmission or trunk mains usually convey large amounts of water over long distances such as from a treatment facility to a storage tank within the distribution system. Distribution mains are typically smaller in diameter than the transmission mains and generally follow the city streets. Service lines carry water from the distribution main to the building or property being served. Service lines can be of any size depending on how much water is required to serve a particular customer and are sized so that the utility's design pressure is maintained at the customer's property for the desired flows. Premise plumbing refers to the piping within a building or home that distributes water to the point of use. In premise plumbing the pipe diameters are usually comparatively small, leading to a greater surface-to-volume ratio than in other distribution system pipes. The three requirements for a pipe include its ability to deliver the quantity of water required, to resist all external and internal forces acting upon it, and to be durable and have a long life (Anon, 2003). The materials commonly used to accomplish these goals today are ductile iron, pre-stressed concrete, polyvinyl chloride (PVC), reinforced plastic, and steel. In the past, unlined cast iron and asbestos cement pipes were frequently installed in distribution systems.

3.4.2 Valves

The two types of valves generally utilized in a water distribution system are isolation valves (or stop or shutoff valves) and control valves. Isolation valves (typically either gate valves or butterfly valves) are used to isolate sections for maintenance and repair and are located

so that the areas isolated will cause a minimum of inconvenience to other service areas. Maintenance of the valves is one of the major activities carried out by a utility. Many utilities have a regular valve-turning program in which a percentage of the valves are opened and closed on a regular basis. It is desirable to turn each valve in the system at least once per year. The implementation of such a program ensures that water can be shut off or diverted when needed, especially during an emergency, and that valves have not been inadvertently closed. Control valves are used to control the flow or pressure in a distribution system. They are normally sized based on the desired maximum and minimum flow rates, the upstream and downstream pressure differentials, and the flow velocities. Typical types of control valves include pressure-reducing, pressure sustaining, and pressure-relief valves; flow-control valves; throttling valves; float valves; and check valves. Most valves are either steel or cast iron, although those found in premise plumbing to allow for easy shut-off in the event of repairs are usually brass. They exist throughout the distribution system and are more widely spaced in the transmission mains compared to the smaller-diameter pipes. Other appurtenances in a water system include blow-off and air release/vacuum valves, which are used to flush water mains and release entrained air. On transmission mains, blow-off valves are typically located at every low point, and an air release/vacuum valve at every high point on the main. Blow-off valves are sometimes located near dead ends where water can stagnate or where rust and other debris can accumulate. Care must be taken at these locations to prevent unprotected connections to sanitary or storm sewers(Anon, 2006).



3.4.3 Hydrants

Hydrants are primarily part of the fire-fighting aspect of a water distribution system. Proper design, spacing, and maintenance are needed to ensure an adequate flow to satisfy fire-fighting requirements. Fire hydrants are typically exercised and tested annually by water utility or personnel from fire service. Fire hydrants are installed in areas that are easily accessible by fire fighters and are not obstacles to pedestrians and vehicles. In addition to being used for fire-fighting, hydrants are also for routine flushing programs, emergency flushing, preventive flushing, testing and corrective action, and for street cleaning and construction projects (Anon, 2006).

3.4.4 Pumps

Pumps are used to impart energy to the water in order to boost it to higher elevations or to increase pressure. Pumps are typically made from steel or cast iron. Most pumps used in distribution systems are centrifugal in nature, in that water from an intake pipe enters the pump through the action of a “spinning impeller” where it is discharged outward between vanes and into the discharge piping. The cost of power for pumping constitutes one of the major operating costs for a water supply (Anon, 2006).

3.4.5 Storage Tanks and Reservoirs

Storage tanks and reservoirs are used to provide storage capacity to meet fluctuations in demand or shave off peaks, to provide reserve supply for fire-fighting use and emergency needs, to stabilize pressures in the distribution system, to increase operating convenience and provide flexibility in pumping, to provide water during source or pump failures, and to blend different water sources. The recommended location of a storage tank is just beyond the centre of demand in the service area (Anon, 2006). Elevated tanks are used most frequently, but other types of tanks and reservoirs include in-ground tanks and open or closed reservoirs. Common tank materials include concrete and steel (Clark *et al.*, 1996).

3.4.6 The Dead-End Sections of Distribution Networks

The purpose of distribution system is to deliver water to consumer with appropriate quality, quantity and pressure. Although there are different types of distribution networks, the dead-end section of distribution networks is mostly used at towns and cities with no definite road patterns. Apart from being relatively cheap, stagnation of water in pipes do occur in many dead ends. Also, many dead-end lines resulted from branch layouts turn to cause problems such as bacteriological, taste, and odour. In addition, they require more frequent flushing and thus waste water (Anon., 2013b). Sometimes dead-end sections of drinking water distribution networks turn to be problematic zones thereby causing water quality degradation. Stagnation due to extended residence time may lead to rapid reduction of disinfectant residuals allowing the regrowth of microbial pathogens (Ahmed *et al.*, 2015).

3.5 Types of Distribution System

A distribution network may incorporate one or more types of pipe layout depending on the size of the community it is serving, the location of the reservoir, and other factors. The common types of distribution systems are radial, grid iron and ring systems.

3.5.1 The Radial System

The radial system is made up of an area divided into different zones whereby the water is supplied from a distribution reservoir sited at the centre of the area. With the pipes laid towards the out boundaries of the area, the radial system makes calculation of pipes easier and gives quick service (Adeosun, 2014).

3.5.2 The Grid Iron System

Most cities and towns that have rectangular layout adopt this type of distribution system to supply water through mains and branches laid in rectangles. Apart from the difficulty in calculating the size of pipe during laying and construction, the water supplied is kept in a good circulating condition with no dead ends created (Adeosun, 2014). The unique feature of this system is that, with all of the pipes being interconnected, water can reach a given point of withdrawal from several directions. This permits more flexible operation, particularly when repairs are required. Although it has high cost of installation, the grid-iron system does not only require large number of cut-off valves but also longer pipe length with larger diameter. Because of the free circulation of water, deposition of sediment and pollution due to stagnation is minimised (Stauffer and Spuhler, 2009).

3.5.3 The Ring System

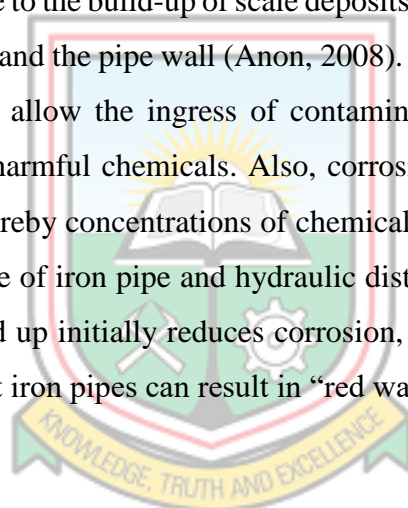
The ring system is most suitable for well-planned towns and cities with access roads and well-spaced buildings. With a system similar to that of the grid-iron system, the supply main is laid all along the peripheral roads. The sub mains are then taken from the mains which have the advantage of the pipe size being easy to determine (Adeosun, 2014).

3.6 Causes of water contamination in pipes

Water from the treatment plant is assumed to be safe before it is transported to the final consumer. However, certain factors can render the treated water unsafe for drinking. The introduction of extraneous substances into the water may contaminate the water, Other contamination factors are corrosion of the pipe transporting the water, leakages, cross-contamination and the formation of disinfection by-products.

3.6.1 Corrosion of Carrier Pipes

Corrosion may be caused by the use of inappropriate materials, including use of metallic products that are incompatible with existing materials in the system. Even though loss of structural integrity is caused by corrosion, hard water provides some protection against metal corrosion, this is due to the build-up of scale deposits within pipes providing a physical barrier between the water and the pipe wall (Anon, 2008). A breach in the system caused by corrosion or fracture can allow the ingress of contaminated groundwater or wastewater containing pathogens or harmful chemicals. Also, corrosion increases with the age of the materials and fittings whereby concentrations of chemicals released by corrosion generally increase with age. The age of iron pipe and hydraulic disturbances influence the release of iron. Although scale build up initially reduces corrosion, the eventual release of this scale from old tuberculated cast iron pipes can result in “red water” (Sarin *et al.*, 2003).



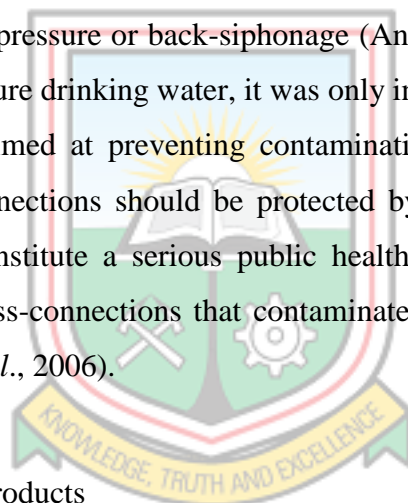
3.6.2 Leakage of Mains

Contamination of water is sometimes caused by leaky water mains in areas of low pressure or with intermittent water supply. Entry of contaminants are due to backflow through leaky joints, air valves, perforations, leaking valves and hydrants (Anon, 2014c). The accidents which happen in the water supply system networks are usually high. Many of the factors that are involved in the leakage of water pipe are; material of the pipe, pipe age, diameter of the pipe, pressure, movement of soil around the pipe, the material of the pipes, the age of the pipes, the diameter of the pipes, the pressure, hit, using unsuitable materials for the basis and coverage of the pipes, incorrect installation, water hammer hit, clogging the components joints and pipes, the effect of temperature, the depth of placement of the pipes, the pressure of the cars on the surface of roads and ground, corrosive waters, the movement of soil, the damages to the pipes by the other service organizations, poor quality connections and

nonstandard, plumbing, the summit of ground, climate conditions (Saghi and Aval, 2015) . High levels of water unaccounted for are usually caused by leakages. Different appropriate methods are adopted in the location and control of leakages in pipes. Apart from using acoustic detectors and leak noise correlation, or surface exposure of leakages, finding a precise leak location can be sometimes be a difficult problem (Trifunovic, 2006).

