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DEPARTMENT OF THEORETICAL & APPLIED BIOLOGY

EFFICIENCY OF WATER TREATMENT BY GHANA WATER COMPANY LIMITED IN DABOASE AT WASSA EAST DISTRICT

BY

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DECLARATION

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

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This work is dedicated to my sons Papa Gyasi (George Myles-Abadoo), Nana Gyamesaye (Joseph Martin Myles-Abadoo) and daughter Maame Yedenua (Matilda Myles-Abadoo)

ABSTRACT

Water is one of the most important resources man needs. The study was conducted to determine the efficiency of water treatment at Daboase headworks of Ghana Water Company Limited in the Mpohor Wassa East of the Western region. To achieve higher treatment efficiency of contaminants, the GWCL plant uses procedures which include flocculation/coagulation, sedimentation, filtration and disinfection. Physico-chemical and bacteriological water quality analyses were conducted on eighty (80) samples for both the raw and treated water from January 2012 to May, 2012. The results indicated that the raw water contain high mean values of 1364.77 ± 326.99 Hu, 1107.05 ± 103.70 NTU, 14.38 ± 3.4 MPN/100ml and 1.91 ± 1.76 CFU/100ml for colour, turbidity, total coliforms and *E. coli* respectively which exceeded the WHO standard limits making it unsafe for drinking. The treated water samples had mean values of 6.92 ± 0.11, 5.59 Hu, 2.70 ± 0.30 NTU, 76.05 ± 4.26mg/L, 0.76 ± 0.26 mg/L, 49.41 ± 3.67 mg/L, 0.10 ± 0.03 mg/L, 0.85 ± 0.12 mg/L, 0.0 MPN/100ml and 0.0 CFU/100ml for pH, colour, turbidity, total hardness, nitrate, sulphate, total irons, residual chlorine, total coliforms and *E. coli* respectively which were within the limits set by the WHO guidelines for drinking water. The results also indicated efficiency of 99.5%, 99.7%, 95.6%, 99.2%, 100% and 100% for colour, turbidity, nitrate, total iron, total coliforms and *E. coli* respectively. The overall efficiency of the treatment plant was 99.0% which makes the GWCL water treatment plant generally satisfactory during the period of this study.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Water treatment has become extremely important all over the world due to population growth, growing urbanization, which has led to environmental pollution and therefore pollution of water bodies. Water is purified or treated to get rid of harmful substances or reduce them to the minimum permissible limit to make them safe and fit for human consumption or suitable for the intended general domestic uses (Oyeleke and Instifanus, 2008).

Water treatment by various water suppliers must conform to certain allowable limits pertaining to substances of physical, chemical and biological interest which if not properly removed can bring onto humans certain diseases of public health concern (WHO, 2011).It may also interfere with some industrial activities if the water contains high quantities of dissolved chemical substances such as Ca^{2+}, Mg^{2+}, phenols etc. Therefore some companies such as West African Mills, Takoradi, Guinness Ghana Breweries, Kumasi and Accra, Cocoa Processing Company Tema etc. also do “post-treatment” on the water they receive from the Ghana Water Company Limited (GWCL) before they use for their industrial activities even though some of the treatment by these companies is to get a specific water quality parameters.

The treatment efficiency of the treatment plant must be high enough since inefficient removal of some contaminants especially pathogens can affect consumers in diverse ways. It is upon this reason that this research seeks to assess the efficiency of the water treatment process at the Daboase Ghana Water Company headworks of the Wassa East

District in the Western Region. The treatment processes at the treatment plant includes; flocculation, sedimentation (clarification) and sludge disposal, filtration, disinfection and post lime addition.

1.2 Problem Statement

Quality of drinking water is a powerful environmental determinant of health and for that matter water safety is a foundation for the prevention and control of waterborne diseases (WHO, 2011) Physico-chemical and bacteriological quality of water for consumption and for other socio-economic activities are considered to be one of the concerns of both the general public and water suppliers. People living within Mpohor Wassa East, Shama, Agona districts and the Sekondi-Takoradi Metropolis use water treated by the GWCL Daboase plant for both consumption and other socioeconomic activities. The GWCL activities with respect to water quality are regulated by the Public Utilities Regulatory Commission (PURC). The PURC among other things have the responsibilities of regulation of the urban water supply and electricity, including the review of request for tariff increases, monitoring of service quality and the protection of the consumers; but the extent of the water quality in the distribution network depends mostly on the efficiency of the treatment plant in its removal of physico-chemical and biological substances which may cause diseases and other undesirable consequences to water users (Cloete, 2004). River Pra and its tributaries serve as a source of water for the treatment plant. Due to human activities such as farming which includes livestock rearing, excessive use of fertilizers, dumping of waste (domestic and sewage) as well as mining activities in the Pra River which makes the water unsafe for drinking and other uses. These human activities release substances of physical, chemical and bacteriological contaminant which must be removed by an efficient treatment facility. It is for this reason that the efficiency of the treatment plant in the removal of substances of physical, chemical and bacteriological parameters was assessed to ascertain its efficiency in the removal of these contaminants and make recommendations for the improvement of the treatment efficiency if found otherwise.

1.3 Objectives

The main objective of this work is to determine the quality of the raw (source) and the treated water from the Daboase treatment plant of the GWCL.

1.4 Specific Objectives

1. To determine colour, pH, turbidity, nitrates, sulphate, total hardness, total iron, residual chlorine.

2. To determine the microbial load (Total coliforms and *E.coli*) of the raw water from the reservoir and treated water from the treatment plant.

1.5 Justification

Protecting the entire populace by providing potable treated water to the communities is a challenge that must be dealt with effectively. This challenge needs a scientific assessment of the water at different stages of the treatment in order to ascertain the efficiency of the treatment plant.

This work was to undertake laboratory analysis of the bacteriological and physico-chemical parameters of the treated water which will serve as bases to assess the efficiency of this water treatment plant.

The results will give an indication of the plant performance, as to whether the water produced from this plant is of high quality and therefore boost consumer confidence in the use of the treated water from this plant for domestic purposes including drinking.

It will also provide information which will guide policy direction on the improvement or otherwise of the already existing performance on the various treatment processes of the plant.

CHAPTER TWO

LITERATURE REVIEW

Safety of drinking water is determined by its bacteriological and physico-chemical parameters. In determining the quality of water in a treatment plant, some parameters including the following were investigated; colour, pH, turbidity, nitrates, sulphate, total hardness, total iron, residual chlorine, *Escherichia coli* and total coliforms.

2.1 Historical background of water supply

The first pipe-borne water supply system was constructed in Cape Coast in 1928 (GWRESP, 2008). The Water Supply Division of the Public Works Department was responsible for the service provision in rural and urban areas of Ghana. After Ghana's independence in 1957, the division was separated from the Public Works Department and placed under the Ministry of Works and Housing. In 1965, it was transformed into the Ghana Water and Sewerage Corporation (GWSC), a legal public utility responsible for the provision of urban and rural water supply for public, domestic, and industrial purposes as well as the establishment, operation, and control of sewerage systems (WaterAid, 2007). Since 1993, various reforms have been introduced to address the problems of the sector. The key objectives of the reforms were to separate rural and urban service, to introduce independent regulatory agencies, and to promote private sector participation (CWSA, 2004)

In order to pay more attention to water supply and sanitation in rural areas, the Community Water and Sanitation Division was founded as a semi-autonomous division of GWSC in 1994. Four years later, it changed its name to the Community Water and

Sanitation Agency (CWSA) and became fully independent (GWRESP, 2008). In 1999, the GWSC was replaced by the publicly owned Ghana Water Company Limited (GWCL). At the same time, the responsibility for rural water supply and sanitation was decentralized to the District Assemblies (Water Aid, 2008) In addition; sanitation was separated from water supply and became a responsibility of the District Assemblies in urban and rural areas (United Nations, 2004). The GWCL remained responsible only for urban water supply. The District and Municipal Assemblies are responsible for sanitation in urban and rural areas (CWSA, 2004)

The regulation of water supply has been shifted from the government to independent agencies. Two commissions were created in 1997 to regulate the sector (CWSA, 2004). These commissions are the Public Utilities Regulatory Commission (PURC) and the Water Resources Commission (WRC). The PURC takes responsibility for economic regulation of urban water supply and sanitation, the Water Resources Commission (WRC) regulates water resources: it is in charge of licensing water abstraction and wastewater discharges (Water Aid, 2008).

2.2 Water treatment processes

2.2.1 Screening

The first step in treating surface water is to remove large debris such as sticks, leaves, tree branches and other large particles which may interfere with subsequent treatment steps. This is done by fixing a wire mesh of size between 2-3 cm at entrance of the intake point.

2.2.2 Coagulation and Flocculation

Flocculation is a process which clarifies the water. Clarifying means removing any turbidity or colour in other to make the water clear and colourless. Clarification is done by causing a precipitate to form in the water which can be removed using simple physical methods (Edzwald, 2011) A significant portion of dispersed solids in surface water are colloids which have relatively large surface area per volume of particles. They have a tendency of adsorbing ions from surrounding water and thus develop an electrostatic charge, because of the charge they carry. These particles do not settle by force of gravity (Reynolds and Richards, 1996). Coagulants are thus added to destabilise the electrostatic charges carried by the colloids. Initially the precipitate forms as very small particles but as the water is gently stirred, these particles stick together to form bigger particles. By this action, the coagulated precipitate takes most of the suspended matter out of the water and is then filtered off, generally by passing the mixture through a coarse sand filter or sometimes through a mixture of sand and granulated anthracite. According to Smethrust (1998) most coagulants are salts of aluminium and iron that act by double decomposition. Coagulants or flocculating agents commonly used are; Iron (III) hydroxide, Aluminium hydroxide and PolyDADMAC (Poly diallyl dimethyl ammonium chloride) which is an artificially produced polymer and is one of a class of synthetic polymers that are now widely used. These polymers have a high molecular weight and form very stable and readily remove flocs, but tend to be more expensive in use compared to inorganic materials. The materials can also be biodegradable.

2.2.3 Sedimentation

Sedimentation is the process of separating suspended particles that are heavier than water by gravitational settling. Waters exiting the flocculation basin may enter the sedimentation basin with slow flow, allowing floc to settle to the bottom. The amount of floc that settles out of the water is dependent on basin retention time and on basin depth (Liptak, 2006). The minimum clarifier retention time is normally 4 hours. A deep basin will allow more floc to settle out than a shallow basin. This is because large particles settle faster than smaller ones, so large particles collide with and integrate smaller particles as they settle. In effect, large particles sweep vertically through the basin and clean out smaller particles on their way to the bottom (Edzwald, 2011).

As particles settle to the bottom of the basin, a layer of sludge is formed on the floor of the tank. This layer of sludge must be removed and treated. The amount of sludge that is generated is significant, often 3 to 5 percent of the total volume of water that is treated. The cost of treating and disposing of the sludge can be a significant part of the operating cost of a water treatment plant. The tank may be equipped with mechanical cleaning devices that continually clean the bottom of the tank or the tank can be taken out of service when the bottom needs to be cleaned.

2.2.4 Filtration

After separating most floc, the water is filtered to remove remaining suspended particles and unsettled floc. The two most common types of filtration process that are used are the rapid sand filtration method and the slow sand filtration method. Their difference is based on the principles by which they operate (Casey, 2005).

The most use type is rapid sand filter. Here water moves vertically through sand which often has a layer of activated carbon or anthracite coal above the sand. The top layer removes organic compounds, which contribute to taste and odour. Most particles that pass through the surface layers are trapped in pore spaces or adhere to sand particles. Effective filtration depends on the depth of the filter, this property of the filter is key to its operation. If the top layer of sand were to block all the particles, the filter would quickly clog (USEPA, 1990).To clean the filter, water is passed quickly upward through the filter, opposite the normal direction (called backflushing or backwashing) to remove embedded particles. Prior to this step, compressed air may be blown up from the bottom of the filter to break up the compacted filter media to aid the backwashing process; this is known as air scouring. This contaminated water is disposed off along with the sludge from the sedimentation basin (USEPA, 2001). Rapid sand filters require less surface area when compared to slow sand filter because they operate under pressure and are commonly used for municipal water treatment plants as the final clarifying step (Vigneswaran and Visvanathan, 1995).

