ASSESSING THE WATER QUALITY OF RIVER ASUOTIA AND SIX HAND-DUG WELLS AT WAMFIE IN THE DORMAA EAST DISTRICT OF BRONG AHAFO REGION, GHANA

BY

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DECLARATION

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

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DEDICATION

To Mrs. Fosuaa Rickia and our beloved daughters Abinah-Ameyaw Geraldine and Abinah-Takyiwaa Victoria, you made it all successful.

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ABSTRACT

The reliance on rivers and hand-dug wells as the only source of good drinking water in most communities in Ghana makes the assessment of the quality of such water sources important. A large section of population of Wamfie is outside the grid of treated water supplied by the Bia water treatment plant and as such depend on River Asuotia and hand-dug wells to meet their basic daily water requirement. These water sources unlike treated piped water are not monitored for pollution indicators even though bulk of the population relies on them for drinking and other domestic activities. The study looked at the water quality of River Asuotia and six hand-dug wells which serve as source of water to the greater section of Wamfie inhabitants in terms of microbial load and some physico-chemical parameters. Water samples were collected and analyzed monthly for four months from December 2011 to March 2012. The results were compared with World Health Organization (WHO) and Environmental Protection Agency (EPA) Ghana standards for drinking water. Physico-chemical parameters such as conductivity and total dissolved solids were low in the wells and the river studied. The pH of the wells was found to be acidic whilst that of the river was neutral. The river showed high turbidity level above WHO/EPA-Ghana recommended guideline value of 0-10NTU. Arsenic and lead were below detection in both water sources. Iron levels in the wells were within standard limit but high in the river. Nitrate concentration was also low in the river. There were presence of total coliforms, faecal coliforms and *E. coli* in both water sources at levels high above WHO/EPA-Ghana maximum control level for drinking water. It is recommended among others that the wells should be disinfected at least once a year, and be sited at higher elevations away from septic tanks, refuse dumps and latrines. Free range system of raising animals should be discouraged in the community to avoid indiscriminate defecating and direct access to the river by grazing and domestic animals to prevent faecal pollution.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABREVIATIONS

APHA	American Public Health Association
CDCP	Center for Disease Control and Prevention
DWAF	Department of Water Affairs and Forestry
EPA	Environmental Protection Agency
EU	European Union
FC	Faecal Coliform
FMDW	Facts Microorganisms in Drinking Water
GWC	Ghana Water Company
HWF	History of Water Filters
IDPH	Illinois Department of Public Health
IEPA	Illinois Environmental Protection Agency
KNUST	Kwame Nkruma University of Science and Technology
N.C DHHS	North Carolina Department of Health and Human Services
NTU	Nephelometric Turbidity Unit
NYSDH	New York State Department of Health
MCL	Maximum Control Level
MPN	Most Probable Number
ODNR	Ohio Department of Natural Resources
RSA	River sampling Site A
RSB	River sampling Site B
RSC	River sampling Site C
TDS	Total Dissolved Solids
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization

USEPA	United State Environmental Protection Agency
USGS	United State Geological Survey
WHO	World Health Organization
WA	Well A
WB	Well B
WC	Well C
WD	Well D
WE	Well E
WF	Well F

CHAPTER ONE

INTRODUCTION

It is said that water is life, meanwhile its distribution is independent of where it is needed. Governments all over the globe make effort to provide water both in quantity and quality to their citizens. This involves harnessing surface and groundwater resources. All people, irrespective of their stage of development and social or economic conditions, have the right to have access to drinking water in quantities and of quality equal to their basic needs (Mar del Plata, 1977)

The above observation notwithstanding, water bodies are under serious threat by natural and anthropogenic activities around the globe. Increase and changes in environmental pressure threaten groundwater quality and complicate the assessment of its present and future spatial distribution (Vissers et *al*., 2005). Pollution of freshwater bodies such as rivers, streams, lakes and ponds is mostly experienced as result of industrial discharge, municipal waste disposal and surface run-off (Akaniwor et *al*., 2007). Inadequate supply of potable water coupled with pollution of surface water have made individuals especially in Wamfie resort to various means of gaining access to and managing their own water supply. Among such means are construction of hand-dug wells and harvesting of rain water.

