KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY KUMASI

COLLEGE OF SCIENCE

DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

POTABILITY OF WATER FROM HAND-DUG WELLS IN THE EJURA TOWNSHIP OF THE EJURA-SEKYEREDUMASE DISTRICT, ASHANTI REGION

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(MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE)

AUGUST, 2014

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A THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE

By

EUNICE NAA ADOLEY ANANG

AUGUST, 2014

DECLARATION

I hereby declare that, under supervision I have personally undertaken the study herein which is my own work submitted towards the MSc Environmental Science and that, to the best of my knowledge it contains no material previously published by another nor material which has been accepted for the award of any other degree of the University or elsewhere, except where due acknowledgement has been made in the text.

Eunice Naa Adoley Anang

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Supervisor	Signature	Date

Dr. I. K. Tetteh

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Head of Department	Signature	Date

DEDICATION

This work is dedicated to my family.

ACKNOWLEDGEMENT

My gratitude goes to the Almighty God, whose grace and protection has brought me this far. Special thanks to Dr. John A. Larbi my supervisor, for his advice, guidance and untiring effort which saw me through to the completion of this thesis.

ABSTRACT

The potability of water from hand-dug wells in the Ejura Township was studied. The presence of total coliform, faecal coliform, faecal enterococci and some physicochemical properties (pH, TDS, salinity, conductivity, temperature, total hardness, chloride, fluoride and nitrate/nitrite ions) were determined and a sanitation survey conducted to assess the state of the wells their nearness to refuse damp sites and places of convenience. The study site was demarcated into four zones and samples of water taken from 10 wells within the zones, analyzed for microbial contamination using Most Probable Number (MPN) method and for the physicochemical parameters using a multi-parameter water quality probe (HANNA) instrument among others. The water samples were all positive for *E. coli* ($2.24x10^5$ -$7.05x10^5$cfu/100ml), Total coliforms ($2.24x10^5$ - 3.80×10^7cfu/100ml) and Enterococci ($5.10x10^2$ -1.15x103 cfu/100ml) except *Salmonella* spp. which was absent from all samples collected. Salinity of water (0.05ppm to 0.84ppm), conductivity (175.40±135.76 - 815.93± 896.35 µS/cm), TDS (473.53-93.7mg/L) and pH (6.5 - 8.5) were within the WHO recommended standards. Concentrations of dissolved ions yielded no significant differences between the four zones. Chloride and Fluoride levels were within acceptable global standards whiles Total hardness in all four zones was not. Nitrite levels in two of the zones, A (50.38±3.41mg/L) and D (90.07±78.19mg/L) were above acceptable global standard of 50mg/L. Wells and boreholes were situated within a good distance (30 to 100 ft.) from dumpsite and places of convenience. The physicochemical properties influenced microbial loads and thus water from hand-dug wells in the town has to be treated by the inhabitants before use.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

The quality of water denotes the physical, chemical and biological properties of water based on a set of standards against which compliance can be assessed (Nancy, 2009). It entails measuring the condition of water in relation to the needs of biotic species as well as any need or purpose of human (Johnson *et al.*, 1997).

Globally, eutrophication; the result of high nutrient (phosphorus and nitrogen) loads, poses a major water quality problem. Some commercial activities such as mining, construction, manufacturing and transport are also major contributing factors to water pollution as well as domestic sewage and contributions from bush fires and burning of fossil fuel (Carpenter *et al.*, 1998).

Water quality, without human influences, is affected by the weathering of bedrock minerals, the deposition of dust and salt by wind and by natural leaching of inorganic material from the soil. The Safe Drinking Water Act of the United States Environmental Protection Agency (EPA), gives mandate for two standard types: primary standards controls elements that potentially affect the health of humans whereas secondary standards prescribe aesthetic qualities like that affecting taste, odor or appearance (US EPA, 1968).

In Ghana, the Ghana Water Company Limited (GWCL) is legally required to maintain the standards for provision of safe drinking water. Other regulatory bodies such as the Public Utilities Regulatory Commission (PURC), the Ghana Standards Authority (GSA), Environmental Protection Agency (EPA) and the Water Research Institute are mandated by law

to protect, improve and check the quality of any water used by the citizenry including bottled mineral water. Routine monitoring or inspections are carried out at the processing plant by the regulatory bodies to ensure that water supply meets the set international standards (GSA, 2008).

In urban areas, water running through municipal water systems is adequately purified using improved water purification technologies to eliminate pollutants from the water source (surface water or groundwater) prior to its supply to communities. Thus water drawn from a tap is somewhat safe for use whereas water taken directly from a lake, stream, or an aquifer without treatment may be of uncertain quality. Contaminants may consist of microorganisms comprising bacteria, protozoa and viruses; inorganic substances (such as salts and metals); organic chemical pollutants from industrial practices and petroleum usage; pesticides and herbicides (Pye and Patrick, 1983).

Water quantity is directly affected by poor water quality in several means. Contaminated water cannot be used for domestic, commercial and industrial purposes effectively reducing the quantity of useable water in a region (UNDESA, 2013). The quality of water for domestic and industrial purpose may be affected by dissolved mineral elements present. For example, Ca^{2+} and Mg^{2+} ions when present in water, can inhibit the cleaning action of soap in water heaters and boilers by forming deposits of hard Sulphate and soft carbonates.

Water quality is commonly assessed by standards that consider its suitability for drinking, human contact safety and the general wellbeing of the ecosystems. Quality guidelines and standards for drinking water aim at providing safe and clean water for human usage, safeguarding the health of humans (US EPA, 2002).

1.2 Problem statement

Quality drinking water is essential for life. It is known that up to 70% by weight of the adult human body constitutes water. Water helps in cell and tissue activity and proper functioning of organs (Mader, 2002). It is also needed for domestic purposes such as drinking, washing, cooking etc., and for commercial, industrial, and agricultural purposes. However in many countries around the world including Ghana, treated water is available to only a few as majority of the population are either too poor to pay for its use or are denied access to good drinking water because of the cost involved in maintaining constant supply of potable water (GSA, 2008).

According to the World Health Organization's report, about 780 million people lack access to good drinking water worldwide. More people especially in most developing nations, rural communities and new settlements, rely on alternative sources of water such as those drawn from streams, rivers, lakes, pools, rain and ground water for drinking. These are mostly harnessed directly from source and are not treated before use (WHO, 2012).

The growth of human populations presents global challenges relating to climate change, agricultural, commercial and industrial growth which can alter the hydrological cycle. The alteration could be so intense resulting in a decline in water quality. Also the inadequate supply of potable clean water and the indiscriminate pollution of existing supplies pose very serious health problems for people in developing countries (WHO, 2011).

The annual global human death toll as a result war violence every year is far beneath that resulting from the usage of unsafe water (WHO, 2013). Contaminated water poses a number of grave health impacts through exposure to diseases such as cholera, typhoid, dysentery, bilharzia

etc. which results in about five million deaths per year of individuals using untreated water (WHO, 2012). It is overwhelming to know that out of 99.8% deaths related to unsafe drinking water, 90% are children under five years (WHO, 2013).

The quality of water for human consumption has seriously come under review due to the high occurrence of water-related diseases. These diseases arise from the presence of high loads of microorganisms such as viruses, protozoa, and bacteria found in water supplies polluted with faecal matter.

Sewage and effluents weighing about two million tons are deposited daily into the global water supply (WHO, 2013). Insanitary conditions arising from poor waste management (indiscriminate disposal of refuse and excreta from humans and livestock) and inefficient drainage systems (pit latrines, leaky septic tanks and soak-away) as well as industrial effluents and bad agricultural practices (such as abuse of pesticides and inorganic fertilizers) have added to water source contamination (Rail, 1989). The potential for contamination of water other than from anthropogenic sources is also high due to natural levels of metals and other chemicals which find their way into water systems. These are also harmful to human health.

According to Johnson *et al* (1987), the global bulk of surface water is neither potable nor lethal. Per the exclusion of seawater (which is highly salty for drinking) occurring in the oceans, this remains true. To sum up, there is limited access to potable water because of its unavailability. In this light therefore, it has become imperative for measures to be put in place to save our water from pollution which puts us at risk of exposure to diseases; so as to save human life and to preserve water resources for future.

1.3 Objectives of the Study

The main objective of the study is to assess the suitability of water for drinking from hand- dug wells within the Ejura Township in the Ejura- Sekyeredumase district.

1.3.1 Specific objectives

The study seeks to determine;

i. The presence of indicator organisms such as, total coliform, faecal coliform, faecal enterococci and *E. coli*
ii. The presence of other pathogenic organisms (e.g. *Salmonella* spp.)
iii. Some physicochemical properties such as pH, temperature, TDS, salinity, total hardness, conductivity, nitrate, fluoride and chloride ions.

1.4 Justification of the Study

According to the Ejura-Sekyeredumase Municipal Assembly (ESMA) report, the major sources of water in the district are: pipe borne, boreholes and wells. Other complementary sources include river/dam and rain with current water coverage of about 77 % (ESMA, 2009). The report further states that there are 316 public water points consisting of 221 boreholes and 95 standpipes. However, there are still some communities which do not have access to potable water due to a number of reasons such as; problems of water distribution, the large rural population and the extent of pollution of the environment and water bodies among others.

With respect to the study area, although the Ejura Township is supplied with pipe borne water and boreholes, most homes do not use water from the taps as most households utilize water from

hand-dug wells for drinking and for other domestic purposes with doubtful quality. These and other related issues have informed this study.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction to Water

Water is a basic necessity for life. It constitutes a large portion of all living tissue; in about fifty to ninety percent by weight of living organisms. Blood in humans and animals and sap in plants, all consists of water. It is important for the transport of food nutrients, oxygen and the removal of waste metabolic products from the body of living organisms. It is also involved in hydrolysis; the metabolic breakdown of proteins and carbohydrates in living cells. In nature, it is found in the lithosphere, hydrosphere and the atmosphere (Behm, 1989).

2.1.1 Composition and Properties

Water is a stable chemical compound formed from two reactive elements, hydrogen and oxygen. A molecule of water consists of two atoms of hydrogen and one atom of oxygen in ratio 11.188% hydrogen to 88.812% oxygen by weight. Thus, its chemical formula is H_2O.

Water in its pure state is transparent or colorless, odorless (has no smell) and has no taste. It is a liquid at room temperature but freezes at 0^oC to form ice and boils at 100^oC to form steam. It has strong ionizing properties hence it is able to dissolve many substances which then impart color, smell and taste to it.

Water combines with some salts to form hydrates and acts as a catalyst in many important chemical reactions.

2.1.2 Sources

Water is got from three main sources; rainwater, which is the most common source, surface water and groundwater (Berner and Berner, 1987**).** Each of these three feeds the other. For example, rainwater is obtained from the evaporation of surface water from water bodies such as oceans, seas, rivers, lakes, streams, ponds coupled with transpiration from plants to form clouds in the sky which later condenses and falls as rain. This then flows as surface run-off back into the water bodies.

Some of the surface water and run-offs percolates into the soil and into the ground and gets trapped in aquifers to form groundwater such as springs, geysers and those that are drawn from wells and boreholes. The aquifers, which are saturated permeable layers able to provide usable supply of water, typically consist of sands, gravels, limestone, or basalts **(**Gustafson, 1993). Due to the structure of aquifers, they are able to purify water. This therefore makes ground water relatively purer than surface water. Rain water is also very pure but during runoff into water bodies, it gets mixed with organic and inorganic solid matter and may also be contaminated with faecal matter. This situation makes surface water impure for drinking purposes. Unlike surface water which remains unprotected and is further exposed to additional pollution, ground water undergoes some level of purification in the aquifers.

Before percolation, the runoff water becomes polluted by impurities such as organic and inorganic solids, microorganisms and dissolved substances. During infiltration most of these contaminants are removed by filtration and biological processes at the unsaturated horizon of the soil. When the water gets into the aquifer, because of its long detention time, it is further purified of its microbiological contamination thus improving its quality (Hutton *et al*, 1976).

Ground water replenishes the flow of surface water thus contributes almost a third of one percent of global water and has been a pivot of many civilizations. However, the relatively high presence of minerals in ground water makes them soft, hence, the need for its treatment before use (Yadawe *et al*, 2010).

2.1.3 Uses and Health Benefits

Due to the important role it plays in the life of humans, water is an essential requirement and its quality is crucial for individual and public health. It is needed for domestic purposes like drinking, food preparation, washing, and for industrial purposes as well as agricultural use in irrigation and animal husbandry.

Water helps in weight loss, digestion (which relieves constipation) and prevention of dehydration which may result in migraines, stress, kidney problems, fatigue, depression and ulcers. It is used in the building of muscles, in the formation of the fetus during pregnancy, helps in the production of breast milk and lubrication of our joints and cartilage tissues.

2.2 Borehole

Any narrow vertical or horizontal channel drilled in the ground is generally referred to as a borehole. Boreholes may be constructed for several functions mainly in extraction of water, petroleum or gases for example, natural gas or methane (Ontario, 2013).

2.2.1 Construction and Types

A borehole built for use as a well is completed by installing a vertical pipe casing and well screen. These help to prevent the caving in of the borehole, prevent contamination from surface as well as the drawing in of sediments by installed. The construction of a borehole in this manner

is more commonly called a well. Types include; water well, oil well and natural gas extraction well (Aqua Earth, 2013).

