CHANGES IN WATER QUALITY FROM SOURCE TO POINT-OF-USE:

A CASE STUDY OF THE OWABI HEADWORKS

By

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CERTIFICATION

I, Opoku Gyamfi, hereby declare that this thesis is a compilation of original research conducted by me and that this work has not been presented in this university or elsewhere for award of a degree. Cited works have been duly acknowledged.

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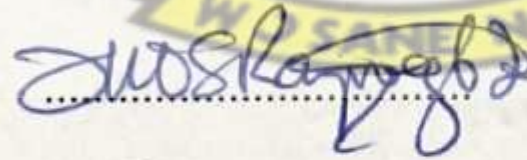
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DEDICATION

This work is dedicated to the memory of my late father, Augustine Kwame Gyamfi whose toil ensured my progress on the academic ladder. May his soul rest in perfect peace. Also to my mother, Ante Ama, whose prayers I could not do without.

ACKNOWLEDGEMENT

ABSTRACT

Water supports all forms of life and is a key natural resource that is inevitable for sustaining human health. Poor quality water is a vehicle for the spread of diseases. This study was conducted to ascertain the change in quality of drinking water from source to point-of-use from the Owabi Headworks supplies to some parts of Kumasi and its environs. Physico-chemical and bacteriological water quality parameters as well as trace metal concentration of water samples from five different treatment points from the Owabi Headworks in Ghana were investigated between December 2011 and April 2012. The raw water was moderately hard with high turbidity and colour that exceeds the WHO standard limits. The concentrations of the nutrients followed the order: $NH_3 < NO_2^- < NO_3^- < PO_4^{3-} < SO_4^{2-}$ and were all below WHO permissible level for drinking water. Trace metal concentration of the reservoir were all below WHO limit except chromium (0.06 mg/L) and copper (0.24 mg/L). The bacteriological analyses showed that the raw water had total coliform (1766 cfu/100 mL) and Faecal coliform (257 cfu/100 mL). These values exceeded the WHO standard limits, thus rendering it unsafe for domestic use without pre-treatment. There was strong positive correlation of colour with turbidity ($r = 0.730$), TSS ($r = 0.922$) and alkalinity ($r = 0.564$) significant at $p < 0.01$. Treatment process at the headworks is adjudged to be good. The treated water quality established indicate that colour, turbidity, Cr and Cu levels reduced with treatment, and fell within the WHO permissible limit for drinking water. A potable drinking water that conforms to the WHO permissible limits was produced from the treatment process.

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LIST OF ABBREVIATION/ ACRONYMS

EC	Electrical conductivity
FAO	Food and Agriculture Organization
FC	Faecal Coliform
mg/L	Milligram per litre
NAS	National Academy of Sciences
SDWQ	Surveillance of Drinking Water Quality
TC	Total Coliform
TDS	Total Dissolved Solids
TH	Total Hardness
TSS	Total Suspended Solids
UNEP	United Nation's Environmental Programme
UNICEF	United Nations International Children's Emergency Fund
USEPA	United States Environmental Protection Agency
WHO	World Health Organisation
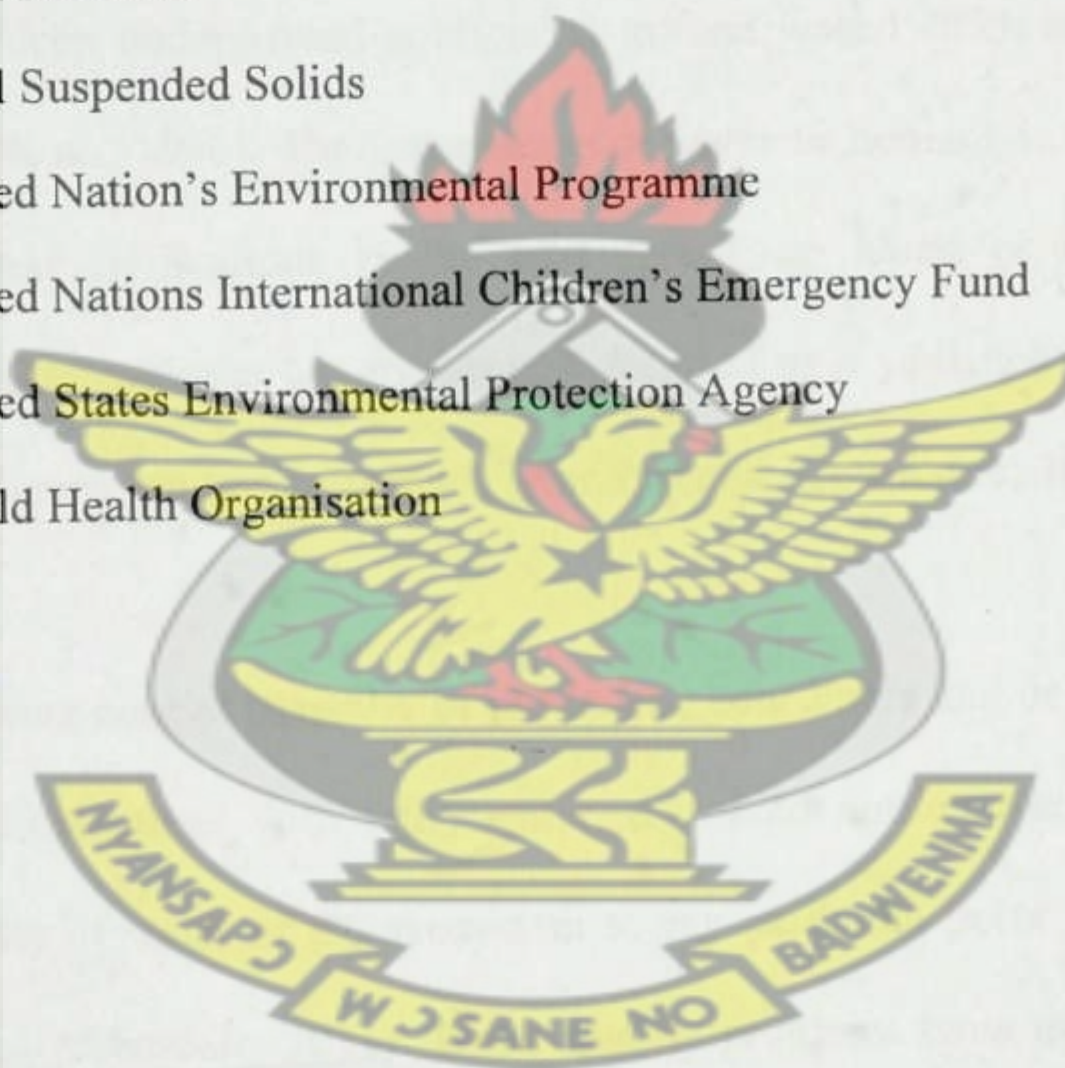
CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

Water resources, comprises of surface water, ground water, as well as marine and coastal waters. These water resources support all forms of life including human beings. Though water is available on earth in huge quantities in the order of 1400×10^6 km^3, only 3% of this water in the universe is fresh water. Among the fresh waters, only about 5% is available for human consumption (Usharani et al., 2010). Nearly 70 % of the remaining fresh water is frozen in the icecaps of Antartica and Greenland. Most of the remainder is present as soil moisture or lies in deep underground aquifers as ground water which is not accessible for human use (Postel et al., 1996). The importance of water to humans is underscored by the fact that many great civilizations in the past sprang up along or near water bodies. Development of water resources has therefore been used as a yardstick for socio-economic and health status of many nations worldwide (Karikari and Ansa-Asare, 2006).

Freshwater ecosystems consist basically of producers, consumers and decomposers (bacteria and fungi). Their interactions with light, water, dissolved nutrients and suspended solids determine the quality of water of the ecosystem at any particular point in time (Humbert et al., 2010; Torto and Mmualefe, 2011). Water quality problems have increased through the ages in response to the increase in human population and concentration of industry along water bodies. Polluted water is an important vehicle for the spread of diseases. In developing countries 1.8 million people, mostly children, dies every year as a result of water-related diseases (WHO, 2004; Karikari et al., 2007).

Due to anthropogenic activities, freshwater systems worldwide are confronted with numerous xenobiotics and are overloaded with nutrients (Terns, 1998, Torto and Mmualefe, 2011). A major contribution to chemical contamination originates from domestic and industrial wastewater discharges containing both organic and inorganic contaminants that negatively impact on water quality (Kolpin et al., 2004; Snyder et al., 2001; Gao et al., 2010; Torto and Mmualefe, 2011). Additional contamination comes from agricultural activities in which millions of tons of fertilizers and pesticides are employed annually (Schriks et al., 2010). Nitrates (NO_3^-) and phosphates (PO_4^{3-}) are common pollutants associated with fertilizers.

In terms of microbial water quality, wide variety of viruses, bacteria and protozoa that can be transmitted via water are of concern. These micro-organisms have mostly been associated with diseases such as gastroenteritis, cholera, hepatitis, typhoid fever, dysentery, salmonellosis, as well as eye, skin and nose infections (DWAF, 1996; van Rensburg et al., 2004). Majority of the pathogens that cause the above diseases are transmitted by the faecal-oral route (DWAF, 1996). Thus transmission of pathogens in faecal matter from one host is introduced into the oral cavity of another potential host.

Metals such as Cr, Mn, Co, Cu, Fe and Zn play biochemical roles in the life processes of aquatic plants and animals, and their presence in trace amounts in the aquatic environment is essential. However, at relatively high concentrations, these metals become toxic (Nurnberg, 1982). A special feature of these metals is that they are not biodegradable. Instead, they go through a biogeochemical cycle with substantially different residence times in the various spheres and compartments of the environment. Within this cycle they will be taken up also by man, predominantly from food and drinking water. In this respect, metals constitute a particular risk to human health because they can accumulate in vital organs of man

(Nurnberg, 1982) and exert progressively growing toxic actions over long periods of exposure (Akoto et al., 2008).

Water supply is one of the key natural resources that is inevitable for sustainability of human and environment health (Marobhe et al., 2007). The adverse impacts of poor water supply have long been recognized in both developing and developed countries. The effect takes the form of outbreaks of diseases and also contributes to increase in rates of diseases outbreaks (Esrey et al., 1991; Ford, 1999; Payment and Hunter, 2001). Millions of people in the developing world use water of poor quality (WHO and UNICEF, 2000). Using water of poor quality leads to outbreak of diseases and sometimes death.

Access to quality water supply in most developing countries is complex as compared to those in developed countries (Howard and Bartram, 2005) due to high cost of treatment of raw water for distribution. It is important that water, tapped from the available resources, is made safer for consumption. It is also essential that the service provider and the consumers shoulder combined responsibility to see that the needed programs and policies are taken up to achieve objectives and missions of "providing safe and sufficient water at minimum cost (WSSP, 2004). Water distribution systems play a pivotal role in preserving and providing quality water to the public (Farooq et al., 2008). The quality of drinking water deteriorates during collection, storage (Andrew et al., 2005) as well as in distribution (Lehtola et al., 2004; Karavoltsosa et al., 2008). It therefore becomes imperative to monitor water quality at each stage of treatment.

Surveillance of Drinking Water Quality (SDWQ) is the continuous and vigilant public health assessment and overview of the safety and acceptability of drinking water supplies (WHO

2004). SDWQ at a drinking water treatment plant is necessary to avoid risk from chemical and bacteriological contamination and to assure that drinking water is safe for consumers and can be consumed without any risk (Leeuwen, 2000). The elements of surveillance include water quality monitoring, study of institutional setup and examination of water for physico-chemical and bacteriological parameters. Analyses of these parameters make up some of the more usual physico-chemical and bacteriological characteristics of water and describe their significance. Some of these parameters like coliform counts constitute a risk to human health; others such as turbidity affect the aesthetic quality of the water supplied while others relate to treatment issues (Ratnayaka et al. 2009).

Ghana's water resources have been under increasing threat from pollution in recent years due to rapid demographic changes, which have coincided with the establishment of human settlements lacking appropriate sanitary infrastructure. This applies especially to peri-urban areas, which surround the larger metropolitan towns. People living in these areas, often utilize contaminated surface water for drinking, recreation and irrigation, which poses serious health risk to them (Verma and Srivastava, 1990).

The Owabi reservoir provides drinking water to parts of the Kumasi metropolis and its environs (Akoto et al., 2008). The functions of the Owabi catchment include: maintenance of water quality, water storage, water recharge, treatment of raw water, reproduction area for fish and other aquatic organisms and climate control. This can be affected adversely by high population and associated increase in human activities (Okurut et al., 2000; Kansiime et al., 2003).

It is widely perceived that human activities within the catchment may be impacting negatively on the water quality and the quality of other resources such as fish and food derived from the area. Human activities found within the catchment include metal fabrication, auto garages, residential facilities, farming, road construction as well as municipal waste disposal. These activities are sources of metals and other chemicals which can pollute ecosystems (Akoto et al., 2010).

1.2 PROBLEM STATEMENT

Pestle (1997) observed that the proportion of available but polluted water is continuously increasing as a result of changes in the modes of industrial activities, agricultural production and increasing urbanization. The Owabi Reservoir may be polluted from the streams that feed the Owabi reservoir as reported by Akoto et al (2010). The Owabi reservoir is under increasing threat of pollution in recent years due to the increase in the number of human settlement which lack proper town planning along the rivers that supply water to the reservoir (Akoto et al., 2010).

The Owabi watershed which lies in a peri-urban community suffers from lack of proper town planning and poor sanitary infrastructure. As a result domestic wastes from towns within the catchment find their way into the Owabi river. There are agricultural activities along the river banks and the streams serving the reservoir, and wastes from these agricultural activities enter these rivers that serve the reservoir. Wastes also enter the river from activities of small scale industries dotted along the tributaries of the rivers that serve the reservoir. These sources of waste pollute the Owabi reservoir and therefore water from the reservoir needs treatment before been used for drinking and other domestic purposes.

1.3 AIMS AND OBJECTIVES

The aim of this study is to assess the changes in the quality of water from the source through treatment through storage of the Owabi water heads.

The specific objectives are:

- To determine the water quality of untreated and treated water from the Owabi headworks.

- To establish changes in water quality from source to consumer.

- To assess the effectiveness of the water treatment process.

1.4 JUSTIFICATION

Currently, the Owabi reservoir is the main source of drinking water for some parts of the Kumasi Metropolis. This work would provide us with the information on the quality of the raw and treated water from the Owabi reservoir in order to help improve the quality of water supplied to the Kumasi Metropolis. It would also serve as a base-line study for future research on the quality of water from the reservoir.

This study would also help us to ascertain the efficiency of the water treatment process for better decision making. This work would also provide information on the extent of pollution of the Owabi reservoir. The Owabi community would have information on the impacts of their activities on the reservoir and also the quality of their drinking water.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 WATER QUALITY

Water is vital to the existence of all living organisms, but this valuable resource is increasingly being threatened as human populations grow and the demand for more water of high quality for domestic purposes and economic activities increases. Water abstraction for domestic use, agricultural production, mining, industrial production, and power generation can lead to deterioration in water quality and quantity (UNEP, 2008).

The quality of water necessary for each human use varies, as do the criteria used to assess water quality. For example, the highest standards of purity are required for drinking water, whereas it is acceptable for water used in some industrial processes to be of less quality. The quality of water required to maintain ecosystem health is largely a function of the natural background conditions (UNEP, 2008).

The degradation of water quality due to human influences is often gradual, and subtle adaptations of aquatic ecosystems to these changes may not be readily detected until a dramatic shift in ecosystem conditions occur (UNEP, 2008). Typically, water quality is determined by comparing the physical and chemical characteristics of a water sample with water quality guidelines or standards. Drinking water quality guidelines and standards are designed to enable the provision of clean and safe water for human consumption, thereby protecting human health. They are usually based on scientifically assessed acceptable levels of toxicity to either humans or aquatic organisms (UNEP, 2008).

Water quality is neither a static condition of a system, nor can it be defined by the measurement of only one parameter. Rather, it is variable in both time and space and requires routine monitoring to detect spatial patterns and changes over time. There is a range of chemical, physical, and biological components that affect water quality and hundreds of variables could be examined and measured. Some variables (e.g. coliform counts) provide a general indication of water pollution, whereas others (e.g. faecal coliform) enable the direct tracking of pollution sources (UNEP, 2008).

2.2 PHYSICO-CHEMICAL CHARACTERISTICS OF WATER

2.2.1 Temperature

Temperature is one of the most important characteristic to be considered when examining water quality. Temperature affects the speed of chemical reactions, the rate at which algae and aquatic plants photosynthesize, the metabolic rate of other organisms, as well as how pollutants, parasites, and other pathogens interact with aquatic residents. Temperature is important because it allows scientists to better understand other hydrological characteristics such as dissolved oxygen, pH and conductivity. Water temperature varies seasonally with ambient temperature. The United States Federal Water Pollution Control Administration (1967) referred to temperature as "a catalyst, a depressant, an activator, a restrictor, a stimulator, a controller, and a killer. It is one of the most important and most influential water quality characteristics to life in water.

Aquatic organisms often have narrow temperature tolerances. Thus, although water bodies have the ability to buffer against atmospheric temperature extremes, even moderate changes in water temperatures can have serious impacts on aquatic life such as bacteria, algae, invertebrates and fish. Thermal pollution comes in the form of discharge of industrial cooling

water into aquatic receiving bodies, or indirectly through human activities such as the removal of shading stream bank vegetation or the construction of impoundments (UNEP, 2008).

2.2.2 pH

The pH of a solution is the negative logarithm of the hydrogen ion activity. In dilute solutions, the hydrogen ion activity is approximately equal to the hydrogen ion concentration. The pH of water is a measure of the acid–base equilibrium and, in most natural waters, is controlled by the carbon dioxide–bicarbonate–carbonate equilibrium system. The pH of most raw water lies within the range 6.5–8.5 (APHA, 1999). The pH of an aquatic ecosystem is important because it is closely linked to biological productivity (UNEP, 2008).

The pH of water is naturally acidic because carbon dioxide (CO_2) in the atmosphere readily dissolves in water exposed to air, forming a weak acid.

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

An increased carbon dioxide concentration in water will lower pH, whereas a decrease will cause pH to rise. Temperature will also affect the equilibrium and the pH. In pure water, a decrease in pH of about 0.45 occurs as the temperature is raised by 25 °C. In water with a buffering capacity imparted by bicarbonate, carbonate, and hydroxyl ions, this temperature effect is modified (APHA, 1999).

Minerals in soils can dissolve in water to influence its acidity and alkalinity (Wurtz, 2003). The overall pH range of natural water is generally between 6 and 8. Industrial wastes may be strongly acidic or basic and their effect on pH of receiving water depends on the buffering capacity of the water. A high value of pH hastens scale formation in water heating apparatus.

It reduces the germicidal potential of chlorine. pH below 6.5 causes corrosion of metal pipes, thereby releasing toxic metals such as Zn, Pb, Cd, and Cu (Thakre et al., 2010) into the water column.

The acidity of water is neutralized by carbonate and silicate minerals as water percolates through soils. This neutralizing capacity in soils determines whether or not acid precipitation will cause water quality impacts in receiving water bodies. The ability of rocks and soils in any given drainage basin to buffer the acidity of rainwater is related to the residence time of water in the soil as well as the levels of calcium carbonate, bicarbonate, and silicate minerals (Friedl et al., 2004; Wetzel and Likens, 2000).

Exposure to extreme pH values results in irritation to the eyes, skin, and mucous membranes. Eye irritation and exacerbation of skin disorders have been associated with pH values greater than 11. In addition, solutions of pH 10–12.5 have been reported to cause hair fibres to swell (WHO, 1986). In sensitive individuals, gastrointestinal irritation may also occur. Exposure to low pH values can also result in similar effects. Below pH 4, redness and irritation of the eyes have been reported, the severity of which increases with decreasing pH. Below pH 2.5, damage to the epithelium is irreversible and extensive (WHO, 1986). In addition, because pH can affect the degree of corrosion of metals as well as disinfection efficiency, it may have an indirect effect on health.

2.2.3 Turbidity

Turbidity is an expression of the optical property that causes light to be scattered and absorbed by particles rather than being transmitted in straight lines through a water sample (USEPA, 1999). It is caused by suspended matter or impurities that interfere with the clarity

of the water which may include clay and silt particles, inorganic and organic matter, and other microscopic organisms. Turbidity actually measures the clarity of water. Clarity is important when producing drinking water for human consumption and for many manufacturing uses. High turbidity, or cloudiness, in drinking water is aesthetically unappealing, and may also represent a health concern. Turbidity provides food and shelter for pathogens and can promote regrowth of pathogens in the distribution system, leading to waterborne disease outbreaks such as gastroenteritis (USEPA, 1999). Although turbidity is not a direct indicator of health risk, some studies (Fox, 1995; USEPA, 1997) showed a strong positive relationship between turbidity, protozoa concentration and other types of pathogens. Microbial attachment to particulate material or inert substances in water systems has been documented by several investigators (Marshall, 1976; Olson et al., 1981; Herson et al., 1984) and has been considered to aid in microbe survival (NAS, 1980). Fortunately, traditional water treatment processes have the ability to effectively remove turbidity when operated properly.