Recent development and research reports confirm that groundwater sources including wells could equally be contaminated. Pollution of groundwater by microbes including

those of public health significance does occur. The two basic factors that determine groundwater quality at a specified point are;

- Quality of the infiltrated water. This includes recharge water (rain, dry deposition, evapotranspiration, surface water) as well as substances (manure, fertilizers, dry deposition, and organic contaminants).
- Post-infiltration reactive processes. These can be split up into various geochemical processes, such as sorption (absorption and adsorption), Redox reactions, buffering, degradation, dissolution, etc. (Engelen, 1981; Vissers et *al*., 1999).

Wells are vulnerable to contamination due to activities around the top of the well. Waller & Roger (1982) asserted that the presence of a well that yields plenty of water does not imply one can just go ahead and take a drink. Indeed, water is such an excellent solvent that it can contain lots of dissolved chemicals and since groundwater moves through rocks and surface soil, it has a lot of opportunity to dissolve substances as it moves. For this reason groundwater will often have dissolved substances than surface water.

Generally, contamination of well may be as a result of the following:

1. Surface run-off that collect into wells that are located in depressions of valley.
2. Open well which allow animals such as rodents and insects to fall into the well.
3. Newly drilled or serviced well may contain bacteria due to materials entering the well from the surface.
4. During floods when flood water overtops the well casing.

5. Shallow groundwater may also be influenced by the onsite disposal of wastewater. If a septic system is too close to the well or not working properly, this can be a bacteria source (Vendrell & Atiles, 2003).

In the United States, a 2006 survey of 450 private wells found coliform bacteria in appropriately 35% and *E. coli* bacteria in about 15% of private wells (USGS, 2007). Besides, Sharma (1995) also asserts that in the Third World Countries, 80 percent of all diseases are directly related to poor drinking water and unsanitary conditions. The UN reports that one person in six lives without regular access to safe drinking water. Over twice that number – 2.4billion people lack access to adequate sanitation. Water related diseases kill child every eight seconds and are responsible for 80% of all illnesses and deaths in the developing world (WHO, 1999).

1.1 Problem statement

Wamfie is one of the fast growing towns in the Dormaa East District of the Brong Ahafo Region. Population growth coupled with increasing developmental activities has widened the gap between demand and supply of potable water both in quantity and quality. The rapid population growth has overwhelmed the capacity of the District Assembly to provide the most basic service of providing potable water to all the inhabitants at the new areas of settlement.

The Asuotia River has its head water at Asuotiano and runs through a valley in Wamfie town between the Zongo community and Poultry community (Nsuta) through

Mpanpanim to join River Wam. Over the years, the Asuotia River has suffered from all kinds of waste from the town including garbage, sludge, rubbish and surface run-off. The major gutters that take waste water from the town are directed into the river. The waste from the auto mechanic at the centre of the town drain into the river and also a car washing bay is just situated at the bank of the river behind the lorry station. There are cow and pig pens around the bank of the river. The water in some of the wells changes colour during heavy storms. Natural or human activities can be a source of contamination to groundwater (US EPA, 1993).

The quality of the water together with its ecological integrity has raised concerns due to indiscriminate disposal of waste into the river. Individuals who do not have access to the water supplied by Ghana Water Company (GWC) depend on the Asuotia River and hand-dug wells for their source of water. Some of these wells are constructed in the riparian areas of the river whilst others are scattered uphill of the town. Some are also located in premises of fuel station. Various observations such as change of the colour of water in the wells have made some of the well owners decided to abandon their wells whilst others heavily depend on them for drinking and other domestic purposes. There are latrines, and septic tanks sited few metres to some of the wells. The wells unlike treated piped water are not monitored for pollution indicators even though bulk of the population relies on them for their daily needs.

The study therefore sought to assess the water quality of River Asuotia and six hand-dug wells in the area in respect to their microbial load and physicochemical parameters.

