KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

KUMASI

ASSESSMENT OF THE QUALITY OF RIVER BUKURUWA AS A DRINKING WATER RESOURCE OF SOME FARMING COMMUNITIES IN THE TECHIMAN MUNICIPALITY

BY

OFORI ISAAC, B.Sc. (Hons.)

Chemistry, KNUST, Kumasi

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DECLARATION

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

OFORI ISAAC (PG 3116109) ---------- ----------

(Student Name & ID) Signature Date

Certified by:

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(Supervisor) Signature Date

Certified by:

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(Head of Dept.) Signature Date

DEDICATION

This work is dedicated to my dearest grandmother Madam Monica Kyeraa and my mother Madam Janet Gyasi for supporting me throughout my education. May God richly bless you.

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ABSTRACT

River Bukuruwa is a prominent river in the Techiman municipality of the Brong Ahafo region of Ghana. It runs through several rural farming communities in the municipality and serves as the main source of drinking water and for other domestic purposes in the communities. An assessment of the quality of the water for drinking purposes was conducted by determining levels of some physico-chemical parameters (pH, colour, total hardness, sulphate, fluoride, phosphate, nitrate, nitrite, conductivity, turbidity), and heavy metals (Fe, Cu, Zn and Pb) as well as enumeration of bacteriological indicators *(E. coli*, faecal coliforms and *Salmonella*) in water samples from the river. Samples were taken from three points along the river at Baamure (upstream point), Kroamoa (midstream point) and Kaniago (downstream point). The results showed that all the investigated physicochemical parameters of water samples from the sampling points were within the minimum permissible limits for drinking water as suggested by WHO except those of pH (5.31 – 6.84), Turbidity(0.00- 6.00 NTU), Nitrite (0.01- 0.7mg/l), Phosphate (0.04 – 4.78mg/l), Conductivity (160 - 455µS/cm) and Colour (0.00 – 185 CU). Atomic Absorption Spectrophotometric (AAS) analysis of samples for dissolved trace metals indicated levels of the investigated metals were within WHO permissible limits except for Pb ($\leq$ 0.01 – 0.05ppm). Bacteriological quality assessment of the water samples also revealed that water samples from all the sampling sites contained indicator bacteria i.e *E. coli* in the range of ($2.58 \times 10^1 - 8.7 \times 10^1$) and faecal coliforms (4.35×10^1 to 3.22×10^2) indicating contamination of the water by materials of faecal origin. *Salmonella* was however not detected in any of the water samples analysed. Water from the Bukuruwa river was therefore found to be unsuitable for drinking purposes.

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LIST OF ABBREVIATIONS

AAS---------- Atomic Absorption Spectrophotometer

ANOVA---------- Analysis of Variance

EPA---------- Environmental Protection Agency

GDP---------- Gross Domestic Product

GWCL---------- Ghana Water Company Limited

MDGs---------- Millennium Development Goals

MPN ---------- Most Probable Number

NTU ---------- Nephelometric Turbidity Units

UNDP ---------- United Nations Development Programme

UNEP ---------- United Nations Environment Programme

UNICEF ---------- United Nations International Children Emergency Fund

WHO ---------- World Health Organization

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Water is essential for the existence of man and all living things and hence a satisfactory (adequate, safe and accessible) supply must be available to all. Improving water access and its quality are necessary for increasing hygiene and sanitation levels that affect productive lives of people, enhance enrolment and retention of children in schools, enhance women's dignity and ability to lead, reduce morbidity and mortality, reduce pre and post natal risks and prevent vector and water borne diseases.(Ghana Government Water Policy document, 2007)

Increasing people's access to sanitation and good drinking water brings large benefits to the development of a country through improvements in health outcomes and economic returns which are estimated by the World Bank to average approximately 2% of GDP (World Bank, 1997).

According to the World Health Organization (2010), the impact of water borne diseases such as diarrhoea on children is greater than the combined impact of HIV/AIDS, tuberculosis and malaria. However the provision of improved sanitation and drinking water could reduce diarrhoeal disease by nearly 90% (WHO/ UNICEF JMP report, 2010).

The two main problems man contends with in relation to water are the quantity (source and amount) and quality (Adeniyi, 2004). The quality of water is a reflection of the source environment and the activities of man including its use and management practices (Oluyemi *et al*, 2010).

In most rural areas in Ghana and other West African countries, the only way to easily access drinking water is from either rivers or streams or for the more fortunate ones, from rudimentary wells: none of which offer water which is potable. Surface water resources hence constitute the basis of existence of a large number of rural dwellers and even in towns and cities in West Africa (Edwards, 1993). However industrial development, harmful sewage and effluent discharge, deforestation and unsustainable land exploitation all tend to threaten the quality of surface water. Moreover, intensified agricultural production also create problems of fertilizer and pesticide runoff and all these deteriorate the quality of the water resource which would have been a reliable source of safe water for the growing population. Contaminants such as bacteria, viruses, heavy metals, nitrates and salts find their way into water supplies as a result of inadequate treatment and disposal of waste (human and livestock), industrial discharges and over-use of limited water resources(Singhl and Mosley, 2003).

These factors have led to the growing rate of water borne diseases such as typhoid fever and cholera experienced in this part of the world (Edwards, 1993). The current status as described by the WHO/UNICEF Joint Monitoring Programme indicates that 2.6 billion people are without improved sanitation and nearly 900 million people lack access to improved source of potable water and this situation is unacceptable (WHO/UNICEF JMP report 2010).

With families living in poverty and local communities often left to look after themselves with none or very little assistance from overstretched or underfunded governments and local communities, a poverty trap is created that simply does not allow for investment in clean water sources and the cycle just continues.

1.2 AIM and OBJECTIVES

1.2.1 Aim

The purpose of this study was to assess the drinking water quality of river Bukuruwa located downstream of the Anyimana landfill in the Techiman Municipality, which serves as drinking water source for the farming communities downstream of the landfill.

1.2.2 Specific objectives

To determine:

1. some physico-chemical parameters i.e. : pH, , PO_4^{3-} , SO_4^{2-} ,NO_3^-, NO_2^-, fluoride, colour, conductivity , turbidity and total hardness of the water sources serving the communities.
2. concentrations of Fe, Pb, Cu, and Zn from water samples collected from the river
3. the levels of faecal coliforms, *E.coli and Salmonella* in the water samples.

1.3 JUSTIFICATION

Despite the clear benefits of improved sources of potable water for human development, many developing countries including Ghana seem to allocate insufficient resources to meet the millennium development goal (MDG) target for sanitation and potable water. There are also great inequalities in access to clean water and sanitation (UNEP, 2009). In high income areas of cities and other urban centres in Ghana and other sub-Saharan African countries people enjoy access to several hundred litres of water a day delivered into their homes at low prices by public utilities. Meanwhile slum dwellers and poor households in rural areas of the same countries have access to much less than 20 litres of water per day (UNEP, 2009)

The above is the case of the rural farming communities located a few kilometers downstream of the Anyimana landfill site in the Techiman Municipality of the Brong Ahafo region of Ghana.

The landfill is unlined or unengineered and serves as the final disposal grounds for municipal solid waste and sewage collected from various neighbourhood trash bins and public and private toilet facilities within the Techiman Municipality. Leachates from the landfill site is believed by the people in the communities to contaminate the Bukuruwa River which flows through some communities and serves as the main drinking water sources for these communities.

The communities along the river use the water mainly for domestic purposes like cooking, drinking, washing and bathing and thus this water source is estimated to supply most of their drinking water needs. Dry season farmers also prepare their nursery beds close to the river and use some of the water for irrigation. The utility of water is limited by its quality. Potential pollution of these streams by the upland landfill coupled with other human activities and depletion of their resources can put the lives of many people in danger. Unfortunately there is no

information on the influence of the landfill on the drinking water resources of these communities even though the communities believe that their water resources are heavily polluted. Moreover the water quality parameters of these communities have not been extensively studied and hence the types and levels of pollutants are unknown.

The mechanism and extent of stream pollution is better understood when the physical, chemical and microbiological parameters of the water are studied.

Determination of physico-chemical parameters will lead one to discover the extent to which human activities such as waste disposal, farming activities etc have impacted on the quality of water serving as drinking water source for the said farming communities.

Heavy metals concentration determination is necessary since high concentrations of these metals cause significant health effects on aquatic life and also on humans who depend on the water resource from this river.

Bacteriological indicators such as faecal coliforms and *E.coli* can enter streams by direct discharge or run-offs. The presence of both faecal coliforms and *E.coli* is indicative of the unsuitability of the stream water for domestic activities such as for drinking and cooking. Therefore constant monitoring of water from the river which serves some of these rural population is needed so as to record any alteration in the quality which may lead to outbreak of health disorder or serious health effect. The water quality data are thus essential for the implementation of responsible water quality regulations for characterizing and remediating contamination. It is hoped that the outcome of this work will provide policy makers with vital information to enable them act accordingly to providing potable water resources for these communities.

CHAPTER TWO

2.0 LITERATURE REVIEW

2. 1 Water, the Elixir of Nature

Water is a necessity for all living beings without which there would be no life. Life originated in water and the ultimate basis of it; the protoplasm of a cell is a colloidal solution of complex organic molecules in a watery medium (70-90% water) [Krishnan R., 2008]. Most biological phenomena take place in a water medium and therefore wherever water exists in nature it always holds life.

It is essential to circulation of body fluids in plants and animals, and it stands as the key substance for the existence and continuity of life through reproduction and different cyclic processes in nature (Krishnan R., 2008).

Natural water has an innate mechanism to maintain its purity after every natural use, but it is unable to do this at the rate at which humans add several pollutants and toxins flowing from industry, agriculture, domestic and other sources. Humans are bound therefore to monitor the impact of this activity on natural freshwater continuously (Krishnan, R. 2008)

2.2 Overview of Global Access to Drinking Water

Potable water or drinking water is water of sufficiently high quality that can be consumed or used with low risk of immediate or long term harm (http/www.bbc.co.uk/health living). Access to drinking water and improved sanitation is a fundamental need and a human right which is vital for the dignity and health of all people. The Millennium Development Goal (MDG) target '7c' calls for reducing by half the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015. Reaching this target implies, inter alia tackling both the quantity (access, scarcity) and quality (safety) dimensions of drinking water provision (WHO guidelines for drinking water, 2010).

The health and economic benefits of improved water supply to households and individuals (especially children) are both indicators used to monitor progress towards the Millennium Development Goals (MDGs) [WHO/UNICEF, 2004].

The most frequently used definition of safe water accessibility is that of the United Nations Development Programme (UNDP) which states that, those with access comprise "the proportion of the population using any piped water, public tap, borehole with a pump, protected well and springs or rainwater" (UNDP, 2002)

The World Bank also provides various definitions dependent on the type of residential area being assessed. In urban areas, such a source (of safe drinking water) may be a public fountain or standpoint located not more than 200 meters away and in rural areas access implies that; members of the household do not have to spend a disproportionate part of the day fetching water.(World Bank Dev't report, 1997).

The use of improved sources of drinking water is high globally, with 87% of the world population and 84% of the people in developing regions getting their drinking water from such sources (WHO/UNICEF JMP Report, 2010). Even so, 884 million people in the world today still do not get their drinking water from improved sources; almost all of them are in developing regions. Sub-Saharan Africa accounts for over a third of that number and is lagging behind in the progress towards the Millennium Development Goal target with only 60% of the population using improved sources of drinking water despite an increase of 11% percentage points since 1990 (WHO/UNICEF JMP Report 2010).

The rural population without access to an improved drinking water resource is over five times greater than that in urban areas. Of almost 1.8 billion gaining access to improved water in the period 1990 — 2008, 59% live in urban areas. In urban areas however the increase in coverage is barely keeping pace with population growth (WHO/UNICEF JMP Report 2010). In Ghana for instance, it is estimated that approximately 10.3 million people (51%) have access to improved water supplies and for the 8.4 million residents in the country's urban areas this increases slightly to 61% with two thirds of these or 40% of the total urban population covered by the Ghana Water Company Limited (GWCL) networks. The estimated rural water supply coverage is much lower at 44% (Water Aid Report, 2008).

2.3 Water quality

Water quality is a measure of the condition of water relative to the requirements of one or more biotic species and to any human need or purpose and it is most frequently used by reference to a set of standards against which compliance can be assessed. (Diersing- Nancy, 2009).

Water quality parameters include the physical, chemical and biological characteristics of water. Monitoring the quality of water facilitates evaluation of nature and extent of pollution, effectiveness of pollutant control measures, water quality trends and prioritization of pollution control efforts (Abid *et al.*, 2005).

The quality of drinking water is a powerful environmental determinant of health. Drinking water quality management has been a key pillar of primary prevention for over one and a half centuries and it continues in all continents – from the poorest to the wealthiest. The most predominant water borne disease, diarrhoea has an estimated annual incidence of 4.6 billion episodes and causes 2.2 million deaths per year (WHO, 2010).

Environmental water quality also called ambient water quality relates to water bodies such as lakes, rivers and oceans but water quality standards for surface waters vary significantly due to different environmental conditions, ecosystems and intended human uses.

Lamb (1985) noted that the evaluation of the quality of a stream or lake or any water body/source must consider both;

(1) Concentrations of various constituents in water and

(2) Uses the resource will be called on to satisfy.

Quality can therefore be judged accurately by comparing concentrations of various constituents in water with those that would be optimum for the intended use.

2.4 Water pollution

Water pollution may be defined as any physical, biological or chemical change in water quality that adversely affects living organisms or makes water unsuitable for desired uses (Fei- Baffoe, 2008).

Another definition indicates that, water is polluted when it contains enough foreign material to render it unfit for a specific beneficial use such as for drinking, recreation or fish propagation. (Fei- Baffoe, 2008).

Water pollution usually occurs when pollutants are discharged directly into water bodies without adequate treatment to remove harmful compounds which affects plants and other organisms living in these bodies of water and in almost all cases the effect is damaging not only to individual species and population, but also to the natural biological communities (http//environment.about.com/environmental events/waterdayqa.htm)

Water pollution is a major global problem which requires ongoing evaluation and revision of water resource policy at all levels (international down to individual aquifers and wells) and has been suggested as the leading worldwide cause of deaths of more than 14,000 people daily. (http/environment.about.com/environmental events/waterdayqa.htm).

Water pollutants can be classified according to the nature of origin or into groups of substances based primarily on their environmental or heath effects. According to the nature of its origin, water pollutants could be classified as Point Source Pollutants (PS) or Non-point Source Pollutants (NPS). A point source is one that reaches the water from a pipe, channel or any other confined and localized source such as discharges from a sewage treatment plant, a factory or a city storm drain.

A non-point or dispersed source is broad, unconfined area from which pollutants enter a body of water; e.g. Surface run-off from agricultural areas carries silt, fertilizers pesticides and animal waste into streams but not at one particular point (Fei Baffoe, 2008)

Other classes of water pollutants are based on their environmental or health effects and may include inorganic chemicals, organic chemicals, oxygen depleting wastes, radioactive materials and thermal pollution.

2.5 PHYSICOCHEMICAL ASSESSMENT OF WATER QUALITY.

Physicochemical parameters are the physical and chemical parameters associated with water which have an influence on its quality and also affect the biological constituents of the water (Oluyemi *et al*, 2010). The physical factors such as temperature, colour, turbidity and conductivity can affect the aesthetics and taste of the water and may also complicate the removal of microbial pathogens during water treatment. The chemical parameters include pH, alkalinity, hardness, anions such as sulphates, phosphates, nitrates, nitrites, fluoride etc, as well as heavy metals which often tend to pose more chronic health risks through the build up of the metals, even though some other components like nitrates, nitrites and arsenic can have a more immediate impact on consumers (http/en.wikipedia.org/wiki/drinking water)

2.5.1 Colour

Colour of water is one of the most important and conveniently observed indicators of its quality. The highest quality drinking water should be colourless (WHO, 2008*).* Potential inorganic, organic or bacteriological contributions of colour to natural water are;

(a) inorganic constituents such as dissolved iron

(b) dissolved organic substances like humic or fulvic acids, from anthropogenic sources such as dyes and

(c) Suspended particulate matter such as plant debris, phytoplankton and zooplanktons.

Some of these contributors may be harmless but others are definitely harmful. Suspended organic matter may itself be harmless but may harbour bacterial and viral contaminants which may be harmful to health.

Traditionally, the colours of liquids including drinking water are classified according to the Alpha/Hazen/Pt-Co colour scale (Abid *et al*, 2005). WHO suggest that, water of colour below 15 Colour Units (CU) is acceptable to consumers although no health based guideline value is proposed for colour in drinking water. (WHO, 2008)

2.5.2 Total hardness

Water hardness is the traditional measure of the capacity of water to react with soap, with hard water requiring considerably more soap to produce lather (Neri *et al*, 1978).

Hardness of water is not caused by a single substance but by a variety of dissolved polyvalent metallic cations mainly calcium and magnesium although other cations such as Barium, Iron, Manganese, Strontium and Zinc may also contribute. The principal natural sources of hardness in water are dissolved polyvalent metallic ions from sedimentary rocks, seepage and run-offs from soils. Ca and Mg, the two principal ions are present in many sedimentary rocks, the most common being limestone and chalk. They are also present in a wide variety of industrial products and are common constituents of food as well (McGowan 2000).