3.6.3 Cross Connections

Under this type of connection, the connections are physically arranged whereby public water supplies are connected, directly or indirectly, with any secondary water supply system, sewer, pool, drain, conduit, plumbing fixture, storage reservoir, or other device which contains or may contain any water, contaminated liquid, or other waste of unknown or unsafe quality that could impart a contaminator pollutant to the drinking water as a result of backflow caused by backpressure or back-siphonage (Anon, 2016). Though man has long recognized the need for pure drinking water, it was only in the last 50 or 60 years that there have been real efforts aimed at preventing contamination caused by cross-connections (Anon, 2012). Cross-connections should be protected by installing backflow prevention devices because they constitute a serious public health risk. There are numerous well documented cases of cross-connections that contaminated drinking-water and resulted in serious illness (Craun *et al.*, 2006).



3.6.4 Disinfectant By-products

All chemical disinfectants have the potential to produce unwanted organic or inorganic by-products that may be of health concern. Disinfection by-products (DBPs) are produced by the reaction between chemical disinfectants and naturally occurring organic material in the source water (Krasner, 2009). The first recognized disinfection by-products (DBPs) were the trihalomethanes, which are produced by the reaction of free chlorine with natural organic matter. When bromide is present in the source water, brominated DBPs may be formed along with chlorinated ones. Other chlorination DBPs include halo acetic acids, halogenated ketones and halo acetonitriles. The concentration of chlorination DBPs tends to increase with water age. Guideline values have been established for a number of DBPs (Anon., 2011b), and keeping concentrations below these values is very much encouraged. However, the importance of disinfection should never be compromised because the health risk of

developing cancer from long-term exposure to disinfection by-products is insignificant compared to the acute danger of ingesting pathogens from insufficiently disinfected water. Some of the DBPs (e.g. Halobenzoquinones) have been found to be carcinogenic (Du *et al.*, 2013) or cause reproductive or developmental effects in laboratory animals, but there is some uncertainty involving the risks to humans posed by chronic ingestion of DBPs (Anon., 2008).

In most cases, trihalomethanes (THMs) and five haloacetic acids (HAAs) are known to be good indicators of chlorination by-products even though there is a wide range of DBPs. However, other DBPs, such as bromate, chlorate or N-nitrosodimethylamine (NDMA) may need to be considered when other types of disinfectants, such as chlorine dioxide, ozone and chloramines are used for disinfection (Anon, 2011a). Other DBPs which are attracting a lot of interest lately are Iodinated DBPs (Krasner, 2009).



CHAPTER 4

FIELDWORK AND LABORATORY ANALYSIS

4.1 Sampling

To access the variation in water quality of communities which gets their water supply from the Kumasi Water Supply System (KWSS), 32 water sampling points were selected. Sample points were chosen carefully to cover all ten water districts within the KWSS. This included raw and treated water sampling points at the Owabi and Barekese Water Treatment Plants, three booster stations and eight dead-ends. Public stand-pipes were preferred where possible to allow for unrestricted access. Sampling was done between January 2018 and April 2018. Each sampling point was marked using a handheld GPS device (GPS Garmin Venture HC) for mapping purposes. The sampling locations are as shown in Figure 4.1. Each sampling point was given a unique sample location ID for easy identification (Table 4.1).

The following precautions were taken during sampling.

- The outlets of the taps from which all the treated water samples were taken were disinfected with alcohol
- Water was allowed to flow through the taps for three minutes after disinfection before samples were taken for analysis
- Sampling bottles were rinsed with water being sampled before samples were taken to prevent contamination
- Duplicates of 500 mL of water samples were taken with sterilized bottles from each sampling point and quickly stored in a melting ice packed box with temperature of about 4°C
- Each bottle used for the bacteriological analysis (except raw water samples) was filled with 2 mL of 10% sterile sodium thiosulphate to neutralize any residual chlorine.
- Sample holding time did not exceed 8 hours for all water samples taken

Table 4.1 Sample IDs and physical locations

| Sample ID | Physical Location |
|------------------|--------------------------|
| K01 | BAREKESE RAW |
| K02 | BAREKESE TREATED |
| K03 | BAREKESE DE |
| K04 | NKETIA |
| K05 | BREMAN |
| K06 | NKWANTWIMA |
| K07 | OWABI RAW |
| K08 | OWABI TREATED |
| K09 | ABUAKWA |
| K10 | SEPEASE |
| K11 | NKAWIE DE |
| K12 | SUAME RESERVOIR |
| K13 | ABREPO |
| K14 | MAAKRO |
| K15 | PATASI EST. |
| K16 | SANTASI |
| K17 | STH. SUNTRESO DE |
| K18 | GYINYASE DE |
| K19 | ASOKWA |
| K20 | KAASE |
| K21 | NKANSAM DE |
| K22 | ABOABO |
| K23 | AYIGYA POL. STA. |
| K24 | KMA DE |
| K25 | AMAKOM |
| K26 | BOMPATA |
| K27 | TAFO NYIAESO DE |
| K28 | PANKRONO BOOSTER |
| K29 | TAFO MARKET |
| K30 | ODUOM DE |
| K31 | ANWOMASO |
| K32 | TECH BOOSTER |

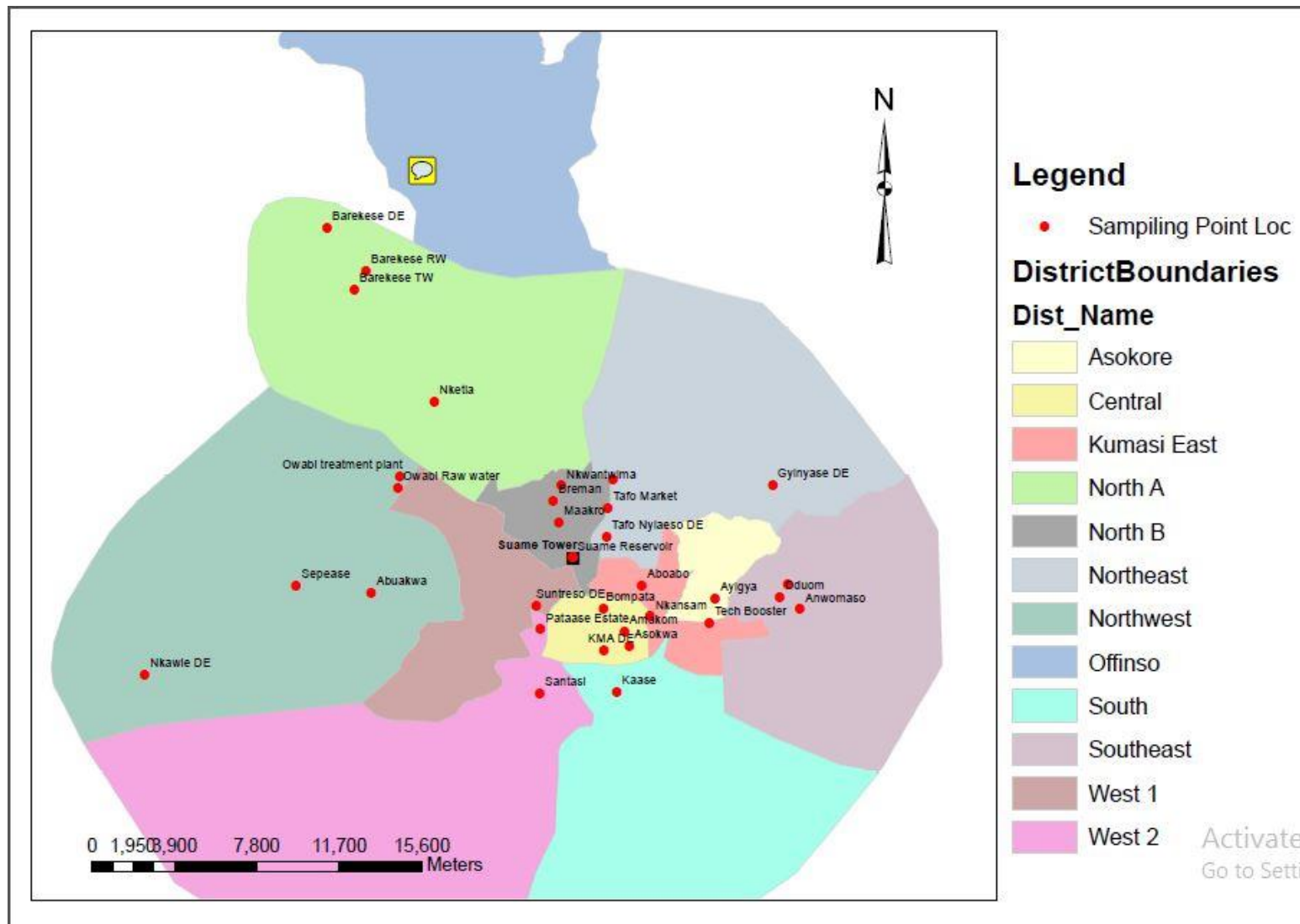


Figure 4.1 Map of sampling points

4.2 Physico-chemical Analysis

pH, TDS, electrical conductivity, salinity and temperature were measured on the field using VWR CO310 and pH110 multi-meters. Calibration was done on each sampling day before recording to ensure accuracy in the results obtained. Residual chlorine was also analysed using LOVI Bond Chlorine Comparator. The physico-chemical parameters were determined according to procedures outlined in the Standard Methods for the Examination of Water and Wastewater (Anon, 1999). The parameters that were determined were Fe, Mg, Ca, chloride, total alkalinity, nitrite, phosphate, sulphate and ammonia at the Suame Water Quality Assurance Laboratory.

4.3 Bacteriological Analysis

Bacteriological analyses were done to test for *Escherichia Coli* (E. coli) and Total Coliform at the Biology Laboratory, KNUST using the Dilution Plate Count method.

MacConkey agar (Fluka BioChemika, 70143) was used as the preferred media for enumeration of total coliforms since it is a selective and differential medium for total coliforms. According to the manufacturer's instruction, 52 grams of MacConkey agar was dissolved in 1 litre of distilled water and heated to dissolve. Ten (10) millilitres of media were then dispensed into universal bottles and sterilized at 121°C for 15 minutes in an autoclave.

Eosin methylene blue agar (EMBA) (Oxoid, 70143) was used as a selective and differential medium for *Escherichia coli* detection. EMBA was prepared by dissolving 37.5 grams in 1 litre of distilled water and sterilized at 121°C for 15 minutes in an autoclave.

