KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

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DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

QUALITY OF WATER FOR DRINKING AND OTHER DOMESTIC PURPOSES IN SOME SELECTED COMMUNITIES IN ASUTIFI NORTH DISTRICT OF BRONG AHAFO REGION, GHANA

A THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN ENVIRONMENTAL SCIENCE

BY

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DECLARATION

With respect to other peoples works, which have been duly acknowledged I, Seth Kofi Amoateng of the Environmental Science Programme, hereby certify that this thesis is the result of research undertaken entirely by myself under the supervision of Prof. Philip Kweku. Baidoo.

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DEDICATION

This piece of work is dedicated to my dear wife Mrs. Ruth Amoateng for her patience, sacrifices, encouragement and inspiration. May the Good Lord grant her long healthy life and prosperity. I am also grateful to Rita Asarewaa Amoateng, Keziah Fosuaa Amoateng, John Philips Amoateng and my parents for their patience, moral support and sacrifices.

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ABSTRACT

The suitability of water for drinking and other domestic purposes from two major towns namely Ntotroso and Kenyasi in the Asutifi North District of Brong Ahafo Region were analyzed from November 2013 to February 2014.Water quality was monitored along four (4) main dimensions, namely metal concentration, physico-chemical, nutrient and microbiological parameters. Water samples were collected from twelve (12) sampling sites comprising two (2) major rivers, four (4) boreholes and six (6) hand dug wells and analyzed for temperature, pH, turbidity, conductivity, total dissolved solids, alkalinity, total hardness and some selected anions (phosphates, sulphates, chlorides, nitrates), some heavy metals (Cd, Pb, Zn, Hg, Cu, As, Fe) and microbiological indicators (faecal coliforms, total coliforms, *Enterococci, E. coli*). The concentration of lead for the water samples ranged from (0.08 mg/l to 0.33 mg/l). The largest (0.33 mg/l) concentration was recorded from the Goa River (located in Kenyasi) whilst the least (0.08 mg/l) was recorded in Borehole (located in Ahenebronum, Ntotroso). All the values recorded were above the WHO and Ghana Standards values of 0.010mg/l. The largest (3.12 mg/l) concentration of iron was recorded from hand dug well (located in Akataase, Ntotroso) whilst the least (0.83 mg/l) was recorded in Tano River (located at Ntotroso). All the iron concentrations were above the WHO limit (0.3mg/l) and Ghana Standard value (0.5mg/l).

Mean alkalinity for the water samples ranged from (198.00 mg/l in borehole located in Ahenebronum, Ntotroso to 398.00 mg/l in hand dug well located in Akataase, Ntotroso). The only sample source found within the WHO acceptable limit (200 mg/l) was borehole located in Ahenebronum, Ntotroso. It was observed that the largest concentration of faecal coliforms was recorded in hand dug well located in Kwadaso, Kenyasi. No faecal coliforms were recorded in Boreholes located in Ampedwee Kenyasi, Adum Kenyasi and Akataase

Ntotroso. Water from these boreholes were therefore found to be within the acceptable WHO and Ghana Standards limits (0.0000 CFU/100ml).The largest concentration of *E. coli* was recorded in the Tano River. No *E. coli* was found in Borehole located in Ampedwee Kenyasi and Adum Kenyasi. Parameters such as mercury, arsenic, cadmium, zinc levels, turbidity, total dissolved solids, potassium and sodium were all within the acceptable limits of the World Health Organization (WHO) and Ghana Standards (GS) 175 – 1: 2008. Levels of lead, copper, iron, pH, conductivity, alkalinity, total hardness, calcium and manganese were above the acceptable guideline limits of the World Health Organization (WHO) and Ghana Standards (GS) 175 – 1: 2008. These make the water in the two communities (Kenyasi and Ntotroso) unsafe for drinking and other domestic uses without prior treatment or purification.

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LIST OF ABBREVIATIONS

AAS – Atomic Absorption Spectrophotometry

APHA – American Public Health Association

BOD – Biological Oxygen Demand

BST – Bacterial Source Tracking

COD – Chemical Oxygen Demand

CWSA – Community Water and Sanitation Agency

DO – Dissolved Oxygen

EPA – Environmental Protection Agency

FDA – Food and Drug Administration

GSS – Ghana Statistical Service

MPL – Maximum Permissible Level

MtBE – Methyl Tertiary- Butyl Ether

NGGL – Newmont Ghana Gold Limited

NTU – NephelometricTurbidityUnits

SMCL Suggested Maximum Contaminant Level

TDS – Total Dissolved Solids

TSS – Total Suspended Solids

UNEP – United Nations Environmental Programme

UNICEF – United Nations Children's Fund

US – United States

USEPA – United States Environmental Agency
USGS – United States Geological Survey

WHO – World Health Organization

CHAPTER ONE

1.0 INTRODUCTION

1.1 General Background

Water quality entails the chemical, physical and biological characteristics of water. It is a measure of the condition of water relative to the requirements of one or more biotic species and or to any human need or purpose. The most common standards used to assess water quality relate to health of ecosystems, safety of human contact and drinking water (Chapman, 1996). Water is very important to the survival of all living organisms including man. Not only do we need water to grow our food, generate our power and run our industries, but we need it as a basic part of our daily lives. Moreover, communities and individuals can exist without many things if they have to. They can be deprived of comfort of shelter, even of food for a period, but they cannot be deprived of water and survive for more than a few days. Because of the close relationship between water and life, water is woven into the fabric of all cultures, religions and societies in a myriad of ways. Surface freshwater resides in rivers, streams and lakes which is an important source of drinking water, habitats for plants and animals and for recreation and transportation purposes. Groundwater remains one of the most important sources of water supply in rural communities and small towns in Ghana. Currently, over 95% of water provided to small communities and towns for domestic use is extracted from groundwater source. However, the occurrence of high levels of minerals including metal compounds, especially iron and manganese in most of these groundwater sources has been identified as a challenge limiting the extent to which this resource can be exploited. (CWSA, 2007). Drinking water sources

include rivers, springs, streams, wells, ponds, reservoirs, rain and piped water. With exception of piped water, all other sources may be faecally contaminated and without treatment (WHO, 1993). Research in the country had revealed that collection of water from these sources, as well as storage and handling of the water at homes, can cause quality deterioration to such an extent that the water poses potential risks of infection to consumers (Ampofo and Karikari, 2006).

We use freshwater for everything from washing, drinking and watering garden to cooling equipment of industrial complexes. After we have finished with it, the water finds its way back into the water cycle that is into stream, river, pond, lake, marsh, or groundwater along with contaminants it picked up along the way.

The clearity of water does not indicate that the water is of higher quality but rather it may contain toxic chemicals or bacterial or viral pathogens that have serious health implications.

In the olden days, surface water source for drinking was determined for contamination by placing a healthy fish into a stream. If the fish died, it meant that the source of water was contaminated and therefore must be purified. The microbial guidelines make sure that drinking water is free of microorganisms that may cause disease. Microbial hazards pose an overall greater threat than chemical hazards, and in developing countries account for 5.7% of the total global burden of diseases (Larmie and Paintsil, 1996; WHO, 2003). The lack of microbiologically safe drinking water and adequate sanitation measures lead to a number of diseases including typhoid, dysentery, cholera, salmonellosis, etc and every year millions of lives are lost in developing countries. In Ghana, it is estimated that 57% of its population is rural and more than half of this number depends on unsafe water sources, and

therefore make water-related diseases predominant in the country (Ghana Statistical Service, 2005).

1.2 Arsenic (As) and Mercury (Hg) in water

Arsenic is poisonous and severe toxicity has been reported after ingestion of only 100 mg of the element. Chronic toxicity can result from a buildup of lower intakes. It is not geologically uncommon and occurs in natural water as arsenate and arsenite. Additionally, arsenic may occur from industrial discharges or insecticide application.

Symptoms of acute arsenic poisoning include gastrointestinal irritation, severe vomiting, diarrhea which may be blood stained followed by abdominal colic with peripheral circulatory collapse and death (Welch, 1988).

It is an established fact that most mercury pollution is caused by anthropogenic activities and it is a metal that can vapourise at room temperatures. Mercury is not an abundant element in the earth's crust. Elucidation of the complex chemistry of mercury and its compounds in natural systems, spurred by certain highly publicized incidents of mercury poisoning, has demonstrated that rather low concentrations of mercury may be highly important if the flux through an aqueous system is high.

Mercury in water bodies settles on the sediments and bacteria convert it to methyl mercury compounds, more toxic form that readily enters the food web. It was found that alkyl mercury, particularly methyl mercury compounds may contaminate environmental subjects with the effluent from the plants and they are absorbed by organisms, accumulated in some

organs and tissues, and give rise directly and indirectly to various disturbances of human beings and animals (Motavalli, 2002).

1.3 Water quality parameters

Water quality parameters involve physical indicators, chemical indicators and biological indicators. The physical indicators include turbidity, conductivity, colour, temperature, odour, total dissolved solids, taste of water, total suspended solids ; chemical indicators include pH, Heavy metals, Biochemical Oxygen Demand, Chemical Oxygen Demand, Dissolved Oxygen, Total hardness, Nitrate ; trace elements parameters and microbiological indicators.

The chemical quality of the aquatic environment varies according to local geology, climate, distance from the ocean and amount of soil cover, etc. If the surface water were totally unaffected by human activities, up to 90 per cent of global freshwaters, depending on the variable of interest, would have natural chemical concentrations suitable for aquatic life and most human uses (Chapman, 1996).

Drinking water experts have realised that taste and odour problems are the first serious sign for potential health hazard; therefore taste and odour are important for aesthetic reasons as a measure of the acceptability of water. Objectionable taste and odour are more likely found at the raw water source than at the consumer's tap. Taste and odour in water are caused by minerals, metals and salts from the soil, constituents of wastewater, and end products produced in biological reactions. The more offensive odours are those caused by hydrogen sulphide gas (H_2S) are common in water supplies.

1.4 Human impact on water quality

The range of requirements for water has increased together with greater demands for higher quality water, with the advent of industrialization and increasing populations. Requirements for water have emerged for drinking and personal hygiene, fisheries, agriculture, navigation to transport of goods, industrial production, cooling in fossil fuel power plants, hydropower generation and recreational activities (Buah-Kwofie, 2003). In real sense, treatment of effluents from industries should be carried out before discharging them into nearby source of natural waters. Heavy metals in water can either be naturally occurring or introduced by human interference through various activities. Water has been considered the best medium to clean, disperse, transport and dispose of wastes including domestic and industrial wastes, mine drainage waters and irrigation.

Vital and legitimate water uses at local, regional or international scale are interfered by pollution and water quality degradation (Meybeck and Helmer, 1989). Degradation of water quality is mainly caused by anthropogenic activities although natural events such as hurricanes, mud flows, torrential rainfall and unseasonal lake overturns can also lower water quality levels. Pollutants get into water bodies in the form of dissolved substances, gases or particulate matter.

1.5 Pollution of water bodies

Enger and Smith (1992) defined water pollution as any physical, biological or chemical change in water quality that adversely affects living organisms or makes water unsuitable

for the desired uses. Pollution of water is a global problem that varies in magnitude and type of pollutant from one region to another (Motavalli, 2002). Water bodies' pollutants can be divided into sediments pollution, sewage, disease causing agents, inorganic plant and algal nutrients, radioactive substances, thermal pollution, inorganic chemicals and organic compounds.

Examples of human diseases that are transmitted by polluted water are Dysentery, Typhoid, Cholera, Poliomyelitis, Ancylostomiasis, Cryptosporidiosis, Schistosomiasis,

etc.

The excessive and prolonged discharge of raw or untreated liquid waste and refuse contaminate lakes, rivers, and groundwater bodies, making them unwholesome for biota consumption. Accidental release of toxic chemical substances, leaking of liquids from solids waste deposits, uncontrolled and excessive use of fertilizers and pesticides also contaminate water bodies (Chapman, 1996).

The sources of water pollution are classified into two types, point source pollution and non-source pollution. Point source pollution is discharged into the environment through pipes, sewers or ditches from specific sites such as factories or sewage treatment plants. Non-point source pollution is caused by land pollutants that enter water bodies over large areas rather than a single point. Non-point source pollution includes agricultural runoff, municipal wastes and construction sediments (Raven and Berg, 2004). The major sources of human induced water pollution are industries, municipalities, and agriculture.

According to the EPA (2002), agriculture is the leading source of water quality impairment of surface waters nationwide.

1.6 Statement of problem

It is an established fact that approximately 1.1 billion people do not have access to improved drinking water sources and 2.4 billion people do not have adequate sanitation in the world yet most of our freshwater sources are affected in a negative way due to human activities (UNICEF, 2006). Moreover, fifty seven percent (57%) of Ghana's population live in rural areas and more than half of the above mentioned figure (57%) depends on unsafe water sources (GSS, 2005).

Surface freshwater and even groundwater are being polluted with persistent organic pollutants, heavy metals and nutrients that have negative effects on health. The levels of the contaminants in these water bodies are being increased by anthropogenic activities (Rail, 1985). However, majority of industries in Ghana fail to treat their effluents which may contain some heavy toxic metals, pathogenic microbes, organic contaminants and other pollutants. If these effluents are not treated to remove the pollutants, it may result in adverse health effects on the environment. Some of the effects of high levels of heavy metals on human health include respiratory organ failure, skin disorders, brain damage, poisoning and even death (Rail, 1985).

1.7 Justification

Most of the inhabitants within Ntotroso and Kenyasi and their catchment smaller communities come into contact with hand dug wells and rivers for various reasons including washing, bathing and collecting water for domestic use. Sometimes, children also play barefooted along some of the rivers in these communities. Moreover, most streams

are found within the confines of Newmont Ghana Gold Limited concessions in the Ahafo Mine which predisposes these communities to water pollution. In addition, illegal mining (galamsey) activities have sprang up in these two major communities. Nevertheless, chemical studies have not been done on some of these rivers and wells.

Within the study area, erratic flow of treated pipe water is a major problem and this has pushed most of the residents to rely on other sources of water of which wells and rivers are the most relied water sources in the communities.

When the concentrations of trace metals and other water quality parameters exceed certain levels, they tend to have a negative consequence on biota including human beings. Without much attention being paid in the treatment of these pollutants, then the study area and the country as a whole stands the risk of severe environmental pollution and associated diseases. Therefore, research in the above mentioned problems, will serves as a resource material for policy formulators to control certain human activities that have the chance to cause negative impact on water bodies.

1.8 Objectives

The main objective of the study was to determine the suitability of water for drinking and other domestic purposes in some selected communities in Asutifi North District of Brong Ahafo Region.

The specific objectives of the study are to:

(i) Determine the concentration level of arsenic, mercury, cadmium, iron, zinc, copper and lead in the selected water bodies.

(ii) Measure the physico chemical parameters such as pH, turbidity, total dissolved solids temperature, conductivity, alkalinity, total hardness, bicarbonate, magnesium, calcium, sodium, potassium, manganese, chlorides, nitrates, phosphates, and sulphates of the selected water bodies.

(iii) Measure microbiological indicators such as faecal coliforms, total coliforms, E. *coli* and enterococci.

CHAPTER TWO

2.0 LITERATURE REVIEW

Large quantities of organic compounds, chemicals, heavy metals, high nutrient concentrations and other number of pollutants can destroy the aquatic environments to a larger extent. Through point and non-point sources discharges, pollutants may get to river bodies and these pollutants may be carried either by water or air from nearby or distant discharge points. The negative impacts of pollutants may be limited to water body or to a

specific organism. Moreover, pollutants in water bodies usually result in chronic rather than acute problems for the affected organisms, making detection far more difficult (Amedzeame, 2004).

There are a number of water quality issues plaguing the water delivery process. These include high iron, fluoride and arsenic contents. A good number of drilled wells for instance have been capped especially in the Northern parts of the country due to high levels of fluoride found in these wells (Community Water and Sanitation Agency, 2007). Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of these contaminants does not necessarily indicate that the water poses a health risk. Water drawn directly from a stream, lake, or aquifer and that has no treatment will be of uncertain quality (Howard, 2000).

Pathogenic agents causing water borne diseases include bacteria and viruses as well as protozoa and helminths. Although they interfere only marginally with aquatic life in general, they cause severe public health problems and are considered responsible for most of the infant mortality in developing countries (WHO, 1993).

2.1 Metals in water and health effects

There has always been a metal on earth, and many of them fulfill essential functions in all living organisms. Nevertheless, a considerable number of metals are harmful to plants, animals and humans in excessive quantities. Several of these metals can be stored in living tissues and remain there for a very long time.

Heavy metals are therefore stable high density metals and some metalloids such as arsenic. These elements are natural constituents of the Earth crust. As a result of anthropogenic activity, the input of heavy metals to the environment has increased sufficiently and has resulted in the increase of their content in air, water, soil and tissues of living organisms (More, 1984).

Water analysis for heavy metals must consider soil particles suspended in the water sample. These suspended soil particles may contain measurable amounts of metals. Although the particles are not dissolved in the water, they may be consumed by people drinking the water.