Slow sand filters may be used where there is sufficient land and space, as the water must be passed very slowly through the filters. The filters are carefully constructed using graded layers of sand, with the coarsest sand, along with some gravel, at the bottom and finest sand at the top. Drains at the base convey treated water away for disinfection. Filtration depends on the development of a thin biological layer, called the zoogleal layer or Schmutzdecke, on the surface of the filter. An effective slow sand filter may remain in service for many weeks or even months if the pre-treatment is well designed and produces water with a very low available nutrient level which physical methods of treatment rarely achieve. Very low nutrient levels allow water to be safely sent through distribution systems with very low disinfectant levels, thereby reducing consumer irritation over offensive levels of chlorine and chlorine by-products. Slow sand filters are not backwashed; they are maintained by having the top layer of sand scraped off when flow is eventually obstructed by biological growth. (Reynolds and Richards, 1996).

Slow sand filters have the following advantages;

- Less energy intensive when compared to rapid sand filters.
- Are simple to design and operate and have minimal requirement for expensive chemicals.
- Develop minimal sludge handling problems and do not demand close monitoring by an operator.

But have the disadvantages of requiring larger land area, large quantities of filtering medium and manual cleaning (Vigneswaran and Visvanathan, 1995).

There is also a less common water filtration method known as Multistage filtration that aim to overcome the limitations of slow sand filters to cope with raw water such as that with high turbidities. Multi-stage filters are a combination of slow sand filters and gravel filters. The sand filters act as a polishing step, while the gravel filters are used as roughing filters for pretreatment (Galvis,1999).

Membrane filtration is also widely used for filtering both drinking water and sewage. For drinking water, membrane filters can remove virtually all particles larger than 0.2μm including giardia and cryptosporidium (INEPA, 2005). Membrane filters are an effective form of tertiary treatment when it is desired to reuse the water for industry, for limited domestic purposes, or before discharging the water into a river that is used by towns further downstream. They are widely used in industry, particularly for beverage preparation (including bottled water). However no filtration can remove substances that are actually dissolved in the water such as phosphorus, nitrates and heavy metals ions (David, 1999).

2.2.5 Disinfection

Disinfection is the process by which pathogenic organisms are destroyed or otherwise inactivated. Water is disinfected to kill any pathogens which pass through the filters and to provide a residual dose of disinfectant to kill or inactivate potentially harmful micro-organisms in the storage and distribution systems (Brian, 2003). Possible pathogens include viruses, bacteria, including *Salmonella, Cholera*, *Campylbacter* and *Shigella* and protozoa including *Giardia lamblia* and *Cryptosporidia*. Following the introduction of any chemical disinfecting agent, the water is usually held in temporary storage – often called a contact tank or clear well to allow the disinfecting action to complete (Brian, 2003).

2.2.5.1 Chlorine Disinfection

The most common disinfection method is the use of chlorine or its compounds such as chloramine or chlorine dioxide. Chlorine is a strong oxidant that rapidly kills many harmful micro-organisms. Because chlorine is a toxic gas, there is a danger associated with its use. This problem is avoided by the use of sodium hypochlorite, which is a relatively inexpensive and releases free chlorine when dissolved in water. A solid form of calcium hypochlorite releases chlorine on contact with water. Handling the solid, however, requires greater routine human contact through opening bags and pouring than the use of gas cylinders or bleach which is more easily automated (Pradyot, 2002).

All forms of chlorine are widely used, despite their respective drawbacks. One drawback is that they react with organic compounds in the water to form potentially harmful by-products. Some of the by-products such as trihalomethanes (THMs) and haloaceticacids (HAAs) are carcinogenic (Aiking, 1999). The formation of THMs and haloacetic acids may be minimized by effective removal of organics from the water prior to chlorine addition. Although chlorine is effective in killing bacteria, it has limited effectiveness against protozoa that form cysts in water such as *Giardia lamblia* and *Cryptosporidium sp.* both of which are pathogenic (Hoon *et al*, 2003).

2.2.5.2 Chloramine Disinfection

The use of chloramine is becoming more common as a disinfectant. Although chloramine is not as strong an oxidant, comparably it provides a longer-lasting residual than free chlorine and it will not form THMs or haloacetic acids (USEPA, 2009). It is possible to convert chlorine to chloramine by adding ammonia to the water after addition of chlorine. The chlorine and ammonia react to form chloramine. Water distribution systems disinfected with chloramines may experience nitrification, as ammonia is a nutrient for bacterial growth, with nitrates being generated as a by-product (Gray, 2005).

2.2.5.3 Ozone Disinfection

Ozone is an unstable molecule which readily gives up one atom of oxygen providing a powerful oxidizing agent which is toxic to most waterborne microorganisms (Bruno and David, 2001). It is an effective method to inactivate harmful protozoa that form cysts. It also works well against almost all other pathogens. Ozone is made by passing oxygen through ultraviolet light or electrical discharges. To use ozone as a disinfectant, it must be created on-site and added to the water by bubble contact. Some of the advantages of ozone include the production of fewer dangerous by-products. Although fewer by-products are formed by ozonation, it has been demonstrated that the use of ozone produces a small amount of the suspected carcinogenic bromate, although little bromine should be present in treated water. Another disadvantage of ozone is that it leaves no disinfectant residual in the water (Christiane *et al*, 2009).

2.2.5.4 Ultraviolet Disinfection

Ultraviolet light (UV) is very effective in inactivating cysts, in low turbid water. UV light's disinfection effectiveness decreases as turbidity increases, as a result of the absorption, scattering, and shadowing caused by the suspended solids (Christensen and Linden, 2010). The main disadvantage to the use of UV radiation is that, like ozone treatment, it leaves no residual disinfectant in the water; therefore, it is sometimes necessary to add a residual disinfectant after the primary disinfection process. This is often done through the addition of chloramines. When used in this manner, chloramines provide an effective residual disinfectant with very few of the negative aspects of chlorination (USEPA, 2009).

2.2.5.5 Hydrogen Peroxide Disinfection

Hydrogen peroxide works in a manner similar to ozone. Activators such as formic acid are often added to increase the efficacy of disinfection. It has the disadvantages that it is slow-working, phytotoxic in high dosage, and decreases the pH of the water it purifies (USEPA, 2001).

2.2.6 Post-lime Addition

Aluminium sulphate used in coagulation significantly reduces the pH of water to acidic level so post lime addition is therefore carried out to raise the pH. Lime is added after chlorination in other not to hinder disinfection as microorganisms are protected by flocs of lime. Lime is also used for corrosion control in the distribution and storage facilities which are made of cast iron (Owusu, 2012).

2.3 Some parameters used to access the efficiency of water treatment

2.3.1 Physico–chemical parameters

2.3.1.1 pH

pH measures the acidity or alkalinity of the water sample (Sullivan *et al* 2005). It determines whether the water is too aggressive to be used in supply and also plays a vital role in determining the type of bacteria that grow in the water and the change they produce. Each organism has its own optimal pH for growth (Hoon *et al*, 2003).

pH of natural water also determines the degree of solubility and chemical forms of most substances which also determines the degree of toxicity of metal ions contained in bottom sediments or suspended in the water. (Davies and Dewiest, 2000). pH of most rivers result from the balance between dissolved CO_2 gas (derived from the atmosphere and biological activities) and the dissolved carbonates and bicarbonates (derived from rocks) through geological and biological cycles.

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

Low pH can cause corrosion and produce metallic taste in water, high pH can also cause bitter/soda taste and deposits. (Davies and Dewiest, 2000).

2.3.1.2 Colour

Colour is the perception registered as radiation of various wavelengths strike the retina of the eye (WHO 2004). This colour may be aesthetically objectionable but not for health reasons. The colour of water may decrease it acceptance for domestic and other uses. Colour in water may be due to several forms of pollution. Normally the colours present are yellow and brown and may be due to decaying organic matter of vegetation such as plant tannins or soil colour, colloidal and soluble iron, manganese, copper and chromate wastes which give only yellow colour.

Colour is due to dissolved or colloidal material substances but suspended material can give an apparent colour. The treatment option for water which has colour includes; filtration, reverse osmosis, ozonization and distillation (Fulton 2000).

2.3.1.3 Turbidity

Turbidity defines the reduction of transparency of water due to the presence of particulate matter. (Seneviratne 2007). The comparison of intensity of light (electro-magnetic radiation) scattered by a given sample, to that of light scattered by a standard reference sample is a measure of the turbidity of the water sample (Raymond, 2002). Highly turbid water reduces its acceptability in its uses and also impairs vision for aquatic organisms, it also increase the cost of treatment as more coagulant is needed to settle suspended particles. Turbidity of raw water is also a characteristic of substances in the water which includes microorganisms such as bacteria algae, fungi and protozoa (Cheesbrough, 2003).Treatment options include filtration and distillation.

2.3.1.4 Water Hardness

Hardness of water is usually caused by the ions of calcium and magnesium dissolved in water. There is no evidence of adverse health effect specifically attributable to high water hardness. Their association with sulphate ions (SO_4^{2-}) may give laxative properties to potable water (Rao, 2004). Hardness commonly is reported as an equivalent concentration of calcium carbonate ($CaCO_3$). The sum hardness due to calcium and magnesium is termed ‘total hardness’. Although concentration of 284 mg/L and 500 mg/L satisfies the recommended values for drinking water by WHO (WHO, 2011) respectively, this may cause excessive use of soap and subsequent “SCUM” formation. Water with high total hardness when used in boilers may result in formation of scales which reduces boilers efficiency (Srinivas, 2008). Chemical softening treatment, reverse osmosis, ion exchange can be used to reduce hardness of water.

2.3.1.5 Nitrate

Nitrate in water supplies owes its origin to several possible sources, including the atmosphere, leguminous plants, plants debris, animal excrement, sewage, nitrogenous fertilizers and some industrial waste (Gray, 2008b). Bacteria decompose organic matter such as sewage whose complex proteins change to ammonia (NH_3), then nitrite and finally to nitrate (NO^{3-}). Nitrate concentrations in water are either as nitrate (NO_3^-) or as nitrate-nitrogen (NO_3-N). Nitrate-Nitrogen in concentration greater than 10 mg/L causes infant methemoglobinemia or blue baby, a disease characterized by cyanosis, a bluish coloration of the skin (Preedy and Patel, 2012). The disease may occur when a child consumes milk that contains large concentrations of nitrate. Also high concentration of nitrate in drinking water for livestock results in abnormally high abortion (LeChavallier and Keung-Au 2004). Treatment options include ion exchange, distillation and reverse osmosis (Xu, 2008).

2.3.1.6 Sulphate

Many sulphate compounds are readily soluble in water. The amount present is related to natural and human pollutions of the atmosphere such as oxidation of hydrogen sulphide (H_2S) gas from decomposition of organic materials and volcanic discharges (Alan, 2000). Water in contact with sulphate rocks such as gypsum often has high concentration of sulphate. Acid mine water, particularly from sulphide-bearing ores and industrial wastes may also contribute large amount of sulphate to natural waters. In the brewing industry high sulphate water are advantageous since they produce better flavours in the product. Concrete is corroded by water containing sulphate in quantities above 1000 mg/L and high sulphate concentrations can also cause scaling on pipes, condensers and boilers (Gray 2008). Sulphate usually occurs at high concentrations in surface waters. Some natural processes reduce the concentration of sulphate by bacteria. These bacteria derived energy from oxidation of organic component, oxygen from sulphate ions and reduce sulphate (SO_4^{2-}) to H_2S. If sufficient iron is present under moderate reducing conditions, iron sulphide (FeS) may be precipitated, thus decreasing the concentrations of both iron and sulphate (Mara and Horan, 2003). Sulphates are difficult to remove from water and produce a detectable metallic taste at concentrations of 300-400 mg/L (Binnie *et al* 2002).