2.3 Hand-dug well (Water well)

This is a shallow well which draws water from a natural aquifer or man-made aquifer. These aquifers can be near sand dams or around ponds, but are not located inside a riverbed. It can include wells that are far from a river, or wells that receive water from shallow aquifers hydraulically connected to the river. Sometimes the holes dug are very large, allowing people and occasionally, animals to walk into the well to locate water. The variation in water wells can be with respect to the water quality, volume or depth (Petersen *et al*, 1997).

2.3.1 Construction of Water Well

Water well created in the ground through excavation by drilling or digging to gain access to groundwater in subversive aquifers. It consists of three main parts: the well head; which is the portion of the well noticeable above the ground and consists generally of a shielding apron and a superstructure that relies on the extraction system type being utilized, the well shaft; and the intake; constituting the section of the well in contact with the aquifer. Water extraction is done by hand pumps or small and efficient motor pumps, or the use of containers, example buckets and ropes, which are raised up by hand or mechanically. The latter mechanism however increases the risk of contamination (West Virginia Plumbers, 2012).

2.4 Conditions for Siting of Water Wells and Boreholes

For wells and boreholes to remain viable, they must be constructed in areas where there are layers of sand and gravel, in weathered rocks in granite regions as well as a river valley.

Therefore, care should be taken so that they are not sited in aquifers with limited recharge capacity and water storage (Seamus, 2000).

Again they should be sited at a significant distance from contamination. The distance from the contamination source such as from a pit latrine to the water intake (screen) must be about 100 to 200 meters, in order to reduce risk of microbiological contamination.

Permeability, porosity and hydraulic gradient influences the travel time. An average distance of 30 meters, covered in an equivalent of 25 days, is the average porosity for a medium sized sand and that of coarser sediments is 100 meters. However, at a sufficient depth of water intake, distance from the source of contamination to the screen can be significantly reduced. This is because, wells or boreholes in the vertical direction have a greater variation in aquifer properties than those occurring in the lateral direction. Thus, a borehole with hand pump could be sited in close proximity to a latrine with marginal risk (Seamus, 2000).

2.5 WATER QUALITY

The quality of water depends on several factors, mostly physical, chemical and biological. It is therefore necessary to consider the physicochemical and biological parameters that render water potable for use, in order to determine the quality of water.

2.5.1 Microbial Parameters

Microbial parameter of water is determined by performing microbial analysis to identify indicator organisms. Microbial analysis involves microbial testing of water for the presence of microorganisms. Such analysis is undertaken to ensure product safety, to determine product

contamination levels and for laboratory control, ensuring that equipment and products used in the laboratory are not contaminated by microbes (Gilmore, 2002).

Consumables such as cosmetics, pharmaceuticals, food and water are chief sources of samples for microbial test to determine safety of product for use. Low levels of microbes that are not a cause for concern will not trigger a positive result, while any reading that exceeds standards set by regulators will register as positive. The result of the microbial test can determine the safety of a product for use (Mittal, 2010).

For the purposes of this study, microbiological analysis was done to check the occurrence of coliform bacteria (total, faecal and *E. coli*), enterococci which are indicators of contamination of drinking water and *Salmonella* spp.

Coliform bacteria are bacteria which are commonly used as indicators of sanitary quality of foods and water. They are rod-shaped Gram-negative non-spore forming bacteria capable of fermenting lactose to release acid and gas when incubated at 35–37°C (Fischetti *et al*., 2000).

Coliforms can occur in water, in soil and on vegetation but ubiquitous in the feces of warm-blooded animals. Normally, coliforms themselves are not causes of serious illness and most of them unable to cause diseases although rare strains of *E. coli*, specifically *E. coli* 0157:H7 can elicit adverse illness. The presence of coliform is therefore used as an indicator of the presence of other pathogenic organisms of faecal origin. These pathogens comprise viruses, protozoan, bacterial and multicellular parasites. They are easy to culture under aerobic or reduced oxygen conditions (Todar, 2007).

2.5.1.1 Total coliform

Total coliform include bacteria that are found in the soil, and in water exposed to contamination by human or animal waste. Total coliform count, a rudimentary bacterial contamination test, gives an overall indication of the hygienic condition of a water. Total coliform includes members of faecal coliform, faecal enterococci and Escherichia coli (*E. coli*). Of the five general groups of bacteria that comprise the total coliforms, only *E. coli* is generally not found growing and reproducing in the environment. Consequently, *E. coli* is considered to be the species of coliform bacteria that is the best indicator of fecal pollution and the possible presence of pathogens.

2.5.1.2 Faecal coliform

Faecal coliforms are the group of the total coliforms considered to be specific to the gastrointestinal tract and feces of warm-blooded animals including humans and are therefore regarded a more precise indication of animal or human waste than the total coliform group of bacteria because their origin is more specific. They are also the common microbiological contaminants of natural waters.

Faecal coliform released in the waste of farm animals, dogs, cats, birds and humans are washed into storm drains, which are then carried by runoff from rain into creeks, streams, rivers and lakes during storms or irrigation. Faecal coliforms can also enter water tables, aquifers, drainage ditches and surface waters from illegal or leaky sanitary sewer connections, poorly functioning septic tanks, and wastewater treatment plants that are not functioning properly. The test can be performed relatively quickly and easily. The EPA has set acceptable limits for faecal coliform in water based upon the use of the water. For example, drinking water cannot contain any faecal coliform but water for swimming may contain up to 400 fecal coliform colonies/100ml

(Bradford *et al*., 2006).Although most of these bacteria are not harmful and are part of the normal digestive system, some are pathogenic to humans. Those that are pathogenic can cause disease such as gastroenteritis, ear infections, typhoid, dysentery, hepatitis A, and cholera (Guardado *et al*., 2006).

2.5.1.3 Faecal Enterococci

Enterococci are Gram-positive bacteria belonging to the phylum Firmicutes, a genus of lactic acid bacteria. Enterococci are facultative anaerobes, hence are able to undertake cellular respiration in both high oxygen and low oxygen environments. They occur in pairs (diplococci) or short chains, and are often difficult to distinguish from streptococci using only the physical characteristics. Of several occurring species, *E. faecalis* (90-95%) and *E. faecium* (5-10%) are common commensals in human intestines. *Enterococci* can tolerate a vast range of conditions, although, they are incapable of producing spores; extreme pH (4.5-10.0), temperature (10-45°C) and high sodium chloride concentrations. Rare clusters of infections occur with other species, including *E. casseliflavus*, *E. gallinarum*, and *E. raffinosus* (Fisher, 2009).

Enterococci causes several infections such as bacteremia, urinary tract infections, diverticulitis, and meningitis among others.

2.5.1.4 *Escherichia coli (E. coli)*

Escherichia coli are the major species in the faecal coliform group. They are rod-shaped and can be distinguished from most other coliforms by their ability to ferment lactose at 44°C in the fecal coliform test, and by their growth and color reaction on certain types of culture media. When cultured on an EMB (eosin methylene blue) plate, a positive result for *E. coli* is metallic green colonies on a dark purple media. Escherichia coli have an incubation period of 12–72 hours with

the optimal growth temperature being 30–37°C (Jin *et al*., 2004). Unlike the general coliform group, *E. coli* are almost exclusively of fecal origin and their presence is thus an effective confirmation of fecal contamination. Most strains of *E. coli* are harmless, but some can cause serious illness in humans. Recent outbreaks of disease caused by *E. coli* 0157:H7 have generated much public concern about this organism. *E. coli* 0157:H7 has been found in cattle, chickens, pigs, and sheep. Most of the reported human cases have been due to eating under cooked hamburger. Cases of *E. coli* 0157:H7 caused by contaminated drinking water supplies are rare (Jin *et al*., 2004).

Human or animal feces infected with *E. coli* sometimes get into lakes, pools, and water supplies. People can become infected when a contaminated city or town water supply has not been properly treated with chlorine or when people accidentally swallow contaminated water while swimming in a lake, pool, or irrigation canal. The bacteria can also spread from one person to another, usually when an infected person does not wash his or her hands well after a bowel movement. *E. coli* can spread from an infected person's hands to other people or to objects.

E. coli infection occurs by coming into contact with the faeces, or stool, of humans or animals through drinking of water or eating food contaminated by faeces. The bacteria can cause severe anemia, urinary tract infections, respiratory illnesses, kidney failure or pneumonia, which can lead to death. Signs and symptoms of infection include fever, vomiting, bloody diarrhea, and stomach cramps. When *E. coli* causes serious problems with the blood or kidneys, symptoms include pale skin, fever, weakness, bruising, passing only small amounts of urine (Guardado *et al.*, 2006).

2.5.1.5 Salmonella

Salmonella spp. are a genus of rod-shaped, Gram-negative non-spore-forming facultative anaerobes, predominantly motile with diameters around 0.7 to 1.5 µm, lengths from 2 to 5 µm. They are facultative intracellular pathogens with peritrichous flagella (flagella that are all around the cell body). They are also chemoorganotrophs, acquiring their vitality from oxidation and reduction responses utilizing carbon-based sources (Ryan, 2004). Salmonellae are discovered in both cold and warm-blooded animals around the world. They can be put into two classes─ typhoidal and non typhoidal *Salmonella* serovars (serotypes). Non typhoidal serovars are more common, and usually cause self-limiting gastrointestinal disease. They are zoonotic, that is, they might be exchanged between people and other animals. Typhoidal serovars include *Salmonella typhi* and *Salmonella paratyphi* A, which are adapted to humans and do not occur in other animals (Feasey *et al*., 2012).

Salmonella bacteria are not affected by freezing and can persist for weeks outside a living host. They are, however damaged by ultraviolet radiation and high temperatures of 55°C (131°F) for 90 min, or to 60 °C (140 F) for 12 min. To protect against *Salmonella* infection, heating food for at least ten minutes at 75°C (167°F) is recommended (Janda and Abbot, 2006).

Salmonella causes several ailments including food poisoning, typhoid and paratyphoid. *Salmonella* serotypes strictly adapted to higher primates or people, causes typhoid fever; these include *Salmonella typhi*, Paratyphi A, Paratyphi B and Paratyphi C. In the systemic manifestation of infection, salmonellae migrate through the lymphatic framework of the intestine into the host's blood and are conveyed to a variety of organs including spleen, kidneys, liver (Mittal *et al*., 2010).

2.6 Physicochemical Parameters

Physicochemical analysis with respect to water quality involves the measurement of various physical and chemical properties such as pH, temperature, salinity, total dissolved solids (TDS), and conductivity, as well as total hardness(calcium and magnesium ions), nitrate, chloride, fluoride, sulphate, iron, heavy metals etc. For the purposes of this experiment however, total hardness, nitrate/nitrite, chloride, and fluoride are the chemical properties of water that were considered.

2.6.1 pH

pH is the scale of intensity of acidity and alkalinity of water and measures the concentration of hydrogen ions. The pH of water gives an indication of how acidic or basic it is. pH scores usually range from 0 to 14 even though more extreme values could be encountered. A pH of 7 is neutral whereas a value above 7 is basic and a measurement below 7 is acidic. The pH of water can be measured using a pH meter with a probe, or litmus paper. pH can be affected by chemicals in the water. The pH of water determines solubility of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.) and its biological availability which is the amount that can be utilized by aquatic life. For example, to know how much and what form of phosphorus is most abundant in a quantity of water, pH also determines whether aquatic life can use it (USGS, 2014).

2.6.2 Temperature

Temperature is the numerical measure of the hotness and coldness of a body. This is based on the detection of heat radiation or particle velocity or kinetic energy, or by the total behavior of a thermometric material. Temperature is calibrated using the Celsius, Fahrenheit and Kelvin

scales. The scales are different in two ways: the point chosen as zero degrees, and the magnitudes of incremental units or degrees on the scale **(**Hutchinson, 1957).

The Celsius scale, denoted by degree Celsius (°C), is an empirical scale which is used for common temperature measurements in most parts of the world. The scale ranges from a zero point (0°C) defined by the freezing point of water to 100°C, the boiling point of water; both at sea-level atmospheric pressure. Because of the 100 degree interval, it is also called the centigrade scale.

The Fahrenheit scale, also denoted by degree Fahrenheit (°F) is another scale for measurement of temperature. The Fahrenheit scale is part of the English system of measurement. On this scale, water freezes at 32°F and boils at 212°F at sea-level atmospheric pressure. It is commonly used in the United States.

The Kelvin scale (K) is adopted by the International System of Units as the standard scale to be used worldwide by scientist for measurement of temperature. On the Kelvin scale, temperature increase of one degree Celsius (1°C) is equivalent to one Kelvin (1K), though they differ by an additive offset of 273.15. The temperature scale begins at absolute zero (0K) which is equal to -273.15°C or −459.67 °Fahrenheit, and the freezing point of water at sea-level atmospheric pressure occurs at 273.15 K equal to 0°C.

Temperature measurements are taken using the thermometer instrument. Temperature of a body of material can vary from time to time and from place to place. If change happens too fast, or

with a small interval, within a body, it may be impossible to define its temperature (UCAR, 2014).