Hardness is most commonly expressed as mg/l of $CaCO_3$. Water containing less than 60mg of $CaCO_3$ per liter generally is considered as being soft. Concentrations of up to 100 mg of $CaCO_3$ per liter are fairly common in natural sources of water; whilst sources containing 200mg of $CaCO_3$ per liter are rare (McGowan, 2000).

Mg salts are soluble in water with natural sources typically containing concentrations of up to 10mg/l. Natural sources rarely contain more than 100mg of Mg per liter and it is usually Ca hardness that predominates. (National Research Council, 1997)

In drinking water, hardness is in the range of 10-500mg $CaCO_3$ per liter (Marie *et al*, 1975). It appears there is no convincing evidence to indicate that water hardness causes adverse health effects in humans however the results of a number of epidemiological studies have suggested that there is an inverse relationship between the hardness of drinking water and cardiovascular diseases (Anderson *et al*, 1995) but in some other studies no such association has been found. (Mackinnon *et al*, 1980).

Depending on the interaction of other factors such as pH and alkalinity, water with hardness above approximately 200mg/l may cause scale deposition in the treatment works, distribution system and pipe work and tanks within buildings (WHO, 2008)

2.5.3 pH

pH is a measure of the acidity or alkalinity of a solution. Pure water is said to be of neutral pH which is approximately 7.0 at 25^0C. Although pH usually has no direct impact on consumers, it is one of the most operational water quality parameters (WHO, 2008). Careful attention to pH control is necessary at all stages of water treatment to ensure satisfactory water clarification and disinfection. For effective disinfection with chlorine, the pH should preferably be less than 8,

however lower pH water is likely to be corrosive. Failure to minimize corrosion can result in the contamination of drinking water and have an adverse effect on its taste and appearance. WHO guidelines suggest that the optimum pH required in drinking water should be in the range 6.5-8.5 (WHO, 2008).

2.5.4 CONDUCTIVITY

Conductivity is a measure of the ability of water to pass on or transmit an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids such as chlorides, nitrates, sulphates, phosphate anions or sodium, magnesium, calcium, iron and aluminum cations (US EPA, 1996) .Organic compounds like oil, phenol, alcohol and sugar do not conduct electrical current very well and therefore have low conductivity when in water.

Conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows (Kortatsi, 2006). Streams that run through areas with granite bedrock tend to have lower conductivity because granite is composed of more inert materials that do not ionize (dissolve into ionic components) when washed into the water. On the other hand, streams that run through areas with clay soils tend to have relatively higher conductivity because of the presence of materials that ionize when washed into the water. Groundwater inflows can have the same effects depending on the bedrock they flow through (Kortatsi, 2006). Conductivity is useful as a general measure of stream water quality because each stream tends to have a relatively constant range of conductivity, thus once established can be used as a baseline for comparison with regular conductivity measurements (Kortatsi, 2006). Significant changes in conductivity could then be an indication that a discharge or some other sources of pollution has entered a stream.

2.5.5 NITRATES (NO_3^-) and NITRITES (NO_2^-)

Nitrates and nitrites are naturally occurring ions that are part of the nitrogen cycle. Nitrates are normally present in natural, drinking and waste waters. Nitrates enter water supplies from the breakdown of natural vegetation, the use of chemical fertilizers in modern agriculture and from the oxidation of nitrogen compounds in sewage effluents and industrial wastes.

The nitrate concentration in groundwater and surface water is normally low but can reach higher levels as a result of leaching or run-off from agricultural land or contamination from human or animal waste as a consequence of the oxidation of ammonia and similar sources (WHO, 2003).

Anaerobic conditions may result in the formation and persistence of nitrite. The formation of nitrite is as a consequence of microbial activity and may be intermittent.

The primary health concern regarding nitrate and nitrite is the formation of methaemoglobinaemia, so called "blue baby syndrome". In this condition nitrate is reduced to nitrite in the stomach of infants and nitrite is able to oxidize haemoglobin (Hb) to methaemoglobin (met Hb) which is unable to transport oxygen around the body. Studies with nitrite in laboratory rats have reported hypertrophy of the adrenal zona glomenulosa (WHO, 2003). N- Nitrosodimethylamine(NDMA) which may be produced as a by- product of industrial processes that use nitrates and/or nitrites and amines under a range of pH has also been found as a potent carcinogen in drinking water (WHO, 2002). The WHO suggests a guideline value of 50mg/l of nitrate in drinking water to protect against methaemoglobinaemia in bottle fed infants and 0.2mg/l as a provisional guideline value for nitrite. (WHO, 2008).

2.5.6 SULPHATE

Sulphates occur naturally in numerous minerals and are used commercially, especially in the chemical industry. They are discharged into water in industrial wastes and through atmospheric deposition; however the highest levels usually occur in groundwater and are from natural sources (WHO, 2008). The existing data do not identity a level of sulphate in drinking water that is likely to cause adverse human health effects. A study from a liquid diet piglet and from tap water studies with human volunteers revealed a laxative effect at concentrations of 1000-1200mg/l with no increase in diarrhoea, dehydration or weight loss (WHO, 2008).

No health based permissible limit is proposed for sulphate, however because of the gastrointestinal effects resulting from ingestion of drinking water containing high sulphate levels, it is recommended that health authorities be notified of sources of drinking water that contain sulphate concentrations in excess of 500mg/liter (WHO, 2008). The presence of sulphate in drinking-water may also cause noticeable taste and may contribute to the corrosion of distribution systems. (WHO, 2008).

2.5.7 FLUORIDE

Fluoride accounts for about 0.3kg of the earth's crust and exist in the form of fluorides in a number of minerals (WHO, 2008). The most important source of fluoride in drinking water is naturally occurring. Fluorides can be released into the environment from the phosphate containing rock used to produce phosphate fertilizers. These phosphate deposits contain about 4% of fluoride (WHO, 2008). Daily exposure to fluoride depends mainly on the geographical area. In most circumstances, food seems to be the primary sources of fluoride intake, with lesser

contributions from drinking water and toothpaste. In areas with relatively high concentrations, particularly in groundwater, drinking water becomes increasingly important as a source of fluoride.

Epidemiological studies of possible adverse effects of long term ingestion of fluoride via drinking water clearly established that fluoride primarily produces effects on skeletal tissues (bones and teeth) [WHO, 2008]. Low concentrations provide protection against dental caries especially in children. Flouride can also have an adverse effect on tooth enamel and may give rise to mild dental fluorosis at drinking water concentrations between 0.9 and 1.2mg/l depending on intake WHO suggest a guideline value of 1.5mg/liter in drinking water (WHO, 2008).

2.5.8 PHOSPHATE

Phosphate exists in three forms in water; orthophosphate, metaphosphate (or polyphosphate) and organically bound phosphate. Each compound contains phosphorus in a different chemical state. Organic phosphates are important in nature. Their occurrence may result from the breakdown of organic pesticides which contain phosphates. Phosphates enter water ways from human and animal wastes, phosphorus rich bedrock, industrial effluents and fertilizer runoff from agriculture. This stimulates the wild growth of algae and aquatic plants which choke up the waterway and use large amount of oxygen a condition known as eutrophication or over-fertilization of receiving waters. This process causes the death of aquatic life because of the lowering of dissolved oxygen levels. In a river or stream, the turbulent nature of the flowing water might however prevent the development of algae and aquatic plants. (Fei Baffoe, 2008)

Phosphate are not toxic to people or animals unless they are present in very high levels, which could cause digestive problems. (http//www. water research.net /watershed/phosphates.htm)

2.6 Heavy metals

The term heavy metal refers to any metallic chemical element that has a specific gravity that is at least five (5) times the specific gravity of water (Osei Akoto, 2009). Specific gravity is a measure of density of a given amount of a solid substance when it is compared to an equal amount of water. Heavy metals are also toxic or poisonous at low concentrations examples include mercury (Hg), lead (Pb) copper(Cu), and Zinc(Zn) [http:enmedicine.medscape.com/article/814960]

Heavy metals are natural components of the earth's crust but they cannot be degraded, however to a small extent they enter our bodies via food, drinking water and air. As trace elements, some heavy metals (e.g. Cu, Se, and Zn) are essential to maintain the metabolism of the human body but at higher concentrations they can lead to poisoning. Heavy metals are dangerous because they tend to bioaccumulate; a process which results in an increase in the concentration of a chemical in a biological organism over time compared to the chemicals concentration in the environment. Heavy metals can enter a water supply by industrial and consumer waste or even from acidic rain breaking down soil and releasing the metals into streams, lakes, rivers and groundwater. (http:www.lentch.com/heavy metals .htm).

2.6.1 Copper

Copper is both an essential element and a drinking water contaminant. The concentration of copper in water varies widely with the primary source most often being the corrosion of interior copper plumbing.

Levels in running or fully flushed water tend to be low, whereas those in standing or partially flushed water are more variable and can be substantially higher (frequently > 1mg/l). Recent

studies have delineated the threshold for the effects of copper in drinking water on the gastrointestinal tract, but there is still some uncertainty regarding the long term effects of copper on sensitive populations such as carriers of the gene for Wilson disease and other metabolic disorders of copper homeostasis. (WHO, 2008).

2.6.2 Lead (Pb)

Lead is used principally in the production of lead –acid batteries, solder and alloys. The organolead compounds tetraethyl and tetramethyl lead have also been used extensively as antiknock and lubricating agents in petrol, although their use for these purposes in many countries is being phased out (WHO, 2008).

Owing to the decreasing use of lead containing additives in petrol and of lead containing solder in the food processing industry, concentration in air and food are declining, and intake from drinking water constitute a greater proportion of total intake (WHO, 2008).

Lead is rarely present in tap water as a result of its dissolution from natural sources; rather its presence is primarily from household plumbing systems containing lead in pipes, solder fittings or the service connections to homes.

The amount of lead dissolved from the plumbing systems depends on several facts including pH, temperature, and water hardness and standing time of the water, with soft acidic water being the most plumbosolvent. Concentrations in drinking water are generally below 5ug/l although much higher concentrations (above 100ug/litre) have been measured where lead fittings are present (WHO, 2008).

Lead is a general toxicant that accumulates in the skeleton. Infants and children up to 6 years of age are most susceptible to its adverse health effects (WHO, 2008). Lead also interferes with calcium metabolism both directly and by interfering with vitamin D metabolism. Lead is toxic to both the central and peripheral nervous system, inducing supencephalopathic neurological and behavioral effects. Results from epidemiological studies also suggest that prenatal exposure to lead may have early effects on mental development that do not persist to the age of 4 years. There is also evidence from studies in humans that adverse neurotoxic effects other than cancer may occur at very low concentrations (WHO, 2008)

WHO proposes a guideline value of 0.01mg/l in drinking water.

2.6.3 Iron

Iron is one of the most abundant metals in the earth crust. It is found in natural fresh waters at levels ranging from 0.5-50 mg/l. Iron may also be present in drinking water as a result of the use of iron coagulants or the corrosion of steel and cast pipes during water distribution. Iron is mainly present in water in two forms: either the soluble ferrous iron or the insoluble ferric iron. Water containing ferrous iron is clear and colourless because the iron is completely dissolved. When exposed to air in the pressure tank or atmosphere, the water turns cloudy and a reddish brown substance begins to form.

Iron is an essential element in human nutrition. It helps transport oxygen in the blood. Estimates of the minimum daily requirement for iron depends on age, sex, physiological status and iron bio availability and range from about 10 to 50mg/day (WHO, 2003). Iron is not hazardous to health, but it is considered a secondary or aesthetic contaminant.

2.6.4 Zinc

Zinc is a very common substance that occurs naturally. Many foodstuffs contain certain concentrations of zinc. Drinking water also contain certain amounts of zinc which may be higher when it is stored in metal tanks, however zinc concentrations are rising unnaturally due to addition of zinc through human activities (http//www.lentech.com/periodic/elements.zn.htm). Some soils are heavily contaminated with zinc and these are found in areas where zinc is mined or refined or where zinc sewage sludge is used as fertilizer. In natural surface waters, the concentration of zinc is usually below 10µg/l and in groundwater's; 10 - 40µg/l (Nriagu, 1980)

Food poisoning attributable to the use of galvanized zinc containers in food preparation has been reported; a situation in which symptoms occurred within 24hrs and included nausea, vomiting and diarrhea accompanied by bleeding and abdominal cramps (Elinder, 1980). Drinking water containing zinc at levels above 3mg/l tends to be opalescent, develops a greasy film when boiled and has an undesirable taste (WHO, 2003)

2.7 Bacteriological hazards associated with drinking water.

The greatest risk from microbes in water is associated with consumption of drinking water that is contaminated with human excreta, although other sources and routes of exposure may also be significant (WHO, 2008).

Infectious diseases caused by pathogenic bacteria, viruses and parasites (e.g. protozoa and helminthes) are the most common and widespread health risks associated with drinking water. Some of these pathogens that are known to be transmitted through contaminated drinking water

lead to severe and sometimes life threatening diseases like typhoid, cholera, infectious hepatitis (caused by A virus [HAV or HEV] and diseases caused by *Shigella spp and E- coli O157*. Others are typically associated with less severe outcomes such as self limiting diarrhoeal disease e.g.; Norovirus and Cryptosporidium

The number of known pathogens for which water is a transmission route continue to increase as new or previously unrecognized pathogens continue to be discovered (WHO, 2003)

2.8 INDICATOR ORGANISMS

Indicator organisms are used to measure potential feacal contamination in water. In water quality analysis it may be possible to isolate microbial pathogens from contaminated water especially when it is heavily polluted, however large volumes (several litres) of the water may be required , selective media are required for isolation and the subsequent identification of the organisms involves biochemical, serological and other tests on pure cultures. Reliance is therefore placed on relatively simple and more rapid bacteriological tests for the detection of certain commensal intestinal bacteria (especially *E . coli* and other coliform bacteria) as indicator organisms. This is because they are easier to isolate and characterize and also present always in feaces of man and warm blooded animals and hence in sewage in large numbers. The presence of such feacal indicator organisms in a sample of drinking water thus denotes that intestinal pathogens could be present, and that the supply is therefore potentially dangerous to health (Berg, 1978)

2.8.1 Faecal coliforms

A feacal coliform is a facultatively anaerobic rod shaped gram negative, non sporulating bacterium. Feacal coliform are capable of growth in the presence of bile salts or similar agents, are oxidase negative and produce acid and gas from lactose within 48hrs at 44+ 0.50^{o}C (Doyle, 2006).

The presence of faecal coliform bacteria in aquatic environments indicates that the water has been contaminated with a feacal material of man or animals. Feacal coliform bacteria can enter rivers through direct discharge of waste from mammals and birds, from agricultural and storm runoff and from untreated human sewage. Individual home septic tanks can become overloaded during the rainy season and allow untreated human waste to flow into drainage ditches and nearby waters.

Agricultural practices such as allowing animal wastes to wash into nearby streams during the rainy season, spreading manure and fertilizer on fields during rainy periods and allowing livestock watering in streams can all contribute to feacal coliform contamination. Feacal coliform bacteria do not directly cause diseases, but high quantities suggest the presence of disease causing agents. Feacal coliforms like other bacteria can usually be killed by boiling water or treating with chlorine. Washing thoroughly with soap after contact with contaminated water can also help prevent infections.

2.8.*2* *E- coli*

Escherichia coli (commonly abbreviated *E. coli*) is a gram negative rod shaped bacterium that is commonly found in the lower intestines of warm blooded organisms.

E- coli and related bacteria constitute about 0.1% of gut flora (Eckburg *et al*, 2005) and faecal oral transmission is the major route through which pathogenic strains of the bacterium cause diseases. Cells are able to survive outside the body for a limited amount of time which makes them ideal organisms to test environmental samples for faecal contamination. *E. coli* can be differentiated from other thermotorelant coliforms by the ability to produce indole from typtophan or by the production of the enzyme β-glucuronidase.

E. coli is present in very high numbers in human and animal faeces and is rarely found in the absence of faecal pollution. It is considered the most suitable index of faecal contamination and as such it is the first organism of choice in monitoring programmes for verification, including surveillance of drinking water quality (Asbolt *et al*, 2001). Water temperatures and nutrient conditions present in potable water distribution systems are highly unlikely to support the growth of these organisms (Grabow, 1996)

2.8.3 *Salmonella*

Salmonella spp. belong to the family of enterobacteriaceae. They are motile gram negative bacilli that do not ferment lactose but most produce hydrogen gas from carbohydrate fermentation (Clarke, 1987)

Common species include *Salmonella enterica* or *Salmonella cholaesius*, *Salmonella bongori* and *Salmonella typhi*. All of the enteric pathogens except S. typhi are members of the species of *Salmonella enterica*.