2.2.4 Electrical Conductivity

Electrical conductivity is a measure of dissolved ions in water and is expressed as mS/cm or μScm^{-1} (Daniel et al., 2002). The major ions that contribute to conductivity are Na^+, Ca^{2+}, K^+, Mg^{2+}, Cl^-, SO_4^{2-} and CO_3^{2-}. Bicarbonates, NO_3^- and PO_4^{-3} are minor contributors to conductivity but very important biologically (CWT, 2004). These ions help to control the acid-base balance in blood, maintain fluid balance in cells as well as transport CO_2 from blood to lungs. Conductivity can help in detecting changes in natural water, mineralization and also determine the amounts of treatment chemicals to be added to water sample (Farrel-Poe, 2000).

2.2.5 Hardness

Water described as 'hard' contains high amounts of dissolved Ca^{2+} and Mg^{2+}. Hard water is not a health risk but is a nuisance because of mineral build-up on plumbing fixtures and poor soap and detergent performance. Water containing calcium carbonate at concentrations 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, very hard (McGowan, 2000). The major sources of hardness in water are dissolved metallic ions from sedimentary rocks, seepage and runoff from soils. Calcium and magnesium are the two principal ions that are present in many sedimentary rocks, the most common being limestone and chalk. They are also common essential mineral constituents of food (WHO, 2009).

Calcium concentrations exceeding 100 mg/L are common in natural sources of water, particularly groundwater. Magnesium is present in natural groundwater usually at lower concentrations (from negligible to about 50 mg/L and rarely above 100 mg/L), so calcium-based hardness usually predominates (WHO, 2009).

Both calcium and magnesium are essential minerals and beneficial to human health in several respects. Inadequate intake of either nutrient can result in adverse health consequences. Recommended daily intake of each element has been set at national and international levels. Individuals vary considerably in their needs for and consumption of these minerals (WHO, 2009). Inadequate intake of calcium has been associated with increased risks of osteoporosis, kidney stones, colorectal cancer, hypertension and stroke, coronary artery disease, insulin resistance and obesity (Adelekan and Ogunde, 2010).

2.2.6 Alkalinity

Alkalinity is associated with the buffering capacity of a water body. It measures the ability of water bodies to neutralize acids and bases thereby maintaining a fairly stable pH. Water that is a good buffer contains radicals, such as bicarbonates, carbonates, and hydroxides, which combine with H^+ ions from the water thereby raising the pH of the water. Without this buffering capacity, any acid added to a lake would immediately change its pH. Alkalinity is an indirect measure of the concentration of anions in water. The dissolved anions may be sourced from bicarbonates, carbonates, hydroxides, phosphates, borates or silicates which may be derived from industrial wastes, dissolved rocks, salts, soils or bottom sediments (McNeely et al 1979). High alkalinity results in physiological stress on aquatic organisms and may lead to loss of biodiversity. Alkalinity is not detrimental to humans. Water with low alkalinity (less than 75 mg/L), is subject to changes in pH because the buffering capacity of the water is low (Lawson, 2011).

2.2.7 Total Dissolved Solids (TDS)

TDS is the term applied to the residue remaining in a weighed dish after the sample has been passed through a standard fibre glass filter and dried to constant mass (APHA, 1999). Many dissolved substances are undesirable in water. Dissolved minerals may produce displeasing colour, taste and odour. Water with higher TDS often has a laxative effect upon people whose bodies cannot be adjusted to them (Parmar and Parmar, 2010).

2.2.8 Chloride

Chlorides are widely distributed in nature as salts of sodium, potassium, calcium and are one of the most abundant inorganic ions in natural and wastewater. In normal fresh surface water, chloride concentrations are usually less than 10 ppm (Adelekan and Ogunde, 2012). In water

intended for human consumption, the maximum allowable limit of chloride is usually 250 ppm, as a notably salty taste emerges at concentrations higher than this. Water with chloride concentration greater than 250 ppm is also known to intensify corrosion in water transportation systems. The taste threshold of the chloride anion in water is dependent on the associated cation. Taste thresholds for sodium chloride and calcium chloride in water are in the range 200–300 mg/L (Zoeteman, 1980). Chloride toxicity has not been observed in humans except in the special case of impaired sodium chloride metabolism, e.g. in congestive heart failure (Wesson, 1969). Healthy individuals can tolerate the intake of large quantities of chloride provided that there is a concomitant intake of fresh water (Apte et al., 2011).

2.2.9 Fluoride

Fluoride can enter public water systems from natural sources, including runoff from weathering of fluoride-containing rocks and soils and leaching from soils into groundwater (Pruss-Ustun et al., 2011). In areas rich in fluoride-containing minerals, well water may contain up to about 10 mg/L of fluoride (Slooff et al., 1988).Fluoride pollution from various industrial discharges and emissions can also contaminate water supplies. Fluoride in drinking waterat low concentrations is beneficial, but can pose health concerns at higher concentrations. Many studies of possible adverse effects of fluoride via drinking-water have been carried out. These studies clearly establish that fluoride produces effects on bones and teeth. Low concentrations provide protection against dental caries, especially in children. However, fluoride can also have an adverse effect on tooth enamel and may give rise to dental fluorosis at drinking-water concentrations above 0.5 mg/L (Dean, 1942). This has been confirmed in numerous subsequent studies, including a large-scale survey carried out in China (Chen et al., 1988). High fluoride intakes can also have more serious effects, such as crippling skeletal fluorosis and osteoporosis, on skeletal tissues (IPCS, 2002; Meseret, 2011).

2.2.10 Sulphate

Sulphates occur naturally in numerous minerals including $BaSO_4$, $MgSO_4.7H_2O$ and $CaSO_4.2H_2O$ (Greenwood and Earnshaw, 1984). These minerals when dissolved contribute to the SO_4^{2-} content of many drinking-water sources.

Levels of sulphate in rainwater and surface water correlate with emissions of sulphur dioxide from anthropogenic sources (Keller and Pitblade, 1986).According to GEMS/Water (a global network of water monitoring stations), typical sulphate levels in fresh water are in the vicinity of 20 mg/L and range from 0 to 630 mg/L in rivers, from 2 to 250 mg/L in lakes and from 0 to 230 mg/L in groundwater (UNEP, 1990). In 1970, the US Public Health Service measured sulphate levels in the drinking-water sources of nine geographic areas. SO_4^{2-} was present in 645 of 658 groundwater supplies and in all of the 106 surface water supplies sampled and the levels ranged from <1 to 770 mg/L (US EPA, 1999a). The mean sulphate level in municipal drinking-water supplies may be increased by treatment.

Cathartic effects are commonly reported to be experienced by people consuming drinking-water containing sulphate in concentrations exceeding 600 mg/L (Morris and Levy, 1983; Chien et al., 1968), although it is also reported that humans can adapt to higher concentrations with time (US EPA, 1985). Dehydration has also been reported as a common side-effect following the ingestion of large amounts of magnesium or sodium sulphate (Fingl, 1980). Children, transients and the elderly may have potentially high risk of dehydration from diarrhoea that may be caused by high levels of sulphate in drinking-water (US EPA, 1999a, b). There have been reports of diarrhoea in infants exposed to water containing high levels of sulphate (Chien et al., 1968)

2.2.11 Phosphate

Phosphorus is a non-metallic element which is essential for life and is found in rock as phosphates. As water runs over and through rocks it dissolves the minerals. Phosphates are a plant nutrient and are taken in by plants with water and incorporated into organic phosphate compounds. Animals obtain their essential phosphorus from phosphates in water and plant material. Natural waters have a phosphorus concentration of approximately 0.02 mg/L which is a limiting factor for plant growth but large concentrations of this nutrient accelerate plant growth (Nthumbi et al., 2012).

Phosphates can also enter waterways through man-made sources. The addition of large quantities of phosphates to waterways accelerates algae and plant growth in natural waters; enhancing eutrophication and depleting the water body of oxygen (Tanada et al., 2003). This can lead to fish kills and the degradation of habitat with loss of species. Large mats of algae can form and in severe cases can completely cover small lakes. As a result, water can become putrid from decaying organic matter (Tanada et al., 2003). When the concentration of phosphates rises above 100 mg/L the coagulation processes in treatment plants for drinking water may be adversely affected. Phosphates are not toxic to people or animals unless they are present in very high levels. Digestive problems could occur from extremely high levels of phosphate (Nthumbi et al., 2012).

2.2.12 Nitrate and Nitrite

Nitrate and nitrite are naturally occurring ions that are part of the nitrogen cycle. The nitrate ion (NO_3^-) is the stable form of combined nitrogen for oxygenated systems. Although chemically unreactive, it can be reduced by microbial action. The nitrite ion (NO_2^-) contains nitrogen in a relatively unstable oxidation state. Chemical and biological processes can further reduce nitrite to various compounds or oxidize it to nitrate (ICAIR, 1987).

Nitrate can reach both surface water and groundwater from agricultural activity, wastewater treatment and oxidation of nitrogenous waste products in human and animal excreta. Nitrite can also be formed chemically in distribution pipes by Nitrosomonas bacteria during stagnation of nitrate-containing and oxygen-poor drinking-water in galvanized steel pipes. In surface water, nitrification and denitrification may also occur, depending on the temperature and pH. The uptake of nitrate by plants, however, is responsible for most of the nitrate reduction in surface water.

In most countries, nitrate levels in surface water do not exceed 10 mg/L. In some areas, however, concentrations are higher as a result of runoff and the discharge of sewage effluent and certain industrial wastes. Chloramination may give rise to the formation of nitrite within the distribution system, and the concentration of nitrite may increase as the water moves towards the extremities of the system. Nitrification in distribution systems can increase nitrite levels, usually by 0.2–1.5 mg/L, but potentially by more than 3 mg/L (AWWARF, 1995).

The toxicity of nitrate to humans is mainly attributable to its reduction to nitrite. The major biological effect of nitrite in humans is its involvement in the oxidation of normal haemoglobin to methaemoglobin, which is unable to transport oxygen to the tissues. The haemoglobin of young infants is more susceptible to methaemoglobin formation than that of older children and adults. This higher susceptibility is believed to be the result of the large proportion of fetalhaemoglobin still present in the blood of these infants. This fetalhaemoglobin is more easily oxidized to methaemoglobin. In addition, there is a deficiency in the methaemoglobinreductase responsible for the reduction of methaemoglobin back to haemoglobin (Speijers et al., 1989; FAO/WHO, 1996). Other groups especially

susceptible to methaemoglobin formation include pregnant women and people deficient in glucose-6-phosphate dehydrogenase or methaemoglobinreductase (Speijers et al., 1989).

2.2.13 Ammonia

Ammonia is a nitrogen waste released by aquatic animals into the water. Ammonia is also excreted directly from the fish gill into water. Ammonia is toxic to aquatic life and toxicity is affected by pH. Ammonia-nitrogen (NH_3-N) exists as un-ionized ammonia (NH_3) in a high pH system which is more toxic than its ionized ammonia (NH_4^+), which is the stable form in a low pH system. In addition, ammonia toxicity increases as temperature rises (Hargreaves and Tucker, 2004).

Natural levels of NH_3 in ground waters are usually below 0.2 mg/L. Surface waters may contain up to 12 mg/L (WHO, 1986). Ammonia may be present in drinking-water as a result of disinfection with chloramines. Taste and odour problems as well as decreased disinfection efficiency are to be expected if drinking-water containing more than 0.2 mg/L ammonia is chlorinated, since up to 68% of the chlorine may react with the ammonia and become unavailable for disinfection (WHO, 1996).

The presence of elevated ammonia levels in raw water may interfere with the operation of manganese-removal filters because too much oxygen is consumed by nitrification, resulting in mouldy, earthy-tasting water. The presence of the ammonium cation in raw water may result in drinking-water containing nitrite as the result of catalytic action or the accidental colonization of filters by ammonium-oxidizing bacteria (WHO, 1996).Ammonia has a toxic effect on humans when the intake becomes higher than the capacity to detoxify. If ammonia is administered in the form of its ammonium salts, the effects of the anion must also be taken

into account. With ammonium chloride, the acidotic effects of the chloride ion seem to be of greater importance than those of the ammonium ion (WHO, 1986). At a dose of more than 100 mg/kg of body weight per day, ammonium chloride influences metabolism by shifting the acid–base equilibrium, disturbing the glucose tolerance, and reducing the tissue sensitivity to insulin (USEPA, 1989).

2.2.14 Odour

Odour is recognized as a quality factor affecting acceptability of drinking water and food prepared from it, tainting of fish and other aquatic organisms as well as aesthetics of recreational waters. Most organic and some inorganic chemicals such as salts of iron, copper and zinc contribute to taste or odour. Blue-green algae and actinomycetes also contribute taste and odour to water (AWWA, 2007). These chemicals may originate from municipal and industrial waste discharges, natural sources, such as decomposition of vegetation or from associated microbial activity (CAWST, 2009).

2.2.15 Colour

Colour in water may be due to the inorganic ions, such as Fe^{2+} and Mn^{2+}, humus and peat materials, plankton, weeds and industrial wastes. The term colour is used to mean the true colour of water from which turbidity has been removed. The term apparent colour includes not only the colour due to substances in solution but also that due to suspended matter. Apparent colour is determined on the original sample without filtration or centrifugation (CAWST, 2009).

2.3 PROPERTIES OF SOME COMMON METALS FOUND IN WATER

Metals such as copper, selenium, and zinc are essential metabolic components at trace concentrations. However, some metals tend to bioaccumulate in tissues and prolonged exposure of low concentrations or exposure at higher concentrations can lead to illness (Abdul Aziz et al., 2010; Taghinia et al., 2010). Human activities such as mining and heavy industry can result in higher concentrations of metals in water than those that would be found naturally. Metals tend to be strongly associated with sediments in water bodies and their release to the surrounding water is largely a function of pH, oxidation-reduction state, and organic matter content of the water (Hiller et al., 2010). Metals in water can pose serious threats to human health. In particular, arsenic (a semi-metallic element which occurs naturally in some surface and ground water sources) may lead to development of skin lesions and cancer in people exposed to excess concentrations (UNEP, 2008).

2.3.1 Copper

Copper is found in surface water, groundwater and in seawater primarily in complexes or as particulate matter (ATSDR, 2002). Copper enters the water system through dissolution of minerals that contain copper, industrial effluents and through corrosion of copper alloy used as water distribution pipes. Dissolved copper can sometimes impart a light blue or blue-green colour and an unpleasant metallic bitter taste to drinking water (Zacarias et al., 2001). The test for copper in water is essential because dissolved copper salts even in low concentrations are poisonous to some biota.

Desirable limit for copper in potable water is 0.05 mg/L maximum which can be relaxed in the absence of better alternate source to 1.5 mg/L. Copper concentrations in natural surface waters ranged from 0.0005 to 1 mg/L in several studies in the USA (ATSDR, 2002).Copper

concentrations in drinking-water vary widely as a result of variations in water characteristics, such as pH, hardness and copper availability in the distribution system.Copper concentrations in drinking-water often increase during distribution, especially in systems with an acid pH or high-carbonate waters with an alkaline pH (US EPA, 1995).

Individuals ingesting large doses of Cu develop gastrointestinal bleeding, haematuria, intravascular haemolysis, methaeglobinaemia, hepatocellular toxicity, acute renal failure and oliguria (Agarwal at al., 1993). At lower doses, copper ions can cause symptoms typical of food poisoning such as headache, nausea, vomiting and diarrhoea.

2.3.2 Manganese

Manganese is an element essential to the proper functioning of both humans and animals, as it is required for the functioning of many cellular enzymes e.g. pyruvate carboxylase. Manganese can also activate many other enzymes. The most environmentally and biologically important manganese compounds are those that contain Mn^{2+}, Mn^{4+} or Mn^{7+} (USEPA, 1994). Manganese occurs widely in many surface and ground water sources and in soils that may erode into these waters. However, human activities are also responsible for much of the manganese contamination in water in some areas. ATSDR (2000) reported that a river water survey in the USA found dissolved manganese levels ranging from <11 to >51 µg/L. Higher levels in aerobic waters are usually associated with industrial pollution. Similarly, manganese is detected in about 97 % of surface water sites and universally in sediments and tissues of aquatic biota. The levels are far below those likely to cause health effects and suggest that manganese does not bioaccumulate (USEPA, 2002).

Adverse health effects can be caused by inadequate intake or overexposure. Neurological effects of inhaled manganese have been well documented in humans chronically exposed to elevated levels in the workplace (Roels et al., 1999; ATSDR, 2000). The syndrome known as "manganism" is caused by exposure to very high levels of manganese dusts or fumes and is characterized by a "Parkinson-like syndrome", including weakness, anorexia, muscle pain, apathy, slow speech, monotonous tone of voice, emotionless "mask-like" facial expression and slow, clumsy movement of the limbs. In general, these effects are irreversible (WHO, 1996).

2.3.3 Iron

Iron is commonly found in nature in the form of its oxides (Elinder, 1986).In drinking-water supplies, iron(II) salts are unstable and are precipitated as insoluble iron(III) hydroxide, which settles out as a rust-coloured silt. Iron is an essential element in human nutrition. Estimates of the minimum daily requirement for iron depend on age, physiological status, sex and iron bio-availability and range from about 10 to 50 mg/day (FAO/WHO, 1988).

Although iron is of little concern as a health hazard it is still considered as a nuisance in excessive quantities. The average lethal dose of iron is 200–250 mg/kg of body weight, but death has occurred following the ingestion of doses as low as 40 mg/kg of body weight (NRC, 1979). Chronic iron overload results primarily from a genetic disorder characterized by increased iron absorption (Bothwell, 1979). High concentration of iron in water is not suitable for processing of food, beverages, dyeing, bleaching and many other items. Water with high concentration of the iron when used in preparation of tea and coffee, interacts with tanning giving a black inky appearance with a metallic taste (Colter and Mahler, 2006).

2.3.4 Aluminium

Aluminium is released to the environment mainly by natural processes. Several factors influence aluminium mobility and subsequent transport within the environment. These include chemical speciation, hydrological flow paths, soil–water interactions, and the composition of the underlying geological materials (ATSDR, 1992). Acid environments caused by acid mine drainage or acid rain can cause an increase in the dissolved aluminium content of the surrounding waters (ATSDR, 1992; WHO, 1997). Where residual concentrations are high, aluminium may be deposited in the distribution system. Disturbance of the deposits by change in flow rate may increase aluminium levels at the tap and lead to undesirable colour and turbidity (WHO, 1996). Concentrations of aluminium at which such problems may occur are highly dependent on a number of water quality parameters and operational factors at the water treatment plant.

Concentration of aluminium in natural waters can vary significantly depending on various physicochemical and mineralogical factors. Dissolved aluminium concentrations in waters with near-neutral pH usually range from 0.001 to 0.05 mg/L but rise to 0.5–1.0 mg/L in more acidic waters or water rich in organic matter (WHO, 1997). Aluminium levels in drinking-water vary according to the levels found in the source water and whether aluminium coagulants are used during water treatment. There is little indication that aluminium is acutely toxic despite its widespread occurrence in drinking water and many antacid preparations (WHO, 1997).

2.3.5 Potassium

Potassium occurs widely in the environment, including all natural waters. It can also occur in drinking water if potassium permanganate is used as an oxidant in water treatment. Although

concentrations of potassium normally found in drinking-water are generally low and do not pose health concerns, the high solubility of potassium chloride and its use in treatment devices such as water softeners can lead to significantly increased exposure (Health Canada, 2008). Data from Canada indicate that average concentrations of potassium in raw and treated drinking water in different areas vary between <1.0 and 8.0 mg/L. However, concentrations ranged up to 51.0 mg/L in Saskatchewan, which is the largest production area for potassium chloride in Canada (Health Canada, 2008).

Adverse health effects due to potassium consumption from drinking-water are unlikely to occur in healthy individuals. Potassium intoxication by ingestion is rare, because potassium is rapidly excreted in the absence of pre-existing kidney damage and because large single doses usually induce vomiting (Gosselin et al., 1984). Case-studies of toxicity resulting from high doses of salt substitutes have described chest tightness, nausea and vomiting, diarrhoea, hyperkalaemia, shortness of breath and heart failure (Wetli and Davis, 1978).

2.3.6 Zinc

Zinc occurs in small amounts in almost all igneous rocks and imparts an undesirable astringent taste to water (Elinder, 1986).Water containing zinc at concentrations in the range 3.0–5.0 mg/L also tends to appear opalescent and develops a greasy film when boiled (Cohen et al., 1960).In natural surface waters, the concentration of zinc is usually less than 10 µg/L, and in groundwaters, 10–40 µg/L (Elinder, 1986). In tapwater, the zinc concentration can be much higher as a result of the leaching of zinc from piping and fittings (Nriagu, 1980). The most corrosive waters are those of low pH, high carbon dioxide content, and low mineral salts content.

