KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

KUMASI

COLLEGE OF SCIENCE

MICROBIOLOGICAL AND PHYSICOCHEMICAL ASSESSMENT OF WATER FROM BOREHOLES AND HAND-DUG WELLS IN URBAN COMMUNITIES WITHIN EJISU-JUABEN MUNICIPALITY

Yaw Owusu Afriyie Kusi

JUNE, 2014

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

KUMASI

COLLEGE OF SCIENCE

MICROBIOLOGICAL AND PHYSICOCHEMICAL ASSESSMENT OF WATER FROM BOREHOLES AND HAND-DUG WELLS IN URBAN COMMUNITIES WITHIN EJISU-JUABEN MUNICIPALITY

A Thesis submitted to the Department of Theoretical and Applied Biology of the Kwame Nkrumah University of Science and Technology, Kumasi, in partial fulfillment of the requirements of

Master of Science Degree in Environmental Science

By

Yaw Owusu Afriyie Kusi

(BSc Natural Resources Management)

JUNE, 2014

DECLARATION

I, Yaw Owusu Afriyie Kusi hereby declare that this submission is my own work 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, except where due acknowledgement has been made in the text.

Yaw Owusu Afriyie Kusi

……………………….....　　　….. .....……………　　　………………….

PG6090411　　　Signature　　　Date

Certified by:

Dr. John A. Larbi

……………………...　　　…………………………　　　…………………..

Supervisor　　　Signature　　　Date

Certified by:

Dr. I. K. Tetteh

……………………..　　　…………………………　　　…………………..

Head of Department　　　Signature　　　Date

ACKNOWLEDGEMENTS

I wish to express my greatest gratitude to my supervisor, Dr. John A. Larbi for guiding me in writing this thesis. His intellectual guidance, constructive comments and critical review of my work made it possible for me to complete this thesis.

I am also grateful to all the lecturers of the Department of Theoretical and Applied Biology for their inspiring lectures, invaluable advice and support throughout my studies.

Profound thanks go to Dennis Amoah and all the staff of civil engineering water laboratory whose cooperation and support made my fieldwork a success.

I am very much grateful to all those who in diverse ways have contributed to the success of this study especially my dad, George Anane Kusi, my mum, Juliana Adjei-Boateng and my wife Grace Achiaa; I wish you God's blessings beyond measure.

Finally, I thank the Almighty God for bringing me this far and for always being with me.

ABSTRACT

The microbial and physico-chemical quality of water from boreholes and hand-dug wells in urban communities within the Ejisu-Juaben Municipality of Ashanti region was studied. Water samples were collected from three boreholes and three hand-dug wells selected randomly from each community and the water samples analyzed using various standard methods. From the results, pH of the water from boreholes and hand-dug wells ranged from pH 4.34-5.13 units which fell below WHO guideline value for drinking water. The water was non-saline with all TDS values less than 1000 mg/l and soft to slightly hard (18.89-127.00 mg/l $CaCO_3$). The anion (SO_4^{-2}, NO_3^-, Cl^- and F^-) levels in the water samples from selected boreholes and hand-dug wells were observed to be low and fell within the WHO guideline values. With the exception of two hand-dug wells at Ejisu (EJW2) and Juaben (JW2) recording iron (Fe) levels of 0.6810 and 0.3220 mg/l respectively, all boreholes and hand-dug wells had heavy metal (Fe, Mn, Zn and Cd) levels within the WHO guideline values. One borehole at Ejisu (EJBH3) and two boreholes at Juaben (JBH1 and JBH2) recorded total coliform in water samples with mean values of 2.08×10^4 and 3.06×10^4 CFU $100ml^{-1}$ respectively with zero counts for faecal coliform and *E. coli*. Boreholes at Fumesua and Bonwire recorded zero counts for total coliforms, faecal coliforms and *E. coli*. Only one borehole at Besease (BEBH1) recorded total coliforms, faecal coliforms and *E. coli* in water samples. Most hand-dug wells selected for the study recorded total coliforms, faecal coliforms and *E. coli* in samples with mean values of 4.92×10^5, 1.01×10^5 and 3.81×10^4 CFU $100ml^{-1}$ respectively. A total number of nine helminths were found out of the fifteen hand-dug wells. Six out of the nine helminths encountered were *Ascaris* species (66.7%), two out of the nine were *Hookworm* (22.2%) and one of the nine was *Schistosoma haematobium* (11.1%) which were recorded at Ejisu(EJW1), Juaben(JW2), Fumesua(FW3) and Besease(BEW1 and BEW2). A brief sanitation survey at each sampling community showed that, most hand-dug wells were sited near pit latrines, refuse dumps, septic tanks, farmlands, piggeries and in the vicinity of domestic animals with a minimum distance of 5m. Bacteriological quality of the water from all hand-dug wells were very poor (above detectable limits) compared to the boreholes and thus must be treated before use.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectrophotometer
APHA	American Public Health Association
CBO's	Community Based Organisations
CDC	Centre for Disease Control and Prevention
CWSA	Community Water and Sanitation Agency
EPA	Environmental Protection Agency
EC	Electrical Conductivity
E. coli	*Escherichia coli*
GWCL	Ghana Water Company Limited
HU	Hazen Unit
IDPH	Illinois Department of Public Health
IFAS	Institute of Food and Agricultural Science
MassDEP	Massachusetts Department of Environmental Protection
MCL	Minimum Contaminant Level
MDG	Millennium Development Goal
Mg/l	Milligram per litre
NGO's	Non-Governmental Organisations
NGWA	National Ground Water Association
NTU	Nephelometric Turbidity Unit
SRB	Sulphur Reducing Bacteria
SMCL	Suggested Maximum Contaminant Level
TDS	Total Dissolved Solids
UN	United Nations
UNEP	United Nations Environmental Program

UNICEF	United Nations Children's Fund
UNO	United Nations Organisation
USEPA	United State Environmental Protection Agency
USGS	United State Geological Survey
WHO	World Health Organisation
WVI	World Vision International
WRI	Water Research Institute

CHAPTER ONE

1.1 Introduction

Water is life and one of the earth's most precious resources. It is very crucial for survival yet over one billion men, women, and children do not have enough safe water to drink and thus their chance of living a healthy life is compromised (Oki and Kanae, 2006). Those mostly affected are innocent children and desperate families living in overcrowded urban slums, in refugee camps, and in poverty-stricken towns and villages in rural areas of developing countries around the world (WHO/UNICEF, 2010).

The consumption of water worldwide increases yearly whiles most of the world's water resources continue to dwindle due to improper environmental management practices. Globally, more than 25000 people die daily as a result of water related diseases (UNEP, 2000).

Waterborne diseases are caused by pathogenic microorganisms that most commonly are transmitted in contaminated water. Infection commonly results during bathing, washing, drinking, in the preparation of food, or the consumption of food thus infected. Various forms of waterborne diarrheal disease such as dysentery, cholera and typhoid probably are the most prominent examples, and affect mainly children in developing countries and it is attributable to unsafe water supply, sanitation and hygiene (WHO, 2004).

Every year, around 250 million people are infected with water-borne pathogens resulting in 10 to 20 million deaths world-wide. It has been estimated that 80% of all illness in developing countries is related to water and sanitation and 15% of all child deaths under the age of five years in developing countries result from diarrheal diseases (WHO, 2004).

Helminths are parasitic worms that cause a wide variety of infectious diseases. They may be classified into nematodes or roundworms, trematodes or flatworms, and cestodes or tapeworms. Common worldwide diseases contracted from parasite-infected drinking water include amoebiasis, cryptosporidiosis, giardiasis, dracunculiasis and schistosomiasis. Populations in the developing world are at particular risk for infestation with helminths due to inadequate water treatment, use of contaminated water for drinking, cooking and irrigation, and walking barefoot (Crompton and Whitehead, 1993). According to Gale (2001), *Ascaris* ova have been found in surface water and groundwater and may be a source of waterborne exposure for persons who consume untreated water in areas where sanitation is especially poor.

This is the reason why the quality of our food and water are monitored, personal hygiene and policies established in order to prevent contamination in the first place. Studies have shown that faecal indicator bacteria survive from a few hours up to several days in water, but may survive for days or months in sediments, where they may be protected from sunlight and predators (Darakas, 2002).

Every year, millions of people die in developing countries from diseases such as dysentery, salmonellosis, shigellosis and typhoid due to inadequate safe drinking water and sanitation measures. The assessment of potable water supplies for coliform bacteria is very significant in evaluating the sanitary quality of drinking water because high levels of coliform counts suggest a contaminated source, inadequate treatment or post treatment deficiencies (Mathew *et al.*, 1984). It has been shown that drinking water supplies have a long history of association with a wide spectrum of microbial infections (Grabow, 2000).

The basic goal of water quality management from the wellness view point is to make sure that, consumers are not exposed to doses of pathogenic organisms that are likely to cause diseases (Gray, 2008). This has contributed to the reduction of incidence of water related diseases in developed countries because their water sources are protected and their water supplies are also well treated (Craun *et al.,* 2006: Grabow, 2000).

Physicochemical parameters such as temperature, pH, and turbidity of the water are affected by external factors such as pollution and meteorological events. These external factors influence biochemical reactions within the water. Abrupt changes in these parameters may indicate a change in water conditions (Nishiguchi, 2000).

Groundwater forms part of the hydrologic cycle and it is the water that is found underground in the cracks and spaces in soils, sand and rock. It is stored in and moves slowly through layers of soil, sand and rocks called aquifers. It is protected from the surface contamination by a layer of clay and fine grain sediments.

Boreholes and shallow wells are most common water sources used in rural water supply projects due to low-cost technology option for domestic water supply in developing countries and are generally considered as 'safe sources' of drinking water (Iyasele and Idiata, 2012). When properly constructed and maintained, they provide consistent supplies of 'safe' and good water with low microbial load and little need for treatment of the water before drinking or for other domestic use.

1.2 Problem statement and Justification

Majority of the people in developing countries are not adequately supplied with potable water and are thus compelled to use water from alternate sources like shallow wells, rivers and streams that may not be unsafe for domestic and drinking purposes due to high possibilities of contamination (WHO 2004; 2006). At the moment, many communities throughout the world are prone to water related diseases because water is either scarce or polluted or may not exist at all (WHO, 2012).

According to the WHO (2006), contaminated water causes 80% of the health problems throughout the world. The lack of clean drinking water and sanitation systems is a major public concern in Ghana, contributing to 70% of diseases in the country. Consequently, households without access to clean water are forced to use less reliable and hygienic sources of water (Gyamfi et al., 2012).

The Government of Ghana in conjunction with development partners, Non-Governmental organizations (NGO's), Community Based Organisation (CBO's) and some individuals in an effort to provide safe drinking water to the rural and urban dwellers, have exploited groundwater reserves. However, fertilizer application, agrochemicals, abandoned or inactive mine site, septic tanks and landfill if not managed properly and the presence of heavy metals could result in the contamination of groundwater (Nonner and Nonner, 2002).

The United Nations Organisation (UNO) selected 1981-1990 as the International Drinking Water Supply and Sanitation Decade with the objective of supplying safe drinking water and adequate sanitation for all. 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 have been identified as a challenge limiting the extent to which this resource can be exploited (CWSA, 2012). Iron and manganese are common household water contaminants with unknown direct health effects at levels found in water (WHO, 2003). Studies have shown that iron and manganese levels greater than 0.3 mg/l and 0.5 mg/l in water may cause staining, offensive tastes and odours (USEPA, 2012).

For the past 20 years, Ejisu-Juaben Municipal has been without pipe borne water supply. Until 1984, Ghana Water Company limited (GWCL) was supplying water to some selected areas of the district with water from its head works at Barekese a suburb of Kumasi (Anornu *et al.*, 2009). Currently, the municipality relies mainly on groundwater for its water supply needs and information on water quality is inadequate. Studies have shown that groundwater contamination often correlates with areas of poor hygiene standards and sanitation (Amadi *et al.*, 2013: Adetunji and Odetokun, 2011: Obiri-Danso *et al.*, 2009). Majority of the boreholes and hand-dug wells since being constructed have scarcely been maintained, rehabilitated or any major assessment carried out on the quality of water being pumped from it. Also professional consultation was not properly done because most of the boreholes and hand-dug wells are close to pit latrines, refuse dumps, septic tanks, farmlands and piggeries which pose a threat to groundwater quality.

It is therefore important to determine the groundwater quality for effective and efficient management of the groundwater resource so as to prevent diseases among the inhabitants living within the municipality.

1.3 Objective

The main objective of this study was to assess the quality of water from boreholes and hand-dug wells in the Ejisu-Juaben municipality of Ashanti Region.

1.3.1. Specific Objectives

These are to determine the:

i. temperature, pH, colour, conductivity, total hardness, total dissolved solids (TDS) and turbidity of water samples from selected boreholes and hand-dug wells.
ii. sulphate, chloride, fluoride, nitrate, zinc, cadmium, iron and manganese levels of water samples from borehole and hand-dug well.

iii. microbiological quality (helminths, total coliform, faecal coliform, *E.coli*) of borehole and hand-dug well water samples.

iv. distance from hygiene and sanitation sites (pit latrines, refuse dumps, septic tanks, farmlands and piggery) to boreholes and hand-dug wells.

CHAPTER TWO

LITERATURE REVIEW

2.1 Water resources

Water resources are sources of water that are beneficial or potentially useful. Water resources include surface waters (i.e., coastal bays, lakes, rivers, and streams) and groundwater. These water resources may be used for drinking water, industrial processes, agriculture, and irrigation (USEPA, 2008). 97% of the water on the Earth is made up of salt water and only 3% is freshwater. 68.7% of freshwater is frozen in glaciers and polar ice caps. 30.1% of the unfrozen freshwater is found mainly as groundwater, with 1.2% of the freshwater present above ground and in the air (USGS, 2008). Surface water is water in a river, lake or fresh water wetland. Surface water is naturally restocked by precipitation but it is naturally lost through discharge to the oceans, evaporation, evapotranspiration and sub-surface seepage. Sub-surface water, or groundwater, is fresh water located in the pore space of soil and rocks. It is also water that is flowing within aquifers below the water table. Groundwater is distributed in saturated zone, vadose or unsaturated zone and capillary fringe (Keller, 2000). Groundwater is replenished by recharge, which is the percolation of precipitation downward into an unconfined aquifer. Groundwater is reduced by groundwater discharge, which is often into surface water bodies or springs (Keller, 2011).

2.2 Groundwater development

Improvement of groundwater has been part of man in the ancient days. Bulk of early civilization acquired their water from groundwater and surface water. In 1183, it was told that crusade prisoners in Egypt built their wells from excavated bedrock which was named Josephs well to make sure the bastions supply of water (Osiakwan, 2002).

The Holy Bible talks of groundwater, first in the story of Moses hitting a rock with his stick and bringing forth a fountain of water for the people to drink at Mount Sinai (Exodus 17:6). Tapping groundwater sources involves digging or drilling through the ground and into an aquifer. Groundwater sources have their roots in the water cycle and are contained in aquifers beneath the ground surface. The drilling as an alternative of the digging of wells started in the 12th century with the effective drilling of a well at Artois, France in 1226 (Osiakwan, 2002).

2.3 Groundwater recharge

When it rains, the water does not stop moving. Some of it flows along the surface to streams or lakes, some of it is used by plants, some evaporates and returns to the atmosphere, and some sinks into the ground like a glass of water poured on a pile of sand (Clark *et al.*, 1993). Groundwater is deposited in and moves slowly through layers of soil, sand and rocks called aquifers. Aquifers usually consist of gravel, sand, sandstone, or fractured rock, like limestone. These materials are permeable because they have large connected spaces that allow water to flow through. The water moves down through soil layers and rock fractures until it is intercepted by impermeable layer of clay or rock. Water accumulates on these impermeable layers which occupy all the available spaces in the soil or rock until they are saturated. The stored water becomes the groundwater and the top of the groundwater or the saturated zone is the water table. The water table can be found only a foot below the ground's surface or it can be seated hundreds of feet down.

2.4 Aquifers, boreholes and hand-dug wells

Groundwater sources can be tapped by digging or drilling through the ground and into an aquifer. An aquifer is a water bearing rock that is capable of yielding a quantity of water that can be used. Supply of water to wells from aquifers is not constant due to seasonal variation in rainfall and occasional drought. The quantity of water produced by an aquifer is also dependent on the porosity and permeability of the material than is found in the earth layer. The level of groundwater can be lowered if the rate of pumping is faster than the rate of recharge. Most groundwater is clean but it can be polluted, or contaminated due to human activities or through natural conditions. Elements such as iron, magnesium, sodium, zinc, calcium and chloride can be picked up by water and dissolve in the water as it moves through underground rocks and soil. Some of these natural contaminants when present in high concentrations can pose a health risk. Some of the current human practices that impact groundwater are excessive use of fertilizer or pesticides, leaks from industrial operations, infiltration from urban runoff, and leachates from landfills. The usage of contaminated groundwater poses public health hazards by poisoning or the spread of disease (Nonner and Nonner, 2002).

2.5 History of boreholes and hand-dug wells construction in Ghana

Improvement of groundwater can be dated back from the 19th Century where it was observed that most communities in Ghana totally depended on hand-dug wells for their source of potable water. The colonial governments from 1920-1945 embarked on a national hand dug well program with the support of Rural Water Division (Osiakwan, 2002). Borehole construction in Ghana began in the 1940's to boost the supply of water to rural and urban communities. From 1978-2000, 3000 boreholes were drilled in southern Ghana with the help of the German government (Issah, 2002). During 1985 to 2000, the World Vision International (WVI) constructed 1,523 boreholes throughout the country (WVI, 2000). Borehole and hand-dug well water are very essential source of potable water supply in most Ghanaian communities.

2.6 Groundwater quality

Groundwater in its natural state is usually of very good quality because of the rocks acting as filters. Any bacterial contamination from surface sources or the soil is removed after groundwater passed through 30 meters of saturated sand or unfissured rock but within the unsaturated zone no more than 3 meters may be necessary to purify water percolating through the zone. Rainfall is a dilute chemical solution and adds significant proportions of some components in groundwater, particularly in regions with little soil cover where hard compact rocks are found at or near the surface. When water passes through the soil, the dissolution of minerals continues and the concentration of dissolved constituents increases with increasing length of the flow path. The speed of flowing water in the small inter-granular pore spaces of the unsaturated zone of sandstone is very low. The Matrix tends to absorb and may degrade organic compounds, bacteria and virus. Some metals may also be absorbed, diluted or modified into simpler products by chemical reactions. These processes retard the movements and concentration of contaminants through an aquifer. But in fissured aquifer, contaminants can speedily move through the unsaturated zone to the water table reducing the purifying process. This is particularly likely after a period of powerful or lengthy rainfall (Wagner and Gorelick, 1987).

2.7 Groundwater quality in Ghana

Geology plays a vital role in the determination of groundwater quality and potential water-quality problems. As the country is dominated by crystalline silicate rocks and weathered derivatives, groundwater is primarily of low salinity and usually acidic in composition (pH<6.5), with low values of total hardness but exceptions occur in areas of limestone (parts of the south-east) and along the coastal margins where hardness and pH values are higher and where seawater intrusion of the coastal aquifers may increase groundwater salinity. Slight occurrences of saline groundwater have also been noted in isolated boreholes in rocks of the Voltaian Basin. The salinity over there is characteristically related to high sulphate concentrations (Pelig-Ba, 1999). The main groundwater-quality problem observed in Ghana is high iron concentrations, seen in many groundwater supplies. The most serious direct health problems related to drinking water are considered to be from fluoride excess and iodine deficiency which have been noted in parts of the Upper Regions of northern Ghana (Antwi *et al.*, 2011). Arsenic has also been identified in a few groundwater supplies, though not generally at concentrations significantly above guideline values. Arsenic problems are unlikely to be of large lateral extent (Buckley, 1986).

Table 1: Summary of potential groundwater-quality problems in Ghana (British Geological Survey Report "Groundwater: Ghana" to WaterAid Ghana).

Determinant	Potential Problem	Geology	Location
Iron (Fe)	Excess, often significant	All aquifers	Many locations
Manganese (Mn)	Excess	All aquifers	Several locations
Fluoride (F)	Excess (up to 4mg/l)	Granites and some Birimian rocks	Upper Regions
Iodine (I)	Deficiency (less than 0.005 mg/l)	Birimian rocks, granites, Voltaian	Northern Ghana (especially Upper Regions)
Arsenic (As)	Excess (> 0.01mg/l)	Birimian	Especially south-west Ghana (gold belt).