Salmonella infections typically are zoonotic and can be transferred between humans and non human animals. The pathogens typically gain entry into water systems through feacal contamination from sewage discharges, livestock and wild animals. Salmonella can survive for weeks outside a living body and are not destroyed by freezing. However UV-radiation and heat accelerate their demise (Sorrell *et al*, 1970)

Salmonella infections cause four clinical manifestations: gastroenteritis (ranging from mild to fulminant diarrhoea, nausea and vomiting) bacteraemia or septicaemia (high spiking fever with positive blood cultures), typhoid fever/ enteric fever sustained fever with or without diarrhoea) and a carrier state in persons with previous infections (Angulo *et al*, 1997). Typhoid fever is a more severe illness and can be fatal. Over 16 million people worldwide are infected with typhoid fever each year with 500,000 to 600,000 fatal cases

(WHO, 2003).

2.9 Self purification of rivers

Running water is capable of purifying itself with distance through a process known as self purification; the ability of a river to purify itself of sewage or other waste naturally. The self purification mechanism of rivers can be in the form of dilution of polluted water with influx of surface and groundwater or through certain complex hydrologic, biologic and chemical processes such as sedimentation, coagulation, volatilization, precipitation of colloids and its subsequent settlement at the base of the channel or due to biological uptake of pollutants.

On the other hand certain streams are capable of adding up more materials as they flow downstream through riparian inputs (Ongley, 1991)

The extent of self purification in any stream depends on certain factors some which are temperature, level of river, river velocity, amount of inorganic compound in the river or stream and the types of aquatic weeds along the channel.

In a study of the self purification of fresh water stream in Ile- Ife a typical Nigerian urban town, Ifabiyi (2008) observed that some water quality parameters under study decreased in their concentration as the stream flowed downstream whilst other parameters had their concentrations increasing. The decrease in concentration was attributed to processes such as coagulation, sedimentation and volatilization whereas the increase was assigned to effects of riparian inputs or plants senescence along the river channel. A similar study by Ajibade (2004) reported of either an increase or decrease in concentration of water chemical parameters in the study area.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study area

The Techiman municipality within which the study was conducted is one of the administrative districts in the Brong Ahafo region of Ghana. It is located on latitude 7^0 34' 38N, longitude 1^0 55' 45W and shares common boundaries with Wenchi district to the north and west, Kintampo South district to the north east, Nkoranza South district in the south east and Offinso district of the Ashanti region to the south. Techiman, the municipal capital is the second largest town in the region. It is 126km north west of Kumasi and 392km from Accra. The municipality is home to the famous Techiman market, the largest food crop market in Ghana. Its strategic location as a commercial centre and a major transit point attracts a large number of people in and out of the municipality daily for business (Kortatsi and Quansah, 2004).

The municipality has two main seasons that is the rainy and dry seasons. The major rains start from April to July and the minor from September to November whereas the dry season starts from November and lasts till March . The highest rainfall is 1650mm recorded in the south west and declines northwards to about 1250mm and the temperature ranges between 26 and 30^0 C

The municipality has three main vegetation zones namely; the guinea savannah woodland located in the north- west, semi deciduous zone located in the south and the transitional zone which stretches from the south east and west up to the north of the municipality (Techiman Municipal Assembly).

Regarding the geology of the area, sandstones of the Upper Voltain underlie Techiman. Due to the moderately high rainfall the rocks are largely weathered into a mixture of sand and clay.

Other rocks types of the area include rocks of the upper Birimian formation (Metamorphosed lavas, pyroclastic rocks and hypabyssal basic intrusives) [Kortatsi and Quansah, 2004].

River Bukuruwa (the river under study) rises out of a spring located at Baamure in the south-east of the Techiman municipality , runs eastwards through some farming communities in the Techiman municipality and merges with river Fia at a site within the Kaniago forest (a rural farming community in the Techiman municipality (Survey department of Ghana, 1977)

3.2 Sampling sites.

Three sampling points (Fig 1.0) were purposefully selected along river Bukuruwa for water sampling. These included the Baamure sampling point which is at the upstream end of the river, the Kroamoa sampling point which is at the midstream portion and the Kaniago site which represents the downstream part of the river. For the selection of the sampling points within the said communities preference was given to points where water is fetched by the people for drinking and other domestic purposes.

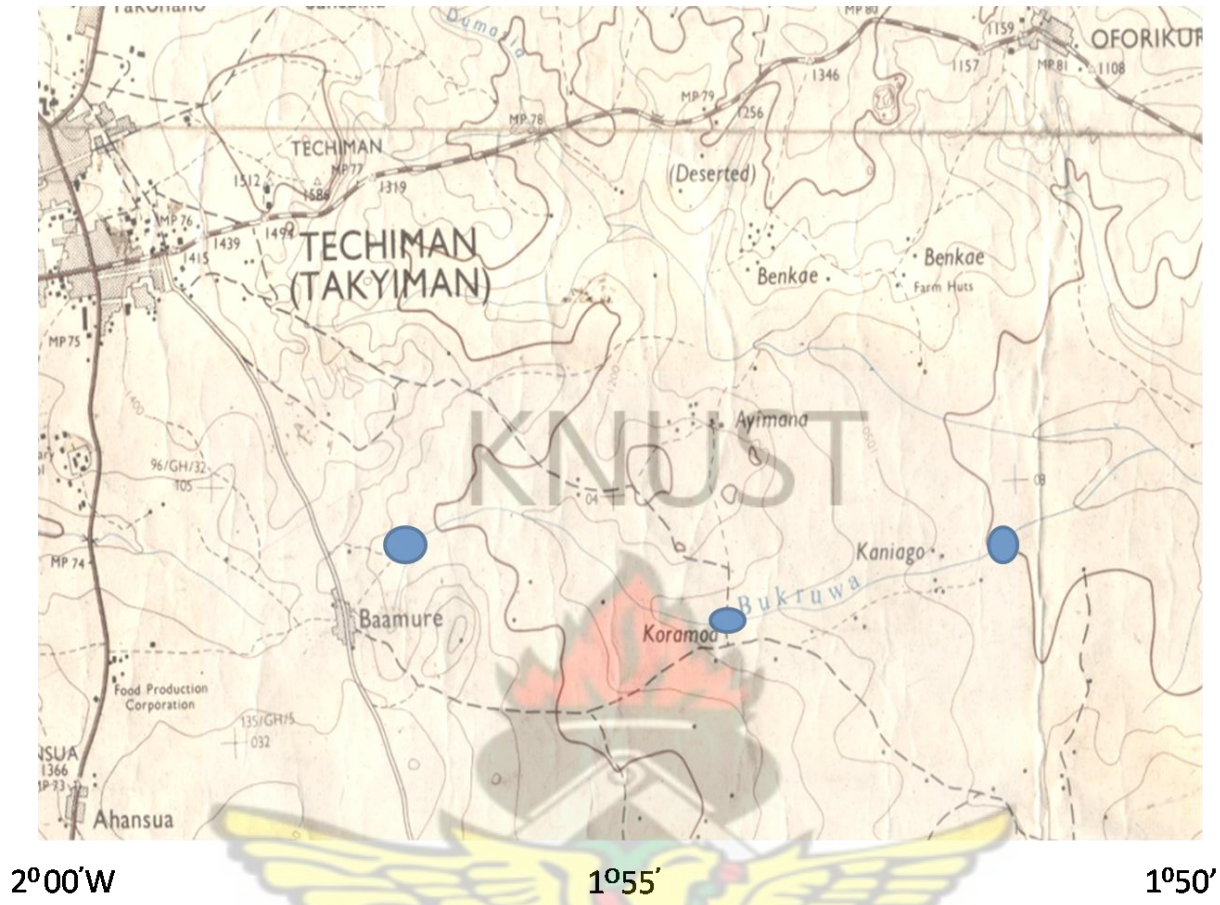

Fig 1.0: Map of the Techiman municipality showing river Bukruwa and the sampling points (Baamure, Kroamoa and Kaniago)

The Baamure sampling site (Plate 1.0) located upstream is about 2km from the Anyimana refuse dump site which serves as the final disposal grounds for solid waste and faeces collected from all parts of the Techiman Township. Vegetation around the river at this point consists mainly of farmlands used to cultivate food crops like yams and cassava. Vegetables like tomatoes, pepper and okro farms are also located at each side of the river bank. Herds of cattle occasionally graze on the vegetation around the river.

Plate 3.1 : The Baamure sampling point

Plate 3.2: The Kroamoa sampling point

The Kroamoa sampling site (plate 2) is about 500m away from the Anyimana refuse dump site whilst the refuse dump site of Kroamoa village is located about 100m away from the sampling point. Inhabitants of Kroamoa and neighbouring farming communities fetch water for drinking and other domestic purposes at this point of the river. A vegetable farm for the cultivation of pepper and garden eggs is sited very close to the river and thus farmers use the river water to irrigate crops most especially in the dry seasons. The use of fertilizers and other agrochemicals by the farmers in their vegetable farms is a common practice here. Run-offs from the farms to a greater extent end up in the river.

The Kaniago sampling site (Plate 3.0) is located at the downstream end of river Bukuruwa. The river flows over a bed of rocks at this site. Vegetations around the river at this point consist mainly of trees with palms. There is also a nearby large farm for cultivation of yams and cashew nuts. This sampling site is however about 200m away from the Kaniago village and 1.5km from the Anyimana refuse dump site.

Plate 3.3 : The Kaniago sampling point **X 0.05**

3.3 Water sampling

3.3.1 Washing of sample containers

Polyethylene bottles were used as the water sampling containers. Sample containers were pre-washed with detergent, rinsed with doubly deionsed distilled water and soaked in dilute nitric acid solution after which they were rinsed again with deionised water. This was done to ensure that the containers were not contaminated prior to collection of samples.

3.3.2 Sample collection

Prior to collection, the bottles and caps were rinsed three (3) times with the water to be sampled. Water samples were collected directly into the pre-washed containers and stored in an ice box at a temperature of about 4^0 C. Samples for metal determination were acidified with concentrated Nitric acid to a pH of 2 and kept in a refrigerator in order to prevent precipitation. Samples were transported to the Chemical Laboratory of the Institute of Renewable Natural Resources-KNUST, Kumasi within 24hrs for analysis.

Microbiological analyses were carried out at the Microbiology Laboratory of the Department of Theoretical and Applied Biology, KNUST.

3.3.3 Sampling frequency

Each sampling point was sampled six times at six different sampling periods. Samples were collected every two weeks in January, March and April 2011. Three of the samples were collected in the dry season and three others after some major rains. Meanwhile levels of heavy metals were determined once in a month. The first three batches of samples were taken in the dry seasons whilst the next three batches were sampled in the rainy season

3.4 EXPERIMENTAL METHODS

3.4.1 Determination of Physico-chemical parameters

Some of the parameters were determined on site whilst others were sent to the laboratory for analysis. The determination of sulphate, phosphate, turbidity, total hardness, fluorides, nitrites, nitrates and iron in the water samples were carried out using the methods employed in a Wagtech Potolab Photometer.

3.4.2 pH

The pH of the samples was determined on site with a portable Testr 20 pH meter. The pH meter was first calibrated with standardized buffers of pH 4, 7, and 10. The electrode was rinsed with distilled water after every test. The electrode was then dipped into the sample in a beaker and readings taken directly from the meter.

3.4.3 Determination of Colour

The Platinum- Cobalt method was used to determine the colours of water samples. A sample was first filtered into a clean beaker in order to remove interferences by turbidity. Ten milliliters of the filtered sample was put into a cuvette and inserted into the sample chamber of a Wagtech Potolab photometer 7100 series which had already been calibrated with coloured standards of known platinum cobalt concentrations. The photometer readings were recorded and reported in colour units (CU).

3.4.4 Determination of Conductivity

The conductivities of the water samples were determined using a 6- Series Multiparameter Water Quality Sondes -6600 V2-4 model. The Sonde was first calibrated with standardized solutions of conductivities 1.0, 10.0 and 50.0 µS/cm. The Sonde was then placed into about 10ml of the sample solution in a beaker and agitated to remove any bubbles. It was then allowed to stabilize for 1 minute and readings were taken on the meter directly in microsiemens per centimeter (µS/cm).

3.4.5 Determination of Turbidity

A 10 ml sample of the water was poured into a cuvette and then inserted into the chamber of a Wagtech Potolab photometer 7100 series. PHOT 48 was then selected on the photometer which automatically displayed the turbidity readings of the sample in Nephelometric Turbidity Units (NTU).

3.4.6 Determination of Total hardness

Total hardness was determined using the Palintest method employed in a Wagtech photometer. Fifty millilitres of the sample was filtered using a filter paper to obtain a clear solution of the sample water and 10ml of the filtered sample was put into a beaker. One Hardicol No 1 tablet (containing lithium hydroxide monohydrate, potassium chloride, EDTA, magnesium, disodium salt, leucine and ammonium chloride) was crushed and mixed with the sample in the test tube to dissolve after which one Hardicol No 2 tablet (containing sodium hydroxide) was also crushed and mixed with the sample to dissolve. The sample was allowed to stand for about 30minutes until the particles were completely dissolved to produce a purple colour.

A wavelength of 570nm was selected on the photometer and readings recorded from the LCD screen

3.4.7 Determination of Sulphate (SO_4^{2-})

About 10 ml of the test sample was filtered and put into a test tube. One Sulphate turb tablet (containing Barium Chloride in a slightly acidic formulation) was crushed and mixed with the sample to dissolve. A cloudy solution indicates the presence of sulphates. The solution was allowed to stand for 5 minutes and then mixed again to ensure uniformity. A wavelength of 520nm was selected on a Wagtech photometer and the concentration of sulphate in samples displayed on the screen.

3.4.8 Determination of Fluoride (F^-)

About 10ml of the test sample was filled into a test tube. One fluoride No.1 tablet was crushed and mixed to dissolve after which another tablet of fluoride No. 2 was also crushed and mixed with the sample to dissolve. The solution was allowed to stand for 5minutes for full colour development. A wavelength of 570nm was selected on the photometer and readings taken.

3.4. Determination of Phosphates (PO_4^{3-})

A test tube was filled with 10ml of the water sample. One Phosphate High Range tablet was crushed and mixed to dissolve. This was allowed to stand for about 10 minutes to allow for full colour development. A wavelength of 490nm was selected on the photometer and readings taken.

3.4.10 Determination of Nitrites (NO_2^-)

About 50ml of the test sample was filtered with a Whatman 1 filter paper to obtain a clear solution. A measuring syringe was used to take 1ml of the filtered sample and transferred into a test tube and made up to 10ml with distilled water. One Nitrophot No.1 tablet was crushed and mixed with the sample to dissolve. One Nitrophot No 2 tablet was also crushed and mixed with the sample solution to dissolve. The test tube was capped immediately and allowed to stand for exactly 2 minutes for full colour development. Photometer readings were then taken.

3.4.11 Determination of Nitrates (NO_3^-)

A Nitratest tube was filled with 20ml of the water sample. One level spoonful of nitratest powder and one nitratest tablet were added. The tablet was not crushed. The test tube was capped and shaken well for 1 minute. Afterwards it was allowed to stand for about two minutes and gently inverted three or four times to aid flocculation and then allowed to stand for further two minutes to ensure complete settlement. The cap was then removed and the mouth wiped with a clean tissue. About 10ml of the clear solution was then decanted into another test tube. One nitrocol tablet was crushed and mixed to dissolve and this was allowed to stand for 10minutes for full colour development and inserted into the sample chamber of the photometer. A wavelength of 570nm as specified by the photometer for the determination of nitrates was selected on the photometer and readings taken in the usual manner.

3.5 Determination of the levels of heavy metals

3.5.1 Iron: A test sample of the water was filled into a test tube to about 10 ml. One tablet of iron High Range tablet was crushed and mixed to dissolve in the water. This was allowed to stand for one minute for full colour development. A wavelength of 570nm was selected on the

photometer as specified by the photometer for the determination of iron and readings taken directly.

3.5.2 Heavy metal analysis with Atomic Absorption Spectrophotometer (AAS)

Water samples were analysed for the presence and concentrations of lead, zinc and copper at the Environmental Laboratory at AngloGold Ashanti in Obuasi using the AAS method. Digested water samples were analysed with Varian AAS-220

The digest was prepared by measuring 50ml of the water sample into a 100ml beaker. Five milliltres of concentrated nitric acid was added and the mixture swirled to mix .The mixture was heated and concentrated on a hot plate at about 150 ± 5^0c until the volume was below 10ml. The digest was cooled to room temperature and quantitatively transferred into a 10ml beaker and made to the mark with distilled water. The digest was filtered through Whatman 1 acid washed filter paper and kept for the AAS analysis. A blank sample was also digested through similar procedure and used to set and zero the machine automatically before readings were taken.

During the AAS analysis, the required hollow cathode lamp (metal specific) was inserted into the lamp holder. The lamp was switched on, and alignment checked. The wavelength for the determination of the specific metal (Pb 217.0nm, Cu; 324.8nm, Zn; 213.9nm) was keyed and the flame lighted. The standard as well as the blank was aspirated into the flame using a nebulizer and the calibration curve was plotted on the machine. The sample solutions were also aspirated into the flame using the nebulizer and the concentrations recorded.