Acute toxicity arises from the ingestion of excessive amounts of zinc salts, as an emetic or dietary supplement. Vomiting usually occurs after the consumption of more than 500 mg of zinc sulphate. Mass poisoning has been reported following the drinking of acidic beverages kept in galvanized containers; fever, nausea, vomiting, stomach cramps, and diarrhoea occurred 3–12 h after ingestion (Jackson et al., 1988). Food poisoning attributable to the use of galvanized zinc containers in food preparation has also been reported; symptoms occurred within 24 h and included nausea, vomiting, and diarrhoea, sometimes accompanied by bleeding and abdominal cramps (Elinder, 1986).

2.3.7 Chromium

In water, chromium forms hydroxides and some complexes, and is adsorbed at relatively high pH. The ratio of Cr^{3+} to Cr^{6+} varies widely, and relatively high concentrations of Cr^{6+} can be found in surface waters. In general, Cr^{6+} salts are more soluble than those of Cr^{3+}, making Cr^{6+} relatively mobile (Slooff W et al., 1989). Total chromium content of natural surface waters is approximately 0.5–2.0 µg/L and the dissolved chromium content 0.02–0.30 µg/L (Slooff W et al., 1989).

Ingestion of 1–5 g of chromium salts results in severe acute effects such as gastrointestinal disorders, haemorrhagic diathesis, and convulsions. Death may occur following cardiovascular shock (Janus, 1990).In some occupational studies, increased incidences of genotoxic effects such as chromosomal aberrations and sister chromatid exchanges have been found in workers exposed to Cr^{6+} compounds (Janus, 1990). An association has been found between occupational exposure to Cr^{6+} compounds and mortality due to lung cancer. On the basis of these studies, it has been concluded that there is sufficient evidence of respiratory carcinogenicity in humans exposed to Cr^{6+} in these occupational settings (IARC, 1990).

2.4 WATER TREATMENT

2.4.1 History of water treatment

The importance of good drinking water in maintaining health was recognised early in history. However, it took centuries before people understood that their senses alone were not adequate for judging water quality. The earliest water treatments were based on filtering and driven by the desire to remove the taste and appearance of particles in water (USEPA, 2000). Filtration was established as an effective means of removing particles from water and widely adopted in Europe during the nineteenth century. Exactly why a clean and reliable water supply was needed, apart from looking and tasting better, was not understood until the second half of the nineteenth century. That was when the nature of infectious disease was recognised and the ability of water supplies to transmit diseases such as cholera and typhoid was first demonstrated (USEPA, 2000).

After this, concerns about the quality of drinking water were focused on disease-causing microorganisms (pathogens) in public water supplies. Scientists discovered that visible cloudiness, or turbidity does not only make the water look unappealing, it could also indicate a health risk. The turbidity was caused by particles in water that could harbour pathogens. As a result, drinking water treatment systems were designed to reduce turbidity, thereby removing pathogens that were causing typhoid, cholera and other waterborne illnesses (USEPA, 2000).

2.4.2 Descriptive Procedure of Water treatment at the Owabi Headworks

The treatment of drinking water by the Owabi Headworks involves a few key steps as presented in Scheme 2.1:

Aeration: The water from the reservoir flows into rapid lift mixers that thoroughly mix water treatment chemicals to liberate dissolved gases and to settle suspended particles in the water column.

Flocculation: The materials and particles present in drinking water (clay, organic material, metals, microorganisms) are often quite small and so will not settle out from the water column without assistance. To help the settling process along, "coagulating" compounds (aluminium sulphate) are added to the water, and suspended particles "stick" to these compounds and create large and heavy clumps of material.

Sedimentation: The water is left undisturbed to allow the heavy clumps of particles and coagulants to settle out.

Filtration: The water is run through a series of filters which trap and remove particles still remaining in the water column. Typically, the filters have an under drain system covered by graded gravel, several inches of fine sand, topped with over two feet of granular activated carbon. The granular activated carbon not only filters but also removes taste and odours and other organic compounds by adsorption.

Disinfection: The water, now largely free of particles and microorganisms, is treated to destroy any remaining disease-causing organisms. This is commonly done with dichlorine. The water is now safe to drink and is sent to pumping stations for distribution to homes and businesses.

Scheme 2.1

Diagrammatic representation of the water treatment process at the Owabi Headworks.

RESERVOIR

Water from the reservoir is channelled through pipes to the aeration area.

1 →

AERATION AREA

Water exposed to air to remove odour. Aluminium sulphate is added to the water to effect flocculation.

2 ↓

SEDIMENTATION TANK

The 'Floc' settles to the bottom of the tank

← 3

FLASH MIXER

The water seeded with the aluminium sulphate is stirred thoroughly to allow effective flocculation.

4 ↓

FILTER BED

Water now passes through the filter bed where particles and some pathogens are removed from the water.

5 →

DISINFECTION TANK

Chlorine is added to water to kill disease causing organisms left in the water.

6 ↓

PUMPING STATION

Water is pumped through distribution network to consumer end.

3.0 MATERIALS AND METHODS

3.1 STUDY AREA

The Owabi reservoir 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. The main river is the Owabi river with seven other

tributaries coming together to form the reservoir. The average area of the entire reservoir is

35 m^2 with average depth of 6.86 m when spilling. It has a capacity of 13.7 billion gallons of

water. The Owabi reservoir (Fig 3.1) is designed to produce 20% of the total potable water

requirement in the Kumasi metropolis and nearby townships (Akoto et al., 2010).

Fig 3.1 The Owabi Reservoir.

A water treatment plant is built near the reservoir and it provides about 3 million gallons of

potable water to the Kumasi Metropolis per day. The surround land of the study area can be

demarcated into four categories: agriculture, human settlement, vegetation cover, and water

bodies. The catchment area is densely populated because of rapid urbanization and

agricultural growth 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., 2010).

3.2 WATER SAMPLING

Samples were collected from the reservoir (RSV), sedimentation tank (MDT), filtered water tank (MDT1), disinfected water (AFT) and from distribution points (DST) of consumers every month for a period of five months, between December, 2011and April, 2012. Pictures of sampling locations are shown in Fig 3.2. Water samples were collected with plastic containers previously cleaned by washing with non-ionic detergents then rinsed with tap water and later soaked in 10% HNO_3 for 24 hours and finally rinsed with de-ionized water prior to usage. They were then air dried. Sample containers at the point of sampling were rinsed with sample water three times before filling. The samples were labelled, stored in an ice-box and transported to the laboratory. They were stored in the refrigerator at about 4°C prior to analysis. Water samples for bacteriological analysis were collected into stopper pre-sterilized 500 ml glass bottles to protect the samples from contamination. Bacteria test on samples were conducted within six hours after sampling. All samples were kept in a cool box (8-10°C) immediately after collection and transported to the Ghana Water Company Laboratory on the same day.
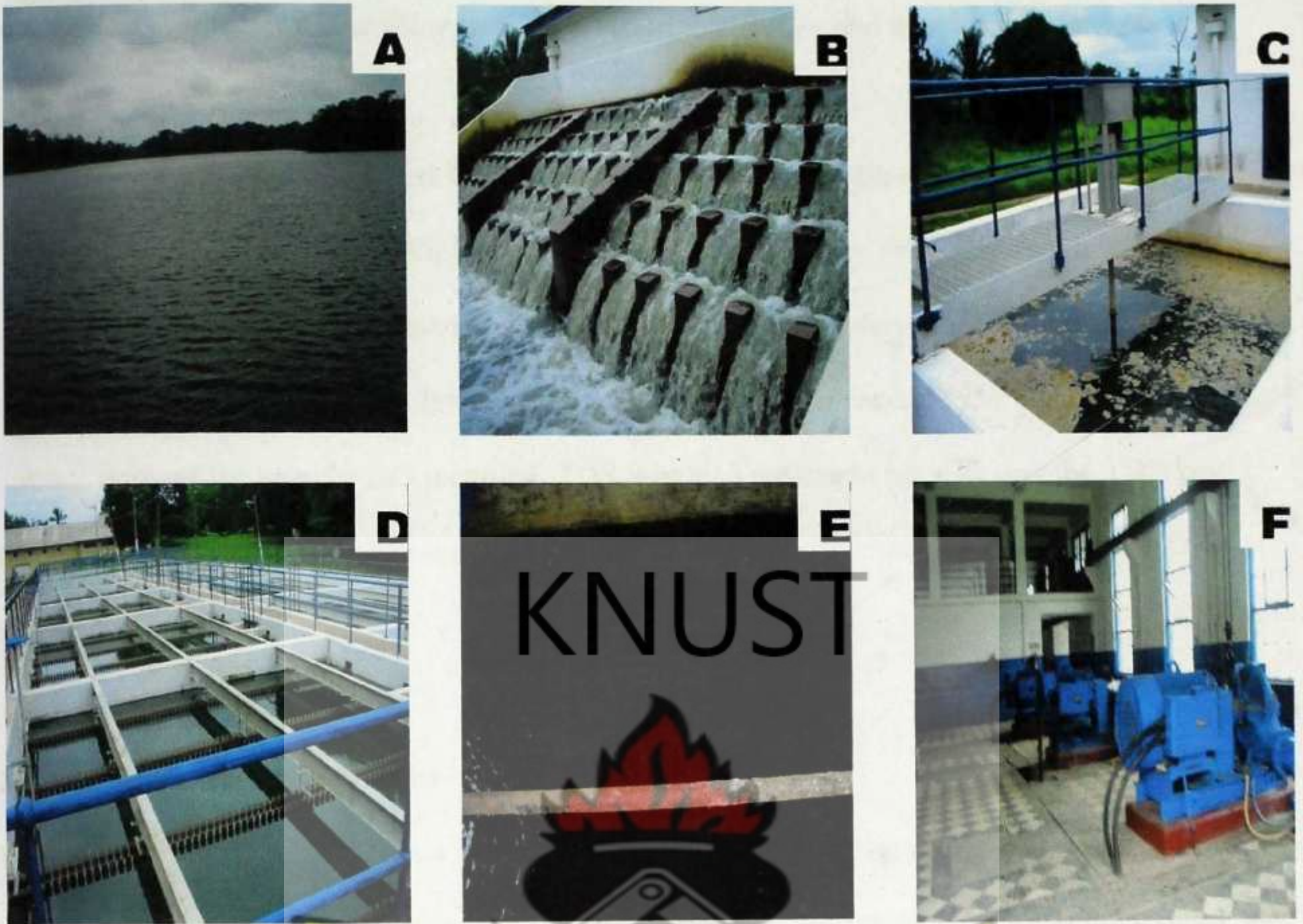
Fig 3.2 sampling locations showing: (A) the reservoir, (B) aeration area (C) Coagulant mixer

(D) sedimentation tank (E) filter bed and (F) pumps pumping chlorinated water.

3.3 MEASUREMENT OF PHYSICO-CHEMICAL PARAMETERS

Non conservable (unstable) parameters such as pH, TDS, temperature, turbidity and electrical

conductivity were determined at the sampling point.

3.3.1 Measurement of pH

The pH meter (Model 3150 JENWAY) was calibrated by immersing the electrode in two

buffer solutions of pH 4.01 and 7.00 prepared from capsules of BDH buffer. The pH meter

was adjusted to correspond to the standard buffers (4.01 and 7.00). The water sample was

placed in a beaker and the electrode of the pH meter was rinsed with distilled water and

lowered into the sample. The pH meter was allowed to stabilize and the pH of the sample was read.

3.3.2 Measurement of Electrical Conductivity (EC) and Total Dissolved Solids (TDS):

These were measured with a digital conductivity meter with a cell constant of 1.0. The instrument was kept clean and standardized with KCl solution before use. The electrode was rinsed with distilled water and lowered into the sample in the beaker. The conductivity in μScm^{-1} units of the sample was recorded. TDS was also measured by selecting the TDS key while the electrode remained in the water sample used to measure conductivity and the TDS value was recorded in mg/L.

3.3.3 Measurement of Turbidity

Values were taken using Hanna instrument; LP 2000 turbidimeter. The turbidimeter was calibrated with the 1000, 100, 10 and 0.02 NTU standards. The cuvette was rinsed three times with the samples to be tested. The light shield cap was replaced and all outside surfaces cleaned and made dry. The cuvette was pushed firmly into the optical well and index to the lowest reading. The NTU values were measured by pressing and releasing the arrow button and the value recorded.

3.3.4 Measurement of Total Hardness:

EDTA Titrimetric method was used to determine the total hardness in the samples. Determination of total hardness was carried out by measuring 50 mL of the water sample into a 250 mL conical flask. About 4 mL of ammonium chloride in concentrated ammonia as the buffer solution and 6 drops of Erichrome black T indicator solution were added prior to titration. The content in the conical flask was titrated against 0.01 M EDTA to the endpoint

indicated by a distinct colour change from violet to blue colouration. Titration was repeated for consistent titre values from which an average titre was calculated (APHA, 1992).

$$\text{Total Hardness in mg/L } CaCO_3 = \frac{\text{vol of EDTA} \times M \times 1000}{\text{vol of sample}}$$

Where M = Molarity of EDTA used.

3.3.5 Measurement of Calcium (Ca)

EDTA Titration Method was used to determine calcium hardness in the sample. Two millilitres (2.0 mL) of 1 M NaOH was added to 50 mL of the sample. The mixture was stirred and 0.1 g of murexide (ammonium purpurate) indicator was added to it. Titration was done immediately after the addition of the indicator. EDTA titrant was slowly added with continuous stirring until the colour changed from pink to purple. The end point was checked by adding 2 drops of titrant in excess to make sure that no further colour change occurred (APHA, 1992).

The value was calculated using the formula:

$$Ca \ (mg/L) = \frac{A \times B \times 400.8}{\text{vol of sample}}$$

Where A = volume of EDTA titrant used

$$B = \frac{\text{vol of standard calcium solution}}{\text{Volume of EDTA}}$$

3.3.6 Measurement of Magnesium (Mg)

Calcium and total hardness were determined by EDTA titration method. Magnesium hardness was calculated from the difference between the total hardness and the calcium hardness

which is expressed in mg/L. The magnesium concentration was obtained by multiplying magnesium hardness by 0.243.

Mg (mg/L) = magnesium hardness × 0.243

3.3.7 Measurement of Alkalinity

This was determined by measuring 50 ml water sample in to a conical flask. 2 drops of phenolphthalein indicator was added and the resulting mixture titrated against a standard 0.10 M H_2SO_4 solution until the pink colour disappeared. The burette reading was recorded and three drops of methyl orange indicator was added to the solution and titrated against the standard 0.10 M H_2SO_4 solution to the first permanent pink colour at pH 4.5 (APHA, 1992). Alkalinity was then calculated using the formula:

$$\text{Alkalinity (mg/L)} = \frac{V \times M \times 1000}{\text{vol of sample}}$$

Where V = volume of acid used

M = molarity of H_2SO_4

3.3.8 Measurement of Chloride

The Argentometric method was used to determine the chloride concentration in the sample. 50 mL of water sample was pipetted into a 250 mL conical flask. 1 mL of 0.25 M potassium chromate (K_2CrO_4) was added to the conical flask. Water sample was titrated against the standard $AgNO_3$ solution slowly while swirling gently until the colour changed from yellow to brick-red. Blank (distilled water) was titrated using the same procedure. Volume of $AgNO_3$ for the blank was subtracted from the average volume of sample. This volume was used to determine the concentration of chloride ion in the water sample.

The value was calculated using the formula

$$Cl^- \text{ (mg/L)} = \frac{(A-0.2) \times M \times 35.450}{\text{vol of sample}}$$

Where A = titre value

M = molarity of $AgNO_3$

3.3.9 Measurement of Sulphate, Phosphate, Nitrate, Ammonia, and Fluoride

The Palintest Photometer method was used to determine the concentration of SO_4^{2-}, PO_4^{3-}, NO_3^-, NH_3 and F^- in the water sample. Analytical water test tablets (photometer grade) reagents for specific test were used for the preparation of all sample solutions. The samples were allowed to stand for the colour to develop. The tablets were added to the samples to form complexes with the analyte which impart colour to the samples. The required wavelength for the specific test was selected by moving the slide control. Distilled water was used to zero the instrument. The ON button was pressed and kept depressed until the display reads 100 (100% T). The sample was immediately submitted to the instrument to read the % transmittance. The displayed reading was taken to a calibration chart from which the concentration of the analyte was determined from the read % transmittance.

3.3.10 Measurement of Nitrite

Colourimetric method was employed in the determination of the nitrite concentration in the samples. 50 mL of the water sample was measured into an conical flask and 2 mL each of Griess-Ilosvay's solution No. 1 and Solution No. 2 were added to the sample. The mixture was swirled gently and allowed to stand for fifteen (15) minutes. The mixture was transferred into a Nesseler's tube. The colour was compared with the standard colours of the nitrite disc. The value of the matching colour was read using the nitrite disc and comparator. The Ilosvay's solution No. 1 is prepared from 0.5 g sulphanilic acid, 30 mL glacial acetic acid and 120 mL distilled water whereas the solution No. 2 is prepared from 0.1 g of α-Naphthylamine, 30 mL glacial acetic acid, and 120 mL distilled water.

3.4 METAL ANALYSIS

The Palintest Photometer (5000) was used in the determination of metals (Cr, Mn, Cu, Zn, K, Al and Fe) concentrations. Analytical water test tablets (photometer grade) reagents for specific test were used for the preparation of all sample solutions. The samples were allowed to stand for the colour to develop. The tablets were added to the samples to form complexes with the analyte which impart colour to the water. The required wavelength for the specific test was selected by moving the slide control. Distilled water was used to zero the instrument. The ON button was pressed and kept depressed until the display reads 100 (100% T).The sample was immediately submitted to the instrument to read the % transmittance. The displayed reading was taken to a calibration chart from which the concentration of the analyte is determined from the read % transmittance.

3.5 MEASUREMENT OF BACTERIOLOGICAL PARAMETERS

The Most Probable Number method was used to determine Total Coliform and Faecal Coliform in the samples (APHA, 1999).

3.5.1 Measurement of Total Coliform

Serial dilutions of the water samples of 10^{-1} to 10^{-5} were prepared by measuring 1 mL of the sample into 9 mL sterile distilled water. One millilitre aliquots from each of the dilutions were inoculated into 5 mL of MacConkey Broth with inverted Durham tubes and incubated at 35°C for total coliform for 18 – 24 hours. Tubes showing colour change from purple to yellow and gas collected in the Durham tubes after 24 hours were identified as positive for Total Coliform. Counts per 100 mL were calculated from Most Probable Number (MPN) tables (APHA, 1999).

3.5.2 Measurement of Faecal Coliform

Serial dilutions of the water samples of 10^{-1} to 10^{-5} were prepared by measuring 1 mL of the sample into 9 mL sterile distilled water. One millilitre aliquots from each of the dilutions were inoculated into 5 mL of MacConkey Broth with inverted Durham tubes and incubated at 44°C for total coliform for 18 – 24 hours. Tubes showing colour change from purple to yellow and gas collected in the Durham tubes after 24 hours were identified as positive for Faecal Coliform. Counts per 100 mL were calculated from Most Probable Number (MPN) tables (APHA, 1999).

3.6 Statistical Analysis

The raw data (Appendix 1) were statistically analysed using the SPSS version 16 and the OriginPro 8 software applications. The statistical analysis was done in three parts: I. part one seeks to establish whether the data taken at different times from the same sampling points within the study period differ significantly; II. part two performs tests to establish whether significant differences existed between the means for the different sampling points; III. part three is the graphical analysis and correlations of the parameters that were measured for water quality. The statistical tool used is the one way analysis of variance (ANOVA). ANOVA was performed for the 29 parameters that were measured for water quality to check if significant differences exist (Appendix 2 and 3). The ANOVA is a technique that allows statisticians to compare two or more independent data. The procedure works by analyzing the variances of the populations in question, hence the name. Thus the technique analyze the variance of the data to determine whether it can be inferred that the population means differ.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 PHYSICO-CHEMICAL CHARACTERISTICS

The mean, standard error of the mean and the range of the physico-chemical parameters measured in the water samples at the different treatment points are presented in Table 4.1. The treatment points where water samples were collected are: Reservoir (RSV), settling tank (MDT), filtered tank (MDT 1) Chlorinated tank (AFT) and distribution point (DST)

The raw water had a mean pH of 7.14 ± 0.16. This is slightly higher than the pH observed for the settled and filtered water which had mean values of 6.85 ± 0.09 and 6.80 ± 0.13 respectively. The pH increased slightly from the filtered water to the treated and the distributed water which recorded mean pH values of 6.88 ± 0.134 and 6.92 ± 0.11 respectively. Even though there were slight changes in pH as the water moved through the various treatment points, these changes were not statistically significant ($p > 0.05$). This shows that the various treatment procedures do not impact significantly on the pH. The pH of the treated water in the distribution chamber falls within the WHO value of $6.5 - 8.5$ recommended for drinking water (WHO, 2004). The changes in pH may be due to the aluminium sulphate added to effect flocculation. The aluminium sulphate is an acid salt and reacts with the alkalinity present in the water to lower the pH.