2.3.1.7 Total Iron

Iron can find its way into drinking water as a result of leaching from cast iron pipes in water distribution and storage systems including tanker services. Iron in drinking water supplies is objectionable for a number of reasons, most of which are not related to health. However, iron promotes the growth of 'iron bacteria' such as *Gallionlla ferruginea, Clonothrix fusca* and *Leptothrix ochracea* which deposit a slimy coating giving rise to metallic taste problems in drinking water (Verma, 2004). Iron particles deposited in water supplies may render the water unstable for laundry purposes, since they colour and stain clothing, utensil, receptacles and plumbing fixtures (Clement, 2002). Rice and vegetables develop brown deposits while tea develops an inky colour when they are cooked in water containing high concentrations of iron (Pipkin and Hazlett, 2010). Iron in its dissolved form exists as ferrous ions (Fe^{2+}). On exposure to air or oxygen the ferrous ions (Fe^{2+}) are oxidized to form insoluble or colloidal brown ferric hydroxide. Treatment option includes sand mechanical filtration.

2.3.1.8 Residual Chlorine

The residual chlorine concentration in water is an essential treatment technique that inactivates or kills pathogens or bacteria remaining in water for storage and along the distribution systems. (WHO, 2011) recommended that, the benefits of maintaining free chlorine residual throughout the distribution systems at or above 0.2 mg/L should be considered. Residual chlorine disinfection for drinking water is done primarily by using either a liquid form of hypochlorite acid or dry form as calcium hypochlorite or sodium dichloroisoyanurate (WHO, 2011). High residual chlorine may have taste problems (Casey, 2006). Chlorine also has a disadvantage of its ability to react with natural organic matter to produce chloromethane; however by-product formation may be controlled by optimization of the treatment system (Crites and Tchohanoglons, 1998).

2.3.2 Bacteriological Parameters

Bacteriological water analysis is a method used to estimate the numbers and type of bacteria present in the water (Horrocks, 2009). The results of this process are used to routinely confirm the suitability of the water for human consumption or other uses such as bathing and recreational (HACH, 2003). Safe and potable water must be free from pathogens. Good health depends also on clean, potable and safe water supply. Faecal contamination of drinking water is the most common source of pathogens. High faecal levels imply the water is unsafe to drink. Faecal contamination can be detected by testing for the presence of various indicator bacteria that colonize the intestines of birds and mammals. In testing the microbial quality of water it is difficult to analyse the numerous pathogens so indicator organisms are tested (Surampalli and Tyagi, 2004).

Indicator organisms are bacteria whose presence in water indicates the presence of pathogens. Indicator organisms are present in water when other pathogens are present and absent when pathogens are absent in water (HACH, 2003). Since these indicator organisms survive longer in water, they can be detected and identified more readily than the associated pathogens (WHO, 2011). Enteric bacteria most useful in the routine monitoring of microbial pollution are coliform which survive in natural water but do not multiply there (Mara and Horan, 2003). Some common water borne diseases are bacterial dysentery, typhoid fever, cholera, infantile paralysis, guinea worm and infectious hepatitis (Percival, 2004).

2.3.2.1 Total coliforms

Coliforms are gram-negative, lactose-fermenting, gas producing bacteria and characterized by possession of the enzyme β- galatosidase and β-glucuronidase (Belkin and Gabby, 2000) Coliforms grow at 44 – 45 ^{o}C on complex media. However some strains can grow at 37 ^{o}C but not at 44 – 45 ^{o}C and some also do not produce gas. Some gas producing ones are *Escherichia coli, Enterobacter spp. and Citrobacter spp.* (Srinivas, 2008). High levels of coliforms can cause gastrointestinal illness. It sources includes, livestock facilities, septic systems, manure lagoons, household waste water and naturally occurring coliforms. Treatment options include chlorination, UV treatment, distillation and iodination (Adam and Bander, 2011).

2.3.2.2 Escherichia coli

E. coli is gram-positve, facultative anaerobic and non-sporulating bacteria. *E. coli* uses mixed-acid fermentation in anaerobic conditions, producing lactate, succinate, ethanol, acetate and CO_2. (Clark, 2010) Optimal growth of *E. coli* occurs at 37 ^{o} C but some laboratory strains can multiply at temperatures of up to 49 ^{o} C (Fodder *et al*, 2005). The detection of *E. coli* in water samples gives an indication of faecal contamination (Peavy, 1999). The characteristic that makes *E. coli* unique from the other thermotolerant coliforms is their ability to produce indole from tryptophan or by the producing enzyme β-glucuronidase (Stanbury *et al*, 2000). Though there is some evidence of *E. coli* growth in tropical soil, they are rarely found in absence of faecal pollution and occur in very large numbers in human and animal faeces (Peavy, 1999). Most strains of *E. coli* are themselves harmless and live in the intestine of healthy humans and animals. An example of a harmful strain is *E. coli* 0157: H7, which produces a powerful toxin and can cause severe illness (Fodder *et al*, 2005). Treatment options include chlorination, UV treatment, distillation and iodination.

2.4 Water Quality Standards and Guidelines

Different countries and international organizations have proposed water quality standards to ensure safe drinking water. This section compares water quality standards and guidelines set by WHO and the GSA (Ghana Standards Authority) of the specific parameters of interest including pH, colour, turbidity, (physical water quality), nitrate, sulphate, total hardness, total iron, residual chlorine (chemical water quality), *Escherichia coli* and total coliform (microbial water quality).

The term “standard” is used to refer to legally enforceable threshold values for the water parameter analysed, while “guidelines” refer to threshold values that are recommended and do not have any regulatory status. The Ghana Standards for drinking water indicated the required physical, chemical and microbial properties of drinking water. The Standards are adapted from the WHO, Guidelines for Drinking Water Quality (WHO, 2011) but also incorporate natural standards that are specific to the country`s environment. The

WHO guidelines also give permissible and threshold values for water intended for consumption.

Table 2.1: Summary of water quality requirements for some parameters.

Parameter	**Ghana Standards**	**WHO Guidelines (2011)**
pH	6.5-8.5	6.5-8.5
Colour	15 TCU/Hazen max.	15 TCU/Hazen max.
Turbidity	5 NTU max	5 NTU (median of 0.1) for effective disinfection.
Residual Chlorine	0.5-1.0 mg/L	0.5-1.0 mg/L
Nitrate	50 mg/L max	50 mg/L max
Sulphate	0- 250 mg/L	0-250 mg/L
Hardness	500 mg/L max	500 mg/L max
Iron	0.3 mg/L	0.3mg/L
Total coliforms	0 CFU/100ml	0 CFU/100ml
E.coli	0 CFU/100ml	0 CFU/100ml

CHAPTER THREE

MATERIALS AND METHODS

3.1 The Study Area

Mpohor Wassa East District is located at the south-eastern end of the Western Region. The district covers an area of 1880 Km^2 with Daboase as its capital (MWED, 2009). The district falls within the tropical climate zone. The mean annual rainfall is 1500 mm and ranges from 1300 to 2000 mm. The wet period in the district is between March and July while November to January is dry (MWED, 2009).

The landscape is generally undulating with an average height of about 70m. The highest elevation ranges between 150 and 200m above sea level. The drainage pattern of the district is largely dendriatic. There are medium and small rivers and streams. Most of them originate from the Akwapim ranges and flow southwards towards the coast. The main rivers are the Pra, Subri, Butre, Brempong, Suhyen, Abetumaso, Hwini and Tipae (MWED, 2009). The natural environment is being degraded as a result of farming, lumbering and logging as well as building activities thus reducing portions of the original forest to secondary. The activities of timber firms and contractors with concessions in the Subri Forest are leading to changes in the rainfall pattern and agricultural production. These activities also lead to increased soil erosion and loss of valuable nutrients. Large and small scale mining activities in the district is impacting negatively on the environment. These have led to extensive land degradation and soil erosion and the development of trenches and pollution of water bodies and the air as well as buildings. The indiscriminate use of mercury brings severe health implications. The Forestry

Commission relies on their forest guards and Community Forest Committee (CFC) to protect the water bodies and the forests (MWED, 2009)

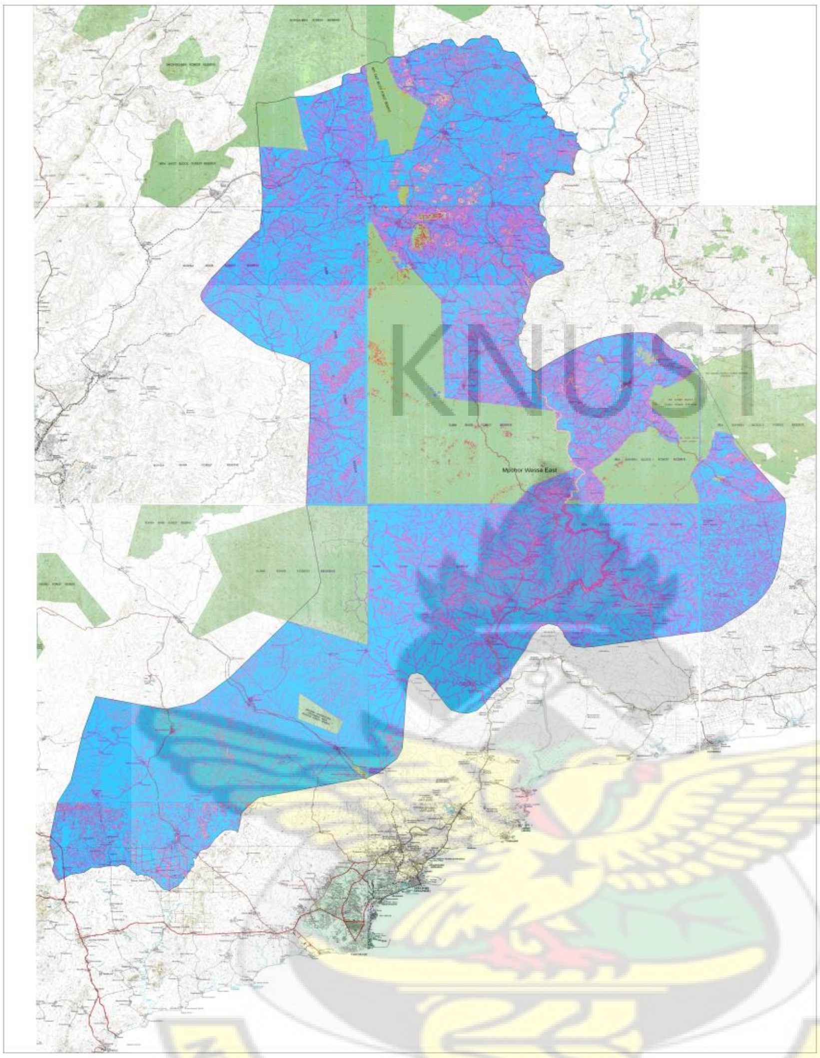

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Figure 3.1: **Map of Mpohor Wassa East District**

3.2 The Daboase Water Treatment Plant

The water treatment plant is located at Daboase which is 400 m away from the Pra River which is the source of water for the treatment plant. The water treatment plant covers approximately 30 ha of land and has been in operation since its establishment in 1969. The treatment plant consist of the following treatment processes; coagulation, flocculation, settling and sludge disposal, filtration, disinfection, post liming, storage and finally distribution of the treated water. Figure 1 shows the intake structure. Inside the structure are three pumps, two in operation at a time which drives water from the river to the treatment plant. The pumps have the ability to pump approximately 2 million gallon of raw water a day to the plant for treatment.