Automatic pipette tips were also autoclaved at 121°C to get rid of any residual microorganism before using it for inoculation. Samples were thoroughly mixed by inverting the sample bottles several times before preparing serial dilutions. Using an automatic pipette and sterile 1 ml pipette tip, a 1 ml aliquot from an inch below the surface was taken and added to 9ml of sterile distilled water in a test tube to make a 1 in 10 or 10^{-1} dilution. With a fresh sterile pipette tip, 10^{-1} dilution was well mixed by drawing the suspension up and

down ten times before transferring 1 ml into another tube containing 9 ml of sterile distilled water to make 10^{-2} , followed by subsequent dilutions to make 10^{-3} , 10^{-4} and 10^{-5} .

Enumeration of the total coliforms in water samples were done by pour plate technique. Using a fresh sterile pipette tip for each dilution, 1 ml of each of the dilutions of the water samples was aseptically transferred into universal bottles containing 10 ml of sterile molten MacConkey agar at 40°C. Samples and agar were mixed thoroughly by rotating the bottle between the palms (hands) taking care not to form bubbles. Inoculated agar were aseptically poured into fresh sterile Petri dishes labelled with location and dilution of samples. Media plates were allowed to solidify before bulking and fastening them together with masking tape.

Enumeration of *Escherichia coli* in water samples were obtained by pour plate technique. Dilutions of 10^{-1} to 10^{-5} of water samples were prepared in sterile distilled water and 1 ml aliquot of each dilution inoculated into 9 ml of sterile molten Eosin methylene blue agar in universal bottles. These were then thoroughly mixed, poured into sterile Petri dishes and allowed to solidify.

Solidified agar plates were incubated in inverted positions at 37°C for 48 hours for growth to occur. After 48 hours, the colony counter was used to enumerate the number of microorganisms on the countable plate(s). Petri dishes from dilutions containing countable discrete colonies (usually ranging from 30 to 300) were counted and the results expressed as colony forming unit (CFU) per 100ml.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Statistical Analyses

The analyses of data were done using Statistical Package for the Social Sciences - SPSS (version 23). One - way ANOVA (Analysis of Variance) was used to determine whether there were significant variations within the means of the various parameters under investigation as water moves through the KWSS. The null hypothesis for ANOVA is that the mean is the same for all groups. The alternative or research hypothesis is that the mean is not the same for all groups. If $p < 0.05$, then the null hypothesis should be rejected. The conclusion then is that the mean of the dependent variable is not the same for all groups. Pearson's rank correlation (two – tailed) was used to establish the extent to which each parameter affected each other.

5.2 Results of Water Analysis

The detailed results of the samples analysed for the entire study period of this work is presented in Tables 5.1a, 5.1b, 5.2a, 5.2b, 5.3a and 5.3b. To be able to do a thorough analysis, the data obtained were categorised into two.

The first batch of data set was made up of the means and p-values for parameters of all water samples analysed from OWTP raw water, OWTP treated water, all communities which gets their water supplies directly from OWTP, the SWR and all communities which gets their water supplies directly from SWR after re-chlorination (Table 5.1a, 5.2a and 5.3a). The second batch of data set are the means and p-values for parameters of all samples analysed from BWTP raw water, BWTP treated water, all communities which gets their water supplies directly from BWTP, the SWR and all communities which gets their water supplies directly from SWR after re-chlorination (Table 5.1b, 5.2b and 5.3b).

5.2.1 pH

The Owabi raw water had pH ranging between 7.08 and 7.78. Owabi treated water also recorded minimum and maximum pH values of 6.85 and 7.83 respectively. Distributed

water samples from Abuakwa, Sepease and Nkawie also recorded minimum and maximum pH values of 6.90 and 7.73 respectively, with Sepease recording the minimum and Abuakwa, the maximum. It was observed that pH kept changing from the untreated to treated water and distributed water from OWTP before it finally reaches SWR as shown in Table 5.1a. This variation in pH values may be due to the variation in TDS and total alkalinity values along that section of the distribution network. The Barekese raw water had pH ranging between 6.59 and 7.02.

Barekese treated water also recorded minimum and maximum pH values of 6.62 and 7.13 respectively. Distributed water samples from Barekese DE, Nketia, Breman and Nkwantwima also recorded minimum and maximum pH values of 6.59 and 7.30 respectively. Treated water from BWTP recorded the minimum and Nkwantwima recording the maximum. It was also observed from Table 5.1b that pH kept changing from the untreated to treated water and distributed water along the distribution network before SWR. This variations in pH can also be attributed to alkalinity values along that section of the distribution network.

From Tables 5.1a and 5.1b, pH measured at the SWR ranged between 6.78 and 7.34. After re-chlorination and redistribution, water is supplied through the distribution network to Abrepo, Maakro, Patasi Estate, Santasi, South Suntreso, Gyinyase, Asokwa, Kaase, Nkansam, Aboabo, Ayigya, KMA, Amakom, Bompata, Tafo Nhyiaso, Pankrono, Tafo Market, Anwomaso and Tech. Ayigya and Asokwa both recorded the minimum pH of 6.72 and Kaase recorded the maximum pH value of 7.78. Changes were observed in the minimum and maximum pH values recorded between SWR and various communities which gets their supply from Suame. Even though there were variations in pH, values recorded along distribution network all fell within WHO Limits of 6.5 – 8.5 (Anon, 2011b). This might be attributed to leaching of inorganic salts from the distribution pipes (Schock, 1999; Agatemor and Okolo, 2007).

5.2.2 Turbidity

High turbidity is often an indicator of microbial contamination and may render water to be more expensive to disinfect thoroughly (Anon., 1998). Mean turbidity value for raw water at OWTP was 118.75 NTU. This was very high when compared to that of OWTP final water, Abuakwa, Sepease and Nkawie DE which had 0.39 NTU, 0.76 NTU, 0.62 NTU and 0.10 NTU respectively as shown in Table 5.1a.

From Table 5.1b, the mean turbidity value recorded for BWTP raw water sample was 12.73 NTU. This was quite low when compared to raw water sample from OWTP which recorded a mean turbidity value of 118.75 NTU. This implies that the OWTP raw water source had more suspended particles than the BWTP and therefore may be more expensive to treat than the BWTP raw water source. The Owabi raw water sample's high turbidity can be attributed to the fact that the river and its tributaries within the catchment area run through some communities within the Kumasi Metropolis. This makes the water susceptible to pollution from soil and erosion human activities especially from communities like Abrepo and Suame. The mean values measured for BWTP treated water was 0.03 NTU, Barekese DE had 0.08 NTU, 0.05 NTU for Nketia, 0.88 NTU for Breman and 0.02 NTU for Nkwantwima. The significant drop in turbidity values can be attributed to the effectiveness of the use of poly-electrolyte for coagulation, sedimentation and filtration processes at the treatment plants. The turbidity values recorded for treated and distributed water were lower than the WHO recommended value of 5 NTU but raw water from both treatment plants far exceeded it. This may render raw water from OWTP and BWTP not safe for drinking and industrial purposes.

Communities which received their water supply from SWR recorded varying turbidity mean values. Patasi Estate and Kaase recorded the minimum mean turbidity value of 0.0125 NTU. Nkansam DE, KMA DE and Oduom DE which are all dead-end communities recorded mean values above 1 NTU. Dead-ends are known to have higher amounts of sediments and may require frequent flushing to improve the aesthetic and bacteria quality of the water (Benoit *et al.*, 2005). However, they did not exceed the recommended 5 NTU.

From Table 5.1a the p-value obtained for samples taken from water samples analysed from OWTP raw water, OWTP treated water, all communities which get their water supplies

directly from OWTP, the SWR and all communities which gets their water supplies directly from SWR after re-chlorination was 3.37×10^{-35} . The p-value obtained for samples analysed from BWTP raw water, BWTP treated water, all communities which gets their water supplies directly from BWTP, the SWR and all communities which gets their water supplies directly from SWR after re-chlorination was 3.44×10^{-36} as shown in Table 5.1b. It can therefore be concluded that the variations in turbidity were significant for the entire Distribution network because $p < 0.05$.

5.2.3 Electrical Conductivity (EC)

The mean electrical conductivity recorded for OWTP raw water was 336.80 $\mu\text{S}/\text{cm}$. OWTP treated water, Abuakwa, Sepease and Nkawie DE recorded values of 342.40 $\mu\text{S}/\text{cm}$, 338.45 $\mu\text{S}/\text{cm}$, 354.75 $\mu\text{S}/\text{cm}$ and 346.48 $\mu\text{S}/\text{cm}$ respectively as shown in Table 5.1a. This implies that the treatment processes at the OWTP does not impact significantly on EC. The EC values did not also change significantly as water travelled through the distribution network. The mean EC value reported by Akoto *et al.* (2014) for Owabi raw water was 324.40 $\mu\text{S}/\text{cm}$. Table 5.1b shows the mean electrical conductivity values recorded for the Barekese section of the distribution network. Mean values recorded were 130.78 $\mu\text{S}/\text{cm}$, 136.25 $\mu\text{S}/\text{cm}$, 179.45 $\mu\text{S}/\text{cm}$, 135.90 $\mu\text{S}/\text{cm}$, 138.55 $\mu\text{S}/\text{cm}$, 138.60 $\mu\text{S}/\text{cm}$, for BWTP raw water, BWTP treated water, Barekese DE, Nketia, Breman and Nkwantwima respectively.

From the EC values obtained from Tables 5.1a and 5.1b, it was observed that samples which had the Owabi River as their direct water source had higher EC than those which took their direct source from the Barekese River. This explains why these sampling points from the Owabi section of the distribution network had a higher salinity value of 0.2 mg/L, and 0.1 mg/L for all samples from Barekese section. SWR also recorded mean EC value of 181.05 $\mu\text{S}/\text{cm}$. The minimum and maximum mean EC values recorded for communities which are served directly from SWR were 119.43 $\mu\text{S}/\text{cm}$ and 546.93 $\mu\text{S}/\text{cm}$ respectively. The maximum mean EC recorded at KMA DE may be as a result increased concentration of Cl^- ions as shown in Table 5.2a. Mean Cl^- ion concentration recorded was 89 mg/L. The p-values obtained for the entire distribution network showed significant changes in EC values as water travelled through the KWSS ($p < 0.05$). However, values obtained did not exceed the WHO recommended limit of 1000 $\mu\text{S}/\text{cm}$. It can therefore be inferred from the variations

that the distribution network has an effect on the EC as water is transported to consumers at their various points of use.