2.6.3 Salinity

Salinity is the quantity of dissolved salt content of the water. Salts are compounds like sodium chloride, magnesium sulfate, potassium nitrate, and sodium bicarbonate which dissolve into ions. Dissolved matter is defined as that which can pass through a very fine filter (a filter with a pore size usually of 0.2 μ m) **(**Cotruvo and Vogt, 1987). Salinity can be expressed in the form of mass of the dissolved material in a unit mass of solution. Salinity varies in different water bodies. In rivers, lakes, and the ocean, it is conceptually simple, but technically challenging to define and measure precisely.

Seawater has the highest salinity of about 35g/kg although lower values are typical near coasts where rivers enter the ocean. Rivers and lakes have a wide range of salinities, from less than 0.01g/kg to a few g/kg although there are many places where higher salinities are found. Whatever pore size is used in the definition, the resulting salinity value of a given sample of natural water will not vary by more than a few percentages (Del Aqua, 2014).

Salinity is an ecological factor of importance, influencing the types of organisms that live in a body of water. It can for example, influence the kinds of plants that will grow either in a water body or on land fed by water (or by a groundwater). Salt is expensive to remove from water, and salt content is an important factor in water use (such as potability).

2.6.4 Total Dissolved Solids (TDS)

Total dissolved solid is a measure of the combined content of all organic and inorganic substances contained in a liquid in molecular, ionized or micro-granular (colloidal sol) suspended form. The chemicals present may be cations, anions, molecules or agglomerations on the order of one thousand or fewer molecules (Goltzman *et al*., 1978).

Usually for the solids to pass through a filter with nominal pore size of two-micrometer or less, their sizes must be small enough so as not to be filtered out of the solution. Total dissolved solids are parameters applied to fresh water systems because the measurement for salinity may involve some of the ions constituting TDS. Thus it is applied to the study of water quality for streams, rivers and lakes.

Primary sources for TDS in receiving waters are agricultural and residential runoff, leaching of soil contaminants and point source water pollution discharge from industrial or sewage treatment plants. The most common chemical constituents are calcium, phosphates, nitrates, sodium, potassium and chloride, which are commonly found in nutrient runoffs, storm water runoffs and runoffs from snowy climates where road de-icing salts are applied (Trevedi and Goel, 1984). Other foreign and more harmful elements of TDS are pesticides originating from surface runoff. Total dissolved solids can also occur naturally from the weathering and dissolution of rocks and soils (Singh and Kalra, 1975).

TDS is mostly checked for the aesthetic characteristics of drinking water and as an aggregate indicator of the presence of a broad array of chemical contaminants and generally not indicative of any health effect as it is not considered to be a primary pollutant.

2.6.5 Conductivity

Electrical conductivity in water is a measure of the ion-facilitated electron flow through it. Water molecules dissociate into ions as a function of pH and temperature and result in a very predictable conductivity. Some gases, most notably carbon dioxide, readily dissolve in water and interact to form ions, which predictably affect conductivity as well as pH. For the purpose of this discussion, these ions and their resulting conductivity can be considered intrinsic to the water.

Water conductivity is also affected by the presence of extraneous ions such as chloride and sodium ions. These ions may have significant impact on the water's chemical purity and suitability for use in for example, pharmaceutical applications (USGS, 2014).

2.6.6 Total hardness

It is the sum of calcium and magnesium hardness expressed in mg/L of calcium carbonate ($CaCO_3$). It gives an indication of the soil type and the nature of the properties of the bedrock. Waters' total hardness is imparted mainly by the calcium and magnesium ions, which apart from sulphate, are found in combination with carbonates and bicarbonates (Wilson et al., 1981).

Hard water due to high levels of Ca^{2+}, Mg^{2+} and HCO^{3-} ions increases greatly when water passes through or over deposits of limestone. High levels of hard water ions can cause scaly deposits in plumbing appliances and boilers. Although high levels of these ions present in water is not so much of a health concern, however, calcium forms an essential component of cell walls of aquatic plants and helps in the formation of bones and shells of aquatic organisms. Magnesium is also an important nutrient for plants and is a component of chlorophyll.

2.6.7 Chloride

Chloride consists of anions (negatively charged ions) with the formula Cl^-. Chloride is produced through a process where the element chlorine, a halogen, is reduced by gaining an electron. It can also be produced by dissolving hydrogen chloride in a polar solvent such as water (Zumdahl, 2009).

Chloride is also oxidized to other oxides and oxyanions including hypochlorite (ClO^-, the active ingredient in chlorine bleach), chlorate (ClO_3^-), perchlorate (ClO_4^-) and chlorine dioxide (ClO_2).

The chloride ion is a vital electrolyte found in all body fluids and is responsible for maintaining acid/base balance, transmitting nerve impulses and regulating fluid in and out of cells. It also forms the structural component of some proteins like the amylase enzyme.

Chloride also forms a valuable indicator of fecal contamination of rivers and groundwater. Thus it is used by many water regulating companies determine the level of contamination of rivers and potable water sources. Chloride salts from calcium, magnesium, and potassium have varied uses such as for medical treatments and cement formation. Calcium chloride is a salt with the chemical formula $CaCl_2$ that is sold in pellet form for removing dampness from rooms, for maintaining unpaved roads and for fortifying road bases for new construction. It is also widely used as a De-icer. Phosphorus dichloride, phosphorus pent chloride and thionyl chlorides are used for laboratory work (Sanger and Riegel, 1912).

2.6.8 Fluoride

Fluorine, a chemical element which forms fluoride ions, is the 13th most abundant element representing about 0.3g/kg of the earth's crust. It occurs naturally in the combined state as fluorite (fluorspars), apatite, fluorapatite, topaz and cryolite (Rakshit, 2004).

Fluorides enter the environment as a pollutant through two ways; natural and anthropogenic (Cengeloglu *et al*, 2002). Natural fluoride is found in the minerals and in geochemical deposits and is released in underground water by slow degradation of fluorine in rocks (Rakshit, 2004). It is also released through anthropogenic activities such as industrialization, mechanization, the use of pesticides containing fluoride (Low and Bloom, 1988).

Ingestion of high levels of fluoride can lead to dental caries and bone density deterioration (Jha *et al*, 2013).

2.6.9 Nitrate

Nitrate (NO_3^-) are ions that occur naturally in the soil by the combination of nitrogen and oxygen. Nitrogen is important for all living things and exists in many forms in the environment. The process of nitrification converts nitrogen to nitrites and then to nitrates, changing its form as it moves through the nitrogen cycle. Nitrate ions are more steady than nitrite but although chemically nonreactive, they can be reduced by the activity of microorganisms. Nitrite, however, comprises nitrogen in a rather unstable oxidation state and is reduced to other compounds or oxidized to nitrate.

Nitrates occur naturally in plants as a key nutrient. It is used for making inorganic fertilizers and for producing explosives. It is also used as an oxidizing agent and in the form of purified

potassium nitrate; it is used for glassmaking. Sodium nitrite is used as a food preservative for curing meat.

As a consequence of agricultural activities such as excessive application of inorganic fertilizers, nitrate enters surface and ground water. Another source through which nitrate enters ground water is through the release of effluents from wastewater treatment plants and the release of human excreta from faulty septic tanks. Nitrate is broken down to nitrite by Nitrosomonas bacteria in distribution pipes during stagnation of nitrate-containing and oxygen-poor drinking water (Carpenter *et al*., 1998). At concentrations higher than 10 mg nitrogen per liter (mg-N/L), nitrate becomes toxic to fetuses and young of livestock and humans. Nitrate also promotes eutrophication which can lead to the death of some important aquatic organisms (Carpenter *et al*., 1995).

CHAPTER THREE

3.0 MATERIALS AND METHODS

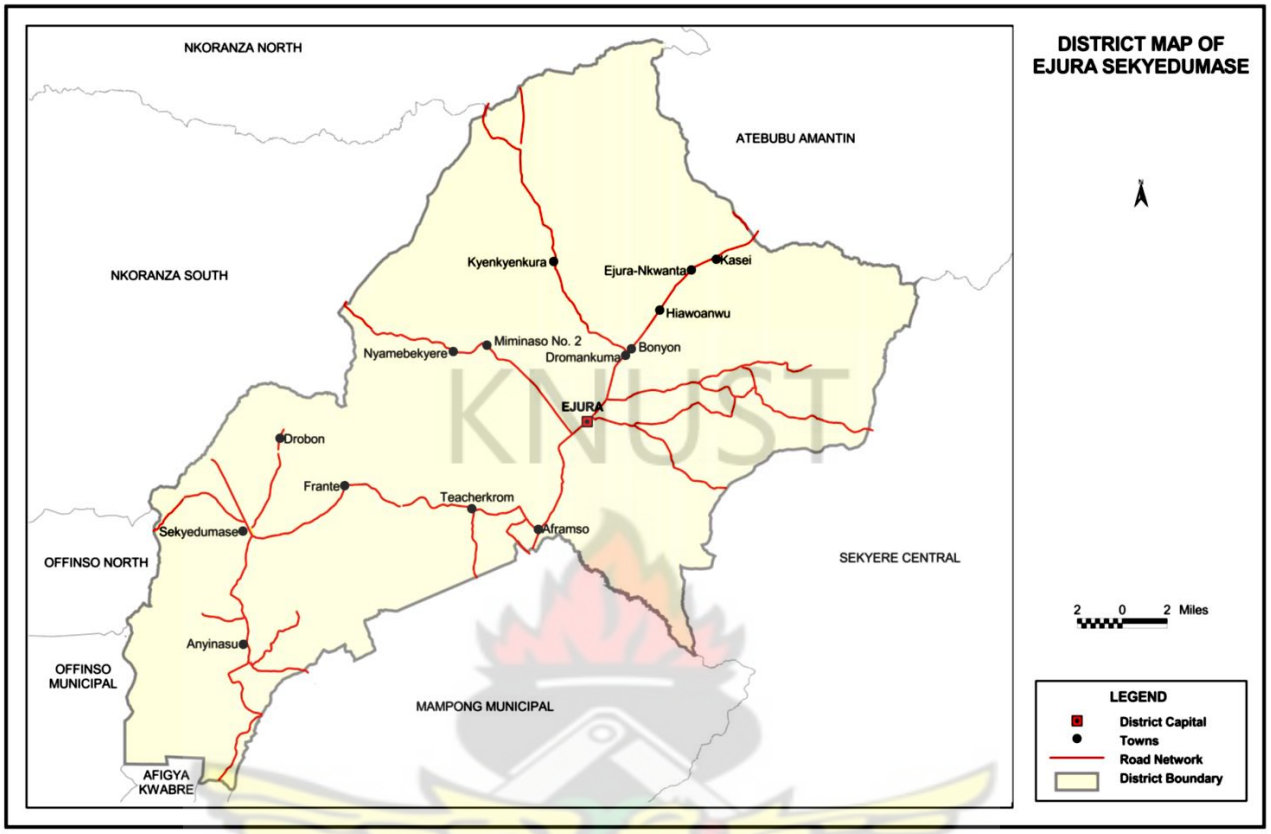
3.1 Study Area

The study took place within the Ejura Township in the Ejura-Sekyeredumase Municipality of the Ashanti Region in Ghana. Ejura-Sekyeredumase Municipality is situated in the northern portion of the Ashanti Region, sharing borders with the Atebubu-Amantin District in the North-West, Mampong Municipality in the East, Sekyere South District in the South and Offinso Municipality in the West. It lies within Longitudes 1°5'W and 1°39' W and Latitudes 7°9' N and 7°36'N, (ESMA, 2009).

Ejura has an approximate land area of 1,782.2 km^2. It encompasses about 7.3% of land area of the Ashanti region with a third of its size in the Afram Plains. The area has partly hilly and low-lying topography and well-drained and falls between the transitional zone of the Semi-Deciduous Forest of the South and the Guinea Savannah of the North. Thus, both forest and savannah climatic conditions can be encountered in the area.

3.2 Study Population

The targeted area of study has a population of 101,826 persons of which 58,868 are males and 50,146 are females.



(mapcarta, 2015)

Figure 3.1: District map of the Ejura Sekyeredumase municipality

3.3 Sampling Method

According to Leedy and Ormrod, (1974), sampling a large area with the view of making generalizations does not appropriately shed light on the phenomenon or study under consideration. They therefore suggested that easy sampling of the population would be more suitable. Thus for this research, the study site was divided into four zones:-

Zone A- representing the area between the Police Barracks and the Lorry Station

Zone B-representing the area between the Ejura Central Market and Badukrom

Zone C- representing the whole Saabon line community

Zone D- represented by the Masalachi, Ashakoko and Mpeasem communities.

3.4 Sampling

Water samples were fetched from ten different hand dug wells and two boreholes during the sampling period. All wells and boreholes were selected at random depending on the number of wells in each zone. Samples were collected early in the morning before sunrise with 750 ml sterile bottles. This was carried out for five months (December- April). Two samples were taken from zone A and labeled P1, P2, two from zone B and labeled B1, B2, three from Saabon line; labeled S1,S2,S3 and the other three from Masalachi- Ashakoko –Mpeasem down were labeled M1, M2, M3.

The two boreholes each selected from Saabon line and Masalachi-Ashakoko-Mpeasem down area were labeled BH1 and BH2 respectively. These numbers are a representation of the available number of wells in each zone, since some zones have more wells than others. The pH and temperature were measured immediately after sampling. Samples were kept in an icebox and transported to the laboratory for analysis.