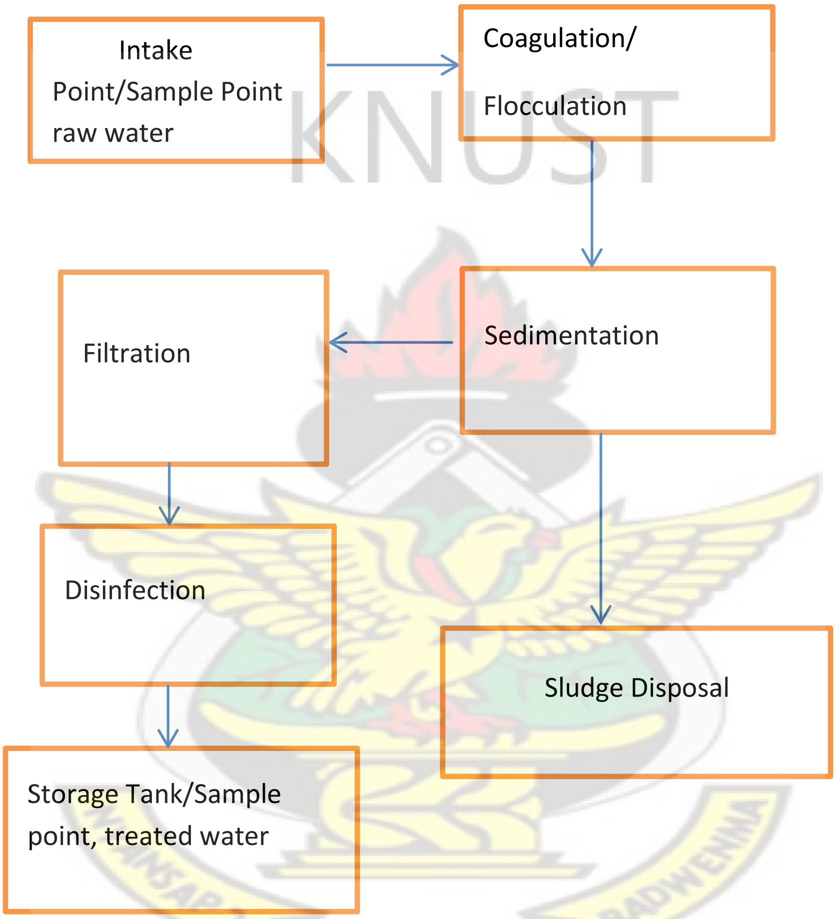

Figure 3.2. Schematic flow diagram of Water Treatment Plant showing sample points

Figure 3.3 Intake Structure of the Daboase Water Treatment Plant

3.2.1 Coagulation and Flocculation

Coagulation and flocculation at the plant is carried out by feeding a known concentration of aluminium sulfate (alum) solution into the coagulation or flocculation chamber, followed by rapid mixing to disperse it effectively throughout the water. Mixing of the coagulant is carried out mechanically by electrically driven propellers mounted on an over-hung shaft that is attached to the coagulation or flocculation chamber to disperse them effectively. Figure 2 show a picture of the coagulation chamber of the water treatment plant.

Figure 3.4 Coagulation chamber of the Daboase Water Treatment Plant

Sedimentation and sludge disposal forms part of the treatment process at the Daboase headworks. Sedimentation is the process of separating suspended particles that are heavier than water by gravitational settling. At the Daboase water treatment plant, sedimentation takes places after flocculation in two circular sedimentation tanks with upward flow (clarifier) as shown in Figure 3. The sedimentation tanks are circled by weirs to direct the supernatant flow. The tanks have sludge rakes at the bottom that scrape out settled sludge. Sludge removal is by suction; here the sludge is pumped out and disposed via an outlet chamber into the Pra River downstream.

Figure 3.5 Clarifier showing the sedimentation chamber of the Daboase Water Treatment Plant

3.2.2 Filtration

Filtration; At the Daboase water treatment plant, the supernatant from the sedimentation chamber is directed to rapid sand filters which filters the water after coagulation, flocculation and settling. Six filters are provided and one is presented in Figure 4. It is occasionally cleaned by backwash if filtrate quality in terms of flow becomes low.

Figure 3.6 One of the six rapid sand filters at the treatment plant

3.2.3 Disinfection

Disinfection to destroy or otherwise inactivate pathogenic organisms at the Daboase Water Treatment Plant is carried out by adding a calculated chlorinated chemical (Sodium hypochlorite) and if not available a chlorine gas stored as liquefied gas in chlorine cylinders is used instead.

3.2.4 Post-lime addition

Aluminium sulfate reduces the pH of water to acidic levels during the coagulation process. At the Daboase water treatment plant post lime addition is carried out to raise the pH. The process is done after chlorination in order not to hinder disinfection whereby microorganisms may be protected by flocs of lime. This is done by feeding the lime into the chlorinated water.

3.2.5 Storage

The treated water is then stored in an underground well as shown in Figure 5, of six (6) million gallon capacity before pumping through to the distribution network to consumers.

Figure 3.7 Underground water storage well of the Daboase Water Treatment Plant

3.3 Sampling and Sample Preparation

The raw and treated water samples for the investigation was taken from the feed intake point and the underground well storage sampling point on weekly basis from January 2012 to May 2012. In all 80 samples were taken for analysis within the 5 months sampling period.

Glasswares and sampling bottles used were thoroughly washed with detergent solution such as cleaning gel and properly rinsed with tap water. They were again rinsed with 70% alcohol and double rinsed with distilled water. Taps were allowed to run for about a minute before all samples were taken. In the bacteriological analyses, mouths of taps as well as caps of culture tubes were flamed for about 2 minutes with spirit lamp to kill all bacteria around the mouth. This was done so that results obtained will be a true reflection of the characteristics of water in the distribution line. Sampling bottles and culture tubes were immediately covered and neatly labeled. Sampling bottles containing samples were transported in a strong ice chest to prevent breakages. There was sufficient space in the box which was made to contain bags of freezing mixtures (4^0C-10^0C) to keep the sample. Although the samples were able to get to the laboratory within 24 hours after collection, the freezing mixtures were used to ensure the complete prevention of any change in water quality parameter, should there be any delay during the time of transportation. Samples were analyzed at Ghana Water Company Limited Quality Assurance Laboratory, at Daboase and Takoradi.

3.4 Physico-chemical analysis

3.4.1 Colour Determination

The HACH laboratory spectrophotometer (model DR/2500) was used. The specific program ‘’120 color, 455mm’’ was selected and the ‘start’ icon touched. 200 mL of sample was collected in a 400 mL beaker. A round sample cell was then filled with 10 mL of filtered deionized water and used as the blank. A second sample cell was filled with 10mL of filtered sample. The blank sample was placed into the cell holder. The

‘’Zero’’ ion was touched for the display to show unit of 0 PtCo. The prepared sample was placed into the cell holder and the stable result in ptCo Units read and recorded.

3.4.2 pH Determination

pH measurement was determined using the combined electrode pH meter. The measurement was done first by standardizing the pH meter followed by immersing the combined electrode in the sample. The stable pH value displayed was read and recorded. The standardization was done by switching on the pH meter for ten minutes and setting its temperature knob to room temperature. The electrodes were immersed in a standard solution of pH 7 and the pH knob adjusted till meter displayed a stable pH value of 7. After this the electrode was removed, cleaned with distilled water and the process repeated using standard solution of pH 4

3.4.3 Turbidity Determination

The stored programme number for turbidity was entered into the HACH DR/2500 spectrophotometer under wavelength set to display “NTU TURBIDITY” UNITS. Two sample cells were obtained. One was filled with 25 mL of deionised water which serves as the blank and the other was filled with 25 mL of the prepared sample). The blank was placed into the cell holder to zero the spectrophotometer followed by the prepared sample, the result in the Nephelometric Turbidity Units (NTU) was displayed and the value recorded, the procedure was repeated for other sample.

3.4.4 Nitrate Determination

The specific program‘’355 N. Nitrate HR`` was selected and the ‘’start’’ icon touched. The sample cell was filled with 10 mL of sample, the content of one NitraVer 5 Nitrate Reagent Powder Pillow was added and then capped (this is prepared sample), and reaction timed for one minute while shaking the cell vigorously. The cell was then left undisturbed for another five-minute reaction. After this a second sample cell was filled with 10 mL of distilled water (this was the blank). The blank cell was placed into the cell holder and the ‘’Zero’’ icon touched to display 0.0 mg/L NO_3-N. The prepared sample cell was placed into the cell holder. The stable result in mg/L NO_3-N displayed was recorded (Gelder *et al*, 2000).

3.4.5 Sulphate Determination

A clean sample cell was filled with 10 mL of the sample, the content of one Sulfa Ver 4 Reagent Powder Pillow added and swirl to mix (this was the prepared sample). A five minute reaction period was allowed without disturbing the sample cell. A second sample cell was filled with 10 mL of the distilled water (this was the blank), placed into the cell holder and the ‘zero’ icon touched to display 0 mg/L SO_4^{2-}. The prepared sample was placed into the cell holder within five minutes after the reaction time and the stable result in mg/L SO_4^{2-} recorded (Crompton, 2003).

3.4.6 Total Hardness Measurement

EDTA titrimetirc method was used to determine total hardness (Suffredini, 1994)

Procedure: 50 mL of the sample was measured in a conical flask and 2 mL of ammonium buffer solution added. This was swirled to mix very well, followed by the addition of few grain of powdered Eriochrome Black T indicator. While swirling the contents of the conical flask constantly, it was at the same time titrated with 0.01 M EDTA solution until the last trace of purple disappeared and the colour turned bright blue indicating the end point.

Calculation

$$\text{Total hardness} = \frac{\text{volume (mL)of EDTA}}{\text{Volume (mL)of sample}} \times 1000\text{m/L} \ \text{as } CO_3^{2-}$$

3.4.7 Total Iron Determination

A clean sample cell was filled with 10 mL of the sample, the content of one FerroVer Iron Reagent Powder Pillow was added, the mixture was swirled to mix and a three minutes reaction time allowed. Another sample cell was filled with 10 mL of the distilled water (this was the blank), placed into the cell holder and the ‘zero’ icon touched to display 0.0 mg/L Fe. The prepared sample was placed into the cell holder, the stable result in mg/L Fe recorded (Gelder, *et al*, 2000)

3.4.8 Residual Chlorine Determination

Colour Wheel Test kit method (Sarai, 2006)

5 mL of the sample (treated water) was placed in a clean test tube. Four-drops of DPD (N-N diethyl-p-phenylenediamine) indicator were added to the sample in the test tube. A colour wheel comparator was then used to visually match the colour formed to numerical free chlorine reading on the wheel. The corresponding reading that matched the colour of the sample was then recorded.

3.5 Bacteriological Analysis

Bacteria were identified by biochemical tests as described by Chessbrough (2003).

All samples were analysed to determine the presence, number and type of microorganisms in the water sample. This involved presumptive and confirmatory test.

3.5.1 Multiple-Tube fermentation method

3.5.1.1 Presumptive test (Csuros 1999)

Each sample was inoculated into a sterile set of five small bottles each containing an inverted Durham tube and 10 mL of double strength MacConkey broth. Volume of sample inoculated was 10 mL using digital pipette with disposal sterile pipette tips. The inoculated bottles were inverted to ensure the Durham tubes contain no air and then incubated at 37 ^{o}C for 24 hours. The bottles were removed from the incubator, inspected and those with slightly positive result incubated for additional 24 hours. A confirmatory test was then carried out on those broths which gave positive test of yellowish colour and CO_2 gas in the inverted Durham tube.

3.5.1.2 Confirmatory Test

Each sample that showed positive in the presumptive test was both inoculated into a brilliant green lactose bile broth (for confirming the presence of *Escherichia coli* of faecal origin) and into indol broth (for confirming *E. coli* of non-faecal origin). The brilliant green bile and indol tests were then incubated at 44 ^{o}C for 24 hours before a positive test confirmed. Formation of gas in any amount in the inverted Durham tube of brilliant green lactose bile broth and indole broth fermentation tube at any time within 48 hours constitutes a positive confirmed phase (Montgomery, 2005).