3.6 Enumeration of bacteriological Indicators

3.6.1 Enumeration of faecal coliforms and *E. coli*

The most probable number (MPN) method was used to determine feacal coliforms in the samples. Serial dilutions of 10^{-1} to 10^{-6} were prepared by picking 1ml of the sample using an automatic pipette and sterile 1ml pipette tip into a 9ml sterile distilled water (diluent) in a test tube for the 10^{-1} dilution; 1ml of the 10^{-1} dilution was pipette into another tube containing 9ml of sterile distilled water. Dilutions down to 10^{-3} to 10^{-6} were done by repeating the above procedure further four times. 1ml aliquots from each of the dilutions were inoculated into 5ml of MacConkey Broth with inverted Durham tubes and incubated at 44^0 C for 18 – 24 hours. Tubes showing colour change from purple to yellow and gas collected in the Durham tubes after the 24 hrs were identified as positive for faecal coliforms. Counts per 100ml were calculated from the MPN tables.

From each of the positive tubes identified, a drop was transferred into a 5ml test tube of trypton water and incubated at 44^0 C for 24 hrs. A drop of Kovac's reagent was then added to the tube of trypton water. All tubes showing a red ring colour development after gentle agitation denoted the presence of indole and recorded as presumptive for thermotolerant coliform (*E. coli*). Counts per 100ml were calculated from MPN tables.

3.6.2 Enumeration *of Salmonella*

Ten milliliters of manufactured formula of buffered peptone water (BPW) was prepared in a universal bottle and serial dilutions (10^{-1} to 10^{-6}) of the samples added to it. It was incubated at 37^0 C for 24 hrs. A volume of 1.0 ml of the test sample was placed in 10ml of Selenite Broth in universal bottle and incubated at 44^0 C for 48 hrs. Innoculum loop was used to streak the

sample onto an SS agar and incubated at 48 hrs at 37^0 C. Black colonies on the SS agar indicated the presence of *Salmonella*. Counts per 100ml were calculated from MPN tables.

3.7 Analysis of Data

Statistical analysis of data was carried out using Microsoft Excel (2010 edition) and Statistical Package for Social Science (SPSS- version 19). Analysis of Variance (ANOVA) was used to determine the differences in the mean values of the parameters at the various sampling sites.

CHAPTER FOUR

4.0 RESULTS

4.1 pH and Turbidity at the three sampling sites

The pH values of the river ranged from 5.31 to 6.84 with the lowest and the more acidic pH value recorded at the Kaniago sampling site during the dry season and the highest also at Kaniago recorded during the rainy season (Fig 2.0) . The highest pH of 6.84 falls within the range of 6.5-8.5 set by the World Health Organization (WHO) for drinking water (WHO, 2008). Meanwhile the lower pH values of 5.31 and 5.56 recorded at Kaniago and Baamure are slightly acidic and outside the permissible range for quality drinking water.

The Baamure site recorded a pH range of 5.56 to 6.00 whilst the Kroamoa site recorded a range of 6.21-6.50 The differences in the mean pH of the sampling sites along the river were significant at $p \leq 0.05$ significant level (Appendix 2B).

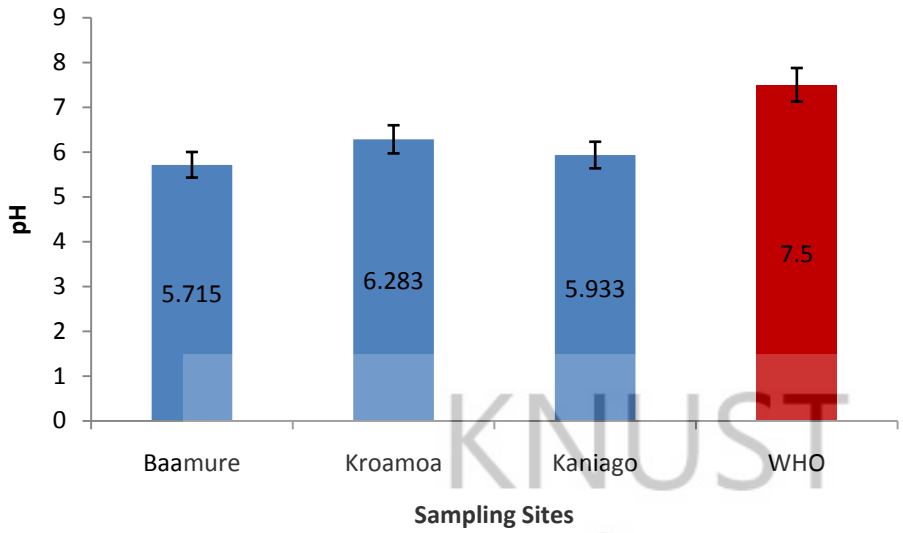

Fig 2.0: Mean pH of water from sampling sites compared to WHO guide

Turbidity values ranged from 0.00 to 6.00 NTU at Kroamoa. The lowest turbidity value at the Kroamoa site was recorded during the rainy season. However the highest of 6.00 NTU was recorded both in the dry and the rainy season. Turbidity measurements also ranged from 2.00 to 6.0 NTU at Kaniago whilst the values at Baamure were in the range of 1.00 to 6.00 NTU. The maximum turbidity value of 6.00 NTU was however higher than the standard for a drinking water which is $\leq$ 5NTU. The mean turbidity values recorded were higher in the wet season at Baamure and Kaniago but was however lower at Kroamoa. (Appendix 3) .There were no significant differences ($p = 0.988$) among the turbidity measurements at the various sampling sites at $p \leq 0.05$ significant level.

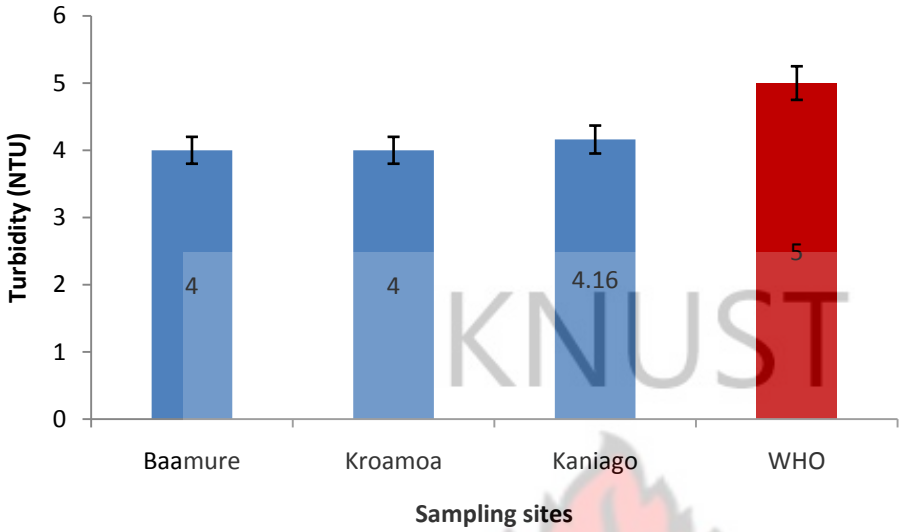

Fig 3.0 The mean turbidity at the sampling sites as compared to WHO drinking water guide.

4.2 Total hardness (mg/l) of the water samples from the sampling sites

The mean total hardness of the river as sampled from the three sampling sites was in the range of 0.00 to 10mg/l of $CaCO_3$. The total hardness level at Kroamoa ranged from 5.00 – 10mg/l whereas that of Kaniago and Baamure were from 0.00 -5.00mg/l and 0.00 to 10.00mg/l respectively. The maximum mean total hardness among the three sampling sites was recorded at Kroamoa during the wet season meanwhile there was a decrease in the mean total hardness of water samples at Baamure and Kaniago during the wet season(Appendix 3)

There were significant differences (p = 0.019) in the mean total hardness values recorded for the sampling sites (Appendix 2B).

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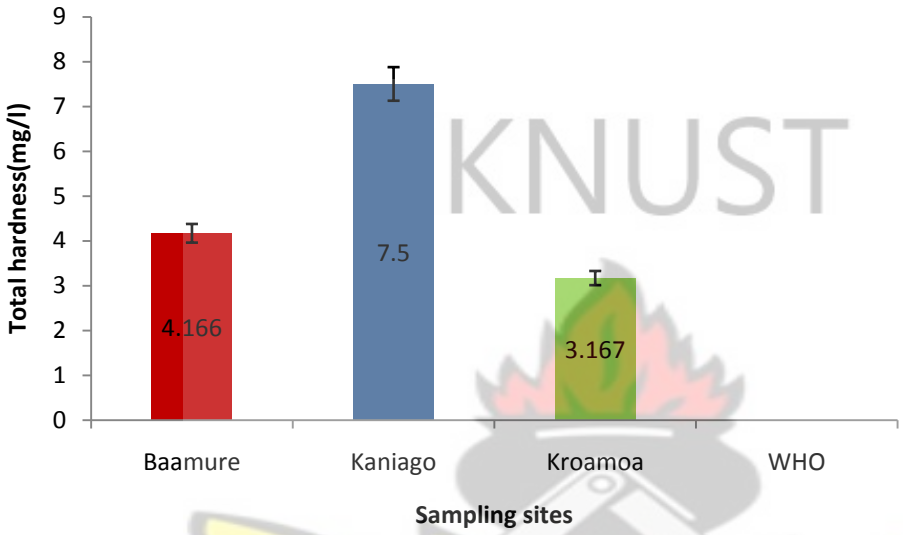


Fig 4.0 : Variation of mean total hardness(mg/l) at the sample sites

4.3 Nitrates (NO_3^-), and Sulphates (SO_4^{2-})

The mean concentration of nitrate, nitrite and phosphate and their ranges of occurrence in the water samples are shown in Appendix 2A.

The highest nitrate concentration (0.75 mg/l) was recorded at the Kroamoa sampling site during the rainy season and the lowest at Baamure in the dry season but did not vary significantly at Kaniago. A mean nitrate concentration of 0.231±0.10mg/l was recorded for Kroamoa, 0.066±0.01mg/l for Kaniago and 0.069 ±0.03mg/l for Baamure sampling sites.

Concentrations of nitrate at the various sampling sites however were far below the WHO guideline value of 50mg/l for drinking water. There were no significant variation in the mean nitrate levels recorded for the sampling sites at the $p \leq 0.05$ significant level.

Sulphate concentrations (mg/l) of the water samples from the various sites recorded a maximum of 5.00mg/l at all the sampling sites; ie Baamure, Kaniago and Kroamoa.

Mean sulphate concentrations (mg/l) for the sampling sites were Baamure (1.503±0.95). Kaniago (1.503±0.95) and Kroamoa (3.333±0.61). There was no significant variation ($p = 0.251$) of sulphate concentrations in the water samples among the sampling sites at $p \leq 0.05$ but there was an increase in the mean concentrations at Baamure and Kaniago during the wet season (Appendix 3)

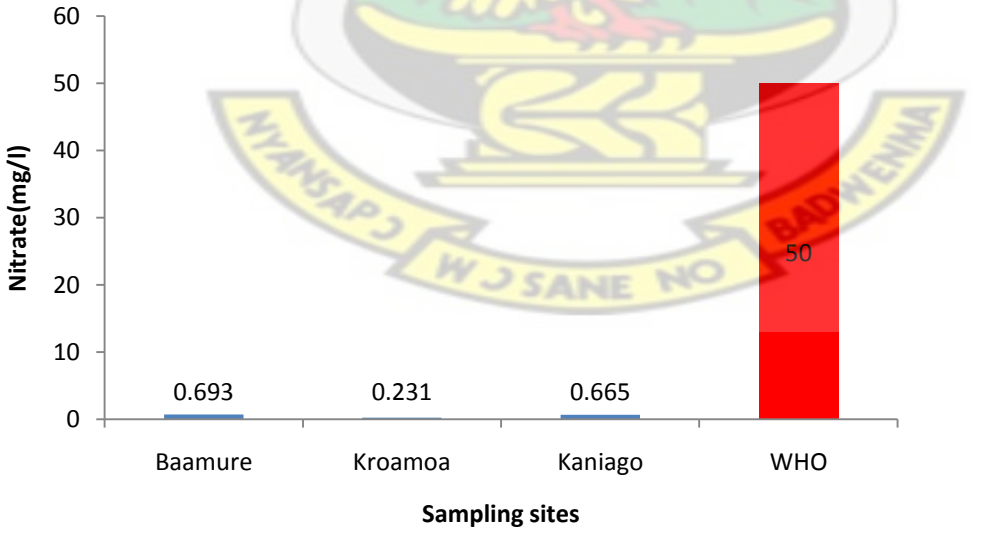


Fig 5.0: Mean nitrate levels (mg/l) at the sampling sites.

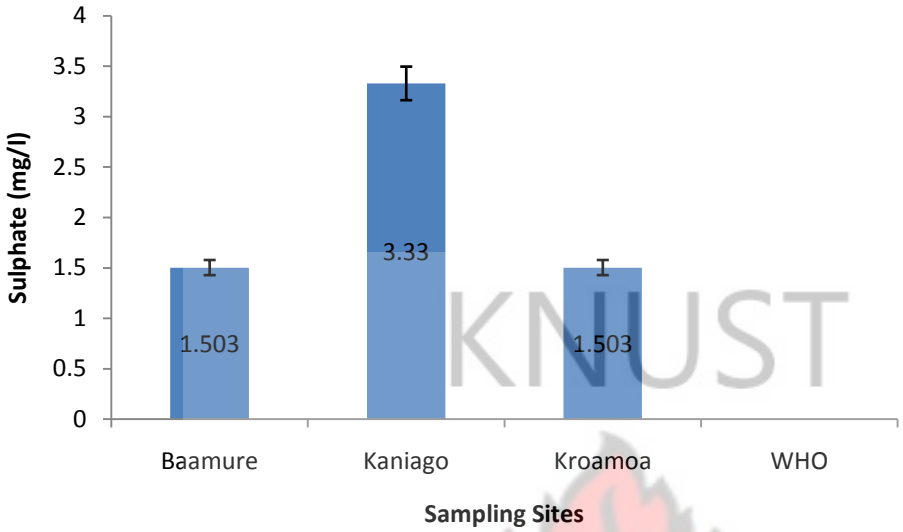


Fig 6.0 : Mean Sulphate levels (mg/l) at the sampling sites.

4.4 Nitrites (NO_2^-), Phosphates (PO_4^{3-}) and Fluorides (F^-)

The nitrite (NO_2^-) concentrations determined recorded its maximum value of 0.70 mg/l at the Kaniago sampling site and the lowest of 0.01mg/l at the Kroamoa and Baamure sites. The mean concentration values (mg/l) were 0.248±0.012 at Kaniago, 0.176 ±0.08 at Baamure and 0.069 ±0.12 at Kroamoa. Nitrite concentrations were generally high as compared to the WHO guideline value of 0.2mg/l for drinking water (Fig 8.0). There were no significant variations ($p = 0.389$) of the nitrite concentration among the sites at $p \leq 0.05$. During the wet periods nitrite concentrations were generally higher (Appendix 3).

The phosphate (PO_4^{3-}) concentration measured ranged between 0.04mg/l and 4.78mg/l. The maximum value was recorded at the Kaniago sampling site whilst the minimum was determined

at the Baamure site. The mean concentration values were 0.701± 0.29mg/l at Kroamoa, 1.006 ±0.75mg/l at Kaniago and 0.869± 0.63mg/l at the Baamure site. The mean phosphate concentrations at all the sampling sites were higher than the WHO guideline values for phosphate in drinking water (Fig 8.0). The mean concentration during the wet season were higher than the dry periods at Baamure and Kaniago but was almost constant at Kroamoa.

Fluoride concentrations recorded had the highest mean value of 0.136mg/l and a range of 0.00 to 0.32mg/l. The lowest value was recorded at the Baamure sampling site whilst the highest was determined at Kaniago. There was no significant differences (p = 0.433) in the fluoride concentration among the sampling sites, however a general increase in concentrations was recorded at all the sampling sites during the wet period as compared to the dry season (Appendix 3)

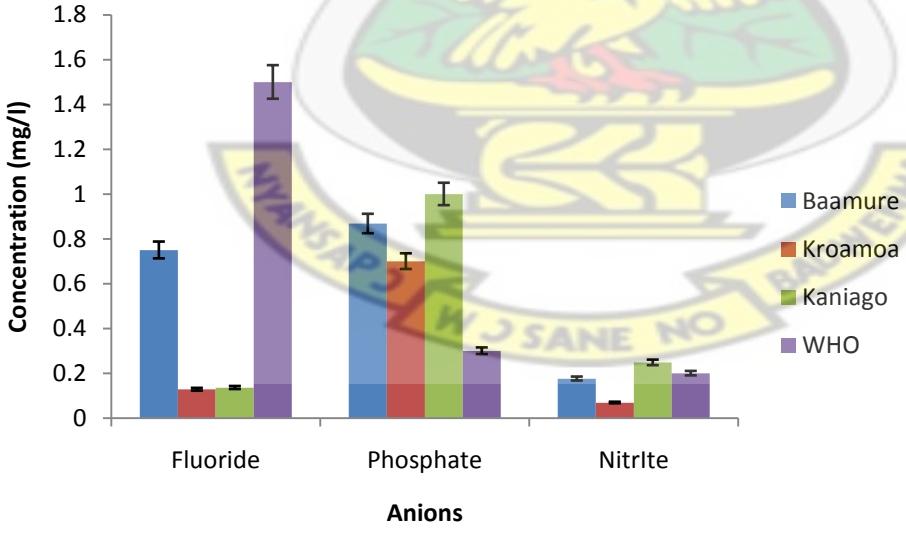


Fig 7.0 : Mean Fluoride, Phosphate and Nitrite concentrations (mg/l) at the sampling sites as compared to WHO guide.