1.2 Justification of the study

The fact that water is life to every living organism including humans implies that potable water is made accessible to all citizens devoid of contaminants that may have negative effect on their health. Infectious diseases caused by pathogenic bacteria, viruses, and protozoa or by parasites are the most common and wide spread health risk associated with drinking water (WHO, 1993). If sustainable development is to mean anything, such development must be based on an appropriate understanding of the environment i.e. an environment where knowledge of water resources is basic to virtually all endeavours (UMO/UNESCO, 1991). A larger population of Wamfie is outside the grid of treated water supplied by the Bia water treatment plant and as such depend on River Asuotia and the wells for drinking and for other domestic activities. It is therefore important that citizens, policy makers and stakeholders in the water sector are informed about the quality of water accessible to the populace in Wamfie.

The research data will provide significant and credible scientific basis for decision makers, planners, non-governmental organizations, the public sector to cost effectively deal with issues relating water quality in terms of natural and human influence on water quality and its impact on human health and aquatic ecosystem. Besides, the findings may also assist advising government on policy regarding regulation and monitoring of surface and groundwater quality for domestic and commercial activities in the country. The study will also give insight into the negative impact of anthropogenic activities on water bodies.

1.3 Objective:

The main objective of the study was to assess the water quality of river Asuotia and six hand-dug wells at Wamfie in the Dormaa East District of the Brong Ahafo Region.

1.4 Specific objectives:

The specific objectives were to:

1. Determine the level of total coliform, faecal coliform and *E.coli* in the water samples.
2. Measure the pH, turbidity, conductivity, total dissolved solids and nitrate in the water samples.
3. Determine the concentration of dissolved metals, i.e. iron, lead and arsenic in the water samples.

CHAPTER TWO

LITERATURE REVIEW

2.1 Surface water

Water supplies fall into two basic categories; surface water and groundwater. Surface water is the water that exists in streams, rivers, lakes and wetlands. When rain falls on the ground or snow melts, much of this precipitation drains in ravines, streams and creeks. Gradually, these smaller waterways join together and form rivers (Encarta, 2009). Surface water remains a significant source of water. It may be readily available and easily abstracted but is typically polluted (Barrell, 2000). In some sparsely populated areas, streams, lakes, and ponds are subject to substantial faecal pollution (Hofdes, 1986; Petts, 1994) due to poor sewage disposal. The water running across the surface of the ground is designated surface water. It picks up many substances such as micro-organisms, organic matter and minerals as it flows. It is rich in nutrients and therefore, become a perfect medium for the growth of all type of micro-organisms (Mckinney, 1962). Karikari and Bosque-Hmanilton (2004) maintained that good quality surface water is essential in maintaining and ensuring the multiple use of it.

2.2 Groundwater

Groundwater refers to any surface water that occurs beneath the water table in the soil and other geologic forms (Rail, 2000). The chemical composition is derived mainly from the dissolution of minerals in the soil and rocks with which it is or has been in contact. The type and extent of chemical contamination of groundwater is largely dependent on

the geochemistry of the soil through which the water flows prior to reaching the aquifers (Zuane, 1990). The chemical alteration of groundwater depends on several factors, such as interaction with solid phases, residence time of groundwater, seepage of polluted runoff water, mixing of groundwater with pockets of saline water and anthropogenic impacts (Stallord and Edmond, 1983; Umar et *al*., 2006).

It is estimated that groundwater make up 95% of all freshwater available for drinking and remain a significant source of municipal water system, and rural residents drawing water from wells (HWF, 2010). Unfortunately, dangerous chemical/ organic substances, and bacteria contaminate the water we drink. When combined with these elements, water, crucial to our survival as it is, can present significant health risk. The contaminants, many of which are undetectable by sight or taste, can lead to diseases ranging from asthma to the debilitating Parkinson's disease (CDCP, 1993).

Engelen (1981) and Vissers et *al*.(1999) asserted that two basic factors determine groundwater quality at a specified time. These are:

- Quality of the infiltrated water- This includes recharging water (rain, dry deposition, evapotranspiration, surface water) as well as added substances (manure, fertilizers, and organic contaminants).
- Post-infiltration reactive processes-These can be split up into various geochemical processes, such as sorption (absorption and adsorption), redox reactions, buffering, degradation, dissolution, etc. When the spatial distribution of groundwater quality is taken into account, a third factor is groundwater flow.