Table 4.1: The mean, standard error of the mean and the range of the physico-chemical properties of the water samples from the OwabiHeadworks. n = 5

PARAMETERS		RSV	MDT	MDT 1	AFT	DST	WHOVALUE
pH	Mean ± S.E	7.14±0.16	6.85±0.08	6.80±0.13	6.88±0.134	6.92±0.11	6.5-8.5
	Range	6.8-7.74	6.59-7.13	6.48-7.14	6.60-7.37	6.61-7.58	
Temperature (°C)	Mean ± S.E	26.62±0.48	26.28±0.62	26.52±0.58	26.62±0.61	26.53±0.33	-
	Range	25.7-28.4	25.1-28.6	25.0-28.6	25.5-28.9	25.7-28.5	
Colour (Hz)	Mean ± S.E	66.80±16.71[a]	59.20±24.77	12.60±2.82[b]	16.20±3.43	15.30±3.13[c]	15
	Range	30-115	17-150	7-22	7-26	0-30	
Turbidity (NTU)	Mean ± S.E	6.30±1.96[a]	3.77±0.53	1.01±0.16[b]	1.10±0.17[c]	0.95±0.20[d]	5
	Range	2.66-13.89	1.82-4.77	0.56-1.52	0.63-1.59	0.33-2.05	
Conductivity (µS/cm)	Mean ± S.E	324.40±17.98	328±22.98	327.40±19.69	329.60±22.08	331.90±13.48	1000
	Range	277-365	256-368	265-375	258-371	263-379	
TDS	Mean ± S.E	196.60±11.36	199.22±14.74	198.54±12.54	201.26±14.33	202.03±8.62	1000
	Range	166.2-219	153.6-225	159-223	154.8-230	157.8-230	
TSS	Mean ± S.E	7.60±3.23[a]	6.00±2.40	1.40±0.93	1.60±0.40	1.10±0.28[b]	-
	Range	3-20	2-15	0-5	1-3	0-2	
Total Hardness	Mean ± S.E	81.20±2.06	88.00±8.10	86.40±4.83	86.40±2.48	90.00±3.27	500
	Range	76-88	76-120	76-100	80-92	80-114	
Calcium Hardness	Mean ± S.E	75.20±1.86	72.40±3.37	73.60±4.21	65.40±1.78	72.20±2.93	-
	Range	70-80	64-84	62-88	60-70	58-84	
Magnesium hardnesss	Mean ± S.E	6.00±2.09	15.60±5.67	12.80±3.67	21.00±3.74	17.80±4.58	-
	Range	2-12	6-26	6-26	10-32	6-56	
Alkalinity	Mean ± S.E	138.60±4.26[a]	121.80±5.39	106.80±6.56[b]	105.60±6.97[c]	103.40±5.52[d]	200
	Range	126-150	102-132	88-120	82-120	72-128	

*. All parameters are in mg/L except otherwise stated. *. WHO (2004) VALUES

*.a, b, c and d denote different means.

*. S.E = standard error of the mean

The mean water temperatures for the raw, settled, filtered, treated and distributed water were 26.62 ± 0.48 °C, 26.28 ± 0.62°C, 26.52 ± 0.58 °C, 26.62 ± 0.61 °C and 26.53 ± 0.33 °C respectively. There was no significant difference in the temperatures recorded for the water samples ($p > 0.05$). Increased water temperature decreases gas solubility and increases the photosynthetic rate of algae and aquatic plants leading to increased plant growth and algal blooms (UNEP, 2008; Usharani et al., 2010). A change in water temperature can affect the general health of aquatic organisms. In too hot or too cold temperatures, organisms become stressed, lowering their resistance to diseases and pollutants (UNEP, 2008; Deas and Lowney, 2000). The temperature of the raw water (26.62±0.48 °C) is good to support life of the aquatic organisms. Alabaster and Lloyd (1980) reported that temperature of natural inland waters in the tropics generally varies between 25 °C and 35 °C. This agrees well with data reported by Zabbey (2002), between 26.3 °C and 30.4 °C and Ansa (2005), between 25.9 °C and 32.4 °C.

The raw water had a mean colour of 66.80 ± 16.71 Hz. The settled water had a mean colour of 59.20 ± 24.766 Hz. The filtered water recorded a drop in colour with a mean value of 12.60 ± 2.821 Hz, while samples from the treated water and the distribution system recorded mean colour of 16.20 ± 3.43 Hz and 15.30 ± 3.13 Hz respectively. Colour distribution pattern at the various treatment points is represented in Fig. 4.1. There were significant difference between colour of the raw water and that of the treated water ($p < 0.05$). This indicates that colour was significantly reduced to acceptable levels during treatment. Colour was not affected significantly during distribution since no significant variations were recorded between treated samples and samples for the distribution system at $p > 0.05$.
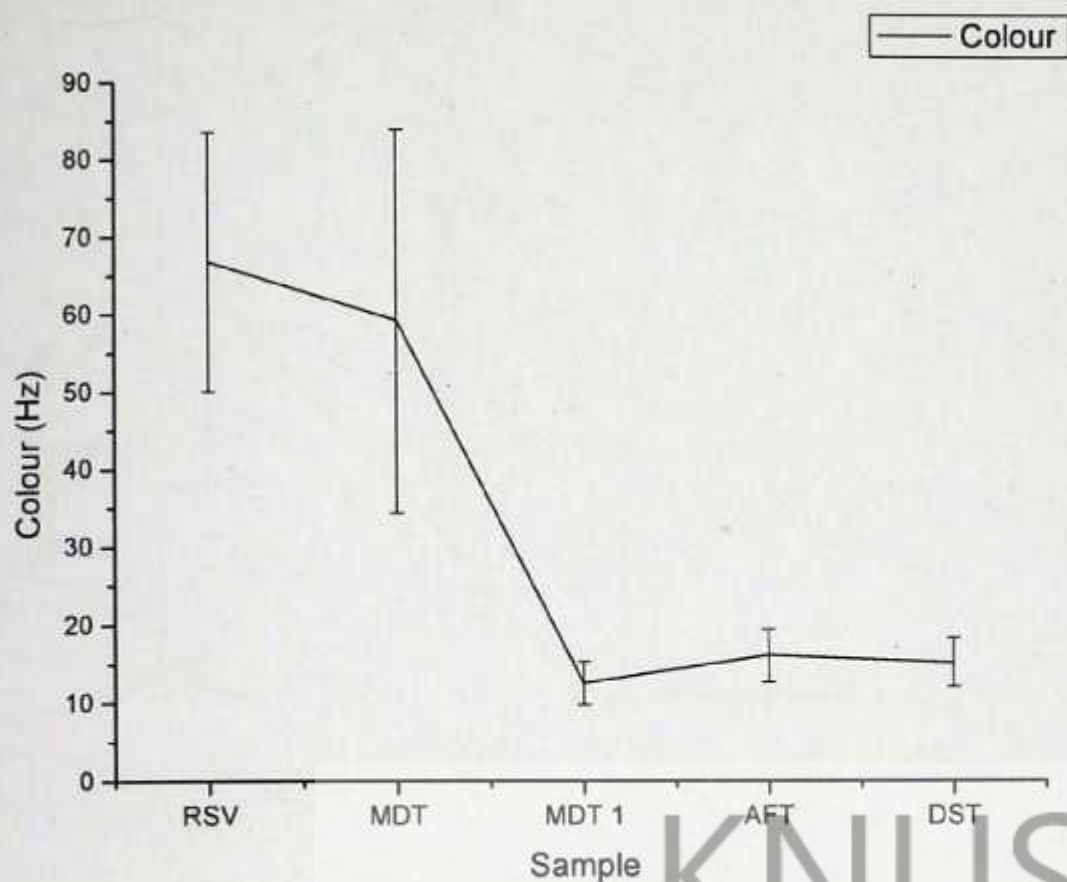
Fig. 4.1 Graph showing the changes in colour at different stages of treatment.

Colour of water is usually due to the presence of inorganic ions, such as iron and manganese, humus and peat materials, plankton and weeds. The flocculation, sedimentation and filtration processes resulted in the reduction of colour in the samples.

Mean turbidity values were 6.30 ± 1.96 NTU, 3.77 ± 0.53 NTU, 1.01 ± 0.157 NTU, 1.10 ± 0.16587 NTU and 0.9540 ± 0.199 NTU for the raw, settled, filtered, treated and distributed water respectively. The turbidity changed significantly from the raw water to the filtered water ($p < 0.05$) as presented in Fig. 4.2. The processes of flocculation, sedimentation and filtration reduced significantly the turbidity of the raw water to acceptable levels as prescribed by WHO (2004).
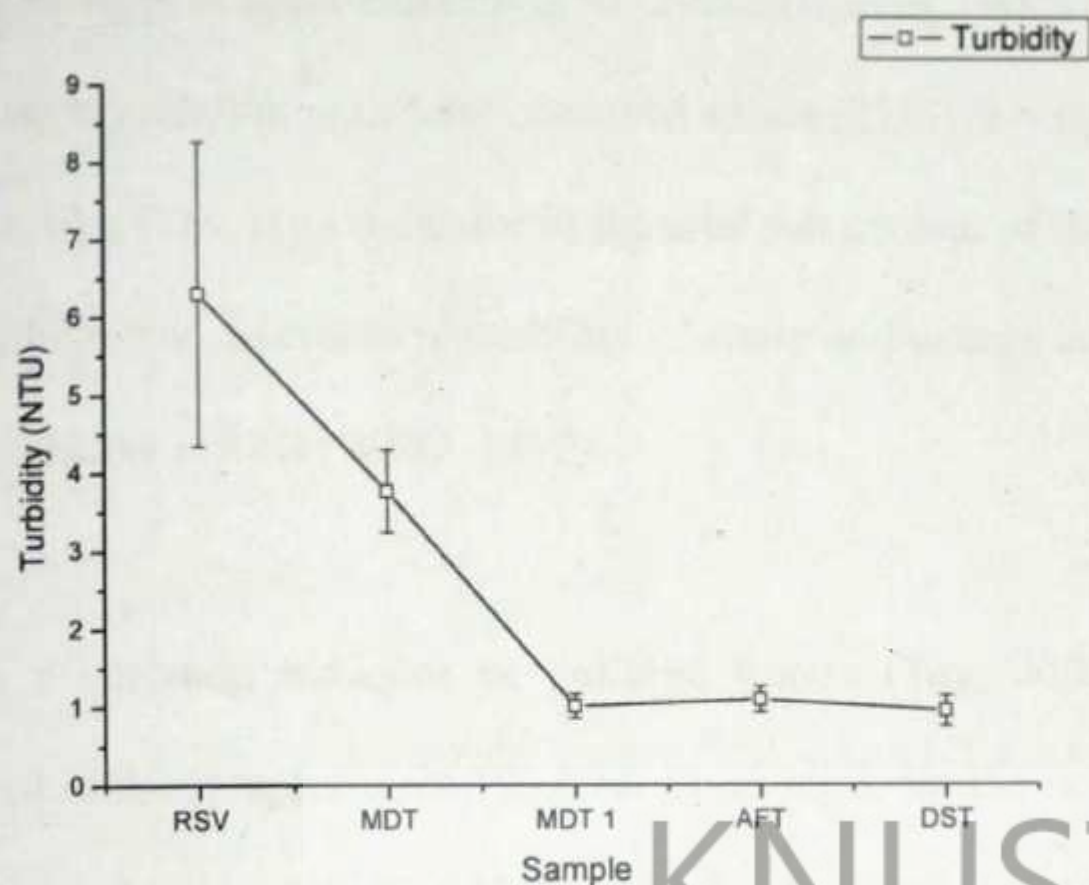
Fig. 4.2 Graph showing changes in turbidity during treatment at the different sampling sites.

Excessive turbidity in water causes problems with water purification processes and leads to an increase in treatment cost (DWAF, 1998). Turbid water is often associated with the possibility of microbial contamination as high turbidity makes it difficult to disinfect water properly (DWAF, 1998), because the adsorptive characteristics of some colloidal materials and solids may partly shield organisms from disinfection. Soil erosion and run-off from the catchments could be the source of high turbidity in the raw water. There was no significant change in turbidity from the treated water to distributed water ($p > 0.05$).

Electrical conductivity recorded mean values of 324.40 ± 17.98 µS/cm, for the raw water. The settled water had a mean EC of 328 ± 22.98 µS/cm. 327.40 ± 19.69 µS/cm was recorded for the filtered water samples and the treated water had mean EC of 329.60 ± 22.08 µS/cm. The distributed water recorded mean EC of 331.90 ± 13.48 µS/cm. There was no significant change in EC in the water sampled at the different sites (p > 0.05). This means that the treatment processes did not impact significantly on EC. The average value of a typical,

unpolluted river is approximately 350 μS/cm (Koning and Roos, 1999). The change in EC had strong correlation with total dissolved solids (TDS) (r = 0.984) at the 0.01 level. The EC of water, like TDS, is an indicator of the total salt content of the water (Oluyemi et al., 2010). High salt content decreases palatability of water and causes intestinal irritation in humans as well as laxative effects (WHO, 1997).

TDS is a common indicator of polluted waters (Tay, 2007). The mean levels of TDS measured in the samples were 196.60 ± 11.36 mg/L for the raw water, 199.22 ± 14.74 mg/L, for the settled water, 198.54 ± 12.54 mg/L for the filtered water, 201.26 ± 14.33 mg/L for the treated water and 202.03 ± 8.62 mg/L for the distributed water. There were no significant differences in TDS of the different sampling points ($p > 0.05$) and were all within acceptable levels for drinking (WHO, 2004). The values did not exceed the critical value (1000 mg/L) above which some long-term health problems might be anticipated (Kempster et al., 1997). According to MacCutcheon et al. (1983), the palatability of water with TDS level less than 600 mg/L is generally considered to be good, whereas water with TDS greater than 1200 mg/L becomes increasingly unpalatable. Hence, the water from the Headworks could be considered palatable since the mean TDS for the samples in the distribution system were less than 600 mg/L.

Total suspended solids (TSS) are also indicators of pollution. Mean TSS values were 7.60 ± 3.23 mg/L for the raw water, the settled water had mean TSS value of 6.00 ± 2.40 mg/L, 1.40 ± 0.93 mg/L was recorded for the filtered water, 1.60 ± 0.40 mg/L for the chlorinated water and 1.10 ± 0.28 mg/L for the distributed water. The difference in TSS from the raw water to the distributed water is significant ($p < 0.05$) as shown in Fig 4.3. This means that the processes of flocculation, sedimentation, filtration and chlorination impacted significantly on

the water samples. There was a slight increase in TSS after chlorination and this is as a result of the hypochlorite added to the water samples as a disinfectant.
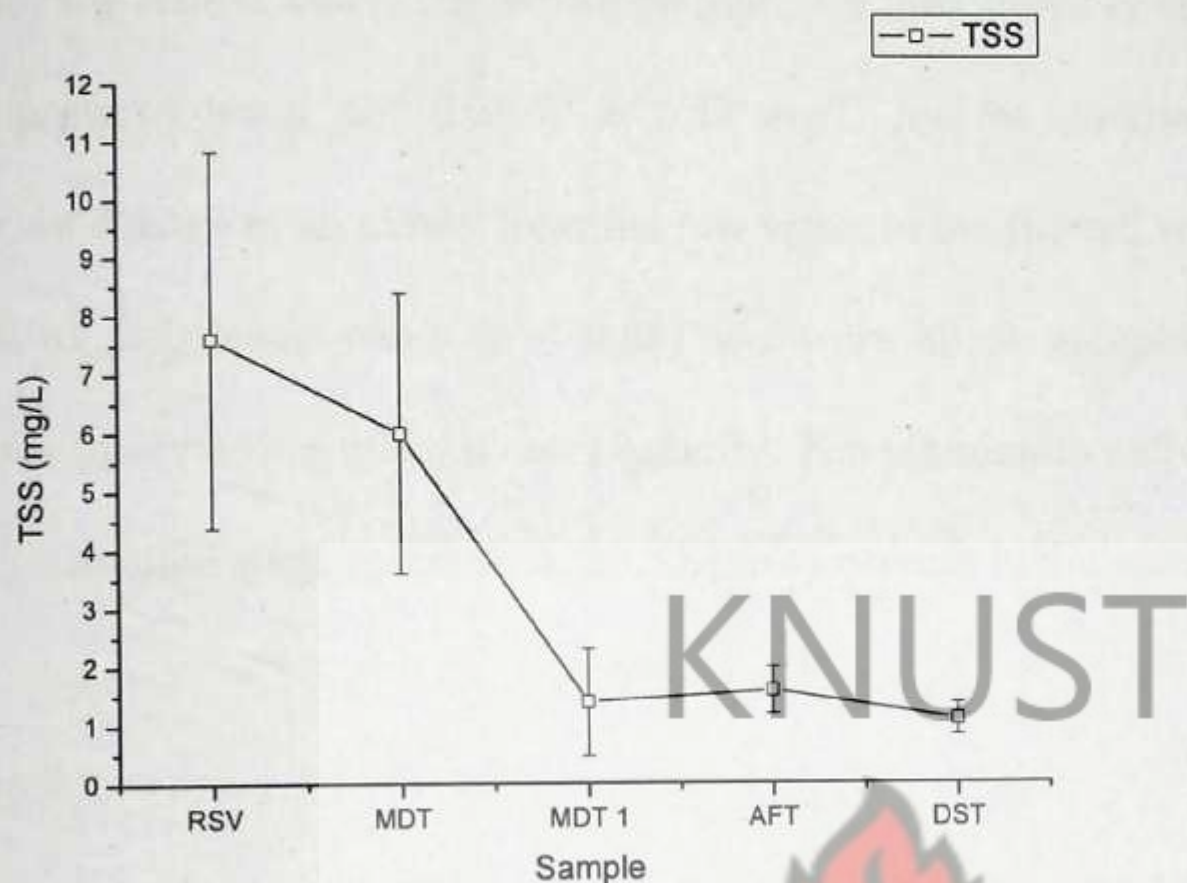
Fig. 4.3 Graph showing changes in TSS at the different sampling points.

It is known that Ca^{2+} and Mg^{2+} along with their carbonates, sulphates and, chlorides naturally confer temporary and permanent hardness (Alexander, 2008). The recommended desirable limit for hardness is 300mg/L and the maximum permissible limit for potable water is 600 mg/L (BIS, 1991), but the World Health Organization (WHO, 2004) recommended safe permissible limit for Total Hardness (TH) is 100 – 500 mg/L. The mean TH values were 81.20 ± 2.06 mg/L for the raw water, 88.00 ± 8.10 mg/L for the settled water, 86.40 ± 4.83 mg/L for the filtered water, 86.40 ± 2.48 mg/L for the chlorinated water and 90.00 ± 3.27 mg/L. There was no significant change in the mean values of TH in the water samples for the different sites (p > 0.05) and were within WHO acceptable levels. Water hardness at concentrations 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, very hard (McGowan, 2000). The results shown in Table 4.1 indicate that the water from the Headworks is moderately hard.

Alkalinity refers to the water's ability to neutralize acids. Highly alkaline waters are usually unpalatable. Mean alkalinity values were 138.60 ± 4.26 for the raw water, 121.80 ± 5.39 mg/L for the settled water, 106.80 ± 6.56 mg/L for the filtered water, 105.60 ± 6.97 mg/L for the chlorinated water and 103.40 ± 5.52 mg/L for the distributed water. There was a significant change in alkalinity from the raw water to the filtered water and chlorinated water as well as distributed water ($p < 0.05$) and were all at acceptable levels. The treatment processes impacted significantly on alkalinity. The aluminium sulphate, an acid salt, added at the sedimentation stage reacts with the alkalinity present in the water and reduces it.

4.2 IONS

The mean, standard error of the mean and range of ions measured in the water samples at the different treatment points are presented in Table 4.2. Ca^{2+} and Mg^{2+} are among the most common ions present in natural waters and they all contribute to water hardness. Ca^{2+} had mean levels of 29.70 ± 0.81 mg/L for the raw water, 30.02 ± 1.30 mg/L for the settled water, 31.68 ± 1.37 mg/L for the filtered water, 26.12 ± 0.81 mg/L for the chlorinated water and 30.09 ± 1.31mg/L for the distributed water. Magnesium on the other hand had mean concentrations of 1.96 ± 0.45 mg/L for the raw water, 4.77 ± 1.33 mg/L for the settled water, 3.74 ± 0.79mg/L for the filtered water, 5.88 ± 0.96mg/L for chlorinated water and 5.54 ± 1.27 mg/L. There was no significant change in the concentrations of Ca^{2+} and Mg^{2+} ($p > 0.05$)which indicate that the processes of water purification employed at the headworks had no significant impact onCa^{2+} and Mg^{2+}contentin the water samples. The filter beds are designed that they do not remove Ca^{2+} and Mg^{2+} from the water samples because they are important ions needed by humans for normal functioning of the human body.

There was no significant difference in the chloride content of all the samples (p > 0.05).This shows the treatment processes had no significant impact on the chloride content of the water samples. The chloride content changed from 28.20 ± 1.46 mg/L for the raw water, 27.80 ± 2.29 mg/L for the settled water, 26.20 ± 2.18 mg/L for the filtered water, 26.20 ± 2.27 mg/L for the chlorinated water to 27.50 ± 1.68 mg/L for the distributed water. The chloride content was lower than the acceptable level (250 mg/L) in all the samples. A high content of chloride gives a salty taste to the water. The limits of chloride have been laid down primarily from taste considerations (BIS, 1991; WHO, 1996). However no adverse health effects on humans have been reported from intake of waters containing even higher concentrations of chloride (Alexander, 2008).