4.5 Electrical conductivity (EC) and Colour

The highest mean conductivity of the water samples was recorded at Kaniago at 420.83µS/cm within a range of 390- 455µS/cm .Water samples from Kroamoa showed the least electrical conductivity with a mean of 294.83±58.07 which had a range of 160- 425 µS/cm

The mean EC values of the water samples at the sampling sites ranged from 160µS/cm to 455µS/cm (Appendix 2A). There was no significant variation in the conductivities of the water during the wet and dry periods (Appendix 3).

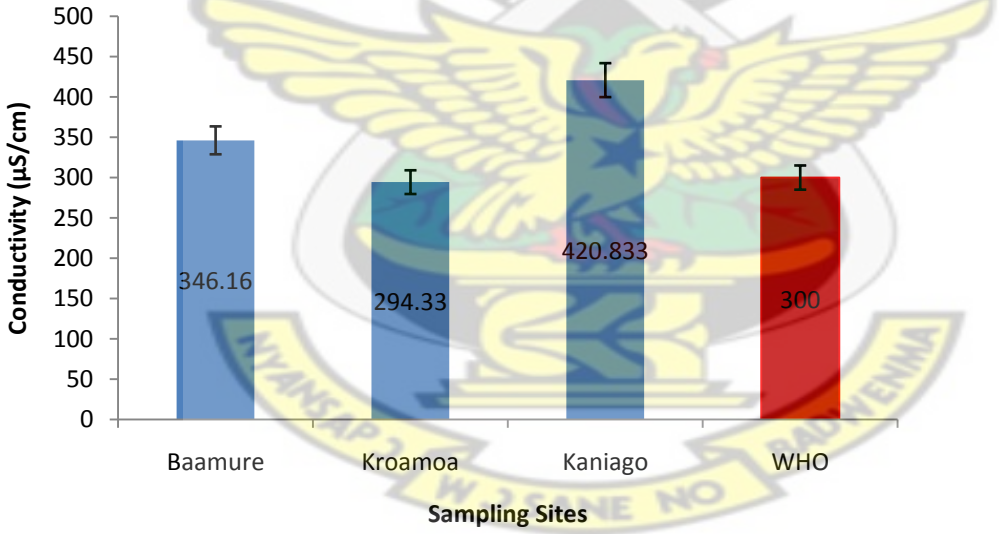


Fig 8.0: Mean conductivities (µS/cm) of water samples from the sampling points

The range of colour determined was from 0.00 to 185 Colour Units (CU). The highest colour value was recorded at Kroamoa during the dry season. In general the colour values recorded in the dry season were quite higher than those in the rainy season.

There were no significant variations (p = 0.399) between the sampling sites in terms of the colour of the water samples at $p \leq 0.05$ (Appendix 2B)

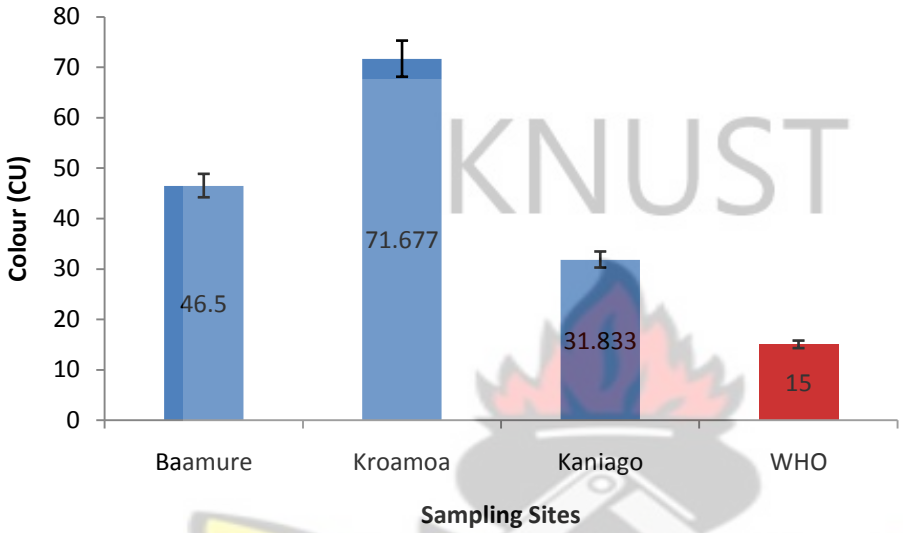


Fig 9.0 : Mean colours (CU) of water samples at the sampling sites

4.6 Heavy metal concentrations at the sampling sites

The concentrations (ppm) of the metals Lead (Pb), Zinc (Zn), Copper (Cu) and Iron (Fe) in the water samples from the three sampling sites are shown in Table 1.0 below.

Concentrations of Cu and Zn at all the sampling sites fell below the detection limit of $\leq$ 0.01ppm of the Atomic Absorption Spectrometer (AAS).

The lead concentration at Baamure was also below the detection limit of the AAS. whilst water samples from Kroamoa and Kaniago were found to contain Lead (Pb) with mean values of 0.028 $\pm$ 0.059 and 0.023$\pm$ 0.04 ppm respectively. These values were however higher than the permissible level of 0.01ppm in drinking water (WHO, 2008).

All the sampling sites were contaminated with iron. The highest concentration of iron was recorded at Kroamoa as 2.35ppm. The highest mean concentration of 0.49 $\pm$ 0.92 ppm of iron was recorded at Kroamoa ranged from 0.25 and 2.35ppm.

There was no significant difference between the concentrations of iron at the sampling points at p$\leq$ 0.05 significant level.

Table 1.0: The Means and Ranges of Heavy Metals at the Sites

Metal	Site	N	Mean (Std dev)	Range
Iron (ppm)	Kroamoa	6	0.4917 (±0.92272)	0.00 – 2.35
	Kaniago	6	0.3550 (±0.4312)	0.00 – 1.05
	Baamure	6	0.1833 (±0.2943)	0.00- 0.75
	Total	18	0.3433 (±0.5894)	0.00 – 2.35
Copper (ppm)	Kroamoa	6	0.0050 (±0.0054)	0.00 -≤0.01
	Kaniago	6	0.0050 (±0.0054)	0.00 –≤ 0.01
	Baamure	6	0.0050 (±0.0054)	0.00 -≤ 0.01
	Total	18	0.0050 (±0.0051)	0.00 -≤0.01
Zinc (ppm)	Kroamoa	6	0.0050 (±0.0054)	0.00 -≤ 0.01
	Kaniago	6	0.0050 (±0.0054)	0.0 –≤ 0.01
	Baamure	6	0.0050 (±0.0054)	0.00 -≤ 0.01
	Total	18	0.0050 (±0.0051)	0.00 –≤ 0.01
Lead (ppm)	Kroamoa	6	0.0283 (±0.0598)	0.00 – 0.15
	Kaniago	6	0.0233 (±0.0476)	0.00 – 0.12
	Baamure	6	0.0050 (±0.0054)	0.00 –≤ 0.01
	Total	18	0.0189 (±0.0428)	0.00 –≤ 0.01

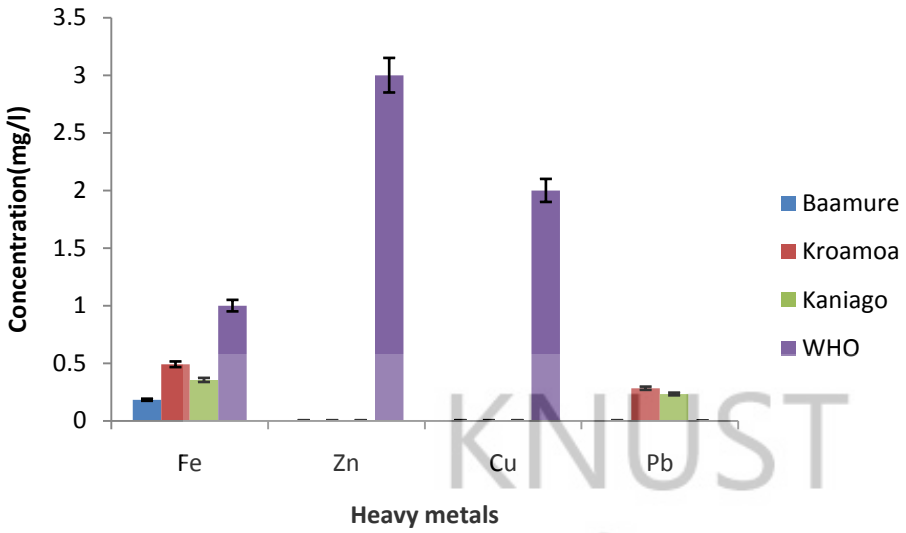


Fig 10.0: Mean concentrations of heavy metals compared with WHO guideline values.

4.7 Results of Bacteriological analysis

4.7.1 Feacal coliform and *E - coli* loads at the various sampling sites

The water from the river at all the sampling sites was contaminated with indicator bacteria (feacal coliform and *E- coli*). The mean feacal coliform counts per 100ml for all the sampling points ranged from 4.35×10^1 to 3.32×10^2. At the Kroamoa sampling site the feacal coliform numbers ranged from 2.30×10^1 to 9.0×10^1 with a mean count of 4.35×10^1.

The Kaniago site recorded a mean value of 3.32×10^2 within a range of 2.3×10^1 to 9.30×10^2 counts per 100ml of water samples.

The Baamure sampling site recorded a mean value of 5.73×10^1 within a range of 9.00×10^0 to 9.30×10^1 . However there were no significant differences in the feacal coliform numbers (cfu/ 100ml) between the sampling sites at $p \leq 0.05$ significant level.

The mean *E. coli* numbers (cfu/100ml) for all the water samples analyzed ranged from 2.58×10^1 to 8.75×10^1. The *E. coli* numbers recorded at Kroamoa ranged from 2.3×10^1 to 4.0×10^1 with a mean value of 2.58×10^1 whilst Kaniago recorded a mean value of 8.75×10^1 within a range of 9.0×10^0 to 2.30×10^2.

The Baamure sampling site recorded a mean value of 3.45×10^1 which falls within a range of 2.30×10^1 to 4.30×10^1 counts per 100ml of water.

There were no significant differences between the mean populations of *E. coli* at the various sampling points at $p \leq 0.05$.

For all the water samples taken from the various points along river Bukuruwa, Salmonella was not identified in any of them.

Variations in the mean faecal coliforms counts (cfu/100ml) and the ranges in the water samples from the three sampling sites along river Bukuruwa are shown in Table 2.0 below

Table 2.0 : Means and Ranges of Bacteriological Parameters at the Sampling sites.

Bacteria	Sites	N	Mean(Std. Dev)		Range
Faecal Coliform (cfu/100 ml)	Kroamoa	6	4.35×10^1 ($\pm$24.56)		2.3×10^1- 9.0×10^1
	Kaniago	6	3.32×10^2 ($\pm$452.50)		$2.3\times 10^1 - 9.3\times10^2$
	Baamure	6	5.73×10^1 ($\pm$32.01)		$9.0 \times 10^0 - 9.3\times 10^1$
E. Coli (cfu/100 ml)	Kroamoa	6	$2.58\ \times10^1$ ($\pm$6.94)		$2.3 \times 10^1 \times 4.0\ \times10^1$
	Kaniago	6	8.75×10^1 ($\pm$110.57)		$9.0 \times 10^0 - 2.3\ \times10^2$
	Baamure	6	3.45×10^1 ($\pm$9.37)		2.3×10^1 - 4.3×10^1

CHAPTER FIVE

5.0 DISCUSSION

5.1 Physico - chemical parameters

The study of the physico chemical parameters along various sampling points of river Bukuruwa ie; Baamure (upstream point) Kroamoa (mid stream) and Kaniago (downstream) showed some variations in the pH of the river as it flowed from the upstream site to the downstream. The mean pH values at the various points indicate slightly acidic pH and this could be adduced to various run-offs from agricultural lands into the river course and may also be attributed to the geology of the underlying rocks of the river bed (Kortatsi, 2006). A particular problem associated with acidification of water is the solubilization of some metals when the pH falls below 4.5 because the resultant increased metal concentrations can be toxic to aquatic organisms and render the water unsuitable for drinking and other uses (Adeniyi, 2004).

Nitrate is a form of nitrogen and a vital nutrient for growth, reproduction and survival of organisms. High nitrate levels (> 1mg/l) are not good for aquatic life (Adeyomo, 2003) due to eutrophication. Mean nitrate concentration for all the sampling sites were relatively lower and fell far below the WHO guideline value of 50mg/l for drinking water. This is however in agreement with an observation in a WHO drinking water quality report which concluded that the nitrate concentration in ground and surface water is normally low but can reach high levels as a result of leaching or runoffs from agricultural land or contamination from human or animal waste, (WHO, 2003).

The highest nitrate concentration was recorded at Kroamoa, the midstream point of the river could be attributed to the closeness of farmlands to the sampling point and a possibility of the

effluents from the dump site being washed into the river. The nitrate concentration in the dry season was relatively higher than that in the wet season. This is in agreement with a study by Wolfhard and Reinhard (1998) who concluded that nitrates are usually built up in the dry season and that higher levels of nitrates are only observed during early rainy seasons. This is because initial rains flush out deposited nitrate from near surface soils and nitrate level reduces drastically as the rainy season progresses due to dilution.

The Nitrate concentration recorded at the sampling sites was generally on the higher side compared to the minimum permissible levels in drinking water. The elevated nitrate levels may be due to run offs from the farm lands near the sampling points into the river because nitrate is a major component in fertilizers

The mean Phosphate concentrations in all the sampling points were higher as compared to the standard guideline value for drinking water by the WHO (2008). Land use around the Bukuruwa river is predominantly for farming and could be a possible explanation to the high levels of phosphate recorded, probably as a result of run offs during the rainy season. Other contributing factors may be due to firm rock deposits and interaction between the water and sediment from dead plant and animal remains at the bottom of the river (Adeyomo *et al*, 2008). High levels of both phosphate and nitrate can lead to eutrophication which increases algal growth and ultimately reduced dissolved oxygen levels in the water (Murdoch *et al*, 2001)

The mean Conductivity values of the water samples ranged from 160 to 455µS/cm. the maximum mean conductivity is however higher than the WHO permissible limit for electrical conductivity which is 300µS/cm. The nature of soil type coupled with run offs might account for

the presence of such large amount of dissolved ions in water and hence the increase in conductivity (Oluyemi *et al* 2010).

Sulphate concentrations recorded at the various sampling sites were generally low and do not pose much health risk to users for drinking purposes.

The fluoride levels within the river were generally low with the mean determined as 0.136mg/l. Permissible limit for fluoride concentration in potable water is 1.0- 1.5mg/l (WHO, 2003) and thus the levels determined do not pose much health risks to the consumers. Fluoride has a significant mitigating effect against dental caries at low concentrations. However continuous consumption of higher concentrations of 4mg/l or more can cause dental fluorosis and in extreme cases can even lead to skeletal fluorosis (Dissanayake, 1991).

The mean turbidity of 6 NTU was higher than the standard value of $\leq$ 5 NTU for drinking water (WHO ,2008). It gives an indication of the possible presence of contaminants in such a water sample which could harbor pathogenic organisms.

5.2 Heavy metals

The concentrations of the metals Copper (Cu) and Zinc (Zn) did not occur in any of the samples at any time above the detection limit of the method employed. The low levels of Cu in the test samples was however expected because Cu is known to be rarely found in natural water bodies and where it is even detected, it exist at very low concentrations (Kortatsi, 2006) .Consumption of high levels of copper can cause nausea, vomiting, diarrhoea, gastric complaints and headaches. Even long term exposure can cause liver damage and death (Kortatsi, 2006). The low

concentration of Cu which is far below the minimum allowable limit of 1.0 ppm does not pose any danger to the consumers.

Concentrations of zinc in natural surface waters is estimated to be below 10µg/l and in ground waters found in the range of 10- 40µg/l (WHO 1996). In this study the levels of zinc were below the detectable limits of the AAS which is $\leq$ 50µg/l and do not pose a problem to consumers.

Iron was detected at various concentrations in all the water samples analysed. The maximum concentration obtained was 2.35 ppm at Kroamoa during the dry season. Iron is known to be present in natural surface waters but it is seldom found at concentrations greater than 10 ppm (Kortatsi, 2006). The concentrations obtained could be attributed to the geology or to the mineral nature of the soil in the area studied. The levels obtained do not however pose any health risk to the consumers but it is considered a secondary or aesthetic contaminant. Concentrations of iron as low as 0.3ppm could leave reddish brown stains on fixtures, tableware and laundry that is very hard to remove and also affect the taste of the water.