2.3 Wells

Wells are thought to have been dug to access groundwater for millennia. The three basic types of wells are dug well, drilled well and driven well. Dug wells are normally constructed in soft material. Generally, they are less than 20m deep and 1-2m diameter although some could be 100m deep and 4m diameter and therefore have large storage capacity. Where water depth makes it possible, people dig their own private or commercial wells and this remains the most common method of groundwater exploitation, probably even more important than drilled wells (Clark, 1998). Notwithstanding this, hand dug wells are vulnerable to contamination from activities around the top of the well. Private Wells are usually safe, but can be affected by nearby septic systems, farm animal wastes, or other source of contamination (Facts Microorganisms in Drinking Water (FMDW, 1997). Contamination of a private well can impact not only the household served by the well, but also nearby households using the same aquifer (Centre for Disease Control and prevention (CDCP, 2010).

Some disease conditions have been identified to have originated from groundwater wells. The top five (5) causes of water borne outbreaks in private groundwater wells are

1. Hepatitis A
2. Giardiasis
3. Shigella spp. Shigella cause over 2 million infections each year, including 60,000 deaths, mainly in developing countries (WHO, 2011)
4. *E.coli* 0157:H7
5. Tied for 5thCampylobacter jejuni and Salmonella serotype Typhimurium.

Other kinds of defects allow for contamination. These include:

1. Missing or defective well cap – seals around wires, pipes, and where the cap meets the casing may be cracked, letting in contamination.
2. Contamination seepage through the well casing – cracks or holes in the well casing allow water that has not been filtered through the soil to enter the well. This seepage is common in the wells made of concrete, clay tile, or brick.
3. Contamination seeping along the outside of the well casing
4. Well flooding during wet weather (NYSDH, 1997).

2.4 Sources of contamination

Contamination is used for situations where a substance is present in the environment but not causing any obvious harm. Low levels of infectious microorganisms are present throughout our environment and only occasionally cause illness in healthy people. Drinking water that is contaminated is only one of the many possible sources of infectious microorganisms.

Water, both groundwater and surface water each has a unique set of contaminants. Groundwater stores pesticide chemicals and nitrate while surface water contains most bacteria and other microorganisms. Due to the interconnectivity of groundwater and surface water, these contaminants may be shared between the two sources (History of Water Filters (HWF), 2010). Contaminants that may be in untreated water include microorganisms such as viruses and bacteria; inorganic contaminants such as salt and

metals; organic chemical contaminants from industrial processes and petroleum use; pesticides and herbicides; and radioactive contaminants.

Wells and other drinking water sources can be contaminated by storm water runoff from roadways, farms and livestock operations, discharges from sewage treatment plants, or septic system discharges. Craun et *al*. (1989) added that contamination of groundwater by pathogenic organisms most frequently cause problems in situations where wells and poorly constructed septic tanks are in proximity. In the opinion of Blankwaardt (1984) most serious source of pollution is contamination by human and animal waste from latrines, septic tanks, and farm manure, resulting in increased level of microorganisms including pathogens. However, the most hazardous gross faecal contamination is most commonly associated with latrines sited too close to the well (Brush, 1979). Indeed the threat of harmful contaminants in drinking water can no longer be reasonably ignored. The correlation between contaminated drinking water and many significant diseases and health problems is far too strong to discount (History of water filters.com, 2010).

2.5 Drinking water standard

Most bacteria in the coliform group do not cause disease, but the greater their number the likelihood that disease-causing bacteria may be present. Since coliform bacteria usually persist in water longer than most disease-causing organisms, the absence of coliform bacteria leads to the assumption that the water supply is micro-biologically safe to drink. Therefore, the drinking water standard requires that no coliform bacteria be present in drinking water. Faecal coliform and *E. coli* bacteria should be totally absent

from drinking water. The recommended permissible limits of bacteriological impurity of public health service standard are follows:

1. The water supply is to be obtained from a source free from pollution, adequately protected by natural agencies against the effects of population.
2. The water is to be clear, colourless, odourless and pleasant to taste, and is not to contain an excessive substances or of any of the chemicals used in the treatment processes.
3. The bacteriological requirement is more restrictive. Not more than 10% of all 10ml portions examined are permitted to show presence of *E.coli* group organisms.
4. Maximum permissible concentrations of water sample are established for heavy metals or, other substances having deleterious, physiological effects are not allowed in water supply system.
5. Water supply system should be free from sanitary defects and health hazards and shall be maintained at all times in a proper sanitary condition (Zoeteman, 1980).