The mean levels of fluoride were 1.23 ± 0.20 mg/L for the raw water, 1.10 ± 0.11 mg/L for settled water, 1.11 ± 0.10 mg/L for filtered water, 1.28 ± 0.18 mg/L for chlorinated water and 1.28 ± 0.16 mg/L for the distributed water. There was no significant change in the mean fluoride levels ($p > 0.05$). The mean levels of fluoride in the water samples were not impacted significantly by the treatment processes. Large amounts of fluoride (above 1.5 mg/L) are associated with dental and skeletal fluorosis whereas low levels below 0.6 mg/L may cause dental caries (BIS, 1991).

The distributed water recorded the highest mean PO_4^{3-} level of 12.88 ± 4.55 mg/L followed by the settled water with a mean level of 11.32 ± 5.05 mg/L. The filtered water had the next highest mean level of 10.34 ± 5.07 mg/L followed by the chlorinated water with a mean level of 9.86 ± 5.35 mg/L and then the raw water with a mean level of 9.21 ± 4.83 mg/L. The differences in the phosphate levels were not significant (P > 0.05) indicating that the purification process did not impact significantly on the PO_4^{3-} levels in the water samples.

Small amounts of PO_4^{3-} are added to the water and this account for the high levels of phosphate in the distribution system. The PO_4^{3-} inhibits corrosion in the water mains and sequesters nuisance metals (Mn, Fe etc) in the water supply. Phosphates can also improve the quality of water in the distribution system by removing scale deposits, discourage microbial film regrowth and stabilizing free chlorine disinfectant residuals.

Table 4.2: The mean, standard error of the mean and the range of the ions in the water samples from the Owabi Headworks. n = 5

PARAMETER		RSV	MDT	MDT 1	AFT	DST	WHO VALUE
Ca	Mean±S.E	29.70±0.81	30.02±1.30	31.68±1.37	26.12±0.81	30.09±1.31	200
	Range	28.0–32.0	27.02–33.6	28.0–35.2	24.0–28.0	23.2–34.0	
Mg	Mean±S.E	1.96±0.45	4.77±1.33	3.74±0.79	5.88±0.96	5.54±1.27	150
	Range	0.49–2.90	1.46–8.75	1.50–6.32	2.40–7.78	1.50–13.60	
Cl	Mean±S.E	28.20±1.46	27.80±2.29	26.20±2.18	26.20±2.27	27.50±1.68	250
	Range	25–33	22–36	18–31	18–32	16–33	
F	Mean±S.E	1.23±0.20	1.10±0.11	1.11±0.10	1.28±0.18	1.28±0.16	1.5
	Range	0.45–1.52	0.65–1.25	0.70–1.23	0.55–1.55	0.30–1.62	
PO_4^{3-}	Mean±S.E	9.21±4.83	11.36±5.05	10.34±5.07	9.86±5.35	12.88±4.55	400
	Range	0.26–27.0	0.20–27.00	0.18–28.00	0.28–30.00	0.34–39.00	
SO_4^{2-}	Mean±S.E	8.00±1.00[a]	46.80±10.69[b]	36.80±7.38	32.00±4.98	33.50±5.65	400
	Range	5–11	16–75	12–57	13–39	10–67	
NO_3^-	Mean±S.E	0.49±0.13	0.42±0.11	0.86±0.22	1.18±0.42	1.54±0.36	50
	Range	0.10–0.88	0.10–0.68	0.08–1.35	0.08–2.33	0.09–3.30	
NO_2^-	Mean±S.E	0.03±0.01	0.02±0.01	0.02±0.01	0.03±0.01	0.07±0.02	3.0
	Range	0.004–0.08	0.004–0.08	0.01–0.06	0.005–0.06	0.016–0.20	
NH_3	Mean±S.E	0.01±0.004	0.01±0.004	0.02±0.01	0.02±0.01	0.01±0.003	1.5
	Range	0.00–0.02	0.00–0.02	0.00–0.05	0.00–0.04	0.00–0.03	
R. Cl	Mean±S.E				1.14±0.42	0.89±0.30	-
	Range				0.09–2.00	0.01–2.00	

*. All parameters are in mg/L except otherwise stated. *. S.E is standard error of the mean

*. a and b denote different means. * Reference values. WHO (2004)

SO_4^{2-} had mean levels of 8.00 ± 1.00 mg/L for the raw water, 46.80 ± 10.69 mg/L for the settled water, 36.80 ± 7.39 mg/L for filtered water, 32.00 ± 4.98 mg/L for chlorinated water and 33.50 ± 5.65 mg/L for the distributed water. There is a significant change in SO_4^{2-} concentration from the raw water to the settled water ($P < 0.05$). This increase is attributed to the aluminium sulphate added to the water to effect flocculation. Water containing magnesium sulphate at levels above 600 mg/L acts as a purgative in humans.

NO_3-N, NO_2-N and NH_4-N are considered to be non-cumulative toxins (Dallas and Day, 1993). High concentrations of NO_3-Nand NO_2-N may serve as potential health risks, particularly in pregnant women and infants under 6 years of age (Kempster et al., 1997). All the samples recorded NO_3-N, NO_2-N and NH_4-N concentrations lower than the WHO permissible limit for drinking water. The results are presented in Table 4.2. The change in nitrate and nitrite concentrations followed a similar pattern; RSV > MDT <MDT 1 < AFT < DST but that of ammonia had a different pattern; RSV < MDT < MDT 1 > AFT > DST. The concentrations of each of NO_3-N, NO_2-N and NH_4-N are not above 2 mg/L at the different sampling points and therefore are not expected to give any taste and odour as well as health problems.

Generally, concentrations of SO_4^{2-}, PO_4^{3-}, NO_3-N, NO_2-N and NH_4-N in the samples were low which could probably be as a result of low runoffs since this work was done in the dry season. Ansa-Asare and Asante (1998) reported that there is a general decrease in the nutrient concentration in the dry season. Of all the nutrients, sulphate had very high concentration followed by phosphate in all the samples. Nutrient concentrations followed the order; Ammonia < Nitrite <Nitrate < Phosphate < Sulphate. The high phosphate concentration can stimulate the rapid growth of photosynthetic algae and cyanobacteria resulting in

eutrophication (Nthumbi et al., 2012) in the Owabi reservoir. The high phosphate level in the reservoir may be attributed to phosphate-rich sewage materials which are dumped into the River from the towns (Akoto et al., 2010). It could also come from drains rich in detergents (Akpabli and Drah, 2001). Eutrophication could increase water treatment cost through filter clogging in treatment works.

4.3 METALS

The mean, standard error of the mean and range of metals concentrations are presented in Table 4.3. Trace metals have been referred to as common pollutants, which are widely distributed in the environment with sources mainly from the weathering of minerals and soils (Marian, 1991; O'Neil, 1993). However, the level of these metals in the environment has increased tremendously in the past decades as a result of inputs from human activities (Marian, 1991).

The mean concentration of manganese in the water samples were 0.005 ± 0.001 mg/L for the raw water, 0.015 ± 0.005 mg/L for the settled water, 0.018 ± 0.006 mg/L for the filtered water, 0.015 ± 0.005 mg/L for chlorinated water and 0.010 ± 0.002 mg/L for water samples in the distribution system. There was no significant change in Mn concentrations at the different sampling sites and are within the WHO permissible level of 0.1 mg/L and so give no cause for any health concern. Mn is an essential metal. However, at excessive levels in the brain it produces extra pyramidal symptoms similar to those in patients with Parkinson's disease (Stredrick et al., 2002), and decreased learning ability in children as well as increased propensity for violence in adults (Finley, 2004).

Chromium had mean concentrations of 0.06 ± 0.005 mg/L, 0.062 ± 0.007 mg/L, 0.046 ± 0.01 mg/L, 0.016 ± 0.012 mg/L and 0.044 ± 0.022 mg/L for the raw, settled, filtered, chlorinated

and distributed water respectively. The raw water had a mean concentration of 0.06 ± 0.005 mg/L which was above the WHO limit of 0.05 mg/L but subsequent treatment reduced it to acceptable levels. This could be explained that chlorine used in disinfection precipitated out some of the Mn and Cr.

Table 4.3: The mean, standard error of the mean and the range of the metals in the water samples from the Owabi Headworks. n = 5

Parameter		RSV	MDT	MDT 1	AFT	DST	WHO (2004) VALUE
Mn	Mean±S.E	0.005±0.001	0.015±0.005	0.018±0.006	0.015±0.005	0.01±0.002	0.1
	Range	0.002–0.008	0.004–0.035	0.003–0.035	0.002–0.030	0.004-0.020	
Cr	Mean±S.E	0.06±0.005	0.06±0.007	0.05±0.010	0.04±0.010	0.04±0.003	0.05
	Range	0.04–0.07	0.04–0.08	0.01–0.07	0.01–0.07	0.03–0.06	
Cu	Mean±S.E	0.237±0.146	0.118±0.084	0.02±0.008	0.016±0.012	0.04±0.02	0.1
	Range	0.02–0.80	0.01-0.44	0.01–0.04	0.01–0.06	0.01–0.20	
Zn	Mean±S.E	0.014±0.005	0.034±0.013	0.018±0.006	0.012±0.004	0.041±0.018	3.0
	Range	0.01–0.03	0.01–0.08	0.01–0.04	0.01–0.02	0.01–0.20	
Fe	Mean±S.E	0.10±0.032	0.10±0.032	0.012±0.008	0.014±0.014	0.013±0.009	0.3
	Range	0.01–0.20	0.01–0.43	0.01-0.04	0.01 –0.07	0.01–0.07	
K	Mean±S.E	15.54±1.713	16.52±2.124	13.30±1.338	10.84±0.952	15.35±1.826	30
	Range	9.6–20.1	10.0–22.6	10.0–17.0	9.0–14.0	8.0–24.0	
Al	Mean±S.E	0.096±0.009	0.262±0.031	0.106±0.056	0.12±0.015	0.11±0.008	0.2
	Range	0.07–0.12	0.15–0.33	0.01–0.31	0.09–0.16	0.07–0.15	

*. All parameters are in mg/L except otherwise stated. *. S.E is standard error of the mean

Cu is an essential mineral in the diet. Too much copper, however, can cause health problems.

Cu recorded a mean level of 0.24 ± 0.15 mg/L for the raw water, 0.12 ± 0.084 mg/L for the

settled water, 0.02 ± 0.008 mg/L for the filtered water, 0.016 ± 0.01 mg/L for the chlorinated water and 0.04 ± 0.02 mg/L for water in the distribution system. Dissolved copper salts are poisonous to some biota. The raw water had a mean concentration that was above the WHO acceptable level of 0.1 mg/L but sedimentation and filtration process during treatment reduced the concentration of Cu to acceptable levels.

Although Zn has been found to have low toxicity to man, prolonged consumption of large doses can result in some health complications such as fatigue, dizziness and neutropenia (Hess and Schmidt, 2002). The Zn concentrations of all the samples analysed were all below the WHO acceptable limit of 3.0 mg/L. The recorded mean levels are 0.014 ± 0.005 mg/L, 0.034 ± 0.013 mg/L, 0.018 ± 0.006 mg/L, 0.012 ± 0.004 mg/L and 0.041 ± 0.018 mg/L for the raw, settled, filtered, chlorinated and distributed water respectively.

Iron is not hazardous to health, but it is considered a secondary or aesthetic contaminant. For good health, Fe helps transport oxygen in the blood. Fe recorded mean concentration of 0.10 ± 0.03 mg/L for the raw water, 0.10 ± 0.03 mg/L for the settled water, the filtered water 0.01 ± 0.008 mg/L, 0.014 ± 0.014 mg/L for the chlorinated water and 0.013 ± 0.009 mg/L for the distributed.

The levels of potassium measured were 15.54 ± 1.71 mg/L for the raw water, 16.52 ± 2.12 mg/L for the settled water, 13.30 ± 1.34 mg/L for filtered water, 10.84 ± 0.95 mg/L for chlorinated water and 15.35 ± 1.83 mg/L for the distributed water. Potassium has no health implications and is an essential element in plant, animal and human nutrition (Lewis, 1997). In humans, K^+ play a critical role in many vital cell functions, such as metabolism, growth, repair and volume regulation, as well as in the electric properties of the cell (Adriogue and

Wesson, 1994). There were no significant changes in the concentrations of all the metals at the different sampling sites (p > 0.05) which indicate that the processes of flocculation, sedimentation, filtration and chlorination had no significant impact on the metal concentrations in the samples.

Al recorded mean levels of 0.096 ± 0.009 mg/L for the raw water, 0.26 ± 0.03 mg/L for the settled water, 0.11 ± 0.06 mg/L for the filtered water, 0.12 ± 0.01 mg/L for the chlorinated water and 0.11 ± 0.008 mg/L for the distributed water. The mean difference is significant at the 0.05 level. The settled water had an elevated level of Al and it could be attributed to the aluminium sulphate added at this stage of treatment for flocculation and sedimentation.

4.4 MICROBIAL WATER QUALITY

The mean, standard error of the mean and range for microbial analysis are presented in Table 4.4. Total and faecal coliforms were present in the raw water, which means that water from the reservoir is not suitable for domestic use without treatment. The raw water had total coliform count of 1766.00 ± 401.55/100 mL and faecal coliform count of 257.00 ± 69.69/100 mL. Akoto et al (2010) observed that the high faecal coliform count in the streams that feed the Owabi watershed are signs of biological contamination of the streams by pathogens. The high faecal coliform levels observed make the reservoir unsuitable for swimming, boating and fishing (WHO, 2004; Millipore, 1991). The results suggest that the general sanitary qualities of the water in the reservoir, as indicated by the total and faecal coliform counts, are unacceptable. For water to be considered as no risk to human health, the total and faecal coliform count/100 mL should be zero (WHO, 2004).

The poor microbiological quality might be due to contamination caused by human activities and livestock. It is a common practice for people living within the river catchment to

discharge their domestic and agricultural wastes into rivers serving the reservoir (Karikari and Ansa-Asare, 2006). However, there was significant reduction in total and faecal coliform counts as the water undergoes sedimentation, filtration and chlorination. The water records zero coliform count after chlorination which is in conformity with the accepted level (WHO, 2004).

Table 4.4: The mean, standard error of the mean, and the range of the microbial quality of the water at the different treatment points of the Owabi water heads.

PARAMETER		Total Coliform. MPN/100 ML	Faecal Coliform. MPN/100 ML
SAMPLE			
RSV	Mean±S.E	1766.00 ± 401.55^a	257.00 ± 69.69^a
	Range	240 – 2400	93 – 430
MDT	Mean±S.E	542.00 ± 440.75^b	38.20 ± 14.64^b
	Range	49 – 2300	5 – 90
MDT 1	Mean±S.E	42.40 ± 10.03^c	0.00^c
	Range	12 – 75	
AFT	Mean±S.E	1.00 ± 1.00^c	0.00^c
	Range	0 -5	
DST	Mean±S.E	18.20 ± 6.26^c	2.30 ± 2.30^c
	Range	0 – 51	0 – 23
WHO (2004) VALUE		0	0

*. a, b, and c denote different means. *. S.E = standard error of the mean.

Colour showed strong linear correlation significant at $p < 0.01$ with turbidity (r=0.730), TSS (0.922) and alkalinity (0.564) as shown in Table. 4.5. NH_3 correlated linearly (r=0.389) with PO_4^{3-}. Mg correlated linearly with F (r = 0.409) and Cr also correlated linearly with Al (r = 0.423) significant at the 0.05 level. Ca correlated negatively with Mg (r = -0.447) significant at $p < 0.05$ level.

Table. 4.5 Pearson's Correlation for Colour, turbidity, TSS and Alkalinity.

	Colour	Turbidity	TSS	Alkalinity
Colour	1			
Turbidity	0.730*	1		
TSS	0.922*	0.843*	1	
Alkalinity	0.564*	0.564*	0.468*	1

*. Correlation is significant at the 0.01 level (2- tailed).

Table. 4.6 Pearson's correlation for the metals

	Mn	Cr	Cu	Zn	Fe	K	Al
Mn	1						
Cr	.239	1					
Cu	-.201	.202	1				
Zn	.089	.209	-.028	1			
Fe	-.196	.342	.459*	.177	1		
K	-.267	.154	-.035	-.174	-.088	1	
Al	.100	.423*	.104	.076	.145	.249	1

*. Correlation is significant at the 0.05 level (2-tailed).

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In this study, the changes in drinking water quality from source to point-of-use was assessed by measuring some water quality parameters at different stages of treatment as well as the distribution system after treatment. The study found out that some physico-chemical parameters like pH, temperature, hardness, TDS, TSS of the raw water were within the WHO acceptable limit and pose no risk to consumers even if the water had been used without prior treatment. However, parameters like colour, turbidity, total and faecal coliform were above the WHO acceptable limit before treatment but were reduced to acceptable levels after passing through the treatment process thus making it wholesome for drinking and domestic use.

Concentrations of all the nutrients (NO_3^-, NO_2^-, SO_4^{2-}, PO_4^{3-} and NH_3) were within acceptable levels in all the samples. Levels of phosphate and sulphate in the raw water were slightly higher which indicates pollution in the raw water. Cr and Cu levels in the reservoir were above the WHO permissible limits. The levels of these two metals fell within acceptable limits after the water had been treated. The other metals (Mn, Zn, Fe, K and Al) recorded concentrations that were within acceptable levels at the different stages of treatment.

From the study it could be said that the microbiological quality of the raw water was poor indicating pollution of the Owabi reservoir. However subsequent treatment reduced the coliform level drastically and the water samples had no coliform count after chlorination. This indicates that each stage of the treatment process is important and an essential part of the overall treatment of water.

The results have also shown that the quality of the water distributed to consumers compares favourably with the water after chlorination and this indicates that the distribution system is working well. Again, it can be concluded that the treatment processes at the Owabi Headworks is efficient, delivering potable quality water to the consumers.