The mean Lead concentrations detected at Kroamoa and Kaniago were 0.028 ($\pm$ 0.059) ppm and 0.023($\pm$ 0.04) ppm respectively. These concentrations were higher than permissible levels of 0.01ppm in drinking water. In humans, high levels of exposure may result in toxic biochemical effect which in turn cause problems in the synthesis of haemoglobin, effects on the kidneys, gastrointestinal tract, joints and reproductive system and acute or chronic damage to the nervous system (WHO, 2008). Water from the river therefore pose some health risks to the consumers and thus need to be treated to make the lead levels meet the standards suitable for consumption.

5.3 Bacteriological parameters

The study also revealed the presence of some indicator bacteria i.e.: feacal coliform and *E- coli* in all the water samples from the various sampling points

The maximum feacal coliform counts per 100ml of water samples was recorded as 9.0×10^2 at Kaniago whilst that for *E- coli* was 2.3×10^2 which was also recorded at Kaniago. The presence of these indicator bacteria gives an indication of the contamination of the river water by feacal matter of either man or animals (Asbolt *et al*, 2001). Occasionally there are herds of cattle which graze on the vegetation around the river banks and eventually may end up releasing feacal materials around the river. Storm water may wash these into the river and hence contaminate the water.

At Kroamoa, the refuse dump site is just about 100m away from the sampling site and the possibility of human excreta being washed from the site during rainfalls could not be ruled out. Microbial populations obtained however were relatively lower although it was believed by the inhabitants of the communities, most especially Kroamoa and Kaniago that their drinking water sources were heavily contaminated by faecal matter from the Anyimana refuse dump site.

Even though the faecal coliforms and *E- coli* counts were relatively low, their presence in the water sample gives an indication of the presence of other potentially harmful bacteria in the water which serves as the drinking water source for these rural communities. The WHO emphasizes that, these indicator bacteria must not be found in a drinking water (WHO, 1996).

Meanwhile all the water samples analysed showed no presence of *Salmonella* spp in them.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

The water quality evaluation of water samples from river Bukuruwa which serves as the main drinking water resource for some rural communities in the Techiman municipality revealed that the mean nitrate, fluoride, sulphate, zinc , copper, iron and total hardness contents were found to be within the limits set by the WHO for drinking and domestic waters (WHO, 1971,1996, 2003, 2008).

Parameters like turbidity, nitrite, lead, conductivity, phosphate and colour contents were however found to be above the standards set (WHO, 2008). The higher concentrations of lead and nitrite tend to pose direct health risks to consumers of such water for drinking and domestic purposes.

The results also showed that the water at the various sampling points was unsuitable for drinking as per the WHO standards since faecal coliforms and *E-coli* were present in the water samples indicating possible contamination of the river water by faecal matter and hence harmful pathogens in the water samples.

In the light of these observations and conclusions, the following are recommended.

1. The Techiman Municipal Assembly should as matter of health importance make efforts to provide quality sources of water, eg bore-holes for the large number of those rural communities which obtain their drinking water from river Bukuruwa.

2. People should be educated to boil water from this source to kill pathogens that could be harmful to their health.

3. Farming activities undertaken very close to the banks of the river should be seriously regulated or if possible avoided altogether.

4. Tree planting activities should be encouraged along the banks of the river to protect it.

REFERENCES

Abid, M.A. and Jamil, A. (2005). The Assessment of Drinking Water Quality and Availability in NWFP,RWSSP, Peshawar.

Adeniyi, I.F. (2004). The Concept of Water Quality In: *Ife Environmentalist*, Official Bulletin of Nigerian Society for Environmental Management (NISEM) O.A.U **1(1)**: 2

Adeyomo, O.K.(2003). Consequences of pollution and degradation of Nigerian aquatic environment in fisheries resources, *The Environmentalist*, **23**(4) 297 - 306

Adeyemo, O.K., Adedokun, O.A., Yusuf, R.K. and Adeleye, E. A. (2008). Seasonal Changes in Physicochemical Parameters and Nutrient load in river sediments in Ibadan City, Nigeria, *Global NEST Journal*, vol **10** No.3 pp: 326 - 336

Ajibade, L. T. (2004). Assessment of Water Quality along River Asa, Illorin, Nigeria. *The Environmentalist* **24:** 11-18

Anderson, T.W., Hodson, P.V. and Baird, D. (1975). Ischemic Heart disease, Water hardness and Myocardial Magnesium. *Canadian Medical Association Journal* , **113**: 119-203

Angulo, F.J., Maybeck, M. and Stanley D.W. (1997). A community waterborne outbreak of *Salmononellosis* and the effectiveness of a boil water order. *American Journal of Public Health* **87** : 580-584

Asbolt, N.J., Grabow W.O.K. and Snozzi, M. (2001). Indicators of Microbial Water quality. In: Fewtrell L, Bartram J, Eds: Water quality Guidelines, Standards and Health Assessment of risk and risk Management for Water Related Infectious Disease. WHO Water Series, London, IWA Publishing Pp: 289-315

Berg, G. (1978). The Indicator System. In Indicators of Viruses in Water and Food (ed.G.Berg), pp. 1-13, Ann Arbor Science Publishers, Ann Arbor, MI.

Clark M.A. and Barret E.L., (June 1987). The pHs gene and Hydrogen Sulphide Production of *Salmonella typhimurium*. *Journal of Bacteriology* **169 (6)** 2391-2397.

Court, J.S. (1979). Decline of Submerged Plants in Chesapeake Bay. *Ecology Monograph*,**59**,329-364

Davis Jan and Robert Lambert (2002). Engineering in Emergencies; A Practical Guide for Relief workers, 2nd Edition. Warwickshire, UK: RedR/ITDG Publishing.

Diersing Nancy (May 2009), Water Quality Frequently Asked Questions. PDA NOAA. http://floridakeys.noaa.gov/pdfs/wqfaq.pdf [Accessed October 18, 2010]

Dissanayake, C.B. (1991). The Fluoride Problem in the Ground Water of Sri Lanka, - Environmental Management and Health Intl. *Journal of Environmental Studies:* ***vol 19:*** 195-203

Doyle,M.P., and Erickson, M. C.(2006). Closing the door on feacal coliform assay. *Microbe* **1**:162-163. ISSN 1558- 7460

Eckburb, P.B., Bik, E.M., Bernstein, C.N., Purdom, E. and Dethlefsen L. (2005). Diversity of the human intestinal microbial flora, *Science 308* : 1635-1638.

Edwards, D.D. (1993). Trouble Waters in Milwaukee. *Am. Soc.Microbial* News, **59**:342

Elinder, C.G,(1986). Zinc. In: Friberg, L., Nordberg, G.F., Vouk, V.B. eds. *Handbook on the toxicology of metals*, **2nd ed**. Amsterdam, Elsevier Science Publishers, 664 - 679

Escartin, E.F. Scott, M., Julie, C. and Tom, W. (2002). Potential Salmonella Transmission from Ornamental Fountains. *Journal of Environmental Health* **65**: 9-12

Fox, K. R. (1995). Turbidity as it relates to Waterborne Disease Outbreak' Presentation at M/DBP Information Exchange Cincinnati, Ohio, AWWA White paper.

Fei- Baffoe, B. (2008). Pollution Control, IDL Course Material for BIOL 505, MSc Environmental Science-KNUST, Kumasi. Pp 50, KNUST Press (2008).

Government of Ghana, Ministry of Water Resources, Works and Housing: National Water Policy Document (2007)

Grabow, W.O.K. (1996). Waterborne Diseases; Update on Water Quality Assessment and Control. Water SA: **22**: 193-202

Greenhalgh Alison (2001). Healthy living water, BBC Health. http/www.co.uk/healthy living. [Accessed November12, 2010]

Ifabiyi, I.P. (2008). Self Purification of a Freshwater Stream in Ile- Ife; Lessons for Water Management*: J. Hum Ecology* **24(2)** 131- 137

Kortatsi, B. K. (2006). Hydrochemical Characterization of groundwater in the Accra Plains of Ghana. *Environmental Geology Journal* vol 50 pp 299 - 311

Kortatsi, B.K. and Quansah, J. (2004). Assessment of Groundwater Potential in the Sunyani and Techiman Areas of Ghana for Urban Water Supply. *West African Journal of Applied Ecology,* **vol 5**: 73-78.

Krishnan, J. R. (2008). Investigation on Hydrobiology and Water Quality Parameters Of Periyar Lake, Thekkady, Kerala (PhD Thesis), Mahatma Ghandi University, Kerala, India

Lamb, J.C. (1985). Water Quality and its Control. John Wiley and Sons Inc. New York. Pp 2.3

McGowan, W. (2000), Water Processing: residential, commercial, light industrial, **3rd ed**. Lisle, IL, Water Processing Association.

MacKinnon, A.U., Taylor, S.H. (1980). Relationship Between Sudden Coronary Deaths and Drinking Water Hardness in Five Yorkshire Cities and Towns. *International Journal of Epidemiology* **(3):**247-248

Marier, J.R., Neri, L.C. and Anderson, T.W. (1979). Water Hardness, Human Health and the Importance of Magnesium, Ottawa National Research Council of Canada

Murdock, T., Cheo, M. and O'Laughlin, K. (2001). Streamkeeper's Field Guide: Watershed Inventory and Stream Monotoring Methods. Adopt - A- Stream Foundation, Everett, WA, 297 pp 107 – 127.

National Research Council (1997). Drinking Water and Health, Washington D.C National Academy of Sciences

Neri, L. C. and Johansen, H. L. (1978). Water hardness and Cadiovascular mortality. *Annals of the New York Academy of Sciences*, **304**: 203- 221

Nriagu, J.O. (1980). Zinc in the environment. Part I, Ecological Cycling. New York, NY, John Wiley.

Oluyemi, E.A., Adekunle, A.S., Adenuga, A. A. and Makinde, W.O. (2010). Physico-Chemical Properties and Heavy Metal content of water sources in Ife North Local Government Area of Osun State, Nigeria : *African Journal of Environmental Science and Technology* **vol 4 (10)** Pp 691-697

Ongley, E. D. (1991). Pollutant Loadings and River Flux Assessment ; In: Information Needs for Water Quality Assessment and Management Report of WHO/UNEP, Expert Consultation (Bratislava), World Meteorological Organization Technical Reports in Hydrology and Water Resources No **:34** (1991)

Osei- Akoto (2009). Environmental Chemistry, IDL Course Material for Chem 514, MSc Environmental Science – KNUST, Kumasi,Pp 59, KNUST Press (2009)

Singhl, S. and Mosley, L. M. (2003). Trace metal levels in drinking water on Vitu Levu, Fiji Islands, South Pacific. *Journal of. Natural Science,* **21,** 31 - 34

Sorrels, K. M, Speck, M. L. and Warren, J. A. (1970). Pathogenicity of *Salmonella gallinarum* After Metabolic Injury by Freezing. *Applied and Environmental Microbiology* **19(1)** 39-43

Survey Department of Ghana (1977). Map of Techiman, Sheet 07023 North B-30

Techiman Municipal Assembly , Survey Department Action Plan Document (2004) pp 6.

United Nations Development Programme in Human Development Report (2002). New York. Oxford University Press 2002 Pp 268.

UN- Global Annual Assessment of Sanitation and Drinking Water Report (2010).

UNEP report (2009). Water, Sanitation and the UN: **14**: 02.

Water Aid (2008). National Water Sector Assessment report in Ghana

WHO/UNICEF (2000). Water Supply and Sanitation Collaborative Council, Global Water Supply and Sanitation Assessment report Pp 4-5, Geneva (2000)

WHO/UNICEF Report (2004). Meeting the Millennium Development Goals; Drinking Water and Sanitation Target. Geneva, 2004

WHO (2003). Nitrate and Nitrite in Drinking Water. Background document for preparation of WHO Guidelines for Drinking Water Quality. Geneva, (WHO/SDE/WSH/03.04/56)

WHO (1996). Guidelines for Drinking Water Quality**. 2nd ed. Vol 2**. Health Criteria and other supporting information, WHO Geneva, 1996

WHO (2007). pH in Drinking Water: Background Document for Preparation of WHO Guidelines for drinking water Quality. Geneva, World Health Organization (WHO/SDE/07.01/1)

WHO (2008). Guidelines for Drinking Water Quality, **3rd ed. Vol 1**. Incorporating the first and Second Addenda, WHO, Geneva (2008): ISBN 978 92 4 154761 1

WHO/UNICEF (2010). Joint Monitoring Programme for Water Supply and Sanitation ; Progress on Sanitation and Drinking Water (2010 Update), WHO library Cataloguing- In Publication. ISBN 978 92 4 156395 6

World Bank (1997). World Development Report . In: New York :. Oxford University Press: 254.

Wolfhard, S., Reinhard, B. (1998). The Heterogeneity of Runoff and its Significance for Water Quality Problems. *Hydrological Sciences Journal* ***43:*** *103-113*

http/www.bbc.co.uk/health living[Accessed December 5, 2011]

http/environment.about.com/environmental dayqa/htlm [Accessed December 17, 2010]

http/www. water research.net/watershed/phosphate.htm [Accessed January 15, 2011]

http:www.freedrinkingwater.com/heavymetals.htm [Accessed Febuary 8, 2011]

(http/en.wikipedia.org/wiki/drinking water) [Accessed February 12,2011]

[http:enmedicine.medscape.com/article/814960] [Accessed February 23, 2011]

(http//www.lentech.com/periodic/elements.zn.htm) [Accessed March 9, 2011]

APPENDICES

APPENDIX 1A: Raw results of 1st batch of samples.

Sampling site/parameter	KROAMOA	KANIAGO	BAAMURE
pH	6.23	5.31	5.63
Turbidity(NTU)	6.00	2.00	1.00
Total hardness(mg/l)	10.00	0.00	5.00
phosphate(mg/l)	0.75	0.30	0.35
Fluoride(mg/l)	0.05	0.00	0.00
Nitrate(mg/l)	0.075	0.004	0.013
Sulphate(mg/l)	5.00	0.00	0.00
Conductivity(µS/cm)	425	390	265
Nitrite(mg/l)	0.0066	0.0165	0.0066
Colour (CU)	185	45	87

Microbial results

Sampling site	Feacal coliform(cfu/100ml)	*E-coli* (cfu/100ml)	Salmonella(cfu/100ml)
Kroamoa	9.0×10^1	4.0×10^1	NIL
Kaniago	2.3×10^1	2.3×10^1	NIL
Baamure	5.3×10^1	3.5×10^1	NIL

Heavy metals

Sampling site	Fe(ppm)	Cu(ppm)	Zn(ppm)	Pb(ppm)
Kroamoa	2.35	< 0.01	< 0.01	0.15
Kaniago	0.55	< 0.01	< 0.01	0.12
Baamure	0.25	< 0.01	< 0.01	< 0.01

APPENDIX 1B: Raw results of 2nd batch of samples.

Sampling site/ water parameter	Kroamoa	Kaniago	Baamure
PH	6.30	5.70	6.00
Turbidity(NTU)	6.00	4.00	6.00
Total hardness(mg/l)	10	0.00	5.00
Phosphate(mg/l)	0.85	0.40	0.30
Fluoride(mg/l)	0.08	0.00	0.00
Nitrate(mg/l)	0.75	0.06	0.02
nitrite(mg/l)	0.080	0.025	0.055
Sulphate(mg/l)	4.00	0.00	0.00
Conductivity(µS/cm)	165	455	430
Colour(CU)	155	55	80

Microbial results

Sampling site	Feacal coliform(cfu/100ml)	E-coli(cfu/100ml)	Salmonella(cfu/100ml)
Kroamoa	2.3×10^1	2.3×10^1	NIL
Kaniago	2.3×10^1	9.0×10^0	NIL
Baamure	4.3×10^1	2.3×10^1	NIL

APPENDIX 1C: Raw results of 3rd batch of samples

Sampling site/ parameter	Kroamoa	Kaniago	Baamure
Ph	6.21	6.45	5.64
Turbidity(NTU)	6.00	4.00	4.00
Total hardness(mg/l)	10.00	5.00	0.00
Phosphate(mg/l)	0.504	0.198	0.402
Fluoride(mg/l)	0.12	0.32	0,13
Nitrate(mg/l)	0.152	0.110	0.000
Nitrite(mg/l)	0.07	0.09	0.06
Sulphate(mg/l)	2.00	0.02	0.02
Conductivity(µS/cm)	160	420	430
Colour(CU)	20	10	20

Sampling site	Feacal coliform(cfu/100ml)	*E- coli* (cfu/100ml)	Salmonella(cfu/100ml)
Kroamoa	4.0×10^1	2.3×10^1	NIL
Kaniago	9.0×10^2	2.3×10^2	NIL
Baamure	9.0×10^0	4.0×10^1	NIL

Sampling site	Fe(ppm)	Cu(ppm)	Zn(ppm)	Pb(ppm)
Kroamoa	0.35	< 0.01	<0.01	<0.01
Kaniago	1.05	<0.01	<0.01	<0.01
Baamure	0.10	<0.01	<0.01	<0.01

APPENDIX 1D: Results of 4th batch of samples

Sampling sites/parameter	Kroamoa	Kaniago	Baamure
Ph	6.21	6.84	5.56
Turbidity(NTU)	0.00	6.00	4.00
Total hardness(mg/l)	5.00	5.00	5.00
Phosphate(mg/l)	0.05	0.19	0.04
Fluoride(mg/l)	0.15	0.20	0.12
Nitrate(mg/l)	0.123	0.075	0.053
Nitrite(mg/l)	0.09	0.06	0.04
Sulphate(mg/l)	5.00	5.00	5.00
Conductivity(µS/cm)	424	433	162
Colour(CU)	0.00	38.00	42.00

Sampling site	Feacal coliform(cfu/100ml)	*E- coli* (cfu/100ml)	Salmonella(cfu/100ml)
Kroamoa	4.3×10^1	2.3×10^1	NIL
Kaniago	9.3×10^2	2.4×10^1	NIL
Baamure	9.3×10^1	4.3×10^1	NIL

APPENDIX 1E: Raw results of 5th batch of samples.