In situation where these standards are not met, vulnerability of the water user to water related diseases are high.

2.6 Water quality

Water is a vital part of both our environment and our body systems. It covers nearly three quarters of the earth's surface and makes up between 60 and 70% of the human body matter. It is an essential component of nearly everything we eat and drink.

Water quality can be thought of as a measure of the suitability of water for a particular use based on selected physical, chemical, and biological characteristics (USGS, 2010). It is a measure of the condition of water relative to the requirements of one or more biotic species and or to any human need or purpose (Wikipedia-the free encyclopaedia, 2011). The term water quality has also been explained to mean the physical, chemical, biological and aesthetic properties of water which determine its fitness for a variety of uses and for protecting the health and integrity of aquatic ecosystems (DWAF, 1996).The parameters for water quality are determined by the intended use-human consumption, industrial and domestic use. Water quality depends on the local geology and ecosystem, as well as human uses such as sewage dispersion, industrial pollution, use of water bodies as a heat sink, and over-use (which may lower the level of the water).

2.6.1 Microbiological quality of drinking water

Water devoid of microbial contaminants is medicinal for good health. Maintenance of the microbiological quality of water has been used as an important means of preventing water borne diseases throughout the 20th century and more recent work suggest that gastro-intestinal disease is more strongly associated with the presence of enterococci than of *E. Coli* (Ellis, 1986). Most type of coliform bacteria are not infectious. Some are

present in faecal matters which are often the source of most water borne infectious microorganisms. In areas with poor standards of hygiene and sanitation, contamination of water with infected faecal material is common (Luksamijarulkul, 1994). Where a number of samples are taken each year, the levels of faecal contamination may vary widely between successive samples. The reasons for this are often obvious and may be related to seasonal influences such as rainfall (Anon, 1995). Drinking water without any coliform in 100ml of water is considered adequately safe.

2.7 Indicator organisms

Indicator bacteria/organisms are organisms which are always excreted in large numbers by warm-blooded animals, irrespective of whether they are healthy or sick. Indicator organisms are typically used to demonstrate the potential presence or absence of groups of pathogens.

Cabilli (1977) noted that the best indicator organism should be the one whose density correlate best with health hazards associated with one or several given types of pollution sources. He also listed the requirements for an indicator as follows:

1. The indicator should be consistently and exclusively associated with the source of pathogens.
2. It must be present in sufficient numbers to provide an accurate density estimate wherever the level of each of the pathogens is such that the risk of illness is unacceptable.

3. It should approach the resistance to disinfectants and environmental stress, including toxic materials deposited therein, of the most resistant pathogen potentially present at significant levels in the sources.
4. It should be quantifiable in recreational waters by reasonably facile and inexpensive methods and with considerable accuracy, precision, and specificity.

These requirements provide a basis to compare available indicators for water quality. The World Health Organisation (WHO, 1997) also gave the following outline as good characteristics of indicator organisms. Indicator organisms should be:

1. Harmless to humans especially laboratory workers
2. Present in polluted waters when pathogens are present or might be present
3. Easy and quick to identify through relatively simple laboratory test
4. Easily grown, isolated and identified by inexpensive methods
5. Present in water in larger numbers compared to the pathogens
6. Easy to enumerate, and
7. Their number should correlate with the probability that pathogens are also present.

It can be inferred from the above discussions that an ideal indicator organism has an easy testing procedure, is of human or animal origin, survives as long as, or longer than pathogens, present at densities related to the severity of faecal contamination, is a "surrogate" for many different pathogens, and useful in fresh and saline waters.

2.7.1 Total coliform

Total coliforms include bacteria that are found in the soil, in water that has been influenced by surface water, and in humans or animal waste. This group of bacteria comprises all aerobic and facultative anaerobic, gram-negative, non spore- forming, rod-shaped bacteria that ferment lactose with gas and acid formation within 48hours at 35°C. Among the coliform group, there are four genera in the Enterobacteriaceae family, *Escherichia, Klebsiella, Citrobacter*, and *Enterobacter* (APHA, 1992). Some of these genera are common in the intestinal tract of mammals (e.g. *E. coli*) and others are common in the soil and on the surface of plants (e.g. Klebsiella).