3.5 Sanitation Survey at Sampling Sites

A sanitation survey was personally conducted by the researcher. This was done through general observation of the study area and based on this; a projection was made for the sanitation conditions within each zone. The survey was to check the state of the wells, their nearness to refuse dumps and public places of convenience.

Photographs of individual hand-dug wells from which samples were collected were taken. This was to ascertain the construction of the wells, mode used for drawing water and the general state of each of the wells. These were then scanned as plates.

Photographs were also taken some distances away from the immediate perimeter of the wells to show the sanitation conditions. This was achieved by measuring a distance of about 30 feet away from the well site and photographs were taken in the general direction of the wells. This enabled the researcher to have an idea about the sanitary conditions and activities close to the wells which have negative impact on the state of the water. The photographs were scanned as plates.

3.6 Microbial Analysis

The Most Probable Number (MPN) method was used which involves dilution plating to determine the colony- forming units (CFU) of faecal coliform, total coliform, *E. coli*, faecal enterococci and *Salmonella* spp.

3.6.1 Total coliform

A fresh sterile pipette tip for each dilution was aseptically used to add 1 ml of each of the dilutions of the water sample to 5 ml of the MacConkey broth provided as follows:

1 ml of the water sample (undiluted) was pipetted into a test tube holding 9 ml of distilled water to acquire a 10^{-1} dilution of the water sample. 1ml of the 10^{-1} diluted water sample was then transferred to three test tubes containing MacConkey broth. 1 ml of the 10^{-1} diluted water sample was then pipette into a second 9 ml distilled water tube to obtain a 10^{-2}. This was repeated until a serial dilution of $10^{-3,}$ 10^{-4}, 10^{-5} and 10^{-6} were obtained. Each of these diluted samples was transferred to three tubes containing MacConkey broth. The bottles and tubes of MacConkey

broth were labeled appropriately and incubated at 37° C for 24h. Tubes with color from violet to yellow were recorded as positive for total coliform and those with no color change as negative.

3.6.2 Faecal coliform

A fresh sterile pipette tip for each dilution was aseptically used to add 1 ml of each of the dilutions of the water sample to 5 ml of the MacConkey broth provided as follows:

1 ml of the water sample (undiluted) was pipette into a test tube comprising 9 ml of distilled water to acquire a 10^{-1} dilution of the water sample. A 1 ml of the 10^{-1} diluted water sample was then transferred to three test tubes of MacConkey broth. 1 ml of the 10^{-1} diluted water sample was then pipette into the second 9 ml distilled water tube to obtain a 10^{-2}. This was repeated until a serial dilution of $10^{-3,}$ 10^{-4}, 10^{-5} and 10^{-6} were obtained. Each of these diluted samples was then transferred into three tubes of MacConkey broth. The bottles and tubes of MacConkey broth were labeled appropriately and incubated at 44°C for 24h. Tubes with color from violet to yellow were recorded as positive for faecal coliform and those with no color change as negative.

3.6.3 *E.coli*

A fresh sterile pipette tip for each dilution was aseptically used to add 1 ml of the positive test tube sample MacConkey broth containing faecal coliform to three set of test tubes containing 5 ml Tryptophan broth to obtain a 10^{-1}solution. This was repeated five times to obtain a 10^{-5} solution. The tubes of Tryptophan broth were labeled appropriately and incubated at 44°C for 24h. After which a Kovacs reagent was added to the broth. A large red layer appearance on the broth was recorded as positive for *E. coli* and those with no layer as negative.

3.6.4 Faecal Enterococci

The Slanetz and Bartley Media, a selective media for Faecal Enterococci, is employed in the test for the presence of Faecal Enterococci.

About 4.2g/L of the Slanetz and Bartley Media was boiled and poured into Petri dishes. These were allowed to set. 1 ml of each of the already prepared dilution was poured serially (10^{-1}, $10^{-2}$and 10^{-3}) unto each plate, labeled appropriately and then incubated at 37ºC for 4h. The plates were then transferred to another incubator and incubated at 44ºC for 24 - 48h. Growth colonies indicative of the presence of Faecal Enterococci were then counted.

3.6.5 Salmonella spp.

1ml of undiluted water sample was inoculated into 10ml peptone water (one for each sample) and incubated at 37ºC for 24h. Selenite broth was then prepared and 5 ml of it was dispensed into test tubes. 1ml of inoculated peptone water was then transferred into the Selenite broth and incubated at 44ºC for 24-48 h. This was then streaked on Salmonella-Shigella (SS) agar and incubated at 44ºC for 24 h. Growth colonies indicative of the presence of *Salmonella* spp. were then counted.

3.7 Physicochemical Analysis

3.7.1 pH

The pH of the wells was determined using a calibrated pH meter. The probe was calibrated with a calibration solution and then placed in 300ml of water sample. Readings displayed on the meter screen were taken.

3.7.2 Salinity/Conductivity/Total Dissolved Solids (TDS)

The salinity, conductivity and TDS were determined using a multi parameter water quality probe

(HANNA) instrument. The probe was calibrated with a calibration solution. 300 ml of the each water sample was transferred into a beaker and the probe placed in it. Readings for each parameter displayed automatically on the monitor were recorded.

3.7.3 Temperature

Temperature readings for each sample were taken onsite using the PSG pocket dial thermometer. The thermometer was dipped directly into the water samples for a 5 min and readings recorded in degrees Celsius (^{o}C).

3.7.4 Total Hardness

Calcium and magnesium levels were determined using the EDTA Titrimetric method. This employs the addition of Eriochrome Black T to a water sample containing calcium and magnesium ions at a pH 10.0 $\pm$0.1. A color change from wine red to blue upon addition of EDTA marks the endpoint of the titration.

Procedure: 25 ml of sample was diluted with 25 ml distilled water to 50 ml in a borosilicate Erlenmeyer and 1 ml standard buffer at a pH of 10 was added to it. 2 drops Eriochrome Black T indicator solution was also added. The solution was then titrated slowly with 0.05M (0.1) EDTA while stirring, until the last reddish tinge disappears.

Calculation: Hardness as mg $CaCO_3$/L= (VxMx100) x 1000/mg sample

Where V = mL EDTA and M = molarity of EDTA

3.7.5 Chloride

Chloride ions in water samples were determined using silver nitrate titration. In this method, potassium chromate was used as an indicator by reacting with silver ions to produce brick-red silver chromate precipitate at the end point. As the silver nitrate solution was slowly added, the chloride ions reacted with the silver ions to form silver chloride precipitate.

$Ag^{+}(aq) + Cl^{-}(aq) \rightarrow AgCl(s)$

10 ml of water sample was pipetted into 250 ml Erlenmeyer flask and diluted to 75 ml with distilled water. The water was tested with litmus paper until a pH of 6.0 was achieved. 1 ml of 0.25 M potassium chromate solution was added into the flask as indicator. The diluted water sample was titrated by using 0.0037 M silver nitrate solution to the end point. A red brown color of silver chromate in yellow suspension shows the end point.

3.7.6 Fluoride

Fluoride ions were measured using colorimetric method. This employs the destruction of the red colored complex formed from the reaction between Zirconyl chloride and Eriochrome cyanine in acid solution by fluoride ions to give a pale yellow color of the Eriochrome Cyanine.

Procedure: A test tube was filled with sample to the 10 ml mark. One tablet Fluoride No.1 was crushed, mixed and added to dissolve. One tablet Fluoride No.2 was also crushed, mixed and added to dissolve. The tube was made to stand for exactly 5 min to allow full color development. An H196729 Fluoride low range portable photometer was then used to take readings between ranges of 0.00- 2.00 mg/l at 575 nm.

3.7.7 Nitrate

Nitrate levels were determined by Nitriphot method which is based on colorimetric procedure using iodide containing reagent system.

Procedure: Water samples were filtered using 0.2µm Millipore membrane filters to obtain clear solutions. To deionized water in a container was transferred 1 ml of the sample using a pipette to the 10ml level. One tablet Nitriphot No.1 was crushed, mixed and added to dissolve. One tablet Nitriphot No.2 was also crushed, mixed and added to liquefy. The tube was capped immediately and made to stand for exactly 2 min to allow full color development. An H196728 Nitrate low range portable photometer was then used to take readings between ranges of 0.00- 30.0 mg/l $NaNO^2$ at 525 nm.

3.8 Using the HANNA (H196728) and (H196729) Portable Photometers

The photometer was used to read the colour changes of Fluoride and Nitrate solutions. This was achieved according to the manufacturer's instructions. The ''Cal Check'' pad on the photometer was pressed to validate the photometer**.** The Cal Check ™ Standard A cuvette was inserted into the cuvette chamber and the zero CFM pad pressed. The cuvette was removed afterwards. The samples were poured into the Cal Check standard cuvette for specimen, inserted into the cuvette chamber and the ''read'' pad pressed. The displayed readings were then compared with the value on the Certificate of Analysis**.**

3.9 Data Analysis and Interpretation

The data obtained from the analysis of samples, was edited for statistical analysis. The results from the microbial and physicochemical analyses were organized into tables and in line with the research questions.

Both inferential and descriptive statistical analysis was performed on data obtained. Descriptive statistics comprised the means and their standard deviations. Thus the data were in a form of, means and graph (bar charts).

The data were recorded using Microsoft Excel® Spread Sheet for descriptive analysis (bar chart) and SPSS ANOVA was used to determine any significant differences in mean values at $p<0.05$.

CHAPTER FOUR

4.0 RESULTS

4.1 Sanitation Survey

4.1.1 State of the wells

It was observed that in some locations, the wells were covered with car tyres and in the rim opening; wooden structures or metallic sheets were constructed over the wells. In other areas, mud or concrete walls were built around the wells and metallic sheets or wooden structures were used as covering. One well did not have a covering. Out of the 10 wells sampled, 70% were of concrete (Plate 2), 20% car tyres (Plate 1) and 10% mud. Out the 70% which were concrete, 40% were covered with wood, 20% covered with metallic sheet and 10% no cover. Half of those covered with car tyres had metallic sheets and the other half with wood.

Plate 1: A well at Saabonline (S1)

Plate 2 .A well at Ashakoko (M2)

4.1.2 Nearness to Refuse Dump

None of the wells were dug near refuse dumps as most of them are located close to residences but the entire vicinity was predominantly covered with litter and rubbish making it difficult to differentiate dumping sites from regular littered areas (Plates 3 and 4).

There were no places of convenience close to the well locations (about 100 m^2 perimeter) However, some localities lacked places of convenience thus making everywhere a likely spot for dumping of faecal matter (Plate 4). Some inhabitants also used the bush as places of convenience.

Plate 3. A well (arrowed) at Mpeasem down (Zone D)

Plate 4. A well near a bathroom (arrowed) (Zone C)

Plate 5. Likely location for dumping of faecal matter at Saabonline (Zone C)

4.2 Microbial Analysis

4.2.1 Total coliform

The mean total coliform count from the 10 wells selected for this study was $2.64x10^7$cfu/100ml. From Fig 4.1, water from zone D had the highest mean count of total coliforms (3.80×10^7cfu/100ml). The least mean count of total coliforms was obtained from Zone C ($2.1x10^7$cfu/100ml). ANOVA did not yield any statistically significant difference ($p=0.814$) between the mean colony counts for the different zones.

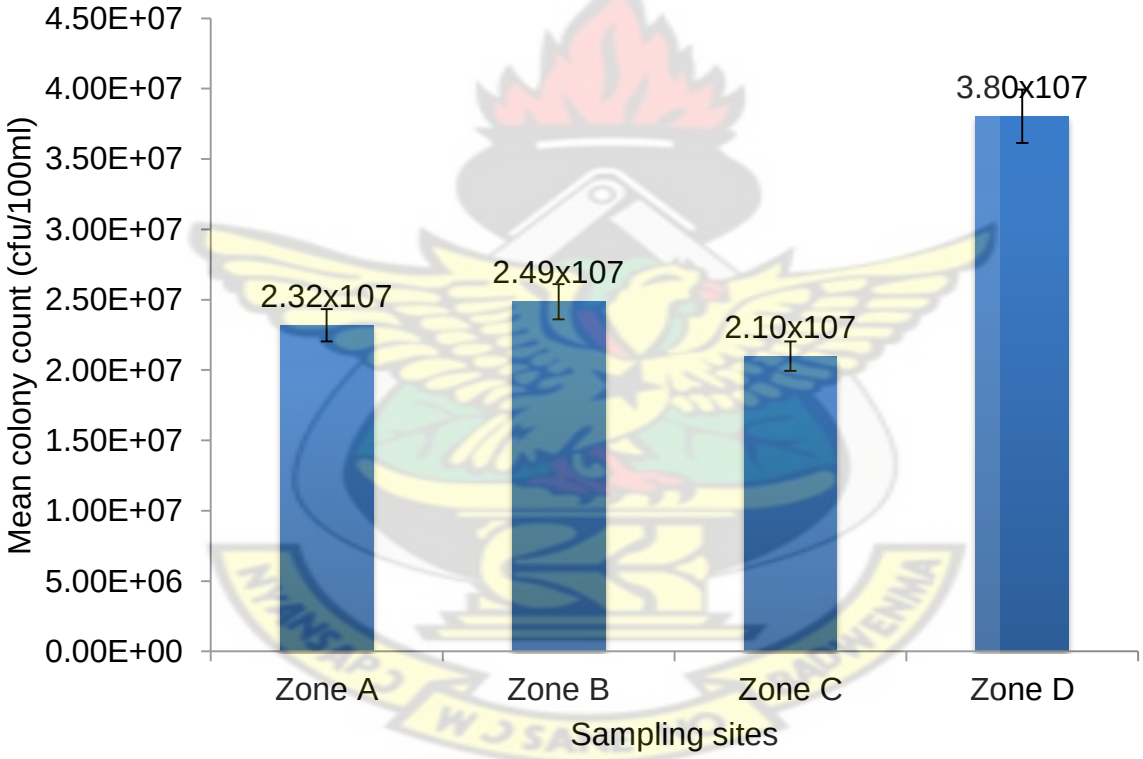


Figure 4.1 Mean total coliform counts from well water in Ejura

4.2.2 Faecal coliform

The mean colony count of the faecal coliform from the study sites was $2.68x10^7$cfu/100ml. From Fig 4.2, the highest mean count was observed in zone D ($3.80x10^8$cfu/100ml). Zone C (1.77x108cfu/100ml) had the least mean number of faecal coliform. ANOVA for the colony counts between the zones did not yield any significant difference (p=0.867) between them.