3.5.2 Preparation of MacConkey broth

The double strength broth was prepared and used to ensure that the smallest number of microorganisms (coliform) was detected by dissolving 240 g of the MacConkey broth in 1 L of distilled water. 10 mL of the dissolved broth was pipette into each bottles fitted with inverted fermentation (Durham) tubes, capped and sterilized by autoclaved to sterilize the reagent.

3.5.3 Preparation of brilliant green bile broth

40g of brilliant green bile powder was dissolved in 1 L of distilled water. It was poured into test tubes and sterilized by autoclaving at 121^{o} C for 15 min.

CHAPTER FOUR

RESULTS

Table 4.1 Physico-chemical and bacteriological quality of the water before and after treatment at Daboase Treatment Plant

	Sampling periods(Weekly)										
	1		2		3		4		5		WHO(2011)
Parameters	RW ± S. D	TW ± S. D	RW ± S. D	TW ± S. D	RW ± S. D	TW ± S. D	RW ± S. D	TW ± S. D	RW ± S. D	TW ± S. D	Guideline
pH	6.5 ± 0.25	6.88 ± 0.08	6.44 ± 0.24	7.01 ± 0.18	6.52 ± 0.14	6.93 ± 0.05	6.69 ± 0.05	6.93 ± 0.14	6.57 ± 0.21	6.93 ± 0.22	6.5 – 8.5
Colour(Hu)	1063 ± 700.9	5.45 ± 0.42	1436.3 ± 372.3	5.65 ± 0.21	1324.2 ± 248.1	5.27 ± 0.22	1356.7 ± 289.9	5.54 ± 0.35	1086.7 ± 610.5	5.25 ± 0.26	15
Turbidity(NTU)	1004.05 ± 13.16	2.70 ± 0.22	1143.45 ± 98.34	2.47 ± 0.36	1053.1 ± 53.62	2.8 ± 0.55	1089.9 ± 43.76	2.7 ± 0.14	1071.9 ± 99.93	2.53 ± 0.35	5
Total Hardness(mg/L)	57.8 ± 6.91	73.38 ± 3.38	58.90 ± 8.02	74.68 ± 5.18	57.08 ± 6.11	71.65 ± 5.34	66.55 ± 5.59	73.65 ± 4.96	63.75 ± 14.86	78.43 ± 7.23	500
Nitrate(mg/L)	11.75 ± 0.78	1.00 ± 0.35	13.40 ± 0.41	0.64 ± 0.31	15.1 ± 2.86	0.77 ± 0.25	13.7 ± 3.55	0.73 ± 0.04	14.2 ± 1.72	0.93 ± 0.05	50
Sulphate(mg/L)	15.85 ± 3.37	45.85 ± 3.53	4.8 ± 0.40	43.98 ± 0.87	5.19 ± 0.42	43.53 ± 1.51	14.83 ± 3.7	49.83 ± 1.15	4.80 ± 0.74	50.9 ± 1.49	0 – 250
Iron(mg/L)	3.37 ± 2.1	0.09 ± 0.01	10.8 ± 0.86	0.11 ± 0.04	12.35 ± 2.53	0.10 ± 0.01	15.05 ± 3.49	0.09 ± 0.02	15.83 ± 3.53	0.09 ± 0.01	0 – 0.3
Residual Chlorine(mg/L)	BDL	0.73 ± 0.17	BDL	0.93 ± 0.13	BDL	0.9 ± 0.08	BDL	0.88 ± 0.17	BDL	0.80 ± 0.11	0.5- 1.0
Total coliforms(MPN/100ml)	16.0 ± 0.0	0.0 ± 0.0	16.0 ± 0.0	0.0 ± 0.0	16.0 ± 0.0	0.0 ± 0.0	10.9 ± 3.4	0.0 ± 0.0	16.0 ± 0.0	0.0 ± 0.0	0
E. coli(CFU/100ml)	0.75 ± 0.96	0.0 ± 0.0	1.5 ± 1.0	0.0 ± 0.0	2.5 ± 2.3	0.0 ± 0.0	1.5 ± 1.1	0.0 ± 0.0	3.74 ± 2.62	0.0 ± 0.0	0

RW – Raw Water TW – Treated Water BDL – Below Detecting Limit S.D – Standard Deviation

	Sampling periods(Weekly)										
Parameters	6		7		8		9		10		WHO(2011) Guideline
	RW ± S. D	TW ± S. D	RW ± S. D	TW ± S. D	RW ± S. D	TW ± S. D	RW ± S. D	TW ± S. D	RW ± S. D	TW ± S. D	
pH	6.59 ± 0.34	6.98 ± 0.07	6.53 ± 0.31	6.92 ± 0.06	6.75 ± 0.06	6.88 ± 0.11	6.59 ± 0.11	6.88 ± 0.07	6.72 ± 0.10	6.86 ± 0.08	6.5 – 8.5
Colour(Hu)	1381.4 ± 198.51	5.28 ± 0.21	1397 ± 205.39	5.92 ± 0.28	1458.8 ± 298.4	5.52 ± 0.29	1456.2 ± 289.9	5.5 ± 0.33	1436.1 ± 377.0	5.8 ± 0.18	15
Turbidity(NTU)	1128.78 ± 53.99	2.65 ± 0.44	1148.05 ± 52.27	2.73 ± 0.30	1117.1 ± 80.55	2.97 ± 0.46	1073.9 ± 99.52	2.8 ± 0.18	1137.0 ± 101.8	2.65 ± 0.26	5
Total Hardness(mg/L)	66.03 ± 6.73	76.95 ± 4.23	59.9 ± 6.84	75.2 ± 4.47	70.15 ± 1.42	73.97 ± 4.2	63.6 ± 8.22	74.55 ± 3.9	67.42 ± 4.8	81.5 ± 2.09	500
Nitrate(mg/L)	15.8 ± 2.96	1.0 ± 0.11	18.12 ± 4.08	1.0 ± 0.18	18.9 ± 2.7	1.0 ± 0.18	17.9 ± 3.36	0.48 ± 0.17	16.48 ± 1.22	0.72 ± 0.15	50
Sulphate(mg/L)	5.58 ± 0.48	51.55 ± 1.45	4.2 ± 1.24	51.72 ± 1.58	4.9 ± 0.77	51.55 ± 2.94	4.05 ± 0.12	50.67 ± 1.55	4.35 ± 0.50	51.47 ± 2.45	0 – 250
Iron(mg/L)	15.15 ± 3.42	0.11 ± 0.03	16.67 ± 1.44	0.09 ± 0.01	14.18 ± 1.48	0.12 ± 0.02	12.37 ± 1.27	0.09 ± 0.01	11.48 ± 1.32	0.10 ± 0.03	0 – 0.3
Residual Chlorine(mg/L)	BDL	0.83 ± 0.09	BDL	0.75 ± 0.05	BDL	0.95 ± 0.13	BDL	0.95 ± 0.12	BDL	0.90 ± 0.03	0.5- 1.0
Total coliforms(MPN/100 ml)	16.0 ± 0.0	0.0 ± 0.0	16.0 ± 0.0	0.0 ± 0.0	12.6 ± 4.8	0.0 ± 0.0	10.9 ± 3.4	0.0 ± 0.0	16.0 ± 0.0	0.0 ± 0.0	0
E. coli(CFU/100ml)	3.7 ± 2.51	0.0 ± 0.0	3.25 ± 2.21	0.0 ± 0.0	0.75 ± 0.5	0.0 ± 0.0	2.0 ± 1.41	0.0 ± 0.0	2.25 ± 2.06	0.0 ± 0.0	0

RW – Raw Water TW – Treated Water BDL – Below Detecting Limit S.D – Standard Deviation

Sampling periods(Weekly)											
	11		12		13		14		15		WHO(2011)
Parameters	RW ± S. D	TW ± S. D	RW ± S. D	TW ± S. D	RW ± S. D	TW ± S. D	RW ± S. D	TW ± S. D	RW ± S. D	TW ± S. D	Guideline
pH	6.57 ± 0.06	6.83 ± 0.04	6.59 ± 0.24	6.96 ± 0.13	6.73 ± 0.09	6.88 ± 0.11	6.74 ± 0.10	6.91 ± 0.05	6.74 ± 0.04	6.82 ± 0.02	6.5 – 8.5
Colour(Hu)	1491.37 ± 326.27	5.7 ± 0.42	1161.02 ± 98.91	5.65 ± 0.12	1543.6 ± 354.9	5.52 ± 0.29	1356.2 ± 285.3	6.0 ± 0.39	1261.6 ± 154.9	5.7 ± 0.60	15
Turbidity(NTU)	1094.97 ± 101.93	2.87 ± 0.3	1126.75 ± 111.3	2.72 ± 0.09	1043.9 ± 33.29	2.97 ± 0.46	1124.3 ± 129.0	2.5 ± 0.35	1030.0 ± 23.59	2.77 ± 0.22	5
Total Hardness(mg/L)	61.0 ± 9.83	78.42 ± 1.3	64.95 ± 5.66	76.75 ± 2.8	62.72 ± 5.16	73.97 ± 4.2	65.07 ± 5.44	78.9 ± 0.95	61.77 ± 10.75	75.75 ± 2.66	500
Nitrate(mg/L)	16.87 ± 4.7	0.82 ± 0.22	18.6 ± 2.39	0.85 ± 0.17	17.65 ± 3.24	1.0 ± 0.18	20.2 ± 0.78	0.95 ± 0.31	18.4 ± 1.74	0.67 ± 0.17	50
Sulphate(mg/L)	5.0 ± 0.31	48.65 ± 4.11	5.25 ± 0.31	47.42 ± 2.91	6.13 ± 0.9	51.55 ± 2.94	4.85 ± 0.12	51.0 ± 2.2	3.95 ± 0.17	46.95 ± 3.01	0 – 250
Iron(mg/L)	12.2 ± 0.52	0.08 ± 0.01	10.85 ± 0.83	0.10 ± 0.03	12.43 ± 0.55	0.12 ± 0.02	11.0 ± 0.52	0.13 ± 0.01	11.92 ± 0.95	0.09 ± 0.01	0 – 0.3
Residual Chlorine(mg/L)	BDL	0.8 ± 0.12	BDL	0.92 ± 0.12	BDL	0.95 ± 0.13	BDL	0.9 ± 0.08	BDL	0.75 ± 0.05	0.5- 1.0
Total coliforms(MPN/100ml)	14.3 ± 3.4	0.0 ± 0.0	16.0 ± 0.0	0.0 ± 0.0	11.4 ± 3.9	0.0 ± 0.0	13.73 ± 3.9	0.0 ± 0.0	14.3 ± 3.4	0.0 ± 0.0	0
E. coli(CFU/100ml)	3.0 ± 2.9	0.0 ± 0.0	1.75 ± 0.95	0.0 ± 0.0	3.25 ± 2.21	0.0 ± 0.0	1.75 ± 17	0.0 ± 0.0	1.5 ± 1.0	0.0 ± 0.0	0

RW – Raw Water TW – Treated Water BDL – Below Detecting Limit S.D – Standard Deviation