2.8 Indicators of groundwater quality

Water quality is a measure of the condition of water in relation to the requirements of one or more biotic species and or to any human need or purpose (Johnson *et al.*, 1997). It refers to refers to the chemical, physical and biological characteristics of water (Diersing, 2009). The quality of water is significantly influenced by the levels of some constituents present in the water. Some of these constituents serve as water quality indicators. Some of these are:

2.8.1 Physicochemical parameters

2.8.1.1 Temperature

Temperature is a physical quantity that measures degrees of hot and cold on a numerical scale. The temperature of water is a degree of how much heat energy the water contains. It refers to the state of matter or radiation in a local region (Bailyn, 1994). Temperature of water is the measure of how hot or cold water is and it is measured by a thermometer which can be calibrated to a variety of temperature scales in degree Celsius or Fahrenheit (APHA, 1995). The temperature of groundwater is generally equal to the mean air temperature above the land surface. It usually stays within a narrow range year-round (NGWA, 1999). Temperature of water at a particular time can be used to some extent to determine the rate of microbial activities in the water. Water freezes and boils at 0˚C and 100˚C respectively.

2.8.1.2 pH

pH is mostly used to refer to the hydrogen ion concentration of a solution. Acidic environments have high hydrogen ions while basic environments have a less hydrogen ion concentration. The pH scale is computed as the negative logarithm of the concentration of hydrogen ion. Pure water has a pH very close to 7 at 25°C. Acidic solutions have pH less than 7 and solutions with a pH greater than 7 are basic or alkaline (Covington *et al.*, 1985). Bicarbonates and carbonate of the alkali and alkaline earth metals have made natural water to have a pH of 4-9. To be able to determine pH involves the activity of hydrogen ions by potentiometric measurements using a standard hydrogen electrode and a reference electrode. Ph measurement is influenced by mechanical effects and chemical effects. The mechanical effects are caused by changes in the properties of the electrode and the chemical effects by equilibrium changes. According to APHA (1995), standard pH buffers have a specific pH at specified temperatures due to the effect of chemical equilibrium on pH.

2.8.1.3 Colour

Colour is common in surface water supplies. It is virtually non-existent in spring and deep wells due to material screening (Amankonah, 2010). Most common cause of water colour is the presence minerals. Water colour is referred as apparent colour and true colour and this depends on the type of solid material that it contains. Apparent colour is the colour of the whole water sample that is made up of dissolved and suspended components. True colour is measured by filtering the water sample to remove every suspended material before measuring the colour of the filtered water, which represents colour due to dissolved components. Tannins and lignins which occur naturally are derived from the decomposition of plant and animal matter, give surface water and groundwater a tea-like yellow-brown chromaticity (IFAS, 2004). The colour of water measured by colometric methods is based on the calibration or absorbance of the water sample at a variety of single wavelengths, usually against the Pt-Co Standard measurement or Alpha-Hazen Scale. Colour of natural water varies from <5mg/L Pt in very clear water to 1200mg/L in dark peaty waters (Keyser, 1997).

2.8.1.4 Conductivity

Conductivity is a measure of the ability of water to transmit an electrical current. The measurement is important for what it indicates about the concentration of dissolved ions in the water, which in turn reflects groundwater input, catchment geology, or diverse human impacts. As the number of charged ions in the water increase, so does the electrical conductivity. Conductivity in water is influenced by the presence of dissolved inorganic anions such as chloride, nitrate, sulphate, and phosphate or cations such as sodium, magnesium, calcium, iron, and aluminium (APHA, 1992). Conductivity of groundwater depends on the bedrock they flow through. The standard unit of measuring conductivity is the mho or siemens. Conductivity can also be measured in microohms per centimeter (µmhos/cm) or microsiemens per centimeter (µs/cm). Portable water has conductivity ranging from 50-10000µmhos/cm. Distilled water has conductivity ranging from 0.5 to 3 µmhos/cm (Hach Company, 1992).

2.8.1.5 Total dissolved solids

Total Dissolved Solids (TDS) is a measure of the combined content of all inorganic and organic substances contained in a liquid in a suspended form. It is used as an indication of aesthetic characteristics of drinking water and as an aggregate indicator of the presence of a broad array of chemical contaminants (DeZuane, 1997). The most common chemical constituents that make up total dissolved solids are chloride, calcium, nitrates, sodium, phosphates, potassium and which are mostly found in nutrient runoff. Other organics can also enter both surface and groundwater through waste dumping. Some naturally occurring total dissolved solids originate from the weathering and dissolution of rocks and soils. The total dissolved solids can be calculated by recording the specific conductance of the water. TDS for distilled water is 0, de-ionized water is 8, rain and snow is 10, brine well is 125000 and Dead Sea is 250,000. The two major methods of recording total dissolved solids are gravimetry and conductivity (USEPA, 1991).

2.8.1.6 Hardness

Hard water contains relatively high levels of calcium and magnesium salts and other metals. Hardness of water depends on the quantity of minerals it contains. Water is referred to as "hard" when it needs more soap for a good lather thereby making it harder to clean with compared to water that is soft. Drinking hard water is normally not harmful to one's health. In domestic settings, it is usually showed by a lack of suds formation when soap is agitated in water (WHO, 2003). The degree of hardness in water is influenced by the quantity of calcium and magnesium salts it contains. Magnesium and calcium combine with chlorides, bicarbonates, nitrates and sulphates to form the salts. The standard domestic measurement for hardness is milligram per liter (mg/l) as $CaCO_3$. Water is considered soft if it contains 0 to 60 mg/l of hardness, moderately hard from 61 to 120 mg/l, hard between 121 and 180 mg/l, and very hard if more than 180 mg/l. Very hard water is not desirable for many domestic uses because it will leave a scaly deposit on the inside of pipes, boilers, and tanks.

2.8.1.7 Turbidity

Turbidity refers to the degree of clarity of the water. Turbidity in drinking water can be naturally occurring and it is caused by suspended matter such as clay, silt, inorganic matter and fine organic, and also by microorganisms. Turbidity in groundwater is common because of natural geology. Poor borehole and well construction also allows surface water to leak into them. Turbidity can cause the discolouring of fabrics. Usually turbidity is measured in NTU (nephelometric turbidity units) typical drinking water have turbidity level of 0 to 1 NTU. Turbidity expresses the optical property that causes light to be scattered and absorbed rather than transmitted in a straight line through the sample. Correlation of turbidity with weight concentration of suspended matter is difficult because the size, shape and refractive index of the particle also affect the light scattering properties of the suspension (USEPA, 2003a).

2.8.1.8 Taste and odour

Water can dissolve many different substances, giving it varying tastes and odours. Humans and other animals have developed senses which (more or less) enable them to evaluate the potability of water by avoiding water that is too salty or putrid. The taste in mineral water is derived from the minerals dissolved in it. Pure water is tasteless and odourless (MassDEP, 2013). Taste and odour at objectionable levels occur in most wells and hydrogen sulphide odour is most often reported. In groundwater supplies, the origin of taste and odour contaminants generally cannot be determined. In surface water, taste and odour problems typically are attributed to algae, cyanobacteria and dissolved organic matter (Environmental Fact Sheet, 2010).

2.8.1.9 Alkalinity

Alkalinity is a measure of the ability of a water sample to neutralize acids. It is an aggregate property that is derived from the sum of the neutralizing capabilities of all bases present in a water sample. Alkalinity is measured by volumetric analysis using a standardized acid titrant. The endpoint is signaled by a colour change of a pH indicator, such as phenolphthalein or methyl orange or by using a pH meter (Csuros, 1997). The optimal amount of alkalinity for given water is a function of several factors including pH, hardness and the concentration of dissolved oxygen and carbon dioxide that may be present. Water might be unsuitable for use in irrigation if the alkalinity level is higher than the natural alkalinity level in the soil. 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 (Amankonah, 2010). Alkalinity values can change significantly from groundwater between samples taken at the wellhead and samples taken from other spots (USEPA, 2003).

2.8.2 Anions levels

2.8.2.1 Nitrates

Nitrate is a form of dissolved nitrogen that comes about naturally in soil and water. Nitrate is the main source of nutrients for plants and can also be used as fertilizer. Almost all the natural concentrations of nitrate are not a health concern to humans but when in excess it causes a problem. Examples of human activities that can introduce nitrates into water are fertilizing, leaky septic tanks, runoff from animal feedlots, wastewater treatment lagoons and industrial wastes (Alloway and Ayres, 1997). Even though any well can become contaminated by nitrates, poorly constructed, shallow, or inappropriately located wells are more prone to contamination. High nitrate concentrations may indicate the possibility of additional contaminants such as pathogens, pesticides, inorganic and organic compounds that could cause health problems. High nitrate levels have been known to cause a potentially fatal blood disorder in infants less than six months of age called methemoglobinemia or "blue-baby" syndrome. In more severe cases, infants will start showing noticeable symptoms of cyanosis: the skin, lips or nailbeds may develop a slate-gray or bluish colour and the infant could have trouble breathing (Kim-Shapiro, 2005).

2.8.2.2 Phosphates

Phosphorus is vital for life due to the fact that it is one of the basic elements necessary for the growth of plants and animals in the food web. Elemental form of phosphorous is toxic and can be bioaccumulated. Phosphate is formed from this accumulation. Phosphate occurs in three forms. Orthophosphate, metaphosphate (polyphosphate) and organically bounded phosphate. The main source of phosphorus in the environment is from soil and rock weathering. In nature, phosphorus usually exists as part of a phosphate molecule (PO_4). There are many sources of phosphorus, both natural and human. These include soil and rocks, wastewater treatment plants, runoff from fertilized lawns and cropland, failing septic systems, runoff from animal manure storage areas, drained wetlands, water treatment, and commercial cleaning preparations (Centre for Earth and Environmental Science, 2013). Phosphate gets into groundwater through leaching. It may not be toxic to people or animals unless they are present in very high levels. Digestive problems could occur from extremely high levels of phosphates.

2.8.2.3 Fluorides

Fluoride compounds are salts that form when the element fluorine combines with minerals in soil or rocks. Fluoride gets into drinking water through discharge from fertilizer or aluminum factories. Some fluoride compounds such as fluorosilicates and sodium fluoride dissolve easily into groundwater as it passes through gaps and pore spaces between rocks. Most water supplies contain some naturally occurring fluoride. Excessive intake of fluoride over a long period of time may cause pitting of teeth and severe skeletal problems such as crippling fluorosis, stiff joints, severe anaemia, and restricted movement. Defluoridation is difficult and expensive so the best option for dealing with excess levels is to switch alternative water sources available. The suggested maximum contaminant level (MCL) for fluoride in drinking water is 4.0 mg/l or 4.0 ppm (USEPA, 2012).

2.8.2.4 Sulphates

Sulphate is a substance that occurs naturally in drinking water. Most sulphate compounds originate from the oxidation of sulphate ores, the presence of the shale and the existence of industrial waste. Sulphate is one of the major nutrients dissolved in rain. As water moves through the soil and rock formations that contain sulphate minerals, some of the sulphate dissolves in the water into the groundwater (USEPA, 2012). Some minerals that contain sulphate are sodium sulphate (Glauber's salt), magnesium sulphate (Epsom salt), and calcium sulphate (gypsum). High concentrations of sulphate in drinking water will cause a laxative effect when combined with calcium and magnesium. The maximum level of sulphate prescribed by the World Health Organization (WHO) is 500 mg/l. European Union standards are more current, broad and firm than the WHO standards, suggesting a maximum of 250 mg/l of sulphate in water intended for human consumption. Sulphate offers a bitter taste to water if it goes beyond of 250 mg/l.

2.8.2.5 Chloride

Every water supply contains some level of chlorine. It is one of the most important anions found in water which normally combines with calcium, magnesium or sodium. Chloride is commonly found in nature as a salt. Most naturally occurring chlorides are in the oceans. Chloride in groundwater may be of natural or human sources. These include dissolving rocks, highway salt, oil wells, irrigation, drainage sewage and leachates from dump sites. Human and animal wastes contain a high concentration of chlorides. The amount of chlorides in water is determined by the type of rocks and soils it has contacted. Chloride dissolves and moves with groundwater. Chloride sources can impact water quality in distant locations. Water supplies having high concentrations of total dissolved solids (TDS) may also contain elevated chloride levels as part of the TDS. The suggested maximum contaminant level (SMCL) for chloride in drinking water is 250mg/l which is due to salty taste produced in drinking water (USEPA, 2003).

2.8.3 Heavy metals

Heavy metal is any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations. Examples are copper, selenium and zinc. They are natural components of the Earth's crust. They are non-degradable. To a small extent they enter our bodies via food, drinking water and air. Heavy metals are hazardous because they accumulate and at higher concentrations lead to poisoning (Lenntech, 2012). Heavy metals get into water supply through industrial, consumer waste and also from acidic rain breaking down soils and thereby releasing heavy metals into streams, lakes, rivers and groundwater. Heavy metal toxicity can result in damaged or reduced mental and central nervous function, lower energy levels, and damage to blood composition, lungs, kidneys, liver, and other vital organs. Long-term exposure may result in slowly progressing physical, muscular, and neurological degenerative processes that mimic

Alzheimer's disease, Parkinson's disease, muscular dystrophy, and multiple sclerosis (International Occupational Safety and Health Information Centre, 1999).

2.8.3.1 Cadmium

Cadmium is a metal found in natural deposits and it is used primarily for metal plating and coating operations such as transportation equipment, machinery and baking enamels, photography, and television phosphors. It is also used in nickel-cadmium solar batteries and pigments. EPA has found cadmium to potentially cause the following health effects when people are exposed to it at levels above the maximum contaminant level (MCL) for relatively short periods of time: nausea, vomiting, diarrhea, muscle cramps, salivation, sensory disturbances, liver injury, convulsions, shock and renal failure (USEPA, 2012). Cadmium may enter aquatic systems through weathering and erosion of soils and bed rock, atmospheric decomposition of direct discharges from industrial operations, leakage from landfills and contaminated sites and the dispersive use of sludge and fertilizers in agriculture (WHO, 1992).

2.8.3.2 Iron

Iron makes up about 5% of the earth's crust and can exist as soluble ferrous iron or as the relatively insoluble ferric form found in water. Soluble ferrous iron is found in groundwater, in anaerobic reservoirs, in dead-ends in water distribution systems, and in scale (hard mineral coatings) within pipes. Rainwater as it infiltrates the soil and underlying geological formations dissolves iron causing it to seep into the aquifer that serves as source of groundwater for boreholes. The primary sources of iron in drinking water are natural geologic sources as well as aging and corroding distribution systems and household pipes (USEPA, 2012). When iron exceeds the required amount needed by the body, it is stored in the liver. The bone marrow contains high amount of iron because it produces haemoglobin. When high concentrations of iron are absorbed, for example by haemochromatose patients, iron is stored in the pancreas, the liver, the spleen and the heart. This may damage these vital organs. The combination of naturally occurring organic materials and iron can be found in shallow wells and surface water. This type of iron is usually yellow or brown but may be colourless (IDPH, 2010).

2.8.3.3 Manganese

Manganese constitutes approximately 0.1% of the earth's crust and it is a naturally occurring component of nearly all soils. It can be found in the air, soil, and water. Manganese is also an essential nutrient for humans and animals (Leach and Harris, 1997; USEPA, 2003). Manganese can occasionally be found alone in a water supply. It is often found in iron-bearing waters. In low concentrations it produces extremely unpleasant stains on everything it comes in contact with. Excessive intake of manganese has been associated with toxicity to the nervous system which produces a syndrome that resembles Parkinsonism. Manganese concentrations higher than 0.5 mg/l become evident by impairing colour, odour, or taste to the water. According to the USEPA, health effects are not a concern until concentrations are about 10 times higher (USEPA, 2012).

2.8.3.4 Zinc

Zinc occurs in small amounts in almost all igneous rocks. The principal zinc ores are sulphides such as sphalerite and wurzite (Elinder *et al.*, 1986). The natural zinc content of soils is estimated to be 1–300 mg/kg. Zinc imparts an undesirable bitter taste to water. Tests indicate that 5% of a population could distinguish between zinc-free water and water containing zinc at a level of 4 mg/litre (as zinc sulphate). Water containing zinc at concentrations in the range 3–5 mg/l also tends to appear opalescent and develops a greasy film when boiled. In natural surface waters, the concentration of zinc is usually below 10 mg/litre and in groundwaters 10–40 µg/l (Elinder *et al.*, 1986). In tapwater, the zinc concentration can be much higher as a result of the leaching of zinc from piping and fittings.

2.8.3.5 Lead

Lead is the commonest of the heavy elements which accounts for 13 mg/kg of Earth's crust. It is found in natural deposits and generally used in household plumbing materials and water service lines. The greatest exposure to lead is swallowing or breathing in lead paint chips and dust (USEPA, 2012). Lead found in fresh water usually indicates contamination from metallurgical waste. Lead that is found in drinking water supply is mainly from corrosion of the lead used to join the copper piping. Excessive intake of lead can cause serious damage to the kidneys, brain, red blood cells and nervous system. Except in related cases lead is probably not a major problem in drinking water although they potentially exist in cases where old lead pipes is still used. Reverse osmosis can be used get rid of 94 to 98% of the lead found in drinking water at the point of use (Manahan, 1999).

2.8.3.6 Mercury

Mercury is a liquid metal found in natural deposits. The major sources of mercury in drinking water are erosion of natural deposits, discharge from refineries and factories, runoff from landfills and runoff from croplands. Drinking water containing mercury well in excess of the maximum contaminant level (MCL) can cause kidney damage (USEPA, 2012). Levels of mercury in rainwater are in the range 5–100 mg/l but mean levels as low as 1 mg/litre have been reported (Amorim *et al.*, 2000). Naturally occurring levels of mercury in groundwater and surface water are less than 0.5 mg/l although local mineral deposits may produce higher levels in groundwater. Few groundwaters and shallow wells surveyed in the USA were reported to have mercury levels that exceeded the maximum contaminant level (MCL) of 2 mg/l set by the US Environmental Protection Agency for drinking-water (Ware, 1989).

2.8.3.7 Arsenic

Arsenic is a chemical element found naturally in rocks and soil, air, water, animals and plants. It is semi-metal element in the periodic table and it is odourless and tasteless. Arsenic contamination of drinking water could be due to natural or human activities. Natural sources include erosion of rocks and minerals, volcanic activity and forest fires. The USEPA has set the arsenic standard for drinking water at 0.010 parts per million to protect consumers from chronic exposure. Excessive intake of arsenic can include stomach pain, nausea, vomiting, diarrhea, and blindness, numbness in hands and feet and partial paralysis. Arsenic has been connected to cancer of the lungs, bladder, kidney, and skin, liver and prostate (USEPA, 2012).

2.9 Groundwater contamination

Groundwater contamination is the detrimental alteration of the naturally occurring physical, thermal, chemical or biological quality of groundwater. Groundwater contamination takes place when dangerous materials come into contact and dissolve in the water that has soaked into the soil. If rain water or surface water gets contact with contaminated soil while seeping into the ground, it can become contaminated and can carry the contaminants to the groundwater. Some liquid harmful substances are immiscible with the groundwater but accumulate within the soil or bedrock. These accumulated materials can act as long-term sources of groundwater contamination as the groundwater flows through the contaminated soil or rock (USEPA, 2012). Some of the main sources of groundwater contaminants include septic systems, landfills storage tanks, hazardous waste sites, and the widespread use of road salts, pesticides and fertilizers (The Groundwater Foundation, 2013).

2.10 Sources of groundwater contamination

Groundwater can be contaminated by agricultural, industrial and residential sources. Groundwater has some impurities though it is unaffected by human activities. The types and concentrations of natural impurities is depended on the nature of the geological material through which the groundwater flows and the quality of the recharge water. Some aquifers have high natural concentration of dissolved constituents such as arsenic. The effects of these natural sources of contamination of groundwater quality depend on the type of contaminants and its concentration (Lenntech, 2012). According to USEPA (1997), some natural contaminants of groundwater include arsenic, chloride, aluminium, chromium, coliform bacteria, copper, fluoride, iron, lead, manganese, mercury, nitrate, sulphate and zinc.

2.10.1 Agricultural sources of groundwater contamination

Pesticides, fertilizers, animal waste and herbicides are agricultural sources of groundwater contamination. The agricultural contamination sources are varied and numerous and they include spillage of fertilizers and pesticides, runoff from feedlots and washing of pesticide sprayers or equipment (Lenntech, 2012). Animal waste is most often gathered in impoundments from which the waste may leach into the ground water. Runoff can get into an aquifer through a poorly sealed well casting (USEPA, 1997).

2.10.2 Industrial sources of groundwater contamination

Shallow underground disposal is used mostly by some industries without sewer systems. Most of them use cesspools, dry holes or septic tanks. Any of these forms of disposal can lead to contamination of underground sources of drinking water especially when there are leakages. Wastewater disposal practices of certain types of businesses including dry cleaners, automobile service stations, photo processors, electrical component or machine manufacturers and metal platters are of major concern because the waste they generate is likely to contain toxic chemicals (Lenntech, 2012). Underground and above ground tanks holding acids, petroleum products, chemicals and solvents can develop leaks from corrosion, defects or improper installation. Additionally mining of fuel and non-fuel minerals can cause ground water contaminations (USEPA, 1997).