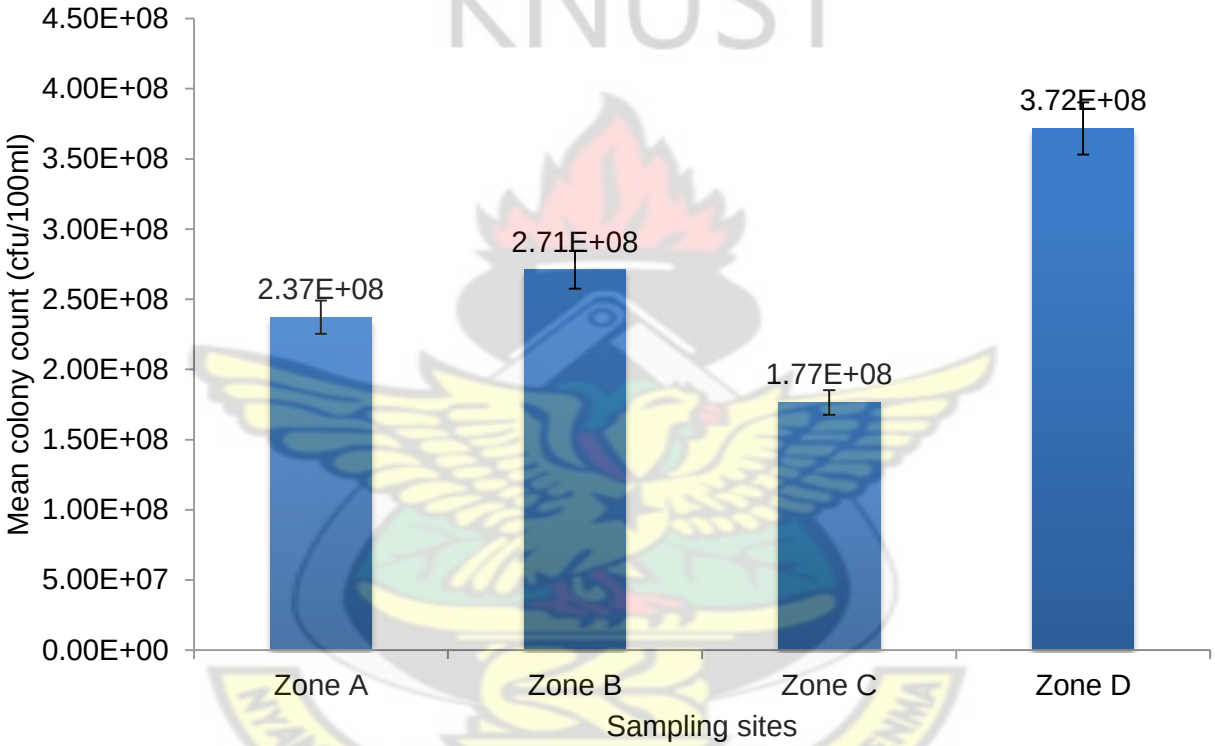


Figure 4.2 Mean faecal coliform counts from well water in Ejura.

4.2.3 *E coli*

The mean *E. coli* colony count was $4.96x10^5$ cfu/100ml. Of the four zones, zone D recorded the highest mean *E. coli* count ($7.05x10^5$cfu/100ml). Zone A had the second highest mean *E. coli*

count and zone C the least ($2.24x10^5$cfu/100ml) (fig 4). A comparison of the mean counts did not yield any statistically significant difference (p=0.373).

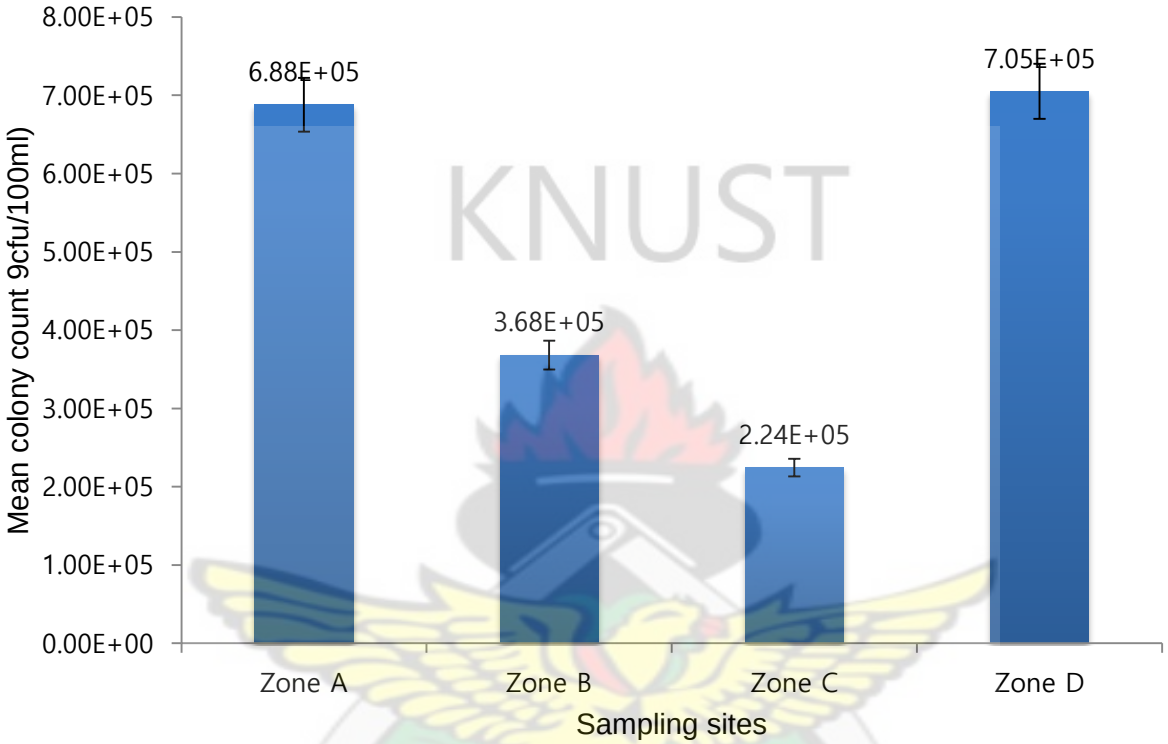


Figure 4.3 Mean *E. coli* counts from well water in Ejura

4.2.4 Faecal Enterococci

The mean faecal enterococci count obtained from the study sites was $7.76x10^2$cfu/100ml. From Fig 4.4, the least mean faecal enterococci count was $5.10x10^2$cfu/100ml. The highest mean faecal enterococci count was observed from zone A (1.15x103 cfu/100ml). The observed mean differences did not vary significantly (p=0.935) for the different zones.

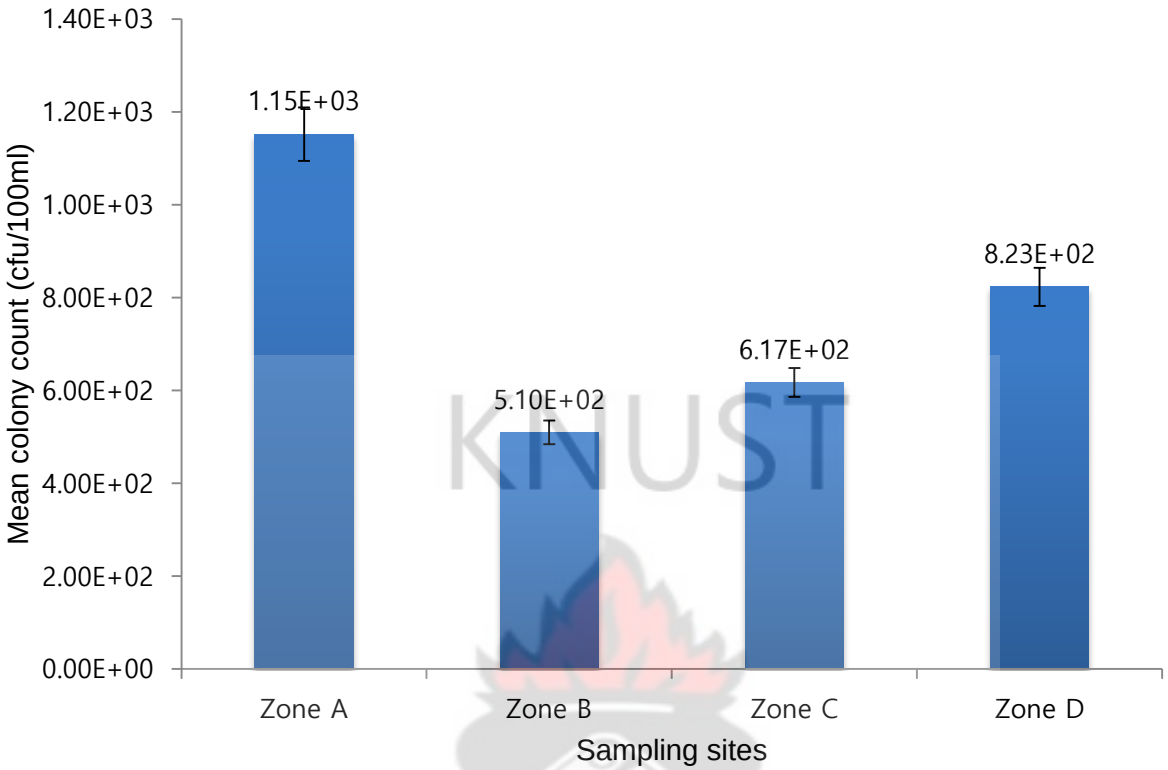


Figure 4.4: Mean enterococci counts of well water in Ejura

4.3 Physicochemical Analysis

4.3.1 pH

Mean pH of the water sampled from the various zones was 6.70. The highest mean was obtained from wells from zone C (6.82±0.02) and the least from zone A (6.49±0.02) [Fig 4.5]. The pH for the wells ranged from 6.47 to 6.84. Comparison of the pH of individual wells within a zone yielded a significant difference. Further comparison of the wells within the different zones showed a significant difference, except zone C and D.

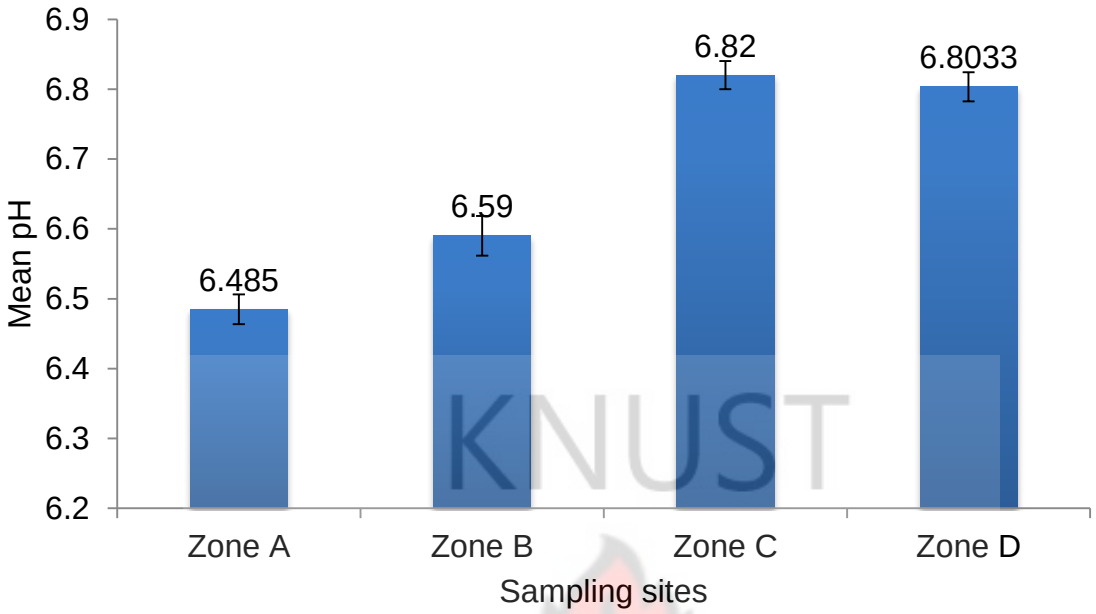


Figure 4.5 Mean pH of well water samples from four zones in Ejura

4.3.2 Total dissolved solids (TDS)

The total dissolved solids for all zones ranged from 45.8 mg/l to 913.8 mg/l. The highest mean total dissolved solids of 473.53±410.24 mg/l in the water sample from the hand- dug wells was obtained from zone D (Figure 4.6). Zone B (93.70±67.74 mg/l) had the least amount of dissolved solids. Zone A (289.30±49.63 mg/l) had the second highest amount of total dissolved solids. ANOVA did not yield any significant difference for observed total dissolved solids from the zones.