Determining the presence and concentration levels of heavy metals in water bodies has become very important because these metals become poisonous at certain concentrations and pose health hazards to consumers of such water (Agyei, 2004).

Table 2.1 Drinking Water Standards for Heavy Metals

Metal	U.S. EPA	WHO
As	50ppb	10ppb
Cd	5ppb	3ppb
Pb	15ppb	10ppb
Hg	2ppb	1ppb

Source: Colin Baird, 2000.

2.1.1 Mercury

This metal vapourises at room temperatures and vapourisation character poses serious challenges to the environment when dealing with mercury. Naturally, small amounts of mercury occur in the environment but human activities are the most cause of mercury pollution. According to USEPA (1997), the largest amount of mercury (33 %) is released into the environment by coal-fired power plants. Coal contains traces of mercury that vapourises and is released into the atmosphere with the flue gases when coal is burned. A form of precipitation can result when mercury in the atmosphere combines with water vapour. Also municipal waste incinerators account for 18% of mercury released into the environment and medical waste incinerators contribute 10% (Raven and Berg, 2004). Mercury in municipal waste comes from fluorescent lights and thermostats whereas thermometers and blood-pressure cuffs are examples of medical waste.

Moreover, when industries release their wastewater, some metallic mercury may enter natural water bodies. Other ways that mercury enters aquatic environment is through the leakage from house garbage containing batteries, paints and plastics. Organic mercury contamination results from some mercury residue produced in chemical plants, fungicides used widely in farms, erratic use of disinfectants and fungicides for medical supplies and clothes. Methyl mercury compounds (a more toxic form of mercury) which readily enters the food web is formed when mercury in water bodies settles into the sediments and being upon acted by bacteria. It was found that alkyl mercury, particularly methyl mercury compounds may contaminate environmental subjects with the effluent from the plants and they are absorbed by organisms, accumulated in some organs and tissues, and give rise directly and indirectly to various disturbances of human beings and animals.

When a developing foetus in pregnant women is exposed to mercury, a variety of conditions result which include cerebral, mental retardation and developmental delays. Similarly, prolonged exposure to methyl mercury compounds results in kidney disorders and severe damage of the nervous and cardiovascular systems (Raven and Berg, 2004).

Methyl mercury compounds are able to cross the body's blood-brain barrier. Low levels of mercury in the brain cause neurological problems such as depression, headache and quarrelsome behaviour.

2.1.2 Arsenic

Arsenic is widely distributed throughout the earth's crust; most often as arsenic sulphide and it exists in oxidation states of -3, +3, 0 and +5. Arsenic is ubiquitous in the environment and their presence may be due to natural and anthropogenic activities. Arsenic is introduced into water bodies through the dissolution of minerals and ores, from industrial effluent and atmospheric deposition (WHO, 2004).

In underground waters, the dominant species of arsenic is the form As^{+3} and in fresh surface water the common species is As^{+5}. An increase in pH may increase the concentration level of dissolved arsenic in water (Sloof, 1990).

Clinical effects of acute arsenic poisoning have been studied. Symptoms include gastrointestinal irritation, severe vomiting, diarrhoea which may be blood stained followed by abdominal colic with peripheral circulatory collapse and death (Welch *et al*., 1988). Humans expose to inorganic arsenicals may increase their risk of cancer of the skin, liver, lung and hematopoietic tissues. For elderly persons, they may show symptoms of chronic arsenic poisoning. Also inorganic arsenicals are weak inducers of chromosomal aberration and exert their strongest effect by inhibiting DNA (Agyei, 2004).

2.1.3 Cadmium

The chemistry of cadmium is similar to that of lead and zinc. Cadmium is found in nature largely in the form of the sulfide, and as an impurity of zinc – lead ores. The abundance of cadmium is much less than that of zinc. Cadmium may enter surface waters as a consequence of mining and smelting operations. It may be present in wastes from electroplating plants, pigment works, textile and chemical industries. Groundwater cadmium concentrations, as great as 3.2 mg/ litre, have resulted from the seepage of cadmium from electroplating plants. Metal and plastic pipes constitute an additional possible source of cadmium in waters (WHO, 2004). Drinking water from surface water where the soil has been acidified contains concentration of cadmium approaching 5 µg/l.

The estimated lethal dose of cadmium for human is 350-3500 mg/l. With chronic oral exposure, the kidney appears to be the most sensitive organ. In addition, the metal can be linked to increased blood pressure and effects on the myocardium in animals, although most human data do not support these findings (Friis *et al.*, 1998).

2.1.4 Iron

Iron is an abundant element in the earth's crust, but exists generally in minor concentrations in natural water systems. Iron is chemically active and forms two major series of chemical compounds, the bivalent iron (II), or ferrous compounds and the trivalent iron (III), or ferric compounds. The form and solubility of iron in natural waters are strongly dependent upon the pH and the oxidation – reduction potential of the water. An increase in the oxidation – reduction potential of the water readily converts ferrous ions to ferric (±3) and allows ferric iron to hydrolyze and precipitate as hydrated ferric oxide. Surface waters in a normal pH range of 6 to 9 rarely carry out more than 1 mg of dissolved iron per litre. However,

subsurface water removed from atmospheric oxidative conditions and in contact with iron-bearing minerals may readily contain elevated amounts of ferrous iron. For example, in ground water systems affected by mining, the quantities of iron routinely measured may be several hundred mg/litre (WHO, 2004).

Iron is one of the most troublesome elements in water supplies. It makes up at least 5 percent of the earth's crust; iron is one of the earth's most plentiful resources. Rainwater as it infiltrates the soil and underlying geologic formations dissolves iron, causing it to seep into aquifers that serve as sources of groundwater for wells. Although present in drinking water, iron is seldom found at concentrations greater than 10 mg/l. However, as little as 0.3 mg/l can cause water to turn reddish brown (Machmeier, 1990). High iron concentration produces an unpleasant taste in drinking water, making it unsuitable for consumption. High quantities in water may cause the staining of plumbing fixtures and laundry (Spellman and Drinan, 2000).

2.1.5 Lead

Lead is a relatively minor element in the earth's crust but is widely distributed in low concentration in uncontaminated sedimentary rocks and soil. Lead concentrations in fresh water are generally much higher. High concentrations of lead result from atmospheric input of lead originating from its use in leaded gasonline or from smelting operations.

Industrial and mine or smelter operations may contain relatively large amounts of lead. Many commonly used lead salts are water soluble. Lead in drinking water may be due to the use of lead pipes or of plastic pipes stabilized with lead compounds. Although the contributions of lead from food and from air are more significant, the World Health

Organization has established 0.05 mg/litre as a guideline value for lead in drinking water. Lead is toxic to aquatic organisms but the degree of toxicity varies greatly, depending on water quality characteristics as well as the species being considered.

Dissolved lead in aquatic environment depends on factors including temperature, pH, dissolved oxygen, water hardness and presence of chloride. Lead is also ingested from pesticide and fertilizer residues on crops, from food cans soldered with lead and from certain types of dinnerware on which food is served (Raven and Berg, 2004). Lead accumulated in the body over a period of time can cause serious toxic effects. Three groups of people at greatest risk from lead poisoning are pregnant women, middle-aged men and children. In 1996, a study conducted by the University of Pittsburgh School of Medicine revealed a link between male juvenile delinquency and high bone lead concentrations. A 2001 study by the American Medical Association reported a link between murder rates and lead levels in the air (Raven and Berg, 2004).

2.1.6 Zinc

Zinc is an abundant element in rocks and ores but it is present in natural water only as a minor constituent because of the lack of solubility of the free metal and its oxides. It is present only in trace quantities in most alkaline surface and ground waters, but more may be present in acid waters. The main industrial use of zinc is in galvanizing and it may enter drinking water from galvanized pipes. Average zinc concentration in surface water is about 10 mg/litre, with a range from 0.2 mg/litre to 1 mg/litre. The guideline value of zinc in drinking water is based on aesthetic considerations. Water containing zinc at concentrations in excess of 5.0 mg/litre has an undesirable astringent taste and may be opalescent, developing a greasy film on boiling. Although drinking water seldom has a zinc

concentration greater than 0.1 mg/litre, levels in tap water can be considerably higher because of the zinc used in plumbing materials. The World Health Organization has proposed that the guideline value for zinc in drinking water should be 5.0 mg/litre, based on taste considerations. Zinc may be toxic to aquatic organisms but the degree of toxicity varies greatly, depending on water quality characteristics as well as the species being considered. Very high levels of zinc can damage the pancreas and disturb the protein metabolism, and cause arteriosclerosis. Extensive exposure to zinc chloride can cause respiratory disorders (Prasad, 1978).

2.1.7 Copper

Copper is a widely distributed trace element but, because most copper minerals are relatively insoluble and because copper is sorbed to solid phases, only low concentrations are normally present in natural waters. The presence of higher concentrations of copper can usually be attributed to corrosion of copper pipes, industrial wastes or, particularly in reservoirs, the use of copper sulfate as an algicide. The presence of copper in water supply, although not considered as a health hazard, may interfere with the intended domestic uses of the water. At levels above 4 mg/litre, it imparts a colour and undesirable bitter taste to water. Staining of laundry and plumbing fixtures occurs at copper concentration above 1.0 mg/litre. The guideline value is 1.0 mg/litre based on its laundry and other staining properties (WHO 2002).

Immediate health effects from drinking water with very high levels of copper include nausea, vomiting, diarrhea and stomach cramps. Drinking water with high levels of copper for many years could cause liver or kidney damage (Pennington and Calloway, 1983).

2.1.8 Manganese

Manganese has numerous applications which have impact on our daily lives as consumers, whether it is of objects made of steel, of portable batteries, or of aluminium beverage cans. Manganese is a hard, brittle and gray-white metal. It is chemically reactive and slowly decomposes in cold water. Manganese is a lesser-known element other than to a circle of technical specialists who are predominantly metallurgists and chemists, yet it is the fourth most used metal in terms of tonnage being ranked behind iron, aluminium and copper.

Manganese has played a key role in the development of various steelmaking processes and its continuing importance is indicated by the fact that about 90% of all manganese consumed annually goes into steel as an alloying element.

Manganese is concentrated in water by contact with rocks and minerals and occasionally man-made materials like iron and steel pipes. It is usually groundwater supplies that may require treatment for high levels of manganese. Occasionally, discharge of acid industrial wastes or mine drainage may increase manganese to levels that may cause problem in surface water. Both manganese and iron react with oxygen in water to form compounds that do not dissolve. In surface water, manganese is most likely to be trapped within suspended organic matter particles. Manganese carbonates in a poor oxygen environment are relatively soluble and can cause high levels of dissolved iron and manganese. Dissolved oxygen generally decreases with depth, so this type of condition is more likely to occur in wells and stagnant waters.

Problems occur when this type of water is pumped to the surface. The chemical equilibrium is changed upon exposure to the atmosphere. The end result is the precipitation of manganese compounds in plumbing, on fixtures and on clothing, dishes and utensils.

Neither iron nor manganese in water presents a health hazard. However, their presence in water may cause taste, staining and accumulation problems. Soaps and detergents do not remove these stains and the use of chlorine bleach and alkaline builders such as sodium carbonate can actually intensify the stains (Hem, 1967).

One vital feature of manganese, which is not widely appreciated, is its role as an essential element in maintaining human health. Recommended daily dietary intake levels have been established by US regulatory in an effort to ensure the maintenance of good health. Too much level of manganese in the body causes maneb and poor movement of the bones and joints (Sculsky, 1983). The exact role of manganese is not fully understood, but complex cellular reactions involving metallo-enzymes have been indentified. Humans have well-developed homeostatic control mechanisms whereby manganese levels are regulated to keep them in the desired range.

Neither iron nor manganese in water presents a health hazard. However, their presence in water may cause taste, staining and accumulation problems. Soaps and detergents do not remove these stains and the use of chlorine bleach and alkaline builders such as sodium carbonate can actually intensify the stains (Hem, 1967).

2.1.9 Sodium

Sodium levels in drinking water that are less than 20 mg per litre are considered safe for most people. In the sea coast are however, elevated levels of sodium and chlorides occur naturally due to the proximity to sea water. Substantially, higher levels of sodium and chloride may also be due to contamination by activities of man including the use of road de-icing salts, discharges from water softeners, human or animal waste disposal, leachate from landfills and many other activities.

At present there are health standards for sodium and chloride in drinking water. A review by EPA in the mid 1980's showed that elevated levels of sodium in drinking water did not cause high blood pressure or heart disease, rather only that sodium should be avoided by those who already had such medical conditions (http://www.centralsupplyinc.com/statenh/ws-3-17.htm).

The Food and Nutrition Board of National Research Council recommends that healthy adults need to consume at least 500 mg of sodium per day and that sodium intake be limited to not more than 2400mg per day. The Food and Drug Administration Publication states that most American adults tend to eat between 4000 and 6000 mg of Sodium per day (USEPA, 2006)

2.1.10 Potassium

It is an alkaline metal closely related to sodium. Potassium is not a major component in public or industrial water supplies. It is however essential in a well-defined balance diet and can be found in fruits such as bananas (USEPA, 1997).

The potassium content of drinking water varies greatly depending on its source. It tends to be greater in mineral water than ordinary tap water. It however on the average, the daily water consumed by adults supplies less than 0.1 % of their potassium intake but tap water is also used to make beverages like tea, coffee, beer and wines. The average total potassium intake in beverages can supply about 13 % of the total daily intake of adults (USEPA, 1997).

2.2 Water and health of biota

Water, although a necessity for life can be a conveyer of many diseases. Infectious waterrelated diseases can be grouped into waterborne, water hygiene, water-contact and water habitat vector diseases (Essien, 2004). Waterborne infectious diseases are those in which the pathogen is present in water and ingested when the water is consumed. Frequent occurring pathogenic bacteria found in water are *Salmonella typhi, Shigella spp, Escherichia coli, Vibrio cholerae, Campylobacter jejuni, Yersina enterocolitica, Legionella spp* etc. Waterborne diseases are caused by pathogenic microorganisms which are directly transmitted when contaminated drinking water is consumed. Contaminated drinking water, used in the preparation of food, can be the source of food-borne disease through consumption of the same microorganisms. According to the World Health Organization, diarrheal disease accounts for an estimated 4.1% of the total daily global burden of disease and is responsible for the deaths of 1.8 million people every year. It was estimated that 88% of that burden is attributable to unsafe water supply, sanitation and hygiene, and is mostly concentrated in children in developing countries.

Two classical water borne diseases which are highly infectious are cholera and typhoid which also have high mortality rates if untreated. Health effects from chemicals in water occur when a person consumes water containing harmful amounts of toxic substances. The incidence, prevalence and severity of water hygiene diseases can be reduced by the observance of high level of personal, domestic and community hygiene (Essien, 2004). Though water is needed for the existence of humans on the earth, it also has direct impact on the health of those who use it (Cobbina, 2004). Excessive application of fertilizers to farmlands, prolonged release of sewage into water bodies and uncontrolled land use are

some of the ways by which man impacted negatively on water bodies (Chapman, 1992). It is estimated that about 3.4 million people in the world, mostly children, die every year from preventable diseases arising from lack of safe drinking water, poor hygiene and inadequate sanitation (UNEP, 2000). In places where water is scarce, consumers have insufficient amounts for personal and domestic uses. Poor hygiene may occur from lack of sufficient water for use which may lead to skin and eye diseases and also increase the transmission of infectious diseases (Howard, 2000) while the consumption of unsafe water continue to be one of the major causes of about 2.2 million diarrheal disease occurring annually, mostly in children (WHO, 2002).

Any physical, chemical or biological changes in water quality that adversely affects living organisms can be described as pollution. Contaminated or polluted water affects the health of 1.2 billion people every year and contributes to death of 15 million children less than five years (UNEP, 2000).

2.3 Microbes and water quality

Water which is free from pathogens can be attained by selecting high-quality uncontaminated sources of water, by efficient treatment and disinfection of water known to be contaminated with human or animal faeces, and by ensuring that water remains free from contamination during distribution to the user.