2.10.3 Residential sources of groundwater contamination

Residential wastewater systems is home of various kinds of contaminants which include including viruses, bacteria and nitrates. Septic systems, drainage wells for storm water runoff, cesspools and groundwater recharge wells are of specific concern to groundwater quality if they are located near wells. Wastes that are dumped or buried in the ground can contaminate the soil and leach into the groundwater (Lenntech, 2012). Lawns with over applied or misapplied fertilizers, herbicides and fungicides might introduce these contaminants such as tetrachloride and heavy metals such as manganese and cadmium into the soil and to groundwater (USEPA, 1997).

2.11 Microbial accumulation in boreholes and hand-dug wells

Most fouling problems found in hand-dug wells and boreholes are caused by bacteria and their associated colonies. Bacteria produce slime or polysaccharide exo-polymers known as biofilm. These bacteria are often spoken of as the slime former which fouls screens, gravels pack and aquifer formations (Amankona, 2010). Sometimes it leads to general fouling of the well because they promote the deposition of minerals in the slime matrix. Anaerobic and sulphur bacteria are mostly found in the anaerobic environment which is usually located in the lower extensions of the hand-dug wells and boreholes. The Sulphur is reduced by sulphur reducing bacteria (SRB) which produce the typical ‘’rotten egg’’ odour of hydrogen sulphide gas. The gas is acidic which alters the pH of the immediate areas making it acidic.

2.12 Coliform bacteria and groundwater contamination

Coliform bacteria are defined and grouped based on their common origin or characteristics. The Total group includes Faecal Coliform bacteria such as *Escherichia coli* naturally found in the soil. Faecal Coliform bacteria are found in the intestines of warm blooded animals and humans, animal droppings, and are found in bodily waste, and naturally in soil. Most of the Faecal Coliform in faecal material is comprised of *E. coli*. The serotype *E. coli* 0157:H7 is noted to cause severe human illness. The presence of Faecal Coliform in well or borehole water may indicate recent contamination of the groundwater by human sewage or animal droppings. This is why Coliform bacteria are considered "indicator organisms". Their presence warns of the potential presence pathogens and precautionary action must be taken (British Columbia Ministry of Health, 1999). Many coliform do not cause illness. However their presence in a water system is a public health concern because of the potential for pathogens to be present. Waterborne diseases from these organisms involve symptoms such as nausea, vomiting, diarrhea and fever (Center for Disease Control, 1998).

2.13 Helminths

Helminth is a term used to describe parasitic worms collectively. Globally, worms are the principal causative agents of human disease. It is anticipated that the number of human infections caused by helminths collectively is on the order of 4.5 billion (Roberts *et al.*, 1996).

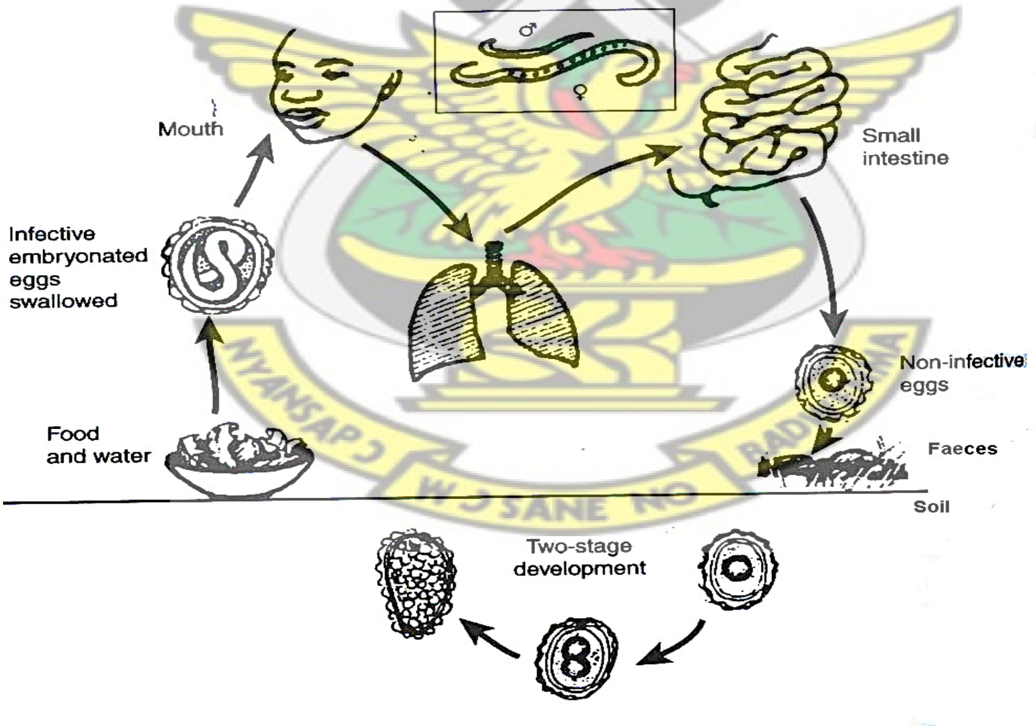
2.13.1 Helminths categorization

Helminths are mostly categorized into three phyla namely: Nematoda (roundworms), Platyhelminths (flatworms), and Annelida (segmented worms). Nearly all human infections are linked with nematodes and flatworms, while the segmented worms are primary ectoparasites, such as leaches. The phylum collectively represents one of the most abundant animal groups on earth, most of which are harmless to humans. Included among its members are the large roundworm *Ascaris lumbricoides*, the whipworm *Trichuris trichuira*, the hookworms *Necator americanus* and *Ancylostoma duodenale* and the threadworm *Strongyloides*. *Ascaris lumbricoides* is considered to be the most prevalent parasitic infection worldwide with over one and half billion persons infected (Crompton 1999; Maier *et al.*, 2000; Roberts *et al.*, 1996). The human infective stage of helminths varies; in some species it is either the adult organism or larvae, while in other species it is the eggs, but it is primarily the eggs that are present in water.

2.13.2 Helminths' life cycle

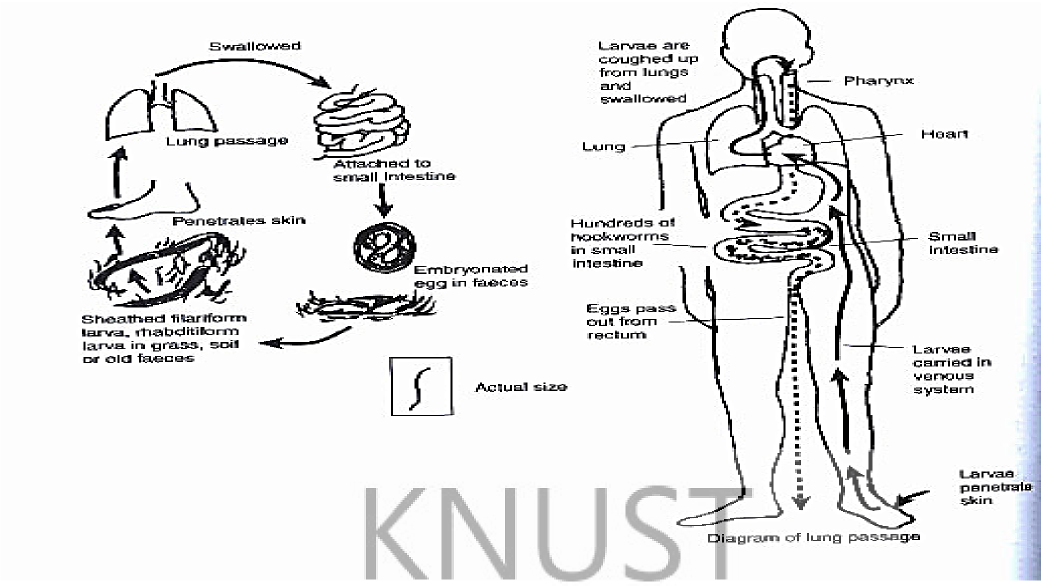
Helminths have different and complex life cycles and ideal living environments. Their life cycle is very different from that of bacteria and protozoan, which are well-known microbes in the sanitary field. *Ascaris lumbricoide*s life cycle illustrates these differences well (Fig. 1). The eggs are not usually infective and to become so they need to develop a larva. The larva develops in the normal temperature and moisture of soil and crops in around 10 days. If a person ingests 1 to 10 *Ascaris* eggs, by consuming contaminated water for instance, the eggs moves to the intestine adhering to the duodenum. There, the larva begins to develop producing an enzyme that dissolves the shell. When the eggs hatch, the larva move out of the egg, it crosses the intestine wall and enters the blood stream. Through the blood *Ascaris* is transported to the heart, lungs and bronchus tubes. It resides in the lungs for approximately 10 days before moving to the trachea from where it is ingested and returned once again to the intestine. During its journey, many larvae are destroyed, as they are lost in tissues unsuited to their development, but in other cases the larva forms cysts in the bladder, kidneys, pancreas, appendix or liver producing damage and that requires surgical removal. Back in the intestine, 2-3 months after its departure, *Ascaris* reaches its adult phase, and, if female, produces up to 27 million eggs. The eggs are passed to the faeces in the unembryonated state and the life cycle begins once again.

Infection with hookworm differs from symptomless to a prolonged debilitating disease with a variety of symptoms. The adult worms live in the upper part of the small intestine (Fig. 2). Their heads are attached to the wall of the intestine by hooks. The hookworm eggs are passed in the faeces already embroyonated. If the faeces are left in warm moist surroundings they develop into larvae. The larvae leave the faeces and bury themselves in moist damp soil. When the larvae come into contact with human skin it attaches itself and penetrates actively through the skin. The larvae pass via the lymphatic system and blood stream to the lungs. The larvae then travel up the trachea and are swallowed a second time. They reach the small intestines where they grow to be adults.



Source: http://wikieducator.org/Lesson_15:_Intestinal_Helminths

Fig. 1: Diagrammatic representation of *Ascaris lumbricoides* Life cycle



Source: http://wikieducator.org/Lesson_15:_Intestinal_Helminths

Fig. 2: Diagrammatic representation of Hookworm Life cycle and transmission

2.13.3 Helminthiases

It is estimated worldwide that there are almost 1,400 people suffering from helminthiases (WHO, 1996) almost all of them in developing countries. Helminthiases are mostly found in regions where poverty and poor sanitary conditions prevail. Under such circumstances the incident rates may reach 90% (Bratton 1993). There are several kinds of helminthiases named after the helminths causing them. Ascariasis is the most common one and is endemic in Africa, Latin America and the Far East, although the morbidity rate differs according to the region. Almost 73% of *A. lumbricoides* infections occur in Asia, while about 12% occur in Africa and only 8% in Latin American (Peters, 1978). Even though the mortality rate is low; most of the people infected are children under 15 years with problems of stumbling growth and/or decreased physical fitness. Children infected with Ascaris have proven to be lower in weight and height and have lower haemoglobin concentration and I.Q. than the control group (El- Nofely and Shaalan, 1999). Around 1.5 million of these children will probably never bridge the growth deficit, even if treated.

2.13.4 Helminths eggs

Helminths are worms which cause a wide variety of diseases globally called helminthiases. Helminthiases almost only occur in developing countries, particularly in areas where sanitation is low. Although helminths are not microscopic animals, their eggs, which are the infective agents, are microscopic. Helminths eggs are released to the environment through faeces and the oral faecal route is the main spreading pathway of the disease (Bethony *et al.*, 2006). An important characteristic of helminths ova is that they have a shell that consists of 3-4 basic layers with a specific chemical composition: a lipoid inner layer, a chitinous middle layer and outer protein layer. All these layers render the eggs very resistant to several environmental conditions. Helminths ova of concern in the sanitary field have a size between 20 to 80 μm and a density of 1.06-1.15 and are very sticky (Ayres *et al.*, 1992). Only contact time at temperatures of around 40˚C has been established for one genus of helminths, Ascaris, and according to US-EPA (1992), it is around 10-20 days.

2.13.5 Sources and routes of transmission

Helminths parasites can be transmitted to human hosts via food and water. The parasites develop and contaminate food and water during their stages of development. Human hosts are impacted by zoonotic infections or contamination. Helminths are transmitted to humans through contaminated food, water, and fomites (Brooker *et al.*, 2006). The transmissible stages contaminate food and water directly or indirectly. Infective stages can be passed through fecal matter, reaching the human host by direct consumption or by use of contaminated water during the preparation of food (Lloyd and Soulsby, 1998).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

Ejisu-Juaben Municipal is one of the 27 administrative and political districts in the Ashanti Region of Ghana. It lies within latitude 1.15˚N and 1.45˚N and longitude 6.15˚W and 7.00˚W. The Municipality is located in the central part of the Ashanti Region and shares boundaries with seven other districts in the region namely Amansie East, Kwabre, Afigya Sekyere, Asante Akim north, Asante Akim South, Bosome Atwima Kwanwoma and Kumasi Metropolis (Fig. 3). The Municipality stretches over an area of 637.2 km^2 constituting about 10% of the entire land area of Ashanti Region and with Ejisu as its capital. The municipality lies within the semi deciduous forest zone of Ghana, which does not differ much in appearance from the rain forest (Mensah and Yankson, 2013). The mean annual rainfall is 1200mm with temperatures range between 20˚C in August and 32˚C in March (MOFA, 2013). The 2010 National Population Census put the population of the Municipality at 143,762 comprising 68,648 males and 75,114 females and the main occupation in the Municipality is farming.

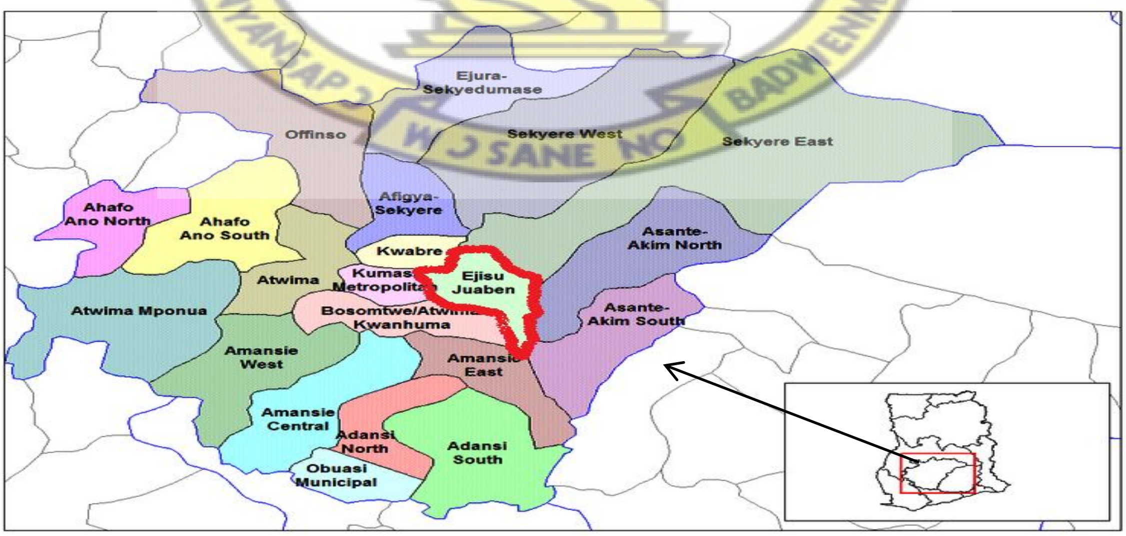


Fig. 3: A map of Ashanti Region showing the study area bounded by seven other districts.

3.2 Geology and soil type

The study area is predominantly underlain by crystalline rocks. These rocks belong to the Birimian, Granites formation (Kesse, 1985). The geology and soil types found in the municipality include the Kumasi- Offin Compound Association, Bomso-Offin Compound Association, Swedru-Nsuba Simple Association, Boamang-Suko Simple Association, Bekwai-Oda Compound Association, Kobeda-Eschiem-Sobenso-Oda Compound Association, Atunkrom-Asikuma Association and Juaso-Mawso Association (Ejisu-Juaben Municipal Assembly, 2006).

3.3 Selection of boreholes and wells

Urban centres are considered as those with population above 5,000. Out of 84 settlements, the municipal has only five (5) urban centres namely: Ejisu, Juaben, Bonwire, Fumesua and Besease. These five towns account for 30.18% of the total population in the district with the municipal capital covering 9.2% (Ejisu Juaben Municipal Assembly, 2006). All the five urban centres were used for the study. The distribution of public boreholes and hand-dug wells in the study area are as shown in Table 2.

Table 2: Total number of public boreholes and hand-dug wells in the 5 urban areas of Ejisu Juaben Municipality that were used for the study.

Urban Centres	Ejisu	Juaben	Bonwire	Fumesua	Besease
Boreholes	4	3	3	3	3
Hand-dug wells	4	5	5	3	4

At Ejisu, three boreholes and three wells were randomly selected for the study. All the boreholes were numbered from one to four. The numbers were mixed together in a plastic bowl and 3 were handpicked representing the 3 boreholes to be used for the study. This same principle of randomization was used to select 3 hand-dug wells from each of the urban areas that were used for the study with the exception of Fumesua. The main reason for using the simple random sampling was ensure that each of the borehole and hand-dug well has equal chance of being selected for the study. At Juaben, it was observed that all the 3 boreholes and one hand-dug well were found particularly in northern part of the town. 4 hand-dug wells were located within the southern part of the town. All the three boreholes were selected and due to the locations of the wells, purposive sampling was done to select one well among the boreholes and the other two wells were randomly selected using the same principle applied in selecting the hand-dug wells from the other towns. All the 3 boreholes in Bonwire, Fumesua and Besease were selected for the study. A total of fifteen boreholes and fifteen hand-dug wells were sampled for the study. A GPS was used to geographically locate all sampling communities (Fig. 4).

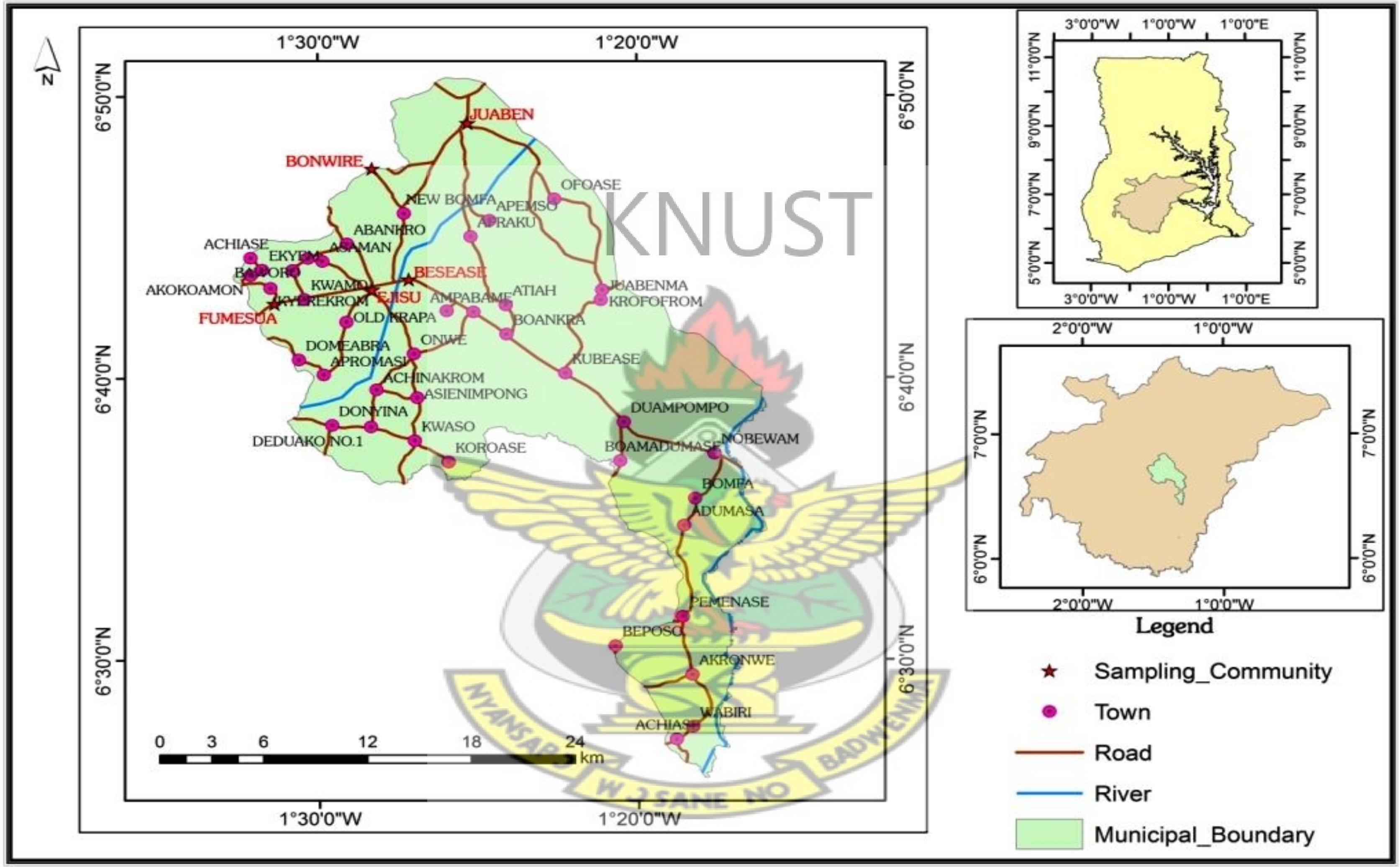


Fig. 4: Map of the Ejisu Juaben area showing the sampling communities (in red print) with an insert of Ghana's map showing Ashanti region in relation to the rest of the country.