Table 5.1a Results of means of physicochemical analyses of samples from OWTP raw and treated water, SWR and communities which receive water from OWTP and SWR ($n=4$)

| PARAMETER | pH | Turb (NTU) | Cond ($\mu\text{S}/\text{cm}$) | TDS (mg/L) | Temp ($^{\circ}\text{C}$) | Salinity (mg/L) | T H (mg/L) | Alk (mg/L) |
|--------------------|-----------|------------------------|-------------------------------------|------------------------|--------------------------------|------------------------|------------------------|-----------------------|
| p-value | - | 3.37×10^{-35} | 1.12×10^{-33} | 9.79×10^{-31} | 1.72×10^{-46} | 7.35×10^{-96} | 2.35×10^{-12} | 2.52×10^{-4} |
| K07 | 7.08-7.78 | 118.75 | 336.80 | 220.38 | 28.75 | 0.20 | 94.50 | 45.00 |
| K08 | 6.85-7.83 | 0.39 | 342.40 | 223.90 | 29.60 | 0.20 | 94.50 | 60.00 |
| K09 | 7.04-7.73 | 0.76 | 338.45 | 221.48 | 29.20 | 0.20 | 87.50 | 50.50 |
| K10 | 6.9-7.76 | 0.62 | 354.75 | 255.43 | 30.65 | 0.20 | 88.50 | 61.00 |
| K11 | 7-7.52 | 0.10 | 346.48 | 228.68 | 30.70 | 0.20 | 95.50 | 60.75 |
| K12 | 6.78-7.34 | 0.89 | 181.05 | 92.98 | 27.05 | 0.10 | 155.00 | 113.00 |
| K13 | 6.85-6.98 | 0.04 | 141.05 | 91.73 | 30.38 | 0.10 | 63.00 | 57.50 |
| K14 | 6.96-7.1 | 0.04 | 138.93 | 90.35 | 31.10 | 0.10 | 56.00 | 51.50 |
| K15 | 7.02-7.45 | 0.01 | 139.83 | 90.95 | 30.05 | 0.10 | 73.50 | 47.00 |
| K16 | 6.93-7.73 | 0.04 | 137.83 | 89.68 | 30.13 | 0.10 | 73.50 | 55.50 |
| K17 | 7.1-7.67 | 0.49 | 158.15 | 102.58 | 30.55 | 0.10 | 83.50 | 57.00 |
| K18 | 7.53-7.61 | 0.52 | 119.45 | 77.85 | 28.45 | 0.10 | 107.75 | 55.50 |
| K19 | 6.72-7.55 | 0.54 | 225.70 | 126.80 | 29.83 | 0.10 | 87.00 | 65.00 |
| K20 | 7.01-7.78 | 0.01 | 140.50 | 88.25 | 29.33 | 0.10 | 76.00 | 42.50 |
| K21 | 6.79-7.2 | 1.14 | 139.03 | 90.55 | 30.60 | 0.10 | 59.00 | 53.00 |
| K22 | 6.86-7.06 | 0.03 | 139.33 | 90.58 | 29.73 | 0.10 | 75.00 | 62.50 |
| K23 | 6.72-6.93 | 0.02 | 138.65 | 90.55 | 29.80 | 0.10 | 59.25 | 63.25 |
| K24 | 6.95-7.34 | 1.77 | 546.93 | 312.53 | 27.80 | 0.15 | 110.00 | 69.00 |
| K25 | 7.11-7.36 | 0.95 | 140.70 | 91.53 | 31.27 | 0.30 | 91.00 | 82.00 |
| K26 | 6.98-7.72 | 0.39 | 137.85 | 89.73 | 31.15 | 0.10 | 57.50 | 46.00 |
| K27 | 6.76-6.95 | 0.25 | 139.93 | 90.98 | 30.60 | 0.10 | 74.00 | 51.50 |
| K28 | 6.85-7.15 | 0.03 | 144.50 | 93.95 | 29.65 | 0.10 | 69.00 | 61.50 |
| K29 | 6.96-7.02 | 0.02 | 139.93 | 91.03 | 29.40 | 0.10 | 65.50 | 60.50 |
| K30 | 6.78-7 | 1.11 | 139.28 | 90.58 | 30.45 | 0.10 | 89.50 | 51.50 |
| K31 | 6.74-6.98 | 0.02 | 137.88 | 89.63 | 30.30 | 0.10 | 76.50 | 71.50 |
| K32 | 7.04-7.2 | 0.06 | 137.75 | 89.53 | 28.05 | 0.10 | 63.50 | 53.00 |
| WHO STANDRD | 6.5-8.5 | 5 | 1000 | 1000 | 30 | - | 500 | 120 |

Table 5.1b Results of means of physicochemical analyses of samples from BWTP raw and treated water, SWR and communities which receive water from BWTP and SWR ($n=4$)

| PARAMETER | pH | Turb (NTU) | Cond ($\mu\text{S}/\text{cm}$) | TDS (mg/L) | Temp ($^{\circ}\text{C}$) | Salinity (mg/L) | T H (mg/L) | Alk (mg/L) |
|---------------------|-----------|------------------------|----------------------------------|------------------------|-----------------------------|-------------------------|------------------------|------------------------|
| p-value | - | 3.44×10^{-36} | 2.35×10^{-26} | 1.27×10^{-27} | 1.2×10^{-47} | 4.37×10^{-101} | 3.35×10^{-13} | 2.54×10^{-10} |
| K01 | 6.59-7.02 | 12.72 | 130.78 | 85.05 | 29.50 | 0.10 | 78.00 | 63.50 |
| K02 | 6.62-7.13 | 0.02 | 136.25 | 88.63 | 29.13 | 0.10 | 66.00 | 62.00 |
| K03 | 6.64-6.95 | 0.08 | 179.45 | 105.23 | 32.13 | 0.10 | 89.00 | 63.00 |
| K04 | 6.86-7.13 | 0.05 | 135.9 | 88.38 | 30.45 | 0.10 | 64.00 | 89.50 |
| K05 | 7.15-7.25 | 0.88 | 138.55 | 90.08 | 31.60 | 0.10 | 48.50 | 90.50 |
| K06 | 7.04-7.3 | 0.02 | 138.6 | 90.10 | 30.60 | 0.10 | 70.50 | 65.50 |
| K12 | 6.78-7.34 | 0.89 | 181.05 | 92.98 | 27.05 | 0.10 | 155.00 | 113.00 |
| K13 | 6.85-6.98 | 0.04 | 141.05 | 91.73 | 30.38 | 0.10 | 63.00 | 57.50 |
| K14 | 6.96-7.1 | 0.04 | 138.93 | 90.35 | 31.10 | 0.10 | 56.00 | 51.50 |
| K15 | 7.02-7.45 | 0.01 | 139.83 | 90.95 | 30.05 | 0.10 | 73.50 | 47.00 |
| K16 | 6.93-7.76 | 0.04 | 137.83 | 89.68 | 30.13 | 0.10 | 73.50 | 55.50 |
| K17 | 7.1-7.67 | 0.49 | 158.15 | 102.58 | 30.55 | 0.10 | 83.50 | 57.00 |
| K18 | 7.53-7.61 | 0.52 | 119.45 | 77.85 | 28.45 | 0.10 | 107.75 | 55.50 |
| K19 | 6.72-7.55 | 0.54 | 225.70 | 126.80 | 29.83 | 0.10 | 87.00 | 65.00 |
| K20 | 7.01-7.78 | 0.01 | 140.50 | 88.25 | 29.33 | 0.10 | 76.00 | 42.50 |
| K21 | 6.79-7.2 | 1.14 | 139.03 | 90.55 | 30.60 | 0.10 | 59.00 | 53.00 |
| K22 | 6.86-7.06 | 0.03 | 139.33 | 90.58 | 29.73 | 0.10 | 75.00 | 62.50 |
| K23 | 6.72-6.93 | 0.02 | 138.65 | 90.55 | 29.80 | 0.10 | 59.25 | 63.25 |
| K24 | 6.95-7.34 | 1.77 | 546.93 | 312.53 | 27.80 | 0.15 | 110.00 | 69.00 |
| K25 | 7.11-7.36 | 0.95 | 140.70 | 91.53 | 31.27 | 0.30 | 91.00 | 82.00 |
| K26 | 6.98-7.72 | 0.40 | 137.85 | 89.73 | 31.15 | 0.10 | 57.50 | 46.00 |
| K27 | 6.76-6.95 | 0.25 | 139.93 | 90.98 | 30.60 | 0.10 | 74.00 | 51.50 |
| K28 | 6.85-7.15 | 0.03 | 144.50 | 93.95 | 29.65 | 0.10 | 69.00 | 61.50 |
| K29 | 6.96-7.02 | 0.02 | 139.93 | 91.025 | 29.40 | 0.10 | 65.50 | 60.50 |
| K30 | 6.78-7 | 1.11 | 139.28 | 90.575 | 30.45 | 0.10 | 89.50 | 51.50 |
| K31 | 6.74-6.98 | 0.02 | 137.88 | 89.625 | 30.30 | 0.10 | 76.50 | 71.50 |
| K32 | 7.04-7.2 | 0.06 | 137.75 | 89.525 | 28.05 | 0.10 | 63.50 | 53.00 |
| WHO STANDARD | 6.5-8.5 | 5 | 1000 | 1000 | 30 | - | 500 | 120 |

5.2.4 Total Dissolved Solids (TDS)

It was also observed in tables 5.1a and 5.1b that the variations in mean TDS values followed in the same trend as EC throughout the distribution network. This is true because EC and

TDS have a linear correlation (Anon., 2015). Communities which had high EC values similarly had high TDS values. KMA DE which recorded the maximum EC of 546.93 $\mu\text{S}/\text{cm}$ recorded the maximum mean TDS of 312.53 mg/L.

The mean TDS recorded for samples were 220.38 mg/L for OWTP raw water, 223.90 mg/L for OWTP Final water, 221.48 mg/L for Abuakwa, 255.43 mg/L for Sepease and 228.68 mg/L for Nkawie. Raw water from BWTP registered mean TDS value of 85.05 mg/L. Treated water from the plant had a value of 88.63 mg/L, Barekese DE, Nketia, Breman and Nkwantwima recorded mean values of 105.23 mg/L, 88.38 mg/L, 90.08 mg/L and 90.10 mg/L respectively.