Water found in rivers, lakes and streams can contain a variety of bacteria that may only be harmless saprophytes, which do not cause disease in humans. It might seem reasonable to directly examine water for the pathogens *Vibro cholerae, Salmonela typhi, Shigella*

dysenteriae among other pathogens. However, this is not the case because it would be tedious and difficult to specifically test for each of the pathogens. Moreover, these pathogens are often fastidious and they might be overgrown by other bacteria in the water if cultured and test for each of the pathogens. Therefore, it is easier to demonstrate the presence of some indicator bacterium, such as *Escherichia coli*, which is routinely found in the soil or water bodies. The presence of *E. coli* in water would then indicate the likelihood of faecal contamination and the potential for serious disease. *E. coli* is abundant in human and animal faeces, where concentrations in fresh faeces of 10 cfu per gram can be attain. It is found in sewage, treated effluents and all natural waters and soils that are subject to recent faecal contamination, whether from humans, agriculture or wild animals and birds. Recent studies suggested that *E. Coli* may be found in tropical waters that are not subjected to human faecal pollution. Frequent examinations for faecal indicator organisms remain the most sensitive and specific way of assessing the hygienic quality of water. Faecal indicator bacteria should fulfill certain criteria to give meaningful results. These microbes should be universally present in high numbers in the faeces of humans and worm-blooded animal and readily detectable by simple methods. It is also important that their persistence in water and their degree of removal in treatment of water are similar to those of water borne pathogens. The faecal coliform test is used to indicate the presence of *E. coli* in water. E. coli is a member of the family Enterobacteriaceae and is characterized by possession of the enzymes β-galactosidase and β-glucuronidase. It grows at 44ºC on complex media, ferments lactose and mannitol with the production of acid and gas, and produces indole from tryptophan (Omari, 2009). A small sample of water is passed through a filter to trap all bacteria. The filter is then transferred to a petri dish that contains nutrients. After an incubation period, the number of greenish colonies present indicates the

number of *E. coli*. Safe drinking water should not contain more than 1 coliform bacterium per 100 ml of water, safe swimming water should not have more than 200 per 100 ml of water and general recreational water (boating, fishing) should not have more than 2000 per 100 ml.

However, raw sewage may contain several million coliform bacteria per 100 ml of water. When dangerous levels of faecal coliform are discovered in a body of water, it is important to determine the source of contamination but it is also difficult to track the source of contamination since contamination could come from different sources. In this line, a new field of science, called Bacterial Source Tracking (BST) is used to properly identify the source using techniques in molecular biology (Raven and Berg, 2004). Some of the methods for identifying E. coli are too complicated and over the years simpler methods with high degree of certainty have been standardized at international levels, whereas others are still in the developmental or evaluative phase. Different types of pollution problems occur in developing countries in much more rapid succession than in developed countries, due to the modern international trade of chemicals, ubiquitous dispersion of persistent contaminants and changing hydrological cycles. Therefore developing countries are, and will be, faced more and more with situations where second and third generation pollution issues appear before much control over traditional pollution sources have been achieved (Meybeck and Helmer 1989).

2.4 Contamination of Ground Water

Groundwater is legally defined as any water beneath the surface of the ground with significant occurrence of microorganisms, insects, algae or pathogens with rapid shift in water characteristics such as turbidity, temperature, conductivity or pH, which closely correlate to climatological or surface water conditions (Spellman and Drinan, 2000).

Groundwater with its increasing demand, can exceed aquifer's rates of replenishment and in many urban aquifers, water levels show long-term decline and undesirable effects which include increased pumping costs, changes in hydraulic pressure and underground flow directions in coastal areas due to sea intrusion, saline water drawn up from deeper geological formations and poor quality water from polluted shallow aquifers leaking downwards (Rail, 1985).

Despite our reliance on groundwater, it has many years been one of the most neglected natural resources. Groundwater has been ignored because it is less visible than other environmental resources such as streams, rivers or lakes. The main problem with groundwater pollution has been human activities which involve improper disposal of wastes, spillage of hazardous substance.

Some major sources of groundwater contamination are underground storage tanks, MtBE used as an octane enhancer in petroleum products and industrial wastes, leakage from septic tanks and leachate seepage from landfills. Also fertilizers and pesticides application in agriculture can leach into groundwater, salt water intrusion in coastal areas, mining and petroleum activities etc.

Other sources of groundwater contamination in Ghana include waste tailing, urban runoff, graveyards, animal feeding operations, animal burial, mine drainage, open burning, atmospheric pollutants, residential disposal and land applied wastewater.

2.5 Water quality parameters

The key basic water quality parameters that need to be addressed in an emergency are bacteriological indicators of faecal contamination, free chlorine residual, pH, turbidity and possibly conductivity and total dissolved solids (Hallock, 2002).

Some physico-chemical parameters used in assessing water quality

2.5.1 pH

The pH of water approximates the activity of free hydrogen ions in water. It is defined as the negative logarithm of the hydrogen ion concentration. The practical pH scale extends from 0 (very acidic) to 14 (very alkaline) with the value of 7 corresponding to exact neutrality at 25◦C. The pH of natural waters is dictated to extent by the geology of the watershed and is governed by the carbon dioxide, bicarbonate and carbonate equilibria. The range in pH for most waters is between 4.5 and 8.5 which encompass the pH value 5.6 for rain water in equilibrium with atmospheric carbon dioxide. The pH may be affected by the presence of organic acids and by biological processes (example photosynthesis and respiration) and physical processes (turbulence and aeration) which can alter the concentration of dissolved carbon dioxide. The pH of water also affects transformation processes among the various forms of nutrients and metals, and influences the toxicity of pollutants consisting of acids and bases because of the ionization of these compounds (APHA 1989).

2.5.2 Turbidity

It is the amount of particulate matter that is suspended in water. Turbidity measures the scattering effect that suspended solids have on light: the higher the intensity of scattered light, the higher the turbidity. Materials that cause water to be turbid include clay, silt, finely divided organic and inorganic matter, soluble coloured organic compounds, plankton, and microscopic organisms.

During the periods of low flow (base flow), many rivers are a clear green colour, and turbidities are low, usually less than 10 NTU. High levels of turbidity increase the total available surface area of solids in suspension upon which bacteria can grow, reduces light penetration and therefore, it impairs photosynthesis of submerged vegetation and algae. Turbidity interferes with the disinfection of drinking water and is aesthetically unpleasant (DWAF, 1989).

2.5.3 Conductivity

Specific conductance is a measure of the ability of water to conduct an electrical current. It is highly dependent on the amount of dissolved solids (such as salt) in the water. Pure water, such as distilled water, will have a very low specific conductance, and sea water will have a high specific conductance. Specific conductance is an important water quality measurement because it gives a good idea of the amount of dissolved material in the water. High specific conductance indicates high dissolved solids concentration; dissolved solids can affect the suitability of water for domestic, industrial and agricultural uses. At higher levels, drinking water may have an unpleasant taste or odour or may even cause gastrointestinal distress. The standard unit of electrical conductivity is the Siemen per meter. Conductivity is generally reported as millisiemens per meter. The conductivity of most freshwaters ranges from 10 to 1000 microsiemens per centimeter but may exceed

1000 microsiemens per centimeter, especially in polluted waters, or those receiving large quantities of land run off. In addition to being a rough indicator of mineral content when other methods cannot easily be used, conductivity can be measured to establish a pollution zone example around an e m,.l9 effluent discharge, or the extent of influence of run off waters (APHA, 1989).

2.5.4 Chemical Oxygen Demand

Chemical Oxygen Demand (COD) is the measure of the oxygen equivalent of the organic matter in water sample that is susceptible to oxidation by a strong chemical oxidant, such as dichromate. The COD is widely used as a measure of the susceptibility to oxidation of the organic and inorganic materials present in water bodies and in the effluents from sewage and industrial plants. The test for COD is non-specific, in that it does not identify the oxidisable material or differentiate between the organic and inorganic material present. Similarly, it does not indicate the total organic carbon present since some organic compounds are not oxidized by the dichromate method whereas some inorganic compounds are oxidized. The concentrations of COD observed in surface waters range from 20 mg/l oxygen or less in unpolluted waters to greater than 200 mg/l oxygen in waters receiving effluents. Industrial wastewaters may have COD values ranging from 100 mg/l oxygen to 60000 mg/l oxygen (Chapman, 1996).

2.5.5 Biochemical Oxygen Demand

The Biochemical Oxygen Demand (BOD) is an approximate measure of the amount of biochemically degradable organic matter present in water sample. It is defined by the amount of oxygen required for the aerobic microorganisms present in the sample to oxidize the organic matter to a stable inorganic form. The method is subject to various complicating

factors such as the oxygen demand resulting from the respiration of algae in the sample or the possible oxidation of ammonia (if nitrifying bacteria are also present). The presence of toxic substances in a sample may affect microbial activity leading to a reduction in the measured BOD. The conditions in a BOD bottle usually differ from those in a river or lake. BOD measurements are usually lower than COD measurements. Unpolluted waters typically have BOB values of 2 mg/l oxygen or less, whereas those receiving wastewaters may have values up to 10 mg/l oxygen or more, particularly near to the point of wastewater discharge. Raw sewage has a BOD of about 600 mg/l oxygen whereas treated sewage effluents have BOD values ranging from 20 to 100 mg/l oxygen depending on the level of treatment applied. Industrial wastes may have BOD values up to 25000 mg/l oxygen (Chapman, 1996).

2.5.6 Temperature

It is the measure of how hot or cold water is. This is measured with a thermometer in degree Celsius or Fahrenheit (APHA, 1995). The temperature of water to a large extent determines the extent of microbial activity. Water freezes at zero (0) degrees Celsius and boils at 100 degree Celsius. Temperature level within 150^0C to 250^0C is optimum for bacterial growth and higher temperatures support faster growth rates and enable some biota to attain significant populations (Chapman, 1996). Temperature may be influenced by depth of water, season and air circulation as well as time of day (Peirce *et al.*, 1998).

2.5.7 Hardness

The degree of hardness of water supply is determined by the content of calcium and magnesium salts. Calcium and magnesium combine with bicarbonates, chlorides, sulphates and nitrates to form these salts. The standard domestic measurement for hardness is gains

per gallon (gpg) as calcium carbonate. Water having hardness content less than 0.6 gpg is considered commercially soft. The calcium and magnesium salts which form the hardness are divided into two categories.

Temporal hardness (containing non carbonates) and permanent hardness containing non carbonates. Hardness affects the amount of soap that is needed to produce foam or lather. Hard water requires more soap because the calcium and magnesium ions form complexes with soap preventing the soap from sudsing. Hard water can also leave a film on the hair, fabrics and glassware. Hardness of water is very important in industrial uses, because it forms scales in heat exchange equipment, boilers and pipes.

Hardness mitigates metal toxicity because of the presence of calcium and magnesium. Hardness helps to keep fish from absorbing metals such as lead, arsenic and cadmium into their bloodstream through their gills. The greater the hardness, the harder it is for toxic metals to be absorbed through the gills (Casidey *et al*., 2001). Hard water produces less lather with soap. Industrially, it generates boiler scales as a result of precipitation of calcium and magnesium carbonates, thereby boilers inefficient. Studies have indicated a negative correlation between death from heart diseases and the hardness of water implying that the harder the water, the fewer the deaths resulting from heart diseases (O' Neill, 1985).

2.5.8 Total Dissolved Solids

It is the sum of all the materials dissolved in the water and consists of mainly carbonates, bicarbonates, chlorides, sulphates, phosphates, nitrates, calcium, magnesium, sodium, iron, potassium, manganese and a few others. They do not include gases, colloids or sediments. The Total Dissolved Solids can be estimated by measuring the specific conductance of the water.

Dissolved solids in natural water range from less than 10 mg/l for rain water to more than 100,000 g /l for brines. Below is an indication of TDS from various sources:

Distilled water = 0, Deionized water = 8, Rain and Snow = 10, Brine well = 125000 and Dead sea = 250,000. The TDS of a water sample is determined gravimetrically; a wellmixed volume of sample is evaporated in a weighed dish and dried to constant weight in an oven at 103 to 105 degrees Celsius. The increase in weight over that of the empty dish is the total solid. TDS can also be determined by using an electric probe which also measures temperature and conductivity (APHA, 1992). High TDS in water may produce bad taste, odour and colour, and also induce unfavourable physiological reactions in the consumer (Spellman and Drinan, 2000).

2.5.9 Alkalinity

It is defined as the ability of water to neutralize an acid and is determined by titration against a known standard acid (usually 0.02 N sulphuric acids). The optimal amount of alkalinity for given water is a function of several factors including pH, hardness and concentration of dissolved oxygen and carbon dioxide that may be present.

As a general rule, 30 to 100 mg/l calcium carbonate is desirable although up to 500 mg/ l may be acceptable. Alkalinity is apparently unrelated to public health but is very important in pH control.

Alum, gaseous chlorine and other chemicals are occasionally used in water treatment to act as acids and therefore tend to depress pH. Many waters are deficient in natural alkalinity and must be supplemented with lime or some other chemicals to maintain the pH in desirable range to usually 6.5 to 8.5. Alkalinity values can change significantly from groundwater between samples taken at the well head and samples taken from other spots

(Lasier *et al.*, 1997). Water with high alkalinity is unpalatable, the main problem with such water is the reactions that occur between alkalinity and certain substances which may form precipitate and eventually foul the water (Spellman and Drinan, 2000).

2.5.10 Chlorides

It is one of the major anions found in water and is generally combined with calcium, magnesium or sodium. Since almost all chlorides salts are highly soluble in water, the chloride content ranges from 10 to 100 mg/l. Sea water contains over 30,000 mg/l as sodium chloride. Chlorides are associated with the corrosion of piping systems. The corrosion rate and the iron dissolved into the water from piping increases as the sodium chloride content of the water is increased.

The suggested maximum contaminant level (SMCL) for chloride is 250 mg/l which is due strictly to the objectionable salty taste produced in drinking water (USEPA, 1994).

2.5.11 Nitrates

Nitrates come into water supplies through the nitrogen cycle rather than through dissolved minerals. Most nitrates that occur in drinking water are as a result of contamination of groundwater by septic systems, feedlots and agricultural fertilizers. Nitrate is reduced to nitrite in the body Reverse osmosis will remove 92 to 95 % of the nitrate (Alloway and Ayres, 1997)

2.5.12 Phosphates

Phosphates exist in three forms: Orthophosphate, Metaphosphate and originally bounded phosphate. Each compound contains phosphorus in a different chemical formula. Otho forms are produced by natural processes and are found in sewage. Poly forms are used for

treating boilers and in detergents. In water, they change into ortho form. Organic phosphates are important in nature. Their occurrence may result from the breakdown of organic pesticides which contains phosphate.

Rainfall can cause varying amounts of phosphates to wash from farm soils into nearby waterways. Phosphate stimulates the growth of planktons and aquatic plants which provides food for fishes. It also leeches into groundwater. It may not be toxic to people or animals unless they are present in high levels. Digestive problems could occur from extremely high levels of phosphates (USGS, 1970).

2.5.13 Sulphates

Most sulphate compounds originate from the oxidation of sulphate ores, the presence of the shale and the existence of industrial waste.

As waster moves through the soil and rock formations that contain sulphate minerals, some of the sulphate dissolves in the water into the groundwater. A high concentration of sulphate in drinking water causes a laxative effect when combined with calcium and magnesium, the two most common components of water hardness.

Sulphate has a suggested level of 250 mg/l in the secondary drinking water standards published by the (USEPA, 1994).

2.2 Specification for drinking water quality

Table 2.2: Specification for drinking water quality (GHANA STANDARD GS 175-1:2008) and (WHO) guideline maximum value for domestic use of water.