5.2 RECOMMENDATION

The communities along the banks of the river and the tributaries that feed the Owabi reservoir should be educated on the dangers of dumping domestic, agricultural and industrial waste into the river and the streams. Efforts should be made at preventing these communities from dumping their waste into the river and streams that feed the river. The Headworks should be encouraged to maintain the standard of treatment and also find avenues to improve on them. Further research should be conducted on other contaminants, such as pesticides, that were not analysed in this study.
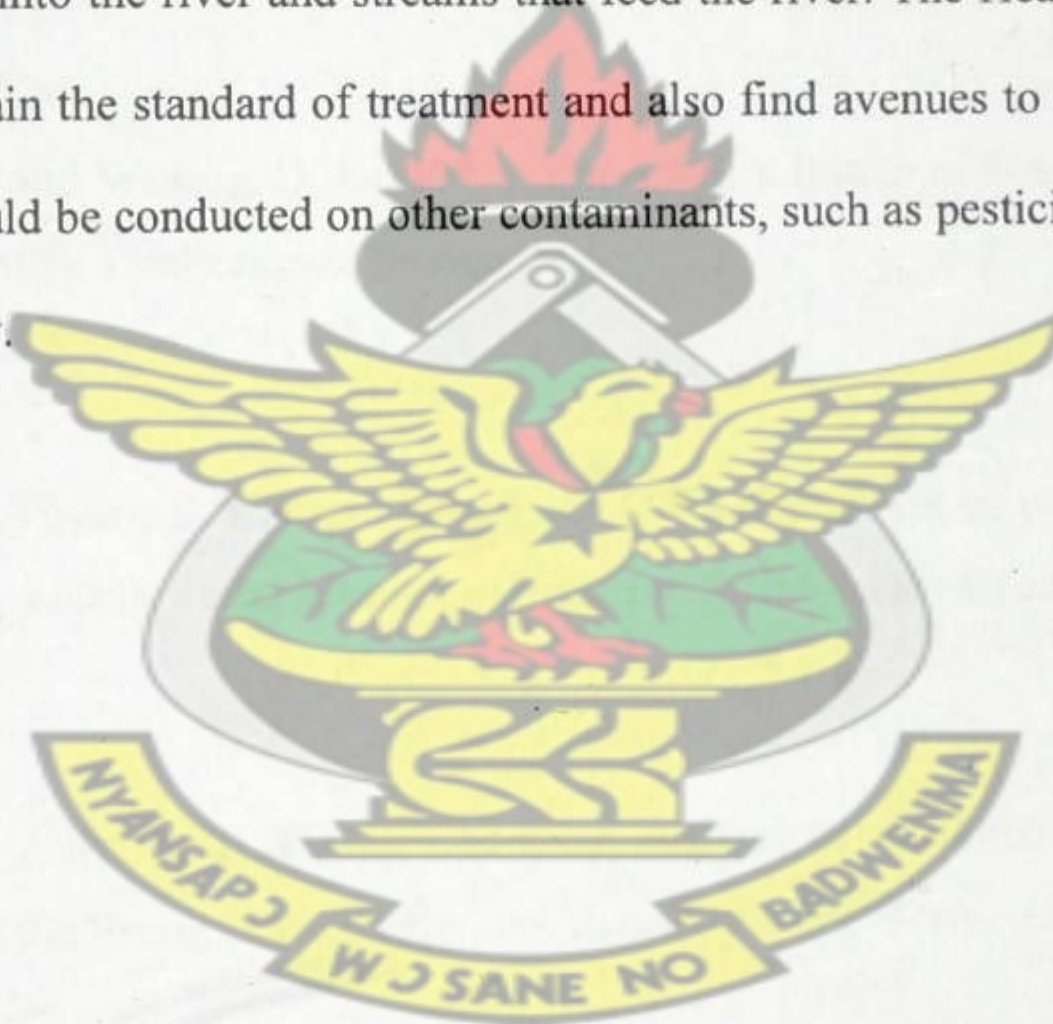
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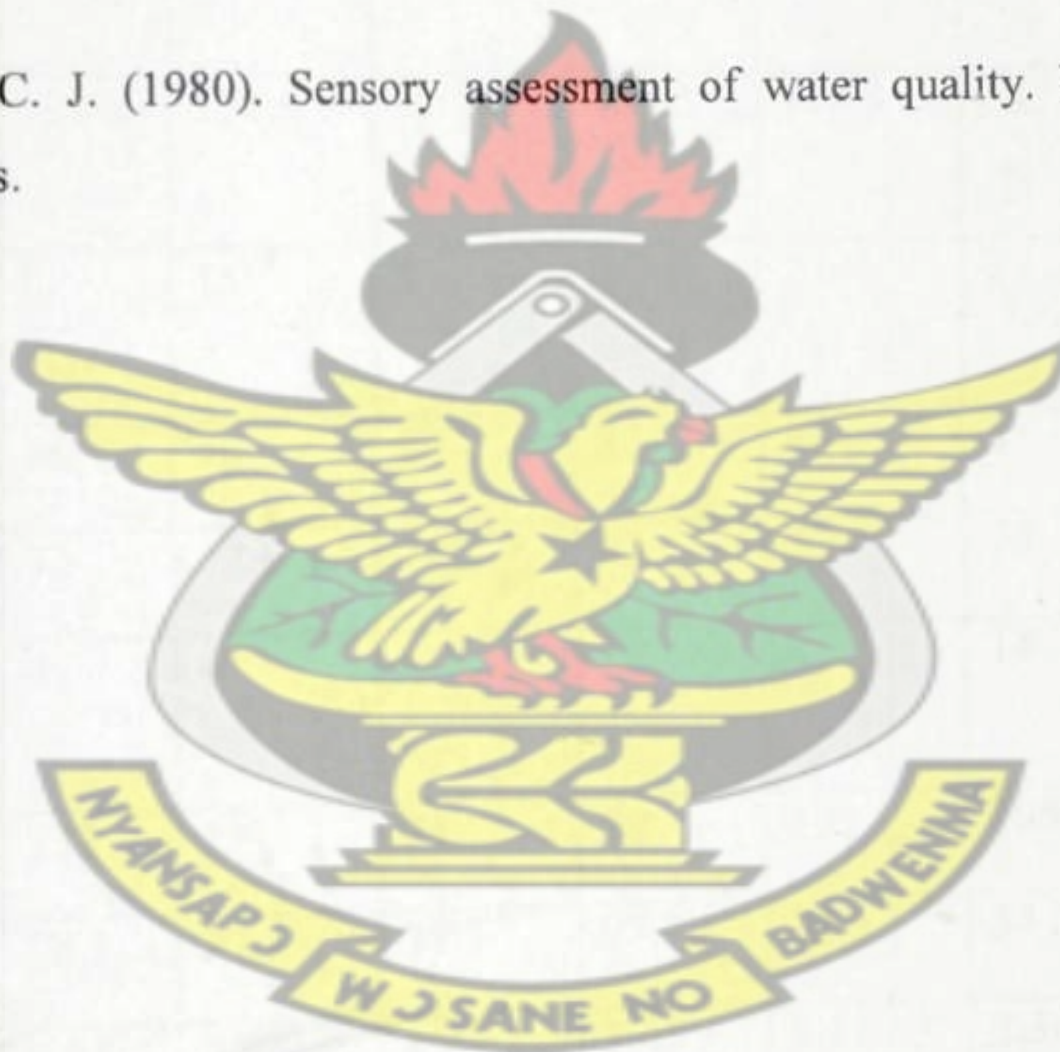
APPENDIX 1

1A: December, 2011 Sampling

PARAMETERS	RSV	MDT	MDT 1	AFT	DST 1	DST 2	GHANA STD
pH	7.18	6.87	6.58	6.60	6.61	6.70	6.5 – 8.5
Temperature(°C)	26.6	26.4	26.3	26.8	26.3	26.5	-
Colour (Hz)	98	150	22	19	30	23	15
Turbidity (NTU)	5.56	3.63	1.52	1.34	1.56	1.57	5
Conductivity (µS/cm)	286	291	301	298	295	298	1000
Total Dissolved solids	171.8	174.5	180.7	181.5	176.5	182.8	1000
Total Suspended Solids	8	15	5	2	2	2	-
Total Hardness	76	76	80	82	80	84	500
Calcium Hardness	72	72	74	63	72	70	-
Magnesium Hardness	4	4	6	19	8	14	-
Alkalinity	132	131	94	98	105	105	-
Calcium	28.1	27.3	31.3	27.7	25.5	34.0	200
Magnesium	1.35	2.92	4.22	7.45	8.11	2.30	150
Chloride	33	28	31	32	30	30	250
Fluoride	1.38	1.21	1.22	1.40	1.44	1.42	1.5
Residual Chlorine				2.0	1.9	2.0	-
Phosphate	27	27	28	30	39	38	400
Sulphate	7	75	42	38	27	33	400
Nitrate	0.58	0.58	0.90	0.60	0.95	0.90	50

Changes in Water Quality from Source to Point-of-Use.

Nitrite	0.004	0.004	0.016	0.050	0.20	0.05	3.0
Ammonia	0.01	0.02	0.02	0.01	0.02	0.01	1.5
Manganese	0.006	0.006	0.035	0.022	0.004	0.015	0.1
Chromium	0.07	0.07	0.06	0.05	0.04	0.05	0.05
Copper	0.10	0.44	0.03	0.01	0.01	0.01	0.1
Zinc	0.01	0.08	0.01	0.02	0.04	0.02	3.0
Iron	0.10	0.43	0.04	0.07	0.06	0.07	0.3
Potassium	15.0	14.0	10.5	9.0	11.5	9.0	30
Aluminium	0.10	0.28	0.04	0.09	0.12	0.08	0.2
Total Coliform cfu/ml	1690	56	42	0	18	0	0
Faecal Coliform cfu/ml	147	5	0	0	0	0	0

All parameters are in mg/L except otherwise stated

Changes in Water Quality from Source to Point-of-Use.

1B: JANUARY, 2012 SAMPLING

PARAMETERS	RSV	MDT	MDT 1	AFT	DST 1	DST 2	GHANA STD
pH	7.07	6.83	6.79	6.85	6.72	6.88	6.5 – 8.5
Temperature(°C)	25.8	25.1	25.0	26.1	25.9	26.1	-
Colour (Hz)	115	74	16	26	19	20	15
Turbidity (NTU)	13.89	4.64	0.97	0.96	0.34	0.82	5
Conductivity (μS/cm)	341	359	353	360	346	362	1000
Total Dissolved solids	214	225	223	230	222	230	1000
Total Suspended Solids	20	7	1	3	1	1	-
Total Hardness	78	80	76	86	84	82	500
Calcium Hardness	76	64	62	68	70	64	-
Magnesium Hardness	2	16	14	18	14	18	-
Alkalinity	142	122	116	112	112	120	-
Calcium	29.2	32.4	34.3	24.5	29.6	33.4	200
Magnesium	2.62	6.83	3.72	5.43	10.40	4.48	150
Chloride	30	27	27	27	33	33	250
Fluoride	1.40	1.20	1.20	1.40	1.45	1.45	1.5
Residual Chlorine				2.0	2.0	2.0	-
Phosphate	0.91	0.20	0.54	1.54	4.00	0.86	400
Sulphate	5.0	29.0	32.0	31.0	26.0	33.0	400
Nitrate	0.44	0.53	0.75	2.33	3.30	1.06	50
Nitrite	0.08	0.08	0.06	0.06	0.08	0.07	3.0
Ammonia	0.0	0.0	0.0	0.0	0.0	0.0	1.5

Changes in Water Quality from Source to Point-of-Use.

Manganese	0.008	0.016	0.012	0.004	0.019	0.006	0.1
Chromium	0.06	0.04	0.01	0.06	0.06	0.03	0.05
Copper	0.80	0.0	0.03	0.01	0.01	0.02	0.1
Zinc	0.0	0.0	0.02	0.02	0.20	0.03	3.0
Iron	0.10	0.01	0.02	0.01	0.01	0.01	0.3
Potassium	9.6	10.0	10.0	9.2	8.0	10.0	30
Aluminium	0.11	0.25	0.01	0.09	0.10	0.07	0.2
Total Coliform cfu/ml	2150	49	38	0	18	0	0
Faecal Coliform cfu/ml	200	16	0	0	0	0	0

All parameters are in mg/L except otherwise stated

Changes in Water Quality from Source to Point-of-Use.

1C: FEBRUARY, 2012 SAMPLING

PARAMETERS	RSV	MDT	MDT 1	AFT	DST 1	DST 2	GHANA STD
pH	6.81	6.59	6.48	6.68	6.65	6.63	6.5 – 8.5
Temperature(°C)	26.6	25.9	26.4	25.5	26.2	26.0	-
Colour (Hz)	49	30	10	19	9	22	15
Turbidity (NTU)	4.89	4.77	0.87	0.99	0.46	1.36	5
Conductivity (µS/cm)	365	366	375	371	368	368	1000
Total Dissolved solids	219	221	223	224	222	218	1000
Total Suspended Solids	4.0	3.0	1.0	1.0	0.0	2.0	-
Total Hardness	82	80	100	92	86	86	500
Calcium Hardness	80	74	88	60	62	76	-
Magnesium Hardness	2.0	6.0	12	32	24	10	-
Alkalinity	150	122	120	116	112	110	-
Calcium	32.0	29.6	35.2	24.0	24.8	30.4	200
Magnesium	0.49	1.46	2.92	7.78	5.83	2.43	150
Chloride	25	26	28	27	29	26	250
Fluoride	1.52	1.21	1.21	1.48	1.55	1.54	1.5
Residual Chlorine				0.09	0.19	0.18	-
Phosphate	8.7	14	11	7.5	12	9.9	400
Sulphate	11	16	12	13	14	10	400
Nitrate	0.10	0.10	0.08	0.08	0.10	0.09	50
Nitrite	0.010	0.016	0.016	0.050	0.050	0.040	3.0
Ammonia	0.01	0.02	0.02	0.03	0.01	0.02	1.5

Changes in Water Quality from Source to Point-of-Use.

Manganese	0.002	0.004	0.003	0.002	0.004	0.004	0.1
Chromium	0.07	0.06	0.04	0.01	0.03	0.05	0.05
Copper	0.02	0.01	0.04	0.01	0.20	0.10	0.1
Zinc	0.01	0.02	0.01	0.01	0.02	0.03	3.0
Iron	0.10	0.01	0.01	0.01	0.01	0.01	0.3
Potassium	20.1	22.6	17.0	14.0	19.0	24.0	30
Aluminium	0.12	0.30	0.03	0.11	0.15	0.09	0.2
Total Coliform cfu/ml	2400	2300	75	5	51	12	0
Faecal Coliform cfu/ml	430	40	0	0	0	0	0

All parameters are in mg/L except otherwise stated

Changes in Water Quality from Source to Point-of-Use.
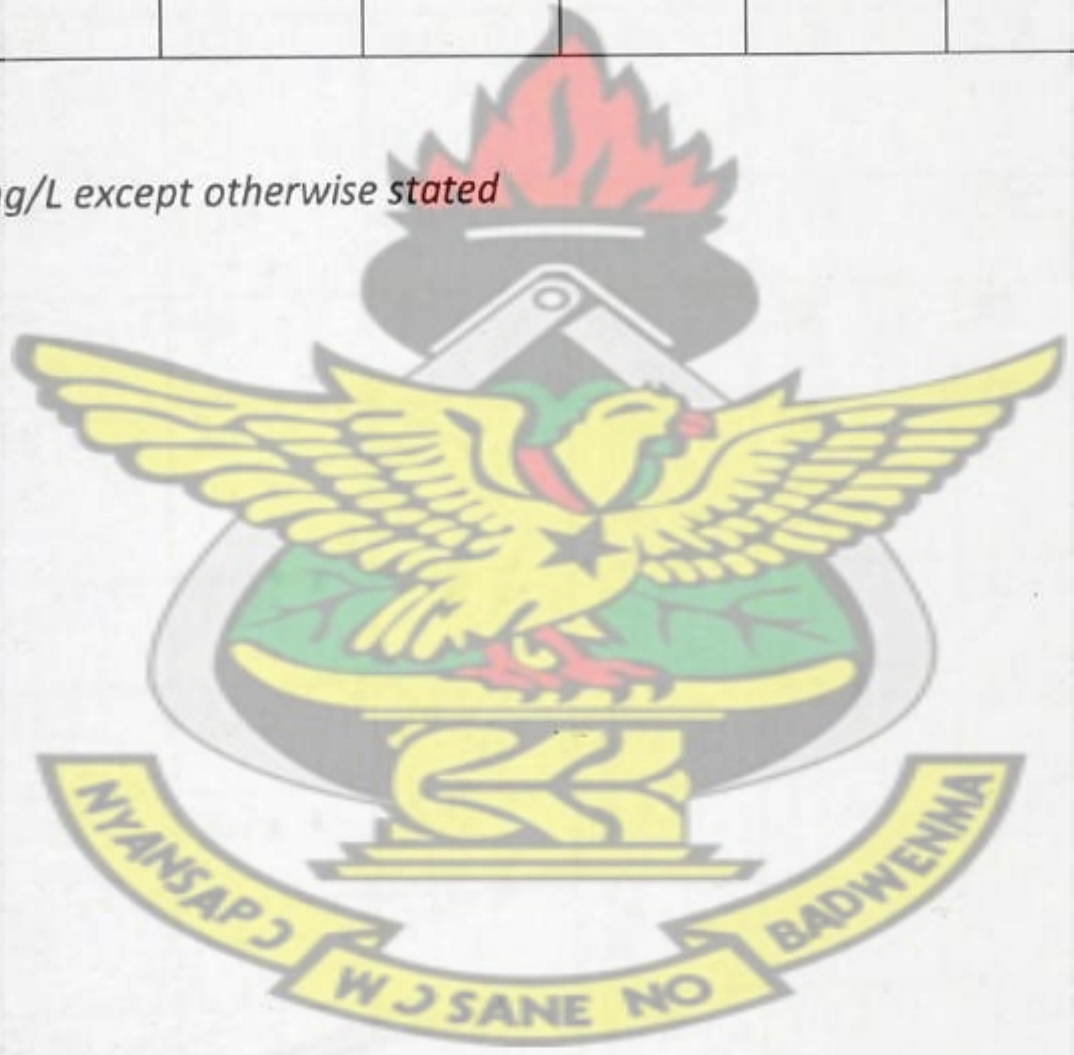
PARAMETERS	RSV	MDT	MDT 1	AFT	DST 1	DST 2	GHANA STD
pH	6.90	6.85	7.02	6.94	7.13	6.89	6.5 – 8.5
Temperature (°C)	28.4	28.6	28.6	28.9	28.5	28.4	-
Colour (Hz)	42	25	8	10	12	18	15
Turbidity (NTU)	4.48	3.99	0.56	0.63	0.70	2.05	5
Conductivity (µS/cm)	277	256	265	258	282	263	1000
Total Dissolved solids	166.2	153.6	159.0	154.8	169.2	157.8	1000
Total Suspended Solids	3.0	2.0	0.0	1.0	1.0	2.0	-
Total Hardness	88	120	96	92	114	100	500
Calcium Hardness	78	84	70	66	58	82	-
Magnesium Hardness	10	36	26	26	56	18	-
Alkalinity	143	132	116	120	128	86	-
Calcium	31.2	33.6	28.0	26.4	23.2	32.8	200
Magnesium	2.43	8.75	6.32	6.32	13.6	4.37	150
Chloride	26	22	18	18	16	21	250
Fluoride	1.40	1.25	1.23	1.55	1.62	1.61	1.5
Residual Chlorine				1.4	0.4	0.2	-
Phosphate	9.2	15	12	10	14	10.2	400
Sulphate	8	54	41	39	30	35	400
Nitrate	0.45	0.68	1.35	1.95	3.01	2.46	50
Nitrite	0.010	0.008	0.012	0.008	0.016	0.20	3.0
Ammonia	0.02	0.01	0.05	0.04	0.01	0.03	1.5

Changes in Water Quality from Source to Point-of-Use.

Manganese	0.005	0.035	0.027	0.015	0.005	0.015	0.1
Chromium	0.06	0.06	0.07	0.02	0.04	0.04	0.05
Copper	0.03	0.01	0.0	0.02	0.01	0.1	0.1
Zinc	0.03	0.04	0.04	0.01	0.02	0.03	3.0
Iron	0.20	0.01	0.01	0.01	0.01	0.01	0.3
Potassium	16.0	18.0	14.0	10	14.0	19.0	30
Aluminium	0.07	0.15	0.31	0.16	0.10	0.12	0.2
Total Coliform cfu/ml	2350	75	45	0	0	0	0
Faecal Coliform cfu/ml	415	40	0	0	0	0	0

All parameters are in mg/L except otherwise stated

Changes in Water Quality from Source to Point-of-Use.
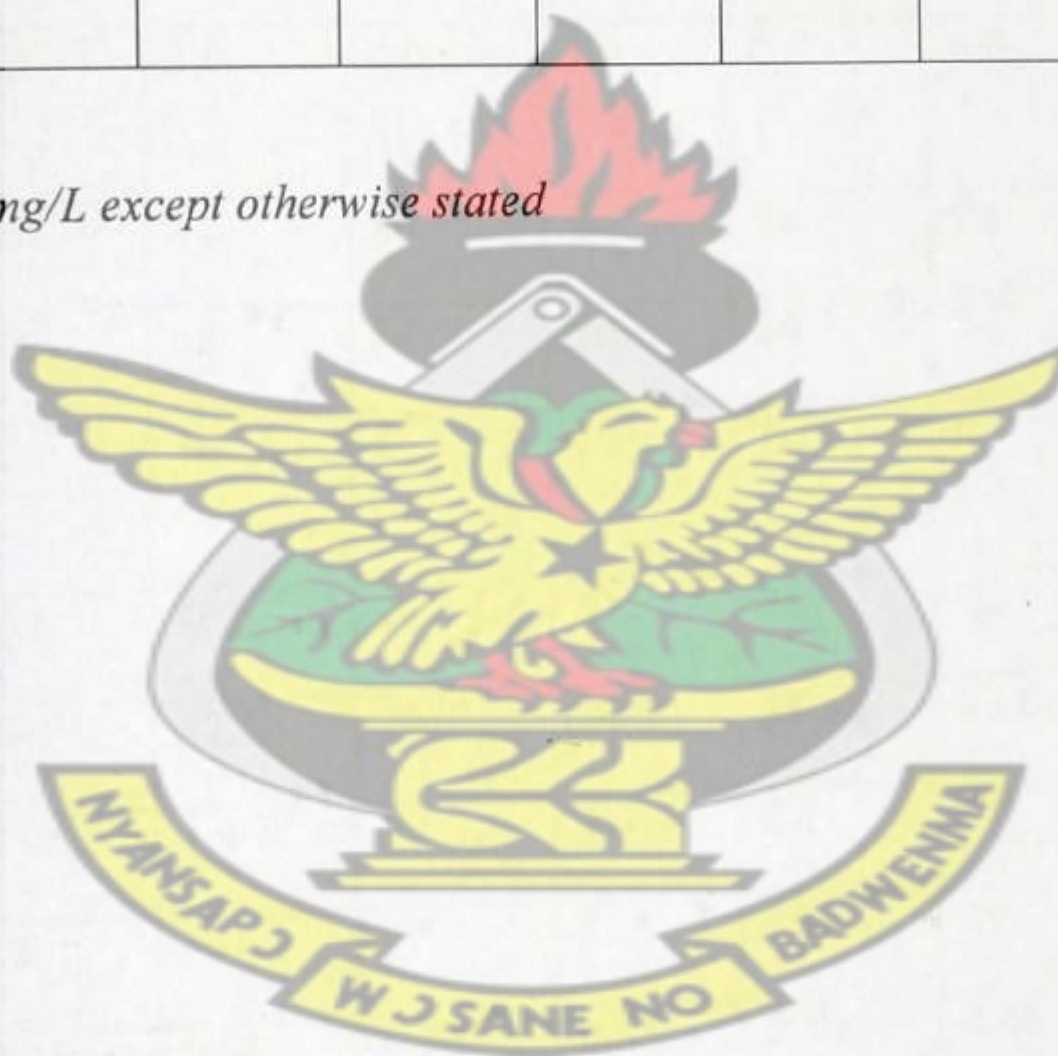
1E: APRIL, 2012 SAMPLING

PARAMETERS	RSV	MDT	MDT 1	AFT	DST 1	DST 2	GHANA STD
pH	7.74	7.13	7.14	7.37	7.58	7.47	6.5 – 8.5
Temperature(°C)	25.7	25.4	26.3	25.8	25.7	25.7	-
Colour (Hz)	30	17	7	7	0	0	15
Turbidity (NTU)	2.66	1.82	1.13	1.57	0.33	0.35	5
Conductivity (µS/cm)	353	368	343	361	358	379	1000
Total Dissolved solids	212	222	207	216	215	227	1000
Total Suspended Solids	3.0	3.0	0.0	1.0	0.0	0.0	-
Total Hardness	82	84	80	80	94	90	500
Calcium Hardness	70	68	74	70	84	84	-
Magnesium Hardness	12	16	6	10	10	6	-
Alkalinity	126	102	88	82	84	72	-
Calcium	28.0	27.2	29.6	28.0	33.6	33.6	200
Magnesium	2.9	3.9	1.5	2.4	2.4	1.5	150
Chloride	27	36	27	27	28	29	250
Fluoride	0.45	0.65	0.70	0.55	0.30	0.40	1.5
Residual Chlorine				0.21	0.01	0.04	-
Phosphate	0.26	0.38	0.18	0.28	0.34	0.56	400
Sulphate	9.0	60.0	57.0	39.0	67.0	60.0	400
Nitrate	0.88	0.21	1.23	0.92	1.36	2.20	50
Nitrite	0.030	0.006	0.010	0.005	0.016	0.020	3.0
Ammonia	0.0	0.0	0.0	0.0	0.0	0.0	1.5

Changes in Water Quality from Source to Point-of-Use.