SWR recorded mean TDS value of 92.98 mg/L. The minimum and maximum values recorded for communities which receives water supplies from SWR were 77.85 and 312.53 mg/L. Gyinyase DE recorded the least TDS and also the least EC. The variations in TDS along the distribution network were significant ($p < 0.05$).

5.2.5 Temperature

Cool water is generally more palatable. Temperature will have an impact on a number of other inorganic and chemical contaminants that may affect taste. The rate of chemical reaction generally increases at higher temperature which in turn affects the biological activity and may increase problems related to taste, odour, colour and corrosion in pipes (Anon, 2011b). The optimal temperature for aquatic life for inland natural waters in the tropics generally varies between 25 and 35°C (Alabaster and Lloyd, 1982). From Tables 5.1a and 5.1b, the mean temperature measured for OWTP and BWTP raw water samples were 28.75 and 29.25 °C which conforms to the findings of Alabaster and Lloyd (1982).

The mean temperature recorded were, 29.60 °C for OWTP treated water, 29.20 °C for Abuakwa, 30.65 °C for Sepease and 30.70 °C for Nkawie as shown in Table 5.1a. The minimum mean temperature recorded for entire distribution network was measured at SWR with a value of 27.05 °C while maximum was recorded at Barekese DE with a value of 32.13 °C as shown in Tables 5.1a and 5.1b. There was a significant change as water travelled from the treatment plant through the network to distribution points ($p < 0.05$). The p-values obtained were 1.72×10^{-46} (Table 5.1a) and 1.2×10^{-47} (Table 5.1b). The change in

temperature could be as a result of heating of the pipelines by the heat radiation from the sun since some of the samples were taken in the afternoon or late afternoon. Water temperature affects the electrical conductivity so that its value increases from 2 up to 3 % per 1 °C change in temperature (Anon, 2015).

5.2.6 Salinity

Salinity is the relative concentration of all dissolved salts in water. The mean salinity values obtained across the section of the KWSS which receive direct water supply from OWTP was 0.20 mg/L and 0.10 mg/L for samples which had BWTP as their direct water source (Tables 5.1a and 5.1b). The values obtained for SWR and most of the communities which are supplied by SWR were 0.10 mg/L except KMA DE, Amakom and Anwomaso which recorded mean values of 0.15, 0.3 and 0.2 mg/L respectively (Tables 5.1a and 5.1b). The variations were significant enough ($p < 0.05$). The p-values obtained for salinity were 7.35×10^{-96} and 4.37×10^{-101} as shown in Tables 5.1a and 5.1b.

5.2.7 Total Hardness

It is common knowledge that Mg^{2+} and Ca^{2+} , in the presence of their sulphate, carbonates and chlorides can impart hardness to water (Alexander, 2008). WHO recommends that, the total hardness of potable drinking water should not exceed 500 mg/L (Anon, 2011b). Water hardness below 60 mg/L is generally considered as soft; 60 – 120 mg/L, moderately hard, 120 - 180 mg/L, hard; and more than 180 mg/L as very hard (McGowan, 2000).

From table 5.1a, the mean total hardness values recorded were, 94.50 mg/L for OWTP raw water, 94.50 mg/L for OWTP final water, 87.50 mg/L for Abuakwa, 88.50 mg/L for Sepease and 95.50 mg/L for Nkawie DE. There was no change in hardness between raw and treated water at OWTP. However, there were variations during the transportation processes. BWTP raw water recorded a mean total hardness of 78 mg/L. After treatment the value reduced to 66 mg/L. Barekese DE, Nketia, Breman and Nkwantwima recorded 89.00 mg/L, 64.00 mg/L, 48.50 mg/L and 70.50 mg/L respectively (Table 5.1b). The variation observed over the entire distribution network were significant enough ($p < 0.05$). All the values did not exceed the WHO limit (Tables 5.1a and 5.1b).

5.2.8 Total Alkalinity

BWTP raw water, BWTP final water, Nketia, Breman and Nkwantwima recorded mean total alkalinity of 63.50 mg/L, 61.90 mg/L, 89.50 mg/L, 90.50 mg/L and 65.50 mg/L respectively. The mean values recorded were 45.00 mg/L, 60.00 mg/L, 50.50 mg/L, 61.00 mg/L and 60.27 mg/L for OWTP raw water, OWTP final water, Abuakwa, Sepease and Nkawie respectively (Tables 5.1a and 5.1b). WHO does not have a standard for total alkalinity but India recommends a maximum permissible standard of 200 mg/L (Awopetu *et al*, 2013). All mean values measured did not exceed 200 mg/L. High alkaline levels can render water unpalatable.

5.2.9 Residual Chlorine Concentration

Residual chlorine in drinking water has long been used as an excellent indicator for assessing bacteriological water quality in distribution networks (Lienyao *et al.*, 2004). The WHO recommends the residual chlorine concentration for treated drinking water should fall within 0.2 - 0.5 mg/L (Anon, 2011b). Generally, residual chlorine levels showed decreasing concentration with increasing distance from the treatment plants and SWR as observed from the results obtained in Tables 5.2a and 5.2b. This trend is normal and could be attributed to the fact that chlorine get used up within the distribution system. The mean levels of chlorine reaching the farthest consumer tap were at minimum levels; about 10 times lower than what was measured at the treatment points.

Apart from the OWTP, BWTP and SWR which had acceptable levels of residual concentrations, all the other communities investigated did not meet the WHO guidelines for water quality. Raw water from both treatment plants recorded zero residual chlorine concentrations because raw water is not chlorinated. From the p-values obtained in Tables 5.2a and 5.2b (i.e. 1.93×10^{-9} and 3.0867×10^{-67}), the variations in residual chlorine levels were significant ($p < 0.05$).

5.2.10 Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) Concentration

In low and medium mineralised underground and surface drinking water, calcium and magnesium are mainly present as Ca^{2+} and Mg^{2+} , with the Ca levels varying from tens to hundreds of mg/L and the Mg concentrations varying from units to tens of mg/L.

Magnesium is usually less abundant in water than calcium with Ca to Mg ratio of about 4 to 1 which corresponds to substance ratio of 2.4 (Pitter, 1999).

Calcium recorded mean concentrations of 22.80 mg/L for OWTP raw water, 21.80 mg/L for OWTP final water, 19.40 mg/L for Abuakwa, 18.25 mg/L for Sepease and 23.20 for Nkawie DE. The mean magnesium concentrations recorded were 9.04 mg/L for OWTP raw water, 9.63 mg/L for OWTP final water, 9.41 mg/L for Abuakwa, 10.96 mg/L for Sepease and 8.24 mg/L for Nkawie DE.

Calcium recorded mean concentrations of 18.80 mg/L for BWTP raw water, 16.40 mg/L for BWTP treated water, 19 mg/L for Barekese DE, 17.60 mg/L for Nketia, 11.00 mg/L for Breman and 14.60 for Nkwantwima. The mean magnesium concentrations recorded were 7.47 mg/L for BWTP raw water, 10.03 mg/L for Barekese DE, 6.02 62 mg/L for BWTP final water, 4.82 mg/L for Nketia, 5.06 mg/L for Breman and 10.47 mg/L for Nkwantwima. SWR and all communities it serves recorded minimum and maximum Ca^{2+} concentrations of 11.7 mg/L and 40 mg/L. Minimum and maximum mean concentrations of Mg^{2+} of 2.92 mg/L and 35.82 mg/L respectively. Statistical analysis showed a much significant variation in Mg^{2+} concentrations than Ca^{2+} ($p < 0.05$) but concentrations recorded did not exceed the WHO standards of 200 mg/L for Ca^{2+} and 150 mg/L for Mg^{2+} .

5.2.11 Chloride (Cl^-) concentration

Of all the samples investigated, KMA DE recorded the highest mean Cl^- concentration with a value of 89 mg/L. This was followed by SWR with 34 mg/L. Mean chloride ion concentrations measured were 27.50 mg/L, 25.50 mg/L, 27.75 mg/L, 29.00 and 26.00 mg/L for OWTP raw water, OWTP final water, Abuakwa, Sepease and Nkawie DE respectively. Mean chloride ion concentrations measured were 22.50 mg/L, 28.00 mg/L, 27.00 mg/L, 22.25 and 21.75 mg/L for BWTP raw water, BWTP final water, Nketia, Breman and Nkwantwima. Concentrations of samples analysed did not exceed the WHO acceptable level of 250 mg/L. High chloride concentration generally impart a salty taste to water but samples analysed had concentrations lower than the WHO acceptable level of 250 mg/L. However, there was a significant variation in Cl^- concentration as water travelled through the distribution network ($p < 0.05$).

Table 5.2a Results of means of anions and residual chlorine analyses of samples from OWTP raw and treated water, SWR and communities which receive water from OWTP and SWR ($n=4$)