3.4 Sample collection

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 content of total dissolved solids (TDS). All plastic bottles were cleaned with warm water and soap then rinsed with distilled water. Water samples for microbial analysis were collected with 500 ml and 2000ml plastic bottles. Water samples for metals and physicochemical analysis were collected with 500 ml and 750 ml plastic bottles respectively.

For boreholes, the mouth of the metal pipe was cleaned with alcohol and flamed. Water was pumped out of the boreholes to cool the metal pipe so as to eliminate the influence of the water temperature with that of the metal pipe. Sample bottles for physicochemical, metal and microbial analysis were rinsed with some of the borehole water and then completely filled to capacity leaving no air space and immediately covered. The cover of the container was sealed with masking tape.

Considering the hand-dug wells, plastic container with rope was used to fetch water from wells. The plastic container was cleaned with warm water and soap and completely rinsed with distilled water. Sample bottles for physicochemical, metal and microbial analysis were rinsed with some of the hand-dug well water and then completely filled to capacity leaving no air space and immediately covered. The cover of the container was sealed with masking tape.

For metal analysis, concentrated nitric acid was immediately added to the water samples for heavy metal analysis reducing the pH to <2. This is to dissolve the metals in the water samples and prevent it from adhering to the inner surface of the bottles.

Distances from boreholes and hand-dug wells were measured with 100m or 330ft fiber glass measuring tape.

Water samples were taken to the laboratory in cool box with ice and analyzed within 6 hours. Samples meant for metal analysis were stored in a refrigerator at 4°C.

3.5 Temperature, pH, total dissolved solids (TDS) and electrical conductivity (EC) determination

These parameters were measured on site using Cyberscan PC 300 Waterproof Handheld pH/Conductivity/TDS/Temperature meter. A digital reading appears upon inserting the probes into the sample indicating first the values of pH and temperature. The sample was stirred and the digital reading was allowed to stabilize before recording. The "MODE" button which allows switching to other parameters was then used to read the values of TDS and EC.

3.5.1 Turbidity determination

Turbidity of water sample was determined by nephelometric method (APHA, 1992). 25 ml of sample was measured with the measuring cylinder and poured into a clean sample cell. The surface of the sample cell was carefully cleaned with tissue paper. The sample cell was placed into the instrument light cabinet and covered with the light shield. Turbidity was read. This is the reading obtained for the turbidity of the sample in NTU.

3.5.2 Colour determination

Colour of water samples was determined by Lovibond® Nessleriser 2150. Nessler tube was filled with water sample to the 50 ml mark. The tube was placed in the right-hand compartment leaving the left-hand compartment empty. The disc NSA was placed in the disc compartment and the light of the Nessleriser switched on. The disc was rotated to obtain a colour match and the colour was read from the disc. This procedure was used to determine the colour of all the water samples.

3.5.3 Total hardness determination

Total hardness of water sample was determined by complexometric titration using Ethylenediamminetetraacetic acid (EDTA) (APHA, 1992). 100 ml of the water sample was transferred to an Erlenmeyer flask of 500 ml volume with pipette. With a dispenser, 1.0ml NH_4Cl – NH_4OH buffer mixture, pH = 10 containing Mg – EDTA was added to the water sample in the Erlenmeyer flask. The flask was shaken and 5 drops of Eriochrome Black T indicator was added to the solution. The solution was titrated immediately but slowly with EDTA. Towards the end – point the last few drops was added at 3-5 seconds interval until the colour changed from wine red to blue. Total hardness as mg $CaCO_3$/L was computed using the equation below:

Calculations: (total hardness) mg/l $CaCO_3$ = $\frac{A \times B \times 1000}{\text{Vol. of sample}}$

Where A=ml of titrant and B=mg $CaCO_3$ equivalent to 1 ml EDTA titrant.

3.5.4 Fluoride determination

Fluoride levels in water samples were determined by Hach DR/2000s spectrophotometer (HACH, USA). A graduated cylinder was used to measure 25 ml of water sample into a dry sample cell and 25 ml of deionised water into a second dry sample cell (the blank). Pipette filler was used to pipette 5 ml of SPADNS Reagent into each cell and the mixture was swirl to mix. The SHIFT TIMER button was pressed for a one minute reaction to begin. The display showed mg/l F^- when the timer beeped. The blank was placed into the cell holder and the light shield closed. The display showed 0.00 mg/l F^- when the ZERO button was pressed. The prepared sample was placed into the cell holder and the light shield closed. The fluoride level in the sample was recorded after the READ/ENTER button was pressed.

3.5.5 Chloride

The presence of chloride ions were determined by the Argentometric method (APHA, 1992). The procedure used in this method involved the addition of 1.0 ml K_2CrO_4 indicator solution to 20 ml of sample water. The solution was titrated with standard $AgNO_3$ titrant to a pinkish yellow end point. The procedure was repeated for an equal volume of distilled water, representing the blank. The concentration of chloride was computed using the equation below:

$$\text{mg Cl}^{-}/\text{L} = \frac{(A - B) \times N \times 35450}{\text{Vol. of sample}}$$

Where:

A = ml titration for sample,

B = ml titration for blank, and

N = normality of $AgNO_3$ (0.0141M)

3.6 Spectrophotometric analysis

The Hach DR/2400 Portable Spectrophotometer (HACH, USA) was used to determine the levels of iron, sulphate and nitrate in the water samples.

3.6.1 Iron determination

The level of iron in sample was determined by FerroVer Method. The concentration of iron was determined by initially selecting Program 265 Iron, FerroVer from the Hach Programs. A clean, round sample cell was filled with a known sample volume diluted to 10 ml and the contents of one FerroVer Iron Reagent Powder Pillow added to it. The sample cell was swirled to mix the contents and the timer icon pressed to begin a three-minute reaction period. Another sample cell was filled with 10 ml distilled water (the blank) and placed in the cell holder of the spectrophotometer after thoroughly wiping it. The 'Zero' button was pressed and a 0.00 mg/l Fe concentration was displayed. After the three-minute reaction period, the prepared sample was also placed in the cell holder and 'Read' button pressed. The concentration of iron was displayed in mg/l Fe.

3.6.2 Sulphate determination

The level of sulphate in sample was determined by SulfaVer 4 Method. Sulphate was determined by selecting Program 680 Sulphate from the Hach Programs. A clean, round sample cell was filled with a known sample volume diluted to 10 ml and the contents of one SulfaVer 4 Reagent Powder Pillow added to it. The sample cell was swirled to mix the contents and the timer icon pressed to begin a five-minute reaction period. Another sample cell was filled with 10 ml distilled water (the blank) and placed in the cell holder of the spectrophotometer after thoroughly wiping it. The 'Zero' button was pressed and a 0.00 mg/l SO_4^{2-} concentration was displayed. After the five-minute reaction period, the prepared sample was also placed in the cell holder after wiping the sample cell and the 'Read' button was pressed. The concentration of sulphate was displayed in mg/l SO_4^{2-}.

3.6.3 Nitrate determination

The level of nitrate in sample was determined by Cadmium Reduction method. The concentration of Nitrate-nitrogen was determined by selecting Program 353 N, Nitrate MR from the Hach Programs. A clean, round sample cell was filled with a known sample volume diluted to 10 ml and the contents of one NitraVer 5 Nitrate Reagent Powder Pillow added to it. The sample cell shaken vigorously to mix the contents and the timer icon pressed to begin a one-minute reaction period. The timer icon is pressed again after the one-minute reaction for a five-minute reaction period to begin. Another sample cell was filled with 10 ml distilled water (the blank) and placed in the cell holder of the spectrophotometer after thoroughly wiping it. The 'Zero' button was pressed and a 0.00

mg/l NO_3^--N concentration was displayed. After the five-minute reaction period, the prepared sample was also placed in the cell holder after wiping the sample cell and the 'Read' button was pressed. The concentration of Nitrate-nitrogen was displayed in mg/l NO_3^-N.

3.7 Analysis of heavy metals

The level of heavy metals such as Zinc, Cadmium and Manganese was determined in the water samples by Buck Scientific 210 VGP model (Flame Atomic Absorption Spectroscopy).

3.7.1 Sample preparation and digestion

Samples were initially acidified with a known volume of concentrated nitric acid (one percent of sample volume) to prevent the bonding of heavy metals to the suspended solids. 30 ml of digestion mixture; $HClO_4$ and HNO_3 (ratio 4:9 respectively) was added to resulting solution and mixed thoroughly. The mixture was heated gradually to about 150 – 200 °C until production of red nitrite fumes ceases. Heating was further continued until the volume of the mixture was reduced to 3 to 4 ml and became colourless ensuring that it was not totally dried. The mixture was allowed to cool and diluted to 50 ml with distilled water.

3.7.2 Measuring concentration of heavy metals

The appropriate hollow cathode lamp was inserted in the selected lamp holder. Solutions which contain no analyte element representing the analytical blanks and a series of calibration solutions containing known amounts of analyte element (standard solutions) were prepared. These standards and their blanks were atomized sequentially and their individual responses measured. A calibration curve indicating the response obtained for each solution was plotted. The sample solution was also atomized and the response measured. The concentration of the sample solution was determined from the calibration curve based on the absorbance obtained.

3.8 Bacterial analysis of water samples

3.8.1 Preparation of serial dilution

The sample was thoroughly mixed by inverting sample bottles several times and preparing serial dilutions as follows:

For 10^{-1}or 1/10, an automatic pipette and sterile 1ml pipette tip a 1 ml aliquot from an inch below the surface was added drawn to 9 ml of sterile ringers in a test tube. This is the 10^{-1} dilution.

For a 10^{-2} or 1/100 dilution, a fresh sterile pipette was used to mix the 10^{-1} dilution by drawing the suspension up and down ten times. 1 ml of the 10^{-1} was drawn and placed into another tube containing 9 ml of the sterile ringer's solution to constitute a dilution.

For a 10^{-3} or 1/1000 dilution, a fresh sterile pipette was used to mix the 10^{-2} dilution by drawing the suspension up and down ten times. 1 ml of the 10^{-2} was drawn and placed into another tube containing 9 ml of the sterile ringer's solution. This is the 10^{-3} dilution. Dilutions were prepared down to 10^{-4}.

3.8.2 Total and faecal coliforms

The three tube Most Probable Number (MPN) method was used to determine the total and faecal coliform counts in the samples. Serial dilutions of 10^{-1} to 10^{-5} were prepared. 1 ml aliquots from each of the dilutions were inoculated into 5 ml of MacConkey Broth with inverted Durham tubes. The tubes were then incubated at 35 ^{o}C for total coliforms and 44 ^{o}C for faecal coliforms for 18-24 hours. Tubes showing colour change from purple to yellow with gas collected in the Durham tubes after 24 hours were identified as positive for both total and faecal coliforms. Counts per 100 ml were calculated from the three tubes Most Probably Number (MPN) Tables (Brenner *et al*, 1993 and APHA, 1992).

3.8.3 *E. coli* (Thermotolerant Coliforms)

From each of the positive tubes identified for total and faecal coliforms, a drop was transferred into a 5 ml test tube of Tryptophan Broth and incubated at 44 ˚C for 24 hours. A drop of Kovacs' reagent was then added to the tube of Tryptophan Broth. All tubes showing a red ring colour development after gentle agitation denoted the presence of indole and recorded as presumptive for thermotolerant coliforms (*E.coli*). Counts per 100 ml were calculated from Most Probable Numbers (MPN) table (Brenner *et al*, 1993 and APHA, 1992).

3.9 Identification of Helminths Eggs

Helminths eggs were enumerated using a combination of the floatation and sedimentation method (Schwartzbrod, 1998). This is a modified US-EPA method, but the same principle of floatation and sedimentation was followed. Water samples from boreholes and hand-dug wells were collected with a 2000ml container and allowed to settle overnight to enable the eggs to settle completely. Much of the supernatant as possible was sucked and the sediment transferred into eight 50 ml centrifuge tubes. The 2000ml containers were rinsed three times with tap water and the rinses were distributed into centrifuge tubes. The tubes containing the sediments were then centrifuged at 1500 rpm for 3 min. The supernatant was discarded and the deposit was re-suspended in about 150 ml $ZnSO_4$ solution (specific gravity = 1.3). The mixture was homogenized with a sterile spatula and centrifuged again at 1500 rpm for 3 min. The $ZnSO_4$ solution was added to cause the helminths eggs to float leaving other sediments at the bottom of the centrifuge tube. The $ZnSO_4$ supernatant (containing the eggs) was poured back into the 2000ml container and diluted with at least

1000ml of distilled water. This was also allowed to stand for at least 3 hours for the eggs to settle again. Much supernatant as possible was sucked and deposit was then transferred into eight centrifuge tubes. The 2000ml container was rinsed two to three times with tap water and the rinsed water added to the centrifuge tubes and centrifuged at 1500 rpm for 3 min. The deposits were regrouped into one centrifuge tube and centrifuged at 1500 rpm for 3 min again. The deposit was re-suspended in 15 ml acid ⁄ alcohol buffer solution (5.16 ml 0.1N H_2SO_4 in 350 ml ethanol) and about 5 ml ethyl acetate was added. The mixture was shaken and the centrifuge tube occasionally opened to let out gas before centrifuging at 2200 rpm for 3 min. After the centrifugation, a diphasic solution was formed. With a micropipette, as much of the supernatant as possible was sucked out leaving about 1 ml of deposit. Pasteur pipette was used to transfer as much sediment unto microscope slide as possible until all the sediment was observed. The helminths eggs were identified on the basis of their shape and size and compared with standard eggs on charts (Guerrant, 1995). The Bench Aid for the Diagnosis of Intestinal Parasites (WHO, 1994) was used for identification. The counting was done under a light microscope in both chambers of a haemocytometer at X40 magnification. Presumptive identification of the helminths eggs was done based on morphological characteristics (Guerrant, 1995).

3.10 Statistical analysis

Analysis of variance (ANOVA) was used to analyze data using the SPSS (version 16) software for windows (SPSS Inc., Chicago, IL, USA) to examine the apparent differences and means of observed data between the different sampling location of the boreholes and hand-dug wells. Tables and graphs were obtained using the Microsoft Excel Programme (Microsoft Corporation, 2010). The statistical analyses were carried out at $P \leq 0.05$ level of significance.

CHAPTER FOUR

RESULTS

4.1 Physicochemical parameters of water from boreholes and hand-dug wells

4.1.1 Boreholes

Boreholes water samples from Ejisu recorded temperature range of 27.00-28.10 ºC with a mean of 27.50 ºC. pH of water samples ranged from 4.20-4.99 pH unit with a mean of 4.71. The total dissolved solids (TDS) of water samples also ranged from 36.30-41.30 mg/l with a mean of 39.20 mg/l. Electrical conductivity (EC) of water samples ranged from 72.60-82.60 µS/cm with a mean of 78.40µS/cm. The total hardness of water samples ranged from 12.00-29.00 mg/l $CaCO_3$ with a mean of 23.00 mg/l $CaCO_3$. Colour of water samples ranged from 5.00-10.00 HU with a mean of 6.67 HU. Turbidity values of water samples also ranged from 0.30-0.57 NTU with a mean of 0.47 NTU (Table 3).

Boreholes water samples from Juaben recorded temperature range of 26.30-31.20 ºC with a mean of 28.36 ºC. pH ranged from 4.01-5.27 pH units with a mean of 4.74. TDS values also ranged from 141.00-155.00 mg/l with a mean of 150.67 mg/l. Electrical conductivity values ranged from 282.00-310.00 µS/cm with a mean of 301.33µS/cm. Total hardness values ranged from 42.00-50.00 mg/l $CaCO_3$ with a mean 46.56 mg/l $CaCO_3$. Colour of water samples from Juaben recorded a mean of 5 HU. Turbidity values ranged from 0.22-0.47 NTU with a mean of 0.34 NTU (Table 3).

Boreholes water samples from Fumesua recorded temperature range of 27.50-28.30 ºC with a mean of 27.93 ºC. pH values ranged from 3.93-5.43 pH units with a mean of 4.53. TDS values also ranged from 75.90-89.00 mg/l with a mean of 82.11 mg/l. Electrical conductivity values ranged from 151.80-178.00 µS/cm with a mean of 164.22µS/cm. Total hardness values ranged from 22.00-28.00 mg/l $CaCO_3$ with a mean of 25.33 mg/l $CaCO_3$.

Colour of water samples recorded a mean of 5 HU. Turbidity values ranged from 0.51-0.80 NTU with a mean of 0.62 NTU (Table 3).

Water samples from boreholes at Bonwire recorded temperature ranging from 25.90-28.00 ºC with a mean of 26.94 ºC. The pH of water samples ranged from 3.84-4.64 pH units with a mean of 4.34. The TDS of water samples ranged from 335.00-343.50 mg/l with a mean of 339.46 mg/l. The electrical conductivity of water samples also ranged from 670.00-687.00µS/cm with a mean of 678.91µS/cm. The total hardness of water samples ranged from 126.00-128.00 mg/l $CaCO_3$ with a mean of 127.00 mg/l $CaCO_3$. The colour of water samples ranged from 5.00-10 HU with a mean of 6.11 HU. The turbidity of water samples of ranged from 0.41-2.98 NTU with a mean of 1.54 NTU (Table 3).

Water samples from boreholes at Besease recorded temperature range of 26.00-27.60 ºC with a mean of 26.93 ºC. Water samples recorded pH values ranged from 4.63-5.55 pH units with a mean of 5.13. Water samples recorded TDS values ranged from 58.30-67.50 mg/l with a mean of 62.29 mg/l. Water samples recorded electrical conductivity values ranged from 116.60-135.00 µS/cm with a mean of 124.58 µS/cm. Water samples at recorded total hardness values ranged from 34.00-39.00 mg/l $CaCO_3$ with a mean of 36.11 mg/l $CaCO_3$. Colour of water samples recorded a mean of 5 HU. Water samples recorded turbidity values ranged from 0.32-0.42 NTU with a mean of 0.38 NTU (Table 3).

With the exception of pH, all the other parameters measured from all the boreholes were within acceptable limits of WHO guideline value for drinking water.

Table 3: Mean (± SD) and range values of physicochemical parameters analysed for borehole water in Ejisu-Juaben Municipality.

Parameters	Temperature (˚C)	pH	Total dissolved solids (mg/l)	Electrical Conductivity (µS/cm)	Total hardness (mg/l $CaCO_3$)	Colour (HU)	Turbidity (NTU)
WHO limits		**6.5-8.5**	**1000**	**1500**	**500**	**15**	**5**
Towns							
Ejisu	**27.50±0.43**	**4.71±0.39**	**39.20±2.16**	**78.40±4.32**	**23.00±5.94**	**6.67±2.50**	**0.47±0.13**
	(27.00-28.10)	(4.20-4.99)	(36.30-41.30)	(72.60-86.60)	(12.00-29.00)	(5.00-10.00)	(0.30-0.57)
Juaben	**28.36±2.07**	**4.74±0.56**	**150.67±4.09**	**301.33±8.19**	**46.56±3.47**	**5.00**	**0.34±0.11**
	(26.30-31.20)	(4.01-5.27)	(141.00-155.00)	(282.00-310.00)	(42.00-50.00)		(0.22-0.47)
Fumesua	**27.93±0.33**	**4.53±0.63**	**82.11±4.30**	**164.22±8.61**	**25.33±2.65**	**5.00**	**0.62±0.13**
	(27.50-28.30)	(3.93-5.34)	(75.90-89.00)	(151.80-178.00)	(22.00-28.00)		(0.51-0.80)
Bonwire	**26.94±0.83**	**4.34±0.37**	**339.46±2.98**	**678.91±5.95**	**127.00±0.87**	**6.11±2.20**	**1.54±1.18**
	(25.90-28.00)	(3.84-4.64)	(335.00-343.50)	(670.00-687.00)	(126.00-128.00)	(5.00-10.00)	(0.41-2.98)
Besease	**26.93±0.63**	**5.13±0.40**	**62.29±3.94**	**124.58±7.88**	**36.11±1.90**	**5.00**	**0.38±0.05**
	(26.00-27.60)	(4.63-5.55)	(58.30-67.50)	(116.60-135.00)	(34.00-39.00)		(0.32-0.42)

4.1.2 Hand-dug wells

For hand-dug wells at Ejisu, temperature of water samples ranged from 26.90-27.50 ºC with a mean of 27.19 ºC. pH of water samples ranged from 4.06-5.10 pH unit with a mean of 4.66. The total dissolved solids (TDS) of water samples ranged from 112.00-122.00 mg/l with a mean of 116.67 mg/l. Electrical conductivity (EC) of water samples also ranged from 224.00-244.00 µS/cm with a mean of 233.33 µS/cm. The total hardness of water samples ranged from 16.00-23.00 mg/l $CaCO_3$ with a mean of 18.89 mg/l $CaCO_3$. Colour of water samples ranged from 10.00-15.00 HU with a mean of 12.22 HU. Turbidity values of water samples ranged from 4.00-12.00 NTU with a mean of 7.79 NTU (Table 4). With the exception of pH and turbidity, all the other parameters were with within WHO guideline values.