	Sampling periods(Weekly)										
	16		17		18		19		20		WHO(2011)
Parameters	RW ± S. D	TW ± S. D	RW ± S. D	TW ± S. D	RW ± S. D	TW ± S. D	RW ± S. D	TW ± S. D	RW ± S. D	TW ± S. D	Guideline
pH	6.60 ± 0.35	7.04 ± 0.15	6.74 ± 0.13	6.93 ± 0.07	6.77 ± 0.05	6.95 ± 0.02	6.66 ± 0.08	6.87 ± 0.07	6.82 ± 0.04	7.10 ± 0.08	6.5 – 8.5
Colour(Hu)	1527.2 ± 482.8	5.9 ± 0.08	1291.85 ± 247.5	5.62 ± 0.51	1329.2 ± 233.1	5.8 ± 0.18	1474.2 ± 290.4	5.2 ± 0.18	1463.6 ± 130.5	5.75 ± 0.19	15
Turbidity(NTU)	1139.37 ± 104.5	2.75 ± 0.31	1070.62 ± 102.5	2.92 ± 0.27	1151.8 ± 132.4	2.52 ± 0.38	1078.8 ± 52.56	2.77 ± 0.25	1324.3 ± 179.8	2.65 ± 0.17	5
Total Hardness(mg/L)	64.77 ± 5.29	76.8 ± 5.21	70.6 ± 1.88	75.17 ± 2.88	64.65 ± 5.48	75.57 ± 5.03	72.75 ± 4.7	79.7 ± 1.61	68.72 ± 5.4	76.9 ± 3.17	500
Nitrate(mg/L)	19.17 ± 0.98	0.89 ± 0.30	18.07 ± 1.8	0.47 ± 0.16	17.05 ± 1.35	0.6 ± 0.08	20.65 ± 0.61	0.55 ± 0.20	21.12 ± 1.7	0.42 ± 0.12	50
Sulphate(mg/L)	6.07 ± 0.66	47.47 ± 3.6	4.67 ± 0.85	47.35 ± 3.97	5.72 ± 0.27	52.42 ± 1.29	4.8 ± 0.29	48.02 ± 0.95	4.25 ± 0.34	51.87 ± 1.36	0 – 250
Iron(mg/L)	10.6 ± 0.95	0.09 ± 0.02	11.25 ± 1.53	0.08 ± 0.01	10.85 ± 0.83	0.09 ± 0.02	11.08 ± 1.51	0.08 ± 0.01	11.23 ± 1.94	0.13 ± 0.04	0 – 0.3
Residual Chlorine(mg/L)	BDL	0.82 ± 0.09	BDL	0.85 ± 0.12	BDL	0.9 ± 0.08	BDL	0.8 ± 0.08	BDL	0.9 ± 0.08	0.5- 1.0
Total coliforms(MPN/100ml)	11.46 ± 3.92	0.0 ± 0.0	12.6 ± 3.92	0.0 ± 0.0	16.0 ± 0.0	0.0 ± 0.0	12.6 ± 3.0	0.0 ± 0.0	13.73 ± 3.92	0.0 ± 0.0	0
E. coli(CFU/100ml)	1.75 ± 1.25	0.0 ± 0.0	1.75 ± 0.95	0.0 ± 0.0	1.25 ± 1.0	0.0 ± 0.0	1.5 ± 1.0	0.0 ± 0.0	1.5 ± 0.7	0.0 ± 0.0	0

RW – Raw Water   TW – Treated Water   BDL – Below Detecting Limit   S.D – Standard Deviation

4.1 Physico-chemical and bacteriological quality of the water before and after treatment at Daboase Treatment Plant

The range, mean and standard deviations of water quality parameters measured in the raw water samples from the Daboase Water treatment plant are presented in Table 4.2.

Table 4.2: The range, mean and standard deviation of water quality parameters of the raw water from Daboase Headworks n = 40

Parameters	Range	Mean ± standard deviation	WHO(2011) guideline
pH	6.27 – 6.88	6.65 ± 0.20	6.5 – 8.5
Colour(HU)	1027.0 – 1998.7	1364.77 ± 326.99	15
Turbidity(NTU)	992.8 – 1222.8	1107.05 ± 103.70	5
Total Hardness(mg/L)	49.4 – 74.2	64.41 ± 7.45	500
Nitrate(mg/L)	10.1 – 23.5	17.36 ± 3.14	50
Sulphate(mg/L)	2.8 – 6.9	5.34 ± 4.51	0 – 250
Total Iron(mg/L)	9.8 – 18.9	12.47 ± 2.40	0 – 0.3
Residual Chlorine(mg/L)	BDL	BDL	0.5 – 1.0
Total Coliforms(MPN/100ml)	9 - 16	14.38 ± 3.4	0
E. coli(CFU/100ml)	0 – 6	1.91 ± 1.76	0

*BDL = Below Detecting Limit

The range, mean and standard deviations of water quality parameters measured in the treated water samples from the Daboase Water treatment plant are presented in Table 4.3

Table 4.3 The range, mean and standard deviation of water quality parameters of the treated water from Daboase Headworks. n = 40

Parameters	Range	Mean ± standard deviation	WHO(2011) guideline
pH	6.64 – 7.2	6.92 ± 0.11	6.6 – 8.5
Colour(HU)	5.0 – 6.5	5.59 ± 0.36	15
Turbidity(NTU)	2.0 – 2.7	2.70 ± 0.30	5
Total Hardness(mg/L)	67.2 – 83.0	76.05 ± 4.26	500
Nitrate(mg/L)	0.25 – 1.5	0.76 ± 0.26	50
Sulphate(mg/L)	41.1 – 54.2	49.41 ± 3.67	0 – 250
Total Iron(mg/L)	0.5 – 0.15	0.10 ± 0.03	0 – 0.3
Residual Chlorine(mg/L)	0.5 – 1.1	0.85 ± 0.12	0.5 – 1.0
Total coliforms(MPN/100ml)	0 – 0	0.0 ± 0.0	0
E. coli(CFU/100ml)	0 – 0	0 ± 0.0	0

CHAPTER FIVE

DISCUSSIONS

5.1 pH

The raw water had a mean pH of 6.65 ± 0.02 which is lower than the mean pH recorded for the treated water which was 6.92 ± 0.11. pH determine the microbial activity as well as the extent to which heavy metals will dissolve in water (USEPA, 2007). Low pH will make heavy metals to dissolve readily in water. Even though there were slight increases in the treated water pH from that of the raw water it was insignificant and still within the WHO (2011a and b) acceptable limit of 6.5 – 8.5 set for drinking water. The changes pH is due to the lime added during the treatment. This forms a base in water and increase the pH of the water.

$CaCO_{3\,(aq)} + H_2O(l) \rightarrow Ca(OH)_{2\,(aq)} + CO_{2\,(g)}$

5.2 Colour

The raw water had a mean colour of 1364.77 ± 326.99 HU. The treated water had a mean colour of 5.59 ± 0.36 HU. There were reductions in the mean colour for the raw and treated water. The colour in drinking water may affect its aesthetic and acceptability by the inhabitants for drinking and other domestic uses such as cooking, washing etc, It therefore makes colour removal a very important process in water treatment. Colour in water may due to the presence of substances such as iron and manganese compounds, decayed organic matter (humus), zoo and phytoplankton (Fulton, 2000). The significant change in the mean colour between the raw and treated water can be accounted for by the efficient sedimentation and filtration processes of the treatment plant as alum added formed flocs which coagulated the particulate matter in the water and causes it to settle. Filtration process filtered out the remaining particles after sedimentation. Eventhough colour for raw water was not satisfactory; the mean colour value of 5.59 ± 0.36 HU for treated water was within the WHO (2011) guideline for drinking water.

5.3 Turbidity

The study recorded a turbidity mean value of 1107.05 ± 103.70 NTU for the raw water. The treated water recorded a turbidity value of 2.70 ± 0.30 NTU. Water which is turbid may reduce it acceptability in its use and may increase the cost of treatment as more coagulant is used to bring about coagulation (DWAF, 1998, Owusu, 2012). DWAF (1998) also reported that turbid water is often associated with the possibility of microbial contamination as high turbidity makes it difficult to disinfect water properly because the adsorptive characteristics of some colloidal materials and solid may partly shield micro-organisms from disinfection. The high mean turbidity value for the raw water might be due to the recent activities of the illegal mining which uses the water upstream for the washing of the soil containing the mineral as well as soil erosion and run-off from catchment areas The reduction in the turbidity to acceptable level may be attributed to the efficient processes of flocculation, sedimentation and filtration. This involved addition of alum to coagulate the particles to settle to the bottom. The remaining unsettled particles in the water after sedimentation were filtered by the sand filters of the treatment plant.

5.4 Total Hardness

The raw water recorded a mean hardness value of 64.41 ± 7.45 mg/L. The treated water sample had a mean value of 76.05 ± 4.26 mg/L. Water hardness due to presence of dissolved calcium and magnesium may have laxative effects when consumed, there is increase in amount of soap used for washing and also affects the efficiency of boilers as they produce scales affecting heat production (WHO, 2011). Alexander (2008) also reported that calcium and magnesium along with their carbonates, sulphate and chlorides naturally confer temporary and permanent hardness. BIS, (1991) recommended that desirable limit for hardness is 300 mg/L and the maximum permissible limit for potable water is 600 mg/L. Whereas WHO, (2011) recommended safe permissible limit of 100 – 500 mg/L for total hardness in drinking water. The variation in total hardness of the treated water was due to the lime which was used to adjust the pH of the treated water. This process increases the Ca^{2+} ions in the water, thus increases the hardness of the treated water. Water hardness at concentrations below 60mg/L is generally considered as soft; 60-120 mg/L, moderately hard; 120-180 mg/L, hard and more than 180 mg/L, very hard (McGowan, 2000). The result of the treated water can therefore be said of being moderately hard. Even though there was an increase in the hardness of the treated water, its mean value of 76.05 mg/L was within the WHO (2011) guideline of 100 – 500mg/L drinking water.

5.5 Nitrate

The raw water had mean nitrate concentration of 17.36 ± 3.14 mg/L. The treated water also recorded 0.7 ± 0.26 mg/L mean value for nitrate. Drinking water with high nitrate levels may have certain problems such as blue baby syndrome (infant methemoglobinemia), if it occurs in concentrations above the WHO guideline of 50 mg/L (Gray, 2008). High level of nitrate can cause eutrophication in rivers as reported by Akoto *et al* (2010) and increase water treatment cost through filter clogging in treatment works. The nitrate concentration of both the raw and treated water were within the acceptable limit of 50 mg/L for drinking water.

5.6 Sulphate

The raw water had mean sulphate value of 5.34 ± 4.51 mg/L and treated water recorded mean sulphate value of 49.41 ± 3.67 mg/L. Sulphate in drinking water may be advantageous in some cases such as in brewing industries, but may affects concrete facilities use for water storage as they corrode the storage facilities due to the formation of dilute H_2SO_4 in solution (Backer, 2000). Water containing magnesium sulphate at levels above 600 mg/L may act as a purgative in humans (USEPA, 1999). There were increases in the sulphate concentration of the treated water as the water went through the treatment processes. The increase in the treated water sulphate concentration may be due to the use of the alum (aluminium sulphate) in the coagulation process which upon dissolving added some amount of SO_4^{2+} ion into the water during the coagulation process. Even though the treated water sulphate concentration was higher, it still was within the WHO (2011) guideline of 0 – 250 mg/L for drinking water.

5.7 Total Iron

The mean concentrations of iron were 12.47 ± 2.40 and 0.1 ± 0.03 mg/L respectively for raw and treated water. Higher iron concentration in water can give metallic taste, encourage certain bacteria to grow and appear as slimy coating which stains clothes and plumbing fixtures. (Gray, 2008). Iron which is sometimes regarded as a trace metal and a common pollutant is widely distributed in the environment with sources from mainly weathered underling rocks (O´Neil, 1993). Iron is also not harmful to health, but it is considered a secondary or aesthetic contaminant. Iron helps in transport of oxygen in blood. The recorded mean concentration of iron in the treated water was within the permissible limit of 0 – 0.3mg/L set for drinking water by the WHO (2011). The reduction was due to the sedimentation and filtration processes of the treatment plant. This probably occurred when Fe^{2+} oxides precipitated to form Fe^{3+} hydroxide which is insoluble and settles out and the remaining filtered out through the rapid sand filters of the treatment plant.