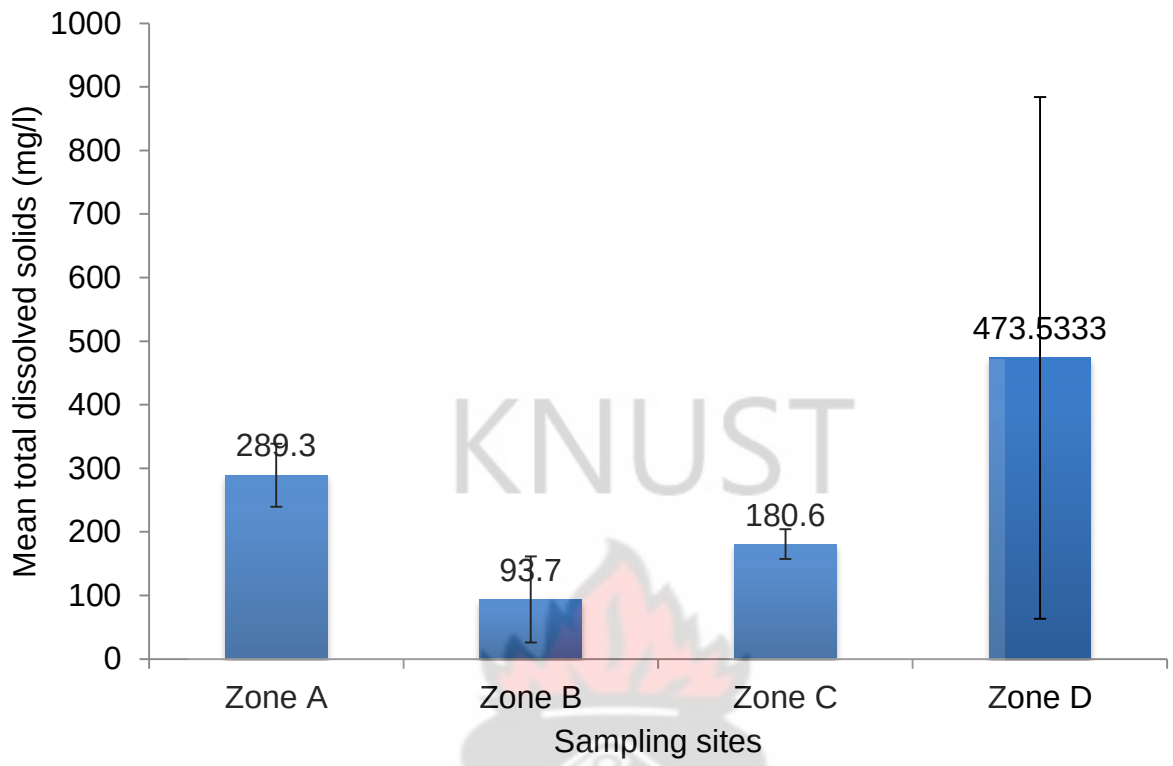


Figure 4.6 Mean total dissolved solids in well water from four zones in Ejura.

4.3.3 Salinity

The mean salinity of the water samples from the four zones involved in this study was 0.23± 0.22 mg/l. The salinity of the water samples from the wells in zone D ranged between 0.05 mg/l and 0.84mg/l making the peak mean salinity values for water samples to be recorded in zone D (0.35±0.43 mg/l) while the least mean salinity (0.095± 0.035 mg/l) was obtained from zone B with low mean salinity values of 0.07mg/l and 0.12 mg/l. ANOVA did not yield a statistically significant difference (p= 0.691) between the mean salinity for the different zones.

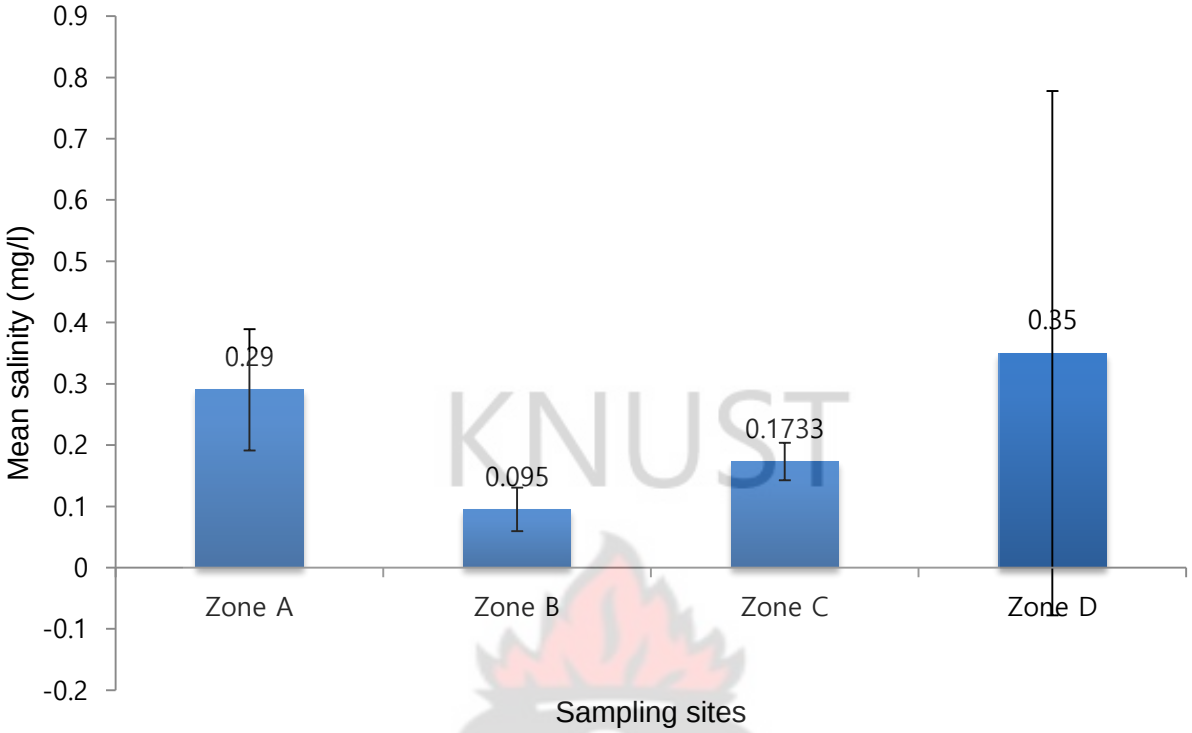


Figure 4.7 Mean salinity of well water from four zones in Ejura.

4.3.4 Conductivity

From Fig 4.8, the highest mean conductivity obtained from the four zones was 815.93± 896.35µS/cm and the least mean conductivity was 175.40±135.76µS/cm. The highest conductivity was observed for water from zone D and the least from zone B. The mean conductivity of the water samples was 511.92±500.27µS/cm. The conductivity of the water samples did not vary significantly (p=0.575) between the different zones.

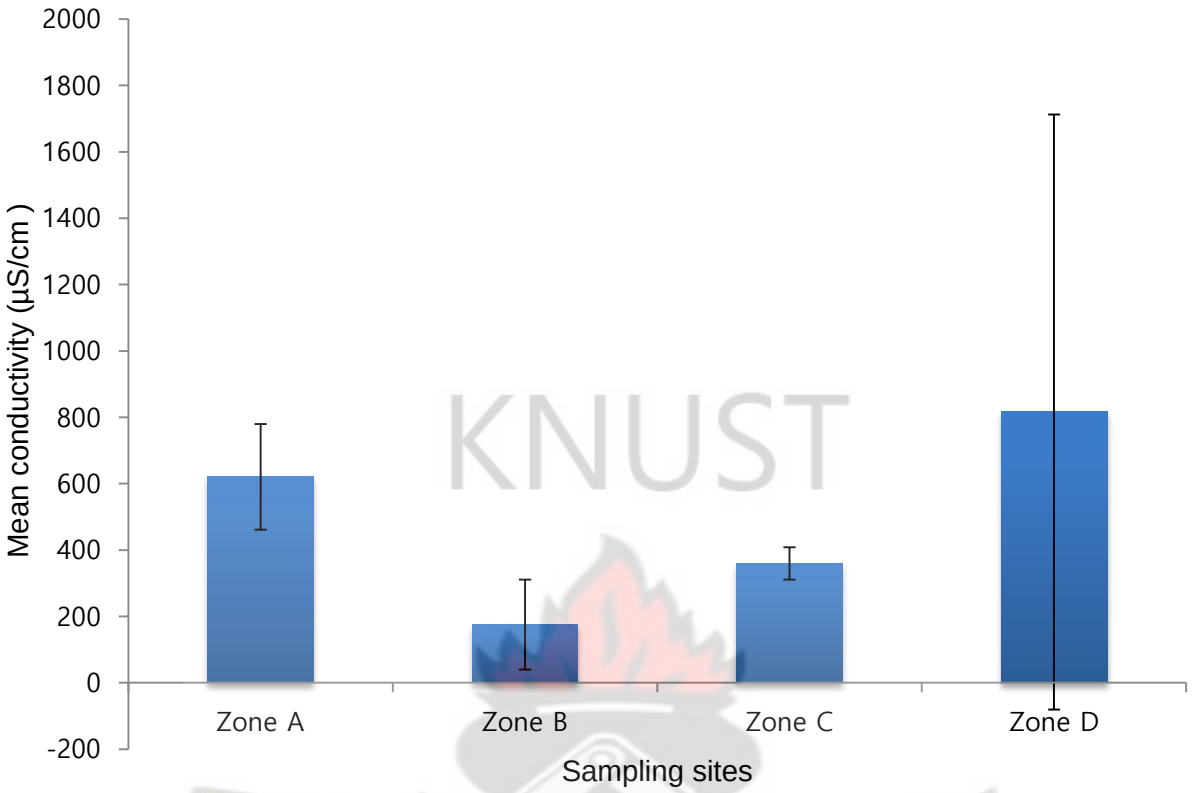


Figure 4.8 Mean conductivity of well water from four zones in Ejura

4.3.5 Temperature

The temperature for the water samples ranged from 21.1^{0}C to 28.5^{0}C. The minimum temperature was obtained from a well from zone B while the highest temperature from zone D. The lowest mean temperature (27.5^{0}C) was recorded from zone B and the highest mean temperature (28.17^{0}C) was from D. Zone C (27.8^{0}C) had the second highest mean temperature. ANOVA yielded a significant difference (p=0.017) between the temperatures for the different zones. A pairwise comparison only yielded significant difference between zone B and D and Zone B and C. All the others yielded insignificant differences.