| PARAMETER | Chloride (mg/L) | Nitrite (mg/L) | Res. Cl (mg/L) | Phosphate (mg/L) | Sulphate (mg/L) | Ammonia (mg/L) |
|---------------------|-----------------------|-------------------------|------------------------|------------------------|------------------------|------------------------|
| p-value | 1.93×10^{-9} | 5.25×10^{-102} | 1.48×10^{-83} | 1.02×10^{-67} | 2.20×10^{-12} | 4.28×10^{-86} |
| K07 | 27.500 | 0.008 | 0.000 | 0.850 | 12.750 | 0.090 |
| K08 | 25.500 | 0.004 | 1.625 | 0.678 | 19.250 | 0.053 |
| K09 | 27.750 | 0.002 | 0.110 | 0.700 | 16.750 | 0.048 |
| K10 | 29.000 | 0.001 | 0.100 | 0.730 | 24.500 | 0.038 |
| K11 | 26.000 | 0.002 | 0.118 | 0.830 | 15.750 | 0.053 |
| K12 | 34.000 | 0.254 | 1.255 | 0.521 | 29.000 | 0.040 |
| K13 | 21.750 | 0.002 | 0.113 | 0.650 | 20.000 | 0.015 |
| K14 | 23.000 | 0.002 | 0.113 | 0.648 | 22.250 | 0.013 |
| K15 | 23.250 | 0.002 | 0.090 | 0.580 | 24.500 | 0.103 |
| K16 | 25.500 | 0.002 | 0.093 | 0.493 | 27.500 | 0.088 |
| K17 | 28.000 | 0.001 | 0.108 | 0.860 | 29.500 | 0.030 |
| K18 | 28.750 | 0.002 | 0.108 | 0.625 | 25.500 | 0.038 |
| K19 | 25.000 | 0.002 | 0.110 | 0.560 | 27.250 | 0.038 |
| K20 | 25.000 | 0.002 | 0.125 | 0.573 | 31.500 | 0.105 |
| K21 | 24.250 | 0.004 | 0.113 | 0.520 | 26.000 | 0.065 |
| K22 | 28.750 | 0.003 | 0.130 | 0.443 | 27.500 | 0.078 |
| K23 | 25.750 | 0.003 | 0.105 | 0.545 | 32.250 | 0.178 |
| K24 | 89.000 | 0.002 | 0.135 | 0.670 | 32.000 | 0.150 |
| K25 | 22.250 | 0.002 | 0.143 | 0.665 | 29.750 | 0.180 |
| K26 | 22.500 | 0.002 | 0.100 | 0.613 | 28.500 | 0.115 |
| K27 | 26.750 | 0.001 | 0.118 | 0.420 | 39.500 | 0.243 |
| K28 | 25.250 | 0.002 | 0.108 | 0.320 | 27.250 | 0.293 |
| K29 | 28.500 | 0.001 | 0.100 | 0.308 | 30.250 | 0.145 |
| K30 | 25.250 | 0.002 | 0.108 | 0.528 | 30.500 | 0.200 |
| K31 | 26.250 | 0.002 | 0.118 | 0.628 | 29.250 | 0.135 |
| K32 | 21.600 | 0.002 | 0.100 | 0.613 | 24.500 | 0.038 |
| WHO STANDARD | 250 | 3 | | 10 | 400 | 1.5 |

Table 5.2b Results of means of anions analyses and residual chlorine of samples from BWTP raw and treated water, SWR and communities which receive water from BWTP and SWR ($n=4$)

| PARAMETER | Chloride (mg/L) | Nitrite (mg/L) | Res. Cl (mg/L) | Phosphate (mg/L) | Sulphate (mg/L) | Ammonia (mg/L) |
|---------------------|-------------------------|--------------------------|--------------------------|-------------------------|-------------------------|-------------------------|
| p-value | 9.241×10^{-11} | 1.867×10^{-107} | 3.0867×10^{-67} | 1.648×10^{-71} | 2.986×10^{-19} | 3.152×10^{-90} |
| K01 | 22.500 | 0.000 | 0.000 | 1.868 | 21.500 | 0.193 |
| K02 | 28.000 | 0.000 | 1.750 | 0.885 | 20.500 | 0.018 |
| K03 | 26.750 | 0.002 | 0.205 | 0.490 | 28.000 | 0.075 |
| K04 | 27.000 | 0.000 | 0.493 | 0.835 | 20.500 | 0.025 |
| K05 | 22.250 | 0.008 | 0.125 | 0.500 | 19.500 | 0.015 |
| K06 | 21.750 | 0.000 | 0.118 | 0.605 | 24.000 | 0.065 |
| K12 | 34.000 | 0.254 | 1.255 | 0.521 | 29.000 | 0.040 |
| K13 | 21.750 | 0.002 | 0.113 | 0.650 | 20.000 | 0.015 |
| K14 | 23.000 | 0.002 | 0.113 | 0.648 | 22.250 | 0.013 |
| K15 | 23.250 | 0.002 | 0.090 | 0.580 | 24.500 | 0.103 |
| K16 | 25.500 | 0.002 | 0.093 | 0.493 | 27.500 | 0.088 |
| K17 | 28.000 | 0.001 | 0.108 | 0.860 | 29.500 | 0.030 |
| K18 | 28.750 | 0.002 | 0.108 | 0.625 | 25.500 | 0.038 |
| K19 | 25.000 | 0.002 | 0.110 | 0.560 | 27.250 | 0.038 |
| K20 | 25.000 | 0.002 | 0.125 | 0.573 | 31.500 | 0.105 |
| K21 | 24.250 | 0.004 | 0.113 | 0.520 | 26.000 | 0.065 |
| K22 | 28.750 | 0.003 | 0.130 | 0.443 | 27.500 | 0.078 |
| K23 | 25.750 | 0.003 | 0.105 | 0.545 | 32.250 | 0.178 |
| K24 | 89.000 | 0.002 | 0.135 | 0.670 | 32.000 | 0.150 |
| K25 | 22.250 | 0.002 | 0.143 | 0.665 | 29.750 | 0.180 |
| K26 | 22.500 | 0.002 | 0.100 | 0.613 | 28.500 | 0.115 |
| K27 | 26.750 | 0.001 | 0.118 | 0.420 | 39.500 | 0.243 |
| K28 | 25.250 | 0.002 | 0.108 | 0.320 | 27.250 | 0.293 |
| K29 | 28.500 | 0.001 | 0.100 | 0.308 | 30.250 | 0.145 |
| K30 | 25.250 | 0.002 | 0.108 | 0.528 | 30.500 | 0.200 |
| K31 | 26.250 | 0.002 | 0.118 | 0.628 | 29.250 | 0.135 |
| K32 | 21.600 | 0.002 | 0.100 | 0.613 | 24.500 | 0.038 |
| WHO STANDARD | 250 | 3 | - | 10 | 400 | 1.5 |

5.2.12 Ammonia (NH₃) and Nitrite (NO₂⁻) concentrations

Plant nutrient can cause unwanted algal blooms and excessive plant growth when present at elevated levels in water storage facilities. Water with nitrite levels exceeding 1.0 mg/L should not be used for feeding babies. It destroys the ability of the red blood cells to transport oxygen. Concentrations greater than 10 mg/L, as nitrogen, may be injurious to pregnant women, children, and the elderly.

NO₂⁻ concentrations were generally low throughout the entire distribution network with Barekese treated water, Nketia and Nkwantwima recording zero concentrations. The maximum mean NH₃ concentration was recorded at Pankrono with a value of 0.2925 mg/L. Raw water from both treatment plants which are mostly suspected to have high concentrations of nitrite and ammonia due to agricultural activities around their catchment areas even recorded acceptable concentrations. This gives an indication of how successful the conservation and preservation programs of Ghana Water in preventing encroachment within their catchment area has been. The variations in ammonia and nitrite concentrations within the distribution network were however significant ($p < 0.05$) (Table 5.2b).

5.2.13 Sulphate (SO₄²⁻) concentration

Sulphate minerals can cause scale build-up in water pipes like other minerals and may be associated with a bitter taste in water and can also have a laxative effect on humans at concentrations between 1000 – 1200 mg/L. However, all the samples analysed for the whole distribution network fell below this range. The maximum SO₄²⁻ mean concentration was recorded at Tafo Nhyiaeso with a value of 39.50 mg/L as shown in Table 5.2a. The WHO recommended guideline is 400 mg/L. Although all the values recorded were within the safe limit, the variations observed within the distribution network were quite significant ($p < 0.05$).

5.2.14 Iron (Fe) concentration

Iron impart colour and may render water undesirable for drinking purposes. At concentrations above 1 mg/L, it can impart bitter taste to the water. The mean concentrations recorded for iron were 1.03 mg/L for OWTP raw water, 0.19 mg/L for OWTP treated water, 0.11 mg/L for Abuakwa, 0.06 mg/L for Sepease and 0.15 mg/L for Nkawie DE as shown in

Table 5.3a. There was a change in iron concentration of the raw water samples compared to the treated and distributed water samples analysed.

From Table 5.3b, the mean concentrations recorded for iron were 1.24 mg/L for BWTP raw water, 0.09 mg/L for BWTP final water, 0.07 mg/L for Nketia, 0.12 mg/L for Breman and 0.04 mg/L for Nkwantwima. The drop in iron concentration of the raw water for both treatment plants may be as a result of the use of polyelectrolyte in the water treatment processes. Polyelectrolytes have the capacity to remove dissolved iron in water. All the samples analysed did not exceed the WHO limit for iron but the variations observed were significant ($p < 0.05$).

5.2.15 Manganese (Mn) concentration

Manganese in water can cause aesthetic problems even in small quantities, as it coats the interior of the distribution mains with black slim and can lead to consumer dis-satisfaction and rejection. Tafo Nhyiaeso recorded the maximum mean concentration of 0.0625 mg/L (Table 5.3a and 5.3b). This is below the WHO permissible guideline value of 0.1 mg/L. There were significant changes in the mean concentrations recorded as water travelled through the distribution network to consumers ($p < 0.05$).

5.2.16 Microbiological Analysis

The presence of *E. coli* and total coliform were used to determine the possible presence of pathogens in the raw, treated and distributed water samples within the distribution network. Raw water samples from OWTP and BWTP recorded the highest *E. coli* values mainly because water from these sources is not treated. The maximum and minimum values recorded OWTP were 227 cfu/100 mL and 4 cfu/100 mL for *E. coli* whiles Barekese raw water recorded a maximum and minimum of 156 and 6 cfu/100 mL respectively (Tables 5.3a and 5.3b). WHO recommends 0 cfu/100 mL presence of *E. coli* for potable water. This implies that raw water from both dams may not be safe for domestic and industrial purposes. However, there was a significant reduction in *E. coli* count after treatment signifying the effectiveness of the treatment processes at the plants. The OWTP treated water recorded ranges between 0 cfu/100 mL and 1 cfu/100 mL (Table 5.3a). The 1 cfu/100 mL recorded in the treated water sample could be as a result of in-adequate chlorination or inadequate

contact time for chlorination at the plant. The highest count was detected in Nkawie DE which ranged between 0 cfu/100 mL and 31 cfu/100 mL. This can be as attributed to lower residual chlorine levels at the dead-end section of the distribution network.

Treated water from the BWTP did not record any *E. coli* count for the entire study period. This gives an indication of the effectiveness of the water purification processes at the plant. However, from Table 5.3b, Nketia recorded counts in the range of 0 – 10 cfu/100 mL, Breman recorded 0 – 1 cfu/100 mL whiles Nkwantwima also recorded 0 – 1 cfu/100 mL. The existence of *E. coli* clearly points to faecal and enteric pathogens contamination (Anon, 2011b).