Parameter	Specification for drinking water EPA (GS 175-1:2008)	WHO (1993) Guideline maximum value
pH	6.5-8.5	6.5-8.5
Temperature (0^0C)	Shall not be objectionable	-
Turbidity (NTU)	5	5
Conductivity (µS/cm)	5*	700
Total Dissolved Solids (TDS)	1000	-
Chloride (mg/l)	250	250
Sulphate (mg/l)	250	250
Nitrate (mg/l)	50	10
Iron (mg/l)	0.5	0.3
Phosphate (mg/l)	To be reported	<0.3
Copper (mg/l)	1	2
Total Arsenic (mg/l)	0.01	0.01
Calcium (mg/l)	-	0.01
Manganese (mg/l)	0.1	

Cadmium (mg/l)	0.003	0.003
Lead (mg/l)	0.01	0.01
Mercury (mg/l)	0.001	0.001
Zinc (mg/l)	3	3
Total Coliforms (MPN/100ml)	0	0
E. coli (MPN/100ml)	0	0
Faecal Coliforms (MPN/100ml)	0	0
Enteroccoci (MPN/100ml)	0	0
Alkalinity (mg/l)		200
Hardness (mg/l)		500
Potassium (mg/l)		30
Sodium (mg/l)		200

Source: WHO, 1993 and EPA Ghana, 2002

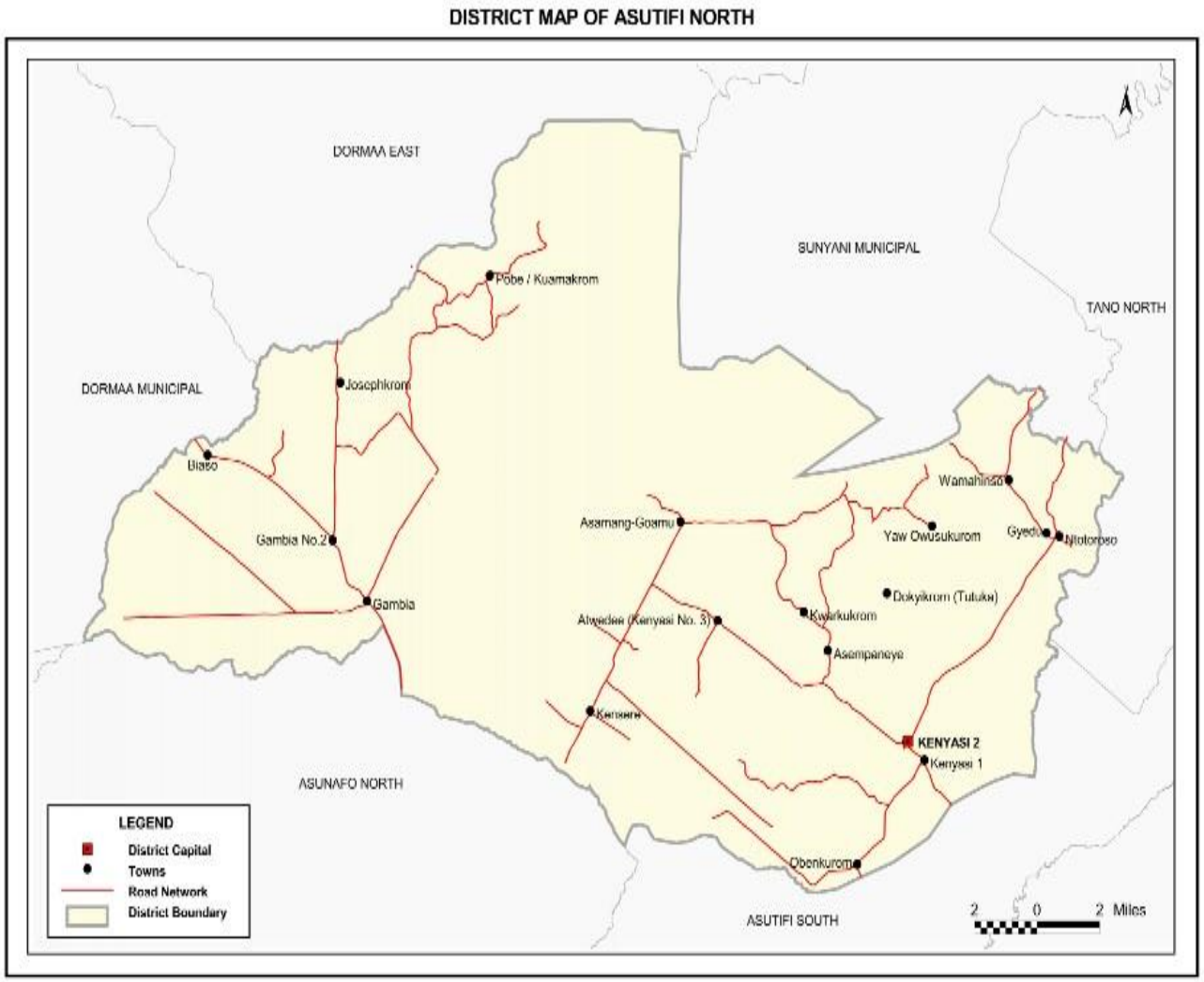
CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The Asutifi North District is one of the districts in the Brong Ahafo Region which was formerly Asutifi District and was divided into Asutifi North and South in 2002. The district shares boundaries with Asutifi South District, Asunafo North District, Sunyani District and Ahafo Ano North District of Ashanti. It is located between latitudes 6^0 to 8^0 North and longitude 2^0 to 3^0 west.

The district can boost of rivers such as Tano, Goa, Subika, Amoma and streams including Awonsu, Nkafrasua, Ayansua, Akrasua, Asuadei, Ntotro, Subri. Presently, the mineral deposits found in the district include gold, diamond, granite, clay and sand. Newmont Ghana Gold Limited (NGGL) is now the only gold mining company licensed for gold mining in the district.



Source: Ghana Statistical Service, GIS

Source: Ghana Statistical Service, 2010

Figure. 3.1: Map of Asutifi-North District and its surrounding districts

3.2 Climate and Vegetation

The District lies within the wet semi equatorial zone and marked by double rainfall maxima; June and October with a mean annual rainfall between 125 cm and 200 cm. Relative humidity is generally high between 75 % to 80 %. The district has a moist semi deciduous forest. This vegetation has however been disturbed by human activities, notably farming, lumbering and occasional bushfires. There are however large areas of forest reserves which include the Biaso Shelter Belt, Bia Tam Forest Reserve, Asukese, Goa, Desiri Forest Reserves. The forest reserves in the district have fauna and varied flora of high economic value.

The physiographic region is underlain by Precambrian rocks of Birimian. The Birimian formations are known to be the gold bearing rocks.

3 Description of sampling sites

The research was conducted in the Asutifi North District of Brong Ahafo Region. Newmont Ghana Gold Limited (NGGL) has a mine concession in the District coupled with galamsey activities. The study was conducted in two (2) major towns namely Ntotroso and Kenyasi. Water samples were taken from two (2) major rivers (Tano and Goa Rivers) from each community. Water samples were also taken from four (4) boreholes that are two (2) boreholes from each community; six (6) hand dug wells with three (3) wells selected from each community. The four (4) boreholes and six (6) hand dug wells were randomly selected from the communities. However, there were six (6) boreholes and eight (8) hand dug wells in each of the communities.

Samples were taken over a four (4) month period beginning November 2013 to February 2014. Water samples were collected in the early hours of the morning. This was to ensure that the water had not been disturbed much through pumping which can affect the temperature and total dissolved solids content.

In all, twelve (12) sampling sites were used for the study and three (3) samples were taken per site. Thorough chemical and biological analysis was carried out on all the samples for the entire duration.

TABLE 3.1: Nature of Sampling Sites

TOWN	SUBURB	SAMPLE TYPE	SAMPLE NAME	DESCRIPTION OF SAMPLE AREA
Ntotroso		River	Tano River	Outskirt of the town surrounded by farmlands
Kenyasi		River	Goa River	Surrounded by farmlands
Ntotroso	Akataase	Borehole	Bore N1	Beside the main farm road
Ntotroso	Ahenebronum	Borehole	Bore N2	In a school compound.
Kenyasi	Ampedwee	Borehole	Bore K1	Opposite cemetery which is separated from the cemetery by the main road
Kenyasi	Adum	Borehole	Bore K2	Within the settlement
Ntotroso	Achiase	Hand dug well	Well N1	Surrounded by farmlands
Ntotroso	Akentenmu	Hand dug well	Well N2	Outskirt of the town
Ntotroso	Akataase	Hand dug well	Well N3	Within settlement
Kenyasi	Ampedwee	Hand dug well	Well K1	Within a market area
Kenyasi	Jericho	Hand dug well	Well K2	Outskirt of the town and 30 metres closer to a filling station
Kenyasi	Kwadaso	Hand dug well	Well K3	Within settlement (Zongo)

Plate 1: People bathing in the River Tano at Ntotroso.

3.4 Water Sampling and Storage

Water samples were collected using 1.5 litres plastic bottles and were immediately kept on ice in an ice chest at 4.0^0C and transported to the laboratory. Samples for trace metals were acidified to pH 2.0 before keeping them in the fridge. Equipment used for the sampling were clean plastic basin, rope, underwater sampler, high density polythene and glass bottles. The appropriate reagents, chemicals and laboratory apparatus were used to determine some water quality parameters both in situ and ex situ. Sample containers and

glassware were washed with phosphate free detergent, rinsed three times with distilled or deionized water. Containers for monitoring nitrates and phosphorus were treated with 10% Hydrochloric acid and rinsed three times with deionized water. In the laboratory, microbiological parameters were analyzed on the same day of water collection from sampling sites.

Plate 2: Water sample taking from a hand dug well at Kenyasi.

3.5 pH Determination

The pH meter was calibrated with 4.0, 7.0 and 10.0 pH buffers. After calibration, the pH meter was tested using distilled water which gives a pH of 7.0. After calibration, the

electrodes were dipped into a 100 ml aliquot of each sample each measured into a beaker and the pH was determined.

3.6 Temperature

This was determined on site at the time of analysis. An aliquot of 50 ml of sample was measured into a 100 ml beaker and a thermometer immersed in the solution. The reading on the thermometer was then recorded.

3.7 Conductivity

The conductivity meter was standardized using KCl solution of 0.01 M which was found to be 1408 µS/cm. A 100 ml of sample was measured into a beaker and its conductivity determined with the WTW Conductivity meter within two hours of sampling. The determinations were made after refrigerated samples had been allowed to attain room temperature.

3.8 Turbidity

A 30 ml aliquot of each sample was measured into the curette of Nephla EU Turbidimeter and the respective reading taken. This was carried out three time s in order to obtain the mean value.

3.9 Total Dissolved Solids

A 50 ml well mixed sample was measured into a weighed crucible. The water sample and crucible weight was then taken. Water sample in the crucible was put on the water bath and allowed to evaporate to dryness. After evaporation, the weight of the crucible was taken. The difference between the weight of the crucible before evaporation and after evaporation gave the value of the total dissolved solids.

3.10 Alkalinity and Total Hardness

The potentiometric titration to end point pH was used to determine the alkalinity and the total hardness of the samples. The hydroxyl ions (OH^-) present in the water samples as a result of dissociation or hydrolysis of compounds react with standardized acid added. 50.0 ml of the raw water sample is measured and titrated against 0.02 M HCl to a pH of 4.5. The titre value was multiplied by a factor 20.

Calculations

$$\text{Alkalinity in mg of } CaCO_3/L = \frac{A \times M \times 50{,}000}{V}$$

A= ml of standard acid used (titre value of acid used)

M= Molarity of standard acid used (0.02 M).

V= Volume of sample used

Calculations on total hardness

Hardness in mg equivalent of $CaCO_3$/L = 2.497 [Ca, mg/l] + 4.118 [Mg, mg/l]

Calculations

Bicarbonate (HCO_3^-) in mg = Alkalinity x 1.2191817

3.11 Sulphate

Ten (10) ml of the filtered sample was measured into a test tube and 1 ml of acid salt solution (60 g NaCl dissolved in 10 ml distilled water) was added. A half millilitres (0.5 ml) glycerol reagent added to the mixture. Another 0.5 g solution of $BaCl_2$ was added and stirred for 1 minute using magnetic stirrer. The solution was allowed to stand for 10 minutes to cool. The resulting solution was fed into the spectrophotometer model: spectronic 21 D at a wavelength of 420 nm. The same procedure was followed for blank and standards. The concentrations for the standards were 15.0, 20.0, 25.0, 30.0 and 35.0 mg/l. A graph of absorbance against concentration for standards was plotted using excel, from which concentrations of samples were determined.

3.12 Nitrate

The concentration of nitrate was determined by the Brusinesulphate Method (Official method 973.50, APHA, 1995). Five (5) ml of the filtered sample was measured into a test tube and 1ml of acid salt solution added. 5 ml of concentrated H_2SO_4 was added to the mixture, followed by 5 drops of Brusine reagent. The mixture was placed on a water bath for 25 minutes at a temperature of 95^0C. The samples were allowed to cool down and their

various absorbance measured at wavelength 410nm using spectrophotometer, model: spectronic 21D.

The same procedure was followed for both Blank sample and Standards. The standards were made up of potassium nitrate reagent of the following concentrations; 0.2, 0.4, 0.6, 0.8 and 1.0 mg/l. Recordings for blank and standards were done according to increasing order of concentrations. A graph of standards was plotted and readings for concentrations of samples also measured using excel software (APHA, 1995).

3.13 Phosphate (Ascorbic Acid Method)

Ten (10) ml of filtered sample was pipette into test tube and 1drop (of about 0.05 ml) phenolphthalein indicator added to the sample. About 2.5 M H_2SO_4 solution was added to the mixture to discharge the red colour developed by the phenolphthalein indicator. Two (2 ml) of combined reagent (Ammonium molybdates and potassium antimonyltartarte) was added to the solution and mixed thoroughly. The solution was allowed to stand for 10 minutes to 30minutes. The resulting solution was poured into an absorption cell and fed into spectrophotometer model; spectronic 21D at 880nm. The same procedure was followed for blank and standards. The concentrations for the standards were 0.2, 0.6, 0.8 and 1.0 mg/l.

At least three standards were used in plotting a graph of absorbance against phosphate concentration to obtain a straight line passing through the origin. The graph developed by excel was used to determine the concentration of samples.

3.14 Chlorides (Argentometric Method)

Twenty (20) ml of the sample was measured into 250ml volumetric flask and 2 drops of potassium chromate indicator added. The solution was titrated against 0.1 M standard silver nitrate titrant and the titre value recorded. The same procedure was followed for the blank sample.

Calculation

$$\text{Concentration of } Cl^- \text{ ions in sample} = \frac{(A - B) \times M \times 35.45 \times 1000}{\text{ml of sample taken}}$$

where A = ml titration volume of sample

B = ml titration volume of blank (0.20 M)

M = Molarity of $AgNO_3$ used (0.0141 M)

35.45 = atomic weight of Cl.

3.15 Determination of Metals

The study considered the following metals for analyses, Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg), Iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn), Lead (Pb), Cadmium (Cd), Arsenic (As) and Mercury (Hg).

3.15.1 Pre-treatment of samples

A five (5) millilitres of samples were measured and 6 ml of 69% nitric acid, 3ml of 37% HCl and 6.25ml of 30% H_2O_2 were added to the sample. The samples were digested using industrial microwave oven (model; ETHOS 900 Lab Station) for 21 minutes at high temperature and pressure. The digested solution is transferred into test tubes for the analyses using atomic absorption spectroscopy. Sodium and Potassium concentrations were measured separately using flame photometer (model: Sherwood 420) which runs on LPG.

3.15.2 Atomic Absorption Spectroscopy

The measurement of major and trace metals concentrations were done by aspirating the acidified, filtered samples directly into the atomic spectrophotometer, model: Varian 240FS. Individual hollow cathode lamps were used to hold samples for the various metals. The concentration of the metal is equal to the concentration as measured by the spectrophotometer multiplied by the dilution factor where applicable. A graph of standards was plotted and readings for concentrations of samples also measured using excel software. Before the measurements were done, the atomic analytical equipment was calibrated using standard solutions of known concentrations of the various major ions and trace metals. The instrumental parameters of the various elements were dependent on the manufacturer specifications.

The appropriate matrix modifiers and ionization buffers were added to both the samples and standards where applicable to suppress interference from other elements, ionisation

and at times to increase the sensitivity of the spectrophotometer. The flame used was airacetylene gas.

3.16 Microbiological Analyses

The samples were analyzed for Faecal coliforms, Total coliforms, *E. coli* and *Enterococci.* The equipment and materials used for the analyses included Automatic pipette, Sterile 1 ml pipette tip, test tubes, MacConkey broth, Petri dishes, Cellotape,

Slanetz and Bartley medium, Tryptophan broth, Kovacs Indole Reagent, Cotton wool and Colony counter.

3.16.1 Method of Sterilization

The equipment for the bacteriological analyses including sampling glass bottles, petri dishes, funnel, etc., were sterilized in industrial microwave model; THOS 900 Lab Station microwave at 121.0^{o}C for 15 minutes before they were used. The working area was cleaned with 70% ethanol (methylated spirit) to prevent contamination from the working area; further contamination from the atmosphere was prevented by working in a heated environment.

3.16

.2 Faecal Coliform

For faecal coliform cultivation and enumeration, the Mac Conkey- Agar (containing 17.0 g peptone from casein, 3.0 g peptone from meat, 5.0 g sodium chloride, 10.0 g lactose, 1.5 g bile salt mixture, 0.03 g neutral red, 0.001 g crystal violet and 13.5 g agar-agar) was used. Fifty grams (50.0 g) of the agar was then suspended in 1.0 litre distilled water and boiled to dissolve completely using boiling water bath. Ten millilitres (10 ml) of 1.0% solution of bacto-rosolic acid in 0.2 M NaOH was added and heated for one minute. The pH was then adjusted to 7.2 with 1.0 M HCl.

Ninety millilitres (90 ml) of sterilized distilled water was fetched into a conical flask. Ten millilitres (10 ml) of the water sample was measured and added to the distilled water using micropipette to make a total volume of 100 ml resulting solution. Nine millilitres (9 ml) of distilled water was measured into a screw-cup test tube. Using an aseptic technique, 1ml of the resulting solution in the conical flask was serially transferred into the 9 ml distilled water in the screw-cup test tube to make volumes of 10^{-1}, 10^{-2}, 10^{-3} and 10^{-4} respectively.

Twenty millilitres (20 ml) of the prepared media (Mac Conkey-Agar) was measured and transferred into Pyrex petri dish. The solutions in the test tube were mixed with the media in the dishes. The mixture was swirled thoroughly to allow a uniform mixture to be formed. The mixture was covered and allowed to stand for 20 minutes to solidify. The petri dishes were turned upside down and incubated from 18 to 24 hours.

Counting of the growth of colonies on the dishes was done using the colony counter.

3.16

.3 Total Coliform

For total coliform cultivation and enumeration, the Violet Red Bile Glucose AgarVRBGA (containing 3.0 g yeast, 7.0 g peptone, 5.0 g sodium chloride, 1.5 g bile salt no.3, 10.0 g glucose, 0.03 g neutral red, 0.002 g crystal violet and 12.0 g agar) was used. A suspension of 38.5 g of the agar was prepared by adding 1.0 litre distilled water and boiled to dissolve completely using boiling water bath. 10.0 ml of 1.0% solution of bactorosolic acid in0.2 M NaOH was added and heated for one minute. The pH was then adjusted to 7.2 with 1.0 M HCl.