For hand-dug wells at Juaben, temperature of water samples ranged from 27.00-27.60 ºC with a mean of 27.28 ºC. pH ranged from 4.40-4.89 pH units with a mean of 4.61. TDS values also ranged from 72.70-79.00 mg/l with a mean of 75.25 mg/l. Electrical conductivity values ranged from 145.40-158.00 µS/cm with a mean of 150.53 µS/cm. Total hardness values ranged from 30.00-38.00 mg/l $CaCO_3$ with a mean 33.22 mg/l $CaCO_3$. The colour of water samples ranged from 5.00-15.00 HU with a mean of 8.33 HU. Turbidity values also ranged from 1.00-2.60 NTU with a mean of 1.32 NTU (Table 4). With the exception of pH, all the other parameters were with WHO guideline values for drinking water.

For hand-dug wells at Fumesua, temperature of water samples ranged from 27.00-27.60 ºC with a mean of 27.26 ºC. pH values ranged from 4.59-5.93 pH units with a mean of 5.03. TDS values also ranged from 86.70-90.00 mg/l with a mean of 88.13 mg/l. Electrical conductivity values ranged from 173.40-180.00 µS/cm with a mean of 176.27 µS/cm. Total hardness values ranged from 25.00-30.00 mg/l $CaCO_3$ with a mean of 27.11 mg/l

$CaCO_3$. Colour ranged from 5.00-10.00 HU with a mean of 6.67 HU. Turbidity values ranged from 4.78-6.98 NTU with a mean of 5.52 NTU (Table 4). With the exception of pH and turbidity, all the other parameters were with within WHO guideline values.

For hand-dug wells at Bonwire, temperature of water samples ranged from 26.90-27.20 ºC with a mean of 27.02 ºC. The pH of water samples ranged from 3.64-6.30 pH units with a mean of 4.83. The TDS of water samples ranged from 219.00-220.00 mg/l with a mean of 220.00 mg/l. The electrical conductivity of water samples ranged from 438.00-444.00 µS/cm with a mean of 440.73 µS/cm. The total hardness of water samples ranged from 116.00-121.00 mg/l $CaCO_3$ with a mean of 118.11 mg/l $CaCO_3$. Hand-dug well water samples recorded a mean 10.00 HU for colour. The turbidity of water samples ranged from 4.10-4.98 NTU with a mean of 4.52 NTU (Table 4). With the exception of pH, all the other parameters were with within WHO guideline values.

For hand-dug wells at Besease, temperature of water samples ranged from 27.00-27.50 ºC with a mean of 27.27 ºC. Hand-dug wells water samples recorded pH values ranged from 4.75-5.20 pH units with a mean of 4.89. Water samples recorded TDS values ranged from 97.90-110.10 mg/l with a mean of 100.00 mg/l. Water samples recorded electrical conductivity values ranged from 195.80-220.20 µS/cm with a mean of 200.02 µS/cm. Hand-dug well water samples recorded total hardness values ranged from 34.00-40.00 mg/l $CaCO_3$ with a mean of 36.78 mg/l $CaCO_3$. Water samples had colour ranged from 10.00-15.00 with a mean of 13.33 HU. Hand-dug well water samples recorded turbidity values ranged from 4.46-7.98 NTU with a mean of 6.18 NTU (Table 4). With the exception of pH and turbidity, all the other parameters were with within WHO guideline values.

Table 4: Mean (± SD) and range values of physicochemical parameters analysed for hand-dug wells in Ejisu-Juaben Municipality.

Parameters	**Temperature (˚C)**	**pH**	**Total dissolved solids (mg/l)**	**Electrical conductivity (µS/cm)**	**Total hardness (mg/l $CaCO_3$)**	**Colour (HU)**	**Turbidity (NTU)**
WHO limits		**6.5 – 8.5**	**1000**	**1500**	**500**	**15**	**5**
Towns							
Ejisu	**27.19±0.24**	**4.66±0.28**	**116.67±3.58**	**233.33±7.15**	**18.89±2.26**	**12.22±2.64**	**7.79±2.94**
	(26.90 – 27.50)	(4.06 – 5.10)	(112.00 – 122.00)	(224.00 – 244.00)	(16.00 – 23.00)	(10.00 – 15.00)	(4.00 – 12.00)
Juaben	**27.28±0.21**	**4.61±0.20**	**75.27±2.89**	**150.53±5.79**	**33.22±3.03**	**8.33±3.54**	**1.32±0.49**
	(27.00 – 27.60)	(4.40 – 4.89)	(72.70 – 79.00)	(145.40 – 158.00)	(30.00 – 38.00)	(5.00 – 15.00)	(1.00 - 2.60)
Fumesua	**27.26±0.23**	**5.03±0.59**	**88.13±1.03**	**176.27±2.05**	**27.11±1.69**	**6.67±2.50**	**5.52±1.06**
	(27.00 – 27.60)	(4.59 – 5.93)	(86.70 – 90.00)	(173.40 – 180.00)	(25.00 – 30.00)	(5.00 – 10.00)	(4.78 – 6.98)
Bonwire	**27.02±0.09**	**4.83±0.83**	**220.37±0.96**	**440.73±1.93**	**118.11±1.62**	**10.00**	**4.52±0.37**
	(26.90 – 27.20)	(3.64 – 6.30)	(219.00 – 222.00)	(438.00 – 444.00)	(116.00 – 121.00)		(4.10 – 4.98)
Besease	**27.27±0.19**	**4.89±0.14**	**100.01±3.86**	**200.02±7.71**	**36.78±2.22**	**13.33±2.50**	**6.18±1.38**
	(27.00 – 27.50)	(4.75 – 5.20)	(97.90 – 110.10)	(195.80 – 220.20)	(34.00 – 40.00)	(10.00 – 15.00)	(4.46 – 7.98)

4.2. Anions in boreholes and hand-dug wells

4.2.1 Boreholes

Boreholes at Ejisu recorded sulphate levels of 6.00-9.00 mg/l with a mean of 7.44 mg/l. The nitrate concentration of water samples ranged from 3.90-8.20 mg/l with a mean of 5.44 mg/l. Chloride levels of water samples ranged from 0.99-4.99 mg/l with a mean of 3.53 mg/l. Likewise, fluoride levels of water samples ranged from 0.21-0.25 with a mean of 0.23 mg/l (Fig. 5).

Boreholes at Juaben recorded sulphate levels ranging from 14.00-16.00 mg/l with a mean of 15.00 mg/l. Water samples recorded nitrate concentration ranged from 12.00-28.30 mg/l with a mean of 19.36 mg/l. Water samples recorded chloride levels ranged from 22.00-31.00 mg/l with a mean of 25.33 mg/l. Water samples recorded fluoride levels ranged from 0.17-0.23 mg/l with a mean of 0.21 mg/l (Fig. 5).

Boreholes at Fumesua recorded sulphate levels of 4.00-8.00 mg/l with a mean of 6.00 mg/l. Water samples with nitrate concentration ranged from 1.70-4.40 mg/l with a mean of 2.77 mg/l. Water samples with chloride levels ranged from 12.00-20.99 mg/l with a mean of 15.55 mg/l. Water samples with fluoride levels ranged from 0.19-0.25 mg/l with a mean of 0.21 mg/l (Fig. 5).

Boreholes at Bonwire recorded sulphate levels of 32.00-38.00 mg/l with a mean of 34.89 mg/l. The nitrate concentration of water samples ranged from 23.70-25.40 mg/l with a mean of 24.57 mg/l. The chloride levels of water samples ranged from 49.98-68.50 mg/l with a mean of 60.99 mg/l. The fluoride levels of water samples ranged from 0.16-0.22 mg/l with a mean of 0.20 mg/l (Fig. 5).

Boreholes at Besease recorded sulphate levels ranging from 2.00-8.00 mg/l with a mean of 6.11 mg/l. Boreholes water samples recorded nitrate concentration ranged from 4.40-9.20 mg/l with a mean of 6.68 mg/l. Water samples recorded chloride levels ranged from 9.90-11.20 mg/l with a mean of 10.95 mg/l. Water samples at recorded fluoride levels ranged from 0.20-0.25 mg/l with a mean of 0.23 mg/l (Fig. 5).

All the parameters measured from all the boreholes were within WHO guideline values for drinking water.

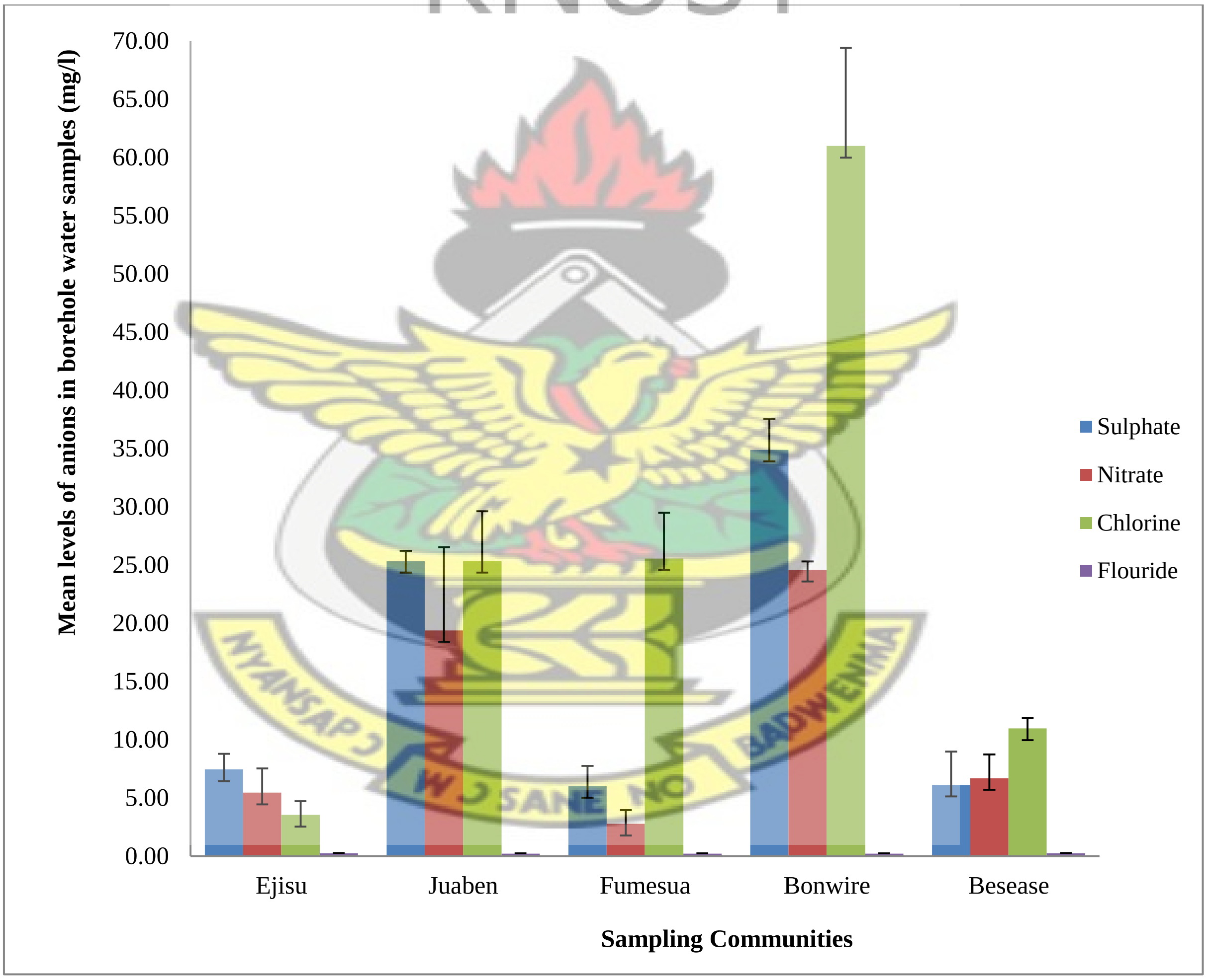


Fig. 5: Mean (± SD) values of anions analysed for boreholes in Ejisu-Juaben Municipality.

4.2.2 Hand-dug wells

For hand-dug wells at Ejisu, sulphate levels in water samples ranged from 20.00-26.00 mg/l with a mean of 22.00 mg/l. The nitrate concentration in water samples also ranged from 11.60-19.20 mg/l with a mean of 13.97 mg/l. Chloride levels of well water samples at ranged from 30.00-38.00 mg/l with a mean of 35.03 mg/l. Fluoride levels of water samples ranged from 0.15-0.19 mg/l with a mean of 0.17 mg/l (Fig. 6).

For hand-dug wells at Juaben, sulphate levels in water samples ranged from 10.00-15.00 mg/l with a mean of 12.22 mg/l. Water samples recorded nitrate concentration ranging from 19.10-24.50 mg/l with a mean of 20.98 mg/l. Water samples recorded chloride levels ranging from 14.00-24.99 mg/l with a mean of 18.22 mg/l. Water samples recorded fluoride levels ranging from 0.20-0.26 mg/l with a mean of 0.23 mg/l (Fig. 6).

For hand-dug wells at Fumesua, sulphate levels ranged from 13.00-15.00 mg/l with a mean of 14.11 mg/l. Water samples had nitrate concentration ranging from 8.00-15.10 mg/l with a mean of 9.37 mg/l. Water samples had chloride levels ranging from 14.00-21.00 mg/l with a mean of 18.22 mg/l. Water samples had fluoride levels ranging from 0.17-0.20 mg/l with a mean of 0.18 mg/l (Fig. 6).

For hand-dug wells at Bonwire, sulphate levels of water samples ranged from 36.00-40.00 mg/l with a mean of 38.22 mg/l. The nitrate concentration of water samples ranged from 15.70-19.50 mg/l with a mean of 17.07 mg/l. The chloride levels of water samples ranged from 29.99-32.50 mg/l with a mean of 31.11 mg/l. The fluoride levels of water samples ranged from 0.18-0.21 mg/l with a mean of 0.19 mg/l (Fig. 6).

For hand-dug wells at Besease, sulphate levels of water samples ranged from 11.00-16.00 mg/l with a mean of 13.11 mg/l. Water samples recorded nitrate concentration ranged from 7.00-12.90 mg/l with a mean of 10.62 mg/l. Water samples recorded chloride levels ranged from 27.99-36.00 mg/l with a mean of 32.93 mg/l. Water samples recorded fluoride levels ranged from 0.29-0.33 mg/l with a mean of 0.31 mg/l (Fig. 6).

All the parameters measured from hand-dug wells were within WHO guideline values for drinking water.

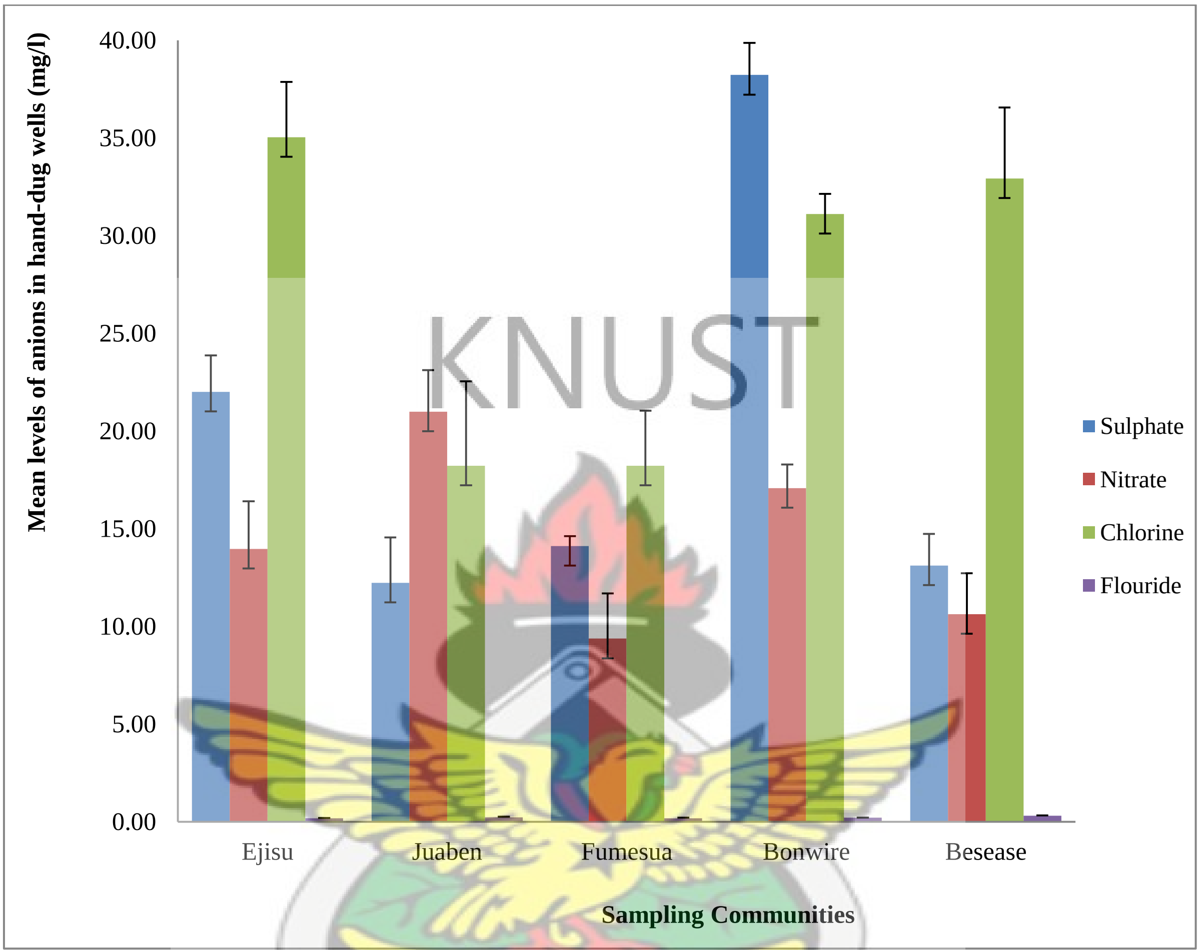


Fig. 6: Mean (± SD) values of anions analysed for hand-dug wells in Ejisu-Juaben Municipality.

4.3. Heavy metals in boreholes and hand-dug wells

4.3.1 Boreholes

For boreholes at Ejisu, iron concentration of water samples was below detection limit of the equipment. Manganese levels of water samples ranged from 0.066-0.069 mg/l with a mean of 0.068 mg/l. The zinc concentration ranged from 0.038-0.086 mg/l with a mean of 0.056 mg/l (Table 5). The concentration of cadmium in water samples was also below detection limit of equipment.

For boreholes at Juaben, iron concentration was below detection limit of the equipment. Water samples recorded manganese levels ranging from 0.043-0.069 mg/l with a mean of 0.054 mg/l. Water samples recorded zinc concentration ranging from 0.017-0.050 mg/l with a mean of 0.027 mg/l. The concentration of cadmium in water samples was also below detection limit of equipment (Table 5).

For boreholes at Fumesua, only one borehole (FBH2) recorded iron levels in water sample with a mean of 0.272 mg/l. The other two boreholes had iron levels below detection limit of the equipment. Water samples had manganese levels ranging from 0.045-0.058 mg/l with a mean of 0.054 mg/l. Water samples had zinc concentration ranging from 0.015-0.036 mg/l with a mean of 0.025 mg/l. The concentration of cadmium in water samples was below detection limit of equipment (Table 5).

For boreholes at Bonwire, only one borehole (BBH1) recorded iron levels in water sample with a mean of 0.215 mg/l. The other two boreholes had iron levels below detection limit of the equipment. The manganese levels of water samples ranged from 0.080-0.084 mg/l with a mean of 0.082 mg/l. The zinc concentration of water samples ranged from 0.020-0.063 mg/l with a mean of 0.045 mg/l. The concentration of cadmium in water samples was below detection limit of equipment (Table 5).

For boreholes at Besease, iron concentration of water samples was below detection limit of the equipment. Water samples recorded manganese levels ranged from 0.041-0.045 mg/l with a mean of 0.043 mg/l. Water samples recorded zinc concentration ranging from 0.017-0.027 mg/l with a mean of 0.022 mg/l. The concentration of cadmium in water samples was below detection limit of equipment (Table 5).

Heavy metals levels were within acceptable limits of WHO guideline values for drinking water.

Table 5: Mean concentration of heavy metal content of water from boreholes in Ejisu Juaben Municipality.