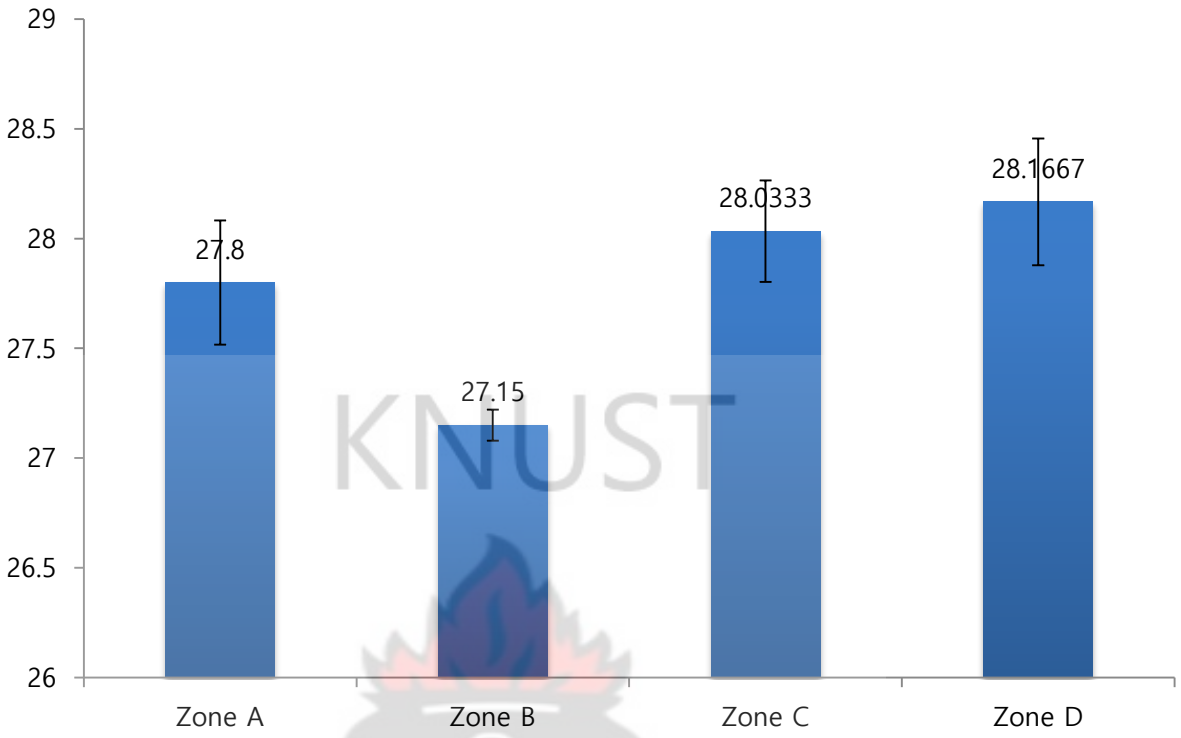


Figure 4.9 Mean well water temperature from four zones in Ejura

4.3.6 Chemical Ions

Table 1 displays the distribution of dissolved chemical ions in water samples from wells in the four zones. From table 1, the highest concentration of dissolved chemical ions was obtained for Ca^{2+} and Mg^{2+} that are responsible for causing hardness of water. The water samples were also observed to have slightly high mean concentration of 97.70mg/l of chloride. The least mean dissolved ion was fluoride (0.419 mg/l). Zone D had the highest concentrations of total hardness (210.60 mg/l) and nitrate (90.07 mg/l) ions. Zone A was observed to have the highest concentrations of chloride ions (97.70 mg/l) and fluoride ions (0.705 mg/l). ANOVA did not

yield any significant difference between the concentrations of the different ions for the different zones.

Table 1 Mean (SD) concentration of Total hardness and ions in well water from four zones in Ejura

Zones	Total hardness (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Nitrate (mg/L)
A	128.2±8.77	97.7±4.38	0.705±0.04	50.38±3.41
B	77.4±22.62	38.9±5.52	0.285±0.09	34.92±7.10
C	109.4±8.52	58.47±6.31	0.5±0.21	37.0067±3.03
D	210.6±212.65	74.46±57.41	0.2367±0.17	90.07±78.19
Total Mean	137.12±114.01	67.198±34.27	0.419±0.23	55.183±44.49

CHAPTER FIVE

5.0 DISCUSSION

5.1 Microbial Contamination

From the study, all the water samples from the wells in the four zones had at least one microbial (faecal coliform, total coliform, *E. coli* and faecal enterococci) contamination except *Salmonella*. However, one well from zone C (S1) and two wells from zone D (M1 and M3) did not record any faecal enterococci counts. From the results of this study, except for enterococci, zone D (Masalachi, Ashakoko and Mpeasem locality) had the highest counts of total coliform, faecal coliform and *E. coli*. This could be attributed to the poor sanitary conditions observed in the three communities (Plate 3).

During the sanitation survey, the three communities within zone D were observed to be littered with all sorts of rubbish. There were no drains and no proper refuse dumps. Wells within zone D were also dilapidated and without covers (Plate 2). Furthermore, water fetching activity of the inhabitants had created puddles around the wells (Plate 2) which gave off an offensive odor suggesting high microbial activity. These conditions therefore allowed microbial growth and subsequent contamination of the wells through percolation of contaminated water into the ground. The containers they use for drawing water from the wells are left lying on the ground and inhabitants who draw water from that well do not wash it before use thereby introducing microbial contamination into the wells.

The wells in zone A and B were mostly located in the homes of the inhabitants and hence were private. They therefore recorded relatively lower microbial counts than those from zone D, which were mostly communal wells. Furthermore, the wells located in these zones A and B were

properly constructed with concrete finishing and with covers (Results 4.1.1, Page 37). Further, these communities had comparatively low levels of filth. Most of the inhabitants also used pipe borne water for drinking and only relied on the wells when the taps were not flowing.

On the whole, findings show that because all the wells had at least one microbial contamination, inhabitants using this water for drinking purposes were prone to diseases such as cholera, dysentery, typhoid, eye infections among others affirming the Ejura Sekyeredumase Municipal Assembly's (2009) health report. The high microbial levels in the wells were also against the laid down world guidelines for water quality which states that for water to be suitable for drinking, there should be no microbial contamination (0 cfu/100 ml of water sample) (WHO, 2011). This makes water from wells in Ejura not suitable for drinking.

5.2 Physicochemical Results

The results of this study revealed that with respect to pH, water from the wells within the town are in the acidic medium (Fig 4.5). According to the WHO (2011) report, the pH for safe drinking water should range from 6.5 to 8.5. The pH values obtained for all samples were within the WHO endorsed standard for drinking water. However, according to the Canadian guideline for drinking water, pH can influence the formation of disinfection by- products (dissolved ions) and effectiveness of treatment because lower pH increases dissolution of ions and toxic chemicals such as heavy metals in water, increasing the shielding of microbes, thus interfering with disinfection. Low pH also increases levels of TDS which affects conductivity to increase shielding of microbes from disinfection (US EPA, 1986). This explains the high microbial contamination of wells in the town.

Also, pH affects *E. coli* by influencing their growth in acidic or alkaline medium. High pH inhibits cell growth of *E. coli* (Zhu, 2007). This also explains the low microbial presence in the wells with low pH values. The recorded significant differences between the water samples could therefore be attributed to the varying microbial counts. Furthermore, the activities around the wells could also contribute to the acidity especially when contaminants leak from the surrounding grey water into the wells.

Total dissolved solids (TDS) were in the range of 473.53-93.7mg/L. Guidelines for Canadian drinking water, suggests that TDS values should be less than or equal to 500mg/l and any value above that will result in excessive scaling in water pipes, water heaters and appliances. From the study, TDS values for all water samples in each of the zones were within the highest desirable or maximum permissible limit set by the World Health Organization (WHO 2011). However comparing individual zones, well M1 in zone D recorded a higher mean TDS value of 913.80 mg/l above standard (500mg/l) suitable for drinking; a situation which could have influenced microbial levels recorded for the zone. This contamination was as a result of introduction of organic and inorganic substances from farm lands, pasture areas, leachate from refuse dumping sites and places of convenience as observed during the sanitation survey (Plate 3). These levels of TDS meant that there would be high dissolved ions entering the water thereby providing shielding for microbes and preventing disinfection (US EPA, 1986).

Dissolved ions in water affect its salinity. Therefore low salinity for the wells suggests low levels of dissolved ions contributed by salt compounds in the water. Also salinity affects portability of water by contributing ions which shields microbes, prevents disinfection and increases formation of biofilms (Anati, 1999). Low salinities thus will mean less shielding and low microbial

infection. However, most microbes are unable to live in high saline water because high salinities have negative effect on them except for salt-loving microbes (WHO, 2011). From the study, the high microbial counts recorded for water samples from the wells are due to the low salinity levels in all water samples. This stands to prove that salinity will affect drinking suitability of the water. According to WHO standards, for water to be suitable for drinking, its salinity must be less than 500mg/l. From the study (Fig 4.7), these were very low implying that water from the wells is suitable for use with respect to its salinity.

Impertinent ions such as chloride and sodium affect water conductivity and thus an increase in TDS will affect salinity which will then influence conductivity. The guideline for Canadian drinking water suggests that conductivity for water must be within levels of 0-800 µS/cm. From the study, the water samples analyzed from the four zones were all within the allowable limit for drinking (Fig 4.8) except for well M1 which recorded a high mean conductivity value of 1845.2µS/cm. From the study, comparatively well M1 in zone D recorded high conductivity due to high mean values obtained for TDS as well (Fig 4.6) since TDS level in water is influenced by the organic and inorganic substances which also impacts conductivity by increasing electron flow of ions in water. There are no prescribed standards suggested by the World Health Organization for electrical conductivity parameters of water for drinking purpose (WHO, 2011). So no comparison can be made from observed values.

Temperature range was between 28.17-27.15 ºC. From Fig 4.9, a common trend is seen in that; zone D records the highest mean values for temperature, TDS, salinity and conductivity whereas zone B records the lowest. This goes to show how related these parameters are with each other. The higher the temperature of water, the more extraneous substances dissolve into it thereby

increasing TDS and affecting salinity and conductivity **(**Goltzman, 1978). This could have also being the reason for the higher microbial loads (for enterococci) obtained for wells from zone D. Temperature effects have impact on pH (Pawlowicz, 2013). This is evident in the higher pH obtained for zone C followed by zone D and the high temperature value recorded for zone D followed by zone C.

Total hardness according to WHO standards should be less than 75mg/l. On the whole, all water sampled from the four zones showed hardness (Table 1). Hardness between 80mg/land 100mg/l provides acceptable balance between corrosion and incrustation. The guideline for Canadian drinking water does not state a value for hardness. This therefore makes the water analyzed from the town not harmful for human consumption but rather its effects will be seen when used for other purposes such as domestic and industrial. Hardness due to calcium carbonate is recommended for drinking purposes because of its health benefit in maintaining strong bones and teeth and can actually serve as a dietary supplement for calcium and magnesium (Mader, 2002). However it's been known that hardness due to magnesium is not so desirable; for example, water containing magnesium sulphide (1000mg/L) acts as a purgative in human adults (WHO, 2003).

Chloride forms a common component of all natural water and is usually not considered as a detrimental constituent in water (Rail, 1989). The observed chloride concentrations in the well water from the four zones (Table 1) were below the acceptable limit of 250mg/L recommended for human consumption. It is a suitable indicator of fecal contamination of rivers and groundwater because it provides shielding effects and thus prevents disinfection which then reduces effectiveness of treatment (Chutia and Sarma, 2009).The concentrations of the ions

obtained could be attributed to dissolution of the rocks in the ground or from the quantity of refuse within each of the zones. This stands to prove the presence of microbes in all the water samples from the four zones in the township.

Fluoride levels in water recommended for drinking; according to standards, is 1.5mg/l (WHO, 2004). This is beneficial in preventing dental caries and bone density deterioration. The concentrations in the well water from the four zones (Table 1) were all within the acceptable limit making the water not harmful for drinking in terms of fluoride content. Fluoride enters ground water through discharge from agricultural activities or from the bedrock which feeds the ground water (Cengeloglu *et al.*, 2002). From the study, none of the hand dug wells from which water was sampled, are located close to farmlands, explaining the low levels obtained.

Nitrate contamination of ground water is due to agricultural activities such as fertilizer application and animal waste from husbandry. Animal wastes concentrate in small pastures leading to ineffective use of nitrogen and the potential contamination of groundwater by nitrate (Hallberg and Keeney, 1993). Nitrate content of 50mg/l is recommended for drinking water according to the world health organization standard; making water from the wells within two zones, B (34.92±7.10) and C (37.0067±3.03) suitable for drinking in terms of nitrate content and water from the other two, zone A (50.38±3.41mg/L) and D (90.07±78.19mg/L) unacceptable. These levels obtained in the water could have been due to exposure of the two wells to animal waste because some inhabitants in some areas of the Ejura Township raise cattle on a free range and from the survey, the environs are littered with cattle dung.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Water from the wells was polluted with bacteria of which some physicochemical parameters such as pH and temperature had influenced. Dissolved ions in the water were generally found to be in relatively low concentrations which are an indication of low influx from the surrounding for example, from refuse leachate, sewage and drainage. From the study, occurrence of microbes (total coliform, faecal coliform, enterococci and *E. coli*) in the water suggests it is not suitable for drinking. The physicochemical conditions except for nitrate concentrations in two zones A and D were all below acceptable levels and did not affect the waters' potability. Some of the parameters may have however influenced microbial contamination. Salmonella contamination was not evident in all the water sampled from the four zones.

6.2 Recommendations

1. It is therefore recommended that individuals who use the water for drinking purposes should treat the water before use.

2. The inhabitants should be educated on ways to keep their surroundings neat and tidy through Municipal Sanitation Programs.

3. Developmental projects should be put in place by government through the Municipal Assembly to provide communities with adequate and proper places of convenience.

4. House to house sensitization should also be put to place to create awareness on personal hygiene so as to reduce introduction of microbes into water systems though improper handling of water fetching tools.

5. To reduce the nitrate levels in the well water, there are two options. A non-treatment technique that comprise amalgamating drinking waters, or changing water sources and an alternative, involving the use of treatment procedures, such as ion exchange, reverses osmosis, biological denitrification and chemical reduction to eradicate portions of the pollutant (Moore, 1991). Inhabitants would have to change their water sources to pipe-borne since the town is adequately supplied.