Ninety millilitres (90 ml) of sterilized distilled water was fetched into a conical flask. Ten millilitres (10 ml) of the water sample was measured and added to the distilled water using micropipette to make a total volume of 100 ml resulting solution. Nine millilitres (9 ml) of distilled water was measured into a screw-cup test tube. Using an aseptic technique, 1 ml of the resulting solution in the conical flask was serially transferred into the 9 ml distilled water in the screw-cup test tube to make volumes of 10^{-1}, 10^{-2}, 10^{-3} and 10^{-4} respectively.

Twenty millilitres (20 ml) of the prepared media (VRBGA) was measured and transferred into Pyrex pertri dish. The solutions in the test tube were mixed with the media in the dishes. The mixture was swirled thoroughly to allow a uniform mixture to be formed. The mixture was covered and allowed to stand for 20 minutes to solidify. The pertri dishes were turned upside down and incubated at 37^{o}C between 18 to 24 hours.

Counting of the growth of colonies on the dishes was done using the colony counter. The process or procedure of analysis and apparatus used were the same as that used for the faecal coliform cultivation and enumeration.

3.16 .4 *Enterococci* Confirmation

After inoculating, it was incubated at 37^0C for 4 hours. After 4 hours, it was incubated again at 44^0C for 24 to 48 hours. The test becomes positive for the *enterococci* when reddish colonies appear in the petri dish.

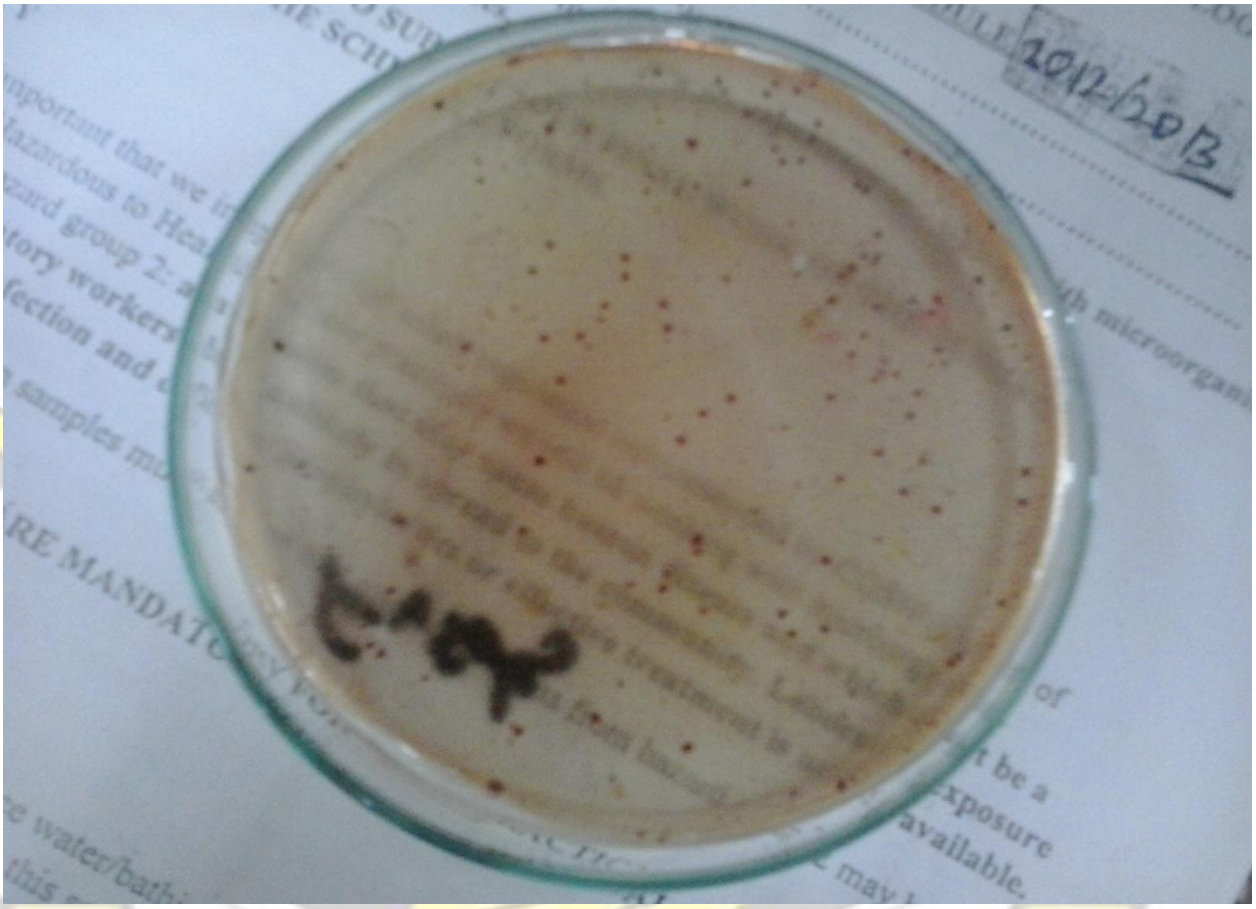


Plate 3: Colonies of *Enterococci* after incubation.

3.16.5 *E. coli* Confirmation

Tryptophan broth was prepared by taking 15 g of the broth and added to 1 litre of water. Five (5) ml of the broth was distributed in test-tubes and sterilized. One (1) ml each from

3.16

the positive tubes of the faecal coliforms was transferred into each of the broth in the test tubes.

After the transfers, the test tubes were incubated at 44^0C for 24 hours. After 24 hours, drop of Kovacs Indole Reagent was added. It is positive for *E. coli* when red layer appears at the top of the broth.

3.17 Data Analyses

Data collected were analyzed using Student Edition of Statistix version 9.0 for the various parameters for the water quality monitoring. Analysis of Variance (ANOVA) was performed on the parameters studied. The means were separated using Tukey HSD.

CHAPTER FOUR

4.0 RESULTS

4.1: Metal Concentration

Table 1: Metal concentration of water from different sources

Sample source	Metal Concentrations Recorded(mg/l)						
	Hg	**As**	**Cd**	**Zn**	**Pb**	**Cu**	**Fe**
Goa River	0.0007^{ab}±0.00008	0.0008^{a}±0.00008	0.0007^{a}±0.00005	0.03^{cde}±0.001	0.33^{a}±0.055	1.09^{a}±0.066	0.95^{d}±0.044
Tano River	0.0008^{a}±0.00008	0.0008^{a}±0.00008	0.001^{a}±0.0008	0.03^{cde}±0.0008	0.31^{ab}±0.037	0.72^{b}±0.082	0.83^{d}±0.048
Well K1	0.0007^{a}±0.00005	0.0007^{a}±0.00009	0.0008^{a}±0.00005	0.04^{c}±0.003	0.28^{abc}±0.026	0.26^{de}±0.034	2.56^{abc}±0.548
Well K2	0.0008^{a}±0.00005	0.0007^{a}±0.00009	0.0007^{a}±0.00008	0.05^{b}±0.006	0.24^{abcd}±0.044	0.32^{cd}±0.018	1.44^{bcd}±0.337
Well K3	0.0007^{ab}±0.0002	0.0007^{a}±0.00005	0.0004^{a}±0.00005	0.45^{a}±0.201	0.23^{abcd}±0.029	0.25^{de}±0.026	2.23^{abcd}±0.702
Well N1	0.0007^{ab}±0.00005	0.0008^{a}±0.00008	0.0008^{a}±0.00008	0.03^{cd}±0.003	0.23^{abcd}±0.059	0.42^{c}±0.059	1.14^{cd}±0.594
Well N2	0.0007^{a}±0.00005	0.0006^{ab}±0.0001	0.0008^{a}±0.00008	0.04^{c}±0.005	0.22^{abcd}±0.024	0.24^{de}±0.044	2.79^{ab}±0.294
Well N3	0.0007^{ab}±0.00008	0.0007^{a}±0.00005	0.0008^{a}±0.00005	0.02^{def}±0.002	0.21^{bcd}±0.026	0.24^{de}±0.048	3.12^{a}±0.258
Borehole K1	0.0005^{bc}±0.0002	0.0004^{bc}±0.00005	0.0003^{a}±0.00005	0.02^{ef}±0.007	0.19^{cde}±0.044	0.19^{de}±0.018	1.11^{d}±0.883
Borehole K2	0.0004^{c}±0.00005	0.0003^{bc}±0.00005	0.0004^{a}±0.00005	0.01^{f}±0.003	0.14^{de}±0.018	0.14^{e}±0.026	1.98^{abcd}±0.379
Borehole N1	0.0003^{c}±0.00005	0.0003^{c}±0.00008	0.0006^{a}±0.00005	0.04^{c}±0.009	0.18^{cde}±0.066	0.19^{de}±0.029	0.85^{d}±0.337
Borehole N2	0.0002^{c}±0.00005	0.0003^{c}±0.00005	0.0003^{a}±0.00005	0.06^{b}±0.007	0.08^{e}±0.018	0.18^{e}±0.055	1.32^{cd}±0.770
P-Value	**0.0000**	**0.0000**	**0.0039**	**0.0000**	**0.0000**	**0.0000**	**0.0000**

Note: Within columns means with the same letter are not significantly different (P > 0.05)

4.1.1: Mercury

The mean concentrations of mercury for the sampling months ranged from 0.0002 mg/l to 0.0008 mg/l. The largest concentration of mercury was recorded at Tano River and Well K2 whilst the least of 0.0002 mg/l was recorded in Borehole N2. All the mercury concentrations were within WHO and Ghana Standards values of 0.001 mg/l. (Table 1) There was no significant difference in the concentrations recorded for the different water samples (P = 0.0000; F = 16.03).

4.1.2: Arsenic

The average concentrations of arsenic for the sampling months ranged from a minimum of 0.0003 mg/l to a maximum of 0.0008 mg/l. The largest concentration were recorded in the Tano River, Goa Rivers and Well N1. The least concentration of 0.0003 mg/l was recorded in Borehole K2, N1 and N2. Arsenic concentrations in all the water samples were within WHO and Ghana Standards values of 0.01 mg/l (Table 1).

Arsenic concentrations from the boreholes and wells differed significantly (F = 23.86; P = 0.0000)

4.1.3: Cadmium

The concentration of cadmium for the water samples ranged from 0.0003 mg/l to 0.001 mg/l. The largest concentration was recorded from the Tano River whilst the least was recorded in Boreholes

K1 and N2. All the cadmium concentrations were within WHO and Ghana Standards values of 0.003 mg/l (Table 1).

There was no significant difference in the concentrations recorded for the different water samples (F = 3.22; P = 0.0039)

4.1.4: Zinc

The mean concentrations of zinc for the sampling months ranged from a minimum of 0.01 mg/l to a maximum of 0.45 mg/l. The largest concentration was recorded in Well K3 and the least concentration was recorded in Borehole K2. Zinc concentrations were within WHO and Ghana Standards values of 3.000 mg/l (Table 1). There was a high significant differences in concentration of zinc from the different water sources. ($F = 2570.33$; $P = 0.0000$)

4.1.5: Lead

The concentration of lead for the water samples ranged from 0.08 mg/l to 0.33 mg/l. The largest concentration was recorded from the Goa River whilst the least was recorded in Borehole N2. All the values recorded were above the WHO and Ghana Standards values of 0.010 mg/l. (Table 1)

There was a significant difference between Goa River and Borehole N2. ($F = 11.88$; $P = 0.0000$)

4.1.6: Copper

The concentration of copper for the water samples ranged from 0.14 mg/l to 1.09 mg/l. The largest concentration was recorded from the Goa River whilst the least was recorded in Borehole K2. Only Goa River was above the Ghana Standard value of 1.000 mg/l. However, all the other values recorded were within the WHO acceptable limit of 2.000 mg/l (Table 1).

Significant difference exists between Goa River and Tano River. ($F = 145.64$; $P = 0.0000$)

4.1.7: Iron

The concentration of iron for the water samples ranged from 0.83 mg/l to 3.12 mg/l. The largest concentration was recorded from Well N3 whilst the least was recorded in Tano River. All the iron concentrations were above the WHO limit (0.3 mg/l) and Ghana Standard value (0.5 mg/l) (Table 1). There was a significant difference between Well N3 and Borehole K1. ($F = 10.77$; $P = 0.0000$).

4.2 Physical Parameters

Table 2: Physical parameters of water samples

Sample source	Temp(^{0}C)	Turbidity(NTU)	Conductivity(µS/cm)	TDS(mg/l)
Goa River	23.93^{ab}±1.024	3.62^{a}±0.026	1190.20^{i}±3.646	69.00^{h}±3.964
Tano River	23.08^{b}±0.780	2.66^{b}±0.014	633.70^{k}±5.164	53.75^{i}±0.373
Well K1	25.15^{ab}±0.854	2.23^{bc}±0.029	6164.00^{b}±9.459	180.00^{b}±0.956
Well K2	25.10^{ab}±0.829	1.72^{cd}±0.589	2481.50^{f}±9.016	105.00^{e}±6.317
Well K3	25.18^{ab}±0.591	1.49^{cde}±0.258	4557.30^{c}±18.221	129.00^{c}±1.134
Well N1	24.65^{ab}±1.047	1.43^{cde}±0.022	2609.00^{e}±23.007	93.00^{f}±1.499
Well N2	25.50^{ab}±1.538	1.43^{cde}±0.439	6192.00^{b}±21.071	288.00^{a}±0.594
Well N3	26.35^{a}±0.580	1.42^{de}±0.008	6598.70^{a}±27.447	292.00^{a}±0.804
Borehole K1	$24..08^{ab}$±0.939	1.34^{de}±0.014	2036.00^{h}±18.348	76.00^{g}±1.278
Borehole K2	25.18^{ab}±1.590	0.85^{e}±0.294	2987.80^{d}±17.474	119.00^{d}±1.699
Borehole N1	23.78^{ab}±0.602	1.34^{de}±0.476	738.50^{j}±19.044	64.00^{h}±0.698
Borehole N2	24.83^{ab}±4.947	0.92^{de}±0.008	2258.70^{g}±12.871	104.00^{e}±0.804
P-Value	**0.0037**	**0.00**	**0.00**	**0.00**

4.2.1: Temperature

Mean temperature for the water samples ranged from 23.08^{0}C to 26.35^{0}C. The highest temperature was recorded in Well N3 whilst the least was recorded in Tano River. Temperature differed significantly among the water sources. (Table 2) (F = 3.24; P = 0.0037)

4.2.2: Turbidity

Mean turbidity for the water samples ranged from 0.85 NTU in Borehole K2 to 3.62 NTU in Goa River. All the samples analyzed were within the WHO and Ghana Standards acceptable limits of 5 NTU (Table 2)

There was a significant difference in turbidity between Tano River and Well N3. Apart from the above mentioned two water samples, turbidity did not differ significantly among the other water sources. (F = 31.92; P = 0.0000)

4.2.3: Conductivity

Conductivity is a measure of the ability of water to conduct an electrical current.

Mean conductivity for the water sources ranged from 633.70 µS/cm in River Tano to 6598.70 µS/cm in Well N3. From the values, the Tano River was the only sample source within the WHO limit of 700 µS/cm (Table 2). Conductivity did not differ significantly between Well K1 and Well N2 but it differed significantly between the other water sources. (F = 64656.1; P = 0.0000)

4.2.4: Total Dissolved Solids

Mean total dissolved solids for the water samples ranged from 53.75 mg/l to 292.00 mg/l. The highest total dissolved solids was recorded in Well N3 whilst the least was recorded in River Tano. The entire sample sources were within the Ghana Standard acceptable limit of 1000 mg/l (Table 2). There was no significant different in total dissolved solids between Goa River and Borehole N1, Well K2 and Borehole N2, Well N2 and Well N3. However, significant difference existed among the other water sources. ($F = 6783.56$; $P = 0.0000$).