SWR recorded zero counts of *E. coli* mainly because that is the point where re-chlorination is done to kill pathogens which may have entered the distribution network through pipe breakages and other system failures within the network. Several communities which receive water supply directly from SWR however, got various counts of *E. coli* above 1 cfu/100 mL.



Table 5.3a Results of means and p-values of metals, cations and microbiological analyses of samples from OWTP raw and treated water, SWR and communities which receive water from OWTP and SWR ($n=4$)

| PARAMETER | Mn (mg/L) | Mg (mg/L) | Fe (mg/L) | Ca (mg/L) | T Coli (cfu/100 mL) | E. Coli (cfu/100 mL) |
|----------------------|------------------------|-----------------------|------------------------|------------------------|---------------------------|----------------------------|
| p-value | 8.91×10^{-96} | 4.88×10^{-2} | 2.03×10^{-71} | 1.93×10^{-09} | 1.8×10^{-5} | 1.8×10^{-5} |
| K07 | 0.008 | 9.038 | 1.025 | 22.800 | 4751.000 | 67.750 |
| K08 | 0.008 | 9.630 | 0.193 | 21.800 | 7.750 | 0.250 |
| K09 | 0.007 | 9.410 | 0.105 | 19.400 | 14.250 | 0.250 |
| K10 | 0.017 | 10.963 | 0.060 | 18.250 | 14.250 | 0.500 |
| K11 | 0.021 | 8.243 | 0.148 | 23.200 | 27.500 | 10.000 |
| K12 | 0.012 | 35.815 | 0.063 | 40.000 | 15.750 | 0.000 |
| K13 | 0.026 | 6.983 | 0.068 | 13.600 | 25.500 | 0.500 |
| K14 | 0.019 | 5.535 | 0.075 | 13.200 | 31.000 | 0.000 |
| K15 | 0.014 | 6.865 | 0.058 | 19.200 | 13.250 | 1.000 |
| K16 | 0.022 | 6.865 | 0.083 | 18.000 | 19.750 | 0.500 |
| K17 | 0.011 | 8.060 | 0.138 | 20.400 | 21.250 | 2.000 |
| K18 | 0.011 | 10.900 | 0.093 | 24.775 | 7.250 | 0.000 |
| K19 | 0.033 | 8.203 | 0.108 | 21.200 | 103.500 | 3.000 |
| K20 | 0.138 | 8.183 | 0.095 | 16.800 | 118.750 | 0.750 |
| K21 | 0.040 | 5.045 | 0.050 | 15.450 | 40.500 | 2.250 |
| K22 | 0.042 | 8.810 | 0.110 | 14.900 | 20.250 | 1.500 |
| K23 | 0.005 | 2.920 | 0.115 | 12.250 | 34.250 | 0.750 |
| K24 | 0.021 | 11.580 | 0.135 | 24.800 | 104.250 | 0.250 |
| K25 | 0.013 | 9.628 | 0.113 | 17.920 | 91.250 | 2.500 |
| K26 | 0.017 | 6.318 | 0.050 | 12.500 | 27.250 | 8.000 |
| K27 | 0.063 | 9.380 | 0.140 | 14.000 | 12.000 | 0.250 |
| K28 | 0.011 | 7.345 | 0.065 | 15.400 | 19.500 | 0.500 |
| K29 | 0.031 | 8.785 | 0.083 | 11.700 | 38.750 | 0.750 |
| K30 | 0.012 | 11.315 | 0.056 | 14.760 | 57.750 | 0.250 |
| K31 | 0.011 | 11.063 | 0.100 | 15.000 | 52.000 | 1.500 |
| K32 | 0.012 | 7.825 | 0.133 | 12.400 | 13.750 | 0.500 |
| WHO STANDARDS | 0.1 | 150 | 0.3 | 200 | 0 | 0 |

Table 5.3b Results of means and p-values of metals, cations and microbiological analyses of samples from BWTP raw and treated water, SWR and communities which receive water from BWTP and SWR ($n=4$)

| PARAMETER | Mn (mg/L) | Mg (mg/L) | Fe (mg/L) | Ca (mg/L) | T Coli (cfu/100 mL) | E. Coli (cfu/100 mL) |
|----------------------|------------------------------|----------------------------|------------------------------|-----------------------------|------------------------|-------------------------|
| p-value | 5.29 x 10 ⁻¹⁰¹ | 0.03 x 10 ⁻² | 4.12 x 10 ⁻¹⁰⁶ | 2.15 x 10 ⁻¹² | 0.000452 | 0.003850 |
| K01 | 0.003 | 7.4675 | 1.238 | 18.800 | 4216.500 | 53.750 |
| K02 | 0.030 | 6.0225 | 0.085 | 16.400 | 2.750 | 0.000 |
| K03 | 0.026 | 10.0275 | 0.113 | 19.000 | 24.250 | 0.500 |
| K04 | 0.015 | 4.8175 | 0.070 | 17.600 | 22.750 | 2.500 |
| K05 | 0.003 | 5.055 | 0.115 | 11.000 | 7.750 | 0.250 |
| K06 | 0.008 | 10.47 | 0.040 | 14.600 | 22.500 | 0.250 |
| K12 | 0.012 | 35.815 | 0.063 | 40.000 | 15.750 | 0.000 |
| K13 | 0.026 | 6.9825 | 0.068 | 13.600 | 25.500 | 0.500 |
| K14 | 0.019 | 5.535 | 0.075 | 13.200 | 31.000 | 0.000 |
| K15 | 0.014 | 6.865 | 0.058 | 19.200 | 13.250 | 1.000 |
| K16 | 0.022 | 6.865 | 0.083 | 18.000 | 19.750 | 0.500 |
| K17 | 0.011 | 8.06 | 0.138 | 20.400 | 21.250 | 2.000 |
| K18 | 0.011 | 10.9 | 0.093 | 24.775 | 7.250 | 0.000 |
| K19 | 0.033 | 8.2025 | 0.108 | 21.200 | 103.500 | 3.000 |
| K20 | 0.138 | 8.1825 | 0.095 | 16.800 | 118.750 | 0.750 |
| K21 | 0.040 | 5.045 | 0.050 | 15.450 | 40.500 | 2.250 |
| K22 | 0.042 | 8.81 | 0.110 | 14.900 | 20.250 | 1.500 |
| K23 | 0.005 | 2.92 | 0.115 | 12.250 | 34.250 | 0.750 |
| K24 | 0.021 | 11.58 | 0.135 | 24.800 | 104.250 | 0.250 |
| K25 | 0.013 | 9.6275 | 0.113 | 17.920 | 91.250 | 2.500 |
| K26 | 0.017 | 6.3175 | 0.050 | 12.500 | 27.250 | 8.000 |
| K27 | 0.063 | 9.38 | 0.140 | 14.000 | 12.000 | 0.250 |
| K28 | 0.011 | 7.345 | 0.065 | 15.400 | 19.500 | 0.500 |
| K29 | 0.031 | 8.785 | 0.083 | 11.700 | 38.750 | 0.750 |
| K30 | 0.012 | 11.315 | 0.056 | 14.760 | 57.750 | 0.250 |
| K31 | 0.011 | 11.0625 | 0.100 | 15.000 | 52.000 | 1.500 |
| K32 | 0.012 | 7.825 | 0.133 | 12.400 | 13.750 | 0.500 |
| WHO STANDARDS | 0.1 | 150 | 0.3 | 200 | 0 | 0 |

5.2.17 Sanitary Survey

Sanitary survey was conducted in various sample locations to identify probable sources of contamination especially where total coliform and E. coli counts were high. It was discovered that several dead-end washouts surveyed were leaking and pose a huge threat to the quality of water consumed in these communities. Figure 5.1 shows a leaking and unprotected dead-end washout at Barekese. There's a public toilet and a refuse dump sited

about 10 meters away. Run-off water moving from toilet and refuse dump site flows towards this unprotected dead-end blow out and can contaminate the water.



Figure 5.1 Unprotected dead-end blow out sited close to a public toilet



Figure 5.2 18-inch and 14-inch mains from Owabi to SWR passing through drainage carrying effluents from the Abrepo community



Figure 5.3 A leaking dead-end blow-out at Nkawie

It was also discovered that the 18 and 14-inch mains transporting treated water from the OWTP to Suame water reservoir passed through draining conveying waste water and sewerage from the Abrepo community. This can expose the water in the mains to contamination in the event of any pipe breakage and back syphonage. This is as shown in Figure 5.2.

Figure 5.3 shows a leaking dead-end washout at Nkawie. This was common for most of the dead-end washouts visited during the study period. They were all identified as hot spots for water contamination.

5.3 Correlation Analyses of *E. coli* and Residual Chlorine

A weak to moderate inverse correlation was observed between residual chlorine and *E. coli* for treated and distributed water samples (Tables 5.6, 5.7 and 5.8). As free chlorine concentration decreases, microbial count increases. This finding agrees with a research work conducted by Farooq *et al.* (2008). The presence of *E. coli* in the water samples collected indicates contamination by faecal matter. This could be due to inadequate residual chlorine,

or accidental point source contamination by burst pipes, installation and repair works within the distribution network.

5.4 Correlation Analyses of Physico-chemical Parameters of sample points

Some physico-chemical parameters investigated throughout the distribution network did not show any strong significant correlation with any other. However, some were found to have a strong correlation with each other.

From Table 5.3, pH correlated negatively with turbidity ($r = -0.984$), electrical conductivity ($r = -0.459$), TDS ($r = -0.358$), total hardness ($r = -0.861$), Alkalinity ($r = -0.641$) and *E. coli* ($r = -0.728$) but correlated positively with temperature ($r = 0.612$) for Owabi raw water samples. On the other hand, turbidity correlated negatively with temperature ($r = -0.714$) but correlated positively with EC ($r = 0.547$), TDS ($r = 0.428$), total hardness ($r = 0.926$), Alkalinity ($r = 0.765$) and *E. coli* ($r = 0.611$). Turbidity showed the strongest positive correlation with total hardness while pH showed strongest negative correlation with turbidity. This means that the turbidity of the raw water samples increased with increased total hardness while the reverse applies to the relationship between pH and turbidity.

pH significantly correlated positively with turbidity ($r = 0.926$) and total hardness ($r = 0.938$) but negatively correlated strongly with total alkalinity ($r = -0.997$) for water samples from OWTP treated water as shown in Table 5.3. It was also observed that TDS had a very strong positive correlation with EC for Owabi treated water samples analysed. *E. coli* correlated positively with turbidity ($r = 0.644$), pH ($r = 0.595$), temperature ($r = 0.38$) and total hardness ($r = 0.38$) but had a very strong negative correlation with total alkalinity ($r = -0.926$).