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APPENDIX

Table 1 ANOVA of physicochemical parameters

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.192	3	.064	131.550	.000
	Within Groups	.003	6	.000		
	Total	.195	9			
TDS	Between Groups	211082.237	3	70360.746	1.225	.379
	Within Groups	344744.787	6	57457.464		
	Total	555827.024	9			
Salinity	Between Groups	.096	3	.032	.508	.691
	Within Groups	.379	6	.063		
	Total	.475	9			
Conductivity	Between Groups	596912.263	3	198970.754	.721	.575
	Within Groups	1655497.033	6	275916.172		
	Total	2252409.296	9			
Temperature	Between Groups	1.387	3	.462	7.740	.017
	Within Groups	.358	6	.060		
	Total	1.745	9			

Table 2 Multiple Comparisons of physicochemical parameters

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Dependent Variable	(I) Sites	(J) Sites	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
pH	Zone A	Zone B	-.10500*	.02205	.019	-.1898	-.0202
		Zone C	-.33500*	.02013	.000	-.4124	-.2576
		Zone D	-.31833*	.02013	.000	-.3957	-.2410
	Zone B	Zone A	.10500*	.02205	.019	.0202	.1898
		Zone C	-.23000*	.02013	.000	-.3074	-.1526
		Zone D	-.21333*	.02013	.000	-.2907	-.1360
	Zone C	Zone A	.33500*	.02013	.000	.2576	.4124
		Zone B	.23000*	.02013	.000	.1526	.3074
		Zone D	.01667	.01800	.949	-.0525	.0859
	Zone D	Zone A	.31833*	.02013	.000	.2410	.3957
		Zone B	.21333*	.02013	.000	.1360	.2907
		Zone C	-.01667	.01800	.949	-.0859	.0525
TDS	Zone A	Zone B	195.60000	239.70287	.971	-725.9811	1117.1811
		Zone C	108.70000	218.81778	.998	-732.5846	949.9846
		Zone D	-184.23333	218.81778	.966	-1025.5179	657.0512
	Zone B	Zone A	-195.60000	239.70287	.971	-1117.1811	725.9811
		Zone C	-86.90000	218.81778	.999	-928.1846	754.3846
		Zone D	-379.83333	218.81778	.576	-1221.1179	461.4512
	Zone C	Zone A	-108.70000	218.81778	.998	-949.9846	732.5846
		Zone B	86.90000	218.81778	.999	-754.3846	928.1846
		Zone D	-292.93333	195.71657	.707	-1045.4011	459.5345
	Zone D	Zone A	184.23333	218.81778	.966	-657.0512	1025.5179
		Zone B	379.83333	218.81778	.576	-461.4512	1221.1179

		Zone C	292.93333	195.71657	.707	-459.5345	1045.4011
		Zone B	.19500	.25137	.977	-.7714	1.1614
	Zone A	Zone C	.11667	.22947	.997	-.7656	.9989
		Zone D	-.06000	.22947	1.000	-.9422	.8222
		Zone A	-.19500	.25137	.977	-1.1614	.7714
	Zone B	Zone C	-.07833	.22947	1.000	-.9606	.8039
		Zone D	-.25500	.22947	.891	-1.1372	.6272
Salinity		Zone A	-.11667	.22947	.997	-.9989	.7656
	Zone C	Zone B	.07833	.22947	1.000	-.8039	.9606
		Zone D	-.17667	.20524	.963	-.9658	.6124
		Zone A	.06000	.22947	1.000	-.8222	.9422
	Zone D	Zone B	.25500	.22947	.891	-.6272	1.1372
		Zone C	.17667	.20524	.963	-.6124	.9658
		Zone B	445.30000	525.27723	.965	-1574.2234	2464.8234
	Zone A	Zone C	260.96667	479.51032	.996	-1582.5976	2104.5309
		Zone D	-195.23333	479.51032	.999	-2038.7976	1648.3309
		Zone A	-445.30000	525.27723	.965	-2464.8234	1574.2234
	Zone B	Zone C	-184.33333	479.51032	.999	-2027.8976	1659.2309
		Zone D	-640.53333	479.51032	.792	-2484.0976	1203.0309
Conductivity		Zone A	-260.96667	479.51032	.996	-2104.5309	1582.5976
	Zone C	Zone B	184.33333	479.51032	.999	-1659.2309	2027.8976
		Zone D	-456.20000	428.88707	.908	-2105.1340	1192.7340
		Zone A	195.23333	479.51032	.999	-1648.3309	2038.7976
	Zone D	Zone B	640.53333	479.51032	.792	-1203.0309	2484.0976
		Zone C	456.20000	428.88707	.908	-1192.7340	2105.1340
		Zone B	.65000	.24438	.205	-.2896	1.5896
Temperature	Zone A	Zone C	-.23333	.22309	.914	-1.0910	.6244
		Zone D	-.36667	.22309	.626	-1.2244	.4910

	Zone A	-.65000	.24438	.205	-1.5896	.2896
Zone B	Zone C	-.88333*	.22309	.044	-1.7410	-.0256
	Zone D	-1.01667*	.22309	.023	-1.8744	-.1590
	Zone A	.23333	.22309	.914	-.6244	1.0910
Zone C	Zone B	.88333*	.22309	.044	.0256	1.7410
	Zone D	-.13333	.19954	.989	-.9005	.6338
	Zone A	.36667	.22309	.626	-.4910	1.2244
Zone D	Zone B	1.01667*	.22309	.023	.1590	1.8744
	Zone C	.13333	.19954	.989	-.6338	.9005

*. The mean difference is significant at the 0.05 level.

Table 3. ANOVA of microbial parameters

		Sum of Squares	df	Mean Square	F	Sig.
Faecal	Between Groups	511904316766666.500	3	170634772255555.500	.202	.891
	Within Groups	5072171319333333.000	6	845361886555555.500		
	Total	5584075636100000.000	9			
Total	Between Groups	59293469333333344.000	3	19764489777777780.000	.315	.814
	Within Groups	375910951666666620.000	6	62651825277777768.000		
	Total	435204421000000000.000	9			
Ecoli	Between Groups	458587333333.333	3	152862444444.444	1.248	.373
	Within Groups	735146666666.667	6	122524444444.444		
	Total	1193734000000.000	9			
enterococci	Between Groups	505252.209	3	168417.403	.135	.935
	Within Groups	7461909.082	6	1243651.514		
	Total	7967161.290	9			

Table 4 Mean physicochemical Parameters of water in four zones

		N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
pH	Zone A	2	6.4850	.02121	.01500	6.47	6.50
	Zone B	2	6.5900	.02828	.02000	6.57	6.61
	Zone C	3	6.8200	.02000	.01155	6.80	6.84
	Zone D	3	6.8033	.02082	.01202	6.78	6.82
	Total	10	6.7020	.14711	.04652	6.47	6.84
TDS	Zone A	2	289.3000	49.63890	35.10000	254.20	324.40
	Zone B	2	93.7000	67.74083	47.90000	45.80	141.60
	Zone C	3	180.6000	23.40855	13.51493	156.00	202.60
	Zone D	3	473.5333	410.24141	236.85299	102.00	913.80
	Total	10	272.8400	248.51269	78.58661	45.80	913.80
Salinity	Zone A	2	.2900	.09899	.07000	.22	.36
	Zone B	2	.0950	.03536	.02500	.07	.12
	Zone C	3	.1733	.03055	.01764	.14	.20
	Zone D	3	.3500	.42790	.24705	.05	.84
	Total	10	.2340	.22984	.07268	.05	.84
Conductivity	Zone A	2	620.7000	159.38187	112.70000	508.00	733.40
	Zone B	2	175.4000	135.76450	96.00000	79.40	271.40
	Zone C	3	359.7333	48.95236	28.26266	307.40	404.40
	Zone D	3	815.9333	896.34530	517.50520	207.00	1845.20
	Total	10	511.9200	500.26763	158.19851	79.40	1845.20
Temperature	Zone A	2	27.8000	.28284	.20000	27.60	28.00
	Zone B	2	27.1500	.07071	.05000	27.10	27.20
	Zone C	3	28.0333	.23094	.13333	27.90	28.30
	Zone D	3	28.1667	.28868	.16667	28.00	28.50

	Total	10	27.8500	.44033	.13924	27.10	28.50

Table 5 Statistical analysis of physicochemical parameters showing squares of means

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.192	3	.064	131.550	.000
	Within Groups	.003	6	.000		
	Total	.195	9			
TDS	Between Groups	211082.237	3	70360.746	1.225	.379
	Within Groups	344744.787	6	57457.464		
	Total	555827.024	9			
Salinity	Between Groups	.096	3	.032	.508	.691
	Within Groups	.379	6	.063		
	Total	.475	9			
Conductivity	Between Groups	596912.263	3	198970.754	.721	.575
	Within Groups	1655497.033	6	275916.172		
	Total	2252409.296	9			
Temperature	Between Groups	1.387	3	.462	7.740	.017
	Within Groups	.358	6	.060		
	Total	1.745	9			

Table 6 Descriptive statistics of dissolved ions from four zones in Ejura

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Total hardness	Zone A	2	128.2000	8.76812	6.20000	49.4215	206.9785	122.00	134.40
	Zone B	2	77.4000	22.62742	16.00000	-125.8993	280.6993	61.40	93.40
	Zone C	3	109.4000	8.51587	4.91664	88.2454	130.5546	103.80	119.20
	Zone D	3	210.6000	212.65945	122.77899	-317.6753	738.8753	59.60	453.80
	Total	10	137.1200	114.00644	36.05200	55.5647	218.6753	59.60	453.80
Chloride	Zone A	2	97.7000	4.38406	3.10000	58.3108	137.0892	94.60	100.80
	Zone B	2	38.9000	5.51543	3.90000	-10.6542	88.4542	35.00	42.80
	Zone C	3	58.4667	6.31295	3.64478	42.7844	74.1489	51.20	62.60
	Zone D	3	74.4600	57.41002	33.14569	-68.1544	217.0744	20.80	135.00
	Total	10	67.1980	34.27079	10.83738	42.6822	91.7138	20.80	135.00
Fluoride	Zone A	2	.7050	.03536	.02500	.3873	1.0227	.68	.73
	Zone B	2	.2850	.09192	.06500	-.5409	1.1109	.22	.35
	Zone C	3	.5000	.21000	.12124	-.0217	1.0217	.35	.74
	Zone D	3	.2367	.16803	.09701	-.1807	.6541	.09	.42
	Total	10	.4190	.22932	.07252	.2550	.5830	.09	.74
Nitrite	Zone A	2	50.3800	3.40825	2.41000	19.7580	81.0020	47.97	52.79
	Zone B	2	34.9200	7.09935	5.02000	-28.8651	98.7051	29.90	39.94
	Zone C	3	37.0067	3.03385	1.75159	29.4702	44.5432	34.77	40.46
	Zone D	3	90.0700	78.18995	45.14299	-104.1646	284.3046	18.79	173.70
	Total	10	55.1830	44.49410	14.07027	23.3538	87.0122	18.79	173.70

Table 7 Mean squares of ions from ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Total hardness	Between Groups	25795.216	3	8598.405	.566	.657
	Within Groups	91182.000	6	15197.000		
	Total	116977.216	9			
Chloride	Between Groups	3849.216	3	1283.072	1.145	.404
	Within Groups	6721.168	6	1120.195		
	Total	10570.384	9			
Fluoride	Between Groups	.319	3	.106	4.132	.066
	Within Groups	.154	6	.026		
	Total	.473	9			
Nitrite	Between Groups	5509.762	3	1836.587	.895	.496
	Within Groups	12307.763	6	2051.294		
	Total	17817.525	9			

Table 8 Mean microbial load for study sites

SAMPLE SITE	FAECAL COLIFORM		TOTAL COLIFORM		*E. coli*		SALMONELLA	ENTEROCOCCI	
	meancfu	SE	meancfu	SE	meancfu	SE	meancfu	meancfu	SE
S1	9.37E+05	7.07E+05	1.09E+08	1.40E+08	2.44E+05	6.67E+04	NIL	0.00E+00	0.00E+00
S2	5.61E+07	3.63E+07	1.55E+07	1.12E+07	3.40E+05	1.96E+04	NIL	1.59E+03	2.29E+03
S3	5.92E+06	5.97E+06	4.05E+08	5.60E+08	8.90E+04	2.88E+04	NIL	2.62E+02	4.20E+02
M1	5.34E+06	9.53E+06	4.63E+07	5.86E+07	5.40E+05	1.98E+05	NIL	0.00E+00	0.00E+00
M2	4.17E+07	5.65E+07	4.74E+08	6.01E+08	1.17E+06	5.69E+04	NIL	2.47E+03	4.37E+03
M3	6.71E+07	9.39E+07	5.95E+08	4.67E+08	4.05E+05	2.09E+05	NIL	3.50E-01	4.95E-01
B1	4.17E+07	1.46E+06	4.22E+08	5.83E+08	2.86E+05	1.06E+05	NIL	1.52E+02	2.05E+02
B2	8.01E+06	9.04E+06	1.20E+08	1.52E+08	4.50E+05	1.77E+05	NIL	8.68E+02	1.32E+03
P1	4.27E+06	5.81E+06	4.39E+08	5.95E+08	2.66E+05	1.56E+04	NIL	2.07E+03	3.30E+03
P2	4.21E+07	5.81E+07	3.55E+07	2.97E+07	1.11E+06	2.67E+05	NIL	2.34E+02	4.04E+02
BH1	2.01E+06	2.74E+06	7.10E+08	9.92E+08	1.41E+05	7.59E+04	NIL	4.50E+02	6.36E+02
BH2	7.63E+05	4.91E+05	2.09E+06	1.52E+06	1.48E+05	1.19E+05	NIL	1.00E+02	1.73E+02