Towns	Metals			
	Fe (mg/l)	Mn (mg/l)	Zn (mg/l)	Cd (mg/l)
WHO Limits	**0.3**	**0.4**	**3.0**	**0.003**
Ejisu	b/d	**0.0677 ± 0.0013** (0.0660 – 0.0690)	**0.0563 ± 0.0220** (0.0380 – 0.0860)	b/d
Juaben	b/d	**0.0540 ± 0.0117** (0.0430 – 0.0690)	**0.0267 ± 0.0103** (0.0170 – 0.0500)	b/d
Fumesua	**0.2723**	**0.0537 ± 0.0065** (0.0450 – 0.0580)	**0.0252 ± 0.0114** (0.0150 – 0.0360)	b/d
Bonwire	**0.2147**	**0.0817 ± 0.0018** (0.0800 – 0.0840)	**0.0446 ± 0.0191** (0.0200 – 0.0630)	b/d
Besease	b/d	**0.0430 ± 0.0017** (0.0410 – 0.0450)	**0.0217 ± 0.0052** (0.0170 – 0.0270)	b/d

b/d = below detection limit of equipment (0.01).

4.3.2 Hand-dug wells

For hand-dug wells at Ejisu, iron concentration of water samples ranged from 0.126-0.681 mg/l with a mean of 0.371 mg/l. Manganese levels ranged from 0.059-0.064 mg/l with a mean of 0.063 mg/l. Zinc concentration ranged from 0.020-0.080 mg/l with a mean of 0.041 mg/l. The concentration of cadmium in hand-dug well water was below detection limit of equipment (Table 6). With the exception of one hand-dug well at Ejisu (EJW2) with iron concentration above limits, all the parameters measured were within WHO guideline values for drinking water.

For hand-dug wells at Juaben, only one hand-dug well (JW2) recorded iron in water sample with a mean of 0.322 mg/l. The other two hand-dug wells had iron levels below detection limit of equipment. Water samples recorded manganese levels ranging from 0.039-0.042 mg/l with a mean of 0.040 mg/l. Only one hand-dug well water sample at Juaben (JW2) recorded zinc concentration with a mean of 0.017 mg/l. The other two hand-dug wells had zinc levels below detection limit of equipment. The concentration of cadmium in water samples was below detection limit of equipment (Table 6). With the exception of one hand-dug well at Juaben (JW2), all the parameters measured were within WHO guideline values for drinking water.

For hand-dug wells at Fumesua, iron levels in water samples were below detection limit of equipment. Water samples recorded manganese levels ranging from 0.045-0.060 mg/l with a mean of 0.054 mg/l. Water samples had zinc concentration ranging from 0.030-0.140 mg/l with a mean of 0.064 mg/l. The concentration of cadmium in water samples was below detection limit of equipment (Table 6). All the parameters measured were within WHO guideline values for drinking water.

For hand-dug wells at Bonwire, only one hand-dug well recorded iron levels in water sample with a mean of 0.280 mg/l mg/l. The other two hand-dug wells had iron levels below detection limit of the equipment. The manganese levels of water samples ranged from 0.079-0.081 mg/l with a mean of 0.080 mg/l. The zinc concentration of water samples ranged from 0.026-0.027 mg/l with a mean of 0.026 mg/l. The concentration of cadmium in water samples was below detection limit of equipment (Table 6). All the parameters measured were within WHO guideline values for drinking water.

For hand-dug wells at Besease, iron levels of water samples ranged from 0.097-0.226 mg/l with a mean of 0.144 mg/l. Water samples recorded manganese levels ranging from 0.049-

0.090 mg/l with a mean of 0.071 mg/l. Water samples recorded zinc concentration ranging from 0.010-0.011 mg/l with a mean of 0.010 mg/l. The concentration of cadmium in water samples was below detection limit of equipment (Table 6). All the parameters measured were within WHO guideline values for drinking water.

Table 6: Mean concentration of heavy metal content of water from hand-dug wells in Ejisu Juaben Municipality.

Towns	**Metal**			
	Fe (mg/l)	**Mn (mg/l)**	**Zn (mg/l)**	**Cd (mg/l)**
WHO Limits	**0.3**	**0.4**	**3.0**	**0.003**
Ejisu	**0.3706±0.2450**	**0.0630±0.0020**	**0.0412 ±0.0291**	b/d
	(0.1260 – 0.6810)	(0.0590 – 0.0640)	(0.0200 – 0.0800)	
Juaben	**0.3220**	**0.0403 ±0.0013**	**0.0173**	b/d
		(0.0390 – 0.0420)		
Fumesua	b/d	**0.0541±0.0067**	**0.0639±0.0475**	b/d
		(0.0450 – 0.0600)	(0.0300 – 0.1400)	
Bonwire	**0.2800**	**0.0799±0.0008**	**0.0262±0.0004**	b/d
		(0.0790 – 0.0810)	(0.0260 – 0.0270)	
Besease	**0.1439±0.0586**	**0.0711±0.0179**	**0.0104±0.0008**	b/d
	(0.0970 – 0.2260)	(0.0490 – 0.0900)	(0.0100 – 0.0110)	

b/d = below detection limit of equipment (0.01).

4.4. Microbiological analysis of water from boreholes and hand-dug wells

4.4.1 Boreholes

At Ejisu, only one borehole recorded total coliform in water sample with a mean of 2.08×10^4 CFU $100ml^{-1}$. The other two boreholes recorded zero count for total coliforms, faecal coliforms and *E. coli* in water samples (Table 7).

At Juaben, two boreholes recorded total coliforms (JBH1 and JBH2) which ranged from 3.00×10^4 - 3.10×10^4 CFU $100ml^{-1}$ with a mean of 3.06×10^4 CFU $100ml^{-1}$. All the boreholes recorded zero counts for faecal coliform and *E. coli* (Table 7).

At Fumesua and Bonwire, all the boreholes recorded zero counts for total coliforms, faecal coliforms and *E. coli* (Table 7).

At Besease, only one borehole (BEBH1) recorded total coliforms, faecal coliforms and *E. coli* in samples with means of 9.37×10^5, 4.13×10^4 and 3.07×10^4 CFU $100ml^{-1}$ respectively. The other two boreholes recorded zero counts for total coliforms, faecal coliforms and *E. coli* in water samples (Table 7).

Table 7: Mean counts of coliforms in water from boreholes in Ejisu Juaben Municipality.

Microbes	Total Coliforms (CFU 100ml^{-1})	Faecal coliforms (CFU 100ml^{-1})	*E. coli* (CFU 100ml^{-1})
WHO Limits	**0**	**0**	**0**
Towns			
Ejisu	**2.08x10^{4}**	**0.00**	**0.00**
		0.00	0.00
Juaben	**3.06x10^{4}**	**0.00**	**0.00**
	(3.00x10^{4} – 3.10x10^{4})	0.00	0.00
Fumesua	**0.00**	**0.00**	**0.00**
	0.00	0.00	0.00
Bonwire	**0.00**	**0.00**	**0.00**
	0.00	0.00	0.00
Besease	**9.37x10^{5}**	**4.13x10^{4}**	**3.07x10^{4}**

4.4.2 Hand-dug wells

For hand-dug wells at Ejisu, total coliform counts of water samples ranged from 2.40×10^{5} - 9.30×10^{5} CFU 100ml^{-1} with a mean of 5.39×10^{5} CFU 100ml^{-1}. Faecal coliform counts of ranged from 4.00×10^{4} - 9.20×10^{4} CFU 100ml^{-1} with a mean of 5.82×10^{4} CFU 100ml^{-1}. *E. coli* counts ranged from 3.00×10^{4} - 3.30×10^{4} CFU 100ml^{-1} with a mean of 3.07×10^{4} CFU 100 ml^{-1} (Table 8). All the microbiological parameters measured were above WHO acceptable guideline value of drinking water.

For hand-dug wells at Juaben, water samples recorded total coliform counts ranging from 2.00×10^{5} - 2.50×10^{6} CFU 100ml^{-1} with a mean of 9.48×10^{5} CFU 100ml^{-1}. Water samples recorded faecal coliform counts ranging from 2.00×10^{4} - 2.30×10^{6} CFU 100ml^{-1} with a mean of 3.24×10^{5} CFU 100ml^{-1}.Only one hand-dug well water samples at Juaben (JW2) recorded *E. coli* counts with a mean of 9.10×10^{4} CFU 100ml^{-1} (Table 8). All the microbiological parameters measured were above WHO acceptable guideline value of drinking water.

For hand-dug wells at Fumesua, water samples had total coliform counts ranging from 8.50×10^4 - 4.50×10^5 CFU $100ml^{-1}$ with a mean of 2.03×10^5 CFU $100ml^{-1}$. All the hand-dug wells recorded zero counts for faecal and *E. coli* (Table 8). With the exception of total coliforms, microbiological parameters measured for hand-dug wells were above WHO acceptable guideline value of drinking water.

For hand-dug wells at Bonwire, total coliform counts of water samples ranged from 4.00×10^4 - 9.60×10^5 CFU $100ml^{-1}$ with a mean of 3.38×10^5 CFU $100ml^{-1}$. Only one hand-dug well at Bonwire (BW1) recorded faecal coliform and *E. coli* in water samples with means of $2.37\text{x}10^5$ and $3.07\text{x}10^4$ CFU $100ml^{-1}$ respectively (Table 8). Microbiological parameters measured for hand-dug wells were above WHO acceptable guideline value of drinking water.

Hand-dug well water samples at Besease recorded total coliform counts ranging from 4.00×10^5 - 4.60×10^5 CFU $100ml^{-1}$with a mean of 4.32×10^5 CFU $100ml^{-1}$. Water samples recorded faecal coliform counts ranging from 9.00×10^4 - 3.20×10^5 CFU $100ml^{-1}$ with a mean of 2.11×10^5 CFU $100ml^{-1}$. Hand-dug well water samples at Besease recorded *E. coli* counts ranging from 4.00×10^4 – 4.50×10^4 CFU $100ml^{-1}$ with a mean of 4.09×10^4 CFU $100ml^{-1}$ (Table 8). All the microbiological parameters measured for hand-dug wells were above WHO acceptable guideline values for drinking water.

Table 8: Mean counts of coliforms in water from hand-dug wells in Ejisu Juaben Municipality.

Microbes	**T. Coliforms (CFU 100ml^{-1})**	**F. Coliforms (CFU 100ml^{-1})**	***E. coli* (CFU 100ml^{-1})**
WHO limits	**0**	**0**	**0**
Towns			
Ejisu	**5.39×10^{5}**	**5.82×10^{4}**	**3.07×10^{4}**
	(2.40×10^{5} - 9.30×10^{5})	(4.00×10^{4} - 9.20×10^{4})	(3.00×10^{4} - 3.30×10^{4})
Juaben	**9.48×10^{5}**	**3.24×10^{5}**	**9.10×10^{4}**
	(2.00×10^{5} - 2.50×10^{6})	(2.00×10^{4} - 2.30×10^{6})	
Fumesua	**2.03×10^{5}**	**0.00**	**0.00**
	(8.50×10^{4} - 4.50×10^{5})		
Bonwire	**3.38×10^{5}**	**2.37×10^{5}**	**3.07×10^{4}**
	(4.00×10^{4} - 9.60×10^{5})		
Besease	**4.32×10^{5}**	**2.11×10^{5}**	**4.09 x 10^{4}**
	(4.00×10^{5} - 4.60×10^{5})	(9.00×10^{4} - 3.20×10$^{5)}$	(4.00 x 10^{4} - 4.50 x 10^{4})

4.4.3. Parasites in water from boreholes and hand-dug wells

All borehole water samples analyzed from the five locations recorded zero counts for helminths.

Some of the water samples from hand-dug wells examined had helminths contamination. Out of the 30 water samples collected and examined, 5 of them had helminths giving an overall prevalence of 16.7% in the study area (Table 9). Hand-dug well water samples were contaminated with 33.3% positivity for helminths (Table 9). On the whole, 3 different helminths were encountered in this study. They include ova of *Ascaris* species which accounted for 66.7% of all the helminths. Hookworm and *S. haematobium* ova had 22.2% and 11.1% respectively.

Table 9. Percentage helminth contamination of water from Ejisu Juaben Municipality.

Water source (no.)	Helminths count ($100ml^{-1}$)			Positive	Percentage
	***Ascaris* eggs**	***Hookworm* eggs**	***S. haematobium* eggs**		
Boreholes (n=15)	0	0	0	0	0.0%
Hand-dug wells (n=15)	6	2	1	5	33.3%
Total n=30	6	2	1	5	16.7%

Ascaris species were found in 3 hand-dug wells at Ejisu (EJW1), Fumesua (FW3) and Besease (BEW2)) out of the 15 hand-dug wells accounting for 20%. Hookworm followed with 13.3% and the least distributed was *S. haematobium* with 6.7% (Table 10).

Table 10: Spread of helminths in all hand-dug wells investigated in Ejisu-Juaben Municipality.

Name of helminths	Locations	Percentage
Ascaris species	3	20.0%
Hookworm	2	13.3%
S. haematobium	1	6.7%

4.5. Distance between boreholes, hand-dug wells and Source of Contamination

Some of the boreholes were not close to sources of contamination. In some circumstances (33.3%), the distance between the boreholes and sources of contamination was estimated to be less than 15 m (the commonly used guideline is that the distance should be at least 15.24 m or 50 ft.). Most of the boreholes were more than 15.24m or 50ft. to sources of contamination and therefore was contamination was less. Most of the boreholes (about

40%) were estimated to be at a distance between 15 and 30 m from the source of contamination and 26% of the total boreholes had a distance more than 30m from source of contamination (Table 11).

Table 11: Distance between sources of contamination and selected boreholes in Ejisu-Juaben Municipality.

Distance (m)	Number of boreholes	Percentage
<15	5	33.3%
15-30	6	40.0%
>30	4	26.7%
Total	15	100%

Most of the hand-dug wells were very close to sources of contamination. In many circumstances (60%), the distance between the hand-dug wells and sources of contamination was estimated to be less than 15 m (the commonly used guideline is that the distance should be at least 15.24 m or 50 ft.). The hand-dug wells that were less than 15.24m or 50ft. to the piggeries, latrines and dumping sites were highly contaminated microbiologically. Some of the hand-dug wells (about 33.3%) were estimated to be at a distance between 15 and 30 m from source of contamination (Table 12).

Table 12: Distance between sources of contamination and selected hand-dug wells in Ejisu Juaben Municipality.

Distance (m)	Number of hand-dug wells	Percentage (%)
<15	9	60
15-30	5	33.3
>30	1	6.7
Total	15	100

4.6 Sanitation survey of sampling sites

The sanitation survey showed that all the boreholes used for the study had platforms with aprons that carried wastewater away from the boreholes. All the boreholes had fitted hand pumps and this prevented human and animals having direct contact with the water body. It was observed that some of the boreholes were loose on their concrete platforms due to lack of periodic maintenance. In some cases, cracks were found at the base of the concrete platforms making it possible for some wastewater to get into the boreholes. Most of all the hand-dug wells did not have cover slabs and windlass. Water was drawn with public fetcher with varying degree of hygiene. The public fetcher was left in the wastewater around the hand-dug wells after drawing water from them. This could account for the levels of contamination. All the hand-dug wells had depth ranging from 1.65 – 7.8 m. The upper part of the inner walls of the hand-dug wells which were cemented were cracked and corroded with the exception of all the hand-dug wells at Fumesua. At Fumesua, all the hand-dug were constructed with coverts and cemented to the bottom. It was observed that most of the boreholes were sited away (15 – 30 m) from communities' utility areas while most of the hand-dug wells were close (< 15 m) to pit latrines, dump sites, piggeries and septic tanks (Table 13).

Table 13. Sanitation survey of sampling sites.

Town (Urban Area)	Sample ID	Distance from sanitary sites(m)	Topography	Inner walls of well	Depth of well(m)
Ejisu	EJBH1	50m from pit latrine.	Level ground	NA	NA
	EJBH2	40m from pit latrine 5m from road and within settlement.	Level ground	NA	NA
	EJBH3	39m from refuse dump. 30m from septic tank. 20m from pig farm.	In gentle slope towards hand-dug well.	NA	NA
	EJW1	10m from septic tank. 8m from refuse dump 25m from pig farm	In gentle slope towards hand-dug well.	Corroded and fissured	2.9m
	EJW2	8m from pit latrine 5m from septic tank 30m from pig farm	In gentle slope towards hand-dug well.	Corroded and fissured	3.6m
	EJW 3	7.5m from road and within settlement.	Level ground	Corroded and fissured	4m
Juaben					
	JBH1	15m from pit latrine 25m from refuse dump	In gentle slope towards hand-dug well.	NA	NA
	JBH2	40m from pit latrine 80m from refuse dump.	Level ground	NA	NA
	JBH3	10m from road and within settlement.	Level ground	NA	NA
	JW1	25m from pit latrine and within settlement.	In gentle slope towards hand-dug well.	Corroded and fissured	1.65m
	JW2	12m from pit latrine. 20m from refuse dump.	In gentle slope towards hand-dug well.	Corroded and fissured	3.5m
	JW 3	18m from pit latrine and within settlement.	In gentle slope towards hand-dug well.	Corroded and fissured	2.3m
Bonwire					
	BBH1	13m from pit latrine	At the lower part of a gentle slope towards hand-dug well.	NA	NA
	BBH2	9m from pit latrine	Level ground	NA	NA
	BBH3	8m from septic tank	Level ground	NA	NA

Con't Table 14. Sanitation survey of sampling sites.

	BWI	8.8m from pit latrine and within settlement and school premises	At the lower part of a gentle slope towards hand-dug well.	Corroded and fissured	4.5m
	BW2	30m from pit latrine and within settlement.	Level ground	Corroded and fissured	3.2m
	BW 3	35m from pit latrine and within settlement.	At the lower part of a gentle slope towards hand-dug well.	Corroded and fissured	4.1m
Fumesua					
	FBH1	45m from pit latrine and within settlement	Level ground	NA	NA
	FBH2	15m from refuse dump and close to farmlands	Level ground	NA	NA
	FBH3	30m from pit latrine	At the top of a gentle slope.	NA	NA
	FW1	8m from pit latrine and within settlement	Level ground	Cemented	7.4 m
	FW2	7m and 8m from two household toilet facility	In gentle slope towards hand-dug well.	Cemented	7.1 m
	FW 3	5m from household toilet facility and within settlement	Level ground	Cemented	7.8 m
Besease					
	BEBH1	18m from cemetery 25m from pit latrine 10m from farmlands	Level ground	NA	NA
	BEBH2	9m from Accra-Kumasi highway 25m from pit latrine	In gentle slope towards hand-dug well.	NA	NA
	BEBH3	25m from school toilet facility. Within school premises.	Level ground	NA	NA
	BEW1	6.9m from refuse dump	In gentle slope towards hand-dug well.	Cemented	2.5m
	BEW2	4.8m from pig farm 10m from refuse dump.	In gentle slope towards hand-dug well.	Corroded and fissured	1.8m
	BEW 3	10m from Accra-Kumasi highway and within a wetland.	In slope towards the wetland.	Corroded and fissured	2.8m

NA refers to measurements not available.

CHAPTER FIVE

DISCUSSION

5.1 Physicochemical parameters of boreholes and hand-dug wells

5.1.1 Temperature

The mean temperature of water samples from boreholes and hand-dug wells was low even though the borehole temperature was slightly higher than the hand-dug wells. There was no statistically significant differences between them ($p<0.658$). The relatively low sampling temperature could be attributed to the fact that most of the samples were collected very early in the morning. Usually, cool water is more palatable for drinking. However, high water temperatures enhance the growth of micro-organisms and hence affect taste and odour (Whelton, 2001). Groundwater having high temperature can dissolve more minerals from the rocks it is in therefore increase its electrical conductivity (USGS, 2014). There is no guideline value recommended for temperature of drinking water by WHO.

5.1.2 pH

In the study area, pH of all groundwater samples analyzed from boreholes and hand-dug wells were found to be far below the acceptable limit of 6.5-8.5 pH units as recommended by the WHO. Even though the mean pH of boreholes was lower than hand-dug wells, there was no statistically significant difference between them ($p<0.361$). Anornu *et al*, (2009) recorded a similarly low pH value (6.6) in the study area. Studies have shown that if the geology of the aquifer containing the groundwater has few carbonate rocks (sandstone, granite and gneisses), the groundwater tends to be acidic (American Ground Water Trust, 2003). The study area is predominantly underlain by crystalline rocks which belong to the Birimian, Granites formation (Kesse, 1985); therefore the low pH could be attributed to the geology of the study area. The groundwater sources in the municipality had low pH values which are considered too acidic for human consumption and can cause health problems such as acidosis (Nkansah *et al.*, 2010). It may also corrode reactive metal fixtures.