4.3: Chemical Parameters

Table 3: Chemical parameters of water samples

Sample source	pH	Alkalinity (mg/l)	HCO3(mg/l)	Total Hardness(mg/l)	K(mg/l)	Na(mg/l)	Ca(mg/l)	Mg(mg/l)	Mn(mg/l)
Goa River	$7.16^{a}\pm0.045$	$287.00^{e}\pm2.174$	$312.20^{j}\pm0.804$	$228.20^{i}\pm1.278$	$9.80^{ab}\pm0.883$	$24.80^{c}\pm1.506$	$15.25^{i}\pm0.681$	$15.30^{j}\pm0.632$	$0.09^{b}\pm0.002$
Tano River	$6.48^{a}\pm0.601$	$220.00^{i}\pm0.775$	$241.50^{l}\pm0.698$	$319.70^{h}\pm0.698$	$7.60^{cd}\pm0.577$	$21.10^{e}\pm0.883$	$25.13^{h}\pm0.457$	$25.00^{i}\pm1.798$	$0.07^{cd}\pm0.002$
Well K1	$7.43^{a}\pm0.643$	$329.00^{c}\pm1.169$	$468.50^{a}\pm1.699$	$540.25^{f}\pm0.635$	$8.10^{bcd}\pm0.439$	$25.00^{c}\pm1.519$	$64.38^{f}\pm0.532$	$64.30^{f}\pm0.770$	$0.08^{bc}\pm0.003$
Well K2	$6.70^{a}\pm0.066$	$272.00^{g}\pm4.004$	$384.20^{d}\pm1.278$	$765.80^{b}\pm2.198$	$7.70^{cd}\pm0.548$	$23.30^{cde}\pm0.548$	$93.95^{c}\pm0.526$	$94.10^{c}\pm1.683$	$0.06^{de}\pm0.004$
Well K3	$6.97^{a}\pm0.994$	$280.00^{f}\pm2.008$	$390.30^{c}\pm0.804$	$660.60^{c}\pm20.142$	$7.70^{cd}\pm0.337$	$21.20^{de}\pm0.770$	$102.25^{b}\pm0.755$	$102.30^{b}\pm0.658$	$0.07^{cd}\pm0.005$
Well N1	$7.37^{a}\pm0.213$	$324.00^{c}\pm1.278$	$375.60^{e}\pm0.594$	$368.10^{g}\pm1.169$	$6.40^{d}\pm0.294$	$20.20^{e}\pm0.337$	$27.70^{gh}\pm1.233$	$28.40^{gh}\pm1.621$	$0.08^{bc}\pm0.006$
Well N2	$6.57^{a}\pm0.282$	$244.00^{h}\pm1.169$	$454.80^{b}\pm1.499$	$632.20^{d}\pm22.825$	$10.90^{a}\pm0.816$	$20.90^{e}\pm1.621$	$85.48^{d}\pm1.050$	$85.20^{d}\pm0.337$	$0.11^{a}\pm0.006$
Well N3	$7.60^{a}\pm0.948$	$398.00^{a}\pm1.699$	$363.40^{f}\pm2.174$	$1289.90^{a}\pm0.804$	$8.70^{bc}\pm0.702$	$22.10^{cde}\pm0.658$	$184.00^{a}\pm2.555$	$186.00^{a}\pm0.770$	$0.05^{e}\pm0.003$
Borehole K1	$7.18^{a}\pm0.725$	$301.00^{d}\pm2.198$	$337.80^{g}\pm0.775$	$601.60^{e}\pm0.698$	$10.70^{a}\pm0.516$	$29.30^{b}\pm1.683$	$91.38^{c}\pm0.991$	$91.60^{c}\pm0.548$	$0.06^{de}\pm0.003$
Borehole K2	$7.53^{a}\pm0.669$	$387.00^{b}\pm0.698$	$325.70^{h}\pm1.699$	$234.10^{i}\pm1.699$	$8.30^{bc}\pm0.439$	$24.50^{cd}\pm0.770$	$28.53^{g}\pm0.591$	$29.10^{g}\pm1.519$	$0.08^{bc}\pm0.004$
Borehole N1	$6.45^{a}\pm0.353$	$218.00^{i}\pm0.594$	$286.60^{k}\pm4.004$	$226.90^{i}\pm1.278$	$8.60^{bc}\pm0.476$	$64.40^{a}\pm1.798$	$24.70^{h}\pm1.039$	$25.20^{hi}\pm0.883$	$0.09^{b}\pm0.006$
Borehole N2	$6.36^{a}\pm0.449$	$198.00^{j}\pm4.199$	$318.30^{i}\pm1.169$	$593.70^{e}\pm1.499$	$9.30^{abc}\pm0.730$	$20.20^{e}\pm0.476$	$77.25^{e}\pm1.519$	$76.70^{e}\pm1.506$	$0.08^{bc}\pm0.006$

P-Value	**0.0218**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

4.3.1: pH

Mean pH for the water sources ranged from 6.36 to 7.53. The highest pH was recorded in Well N3 whilst the least was recorded in Borehole N2. Three (3) out the twelve (12) sample sources namely Tano River, Borehole N1 and N2 did not meet the acceptable WHO and Ghana Standards for pH (6.5- 8.5). (Table 3) There was no significant difference in pH between all the sample sources. (F = 2.44; P = 0.0218)

4.3.2: Alkalinity

Mean alkalinity for the water samples ranged from 198.00 mg/l in Borehole N2 to 398.00 mg/l in Well N3. The only sample source found within the WHO acceptable limit (200 mg/l) was Borehole N2 (Table 3). There was no significant different in alkalinity between Tano River and Borehole N1, Well K1 and Well N1. Significant difference existed among the other water sources. (F = 3548.03; P = 0.0000).

4.3.3: Total Hardness

Mean total hardness for the water samples ranged from 228.20 mg/l to 1289.90 mg/l. The highest total hardness was recorded in Well N3 whilst the least was recorded in Goa River. Sample sources that were found to be within the WHO limit (500 mg/l) include Borehole N1, Borehole K2, Well N1, Tano River and Goa River (Table 3). Significant difference in terms of total hardness did not exist between Goa River, Borehole K2,
Borehole N1 and Borehole K1, Borehole N2. (F = 4672.01; P = 0.0000).

4.3.4: Bicarbonate

Mean bicarbonate for the water samples ranged from 241.50 mg/l in Tano River to 468.50 mg/l in Well K1. (Table 3) Bicarbonate differed significantly among the water sources. (F = 5986.58; P = 0.0000).

4.3.5: Potassium

Average potassium concentration for the water samples ranged from 6.40 mg/l in Well N1 to 10.90 mg/l in Well N2. (Table 3) There was no significant difference for potassium concentration in Well N2 and Borehole K1, Tano River Well K3 and Well K2. (F = 20.23; P = 0.0000).

4.3.6: Sodium

Mean sodium concentration for the water samples ranged from 20.20 mg/l to 64.40 mg/l. The highest sodium concentration was recorded in Borehole N1 whilst the least was recorded in Borehole N2 and Well N1. Sample sources that were found to be within the WHO limit (500 mg/l) include Borehole N1, Borehole K2, Well N1, Tano River and Goa River (Table 3). There was no significant difference between Tano River, Well N1, Well N2 and Borehole N2. However, sodium concentration differed significantly among the other water sources. (F = 441.78; P = 0.0000).

4.3.7: Calcium

Mean calcium concentration for the water samples ranged from 15.25 mg/l in Goa River to 184.00 mg/l in Well N3. (Table 3). All the calcium concentrations were above the WHO permissible level of 0.01 mg/l. There was no significant difference between the following pairs of samples: Tano River and Borehole N1, Well K2 and Borehole K1.

However, significant difference existed in calcium concentration among the other water samples. ($F = 7219.51$; $P = 0.0000$).

4.4: Nutrients

Table 4: Nutrient concentrations of water samples

Sample source	Nutrients Concentrations Recorded(mg/l)			
	Chloride ion	**Nitrate ion**	**Phosphate ion**	**Sulphate ion**
Goa River	$157.00^{b}\pm3.367$	$0.96^{b}\pm0.037$	$127.50^{a}\pm1.291$	$151.75^{a}\pm1.500$
Tano River	$172.00^{a}\pm4.082$	$8.66^{a}\pm0.018$	$131.75^{a}\pm1.708$	$149.25^{a}\pm2.217$
Well K1	$128.00^{cd}\pm5.477$	$0.86b^{c}\pm0.055$	$86.75^{cd}\pm1.500$	$125.50^{c}\pm1.291$
Well K2	$152.00^{b}\pm6.583$	$0.64d^{ef}\pm0.044$	$110.00^{b}\pm7.257$	$136.50^{b}\pm4.509$
Well K3	$154.00^{b}\pm2.582$	$0.54^{f}\pm0.059$	$83.50^{de}\pm3.697$	$146.50^{a}\pm3.109$
Well N1	$124.00^{cd}\pm1.826$	$0.75^{cd}\pm0.066$	$103.50^{b}\pm2.646$	$103.00^{d}\pm2.160$
Well N2	$135.00^{c}\pm4.397$	$0.61^{ef}\pm0.044$	$95.00^{c}\pm0.816$	$130.50^{bc}\pm1.291$
Well N3	$154.00^{b}\pm6.218$	$0.71^{de}\pm0.026$	$74.00^{f}\pm1.826$	$102.75^{d}\pm2.217$
Borehole K1	$76.00^{e}\pm2.582$	$0.53^{f}\pm0.029$	$77.25^{ef}\pm3.594$	$41.00^{g}\pm0.816$
Borehole K2	$42.00^{g}\pm4.397$	$0.31^{g}\pm0.026$	$38.30^{g}\pm0.622$	$53.50^{f}\pm1.291$
Borehole N1	$63.00^{f}\pm4.761$	$0.38^{g}\pm0.018$	$38.40^{g}\pm0.476$	$80.50^{e}\pm1.291$
Borehole N2	$122.00^{d}\pm3.367$	$0.34^{g}\pm0.026$	$30.20^{g}\pm0.183$	$43.75^{g}\pm1.258$

P-Value	**0.0000**	**0.0000**	**0.0000**	**0.0000**

4.4.1: Chloride ion concentration of water samples

Mean chloride ion concentration for the water samples ranged from 42.00 mg/l to 172.00 mg/l. The largest chloride ion was recorded in Tano River whilst the least concentration was recorded in Borehole K2. All the samples analyzed were within the WHO and Ghana Standards acceptable limits of 250 mg/l (Table 4). There was no significant difference in chloride ion concentration for Goa River, Well K2, Well K3 and Well N3. However, chloride ion concentration differed significantly among the other water sources.

(F= 358.86; P= 0.0000).

4.4.2: Sulphate ion concentration of water samples

Average sulphate ion concentration for the water samples ranged from 41.00 mg/l to 151.75 mg/l. Sulphate ion concentration was highest in the Tano River while the lowest concentration was recorded in Borehole K1. All the water samples analyzed were within the WHO and Ghana Standards acceptable limits of 250 mg/l (Table 4). There was no significant difference in sulphate ion concentration between the following pairs of water sources: Goa River and Tano River, Well K1 and Well N2, Well N1 and N3, Borehole K1 and N2. Sulphate ion concentration differed significantly among the other water sources.

(F = 1492.21; P = 0.0000).

4.4.3: Phosphate ion concentration of water samples

Phosphate ion concentration for the water sources ranged from 30.20 mg/l to 131.75 mg/l. Phosphate ion concentration was highest in the Tano River while the lowest concentration was recorded in Borehole N2. All the water samples analyzed were above the WHO limit of less than 0.3 mg/l (Table 4). Phosphate ion concentration differed significantly between Well K1 and Well K2. Moreover, there was no significant difference between the following pairs of water sources: Goa River and Tano River, Borehole K2, Borehole N1 and Borehole N2, Well K2 and N1 ($F = 560.51$; $P = 0.0000$).

4.4.4: Nitrate ion concentration of water samples

Nitrate ion concentration for the water samples ranged from 0.31 mg/l in Borehole K2 to 8.66 mg/l in Tano River. All the water samples analyzed were within the WHO and Ghana Standards acceptable limits of 10 mg/l and 50 mg/l respectively (Table 4). Nitrate ion concentration differed significantly between Well K3 and Well N1.However, there was no significant difference between the following pairs of water sources: Well K3 and Borehole K1, Borehole K2, Borehole N1 and Borehole N2. ($F = 13392.90$; $P = 0.0000$).

4.5: Microbiological quality of water samples

Table 5: Microbiological quality of water from different sources

Analysis of water samples indicated various degree of contamination with Total coliform, Faecal coliform, E. coli and Enterococci. These were identified in all the water sources.

Sample source	**Microbiological Parameters Recorded**(cfu/100ml) $x10^7$			
	Total Coliforms	**Faecal Coliforms**	***E.coli***	***Enteroccoci***
Goa River	$4.95^{a}\pm3.742$	$0.80^{a}\pm0.579$	$0.33^{a}\pm0.309$	$405000^{abc}\pm250532.8$
Tano River	$80.91^{a}\pm130.009$	$1.35^{a}\pm2.109$	$8.64^{a}\pm16.907$	$400002^{abc}\pm336646.5$
Well K1	$139.57^{a}\pm156.379$	$0.75^{a}\pm0.316$	$0.09^{a}\pm0.126$	$450000^{ab}\pm129099.4$
Well K2	$7.36^{a}\pm3.075$	$0.26^{a}\pm0.133$	$0.28^{a}\pm0.000$	$0.00^{c}\pm0$
Well K3	$8.95^{a}\pm5.659$	$3.21^{a}\pm5.266$	$0.16^{a}\pm0.083$	$772500^{a}\pm122576.5$
Well N1	$5.92^{a}\pm4.858$	$3.18^{a}\pm5.289$	$0.16^{a}\pm0.133$	$0.00^{c}\pm0$
Well N2	$9.81^{a}\pm16.167$	$0.85^{a}\pm1.271$	$0.16^{a}\pm0.084$	$350000^{bc}\pm100000$
Well N3	$0.94^{a}\pm1.218$	$1.60^{a}\pm2.644$	$0.17^{a}\pm0.117$	$425000^{ab}\pm150000$
Borehole K1	$0.54^{a}\pm0.336$	$0.00^{a}\pm0.000$	$0.00^{a}\pm0.000$	$0.00^{c}\pm0$
Borehole K2	$2.69^{a}\pm4.314$	$0.00^{a}\pm0.000$	$0.00^{a}\pm0.000$	$0.00^{c}\pm0$
Borehole N1	$2.41^{a}\pm4.343$	$0.00^{a}\pm0.000$	$1.39^{a}\pm2.743$	$0.00^{c}\pm0$
Borehole N2	$2.13^{a}\pm2.437$	$0.77^{a}\pm1.324$	$0.21^{a}\pm0.220$	$0.00^{c}\pm0$
P-Value	**0.0428**	**0.5965**	**0.4842**	**0.0000**

4.5.1: Total Coliforms

Total coliforms for the water samples ranged from 0.54 cfu/100 ml to 80.91 CFU/100ml. The largest concentration of Total coliforms was recorded in Tano River whilst the least concentration was recorded in Borehole K1. However, none of the sample sources was found to be within the acceptable WHO and Ghana Standards limits (0.0000 cfu/100 ml) There was no significant difference in the Total coliforms recorded for the different water samples. (Table 5). (F = 2.14; P = 0.0428).

4.5.2: Faecal Coliforms

Average faecal coliforms for the water samples ranged from 0.00 cfu/100 ml to 3.21 cfu/100 ml. The largest concentration of faecal coliforms was recorded in Well K3. No faecal coliforms were recorded in Boreholes K1, K2 and N1. Water from these boreholes therefore found to be within the acceptable WHO and Ghana Standards limits (0.0000 cfu/100 ml). (Table 5)

There was no significant difference in faecal coliforms recorded for the different water samples. (F = 0.85; P = 0.5965).

4.5.3: *E. coli*

Mean *E. coli* for the water samples ranged from 0.00 cfu to 8.64 cfu/100 ml. The largest concentration of *E. coli* was recorded in the Tano River. No *E. coli* were found in Borehole K1 and K2 and were therefore found to be within the acceptable WHO and Ghana Standards limits (0.0000 cfu/100 ml) (Table 5). There was no significant difference in E. coli recorded for the different water samples. (F = 0.98; P = 0.4842).

4.5.4: Enterococci

Mean *Enterococci* for the water samples ranged from 0.00 cfu to 772500 cfu/100 ml. The largest concentration of *Enterococci* was recorded in Well K3. No *Enterococci* were recorded in Well K2, N1, Borehole K1, N1, K2 and N2. Water from these sources therefore found to be within the acceptable WHO and Ghana Standards limits (0.0000 cfu/100 ml) (Table 5). The *Enterococci* differed significantly between Well K2 and Well K3. However, there was no significant difference among all the borehole water sources. (F = 14.02; P = 0.0000).

CHAPTER FIVE

5.0 DISCUSSION

5.1 Metal concentration of water from different sources

Heavy metal analysis obtained from the water samples are presented in Table 1. These metals are widely distributed in the environment with sources from minerals and soil weathering (O' Neil, 1993).

5.1.1 Mercury

The concentration of mercury in the water samples ranged from 0.0002 to 0.0008 mg/l. These levels did not exceed the WHO and Ghana Standards values of 0.001 mg/l. Although none of the mercury concentrations exceeded the above mentioned standards, if human activities are not controlled, the concentrations in the Tano River which was 0.0008 mg/l can exceed the WHO and Ghana Standards. Comparatively, significant differences exist between the boreholes and the other water sources.

5.1.2 Arsenic

The levels of arsenic concentration in the water samples ranged from 0.0003 to 0.0008 mg/l. Concentration of arsenic analyzed in all the water samples were within the WHO and Ghana Standards values 0.01 mg/l. Tano River and Goa River recorded the largest value of 0.0008 mg/l which might increase if human activities such as illegal mining are not controlled along these water bodies. Humans expose to inorganic arsenicals may have increased risk of cancer of the skin, liver, lungs and hematopoietic tissues (Agyei, 2004).