Sampling site/ parameter	Kroamoa	Kaniago	Baamure
pH	6.25	6.21	5.70
Turbidity(NTU)	6.00	4.00	5.00
Total hardness(mg/l)	5.00	5.00	5.00
Phosphate(mg/l)	0.070	0.170	0.100
Fluoride(mg/l)	0.20	0.15	0.15
Nitrate(mg/l)	0.143	0.080	0.175
Nitrite(mg/l)	0.085	0.070	0.500
Sulphate(mg/l)	2.00	4.00	4.00
Conductivity(µS/cm)	170	410	400
Colour(CU)	20	5	10

Microbial results

Sampling site	Feacal coliform(cfu/100ml)	*E- coil* (cfu/100ml)	Salmonella(cfu/100ml)
Kroamoa	2.3×10^1	2.3×10^1	NIL
Kaniago	2.3×10^1	9.0×10^0	NIL
Baamure	5.3×10^1	2.3×10^1	NIL

Heavy metals

Sampling site	Fe(ppm)	Cu(ppm)	Zn(ppm)	Pb(ppm)
Kroamoa	0.25	< 0.01	< 0.01	< 0.01
Kaniago	0.53	< 0.01	< 0.01	< 0.01
Baamure	0.75	< 0.01	< 0.01	< 0.01

APPENDIX 1F : Raw results of 6th batch of samples

Sampling Site/Parameter	Kroamoa	Kaniago	Baamure
PH	6.50	5.90	5.75
Colour (CU)	45	38	40
Total hardness(mg/l)	5.00	4.00	5.00
Phosphate(mg/l)	1.980	4.780	4.020
Fluoride(mg/l)	0.17	0.15	0.05
Nitrate (mg/l)	0.145	0.070	0.155
Nitrite(mg/l)	0.085	0.600	0.155
Sulphate(mg/l)	2.00	0.00	0.00
Conductivity(mg/l)	425	417	360
Turbidity(NTU)	0.00	5.00	4.00

Microbial results

Sampling Site	Feacal Coliform	*E- coli*	*Salmonella*
Kroamoa	4.2×10^1	2.3×10^1	NIL
Kaniago	9.3×10^1	2.3×10^2	NIL
Baamure	9.3×10^1	4.3×10^1	NIL

APPENDIX: 2A: Means, ranges and Standard deviations of physicochemical parameters.

Sites		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
						Lower Bound	Upper Bound		
pH	Kroamoa	6	6.2833	.11130	.04544	6.1665	6.4001	6.21	6.50
	Kaniago	6	5.9333	.60292	.24614	5.3006	6.5661	5.31	6.84
	Baamure	6	5.7133	.15462	.06312	5.5511	5.8756	5.56	6.00
	Total	18	5.9767	.41943	.09886	5.7681	6.1852	5.31	6.84
Turbidity	Kroamoa	6	4.0000	3.09839	1.26491	.7484	7.2516	.00	6.00
	Kaniago	6	4.1667	1.32916	.54263	2.7718	5.5615	2.00	6.00
	Baamure	6	4.0000	1.67332	.68313	2.2440	5.7560	1.00	6.00
	Total	18	4.0556	2.04284	.48150	3.0397	5.0714	.00	6.00
Colour	Kroamoa	6	71.6667	78.0815	31.8760	-10.2745	153.68	.00	185.00
	Kaniago	6	31.8333	19.9138	8.12985	10.9349	52.738	5.00	55.00
	Baamure	6	46.5000	31.1751	12.7277	13.7835	79.215	10.0	87.00
	Total	18	50.0000	49.8206	11.7429	25.2247	74.773	.00	185.00
Conductivity	Kroamoa	6	294.833	142.261	58.0777	145.5397	444.10	1600	425.00
	Kaniago	6	420.833	21.9038	8.94210	397.8469	443.87	3900	455.00
	Baamure	6	346.167	111.150	45.3808	229.5132	462.81	1620	430.00
	Total	18	353.9444	112.07743	26.41690	298.2097	409.6792	160.00	455.00

Parameter	Site	N	Mean	Std dev	Std error	Lower bound	Upper bound	Min	Max
Total Hardness	Kroamoa	6	7.5000	2.73861	1.11803	4.6260	10.3740	5.0	10.0
	Kaniago	6	3.1667	2.48328	1.01379	.5606	5.7727	.00	5.00
	Baamure	6	4.1667	2.04124	.83333	2.0245	6.3088	.00	5.00
	Total	18	4.9444	2.97978	.70234	3.4626	6.4263	.00	10.0
Phosphate	Kroamoa	6	.7007	.71010	.28990	-.0445	1.4459	.05	1.98
	Kaniago	6	1.0063	1.85075	.75557	-.9359	2.9486	.17	4.78
	Baamure	6	.8687	1.55039	.63295	-.7584	2.4957	.04	4.02
	Total	18	.8586	1.37086	.32311	.1768	1.5403	.04	4.78
Fluoride	Kroamoa	6	.1283	.05636	.02301	.0692	.1875	.05	.20
	Kaniago	6	.1367	.12275	.05011	.0079	.2655	.00	.32
	Baamure	6	.0750	.06716	.02742	.0045	.1455	.00	.15
	Total	18	.1133	.08650	.02039	.0703	.1563	.00	.32
Nitrate	Kroamoa	6	.2313	.25563	.10436	-.0369	.4996	.08	.75
	Kaniago	6	.0665	.03495	.01427	.0298	.1032	.00	.11
	Baamure	6	.0693	.07640	.03119	-.0108	.1495	.00	.18
	Total	18	.1224	.16608	.03914	.0398	.2050	.00	.75
Nitrite	Kroamoa	6	.0694	.03152	.01287	.0364	.1025	.01	.09
	Kaniago	6	.2486	.31364	.12804	-.0806	.5777	.02	.70
	Baamure	6	.1769	.21468	.08764	-.0484	.4022	.01	.50
	Total	18	.1650	.22027	.05192	.0554	.2745	.01	.70
Sulphate	Kroamoa	6	3.3333	1.50555	.61464	1.7534	4.9133	2.0	5.00
	Kaniago	6	1.5033	2.34266	.95639	-.9551	3.9618	.00	5.00
	Baamure	6	1.5033	2.34266	.95639	-.9551	3.9618	.00	5.00
	Total	18	2.1133	2.16401	.51006	1.0372	3.1895	.00	5.00

APPENDIX 2B: Means, standard errors, and p-values of the parameters for the various sampling sites

Parameters	Sampling sites			P-value
	Kroamoa	Kaniago	Baamure	
pH	6.283 (0.045)	5.933 (0.246)	5.713 (0.063)	0.049*
Turbidity	4.00 (1.265)	4.167 (0.543)	4.00 (0.683)	0.988
Colour	71.67 (31.877)	31.83 (8.129)	46.5 (12.727)	0.399
Total Hardness	7.50 (1.118)	3.167 (1.014)	4.167 (0.833)	0.019*
Phosphate	0.701 (0.289)	1.006 (0.755)	0.869 (0.633)	0.936
Fluoride	0.128 (0.023)	0.137 (0.050)	0.075 (0.027)	0.433
Nitrate	0.231 (0.104)	0.067 (0.014)	0.069 (0.013)	0.144
Nitrite	0.069 (0.013)	0.249 (0.128)	0.177 (0.088)	0.389
Sulphate	3.333 (0.615)	1.503 (0.956)	1.503 (0.956)	0.251
Conductivity	294.833 (58.078)	420.833 (8.942)	346.167 (45.380)	0.147
Iron	0.492 (0.377)	0.355 (0.176)	0.183 (0.120)	0.689
Copper	0.005 (0.002)	0.005 (0.002)	0.005 (0.002)	1
Zinc	0.005 (0.002)	0.005 (0.002)	0.005 (0.002)	1
Lead	0.028 (0.024)	0.023 (0.019)	0.005 (0.002)	0.638
Faecal Coliform	4.350 (1.003)	5.750 (1.544)	7.083 (0.959)	0.301
E. Coli	2.583 (0.283)	4.550 (1.407)	3.450 (0.383)	0.296

*. Significant at the 0.05 level (2-tailed)

NB: Standard errors in brackets

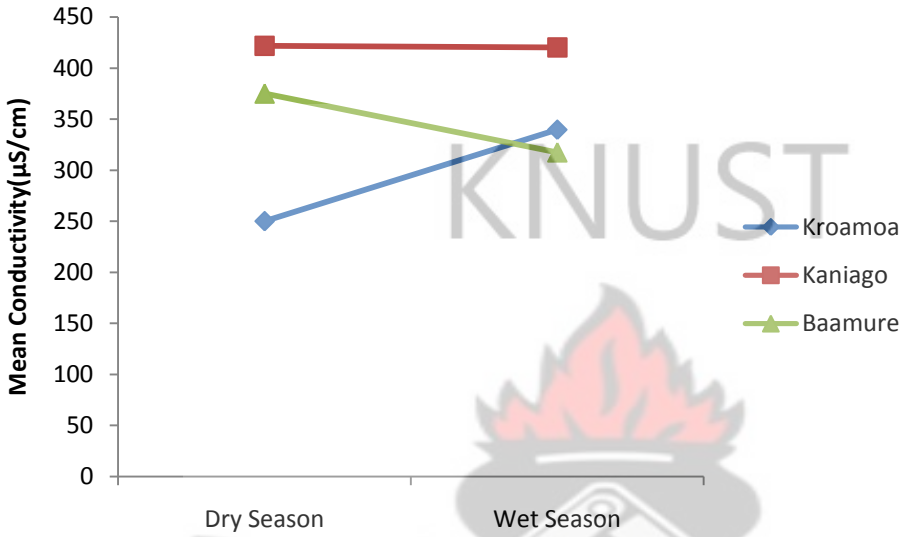
APPENDIX 2C: Statistical comparison of parameters at the sampling sites.

Multiple Comparisons							
LSD							
Dependent Variable	(I) Sampling Site	(J) Sampling Site	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
pH	Kroamoa	Kaniago	.35000	.21077	.118	-.0992	.7992
		Baamure	.57000*	.21077	.016	.1208	1.0192
	Kaniago	Kroamoa	-.35000	.21077	.118	-.7992	.0992
		Baamure	.22000	.21077	.313	-.2292	.6692
	Baamure	Kroamoa	-.57000*	.21077	.016	-1.0192	-.1208
		Kaniago	-.22000	.21077	.313	-.6692	.2292
Turbidity	Kroamoa	Kaniago	-.16667	1.25462	.896	-2.8408	2.5075
		Baamure	.00000	1.25462	1.000	-2.6742	2.6742
	Kaniago	Kroamoa	.16667	1.25462	.896	-2.5075	2.8408
		Baamure	.16667	1.25462	.896	-2.5075	2.8408
	Baamure	Kroamoa	.00000	1.25462	1.000	-2.6742	2.6742
		Kaniago	-.16667	1.25462	.896	-2.8408	2.5075
Colour	Kroamoa	Kaniago	39.83333	28.80033	.187	-21.5531	101.2198
		Baamure	25.16667	28.80033	.396	-36.2198	86.5531
	Kaniago	Kroamoa	-39.83333	28.80033	.187	-101.2198	21.5531
		Baamure	-14.66667	28.80033	.618	-76.0531	46.7198
	Baamure	Kroamoa	-25.16667	28.80033	.396	-86.5531	36.2198
		Kaniago	14.66667	28.80033	.618	-46.7198	76.0531
Total Hardness	Kroamoa	Kaniago	4.33333*	1.40765	.008	1.3330	7.3337
		Baamure	3.33333*	1.40765	.032	.3330	6.3337
	Kaniago	Kroamoa	-4.33333*	1.40765	.008	-7.3337	-1.3330
		Baamure	-1.00000	1.40765	.488	-4.0003	2.0003
	Baamure	Kroamoa	-3.33333*	1.40765	.032	-6.3337	-.3330
		Kaniago	1.00000	1.40765	.488	-2.0003	4.0003
Phosphat	Kroamoa	Kaniago	-.30567	.83886	.721	-2.0937	1.4823

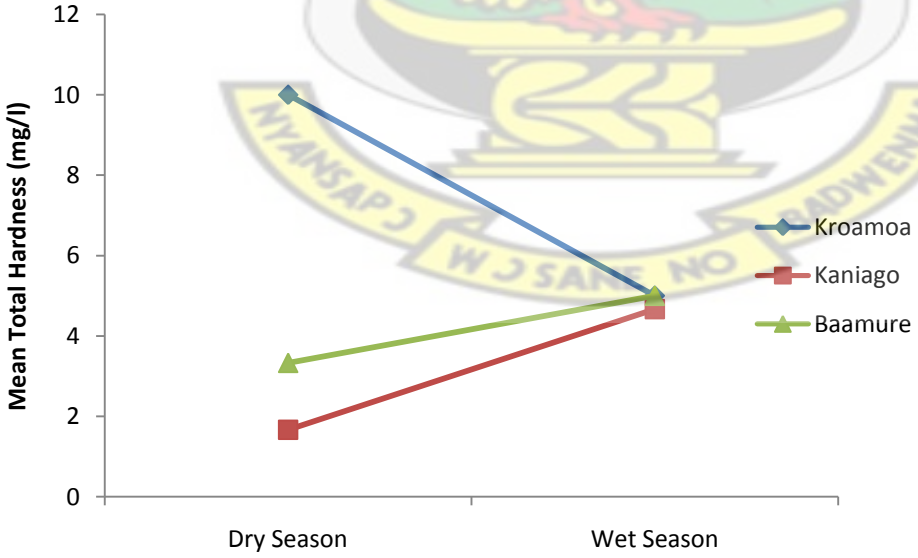
e		Baamure	-.16800	.83886	.844	-1.9560	1.6200
	Kaniago	Kroamoa	.30567	.83886	.721	-1.4823	2.0937
		Baamure	.13767	.83886	.872	-1.6503	1.9257
	Baamure	Kroamoa	.16800	.83886	.844	-1.6200	1.9560
		Kaniago	-.13767	.83886	.872	-1.9257	1.6503
Fluoride	Kroamoa	Kaniago	-.00833	.05028	.871	-.1155	.0988
		Baamure	.05333	.05028	.306	-.0538	.1605
	Kaniago	Kroamoa	.00833	.05028	.871	-.0988	.1155
		Baamure	.06167	.05028	.239	-.0455	.1688
	Baamure	Kroamoa	-.05333	.05028	.306	-.1605	.0538
		Kaniago	-.06167	.05028	.239	-.1688	.0455
Nitrate	Kroamoa	Kaniago	.16483	.08970	.086	-.0263	.3560
		Baamure	.16200	.08970	.091	-.0292	.3532
	Kaniago	Kroamoa	-.16483	.08970	.086	-.3560	.0263
		Baamure	-.00283	.08970	.975	-.1940	.1883
	Baamure	Kroamoa	-.16200	.08970	.091	-.3532	.0292
		Kaniago	.00283	.08970	.975	-.1883	.1940
Nitrite	Kroamoa	Kaniago	-.17915	.12713	.179	-.4501	.0918
		Baamure	-.10750	.12713	.411	-.3785	.1635
	Kaniago	Kroamoa	.17915	.12713	.179	-.0918	.4501
		Baamure	.07165	.12713	.581	-.1993	.3426
	Baamure	Kroamoa	.10750	.12713	.411	-.1635	.3785
		Kaniago	-.07165	.12713	.581	-.3426	.1993
Sulphate	Kroamoa	Kaniago	1.83000	1.21302	.152	-.7555	4.4155
		Baamure	1.83000	1.21302	.152	-.7555	4.4155
	Kaniago	Kroamoa	-1.83000	1.21302	.152	-4.4155	.7555
		Baamure	.00000	1.21302	1.000	-2.5855	2.5855
	Baamure	Kroamoa	-1.83000	1.21302	.152	-4.4155	.7555
		Kaniago	.00000	1.21302	1.000	-2.5855	2.5855
Conductivity	Kroamoa	Kaniago	-126.00000	60.62095	.055	-255.2105	3.2105
		Baamure	-51.33333	60.62095	.410	-180.5438	77.8772
	Kaniago	Kroamoa	126.00000	60.62095	.055	-3.2105	255.2105
		Baamure	74.66667	60.62095	.237	-54.5438	203.8772
	Baamure	Kroamoa	51.33333	60.62095	.410	-77.8772	180.5438