5.1.3 Total dissolved solids (TDS) and electrical conductivity (EC)

Groundwater samples analyzed from boreholes and hand-dug wells were within WHO acceptable limits of 1000mg/l and 1500 μS/cm for total dissolved solids (TDS) and electrical conductivity respectively. Both total dissolved solids and electrical conductivity were higher in boreholes than in hand-dug wells even though there were no statistically significant differences between them ($p<0.462$). The result is not different from Tiimub *et al.*, (2012) who also recorded high TDS and EC values in borehole than hand-dug wells at Achiase and Wabiri within the same municipality. Electrical conductivity (EC) of water is a direct function of its total dissolved salts (Harilal *et al.*, 2004). Hence it is an index to represent the total concentration of soluble salts in water (Purandara *et al.*, 2003). Total dissolved solids in water supplies originate from natural sources, sewage, urban and agricultural run-off, and industrial wastewater (WHO, 2003). The dissolutions of cations and anions in the host-rock by groundwater in the course of its movement accounts for the higher concentration of total dissolved solid (TDS) (Amadi *et al.*, 2013). According to Prakash and Somashekar (2006), all the samples from boreholes and hand-dug wells were non-saline.

5.1.4 Total Hardness

Water samples from boreholes and hand-dug wells were within WHO guideline value of 500 mg/l. Total hardness of boreholes was higher than hand-dug wells and there was statistically significant difference ($p<0.012$) between mean values of total hardness from boreholes and hand-dug wells. Studies have shown that calcium and magnesium accompanied by their sulphates, chlorides and carbonates naturally contribute to temporary and permanent hardness (Freeze and Cherry, 1979). Hardness can affect the taste and lathering ability of water when used for washing. Exceeding the guideline value will cause poor lathering with soap and skin irritation (Narasimha *et al.*, 2011). Comparatively, the hand-dug well water samples will produce lather with soap easily than the borehole water samples.

5.1.5 Colour and Turbidity

Colour and turbidity are important factors for describing water quality. They affect the acceptability of water by the consumers (USEPA, 2012). All the boreholes were clear with colour and turbidity values within WHO acceptable limits of 15 HU and 5 NTU respectively. All the boreholes had colour values within WHO acceptable limits whiles few hand-dug wells (EJW2, FW3, and BEW1) had turbidity values above the acceptable limits of prescribed by WHO. Colour and turbidity of hand-dug wells were significantly higher than that of boreholes ($p<0.001$). High turbidity in some hand-dug wells indicates the existence of suspended and colloidal matter such as silt, clays and fibrous particles suchlike asbestos minerals (WHO, 1992). This could be attributed to the presence of colloidal matter such as clay and silt, leaching of organic matter and domestic waste, and the disturbance associated with the drawing of water with the receptacles as most of the hand-dug wells were not cemented as the same observed by Prakash and Somashekar, (2006) in India. High turbidity of drinking water is of great concern because there are chances for the disease causing organisms to be enclosed in turbidity causing particles and as a result lead to health hazards (Manivaskam, 2005). Generally hand-dug wells derive water from shallow aquifers while most boreholes derive water from deep aquifers thus humates may infiltrate into shallow aquifers and alter the colour and turbidity of the water.

5.2 Anions in boreholes and hand-dug wells

The levels of anions in individual boreholes and hand-dug wells at the various locations vary due to different soil type, water chemistry and different human activities around the water source (Nkansah *et al.*, 2010). Levels recorded in this study could be attributed to run offs from farmlands because most of these anions are found in fertilizers.

5.2.1 Chloride

All the water samples from boreholes and hand-dug wells were within the acceptable limits of 250 mg/l approved by WHO even though mean chloride levels in hand-dug wells were higher than boreholes. There was no statistically significant difference ($p<0.533$) between the mean chloride levels from both boreholes and hand-dug wells. The impact of chloride in the groundwater results from minerals like apatite, mica and liquid inclusions of igneous rocks (Das and Malik, 1988). Human excreta and leachate from landfills (Sharma and Kaur, 2000), septic tanks and pit latrines (Polprasert, 1996) adds a significant amount of chlorides to groundwater. Chloride in water may react with sodium to form sodium chloride and can impact a salty taste in the water. The recommended maximum of 250 mg/l is based on taste considerations.

5.2.2 Sulphate

The levels of sulphate in all the water samples from boreholes and hand-dug wells were within the WHO guideline value of 250 mg/l. Sulphate levels in hand-dug wells were higher compare to boreholes and there was statistically significant difference ($p<0.003$) between mean sulphate levels of boreholes and hand-dug wells. The traces of sulphate in the water sample might have resulted from improper disposal of refuse and sewage in the area and also runoff from farmlands (Ayodele and Aturamu, 2011). Most of the hand-dug wells were very close to public refuse dumps, piggery, soakaways and toilets facilities. Sulphate content in drinking water above 400mg/l causes bitter taste and may also cause gastro-intestine irritation and catharsis (Manivaskam, 2005). Water with high sulphates levels cause laxative effect and gastro intestinal irritation (Narasimha *et al.*, 2011).

5.2.3 Nitrate

The water samples boreholes and hand-dug wells in the study area fell within the stipulated range by WHO of 50mg/l. Mean nitrate concentration in hand-dug wells was slightly higher than boreholes and there was no statistically significant difference ($p<0.0131$) between them. The result is not different from findings by Tiimub *et al.*, (2012) who also recorded high nitrate values in hand-dug wells than boreholes at Achiase and Wabiri within the same municipality. Some traces of nitrate detected in the water samples might have originated from waste dump sites in the area and the use of artificial fertilizer for farming which probably leached and percolated into the soil and polluted the groundwater (Tredoux *et al.*, 2000). High concentration of nitrates in drinking water can cause methemoglobinemia (cyanosis) in infants, which is a disease characterized by blood changes (Prakash and Somashekar, 2006).

5.2.4 Fluoride

Fluoride concentration in both borehole and hand-dug well samples was below the guideline value of 1.5 mg/l as prescribed by WHO guideline value for drinking water. These indicate that water from boreholes and hand-dug wells have not been affected by fluoride. Hand-dug wells had mean fluoride levels slightly higher than boreholes and there was no statistically significant difference ($p<0.857$) between them. Fluoride can get into drinking water through discharge from fertilizer or aluminium factories. Most fluoride that enters our body is found in drinking water (Saralakumari and Rao, 1993). Fluoride is regarded as a vital element though health problems may possibly arise from either deficiency or excess intake (Gopal and Ghosh, 1985). Chronic exposure to excessive consumption of fluoride may cause increased likelihood of bone fractures in adults which may lead to pain and tenderness.

5.3 Heavy metals in boreholes and hand-dug wells

Heavy metals often are referred to as common pollutants which are usually distributed in the environment with sources primarily from the weathering of minerals and soils (Merian, 1991; O'Neil, 1993). With the exemption of Cadmium which was below detection limit of equipment, all the other heavy metals analyzed (Fe, Mn and Zn) were detected in most of the water samples. However, most of them were within the guideline values prescribed by the WHO. The differences in concentrations of metals in individual boreholes and hand-dug wells depends on prevailing factors such as temperature, pH, standing time of water and water hardness (Obiri-Danso *et al.*, 2009).

5.3.1 Iron

Most groundwater supplies contain some iron because iron is common in many aquifers and is found in trace amounts in almost all sediments and rock formations. The borehole water samples in the study area were characterized by iron concentrations within the WHO guideline value of 0.3 mg/l which is based on taste and appearance (WHO, 2004). Observation made at Fumesua showed that, one out of the three boreholes recorded iron in water sample whiles iron levels in all the three hand-dug wells were below the detection limit of equipment. This might be due to corrosion of metallic pipes due to low pH of water samples in the study area because the boreholes are poorly maintained. One hand-dug well each at Ejisu and Juaben respectively had iron levels above the WHO guideline value of 0.3 mg/l. Water with high iron may be due to chemical weathering of the bedrock into lateritic soils and subsequent downward leaching into the shallow aquiferous zones in the area (Amadi *et al.*, 2013). The iron content of drinking water greater than 0.3mg/l, stains cloths during laundering, stains plumbing fixtures, clogs pipes and incrusts well screens (WHO, 2003).

5.3.2 Manganese

Manganese levels of water samples from boreholes and hand-dug wells were within the WHO guideline value of 0.4 mg/l. Mean manganese levels in hand-dug wells were generally higher than boreholes and there was no statistically significant difference ($p<0.318$) between them. The result is similar to Obiri-Danso *et al.*, (2009) who had the same results from wells and boreholes water in some peri-urban communities in Kumasi, Ghana. Health considerations will arise at levels greater than 0.4 mg/l. A high dose of manganese causes apathy, headaches, insomnia and weakness of legs. Under extreme case, nervous system disorders such as Parkinson's disease may develop (Jennings *et al.,* 1996).

5.3.3 Zinc

Zinc levels from boreholes and hand-dug well water samples were within the WHO guideline value of 3 mg/l. Zinc can be introduced into water naturally by erosion of minerals from rocks and soil. Acute adverse health effect of drinking water with too much zinc can lead to stomach cramps, vomiting and nausea. Exposure to zinc for longer periods may cause anaemia, nervous system disorders and damage to the pancreas (IDPH, 2013).

5.4 Microbiological quality of boreholes and hand-dug wells

5.4.1 Boreholes

According to the WHO, drinking water should be free from coliform bacteria. With the exception of Fumesua and Bonwire, total coliforms were recorded from one borehole from Ejisu, two from Juaben and one from Besease. At Ejisu, the borehole was close to a piggery, septic tank and refuse dump. At Juaben, the two boreholes were close to pit latrines and refuse dumps. At Besease, the borehole was close to a cemetery and pit latrine. There is a possibility of leachates contamination and this might account for the presence of coliform bacteria in water samples because studies have made known that pit latrines and soakage pits can spread their influence on groundwater quality up to 10 m or more as groundwater movement is either lateral or vertical (Cairncross and Cliff, 1987). Vertical movements of groundwater undergo filtration by soil particles whiles lateral movement of groundwater does not undergo filtration and could carry pollutant for long distance. At Besease, the platform that carried wastewater away from the boreholes had cracks so wastewater was found around the boreholes. There is a possibility of dirty water leaking into the boreholes and this might also account for coliform contamination in the boreholes. Studies done earlier by Obiri-Danso *et al.*, (2009), and Agbabiaka and Sule, (2010) also recorded high microbial counts in boreholes outside WHO guideline. Boreholes water samples from Fumesua and Bonwire recorded zero counts for total coliform, faecal coliforms and *E.coli*. This agrees with Iyasele and Idiata (2012) that boreholes as low cost technology substitute for developing countries are usually considered as good sources of drinking water when properly constructed and maintained. They also provide regular supplies of good and wholesome water with low microbial load and little need for treatment.

5.4.2 Hand-dug wells

The presence of total coliform (TC), faecal coliforms (FC) and *E.coli* detected in most hand-dug well water samples suggest faecal contamination by human and animal faeces in groundwater system. Three possible reasons may account for the presence of total coliform, faecal coliforms and *E.coli* in samples from hand-dug well water: (1) distance from sanitary sites (pit latrine, refuse tip, septic tanks and piggery) and depth of hand-dug well, (2) sanitary conditions around the hand-dug wells and (3) contamination during fetching with public fetcher.

Studies have shown that tendency of human faeces and leachates migrating from un-lined pit-latrine/soakaway and dumping sites into the shallow, porous and permeable aquifer cannot be over-emphasized once the 15 m minimum safe distance between a hand-dug well and a soakaway/pit-latrine is compromised due to one reason or the other, faecal contamination is inevitable (Amadi *et al.*, 2013). It was observed that 60% of the hand-dug wells used for the studies were close (less than 15m) to sanitary sites such as pit latrines, soakaways and dumping sites. Most pathogens from faecal matter remain near the point of origin or source may travel along with the water flow through pore in the surrounding soil and may enter the hand-dug wells through cracked drum/casing. All the hand-dug wells had their inners walls fissured with the exception of Fumesua which had concrete ring pipes cemented to the bottom. This may account for no faecal coliform and *E.coli* in samples from Fumesua. The depth of the hand-dug wells could explain contamination levels. All the hand-dug wells studied were shallow and ranged approximately from 1.65 m – 7.8 m in depth. The shallowest hand-dug well was located at Juaben which also recorded the highest number of coliform bacteria in samples. The deepest was located at Fumesua which recorded the lowest total coliform and zero counts for faecal coliforms and *E.coli* respectively in samples. Research conducted by Narayan and Rao (1981) in India showed that even though percolating waters lose their bacterial content as percolation progresses through the soil, instances have been reported where bacterial pollution of groundwater has occurred. Studies have also shown that ground water sourced from deep wells are usually of good bacteriological quality because vertical percolation of the water through soil results in the removal of much of the microbial and organic population, by direct contrast, waters from shallow wells are obviously polluted (Geldreich ,1996).

Moreover total and faecal coliform contamination may be due to environmental factors especially human activities around the hand-dug well. Most of the wells did not have cover slabs exposing them to the dust and insects. It was also observed that wastewater and dirty water were found around the hand-dug wells because they lack aprons to carry them away. It was also observed that domestic animals normally visit the hand-dug wells because of the wastewater and dirty water to drink and generally contaminate with their faeces in the process. These activities could enhance bacterial spores to contaminate the water since most of the lack cover slabs. According to Tiedemann *et al.* (1988), the nearness of domestic and grazing animals to sources of water have been made known to play a role in the severity of faecal contamination of water sources. Therefore the hand-dug wells in the study area have experienced varying degree of bacteriological contamination as a result of unhealthy sanitary habit exhibited by the people in the area.

All the hand-dug wells had no windlass and public fetcher with varying degree of hygiene is used to draw water from hand-dug wells. It was observed that after drawing the water, the fetcher is left in the waste water and dirty water that had been spilt around the hand-dug well. This practice also introduces dirty water into the hand-dug well. This is another possible source of contamination. Results for total and faecal coliforms are similar to Obiri-Danso *et al.*, (2009) which recorded levels above WHO guideline value in some hand-dug wells in some peri-urban communities in Kumasi. Also results from Fumesua also support Nkansah *et al.*, (2010) which recorded no faecal coliforms and *E.coli* in some hand-dug wells in Kumasi below the WHO guideline value.

5.4.3 Parasites in boreholes and hand-dug wells

Water samples from boreholes were found to be free from helminths eggs. This is largely attributed to their make-up; all the boreholes had aprons that carry waste and dirty water away from their immediate surrounding area downstream. Unlike other sources that are open to external contamination, boreholes operate a water system that is closed and fitted with hand pumps to avoid direct contact with animals or humans. Results of this study conform to work by Tiimub *et al.*, (2008) and Chollom *et al.*, (2013) who recorded zero helminths eggs in boreholes within some parts of Ghana and Nigeria respectively. Helminths eggs were present in 26.7% of the total hand-dug wells evaluated in the present study. Tiimub *et al.*, 2008 and Chollom *et al.*, (2013) recorded helminths eggs in wells in rural communities in Nigeria and Bawku East District of Ghana respectively. They attributed it to lack of proper toilet facilities, inadequate supply of portable drinking water and poor sewage and waste disposal systems. In this present study it was observed that all wells in these communities do not have windlass and most of them are usually left opened. Some of the wells were close to pit latrines, piggeries, septic tanks and dumps sites. It was also observed that the receptacles used to fetch the water are mostly left in the dirty water around the hand-dug wells and immediately the other person comes, he just uses that same receptacle to fetch the water. This might account for helminths contamination of the hand-dug wells since most of helminths encountered were soil transmitted.

Among the helminths, *Ascaris* species had the highest prevalence rate (66.7%) followed by *Hookworm* (22.2%) and *S. haematobium* (11.1%). Chollom *et al.*, (2013) had similar results in that order of prevalence *Ascaris* species (33.9%), *Hookworm* (20.3%) and *Strongyloides spp* (3%). It is reported that *Ascaris* species is the most prevalent and most economically important internal parasite of swine and the eggs can be transported by infested pigs, insects, fomites, blowing dust, pig manure, and effluent (College of Veterinary Medicine, 2014). This could account for *Ascaris* species having high prevalence rate in the study area because pigs are mostly raised in semi-intensive system in some of the communities.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The study has shown that generally physiochemical parameters of groundwater from selected boreholes and hand-dug wells were within acceptable WHO limits for drinking and domestic activities with the exception of pH which was low (out of recommended range) for all boreholes and hand-dug wells.

The microbial quality of water in one borehole (EJBH3) at Ejisu, two boreholes (JBH2 and JBH3) at Juaben and one borehole (BEBH1) at Besease were unacceptable and require treatment before use. Water from all the hand-dug wells is of poor microbial quality and unsuitable for human consumption without treatment.

6.2 Recommendations

Based on the outcome of the study the following is recommended:

i. Hand-dug wells should be covered and if possible hand pumps or mechanical pumps should be installed to reduce the level of microbial contamination.

ii. Future boreholes and or hand-dug wells should be located far away from dumpsites, pit-latrines and soakaway and the use of existing boreholes and hand-dug wells very close to unlined dumpsites, pit-latrines, piggeries and soakaways should be discontinued.

iii. Tapping of shallow aquifers for domestic purposes should stop due to their vulnerability to pollution. Subsequent boreholes and hand-dug wells should tap water from deeper aquifers that are less prone to contamination.

iv. Receptacles for drawing water from open wells should be kept clean and if possible permanently attached to a windlass when not in use and access to boreholes and hand-dug wells by domestic and grazing animals should be restricted by fencing.

v. Education should be carried out on the need to keep areas around the boreholes and hand-dug wells clean.

vi. The boreholes and hand-dug wells should be periodically maintained and content monitored.

REFERENCES

Adetunji, V. O. & Odetokun, I. A. (2011). Groundwater contamination in Agbowo community, Ibadan Nigeria: Impact of septic tanks distances to wells. *Malaysian Journal of Microbiology*, *7*(3), 159-166.

Agbabiaka, T. O. & Sule, I. O. (2010). Bacteriological Assessment of Selected Hand-dug well Water Samples in Ilorin Metropolis. *International Journal of Applied Biological Research: Vol. 2(2)*: 31-37.

Alloway, B. J. & Ayres D. C. (1997). Chemical Principles of Environmental Pollution. 2nd Ed. University of London UK Pp. 44-46.

Amadi, A. N., Dan-Hassan, M. A., Okoye, N. O., Ejiofor, I. C. & Tukur, A. (2013). Studies on Pollution Hazards of Shallow Hand-Dug Wells in Erena and Environs, North-Central Nigeria. *Environment and Natural Resources Research*, *3*(2), p69.

Amankona, K. B. (2010). Evaluation of the Microbiological and Physicochemical Quality of Hand-dug well Water in the Offinso District of Ashanti Region (MSc Published Thesis). Department of Theoretical and Applied Biology. Kwame Nkrumah University of Science and Technology, Kumasi.

American Ground Water Trust (2003). *Acid Rain and Groundwater pH.* The American Well Owner, *Number 3.*

American Public Health Association (APHA), (1992). Standard Methods for the Examination of Waste and Wastewater, 18th Edition Washington D. C. Pp72-265.

American Public Health Association (APHA), (1995). Standard methods for the examination of water and wastewater, 19th Edition, Washington, D.C. Pp. 84.

Amorim, M. I., Mergler, D., Bahia, M. O., Dubeau, H., Miranda, D., Lebel, J. & Lucotte, M. (2000). Cytogenetic damage related to low levels of methyl mercury contamination in the Brazilian Amazon. *Anais da Academia Brasileira de Ciências*, *72*(4), 497-507.

Anornu, G. K., Kortatsi, B. K. & Saeed, Z. M. (2009). Evaluation of Groundwater Resources Potential in the Ejisu-Juaben District of Ghana. *African Journal of Environmental Science and Technology Vol.3 (10), pp 332-340.*

Antwi, E., Bensah, E. C. & Ahiekpor, J. C. (2011). Use of solar water distiller for treatment of fluoride-contaminated water: The case of Bongo district of Ghana. *Desalination*, *278*(1), 333-336.

Ayodele, O. S. & Aturamu, A. O. (2011). Portability Status of Some Hand Dug Wells in Ekiti State, Southwestern Nigeria. *International Journal of Science and Technolog y*, *1*(2).

Ayres, R., Alabaster, G., Mara, D. & Lee, D. (1992). A Design Equation for Human Intestinal Nematode Egg Removal. In: Waste Stabilization Ponds. *Water Research, 26(6)*: 863-866.

Bailyn, M. (1994). A Survey of Thermodynamics, American Institute of Physics, New York, ISBN 0-88318-797-3, 14.

Bethony, J., Brooker, S., Albonico, M., Geiger, S. M., Loukas, A., Diemert, D. & Hotez, P. J. (2006). Soil-transmitted helminth infections: ascariasis, trichuriasis, and hookworm. *The Lancet*, *367*(9521), 1521-1532.

Bratton, R. L. & Nesse, R. E. (1993). Ascariasis. An infection to watch for in immigrants. *Postgraduate medicine*, *93*(1), 171-3.

Brenner, K. P., Rankin, C. C. & Roybal, Y. R. (1993). New medium for the simultaneous detection of total coliforms and *Escherichia coli. Appl Environ Microbiol*. 59:3534–44.