5.8 Residual Chlorine

The treated water samples recorded mean chlorine value of 0.85 ± 0.12 mg/L. Residual Chlorine inactivates microorganism which may be harmful to water users. However in higher concentrations it may alter taste and produce treatment by-products such as trihalomethanes and haloacetics (Lantagne *et al*, 2006). The mean value of residual chlorine was within the acceptable permissible limit set of 0.5 – 1.0 mg/ L for drinking water. The residual chlorine value of 0.85 mg/L obtained will be able to effectively protect the water against further microbial contaminants after treatment. WHO, (2011) recommended that maintaining free chlorine residual throughout the distribution systems at or above 0.2 mg/L is among the practices in water treatment plant to protect the water from further microbial contaminants.

5.9 Total Coliforms

The raw water had mean coliform count of 16 MPN/100mL while treated water samples recorded mean value of 0.0 MPN/100 mL. High coliform count in drinking water means the water is not safe for drinking; high levels of coliforms can cause gastrointestinal illness (Mara and Haron, 2003). Total coliform levels in the raw water make it unsafe and unsuitable for drinking and other domestic use without treatment. The high coliform count may be due to human activities such as dumping of untreated waste in the river which is the source of water for the treatment plant. The treated water total coliform count was within the acceptable limit of 0.0 MPN/mL set by WHO (2011). The 0.0 MPN/mL obtained for the treated water was due to the addition of chlorine during the treatment which inactivated and killed the coliforms in the water.

5.10 E. coli

E. coli content of raw water was 1.91 ± 1.76/ CFU/100mL whiles treated water recorded a mean value of 0.0 CFU/100mL. The presence of *E. coli* in water samples gives an indication of faecal contamination of the water which may not be safe for consumption. (Udeh, 2004; Akoto *et al*, 2010) The presence of *E. coli* in the raw water might be due to human activities such as dumping of untreated domestic and livestock waste into the tributaries of the Pra river. Karikari and Ansa-Asare (2006) also reported that people living within the catchment area of rivers discharge their domestic and agricultural waste into rivers serving as reservoir for water treatment. The significant reduction in the treated water *E. coli* count was due to the chlorination process which inactivated and killed the *E. coli* in the water. The treated water *E. coli* mean count of 0.0 CFU/100mL was within the acceptable limit of 0.0 CFU/100mL set by WHO(2011) for drinking water.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The efficiency of the Daboase Water Treatment plant of the GWCL situated in the Mpohor Wassa East of the Western Region was evaluated for a period of five months. The efficiency of the treatment plant was assessed measuring the changes in concentrations of the following water parameters; colour, turbidity, total hardness, nitrate, sulphate, total irons, residual chlorine, total coliforms and *E. coli*.

It was observed that pH, total hardness, nitrates and sulphate were within acceptable limits prior to treatment; however colour, turbidity, total iron, total coliforms and *E. coli* were above the acceptable limits set by WHO for water intended for drinking. Concentration levels of these parameters were reduced to acceptable limits after treatment. It can therefore be concluded that the water treatment plant at Daboase was satisfactory during the period of study.

6.2 Recommendations

The following recommendations are made based on the findings of this work;

1. Constant laboratory analysis should be done on the various stages in the treatment processes, so as to maintain the current state of the efficiency of the treatment plant which the research proved to be good.

2. Further research should be conducted on other contaminants such as residue of illegal mining that may affect the efficiency of the treatment plant and its catchment areas.
3. Dumping of domestic as well as the recent illegal mining along the Pra River should be discouraged.

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APPENDIX

Physical, Chemical and Bacteriological Test Results

	Week 1									Week 2							
Parameters	Units	RW_1	RW_2	RW_3	RW_4	TW_1	TW_2	TW_3	TW_4	RW_1	RW_2	RW_3	RW_4	TW_1	TW_2	TW_3	TW_4
pH	-	6.27	6.86	6.40	6.50	6.85	6.90	6.81	6.99	6.60	6.55	6.09	6.53	6.82	7.10	7.2	6.90
Colour	HU	105.5	1099.0	1267.9	1779.8	5.3	6.0	5.0	5.50	1021.5	1222.0	1745.8	1755.9	5.9	5.7	5.40	5.6
Turbidity	NTU	999.7	1001.1	992.8	1024.1	3.0	2.7	2.50	2.6	1004.2	1209.0	1112.60	1212.0	2.8	2.7	2.4	2.0
Total Hardness	mg/L	67.0	59.2	53.0	52.0	77.1	75.0	69.4	72.0	58.0	59.2	49.4	69.0	70.6	79.2	69.8	79.1
Nitrate	mg/L	20.5	13.3	16.2	13.4	1.5	0.7	0.9	0.9	12.5	12.2	16.0	12.9	0.6	0.25	0.7	1.0
Sulphate	mg/L	3.3	2.8	3.4	4.0	42.3	50.1	47.3	43.7	5.0	4.9	4.2	5.1	43.8	44.0	43.0	45.1
Iron	mg/L	12.7	11.9	10.8	11.6	0.09	0.08	0.1	0.08	11.2	9.9	10.3	11.8	0.06	0.09	0.13	0.15
Residual Chlorine	mg/L	-	-	-	-	0.8	0.9	0.5	0.7	-	-	-	-	0.9	1.1	0.9	0.8
Total	MPN/100	>16	16	16	>16	0	0	0	0	>16	>16	16	16	0	0	0	0

coliforms	ml																
E.coli	CFU/100 ml	0	2	1	0	4	0	0	0	3	1	1	1	0	0	0	0

		Week 3								Week 4							
Parameters	Units	RW$_1$	RW$_2$	RW$_3$	RW$_4$	TW$_1$	TW$_2$	TW$_3$	TW$_4$	RW$_1$	RW$_2$	RW$_3$	RW$_4$	TW$_1$	TW$_2$	TW$_3$	TW$_4$
pH	-	6.37	6.46	6.70	6.55	6.95	6.89	6.88	6.99	6.70	6.75	6.68	6.63	6.82	6.80	7.1	6.99
Colour	HU	1154.5	1069.0	1550.9	1522.6	5.4	5.5	5.0	5.20	1101.5	1122.0	1526.0	1675.6	5.9	5.8	5.3	5.2
Turbidity	NTU	1066.7	1021.1	1122.5	1002.1	3.5	2.9	2.60	2.2	1024	1109.0	1122.60	1092.1	2.8	2.7	2.5	2.8
Total Hardness	mg/L	58.0	65.2	51.1	54.0	67.2	70.4	79.4	69.6	70.0	69.0	58.2	69.0	76.0	70.0	69.1	79.5
Nitrate	mg/L	14.5	17.4	17.2	11.3	0.5	0.7	0.8	1.1	12.7	12.3	10.9	18.9	0.9	0.7	0.9	0.4
Sulphate	mg/L	5.8	4.9	5.18	4.9	45.0	43.1	44.4	41.6	44.5	5.0	4.8	5.0	48.3	50.0	51.1	49.9
Iron	mg/L	11.7	15.9	9.9	11.9	0.09	0.12	0.1	0.09	15.2	19.9	13.0	12.1	0.05	0.09	0.10	0.1
Residual Chlorine	mg/L	-	-	-	-	1.0	0.9	0.8	0.9	-	-	-	-	1.1	0.9	0.8	0.7
Total coliforms	MPN/100 Ml	9.2	16	9.2	9.2	0	0	0	0	16	9.2	16	16	0	0	0	0

E.coli	CFU/100 mL	1	6	2	1	0	0	0	0	0	1	1	4	2	1	0	0

		Week 5								Week 6							
Parameters	Units	RW$_1$	RW$_2$	RW$_3$	RW$_4$	TW$_1$	TW$_2$	TW$_3$	TW$_4$	RW$_1$	RW$_2$	RW$_3$	RW$_4$	TW$_1$	TW$_2$	TW$_3$	TW$_4$
pH	-	6.28	6.7	6.55	6.75	6.64	6.87	7.04	7.15	6.70	6.75	6.09	6.83	6.89	6.99	6.9	6.8
Colour	HU	1174.5	199.0	1450.1	1523.2	5.3	5.0	5.1	5.6	1126.5	1322.0	1525.8	1551.3	5.0	5.3	5.5	5.3
Turbidity	NTU	1033	1011.1	1022.3	1221.2	2.9	2.7	2.40	2.1	1121	1119.0	1072.6	1202.5	2.9	3.1	2.5	2.1
Total Hardness	mg/L	78.0	75.0	53.0	49.0	76.8	70.5	88.0	78.4	56.0	69.2	68.5	70.4	72.0	75.1	79.2	81.5
Nitrate	mg/L	14.4	12.0	14.2	16.2	0.9	1.0	0.9	0.9	16.2	17.7	17.8	11.5	0.9	1.1	1.1	0.9
Sulphate	mg/L	4.4	4.1	5.8	4.9	52.4	51.9	50.0	49.3	5.8	5.6	6.0	4.9	53.1	49.8	51.0	52.3
Iron	mg/L	16.4	15.9	19.8	11.2	0.08	0.07	0.1	0.09	17.2	18.9	12.1	12.4	0.09	0.08	0.10	0.15
Residual Chlorine	mg/L	-	-	-	-	0.9	0.7	0.7	0.9	-	-	-	-	0.9	0.8	0.9	0.7
Total coliforms	MPN/100 Ml	9.2	>16	9.2	16	0	0	0	0	>16	9.2	16	16	0	0	0	0
E.coli	CFU/100Ml	6	4	0	5	0	0	0	0	2	0	6	0	2	1	0	0

		Week 7								Week 8							
Parameters	Units	RW$_1$	RW$_2$	RW$_3$	RW$_4$	TW$_1$	TW$_2$	TW$_3$	TW$_4$	RW$_1$	RW$_2$	RW$_3$	RW$_4$	TW$_1$	TW$_2$	TW$_3$	TW$_4$
pH	-	6.09	6.76	6.75	6.55	6.96	6.89	6.99	6.85	6.79	6.65	6.67	6.75	6.85	6.99	6.95	6.73
Colour	HU	1274.9	1179.0	1622.1	1513.0	6.3	5.9	5.9	5.6	1129.5	1332.0	1795.2	1575.4	5.9	5.2	5.6	5.4
Turbidity	NTU	1165.7	1122.1	1092.3	1212.1	3.0	2.9	2.30	2.7	1124.0	1209.0	1123.0	1012.5	2.8	3.3	2.4	3.4
Total Hardness	mg/L	68.0	63.0	55.4	53.2	77.2	79.4	75.2	69.0	70.0	69.4	69.0	72.2	79.2	70.0	71.2	75.5
Nitrate	mg/L	16.4	13.3	22.5	20.3	1.2	1.1	0.9	0.8	20.0	14.8	20.3	20.5	1.1	1.2	0.9	0.8
Sulphate	mg/L	3.9	2.9	4.1	5.9	53.2	49.9	52.9	50.9	4.3	4.2	5.3	5.8	54	54.2	48.9	49.1
Iron	mg/L	14.6	17.9	16.9	17.3	0.09	0.08	0.11	0.1	14.4	13.9	12.4	16.0	0.13	0.12	0.15	0.1
Residual Chlorine	mg/L	-	-	-		0.7	0.8	0.7	0.8	-	-	-	-	1.0	1.1	0.8	0.9
Total coliforms	MPN/100mL	9.2	16	>16	16	0	0	0	0	>16	9.2	16	>16	0	0	0	0
E.coli	CFU/100mL	1	6	4	2	0	0	0	0	1	1	0	1	0	2	0	0