		Kaniago	-74.66667	60.62095	.237	-203.8772	54.5438
Iron	Kroamoa	Kaniago	.13667	.35340	.704	-.6166	.8899
		Baamure	.30833	.35340	.397	-.4449	1.0616
	Kaniago	Kroamoa	-.13667	.35340	.704	-.8899	.6166
		Baamure	.17167	.35340	.634	-.5816	.9249
	Baamure	Kroamoa	-.30833	.35340	.397	-1.0616	.4449
		Kaniago	-.17167	.35340	.634	-.9249	.5816
Copper	Kroamoa	Kaniago	.00000	.00316	1.000	-.0067	.0067
		Baamure	.00000	.00316	1.000	-.0067	.0067
	Kaniago	Kroamoa	.00000	.00316	1.000	-.0067	.0067
		Baamure	.00000	.00316	1.000	-.0067	.0067
	Baamure	Kroamoa	.00000	.00316	1.000	-.0067	.0067
		Kaniago	.00000	.00316	1.000	-.0067	.0067
Zinc	Kroamoa	Kaniago	.00000	.00316	1.000	-.0067	.0067
		Baamure	.00000	.00316	1.000	-.0067	.0067
	Kaniago	Kroamoa	.00000	.00316	1.000	-.0067	.0067
		Baamure	.00000	.00316	1.000	-.0067	.0067
	Baamure	Kroamoa	.00000	.00316	1.000	-.0067	.0067
		Kaniago	.00000	.00316	1.000	-.0067	.0067
Lead	Kroamoa	Kaniago	.00500	.02555	.847	-.0494	.0594
		Baamure	.02333	.02555	.375	-.0311	.0778
	Kaniago	Kroamoa	-.00500	.02555	.847	-.0594	.0494
		Baamure	.01833	.02555	.484	-.0361	.0728
	Baamure	Kroamoa	-.02333	.02555	.375	-.0778	.0311
		Kaniago	-.01833	.02555	.484	-.0728	.0361
Faecal Coliform	Kroamoa	Kaniago	-1.40000	1.69482	.422	-5.0124	2.2124
		Baamure	-2.73333	1.69482	.128	-6.3458	.8791
	Kaniago	Kroamoa	1.40000	1.69482	.422	-2.2124	5.0124
		Baamure	-1.33333	1.69482	.444	-4.9458	2.2791
	Baamure	Kroamoa	2.73333	1.69482	.128	-.8791	6.3458
		Kaniago	1.33333	1.69482	.444	-2.2791	4.9458
E. Coli	Kroamoa	Kaniago	-1.96667	1.21306	.126	-4.5522	.6189
		Baamure	-.86667	1.21306	.486	-3.4522	1.7189
	Kaniago	Kroamoa	1.96667	1.21306	.126	-.6189	4.5522
		Baamure	1.10000	1.21306	.379	-1.4856	3.6856
	Baamure	Kroamoa	.86667	1.21306	.486	-1.7189	3.4522
		Kaniago	-1.10000	1.21306	.379	-3.6856	1.4856

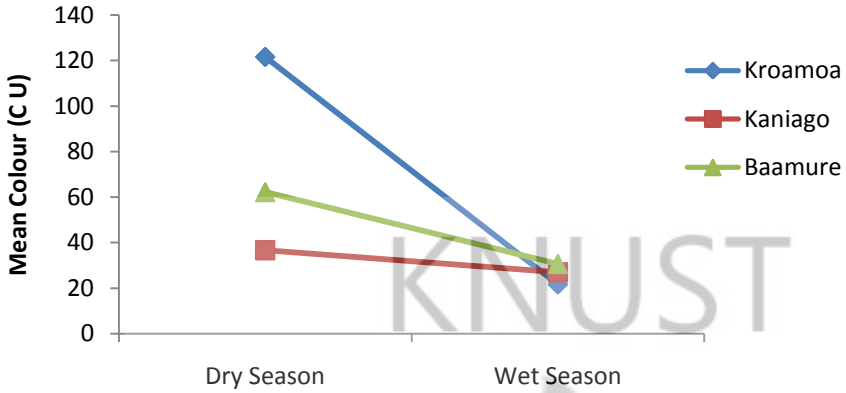
APPENDIX 3 : Graphs showing variations of physicochemical parameters during the dry and wet seasons.



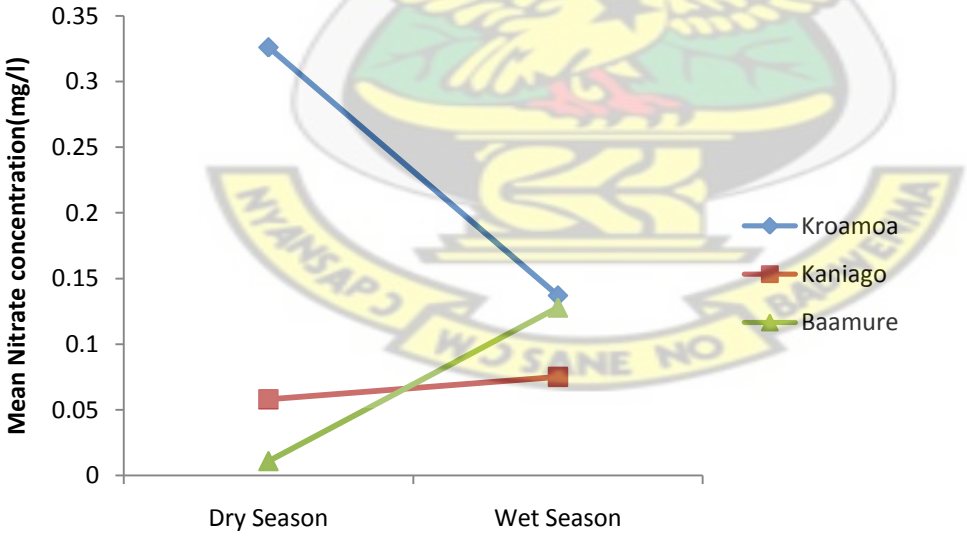
Variation of Conductivity in the dry and wet season



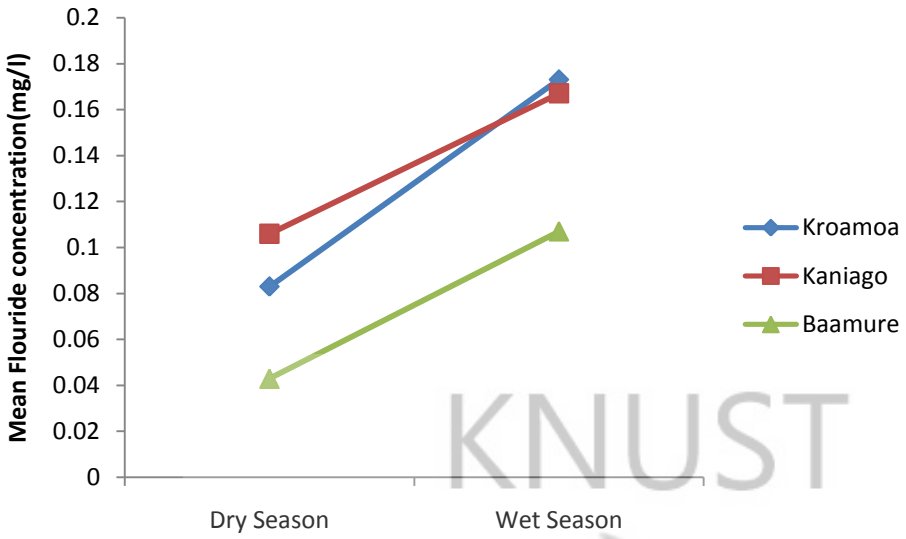
Variation of mean total hardness in the dry and wet season



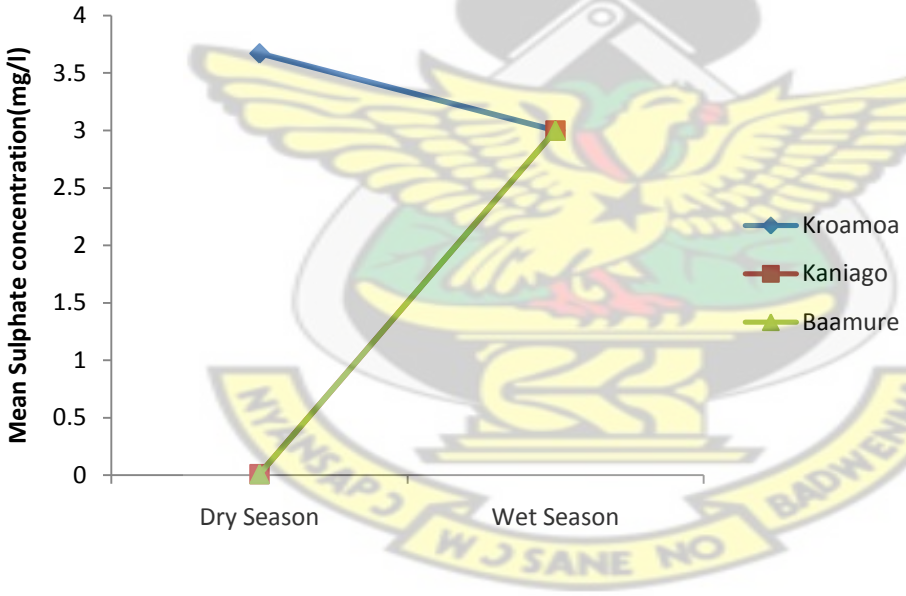
Variation of Mean colour in the dry and wet season



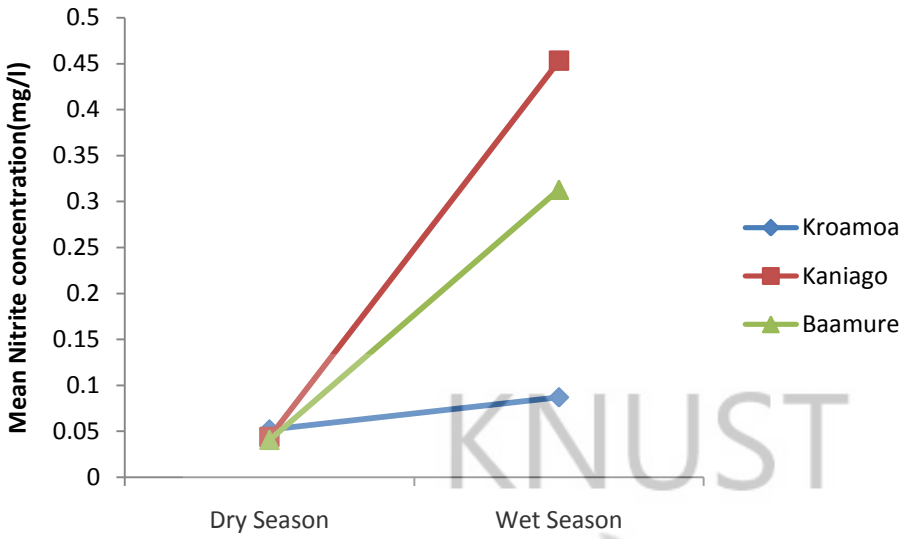
Variation of Mean nitrate concentration in the wet and dry season



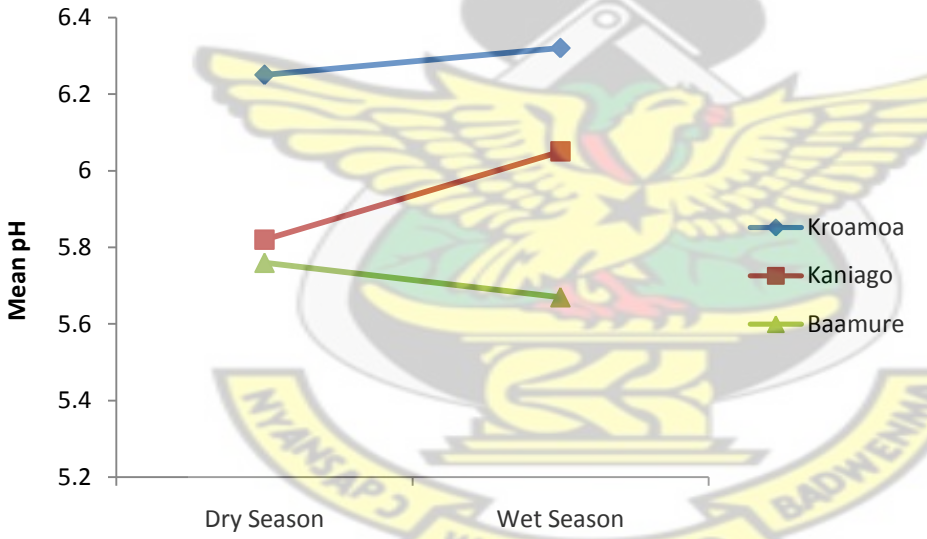
Variation of Mean Fluoride concentration in the dry and wet seasons.

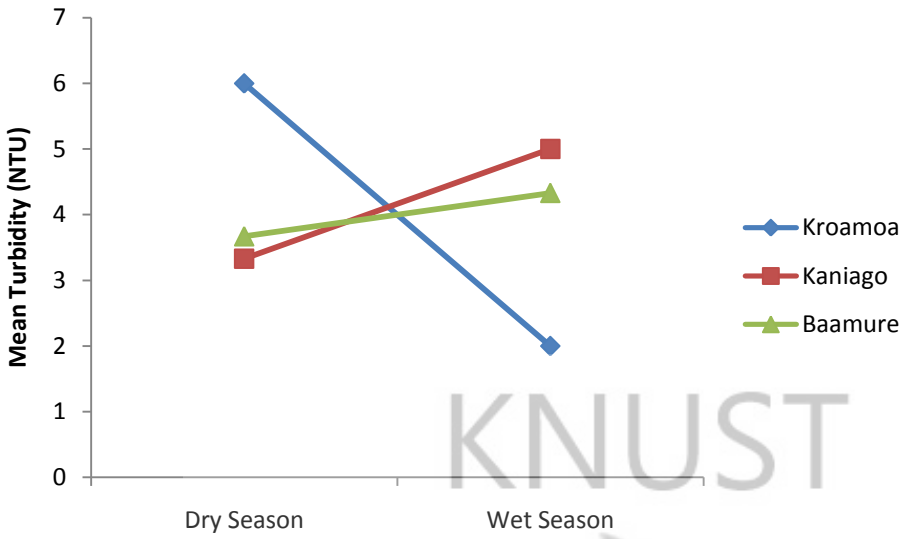


Variation of mean sulphate concentration in the dry and wet seasons

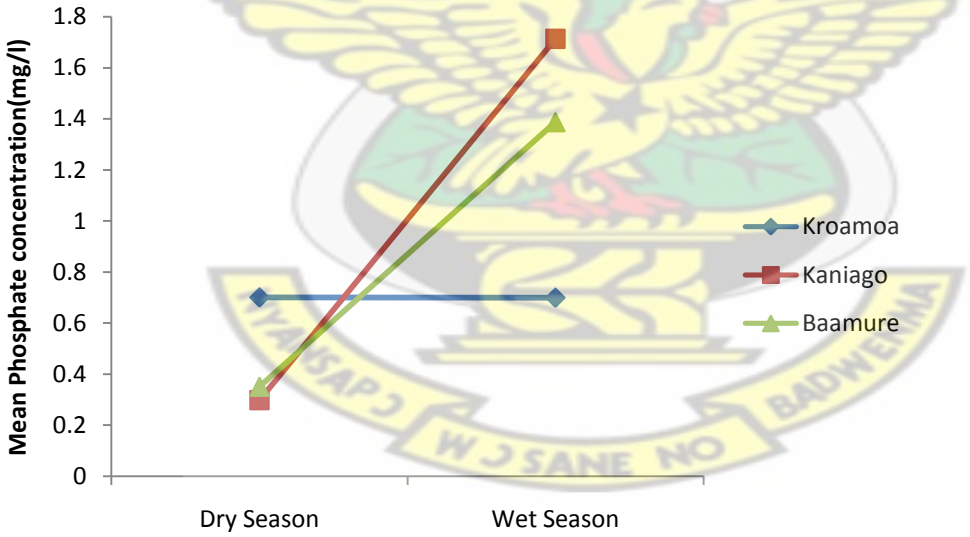


Variation of Nitrite concentration in the wet and dry seasons.





Variation of Mean Turbidity in the dry and wet seasons



Variation of Mean Phosphate concentrations in the wet and dry seasons

APPENDIX 4: WHO Guideline values for the analysed parameters in drinking water.

Parameter	WHO Guideline value
Colour	Below 15 colour units
Total hardness	200mg
pH	6.5 – 8.5
Conductivity	300µS/cm
Nitrates	50mg/l
Nitrite	0.2mg/l
Sulphate	-
Fluoride	500mg/l
Phosphate	1.5mg/l
Copper	-
Lead	0.01mg/l
Iron	10 – 50mg/l
Zinc	3mg/l
E. coli	NIL
Faecal coliforms	NIL
Salmonella	NIL