Table 5.3 Correlation matrix of r - values between *E. coli* and other physico-chemical parameters of OWTP Raw Water samples

| Parameter | pH | Turb (NTU) | EC($\mu\text{s}/\text{cm}$) | TDS | Temp ($^{\circ}\text{C}$) | T H | T A | <i>E. coli</i> |
|--|--------|---------------|-------------------------------|--------|--------------------------------|-------|--------|----------------|
| pH | 1 | | | | | | | |
| Turb (NTU) | -0.984 | 1 | | | | | | |
| EC ($\mu\text{s}/\text{cm}$) | -0.459 | 0.547 | 1 | | | | | |
| TDS | -0.358 | 0.428 | 0.982 | 1 | | | | |
| Temp ($^{\circ}\text{C}$) | 0.612 | -0.714 | -0.279 | -0.090 | 1 | | | |
| T H | -0.861 | 0.926 | 0.811 | 0.707 | -0.683 | 1 | | |
| T A | -0.641 | 0.765 | 0.784 | 0.651 | -0.813 | 0.916 | 1 | |
| <i>E. coli</i> | -0.728 | 0.611 | -0.226 | -0.277 | -0.236 | 0.279 | -0.024 | 1 |

Level of significance $p < 0.05$, $p < 0.01$

Turb Turbidity, EC Electrical Conductivity, TDS Total Dissolved Solids, Temp Temperature, TH Total Hardness, TA Total Alkalinity

Table 5.4 Correlation matrix of r - values between *E. coli* and other physico-chemical parameters of OWTP Treated Water samples

| Parameter | pH | Turb (NTU) | EC($\mu\text{s}/\text{cm}$) | TDS | Temp ($^{\circ}\text{C}$) | T H | T A | Res Cl | <i>E. coli</i> |
|--|--------|---------------|-------------------------------|--------|--------------------------------|-------|-------|-----------|----------------|
| pH | 1 | | | | | | | | |
| Turb (NTU) | 0.926 | 1 | | | | | | | |
| EC ($\mu\text{s}/\text{cm}$) | -0.595 | -0.253 | 1 | | | | | | |
| TDS | -0.512 | -0.149 | 0.987 | 1 | | | | | |
| Temp ($^{\circ}\text{C}$) | 0.582 | 0.836 | 0.307 | 0.388 | 1 | | | | |
| T H | 0.938 | 0.937 | -0.367 | -0.310 | 0.749 | 1 | | | |
| T A | -0.292 | -0.307 | 0.254 | 0.111 | -0.05 | -0.01 | 1 | | |
| Res Ch | -0.601 | -0.260 | 0.950 | 0.973 | 0.237 | -0.47 | -0.05 | 1 | |
| <i>E. coli</i> | 0.595 | 0.644 | -0.287 | -0.130 | 0.384 | 0.377 | -0.93 | -0.05 | 1 |

Level of significance $p < 0.05$, $p < 0.01$

Turb Turbidity, EC Electrical Conductivity, TDS Total Dissolved Solids, Temp Temperature, TH Total Hardness, TA Total Alkalinity

Table 5.5 Correlation matrix of r - values between *E. coli* and other physico-chemical parameters of BWTP treated water samples

| Parameter | pH | Turb (NTU) | EC(μ s/cm) | TDS | Temp ($^{\circ}$ C) | T H | T A | Res Ch | E. Coli |
|--------------------------------------|--------|------------|-----------------|--------|----------------------|-------|-------|--------|---------|
| pH | 1 | | | | | | | | |
| Turb (NTU) | 0.612 | 1.000 | | | | | | | |
| EC (μs/cm) | -0.262 | -0.906 | 1.000 | | | | | | |
| TDS | -0.266 | -0.895 | 0.998 | 1.000 | | | | | |
| Temp ($^{\circ}$C) | 0.773 | 0.447 | -0.042 | -0.004 | 1.000 | | | | |
| T H | 0.680 | -0.164 | 0.514 | 0.497 | 0.550 | 1.000 | | | |
| T A | 0.043 | 0.816 | -0.954 | -0.936 | 0.000 | -0.71 | 1.000 | | |
| Res Ch | -0.925 | -0.338 | 0.021 | 0.047 | -0.57 | -0.84 | 0.248 | 1.000 | |
| <i>E. coli</i> | 0.070 | -0.522 | 0.292 | 0.293 | -0.39 | -0.58 | -0.66 | -0.29 | 1.00 |

Level of significance $p < 0.05$, $p < 0.01$

Turb Turbidity, EC Electrical Conductivity, TDS Total Dissolved Solids, Temp Temperature, TH Total Hardness, TA Total Alkalinity.

From Table 5.6, *E. coli* showed a positive correlation with pH ($r = 0.770$) but had a negative correlation with residual chlorine ($r = -0.58$) and total alkalinity ($r = -0.60$). This means that the *E. coli* count increased with decrease in residual chlorine concentration of water samples taken from Breman. Again, *E. coli* correlated negatively with residual chlorine for BWTP treated water samples with r-value of -0.290 as compared to r-value of -0.58 as shown in Tables 5.5 and 5.6. This shows that the residual chlorine concentration reduces as water travels further away from the treatment plant resulting in increased *E. coli* count.

At Nkwanwima, *E. coli* correlated weakly with pH ($r = 0.070$), EC ($r = 0.292$) and TDS (0.293) but correlated negatively with turbidity ($r = -0.522$), total hardness ($r = -0.58$), total alkalinity and residual chlorine ($r = -0.29$) as shown in Table 5.7.

Table 5.6 Correlation matrix of r - values between *E. coli* and other physico-chemical parameters of Breman water samples

| Parameter | pH | Turb (NTU) | EC(μ s/cm) | TDS | Temp (°C) | T H | T A | Res Ch | E. Coli |
|------------------|--------|---------------|-----------------|--------|--------------|-------|-------|-----------|------------|
| pH | 1.000 | | | | | | | | |
| Turb (NTU) | -0.555 | 1.000 | | | | | | | |
| EC (μ s/cm) | -0.193 | 0.866 | 1.000 | | | | | | |
| TDS | -0.208 | 0.876 | 1.000 | 1.000 | | | | | |
| Temp (°C) | 0.761 | -0.400 | -0.358 | -0.359 | 1.000 | | | | |
| T H | 0.349 | -0.829 | -0.961 | -0.960 | 0.597 | 1.000 | | | |
| T A | -0.510 | 0.994 | 0.842 | 0.854 | -0.30 | -0.78 | 1.000 | | |
| Res Ch | 0.772 | 0.086 | 0.469 | 0.456 | 0.507 | -0.28 | 0.120 | 1.000 | |
| <i>E. coli</i> | 0.770 | -0.573 | -0.086 | -0.107 | 0.183 | 0.070 | -0.60 | -0.58 | 1.00 |

Level of significance $p < 0.05$, $p < 0.01$

Turb Turbidity, EC Electrical Conductivity, TDS Total Dissolved Solids, Temp Temperature, TH Total Hardness, TA Total Alkalinity

Table 5.7 Correlation matrix of r - values between *E. coli* and other physico-chemical parameters of Nkwantwima water samples

| Parameter | pH | Turb (NTU) | EC(μ s/cm) | TDS | Temp (°C) | T H | T A | Res Ch | E. Coli |
|------------------|--------|---------------|-----------------|-------|--------------|------|------|-----------|---------|
| pH | 1.000 | | | | | | | | |
| Turb (NTU) | 0.080 | 1.000 | | | | | | | |
| EC (μ s/cm) | -0.905 | -0.457 | 1.000 | | | | | | |
| TDS | -0.900 | -0.472 | 1.000 | 1.000 | | | | | |
| Temp (°C) | -0.946 | 0.113 | 0.737 | 0.731 | 1.000 | | | | |
| T H | -0.541 | -0.302 | 0.446 | 0.454 | 0.673 | 1.00 | | | |
| T A | -0.797 | 0.227 | 0.514 | 0.510 | 0.948 | 0.78 | 1.00 | | |
| Res Ch | 0.928 | 0.167 | -0.940 | 0.934 | -0.77 | 0.24 | 0.52 | 1.00 | |
| <i>E. Coli</i> | 0.070 | -0.522 | 0.292 | 0.293 | -0.39 | 0.58 | 0.66 | 0.29 | 1.00 |

Level of significance $p < 0.05$, $p < 0.01$

Turb Turbidity, EC Electrical Conductivity, TDS Total Dissolved Solids, Temp Temperature, TH Total Hardness, TA Total Alkalinity

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

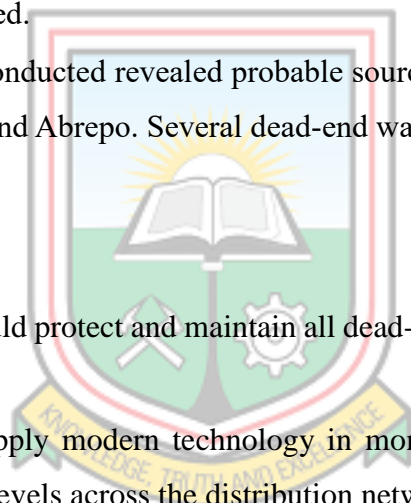
6.1 Conclusions

From the results obtained for this study, it was revealed that:

- All parameters investigated fell within World Health Organization (WHO) guidelines for drinking water quality except for *E. coli* and total coliform which were found to be unacceptable for some sample locations
- The fall in microbial quality was directly related to the poor maintenance of residual chlorine concentration throughout the entire distribution network,
- There were significant variations in all physico-chemical and bacteriological parameters assessed.
- Sanitary survey conducted revealed probable sources of contamination in Barekese DE, Nkawie DE and Abrepo. Several dead-end washouts surveyed were leaking.

6.2 Recommendations

- Ghana Water should protect and maintain all dead-ends washouts of the distribution network.
- Urgent need to apply modern technology in monitoring water quality especially residual chlorine levels across the distribution network.
- Further investigations must be conducted in order to ascertain the direct cause of the contamination.



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