		Week 9								Week 10							
Parameters	Units	RW$_1$	RW$_2$	RW$_3$	RW$_4$	TW$_1$	TW$_2$	TW$_3$	TW$_4$	RW$_1$	RW$_2$	RW$_3$	RW$_4$	TW$_1$	TW$_2$	TW$_3$	TW$_4$
pH	-	6.54	6.76	6.49	6.59	6.85	6.89	6.81	6.99	6.70	6.88	6.70	6.63	6.82	6.80	6.99	6.83
Colour	HU	1315.5	1098.0	1685.8	1725.2	5.3	6.0	5.3	5.4	1021.5	1212.0	1745.7	1765.4	5.9	6.0	5.6	5.7
Turbidity	NTU	1039.7	1021.1	1012.8	1222.3	3.0	2.9	2.70	2.6	1014	1219.0	1222.5	1092.8	3.0	2.7	2.5	2.4
Total Hardness	mg/L	69.0	70.2	63.0	52.2	78.0	77.8	70.2	72.2	72.3	69.4	67.0	61.0	78.4	82.4	83.0	82.2
Nitrate	mg/L	12.9	19.4	19.1	20.2	0.5	0.7	0.3	0.4	15.1	17.0	15.9	17.9	0.6	0.8	0.9	0.6
Sulphate	mg/L	3.9	4.0	4.1	4.2	53.0	49.7	50.1	49.9	3.9	4.0	4.5	5.0	54.1	53.0	49.8	49.0
Iron	mg/L	12.8	11.9	13.9	10.9	0.12	0.09	0.1	0.08	11.7	9.7	11.6	12.9	0.06	0.09	0.1	0.15
Residual Chlorine	mg/L	-	-	-	-	1.0	1.1	0.8	0.9		-	-	-	1.0	0.9	0.9	0.8
Total coliforms	MPN/100ml	16	9.2	9.2	9.2	0	0	0	0	16	>16	16	>16	0	0	0	0
E.coli	CFU/100mL	1	4	1	2	0	0	0	0	4	0	1	4	0	0	0	0

		Week 11								Week 12							
Parameters	Units	RW$_1$	RW$_2$	RW$_3$	RW$_4$	TW$_1$	TW$_2$	TW$_3$	TW$_4$	RW$_1$	RW$_2$	RW$_3$	RW$_4$	TW$_1$	TW$_2$	TW$_3$	TW$_4$
pH	-	6.57	6.66	6.49	6.59	6.85	6.80	6.81	6.89	6.40	6.38	6.78	6.83	6.82	6.90	7.11	7.04
Colour	HU	1515.5	1099.0	1895.8	1455.2	5.3	6.2	5.9	5.4	1027	1236.0	1145.7	1235.4	5.8	5.5	5.6	5.7
Turbidity	NTU	1129.7	1028.1	1222.8	999.3	3.3	2.9	2.70	2.6	1064	1229.0	1002.0	1212.0	2.8	2.7	2.6	2.8
Total Hardness	mg/L	69.0	70.0	53.0	52.0	78.0	77.1	80.2	78.4	70.2	69.4	59.2	61.0	77.8	79.6	76.8	72.8
Nitrate	mg/L	20.9	19.4	17.0	10.2	0.5	0.9	1.0	0.9	15.1	20.2	20.1	19.0	0.6	0.9	1.0	0.9
Sulphate	mg/L	5.3	4.9	4.6	5.2	43.2	48.3	50.1	53.0	4.9	5.1	5.4	5.6	45.0	44.8	50.0	49.9
Iron	mg/L	12.8	11.9	11.8	12.7	0.09	0.06	0.1	0.08	11.7	9.7	10.9	11.1	0.06	0.09	0.14	0.13
Residual Chlorine	mg/L	-	-	-	-	1.0	0.8	0.8	0.7	-	-	-	-	0.9	1.1	0.9	0.8
Total coliforms	MPN/100ml	16	9.2	16	16	0	0	0	0	16	>16	16	16	0	0	0	0
E.coli	CFU/100ml	6	5	0	1	0	0	0	0	1	1	3	2	0	0	0	0

		Week 13								Week 14							
Parameters	Units	RW$_1$	RW$_2$	RW$_3$	RW$_4$	TW$_1$	TW$_2$	TW$_3$	TW$_4$	RW$_1$	RW$_2$	RW$_3$	RW$_4$	TW$_1$	TW$_2$	TW$_3$	TW$_4$
pH		6.77	6.80	6.79	6.59	6.85	6.89	6.81	6.99	6.80	6.58	6.78	6.80	6.87	6.89	6.99	6.90
Colour	HU	1225.5	1298.0	1655.8	1995.2	5.3	5.3	5.0	5.4	1121.5	1212.0	1325.7	1765.4	6.1	6.5	5.8	5.6
Turbidity	NTU	1039.7	1021.1	1022.8	1092.3	2.5	2.7	2.40	2.2	1014	1219.0	1012.5	1252.0	2.8	2.7	2.5	2.0
Total Hardness	mg/L	69.8	60.0	63.1	58.0	76.5	74.9	69.0	72.0	70.1	69.4	59.6	61.2	78.4	79.0	78.0	80.2
Nitrate	mg/L	12.9	18.4	20.1	19.2	0.5	0.7	0.9	0.9	21.1	20.4	20.1	19.2	0.6	0.8	1.3	1.1
Sulphate	mg/L	4.9	6.0	6.9	6.7	53.9	56.0	55.9	57.7	4.9	5.0	4.8	4.7	54.3	49.9	49.9	49.9
Iron	mg/L	12.8	11.9	12.0	13.0	0.08	0.11	0.1	0.08	11.7	10.7	10.5	11.1	0.13	0.15	0.14	0.13
Sulphate	mg/L	3.8	4.0	5.0	3.6	50.1	47.2	50.0	52.1	4.1	3.7	4.1	3.7	44.8	49.7	50.1	49.9
Residual Chlorine	mg/L	-	-	-	-	1.0	0.7	0.8	0.7	-	-	-	-	0.9	1.0	0.9	0.8
Total coliforms	MPN/100ml	16	9.2	>16	9.2	0	0	0	0	16	>16	16	9.2	0	0	0	0
E.coli	CFU/100ml	4	6	2	1	0	0	0	0	1	2	4	0	3	0	0	0

		Week 15								Week 16							
Parameters	Units	RW$_1$	RW$_2$	RW$_3$	RW$_4$	TW$_1$	TW$_2$	TW$_3$	TW$_4$	RW$_1$	RW$_2$	RW$_3$	RW$_4$	TW$_1$	TW$_2$	TW$_3$	TW$_4$
pH	-	6.80	6.76	6.69	6.72	6.85	6.82	6.81	6.79	6.76	6.08	6.78	6.80	6.82	7.05	7.19	7.10
Colour	HU	1145.5	1198.0	1490	1212.9	6.1	6.3	5.0	5.4	1021.5	1212.0	1998.7	1876.6	5.9	6.0	5.9	5.8
Turbidity	NTU	1039.7	1021.1	1057	1002.3	3.0	2.9	2.50	2.7	1114	1219.0	1222.5	1002.0	2.8	2.9	2.6	2.7
Total Hardness	mg/L	72.1	70.0	53.0	52.0	78.0	77.2	75.8	72.0	68.8	69.8	59.3	61.2	70.0	79.1	75.9	82.2
Nitrate	mg/L	18.9	20.4	18.1	16.2	0.5	0.7	0.6	0.9	20.1	19.6	17.8	19.2	0.6	0.7	0.9	1.3
Sulphate	mg/L	3.8	3.9	4.2	3.9	43.9	44.9	48.9	50.1	6.9	6.2	5.9	5.3	43.9	44.9	50.0	51.1
Iron	mg/L	12.8	11.9	10.6	12.4	0.12	0.09	0.1	0.08	11.7	9.7	9.9	11.1	0.06	0.09	0.1	0.13
Residual Chlorine	mg/L	-	-	-	-	0.7	0.8	0.8	0.7	-	-	-	-	0.7	0.9	0.9	0.8
Total coliforms	MPN/100mL	16	9.2	16	16	0	0	0	0	16	>16	9.2	9.2	0	0	0	0
E.coli	CFU/100 mL	2	0	2	2	0	0	0	0	3	2	2	0	0	0	0	0

		Week 17								Week 18							
Parameters	Units	RW$_1$	RW$_2$	RW$_3$	RW$_4$	TW$_1$	TW$_2$	TW$_3$	TW$_4$	RW$_1$	RW$_2$	RW$_3$	RW$_4$	TW$_1$	TW$_2$	TW$_3$	TW$_4$
pH	-	6.85	6.86	6.69	6.59	6.85	6.99	6.89	6.99	6.70	6.78	6.79	6.83	6.89	6.90	6.94	6.93
Colour	HU	1145.5	1098.0	1645.0	1278.9	6.0	6.1	5.0	5.4	1121.5	1214.0	1655.7	1325.4	5.9	6.0	5.7	5.6
Turbidity	NTU	1039.7	1021.1	1222.4	999.3	3.2	3.1	2.80	2.6	1014	1219.0	1302.5	1072.0	2.9	2.7	2.5	2.0
Total Hardness	mg/L	72.2	70.0	68.2	72.0	72.9	77.2	78.1	72.5	68.4	70.2	59.0	61.0	70.5	79.8	80.0	72.0
Nitrate	mg/L	19.0	17.4	15.9	20.0	0.5	0.7	0.3	0.4	15.1	17.8	18.1	17.2	0.6	0.5	0.7	0.6
Sulphate	mg/L	3.9	4.0	5.2	5.6	43.9	44.0	50.0	51.5	6.0	5.9	5.6	5.4	53.3	50.5	53.0	52.9
Iron	mg/L	12.6	11.0	9.6	12.9	0.11	0.09	0.07	0.08	11.7	9.7	10.9	11.1	0.06	0.09	0.1	0.13
Residual Chlorine	mg/L	-	-	-	-	0.9	1.0	0.8	0.7	-	-	-	-	1.0	0.9	0.9	0.8
Total coliforms	MPN/100mL	16	9.2	16	9.2	0	0	0	0	16	>16	>16	16	0	0	0	0
E.coli	CFU/100mL	4	2	1	0	0	0	0	0	1	1	0	3	2	0	0	0

		Week 19								Week 20							
Parameters	Units	RW$_1$	RW$_2$	RW$_3$	RW$_4$	TW$_1$	TW$_2$	TW$_3$	TW$_4$	RW$_1$	RW$_2$	RW$_3$	RW$_4$	TW$_1$	TW$_2$	TW$_3$	TW$_4$
pH	-	6.56	6.76	6.69	6.65	6.85	6.99	6.81	6.86	6.80	6.88	6.78	6.83	7.12	7.20	7.1	6.99
Colour	HU	1815.5	1198.0	1271	1612.3	5.3	5.1	5.0	5.4	1621.5	1312.0	1498	1423	5.6	6.0	5.6	5.8
Turbidity	NTU	1099.5	1121	1092.8	1002.1	2.9	2.9	2.40	2.9	1514	1289.0	1092.5	1402.0	2.8	2.7	2.7	2.4
Total Hardness	mg/L	79.0	70.0	73.6	68.4	78.8	79.6	78.4	82.0	70.2	74.2	69.2	61.3	79.2	79.4	76.4	72.6
Nitrate	mg/L	20.9	21.4	20.1	20.2	0.6	0.8	0.3	0.5	22.1	23.1	20.1	19.2	0.4	0.6	0.4	0.3
Sulphate	mg/L	5.1	4.9	4.8	4.4	49.1	48.3	47.9	46.8	3.9	4.1	4.7	4.3	50.1	51.5	53.0	52.9
Iron	mg/L	12.8	11.9	10.0	9.64	0.09	0.06	0.1	0.08	11.7	13.7	10.4	9.15	0.15	0.1	0.09	0.18
Residual Chlorine	mg/L	-	-	-	-	0.8	0.9	0.8	0.7	-	-	-	-	1.0	0.9	0.9	0.8
Total coliforms	MPN/100mL	16	9.2	16	9.2	0	0	0	0	16	>16	9.2	16	0	0	0	0
E.coli	CFU/100mL	1	1	0	0	6	0	0	0	2	1	1	2	0	0	0	0