5.1.3 Cadmium

Cadmium concentrations in the water samples analyzed ranged from 0.0003 to 0.001 mg/l. The levels of the above mentioned concentrations were found to be below the WHO and Ghana Standards values of 0.003 mg/l. Despite the fact that cadmium concentrations did not exceed the above mentioned standards, care should still be taken especially around the Tano River which recorded 0.001 mg/l. This is because the metal can be linked to increased blood pressure and effects on the myocardium in animals, although most human data do not support these findings (Friis and Edling, 1998). Cadmium concentrations were generally low for all the water samples from the boreholes compared to the wells and rivers. Cadmium concentrations from all the water samples did not differ significantly.

5.1.4 Zinc

The recorded concentrations of zinc in the water samples were not alarming because the values were far below the WHO and Ghana Standard recommended levels of 3 mg/l for drinking water. The concentrations recorded ranged from 0.01- 0.45 mg/l and the variation of zinc in the water among the sampling sites was highly different significantly. The mean concentration of zinc within the water samples show that they do not pose any immediate health threat to humans and other aquatic organisms. The low zinc concentrations was probably due to the fact that metals can easily be absorbed and utilized by organisms in the aquatic environment since it is a micronutrient (Campbell, 1995).

5.1.5 Lead

Lead concentrations from the water sources ranged from 0.08 to 0.33 mg/l. This is a clear indication of water pollution because the concentrations recorded were all above the WHO

and Ghana Standard limits of 0.01 mg/l. The high levels of lead recorded might be due to farming which involves the application of fertilizers and other chemicals increasing lead concentrations especially along the Goa and Tano Rivers due to the residues on crops such as cocoa and vegetables (Raven and Berg, 2004).

According to Raven and Berg (2004), lead accumulated in the body over a period of time can cause serious toxic effects. Three groups of people that are at the greatest risk from lead poisoning are pregnant women, middle-aged men and children.

5.1.6 Copper

Concentrations of copper in the analyzed water samples ranged from 0.14 – 1.09 mg/l. Among the water samples analyzed from the sampling sites, only Goa River was found to be above the Ghana Standard acceptable limit of 1.0 mg/l. However, in terms of WHO limit, all the water samples were within the WHO limit of 2.0 mg/l. Comparing the rivers, wells and boreholes in terms of copper concentrations, the rivers recorded higher concentrations than the wells and boreholes. The high levels of copper concentrations in the Goa River can be due to the use of copper sulphate as an algicide. Copper levels should be closely monitored especially at the Goa River in order to curb health effects such as nausea, vomiting, diarrhea and stomach cramps. Moreover, drinking water with high levels of copper for many years could cause liver or kidney damage (Pennington and Calloway, 1983).

5.1.7 Iron

The concentration of iron in the water samples ranged from 0.83 to 3.12 mg/l. These concentrations fell above the WHO limit of 0.3 mg/l and Ghana Standard value of 0.5 mg/l for portable and domestic water. The high iron concentrations recorded in the water

samples can be attributed to the fact that the underlying rocks in which the water flows are rich in iron. Comparatively, the wells recorded higher concentrations of iron than the boreholes and rivers due to the rich iron underlying geologic formations. This high iron concentration can produce an unpleasant taste in drinking water and therefore making it unsuitable for consumption. Moreover, large quantities in water may cause the staining of plumbing fixtures and laundry (Spellman and Drinan, 2000).

5.2 Physico-chemical parameters of water from different sources

5.2.1 pH

Mean pH for the water samples ranged from 6.36 to 7.53. However, three (3) out of the twelve (12) namely Tano river, Borehole N1 and Borehole N2 did not meet the WHO and Ghana Standards limit for pH (6.5-8.5). The value of pH (6.36) recorded in Tano river may be attributed to the fact that streams serving the river flows through rapidly growing urbanizing towns where degradation of drowned vegetation and other matter cause the release of methane gas which is accompanied by the release of hydrogen sulphide (Connell *et al*. 1984) thereby decreasing the pH of the overlying water. The slightly acidic nature can cause a cascading effects that can harm or kill individual fish, thereby reducing fish population and decrease biodiversity within the river. The slightly acidic nature of some wells namely Well K2, K3 and N2 could be attributed to the different buckets that are being used to fetch the water. Moreover, the slightly acidic nature of some boreholes namely Borehole N1 and N2 can be linked to the rocks in which the water flows.

5.2.2 Temperature

Mean water temperature ranged from 23.08^{0}C to 26.35^{0}C. Temperature may be influenced by depth of water, season and air circulation as well as time of day (Peirce *et al.*, 1998). Temperature range of 15^{0}C to 25^{0}C is optimum for bacterial growth and higher temperatures support faster growth rates and enable some biota to increase in numbers (Chapman, 1996).

5.2.3 Turbidity

Turbidity ranged from a lowest of 0.85 NTU in Borehole K2 to a highest of 3.62 NTU in Goa River. Turbidity values were within the WHO and Ghana Standards acceptable limits of 5 NTU. The low levels of turbidity in the water samples can be attributed to less soil erosion and decay of dead organic matter. Comparatively, the rivers were more turbid than the wells and boreholes. Although, turbidity of the rivers were within the acceptable limits, these rivers must be monitored in order to prevent them from exceeding the permissible levels of 5 NTU. In terms of turbidity, the water is portable for domestic use.

5.2.4 Conductivity

Conductivity of the water samples ranged from 633.70 µS/cm to 6598.70 µS/cm. In terms of conductivity, all the water samples were above the WHO permissible limit of 700 µS/cm with exception of the Tano River. The low conductivity recorded in Tano River can be attributed to less human interactions. However, specific conductance is an important water quality measurement because it gives a good idea of the amount of dissolved materials in the water. The higher specific conductance recorded for water samples gives an indication of high dissolved solids concentration which can affect the suitability of water for domestic, industrial and agricultural uses. Moreover, the high levels of conductivity can affect

drinking water quality by giving an unpleasant taste or odour and may even cause gastrointestinal distress (APHA, 1989).

5.2.5 Total Dissolved Solids

Total dissolved solids recorded for all the water samples were within the WHO and Ghana Standard acceptable limit of 1000 mg/l. McCutheon *et al.,* (1983) established that water with total dissolved solids level less than 600 mg/l is generally considered palatable but levels above 1200 mg/l are considered not palatable. In view of this, the water in the different water bodies can be said to be palatable since all the recorded values in terms of TDS were even less than the 600 mg/l. TDS in water may produce bad taste, odour and colour, and also induce unfavourable physiological reactions in the consumer (Spellman and Drinan, 2000).

5.2.6 Alkalinity

In terms of water quality, alkalinity is a measure of the buffering capacity of water. Alkalinity values of the samples were generally high (above the WHO acceptable limit of 200 mg/l) with exception of Borehole N2. Based on the high alkaline nature of the analyzed water, such water could be unpalatable (Spellman and Drinan, 2000). From the results, alkalinity in the water samples analyzed increased with increasing pH.

5.2.7 Total Hardness

Total hardness of the water from most of the sampling sites were much higher than the WHO recommended levels for drinking water of 500 mg/l namely Well K1, K2, K3, N2, N3, Borehole K1 and N2. The high levels of hardness recorded may be largely attributed to the geology of rocks or soils through which the water is associated. The degree of

hardness of water supply is determined by the content of calcium and magnesium salts. Hard water produces less lather with soap. Industrially, it generates boiler scales as a result of precipitation of calcium and magnesium carbonates, thereby making boilers inefficient. Studies have indicated a negative correlation between death from heart diseases and the hardness of water implying that the harder the water, the fewer the deaths resulting from heart diseases (O' Neill, 1985).

5.2.8 Potassium

Potassium ion levels recorded fell within the WHO maximum acceptable limits for drinking and portable water of 30 mg/l. Although, potassium ion concentrations were within the WHO acceptable limit, Well N2 recorded highest among the water samples analyzed. Improper disposal of garbage and domestic sewage, soap and detergent washing powder, fertilizer from farmlands and fetching of well water with different containers contribute to the level of potassium in Well K2.

5.2.9 Sodium

Sodium ion concentrations ranged from a lowest of 20.20 mg/l in Borehole N2 and Well N1 to a highest of 64.40 mg/l in Borehole N1. In terms of sodium ions levels, all the water samples were within the WHO permissible limit of 200 mg/l for drinking and portable water. A review by EPA in the mid-1980s showed that elevated levels of sodium in drinking water did not cause high blood pressure or heart disease, rather only that sodium be avoided by those who already had such medical conditions (USEPA, 2006).

5.2.10 Calcium

Calcium ion concentrations for all the water samples analyzed from the various sampling sites were above the WHO acceptable limit of 3 mg/l during the study period. Calcium concentrations above 16.0 mg/l have possible scaling and corrosive effects but no adverse health effects (Lester and Birkett, 1999).

5.2.11 Manganese

Recorded manganese concentrations for the water samples fell within GS 175 maximum acceptable limits for drinking water (0.1 mg/l) except Well N2 which exceeded the GS 175 maximum acceptable limit from the value recorded. This may be attributed to water table fluctuation, weathering and geothermal changes in the geological formations (GWSA: Corporate brochure, 2007). Lester and Birkett (1999) noted that the presence of manganese in water produces dark purple to black stains on laundry and plumbing fixtures. At high concentrations, it may have physiological and neurological effects.

5.3 Nutrient concentrations of water samples

5.3 1 Chloride ion

Mean chloride ion concentrations recorded from a minimum of 42.00 mg/l to a maximum of 172.00 mg/l in the water samples were all within the WHO and Ghana Standards acceptable limits of 250 mg/l. Despite the largest chloride ion being recorded in Tano River which is below the above mentioned acceptable limits, care should be taken to prevent this water body from exceeding the standard limits. The large concentration of chloride ion in the Tano River can be attributed to fertilizer application, untreated domestic waste as well as those from anthropogenic sources. Chloride concentrations above 30.0 mg/l can accelerate corrosion in domestic appliances and lead to moderate damage to equipment and

structures due to corrosion particularly if the pH is low and temperature is elevated (US Geological Survey, 1990).

5.3.2 Nitrate ion

Concentration of nitrate in all the water samples analyzed were within acceptable Ghana Standard maximum limit (50 mg/l) and WHO limit (10 mg/l) for drinking water. These limits were not exceeded in all the water samples; thus, nitrate does not pose a threat for the domestic use of water from all the water bodies. Baird (2000) and Spellman and Drinan (2000) indicated that excess nitrate concentrations in drinking water pose an immediate health threat to infants since it can result in methaemoglobinaemia (blue baby syndrome), as well as in adults with a particular enzyme deficiency. Nitrates found in water bodies is derived from human activities, including the disposal of human waste and the use of inorganic fertilizers in agriculture (Cave and Kolsky, 1999).

5.3.3 Phosphate and Sulphate ions

Concentrations of phosphate ions recorded in the water samples were all higher than the WHO acceptable limit of less than 0.3 mg/l. A higher level of phosphate is an indication of pollution which may cause eutrophication (McCutheon *et al.*, 1983). The high levels of phosphate recorded in all the water samples could be attributed to the introduction of phosphate – containing chemicals like detergents that probably found their way into the well water as a result of people fetching water with different containers, overland runoffs or application of fertilizers on farms close to these water bodies. Water from the boreholes might have been flowing from rocks containing high levels of phosphate.

However, sulphate concentrations recorded in the water samples were all within the WHO and Ghana Standards limits of 250 mg/l and therefore making the water portable for

domestic use. Well water with sulphate concentrations within the WHO limits has negligible damaging effect on equipment and structures as a result of corrosion, concrete degradation and scaling of boilers (Spellman and Drinan, 2000).

5.4 Microbiological quality of water samples

The recorded mean values for total coliforms exceeded the WHO and Ghana Standard acceptable limits of 0 cfu/100ml water making the water unsafe for drinking. Total coliforms give a clear indication of the general sanitary quality of water since this group includes bacteria of faecal origin. In addition, many of the bacteria in this group may originate from growth in the aquatic environment. This is used to evaluate the general sanitary quality of drinking water and related water (EPA, GHANA, 2002). According to Chapman (1992), high coliform numbers may be attributed to sewage, land and urban run-off and domestic waste waters.

Faecal coliforms counts were recorded in water samples namely Goa river, Tano river, Well K1, K2, K3, N1, N2, N3 and Borehole N2. However, under normal sense, faecal coliforms should not be found in underground water (Borehole N2). Faecal coliforms found in Borehole water might be due to contamination of the spout of the borehole with faeces by school children at the time of collection of water sample since it is situated in a school compound. The high faecal coliforms in the other water samples could be due to indiscriminate defaecation, throwing of garbage around the rivers, run off which may carry human faeces, animal droppings and other sources of organic matter from farms.

Such high degree of contamination in reference to the above mentioned water sources does not make water suitable for drinking and irrigation purposes due to infection (WHO, 1993). Most of the water samples recorded some amounts of *E. coli and Enteroccoci.* Water can be said to be free of risk to human health if the faecal coliforms count in the water is zero and *E. coli* is absent (WHO, 2004). The high faecal coliforms and E. coli counts is an indication of the water being polluted by pathogenic organisms.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The pollution of water bodies has become a major global concern because apart from the high cost incurred in water treatment, most water bodies are drying up because of excessive pollution.

Despite the fact that some of the metals were within the WHO and Ghana Standards, some metal concentrations (Lead, Copper, Iron) were above the standards which pose health hazard to the inhabitants.

Results indicated that, turbidity, total dissolved solids, potassium, sodium, chlorides, sulphates and nitrates were the only parameters within the WHO permissible limit.

The microbiological quality of most of the water samples were unsafe for use domestically since faecal contamination was present and the level of total coliforms, *E. coli and Enterococci* were high and can cause health problems to the inhabitants. In general, water

quality, from the study area was not suitable for domestic purposes unless treatment methods are applied prior to consumption.

6.2 Recommendations

From the results and discussion, the following recommendations have been made at the end of the study.

- One container should be used in fetching water from the wells in order not to affect the water quality.
- The communities should be educated on the need to keep their surroundings clean especially around rivers, wells and boreholes.
- Residents in the two communities should be educated on the impact of human activities on water bodies and their effects on inhabitants who consume water from these water bodies.
- Water quality analysis should be carried out on all the rivers, wells and boreholes in the district at least once every two years. This is to ensure that the incidence of contamination are noticed earlier.
- Adequate funds must be provided by the government through the district assemblies to support in future for further research into effective ways of protecting and conserving water bodies.
- Chlorine tablets or powder should be supplied by the district to the District Sanitation and Environmental Health Officers to reduce microbial load in well water bodies.

- Regular workshops should be organised by the district to sensitize the inhabitants on treatment methods such as boiling, filtering, disinfecting etc. on raw water from rivers, wells and boreholes prior to consumption.
- Environmental scientist should monitor farming activities around water bodies with regards to the quantity and type of fertilizer used by farmers to reduce enrichment of water bodies.