British Colombia Ministry of Health, (1999). "Safe Water Supply Vital to Your Health." *http://www.healthservices.gov.bc.ca/protect/pdf/PHI052.pdf*. (Accessed on 24-02-2013).

Brooker, S., Clements, A. C. & Bundy, D. A. (2006). Global epidemiology, ecology and control of soil-transmitted helminth infections. *Advances in parasitology*, *62*, 221-261.

Buckley, D. K. (1986). Report on advisory visit to water aid projects in Ghana. *Unpublished Report, British Geological Survey, Hydrogeology Research Group, Wallingford*.

Cairncross, S. & Cliff, J. L. (1987). Water Use and Health in Mireda, Mozambique. *Trans. Royal Soc. Trop. Med. Hyg. 81:* 51-54.

Center for Disease Control and Prevention (CDC), (1998). Parasites, http://www.cdc .gov/parasites/ (Accessed on 16/12/12).

Centre for Earth and Environmental Science, School of Science, Indiana University ~Purdue University, Indianapolis "Water Quality". http://www.cees. iupui.edu/ education/Workshops/Project_Seam/water_quality.htm. (Accessed on 11-02-2013).

Chollom, C. S., Iduh, U. M., Gyang J. B., Idoko A. M., Ujah A., Agada, O. G., Peter, J., Akele, R. Y. & Okwori A. J. (2013). Parasitological Evaluation of Domestic Water

Sources in a Rural Community in Nigeria. *British Microbiology Research Journal 3(3);* 393-399.

Clark, N., Swayze, G. A., Leifer, I., Livo, K. E., Kokaly, R., Hoefen, T. & Dominguez, R. (1993). US Geological Survey.

College of Veterinary Medicine, (2014). Iowa State University, Veterinary Diagnostic and Production Animal Medicine. "Roundworm Infection (Ascariasis)". http:// vetmed. iastate.edu/vdpam/new-vdpam-employees/food-supply-veterinary-medicine/ swine/ swine-diseases/roundworm-infection-a.htm (Accessed on 16-03-2014).

Community Water and Sanitation Agency (CWSA), (2012). Water Quality Issues. Report on Overview of Water Quality-Challenges in Rural Water Supply. http:// cwsagh. org/reports&review/waterqualityissues/overview/cwsa_subcat_linkdetails.cfm.htm (Accessed on 16-05-13).

Covington, A. K., Bates, R. G. & Durst, R. A. (1985). "Definitions of pH Scales, Standard Reference Values, Measurement of pH, and Related Terminology". *Pure Appl. Chem. 57 (3): 531–542.*

Craun, M. F., Craun, G. F., Calderon, R. L. & Beach, M. J. (2006). Waterborne outbreaks reported in the United States. *Journal of Water and Health*, *4*(Suppl 2), 19-30.

Crompton, D. W. T. (1999). How Much Human Helminthiases is there in The World? *Journal of Parasitology, vol. 85, pp. 379-403*.

Crompton, D. W. T. & Whitehead, R. R. (1993). Hookworm infections and human iron metabolism. *Parasitology*, *107*(S1), S137-S145.

Csuros, M. (1997). *Environmental Sampling and Analysis: Lab Manual*. CRC. Press USA.

Darakas, E. (2002). *E. coli* kinetics-effect of temperature on the maintenance and respectively the decay phase. *Environmental Monitoring and Assessment*, *78*(2), 101-110.

Das, P. K. & Malik, S. D. (1988). Groundwater of Khatra Region of Bankura District, West Bengal: Some Chemical Aspects in Reference to its Utilization. *J. Indian Water Res. Soc., 8(3), 31-41.*

DeZuane, J. (1997). Handbook of Drinking Water Quality (2nd Ed.). John Wiley and Sons. ISBN 0-471-28789-X.

Diersing, N. (2009). "Water Quality: Frequently Asked Questions." Florida Keys National Marine Sanctuary, Key West, FL. USA.

Ejisu Juaben Municipal Assembly, (2006). Municipal Information. http://ejisujuaben. ghanadistricts.gov.gh/?arrow=dnf&_=21&r=2&rlv=geology. (Accessed on 28-02-2014).

Elinder, C. G., Friberg, L., Nordberg, G. F. & Vouk, V. B., (1986). Handbook on the Toxicology of Metals. 2nd ed., Amsterdam, Elsevier Science Publishers, 664-679.

El-Nofely, A. & Shaalan, A. (1999). Effect of *Ascaris* Infection on the Nutritional Status and IQ of Children. *International Journal of Anthropology*, *14*(1), 55-59.

Environmental Fact Sheet (2010). 'Taste and Odour in Drinking Water'. New Hampshire Department of Environmental Services, 13: S29-S39.

Freeze, R. A. & Cherry, J. A. (1979). Groundwater. *Prentice~ Hall, Englewood I Cliffs, N.]., USA*, *12*, 145-165.

Gale, P. (2001). Developments in Microbiological Risk Assessment for Drinking Water. *J. Appl. Microbiol*. 91(2), 191–205.

Geldreich, E. E. (1996). Pathogenic agents in freshwater resources. *Hydrological processes*, *10*(2), 315-333.

Ghana Statistical Service Report (2010). "Population and Housing Census". Accra, Ghana.

Gopal, R. & Ghosh, P. K. (1985). Fluoride in Drinking Water-Its Effects and Removal. *Defence Science Journal*, *35*(1), 71-88.

Grabow, W. O. K. (2000). The Safety of Water Disinfection Chem. and Microb. Risks. Radisson Denville Resort, Miami Beach, Florida. USA, 15-17 November.

Gray, N. F. (2008). Drinking water quality. Cambridge University Press.

Guerrant, R.L. (1995). Bench aids for the diagnosis of intestinal parasites-World Health Organization, 1994, Sw.Fr. 35.00 (Sw.Fr. 24.50 in developing countries). *Parasitol. Today, 115: 238-238.*

Gyamfi, E. T., Ackah, M., Anim, A. K., Hanson, J. K., Kpattah, L., Enti-Brown, S. & Nyarko, E. S. (2012). Chemical analysis of potable water samples from selected suburbs of Accra, Ghana. *Proceedings of the International Academy of Ecology and Environmental Sciences*, *2*(2), 118-127.

Hach Company, (1992). Hach water analysis handbook. 2nd ed. Loveland.

Harilal, C. C., Hashim, A., Arun, P. R., & Baji, S. (2004). Hydrogeochemistry of Two Rivers of Kerala with Special Reference to Drinking Water Quality. *Ecology Environment and Conservation*, *10*, 187-192.

Illinois Department of Public Health (IDPH), (2010). Environmental Health Fact Sheet (Iron in drinking water). http://www.idph.state.il.us/envhealth /factsheets/ iron FS.htm (Accessed on 10-06-2013).

Illinois Department of Public Health (IDPH), (2013). Environmental Health Fact Sheet (Zinc). www.idph.state.il.us/envhealth/factsheet/zinc.htm (Accessed on 10-06-2013).

Institute of Food and Agricultural Sciences (IFAS), (2004). A beginner's guide to water management colour, 1st Edition. Department of Fisheries and Aquatic Sciences, University of Florida.

International Occupational Safety and Health Information Centre (1999). Technical Info Sheets: 147 Technical Info-sheets.

Issah, A. (2002). Assessment of Underground Water Quality and Levels of Heavy Metals in the Upper East and Northern Regions of Ghana (Published MSc Thesis) Department of Chemistry Kwame Nkrumah University of Science and Technology, Kumasi.

Iyasele, J. U. & Idiata D. J. (2012). Determining The Hand-dug well Water Quality in Edo South and Edo North areas of Edo State. *Research Journal in Engineering and Applied Sciences: 1(4), 209-213.*

Jennings, G. D., Sneed, R. E. & Clair, M. B. (1996). *St. Metals in drinking water. Published by: North Carolina Cooperative Extension Service Publication no*. AG-473-1.

Johnson, D. L., Ambrose, S. H., Bassett, T. J., Bowen, M. L., Crummey, D. E., Isaacson, J. S., Johnson, D. N., Lamb, P., Saul, M. & Winter-Nelson, A. E. (1997).

"Meanings of Environmental Terms." *Journal of Environmental Quality*. 26: 581-589.

Keller, E. A. (2000). Environmental Geology. Prentice Hall, Upper Saddle River, NJ, 8th edition. ISBN 0-13-022466-9.

Keller, E. A. (2011). Introduction to Environmental Geology. Prentice Hall, 5th edition.

Kesse, G. O. (1985). The rock and mineral resources of Ghana. *Balkema, Amsterdam*.

Keyser, S. L. (1997). 'Colour and Taste' Environmental Toxicology Department, University of Califonia, Davis.

Kim-Shapiro, D. B., Gladwin, M. T., Patel, R. P. & Hogg, N. (2005). The reaction between nitrite and hemoglobin: the role of nitrite in hemoglobin-mediated hypoxic vasodilation. *Journal of Inorganic Biochemistry*, *99*(1), 237-246.

Leach, R. M. & Harris, E. D. (1997). Manganese. Clinical Nutrition in Health and Disease, (Handbook of Nutritionally Essential Mineral Elements), 335-355.

Lenntech, (2012). Groundwater: 'Sources of groundwater pollution'. http://www.lenntech.com/ groundwater/pollution-sources.htm. (Accessed on 14-02-2013).

Lloyd, S. & Soulsby, L. (1998). Is anthelmintic resistance inevitable: back to basics? *Equine Veterinary Journal*, *30*(4), 280-283.

Maier, R. M., Pepper, I. L. & Gerba, C. P. (2000). Microorganisms and Organic Pollutants. *Environmental Microbiology, RM Maier, IL Pepper, and CP Gerba, Eds., Academic Press, San Diego*, pp. 363-402.

Manahan, S. E. (1999). *Industrial ecology: environmental chemistry and hazardous waste*. CRC Press. USA.

Manivaskam, N. (2005). Physicochemical Examination of Water Sewage and Industrial Effluent, 5th Ed., Pragati Prakashan Meerut. India.

Massachusetts Department of Environmental Protection (MassDEP), (2013). 'Water, Wastewater and Wetland.' http://www.mass.gov/dep/water/drinking/color .htm # taste Accessed on 08-02-2013.

Mathew, J. D., Lechevallier, M. W., Cameron, S.C. & Feters, G.A. (1984). Evidence for the Role of Copper in the Injury Process of Coliform Bacteria in Drinking Water. *Applied Environmental Microbiology*. 48 (2): 289-293.

Mensah, S. O. & Yankson, D. A. (2013). The Role of Agriculture in the Economic Empowerment of Women in the Ejisu Juaben Municipality in the Ashanti Region of Ghana. *Journal of Environment and Earth Science*, *3*(11), 113-128.

Merian, E. (1991). *Metals and their compounds in the environment: occurrence, analysis and biological relevance.* VCH Verlagsgesellschaft GmbH. Germany.

Ministry of Food and Agriculture (2013). Districts-Ashanti Region: Ejisu-Juaben. http://mofa.gov.gh/site/?page_id=855. (Accessed on 28-02-2014).

Narasimha Rao C., Dorairaju S. V., Bujagendra Raju M. & Chalapathi P. V. (2011). *Statistical Analysis of Drinking Water Quality and its Impact on Human Health in Chandragiri, near Tirupati, India*. ECO Services International. http://www.eco-web.com/edi/111219.html. (Accessed on 07-05-2014).

Narayan, K. L. & Rao, P. S. H. (1981) Warrangal Well Waters – Bacteriological Quality. *Indian Journal of Environmental Health 23:* 149 – 151.

National Ground Water Association, (1999). NGWA Press publication "*Ground Water Hydrology for Water Well Contractors"*.

Nishiguchi, M. K. (2000). Temperature Affects Species Distribution in Symbiotic Populations of *Vibrio spp*. *Environmental Microbiology* 66 (8): 35550-35555.

Nkansah, M. A., Boadi, N. O. & Badu, M. (2010). Assessment of the Quality of Water from Hand-Dug Wells in Ghana. *Environmental health insights*, *4*, 7.

Nonner, J. C. & Nonner, J. (2002). *Introduction to Hydrogeology: Unesco-IHE Delft Lecture Note Series*. CRC Press.

O'Neil, P. (1993). Environmental Chemistry. Chapman and Hall, London. Pp. 193.

Obiri-Danso, K. S., Adjei, B., Stanley, K. & Jones, K. (2009). Microbiological Quality and Metal Levels in Wells and Hand-dug wells Water in Some Peri-urban Communities in Kumasi, Ghana. *African Journal of Environmental Science & Technology*, *3*(3), 59-66.

Oki, T. & Kanae, S. (2006). Global Hydrological Cycles and World Water Resources . *Science*, *313*(5790), 1068-1072.

Osiakwan, G.M. (2002). 'Baseline Studies into the Groundwater Resources in the Bosomtwi-Atwima-Kwanwoma District of Ashanti Region'. (MSc Published thesis) Kwame Nkrumah University of Science and Technology, Kumasi Ghana.

Pelig-Ba, K. B. (1999). *Hydrogeochemistry of Groundwaters from the Voltaian and Birimian Formations of Ghana, Unpubl* (Doctoral dissertation, PhD Thesis, Univ. Reading).

Peters, W. (1978). Symposia of the British Society for Parasitology 16, 25 Oxford, Blackwell Scientific Press.

Polprasert, C. (1996). Organic Waste Recycling – Technology and Management. 2nd Ed., John Wiley and Sons, Chichester. UK.

Prakash, K. L. & Somashekar, R. K. (2006). Groundwater quality – Assessment on Anekal Taluk, Bangalore Urban district, India. *Journal of Environmental Biology*. *27(4)*, 633-637.

Purandara, B. K., Varadarajan, N. & Jayashree, K. (2003). Impact of Sewage on Ground Water Quality - A case study. *Pollution Research*, *22*(2), 189-197.

Roberts, L. S., Janovy, J. & Schmidt, G. D. (1996). *Foundations of parasitology*. Dubuque: Wm. C. Brown. (p. 658).

Saralakumari, D. & Rao, P. R. (1993). Endemic Fluorosis in the Village Ralla, Anantapuram in Andra Pradesh. An epidemiological study. *Fluoride*, 26(3), 177-180.

Schwartzbrod, J. (1998).Quantification and Viability Determination for Helminth Eggs in Sludge (Modified USEPA Method). 1st Edn. Faculty of Pharmacy, Henri Poincaré University, PO Box 403, 54001, Nancy Cedex France.

Sharma, B. K. & Kaur, H. (2000). Environmental Chemistry, Krishna Prakashan Media (P) Ltd. *Meerut, (96-97).*

The Groundwater Foundation (2013). "Sources of Groundwater Contamination". http://www.groundwater.org/gi/sourcesofgwcontam.html. (Accessed on 23-02-2013).

Tiedemann, A. R., Higgins, D. A., Quigley, T. M., Sanderson, H. R. & Bohn, C. C. (1988). Bacterial Water Quality Responses to Four Grazing Strategies Comparisons with Oregon Standards. *J. Environ. Qual. 17*: 492-498.

Tiimub, B. M., Forson, M. A. & Obiri-Danso, K. (2008). Groundwater Quality, Sanitation & Vulnerable Groups: Case Study of Bawku East District. In *33rd WEDC International Conference, Accra, Ghana*.

Tiimub, B.M., Frimpong, S., Kuffour, R.A., Dwumfour, A.B., Monney, I. & Obiri-Danso, K. (2012), "Groundwater quality at Achiase and Wabiri in the Ejisu Juaben municipality of the Ashanti region in Ghana", *International Journal of Development and Sustainability*, Vol. 1 No. 3, pp. 939-956.

Tredoux, G., Talma, A. S. & Engelbrecht, J. F. P. (2000). The increasing nitrate hazard in groundwater in the rural areas. In *Proceedings of WISA 2000 Biennial Conference. Sun City, South Africa* (Vol. 28).

United Nation Environmental Program (UNEP), (2000). State of the Environment (SOE): overview at regional and global levels. Global Environmental Outlook (GEO), Vol. 2 Washington, DC.

United State Environmental Protection Agency (USEPA), (2008). Water Resource Topics: 'WaterResources'.http://www.epa.gov/tribalcompliance/waterresources/wrwaterdrill.html. (Accessed on 28-02-2014).

United State Environmental Protection Agency (USEPA), (2012). Washington, D.C. "Water: Basic Information about Regulated Drinking Water Contaminants "http://water. epa.gov/drink/contaminants/basicinformation. (Accessed on 12-02-2013).

United States Environmental Protection Agency (USEPA), (1991). Washington, D.C. "Guidance for Water Quality-Based Decisions: The TMDL Process." Doc. No. EPA 440/4-91-001.

United States Environmental Protection Agency (USEPA), (1997). Control of Pathogens and Vector Attraction in Sewage Sludge. EPA/625/R-92-004. Washington, D.C.

United States Environmental Protection Agency (USEPA), (2003a). Chemical contaminants in drinking water. Technical fast sheet on microbes. EPA 816-03-016.

United States Environmental Protection Agency (USEPA), (2003b). Health Effects Support Document for Manganese. United State Environmental Protection Agency, Office of Water. EPA-822-R-03-003. Washington, D.C.

United States Geological Survey (USGS), (2008). USGS Water Science School. The World's Water. http://ga.water .usgs.gov/edu/waterdistribution.html. (Accessed on 28-02-2014).

United States Geological Survey (USGS), (2014). USGS Water Science School. Water Properties: Temperature. http://water.usgs.gov/edu/temperature.html. (Accessed on 20-03-2014).

Wagner, B. J. & Gorelick, S. M. (1987). Optimal Groundwater Quality Management under Parameter Uncertainty. Water Resources Research, 23(7): 1162-1174.

Ware, G. W. (1989). Mercury. USEPA Office of Drinking Water Health Advisories. Reviews of Environmental Contamination and Toxicology, 107:93–102.

Whelton, A. J. (2001). Temperature Effects on Drinking Water Odor Perception (MSc Published Thesis). Faculty of The Virginia Polytechnic Institute and State University, Blacksburg, Virginia. USA.

World Health Organisation (WHO), (1992). Guidelines for Drinking Water Quality. Vol. 1 Geneva, Pp. 145-196.

World Health Organisation (WHO), (2003a). Total Dissolved Solids in Drinking Water. Revised Background Document for Development of WHO Guidelines for Drinking Water Quality. Page 1.

World Health Organisation / United Nations Children's Fund (WHO/UNICEF), (2010). Joint Monitoring Programme on Water Supply and Sanitation – *Progress on Sanitation and Drinking Water Update*. Retreived on 09-08-2013.

World Health Organization (WHO), (1994). Bench aids for the diagnosis of intestinal parasites.

World Health Organization (WHO), (1996). Guidelines for Drinking Water Quality: p. 231.

World Health Organization (WHO), (2003b). Guidelines for drinking water quality. Geneva., (WHO/SDE/WSH 03. 04).

World Health Organization (WHO), (2004). *International statistical classification of diseases and related health problems* (Vol. 1). World Health Organization.

World Health Organization (WHO), (2006). Guidelines for The Safe Use of Wastewater, Excreta and Greywater. Vol. 2 Wastewater Use in Agriculture. WHO, Geneva.

World Health Organization (WHO), (2012). “Progress on Drinking-Water and Sanitation–2012 Update” launched on 6 March 2012.

World Vision International (WVI), (2000). Rural Water Project Ghana, Quarterly Report Kumasi, Pp. 1-3.

APPENDIX

Appendix I: GWCL and WHO guideline values for drinking water.

PARAMETERS	UNITS	GWCL	WHO GUIDELINE VALUES (2004)
Colour	Hazen Units	15.0	15.0
Odour	-	Unobjectionable	
Taste	-	Unobjectionable	
Turbidity	NTU	5.0	5.0
Conductivity	µS/cm	1000.0	1500.0
Temperature	°C	-	-
Total Dissolved Solids (TDS)	mg/l	1000.0	1000.0
pH		6.5-8.5	6.5-8.5
Total Alkalinity	mg/l $CaCO_3$	-	-
Total Hardness	mg/l $CaCO_3$	500.0	500.0
Calcium Hardness	mg/l $CaCO_3$	-	-
Magnesium Hardness	mg/l $CaCO_3$	-	-
Calcium	mg/l	200.0	-
Magnesium	mg/l	150.0	-
Iron	mg/l	0.3	0.3
Manganese	mg/l	0.1	0.4
Zinc	mg/l	-	3.0
Cadmium	mg/l	-	0.003
Phosphate	mg/l	400.0	-
Chloride	mg/l	250.0	250.0
Fluoride	mg/l	1.5	1.5
Sulphate	mg/l	400.0	250.0
Nitrate	mg/l	50.0 max	50.0
Arsenic	mg/l	1.5	0.01
Copper	mg/l	0.1	2.0
Nitrite	mg/l	3.0 max	3.0
Ammonia	mg/l	1.5	-
Total Coliforms	cfu/ $100ml^{-1}$	0.0	0.0
Faecal Coliforms	cfu/ $100ml^{-1}$	0.0	0.0
E. coli	cfu/ $100ml^{-1}$	0.0	0.0
Helminthes	eggs/l	-	0.0