Manganese	0.006	0.012	0.013	0.030	0.017	0.013	0.1
Chromium	0.04	0.08	0.05	0.07	0.03	0.05	0.05
Copper	0.24	0.13	0.01	0.06	0.01	0.017	0.1
Zinc	0.02	0.03	0.01	0.01	0.01	0.02	3.0
Iron	0.01	0.01	0.01	0.01	0.01	0.01	0.3
Potassium	17.0	18.0	15.0	12.0	16.0	23.0	30
Aluminium	0.08	0.33	0.14	0.15	0.13	0.14	0.2
Total Coliform cfu/ml	240	230	12	0	43	40	0
Faecal Coliform cfu/ml	93	90	0	0	23	0	0

All parameters are in mg/L except otherwise stated

Changes in Water Quality from Source to Point-of-Use.
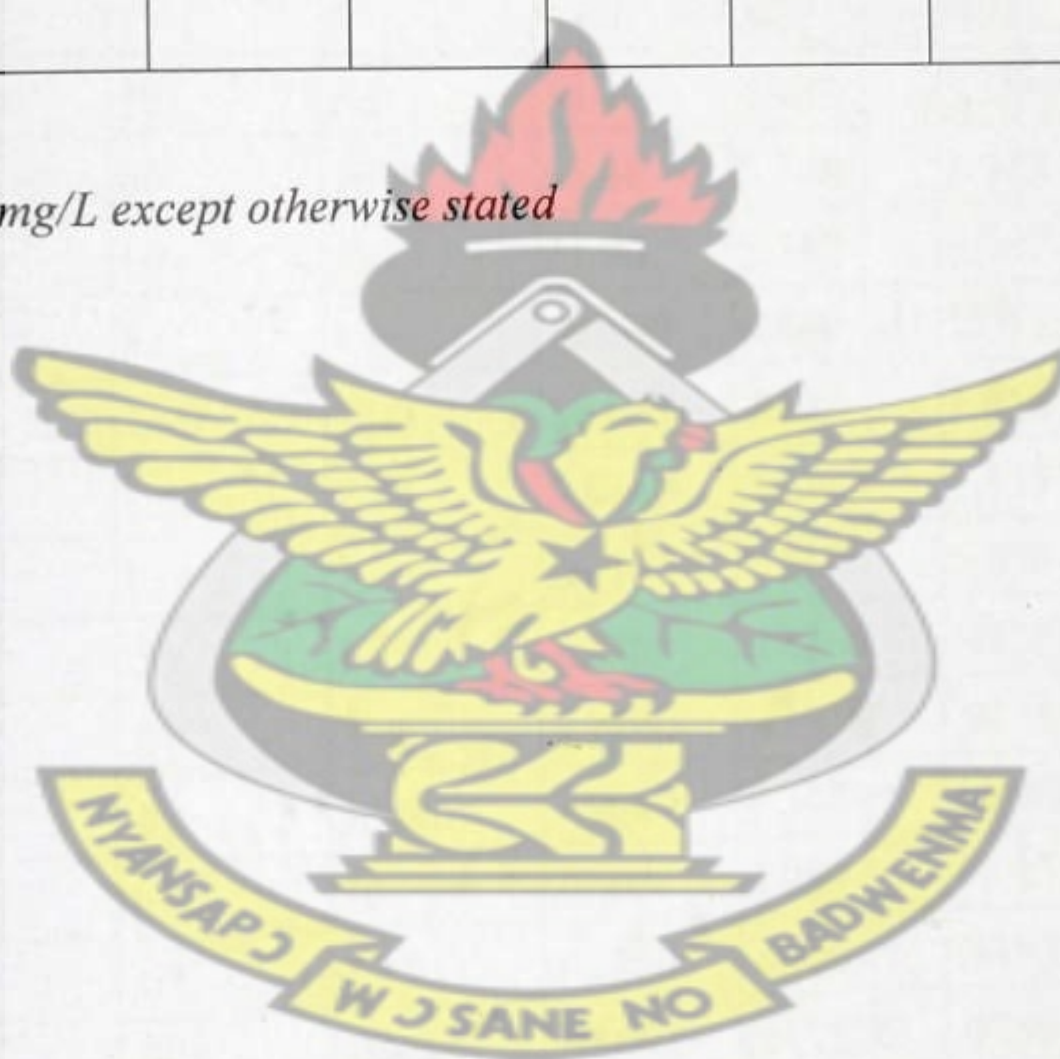
APPENDIX 2

2A

Descriptive Statistics[a]

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Ph	5	6.60	7.37	6.8880	.13466	.30111	.091
Temperature	5	25.5	28.9	26.620	.6094	1.3627	1.857
Colour	5	7	26	16.20	3.426	7.662	58.700
Turbidity	5	.63	1.59	1.1020	.16587	.37090	.138
Conductivity	5	258	371	329.60	22.078	49.369	2.437E3
TDS	5	154.8	230.0	201.260	14.3341	32.0521	1.027E3
TSS	5	1	3	1.60	.400	.894	.800
T_hardness	5	80	92	86.40	2.482	5.550	30.800
Ca_hardness	5	60	70	65.40	1.778	3.975	15.800
Mg_hardness	5	10	32	21.00	3.742	8.367	70.000
Alkalinity	5	82	120	105.60	6.969	15.582	242.800
Calcium	5	24.0	28.0	26.120	.8133	1.8185	3.307
Magnesium	5	2.40	7.78	5.8760	.96388	2.15530	4.645
Chloride	5	18	32	26.20	2.267	5.070	25.700
Fluoride	5	.55	1.55	1.2760	.18365	.41065	.169
R_chlorine	5	.09	2.00	1.1400	.41918	.93731	.879
Phosphate	5	.28	30.00	9.8640	5.34887	11.96043	143.052
Sulphate	5	13	39	32.00	4.980	11.136	124.000
Nitrate	5	.08	2.33	1.1760	.42008	.93932	.882
Nitrite	5	.005	.060	.03460	.011626	.025996	.001
Ammonia	5	.00	.04	.0160	.00812	.01817	.000
Mn	5	.002	.030	.01460	.005307	.011866	.000
Cr	5	.01	.07	.0420	.01158	.02588	.001
Cu	5	.000	.060	.01600	.011662	.026077	.001
Zn	5	.00	.02	.0120	.00374	.00837	.000
Fe	5	.00	.07	.0140	.01400	.03130	.001
K	5	9.0	14.0	10.840	.9516	2.1279	4.528
Al	5	.09	.16	.1200	.01483	.03317	.001
T_coliform	5	0	5	1.00	1.000	2.236	5.000

Changes in Water Quality from Source to Point-of-Use.

					Std.	
F_coliform	5	0	0	.00	.000	.000	.000
Valid N (listwise)	5						

a. Sample = AFT

2B

Descriptive Statistics[a]

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Ph	10	6.61	7.58	6.9260	.11185	.35369	.125
Temperature	10	25.7	28.5	26.530	.3297	1.0425	1.087
Colour	10	0	30	15.30	3.131	9.900	98.011
Turbidity	10	.33	2.05	.9540	.19918	.62985	.397
Conductivity	10	263	379	331.90	13.482	42.634	1.818E3
TDS	10	157.8	230.0	202.030	8.6168	27.2486	742.485
TSS	10	0	2	1.10	.277	.876	.767
T_hardness	10	80	114	90.00	3.266	10.328	106.667
Ca_hardness	10	58	84	72.20	2.928	9.259	85.733
Mg_hardness	10	6	56	17.80	4.575	14.467	209.289
Alkalinity	10	72	128	103.40	5.520	17.456	304.711
Calcium	10	23.2	34.0	30.090	1.3127	4.1512	17.232
Magnesium	10	1.50	13.60	5.5420	1.26542	4.00160	16.013
Chloride	10	16	33	27.50	1.682	5.318	28.278
Fluoride	10	.30	1.62	1.2780	.15645	.49472	.245
R_chlorine	10	.01	2.00	.8920	.29671	.93829	.880
Phosphate	10	.34	39.00	12.8840	4.55122	14.39221	207.136
Sulphate	10	10	67	33.50	5.648	17.859	318.944
Nitrate	10	.09	3.30	1.5430	.36112	1.14198	1.304
Nitrite	10	.016	.200	.07420	.022049	.069726	.005
Ammonia	10	.00	.03	.0100	.00333	.01054	.000
Mn	10	.004	.019	.01020	.001937	.006125	.000
Cr	10	.03	.06	.0420	.00327	.01033	.000
Cu	10	.000	.200	.04370	.021497	.067980	.005
Zn	10	.00	.20	.0410	.01798	.05685	.003
Fe	10	.00	.07	.0130	.00870	.02751	.001
K	10	8.0	24.0	15.350	1.8258	5.7737	33.336

Changes in Water Quality from Source to Point-of-Use.

	10	.07	.15	.1100	.00830	.02625	.001
Al	10	.07	.15	.1100	.00830	.02625	.001
T_coliform	10	0	51	18.20	6.262	19.803	392.178
F_coliform	10	0	23	2.30	2.300	7.273	52.900
Valid N (listwise)	10						

a. Sample = DST

2C

Descriptive Statistics[a]

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Ph	5	6.59	7.13	6.8540	.08565	.19152	.037
Temperature	5	25.1	28.6	26.280	.6208	1.3882	1.927
Colour	5	17	150	59.20	24.766	55.378	3.067E3
Turbidity	5	1.82	4.77	3.7700	.53044	1.18611	1.407
Conductivity	5	256	368	328.00	22.976	51.376	2.640E3
TDS	5	153.6	225.0	199.220	14.7482	32.9779	1.088E3
TSS	5	2	15	6.00	2.408	5.385	29.000
T_hardness	5	76	120	88.00	8.099	18.111	328.000
Ca_hardness	5	64	84	72.40	3.370	7.537	56.800
Mg_hardness	5	4	36	15.60	5.671	12.681	160.800
Alkalinity	5	102	132	121.80	5.389	12.050	145.200
Calcium	5	27.2	33.6	30.020	1.3040	2.9158	8.502
Magnesium	5	1.46	8.75	4.7720	1.32702	2.96730	8.805
Chloride	5	22	36	27.80	2.289	5.119	26.200
Fluoride	5	.65	1.25	1.1040	.11382	.25452	.065
R_chlorine	0						
Phosphate	5	.20	27.00	11.3160	5.04938	11.29076	127.481
Sulphate	5	16	75	46.80	10.693	23.910	571.700
Nitrate	5	.10	.68	.4200	.11221	.25090	.063
Nitrite	5	.004	.080	.02280	.014444	.032299	.001
Ammonia	5	.00	.02	.0100	.00447	.01000	.000
Mn	5	.004	.035	.01460	.005528	.012361	.000
Cr	5	.04	.08	.0620	.00663	.01483	.000
Cu	5	.000	.440	.11800	.083988	.187803	.035
Zn	5	.00	.08	.0340	.01327	.02966	.001

Changes in Water Quality from Source to Point-of-Use.

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
Fe	5	.00	.43	.0880	.08552	.19123	.037
K	5	10.0	22.6	16.520	2.1238	4.7489	22.552
Al	5	.15	.33	.2620	.03089	.06907	.005
T_coliform	5	49	2300	542.00	440.752	985.551	9.713E5
F_coliform	5	5	90	38.20	14.637	32.729	1.071E3
Valid N (listwise)	0						

a. Sample = MDT

2DDescriptive Statistics[a]

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
pH	5	6.48	7.14	6.8020	.12548	.28057	.079
Temperature	5	25.0	28.6	26.520	.5809	1.2988	1.687
Colour	5	7	22	12.60	2.821	6.309	39.800
Turbidity	5	.56	1.52	1.0100	.15783	.35292	.125
Conductivity	5	265	375	327.40	19.692	44.032	1.939E3
TDS	5	159.0	223.0	198.540	12.5496	28.0617	787.458
TSS	5	0	5	1.40	.927	2.074	4.300
T_hardness	5	76	100	86.40	4.833	10.807	116.800
Ca_hardness	5	62	88	73.60	4.214	9.423	88.800
Mg_hardness	5	6	26	12.80	3.666	8.198	67.200
Alkalinity	5	88	120	106.80	6.560	14.670	215.200
Calcium	5	28.0	35.2	31.680	1.3651	3.0524	9.317
Magnesium	5	1.50	6.32	3.7360	.79300	1.77321	3.144
Chloride	5	18	31	26.20	2.177	4.868	23.700
Fluoride	5	.70	1.23	1.1120	.10312	.23059	.053
R_chlorine	0						
Phosphate	5	.18	28.00	10.3440	5.07116	11.33945	128.583
Sulphate	5	12	57	36.80	7.385	16.514	272.700
Nitrate	5	.08	1.35	.8620	.22350	.49977	.250
Nitrite	5	.010	.060	.02280	.009372	.020957	.000
Ammonia	5	.00	.05	.0180	.00917	.02049	.000
Mn	5	.003	.035	.01800	.005727	.012806	.000
Cr	5	.01	.07	.0460	.01030	.02302	.001
Cu	5	.000	.040	.02000	.008367	.018708	.000

Changes in Water Quality from Source to Point-of-Use.

	5	.01	.04	.0180	.00583	.01304	.000
Zn	5	.01	.04	.0180	.00583	.01304	.000
Fe	5	.00	.04	.0120	.00800	.01789	.000
K	5	10.0	17.0	13.300	1.3379	2.9917	8.950
Al	5	.01	.31	.1060	.05573	.12462	.016
T_coliform	5	12	75	42.40	10.033	22.434	503.300
F_coliform	5	0	0	.00	.000	.000	.000
Valid N (listwise)	0						
a. Sample = MDT1							

2E

Descriptive Statistics[a]

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Ph	5	6.81	7.74	7.1400	.16325	.36503	.133
Temperature	5	25.7	28.4	26.620	.4841	1.0826	1.172
Colour	5	30	115	66.80	16.707	37.359	1.396E3
Turbidity	5	2.66	13.89	6.2960	1.95839	4.37909	19.176
Conductivity	5	277	365	324.40	17.977	40.197	1.616E3
TDS	5	166.2	219.0	196.600	11.3598	25.4012	645.220
TSS	5	3	20	7.60	3.234	7.232	52.300
T_hardness	5	76	88	81.20	2.059	4.604	21.200
Ca_hardness	5	70	80	75.20	1.855	4.147	17.200
Mg_hardness	5	2	12	6.00	2.098	4.690	22.000
Alkalinity	5	126	150	138.60	4.261	9.529	90.800
Calcium	5	28.0	32.0	29.700	.8136	1.8193	3.310
Magnesium	5	.49	2.90	1.9578	.45144	1.00946	1.019
Chloride	5	25	33	28.20	1.463	3.271	10.700
Fluoride	5	.45	1.52	1.2300	.19657	.43955	.193
R_chlorine	0						
Phosphate	5	.26	27.00	9.2140	4.82564	10.79047	116.434
Sulphate	5	5	11	8.00	1.000	2.236	5.000
Nitrate	5	.10	.88	.4900	.12578	.28125	.079
Nitrite	5	.004	.080	.02680	.014009	.031324	.001
Ammonia	5	.00	.02	.0080	.00374	.00837	.000
Mn	5	.002	.008	.00540	.000980	.002191	.000

Changes in Water Quality from Source to Point-of-Use.

Cr	5	.04	.07	.0600	.00548	.01225	.000
Cu	5	.020	.800	.23800	.145890	.326221	.106
Zn	5	.00	.03	.0140	.00510	.01140	.000
Fe	5	.00	.20	.1000	.03162	.07071	.005
K	5	9.6	20.1	15.540	1.7134	3.8312	14.678
Al	5	.07	.12	.0960	.00927	.02074	.000
T_coliform	5	240	2400	1766.00	401.554	897.903	8.062E5
F_coliform	5	93	430	257.00	69.691	155.835	2.428E4
Valid N (listwise)	0						
a. Sample = RSV							

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Changes in Water Quality from Source to Point-of-Use.

Tests of Between-Subjects Effects

Dependent Variable:pH

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.339[a]	4	.085	.852	.506
Intercept	1330.947	1	1330.947	1.340E4	.000
Sample	.339	4	.085	.852	.506
Error	2.483	25	.099		
Total	1440.521	30			
Corrected Total	2.822	29			

a. R Squared = .120 (Adjusted R Squared = -.021)

Tests of Between-Subjects Effects

Dependent Variable:Temperature

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.389[a]	4	.097	.067	.991
Intercept	19527.561	1	19527.561	1.343E4	.000
Sample	.389	4	.097	.067	.991
Error	36.353	25	1.454		
Total	21130.750	30			
Corrected Total	36.742	29			

a. R Squared = .011 (Adjusted R Squared = -.148)

Tests of Between-Subjects Effects

Dependent Variable:Colour

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	15637.000[a]	4	3909.250	5.110	.004
Intercept	32148.900	1	32148.900	42.023	.000
Sample	15637.000	4	3909.250	5.110	.004
Error	19125.700	25	765.028		
Total	63407.000	30			
Corrected Total	34762.700	29			

Changes in Water Quality from Source to Point-of-Use.

Tests of Between-Subjects Effects

Dependent Variable:Turbidity

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	124.190^a	4	31.048	8.927	.000
Intercept	191.610	1	191.610	55.091	.000
Sample	124.190	4	31.048	8.927	.000
Error	86.952	25	3.478		
Total	376.488	30			
Corrected Total	211.142	29			

a. R Squared = .588 (Adjusted R Squared = .522)

Tests of Between-Subjects Effects

Dependent Variable:Conductivity

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	208.967^a	4	52.242	.026	.999
Intercept	2993184.100	1	2993184.100	1.471E3	.000
Sample	208.967	4	52.242	.026	.999
Error	50884.500	25	2035.380		
Total	3295692.000	30			
Corrected Total	51093.467	29			

Tests of Between-Subjects Effects

Dependent Variable:TDS

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	120.562^a	4	30.140	.036	.997
Intercept	1105895.025	1	1105895.025	1.325E3	.000
Sample	120.562	4	30.140	.036	.997
Error	20872.593	25	834.904		
Total	1220353.240	30			
Corrected Total	20993.155	29			

Changes in Water Quality from Source to Point-of-Use.

Tests of Between-Subjects Effects

Dependent Variable:TDS

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	120.562[a]	4	30.140	.036	.997
Intercept	1105895.025	1	1105895.025	1.325E3	.000
Sample	120.562	4	30.140	.036	.997
Error	20872.593	25	834.904		
Total	1220353.240	30			

a. R Squared = .006 (Adjusted R Squared = -.153)

Tests of Between-Subjects Effects

Dependent Variable:TSS

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	208.967[a]	4	52.242	3.705	.017
Intercept	348.100	1	348.100	24.688	.000
Sample	208.967	4	52.242	3.705	.017
Error	352.500	25	14.100		
Total	856.000	30			
Corrected Total	561.467	29			

a. R Squared = .372 (Adjusted R Squared = .272)

Tests of Between-Subjects Effects

Dependent Variable:T_hardness

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	266.800[a]	4	66.700	.566	.690
Intercept	207360.000	1	207360.000	1.759E3	.000
Sample	266.800	4	66.700	.566	.690
Error	2947.200	25	117.888		
Total	230284.000	30			
Corrected Total	3214.000	29			

Changes in Water Quality from Source to Point-of-Use.