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APPENDICES

APPENDIX 1: ANOVA TABLES FOR HEAVY METAL CONCENTRATION

1.1 IRON

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Completely Randomized AOV for Iron

Source	DF	SS	MS	F	P
treatment	11	28.8739	2.62490	10.77	0.0000
Error	36	8.7760	0.24378		

Total 47 37.6499

Grand Mean 1.6933 CV 29.16

Homogeneity of Variances F P

Levene's Test 7.51 0.0000

O'Brien's Test 4.81 0.0002 Brown

and Forsythe Test 11.9 0.0000

Welch's Test for Mean Differences

Source DF F P

treatment 11.0 35.57 0.0000

Error 13.8

Component of variance for between groups 0.59528

Effective cell size 4.0

treatment	**Mean**	**treatment**	**Mean**
Bore K2	1.9800	Well N2	2.7900
Bore N1	0.8500	Well N3	3.1200
Bore N2	1.3200	Well N1	1.1400
Bore K1	1.1100	Well K1	2.5600
Goa	0.9500	Well K2	1.4400
Tano	0.8300	Well K3	2.2300

Observations per Mean 4

Standard Error of a Mean 0.2469 Std

Error (Diff of 2 Means) 0.3491

1.2 Copper

Completely Randomized AOV for Copper

Source	**DF**	**SS**	**MS**	**F**	**P**
treatment	11	3.42667	0.31152	145.64	0.0000
Error	36	0.07700	0.00214		
Total	47	3.50367			

Grand Mean 0.3533 CV 13.09

Homogeneity of Variances	**F**	**P**
Levene's Test	7.44	0.0000
O'Brien's Test	4.76	0.0002
Brown and Forsythe Test	7.59	0.0000

Welch's Test for Mean Differences

Source	**DF**	**F**	**P**
treatment	11.0	62.54	0.0000
Error	14.1		

Component of variance for between groups 0.07734

Effective cell size 4.0

treatment	**Mean**	**treatment**	**Mean**
Bore K2	0.1400	Well N2	0.2400
Bore N1	0.1900	Well N3	0.2400

Bore N2	0.1800	Well N1	0.4200
Bore K1	0.1900	Well K1	0.2600
Goa	1.0900	Well K2	0.3200
Tano	0.7200	Well K3	0.2500

Observations per Mean 4

Standard Error of a Mean 0.0231 Std Error (Diff of 2 Means) 0.0327

1.3 Lead

Completely Randomized AOV for Lead

Source	**DF**	**SS**	**MS**	**F**	**P**
treatment	11	0.21200	0.01927	11.88	0.0000
Error	36	0.05840	0.00162		
Total	47	0.27040			

Grand Mean 0.2200 CV 18.31

Homogeneity of Variances	**F**	**P**
Levene's Test	4.15	0.0006
O'Brien's Test	2.65	0.0134
Brown and Forsythe Test	4.50	0.0003

Welch's Test for Mean Differences

Source	**DF**	**F**	**P**
treatment	11.0	19.47	0.0000

Error 14.1

Component of variance for between groups 0.00441

Effective cell size 4.0

treatment	**Mean**	**treatment**	**Mean**
Bore K2	0.1400	Well N2	0.2200
Bore N1	0.1800	Well N3	0.2100
Bore N2	0.0800	Well N1	0.2300
Bore K1	0.1900	Well K1	0.2800
Goa	0.3300	Well K2	0.2400
Tano	0.3100	Well K3	0.2300

Observations per Mean 4

Standard Error of a Mean 0.0201 Std Error (Diff of 2 Means) 0.0285

APPENDIX 2: ANOVA TABLES FOR PHYSICO CHEMICAL PARAMETERS

2.1 pH

Completely Randomized AOV for pH

Source	**DF**	**SS**	**MS**	**F**	**P**
treatment	11	9.1338	0.83034	2.44	0.0218
Error	36	12.2710	0.34086		
Total	47	21.4048			

Grand Mean 6.9829 CV 8.36

Homogeneity of Variances	**F**	**P**	
Levene's Test	1.19	0.3307	
O'Brien's Test	0.76	0.6765	Brown
and Forsythe Test	0.39	0.9493	

Welch's Test for Mean Differences

Source	**DF**	**F**	**P**
treatment	11.0	11.07	0.0001
Error	13.6		

Component of variance for between groups 0.12237

Effective cell size 4.0

treatment	**Mean**	**treatment**	**Mean**
Bore K2	7.5325	Well N2	6.5675
Bore N1	6.4500	Well N3	7.6025
Bore N2	6.3600	Well N1	7.3675
Bore K1	7.1775	Well K1	7.4325
Goa	7.1575	Well K2	6.6975
Tano	6.4800	Well K3	6.9700

Observations per Mean 4

Standard Error of a Mean 0.2919

Std Error (Diff of 2 Means) 0.4128

2.2 Alkalinity

Completely Randomized AOV for Alkalinity

Source	DF	SS	MS	F	P
treatment	11	179711	16337.3	3546.03	0.0000
Error	36	166	4.6		
Total	47	179877			

Grand Mean 288.17 CV 0.74

Homogeneity of Variances	F	P	
Levene's Test	30.8	0.0000	
O'Brien's Test	19.7	0.0000	Brown
and Forsythe Test	25.6	0.0000	

Welch's Test for Mean Differences

Source	DF	F	P
treatment	11.0	12225.7	0.0000
Error	14.1		

Component of variance for between groups 4083.18

Effective cell size 4.0

treatment	Mean	treatment	Mean
Bore K2	387.00	Well N2	244.00
Bore N1	218.00	Well N3	398.00
Bore N2	198.00	Well N1	324.00
Bore K1	301.00	Well K1	329.00

Goa	287.00	Well K2	272.00
Tano	220.00	Well K3	280.00

Observations per Mean 4

Standard Error of a Mean 1.0732 Std Error (Diff of 2 Means) 1.5178

2.3 Conductivity

Completely Randomized AOV for Conductivity

Source	DF	SS	MS	F	P
treatment	11	2.039E+08	1.853E+07	64656.1	0.0000
Error	36	10319.2	286.644		
Total	47	2.039E+08			

Grand Mean 3204.0 CV 0.53

Homogeneity of Variances	F	P	
Levene's Test	5.07	0.0001	
O'Brien's Test	3.25	0.0037	Brown
and Forsythe Test	8.55	0.0000	

Welch's Test for Mean Differences

Source	DF	F	P
treatment	11.0	99479.1	0.0000
Error	13.9		

Component of variance for between groups 4633239

Effective cell size 4.0

treatment	Mean	treatment	Mean
Bore K2	2987.8	Well N2	6192.0
Bore N1	738.5	Well N3	6598.7
Bore N2	2258.7	Well N1	2609.0
Bore K1	2036.0	Well K1	6164.0
Goa	1190.2	Well K2	2481.5
Tano	633.7	Well K3	4557.3

Observations per Mean 4

Standard Error of a Mean 8.4653 Std

Error (Diff of 2 Means) 11.972

2.4 Total Hardness

Completely Randomized AOV for Total Hardness

Source	DF	SS	MS	F	P
treatment	11	4039746	367250	4672.01	0.0000
Error	36	2830	79		
Total	47	4042576			

Grand Mean 538.42 CV 1.65

Homogeneity of Variances		**F**	**P**	
Levene's Test		2.09	0.0471	
O'Brien's Test		1.34	0.2435	Brown
and Forsythe Test		1.14	0.3603	

Welch's Test for Mean Differences

Source	**DF**	**F**	**P**
treatment	11.0	285075	0.0000
Error	14.1		

Component of variance for between groups 91792.8

Effective cell size 4.0

treatment	**Mean**	**treatment**	**Mean**
Bore K2	234.1	Well N2	632.2
Bore N1	226.9	Well N3	1289.9
Bore N2	593.7	Well N1	368.1
Bore K1	601.6	Well K1	540.3
Goa	228.2	Well K2	765.8
Tano	319.7	Well K3	660.6

Observations per Mean 4

Standard Error of a Mean 4.4330 Std

Error (Diff of 2 Means) 6.2692

2.5 Calcium

Completely Randomized AOV for Calcium

Source	DF	SS	MS	F	P
treatment	11	103719	9428.98	7219.51	0.0000
Error	36	47	1.31		
Total	47	103766			

Grand Mean 68.331 CV 1.67

Homogeneity of Variances	F	P	
Levene's Test	1.74	0.1027	
O'Brien's Test	1.12	0.3776	Brown
and Forsythe Test	0.69	0.7376	

Welch's Test for Mean Differences

Source	DF	F	P
treatment	11.0	6345.05	0.0000
Error	14.1		

Component of variance for between groups 2356.92

Effective cell size 4.0

treatment	Mean	treatment	Mean
Bore K2	28.53	Well N2	85.48

Bore N1	24.70	Well N3	184.00
Bore N2	77.25	Well N1	27.70
Bore K1	91.37	Well K1	64.38
Goa	15.25	Well K2	93.95
Tano	25.13	Well K3	102.25

Observations per Mean 4

Standard Error of a Mean 0.5714 Std

Error (Diff of 2 Means) 0.8081

2.6 Manganese

Completely Randomized AOV for Manganese

Source	**DF**	**SS**	**MS**	**F**	**P**
treatment	11	0.01147	0.00104	52.86	0.0000
Error	36	0.00071	0.00002		
Total	47	0.01218			

Grand Mean 0.0767 CV 5.79

Homogeneity of Variances	**F**	**P**
Levene's Test	1.84	0.0821
O'Brien's Test	1.18	0.3342 Brown
and Forsythe Test	1.95	0.0649

Welch's Test for Mean Differences

Source	DF	F	P
treatment	11.0	53.35	0.0000
Error	14.1		

Component of variance for between groups 2.557E-04

Effective cell size 4.0

treatment	Mean	treatment	Mean
Bore K2	0.0800	Well N2	0.1100
Bore N1	0.0900	Well N3	0.0500
Bore N2	0.0800	Well N1	0.0800
Bore K1	0.0600	Well K1	0.0800
Goa	0.0900	Well K2	0.0600
Tano	0.0700	Well K3	0.0700

Observations per Mean 4

Standard Error of a Mean 2.220E-03 Std Error (Diff of 2 Means) 3.140E-03

APPENDIX 3: ANOVA TABLES FOR NUTRIENT CONCENTRATIONS

3.1 Chlorides

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Completely Randomized AOV for Chlorides

Source	DF	SS	MS	F	P
treatment	11	75441.0	6858.27	358.86	0.0000
Error	36	688.0	19.11		
Total	47	76129.0			

Grand Mean 123.25 CV 3.55

Homogeneity of Variances	F	P	
Levene's Test	2.53	0.0175	
O'Brien's Test	1.62	0.1343	Brown
and Forsythe Test	2.75	0.0107	

Welch's Test for Mean Differences

Source	DF	F	P
treatment	11.0	314.04	0.0000
Error	14.1		

Component of variance for between groups 1709.79

Effective cell size 4.0

treatment	Mean	treatment	Mean
Bore K2	42.00	Well N2	135.00
Bore N1	63.00	Well N3	154.00
Bore N2	122.00	Well N1	124.00

Bore K1	76.00	Well K1	128.00
Goa	157.00	Well K2	152.00
Tano	172.00	Well K3	154.00

Observations per Mean 4

Standard Error of a Mean 2.1858

Std Error (Diff of 2 Means) 3.0912

3.2 Nitrates

Completely Randomized AOV for Nitrates

Source	DF	SS	MS	F	P
treatment	11	239.807	21.8006	13392.9	0.0000
Error	36	0.059	0.0016		
Total	47	239.865			

Grand Mean 1.2742 CV 3.17

Homogeneity of Variances	F	P
Levene's Test	4.14	0.0006
O'Brien's Test	2.65	0.0135
Brown and Forsythe Test	4.60	0.0002

Welch's Test for Mean Differences

Source	DF	F	P
treatment	11.0	38974.7	0.0000
Error	14.1		

Component of variance for between groups 5.44975

Effective cell size 4.0

treatment	Mean	treatment	Mean
Bore K2	0.3100	Well N2	0.6100
Bore N1	0.3800	Well N3	0.7100
Bore N2	0.3400	Well N1	0.7500
Bore K1	0.5300	Well K1	0.8600
Goa	0.9600	Well K2	0.6400
Tano	8.6600	Well K3	0.5400

Observations per Mean 4

Standard Error of a Mean 0.0202

Std Error (Diff of 2 Means) 0.0285

3.3 Phosphates

Completely Randomized AOV for Phosphate

Source	DF	SS	MS	F	P
treatment	11	50888.8	4626.25	335.82	0.0000
Error	36	495.9	13.78		
Total	47	51384.7			

Grand Mean 83.492 CV 4.45

Homogeneity of Variances	F	P
Levene's Test	4.14	0.0006
O'Brien's Test	2.65	0.0135
Brown and Forsythe Test	6.30	0.0000

Welch's Test for Mean Differences

Source	DF	F	P
treatment	11.0	1149.86	0.0000
Error	13.4		

Component of variance for between groups 1153.12

Effective cell size 4.0

treatment	Mean	treatment	Mean
Bore K2	38.30	Well N2	92.00
Bore N1	38.40	Well N3	79.00
Bore N2	30.20	Well N1	103.00
Bore K1	75.00	Well K1	89.00
Goa	128.00	Well K2	115.00
Tano	131.00	Well K3	83.00

Observations per Mean 4

Standard Error of a Mean 1.8558

Std Error (Diff of 2 Means) 2.6245

3.4 Sulphates

Completely Randomized AOV for Sulphates

Source	DF	SS	MS	F	P
treatment	11	80850.7	7350.06	392.58	0.0000
Error	36	674.0	18.72		

Total 47 81524.7

Grand Mean 105.33 CV 4.11

Homogeneity of Variances F P

Levene's Test 2.78 0.0101

O'Brien's Test 1.78 0.0947 Brown

and Forsythe Test 2.67 0.0128

Welch's Test for Mean Differences

Source DF F P

treatment 11.0 705.72 0.0000

Error 14.1

Component of variance for between groups 1832.83

Effective cell size 4.0

treatment	**Mean**	**treatment**	**Mean**
Bore K2	54.00	Well N2	127.00
Bore N1	81.00	Well N3	99.00
Bore N2	44.00	Well N1	101.00
Bore K1	37.00	Well K1	128.00
Goa	152.00	Well K2	138.00
Tano	153.00	Well K3	150.00

Observations per Mean 4

Standard Error of a Mean 2.1635

Std Error (Diff of 2 Means) 3.0596

APPENDIX 4: ANOVA TABLES FOR MICROBIOLOGICAL PARAMETERS

4.1 Total Coliforms

Completely Randomized AOV for Total Coliforms

Source	DF	SS	MS	F	P
treatment	11	81729	7429.94	2.14	0.0428
Error	36	125228	3478.55		
Total	47	206957			

Grand Mean 22.182 CV 265.89

Homogeneity of Variances	F	P
Levene's Test	6.47	0.0000
O'Brien's Test	4.14	0.0006 Brown
and Forsythe Test	5.70	0.0000

Welch's Test for Mean Differences

Source	DF	F	P
treatment	11.0	2.83	0.0380
Error	13.3		

Component of variance for between groups 987.849

Effective cell size 4.0

treatment	Mean	treatment	Mean
Bore K2	2.69	Well N2	9.81
Bore N1	2.41	Well N3	0.94
Bore N2	2.13	Well N1	5.92
Bore K1	0.54	Well K1	139.57
Goa	4.95	Well K2	7.36
Tano	80.91	Well K3	8.95

Observations per Mean 4

Standard Error of a Mean 29.490 Std

Error (Diff of 2 Means) 41.705

4.2 *E. coli*

Completely Randomized AOV for *E. coli*

Source	**DF**	**SS**	**MS**	**F**	**P**
treatment	11	262.88	23.8980	0.98	0.4842
Error	36	880.77	24.4657		
Total	47	1143.64			

Grand Mean 0.9659 CV 512.07

Homogeneity of Variances	**F**	**P**
Levene's Test	2.24	0.0339
O'Brien's Test	1.43	0.2008 Brown
and Forsythe Test	0.99	0.4733

Welch's Test for Mean Differences

Source	**DF**	**F**	**P** treatment
11.0	M	0.0000	
Error	M		

Component of variance for between groups -0.14194

Effective cell size 4.0

treatment	Mean	treatment	Mean
Bore K2	0.0000	Well N2	0.1620
Bore N1	1.3863	Well N3	0.1738
Bore N2	0.2143	Well N1	0.1600
Bore K1	0.0000	Well K1	0.0913
Goa	0.3254	Well K2	0.2750
Tano	8.6400	Well K3	0.1633

Observations per Mean 4

Standard Error of a Mean 2.4731 Std

Error (Diff of 2 Means) 3.4976

4.3 *Enterococci*

Completely Randomized AOV for Enterococci

Source	DF	SS	MS	F	P
treatment	11	3.088E+12	2.807E+11	14.02	0.0000
Error	36	7.209E+11	2.002E+10		
Total	47	3.808E+12			

Grand Mean 233542 CV 60.59

Homogeneity of Variances	F	P
Levene's Test	3.13	0.0047

O'Brien's Test 2.00 0.0578 Brown

and Forsythe Test 3.91 0.0009

Welch's Test for Mean Differences

Source	**DF**	**F**	**P**
treatment	11.0	M	0.0000
Error	M		

Component of variance for between groups 6.517E+10

Effective cell size 4.0

treatment	**Mean**	**treatment**	**Mean**
Bore K2	0.0000	Well N2	350000
Bore N1	0.0000	Well N3	425000
Bore N2	0.0000	Well N1	0.0000
Bore K1	0.0000	Well K1	450000
Goa	405000	Well K2	0.0000
Tano	400002	Well K3	772500

Observations per Mean 4

Standard Error of a Mean 70753 Std

Error (Diff of 2 Means) 100060

4.4 Faecal Coliforms

Completely Randomized AOV for Faecal Coliforms

Source	DF	SS	MS	F	P
treatment	11	55.106	5.00962	0.85	0.5965
Error	36	212.898	5.91382		
Total	47	268.003			

Grand Mean 1.0642 CV 228.51

Homogeneity of Variances	F	P
Levene's Test	1.83	0.0846
O'Brien's Test	1.17	0.3396
Brown and Forsythe Test	0.79	0.6457

Welch's Test for Mean Differences

Source	DF	F	P
treatment	11.0	M	0.0000
Error	M		

Component of variance for between groups -0.22605

Effective cell size 4.0

treatment	Mean	treatment	Mean
Bore K2	0.0000	Well N2	0.8479
Bore N1	0.0000	Well N3	1.5980
Bore N2	0.7721	Well N1	3.1763
Bore K1	0.0000	Well K1	0.7488
Goa	0.8016	Well K2	0.2638

Tano	1.3506	Well K3	3.2113

Observations per Mean 4

Standard Error of a Mean 1.2159

Std Error (Diff of 2 Means) 1.7196