Tests of Between-Subjects Effects

Dependent Variable:T_hardness

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	266.800[a]	4	66.700	.566	.690
Intercept	207360.000	1	207360.000	1.759E3	.000
Sample	266.800	4	66.700	.566	.690
Error	2947.200	25	117.888		
Total	230284.000	30			

a. R Squared = .083 (Adjusted R Squared = -.064)

Tests of Between-Subjects Effects

Dependent Variable:Ca_hardness

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	282.167[a]	4	70.542	1.187	.341
Intercept	143041.600	1	143041.600	2.406E3	.000
Sample	282.167	4	70.542	1.187	.341
Error	1486.000	25	59.440		
Total	156569.000	30			
Corrected Total	1768.167	29			

a. R Squared = .160 (Adjusted R Squared = .025)

Tests of Between-Subjects Effects

Dependent Variable:Mg_hardness

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	688.567[a]	4	172.142	1.360	.276
Intercept	5953.600	1	5953.600	47.048	.000
Sample	688.567	4	172.142	1.360	.276
Error	3163.600	25	126.544		
Total	10753.000	30			
Corrected Total	3852.167	29			

Tests of Between-Subjects Effects

Dependent Variable:Alkalinity

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	5049.467[a]	4	1262.367	5.719	.002
Intercept	368896.044	1	368896.044	1.671E3	.000
Sample	5049.467	4	1262.367	5.719	.002
Error	5518.400	25	220.736		
Total	395448.000	30			
Corrected Total	10567.867	29			

a. R Squared = .478 (Adjusted R Squared = .394)

Tests of Between-Subjects Effects

Dependent Variable:Calcium

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	85.509[a]	4	21.377	2.114	.109
Intercept	24209.680	1	24209.680	2.394E3	.000
Sample	85.509	4	21.377	2.114	.109
Error	252.833	25	10.113		
Total	26652.750	30			
Corrected Total	338.342	29			

a. R Squared = .253 (Adjusted R Squared = .133)

Tests of Between-Subjects Effects

Dependent Variable:Magnesium

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	55.776[a]	4	13.944	1.625	.199
Intercept	532.112	1	532.112	61.998	.000
Sample	55.776	4	13.944	1.625	.199
Error	214.569	25	8.583		
Total	897.157	30			
Corrected Total	270.345	29			

Changes in Water Quality from Source to Point-of-Use.

Tests of Between-Subjects Effects

Dependent Variable:Magnesium

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	55.776[a]	4	13.944	1.625	.199
Intercept	532.112	1	532.112	61.998	.000
Sample	55.776	4	13.944	1.625	.199
Error	214.569	25	8.583		
Total	897.157	30			

a. R Squared = .206 (Adjusted R Squared = .079)

Tests of Between-Subjects Effects

Dependent Variable:Chloride

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	17.667[a]	4	4.417	.184	.944
Intercept	20520.900	1	20520.900	855.465	.000
Sample	17.667	4	4.417	.184	.944
Error	599.700	25	23.988		
Total	22867.000	30			
Corrected Total	617.367	29			

a. R Squared = .029 (Adjusted R Squared = -.127)

Tests of Between-Subjects Effects

Dependent Variable:Fluoride

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.174[a]	4	.043	.264	.898
Intercept	40.000	1	40.000	242.608	.000
Sample	.174	4	.043	.264	.898
Error	4.122	25	.165		
Total	48.437	30			
Corrected Total	4.296	29			

Changes in Water Quality from Source to Point-of-Use.

Tests of Between-Subjects Effects

Dependent Variable:Phosphate

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	60.334[a]	4	15.083	.096	.983
Intercept	3194.799	1	3194.799	20.342	.000
Sample	60.334	4	15.083	.096	.983
Error	3926.424	25	157.057		
Total	7672.631	30			
Corrected Total	3986.758	29			

a. R Squared = .015 (Adjusted R Squared = -.142)

Tests of Between-Subjects Effects

Dependent Variable:Sulphate

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	4111.267[a]	4	1027.817	3.799	.015
Intercept	27422.678	1	27422.678	101.354	.000
Sample	4111.267	4	1027.817	3.799	.015
Error	6764.100	25	270.564		
Total	41149.000	30			
Corrected Total	10875.367	29			

a. R Squared = .378 (Adjusted R Squared = .279)

Tests of Between-Subjects Effects

Dependent Variable:Nitrate

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	6.180[a]	4	1.545	2.295	.087
Intercept	22.410	1	22.410	33.282	.000
Sample	6.180	4	1.545	2.295	.087
Error	16.834	25	.673		
Total	53.355	30			
Corrected Total	23.014	29			

Changes in Water Quality from Source to Point-of-Use.

Tests of Between-Subjects Effects

Dependent Variable:Nitrate

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	6.180[a]	4	1.545	2.295	.087
Intercept	22.410	1	22.410	33.282	.000
Sample	6.180	4	1.545	2.295	.087
Error	16.834	25	.673		
Total	53.355	30			

a. R Squared = .269 (Adjusted R Squared = .152)

Tests of Between-Subjects Effects

Dependent Variable:Nitrite

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.015[a]	4	.004	1.717	.178
Intercept	.036	1	.036	16.196	.000
Sample	.015	4	.004	1.717	.178
Error	.056	25	.002		
Total	.126	30			
Corrected Total	.072	29			

a. R Squared = .216 (Adjusted R Squared = .090)

Tests of Between-Subjects Effects

Dependent Variable:Ammonia

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.000[a]	4	.000	.534	.712
Intercept	.004	1	.004	22.816	.000
Sample	.000	4	.000	.534	.712
Error	.005	25	.000		
Total	.009	30			
Corrected Total	.005	29			

Changes in Water Quality from Source to Point-of-Use.

Tests of Between-Subjects Effects

Dependent Variable:Mn

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.000ª	4	.000	1.420	.256
Intercept	.004	1	.004	50.087	.000
Sample	.000	4	.000	1.420	.256
Error	.002	25	8.749E-5		
Total	.007	30			
Corrected Total	.003	29			

a. R Squared = .185 (Adjusted R Squared = .055)

Tests of Between-Subjects Effects

Dependent Variable:Cr

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.002ª	4	.001	1.925	.137
Intercept	.071	1	.071	243.646	.000
Sample	.002	4	.001	1.925	.137
Error	.007	25	.000		
Total	.082	30			
Corrected Total	.009	29			

a. R Squared = .235 (Adjusted R Squared = .113)

Tests of Between-Subjects Effects

Dependent Variable:Cu

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.184ª	4	.046	1.875	.146
Intercept	.211	1	.211	8.610	.007
Sample	.184	4	.046	1.875	.146
Error	.612	25	.024		
Total	.988	30			
Corrected Total	.796	29			

a. R Squared = .231 (Adjusted R Squared = .108)

Changes in Water Quality from Source to Point-of-Use.

Tests of Between-Subjects Effects

Dependent Variable:Zn

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.005[a]	4	.001	.839	.513
Intercept	.016	1	.016	11.539	.002
Sample	.005	4	.001	.839	.513
Error	.034	25	.001		
Total	.060	30			
Corrected Total	.039	29			

a. R Squared = .118 (Adjusted R Squared = -.023)

Tests of Between-Subjects Effects

Dependent Variable:Fe

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.044[a]	4	.011	1.546	.219
Intercept	.057	1	.057	8.028	.009
Sample	.044	4	.011	1.546	.219
Error	.178	25	.007		
Total	.270	30			
Corrected Total	.222	29			

Tests of Between-Subjects Effects

Dependent Variable:K

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	107.205[a]	4	26.801	1.332	.285
Intercept	5688.225	1	5688.225	282.795	.000
Sample	107.205	4	26.801	1.332	.285
Error	502.857	25	20.114		
Total	6903.070	30			
Corrected Total	610.062	29			

Changes in Water Quality from Source to Point-of-Use.

Tests of Between-Subjects Effects

Dependent Variable:Al

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.100[a]	4	.025	6.670	.001
Intercept	.535	1	.535	143.058	.000
Sample	.100	4	.025	6.670	.001
Error	.094	25	.004		
Total	.732	30			
Corrected Total	.193	29			

a. R Squared = .516 (Adjusted R Squared = .439)

Tests of Between-Subjects Effects

Dependent Variable:T_coliform

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	1.232E7[a]	4	3080895.542	10.824	.000
Intercept	6238893.511	1	6238893.511	21.919	.000
Sample	1.232E7	4	3080895.542	10.824	.000
Error	7115724.800	25	284628.992		
Total	2.419E7	30			
Corrected Total	1.944E7	29			

a. R Squared = .634 (Adjusted R Squared = .575)

Tests of Between-Subjects Effects

Dependent Variable:F_coliform

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	262694.067[a]	4	65673.517	16.112	.000
Intercept	98340.278	1	98340.278	24.127	.000
Sample	262694.067	4	65673.517	16.112	.000
Error	101898.900	25	4075.956		
Total	439493.000	30			
Corrected Total	364592.967	29			

a. R Squared = .721 (Adjusted R Squared = .676)

Changes in Water Quality from Source to Point-of-Use.
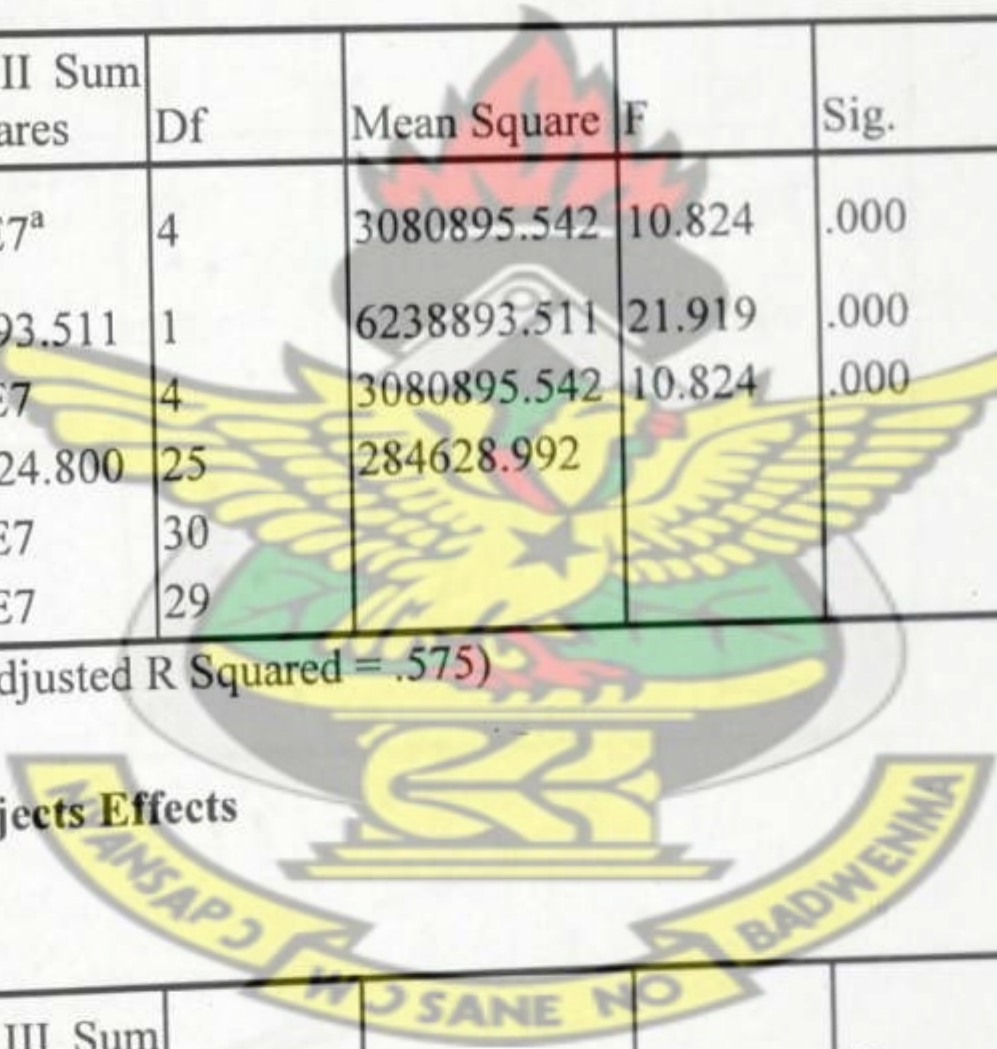
APPENDIX 4

CORRELATIONS

4A

Correlations

Changes in Water Quality		Colour	Turbidity	TSS	Alkalinity
Colour	Pearson Correlation	1	.730**	.922**	.564**
	Sig. (2-tailed)		.000	.000	.001
	N	30	30	30	30
Turbidity	Pearson Correlation	.730**	1	.843**	.564**
	Sig. (2-tailed)	.000		.000	.001
	N	30	30	30	30
TSS	Pearson Correlation	.922**	.843**	1	.468**
	Sig. (2-tailed)	.000	.000		.009
	N	30	30	30	30
Alkalinity	Pearson Correlation	.564**	.564**	.468**	1
	Sig. (2-tailed)	.001	.001	.009	
	N	30	30	30	30

**. Correlation is significant at the 0.01 level (2-tailed).

Changes in Water Quality from Source to Point-of-Use.

Correlations

		Mn	Cr	Cu	Zn	Fe	K	Al
Mn	Pearson Correlation	1	.239	-.201	.089	-.196	-.267	.100
	Sig. (2-tailed)		.203	.288	.640	.299	.154	.599
	N	30	30	30	30	30	30	30
Cr	Pearson Correlation	.239	1	.202	.209	.342	.154	.423[*]
	Sig. (2-tailed)	.203		.286	.268	.064	.416	.020
	N	30	30	30	30	30	30	30
Cu	Pearson Correlation	-.201	.202	1	-.028	.459[*]	-.035	.104
	Sig. (2-tailed)	.288	.286		.884	.011	.856	.585
	N	30	30	30	30	30	30	30
Zn	Pearson Correlation	.089	.209	-.028	1	.177	-.174	.076
	Sig. (2-tailed)	.640	.268	.884		.350	.358	.688
	N	30	30	30	30	30	30	30
Fe	Pearson Correlation	-.196	.342	.459[*]	.177	1	-.088	.145
	Sig. (2-tailed)	.299	.064	.011	.350		.645	.446
	N	30	30	30	30	30	30	30
K	Pearson Correlation	-.267	.154	-.035	-.174	-.088	1	.249
	Sig. (2-tailed)	.154	.416	.856	.358	.645		.185
	N	30	30	30	30	30	30	30
Al	Pearson Correlation	.100	.423[*]	.104	.076	.145	.249	1
	Sig. (2-tailed)	.599	.020	.585	.688	.446	.185	
	N	30	30	30	30	30	30	30

*. Correlation is significant at the 0.05 level (2-tailed).

Changes in Water Quality from Source to Point-of-Use.

Correlations

|		pH	Temperature	Conductivity	TDS	T_hardness
pH	Pearson Correlation	1	-.063	.081	.050	.035
	Sig. (2-tailed)		.742	.671	.791	.852
	N	30	30	30	30	30
Temperature	Pearson Correlation	-.063	1	-.834**	-.848**	.648**
	Sig. (2-tailed)	.742		.000	.000	.000
	N	30	30	30	30	30
Conductivity	Pearson Correlation	.081	-.834**	1	.984**	-.366*
	Sig. (2-tailed)	.671	.000		.000	.047
	N	30	30	30	30	30
TDS	Pearson Correlation	.050	-.848**	.984**	1	-.398*
	Sig. (2-tailed)	.791	.000	.000		.029
	N	30	30	30	30	30
T_hardness	Pearson Correlation	.035	.648**	-.366*	-.398*	1
	Sig. (2-tailed)	.852	.000	.047	.029	
	N	30	30	30	30	30

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Changes in Water Quality from Source to Point-of-Use.

4D

Correlations

		Calcium	Magnesium	Chloride	Fluoride
Calcium	Pearson Correlation	1	-.447*	.136	-.216
	Sig. (2-tailed)		.013	.475	.252
	N	30	30	30	30
Magnesium	Pearson Correlation	-.447*	1	-.304	.409*
	Sig. (2-tailed)	.013		.103	.025
	N	30	30	30	30
Chloride	Pearson Correlation	.136	-.304	1	-.226
	Sig. (2-tailed)	.475	.103		.231
	N	30	30	30	30
Fluoride	Pearson Correlation	-.216	.409*	-.226	1
	Sig. (2-tailed)	.252	.025	.231	
	N	30	30	30	30

*. Correlation is significant at the 0.05 level (2-tailed).

Changes in Water Quality from Source to Point-of-Use.

4E
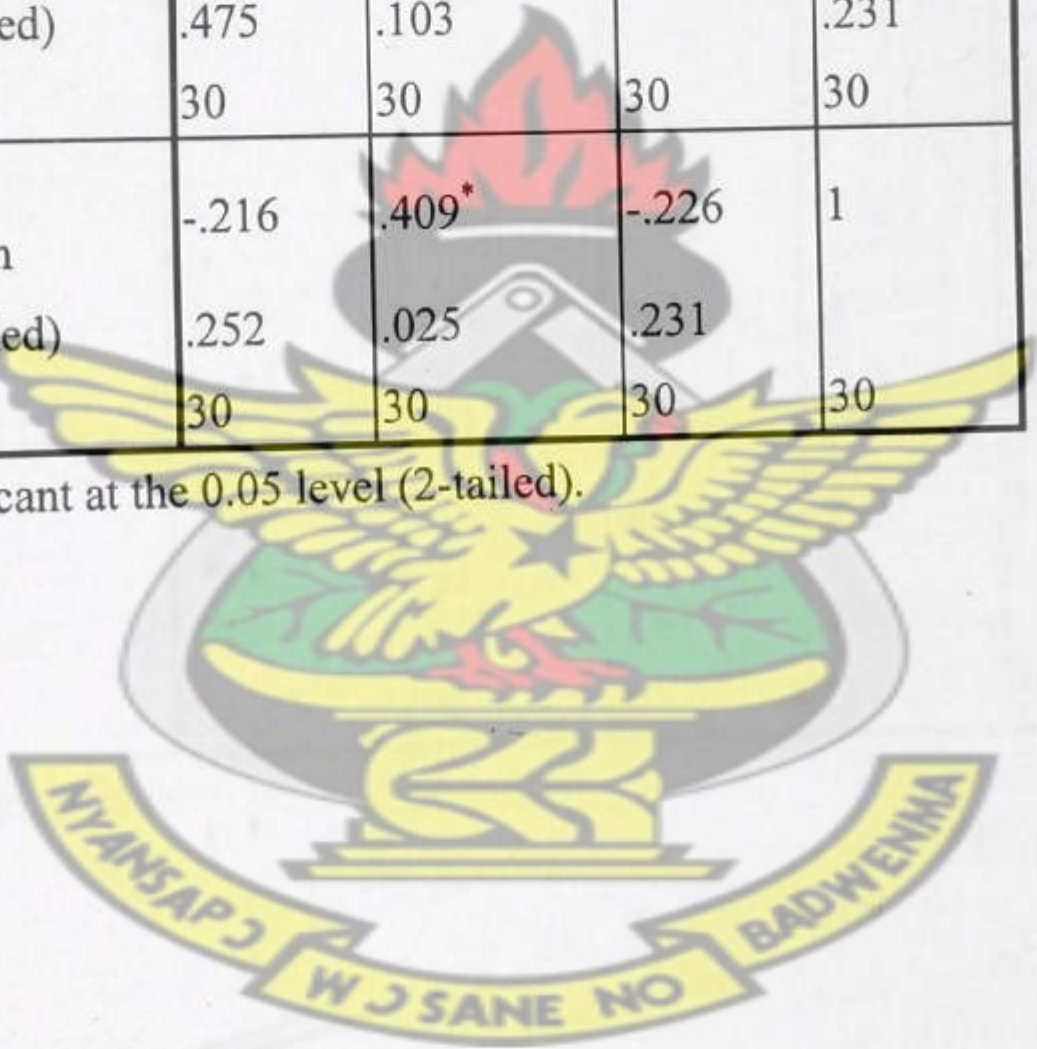
Correlations

		Phosphate	Sulphate	Nitrate	Nitrite	Ammonia
Phosphate	Pearson Correlation	1	-.009	-.147	.171	.389*
	Sig. (2-tailed)		.963	.439	.367	.034
	N	30	30	30	30	30
Sulphate	Pearson Correlation	-.009	1	.289	-.177	-.096
	Sig. (2-tailed)	.963		.122	.348	.613
	N	30	30	30	30	30
Nitrate	Pearson Correlation	-.147	.289	1	.240	-.052
	Sig. (2-tailed)	.439	.122		.201	.787
	N	30	30	30	30	30
Nitrite	Pearson Correlation	.171	-.177	.240	1	.053
	Sig. (2-tailed)	.367	.348	.201		.780
	N	30	30	30	30	30
Ammonia	Pearson Correlation	.389*	-.096	-.052	.053	1
	Sig. (2-tailed)	.034	.613	.787	.780	
	N	30	30	30	30	30

*. Correlation is significant at the 0.05 level (2-tailed).

Changes in Water Quality from Source to Point-of-Use.