Under certain conditions coliform organisms may persist on nutrients derived from non-metallic construction materials. For these reasons, the presence of small numbers of coliform organisms (1-10 organisms per 100ml), particularly in untreated groundwater, may be of limited sanitary significance provided faecal coliform organisms are absent (Deaner et *al*., 1980). After being isolated and associated with the faecal waste of warm-blooded animals in the late 1800s and 1900s, coliforms have been used as indicator for indexing health hazards in drinking and recreational waters (Cabelli, 1977).

2.7.2 Faecal coliform

Faecal coliform (FC) are those coliforms which respond at an elevated temperature of 44.5 ^{0}C. A more accurate name for organisms which show positive on the FC test would be heat tolerant coliforms. They are able to ferment lactose and produce gas at 44.5+/-0.2 ^{0}C within 24+/-2 hours (APHA, 1992). Faecal coliform include *Esherichia, Klebsiella*,

Citrobacter (60% to 90% of total coliforms are faecal coliforms) 90% of faecal coliform are *Escherichia coli* (APHA, 1992).

This group of total coliform is considered to be present specifically in the gut and faeces of warm-blooded animals. Because the origins of faecal coliforms are more specific than the total coliform group of bacteria, faecal coliform are considered a more accurate indication of animal or human waste than the total coliforms (NYSDP, 2011). The presence of faecal coliform bacteria in a well indicates that the well is contaminated with faeces or sewage, and it has the potential to cause disease (North Carolina Department of Health and Human Services (N.C DHHS, 2009). Faecal indicator bacteria are used to assess the quality of water because they are not typically disease causing, but are correlated to the presence of several water borne disease-causing organisms. The concentration of faecal indicator bacteria is a measure of water safety for body contact recreation or for consumption. For bathing water, the geometric mean concentration established for faecal coliform bacteria is 200col/100ml (USEPA, 1976).

2.7.3 *Escherichia coli*

Microbial monitoring of drinking water source requires the use of microorganisms as indicators of contamination. The most commonly used indicator of faecal pollution of water sources is *Escherichia coli* (Burger et al., 1984; Arion, 1994; Satory et *al*., 1998). The presence of *E. coli* in water is direct evidence of faecal contamination from warm-blooded animals and indicates the possible presence of pathogens (Dufour, 1977). *E. coli* is noted to be the major species in the faecal coliform group. Of the five general

groups of bacteria that comprise the total coliforms, only *E. coli* is generally not found growing and producing in the environment. Consequently, it is considered to be the species of coliform bacteria that is the best indicator of faecal pollution and the possible presence of pathogen. A positive *E. coli* result is much more serious than coliform bacteria alone because it indicates that human or animal waste is entering the water supply and can cause diarrhoea, dysentery, and hepatitis (Brayan, et *al*., 2007; Center for Disease Control and Prevention (CDC P, 2010).

In interpretation of microbial data, it is very important to note that microbial constituents have strong non-conservation behaviour in water. The concentration of the amount of microbes entering the water could change independently through various processes such as growth, settling to the sediments, chemical reactions and decay (DWAF, 2000).

2.8 Rational for the use of indicator organisms

Coliform bacteria are often referred to as indicator organisms because they indicate the potential presence of disease causing bacteria in water. The presence of coliform bacteria in water does not guarantee that the drinking water will cause illness. Rather, their presence indicates that contamination path way exists between a source of bacteria (surface water, septic system, animal waste etc.) and the water supply. Disease causing bacteria may use this pathway to enter the water supply.

Coliforms come from the same sources as pathogenic organisms. They are relatively easily to identify, are usually present in large numbers than more dangerous pathogens

and respond to the environment, wastewater treatment and water treatment similarly to many pathogens. As a result, testing for coliform bacteria can be a reasonable indication of whether other pathogenic bacteria are present.

Indicator microbes are selected for the following reasons:

1. They are initially abundant in the matrix to be observed
2. A relatively rapid, accurate, and cost effective analytical method for enumerating the indicator exists or can be readily developed.
3. A reasonable strong correlation exists between the presence of the indicator and particular pathogen or group of pathogens (Environmental Fact sheet, 2003).

2.9 Physical parameters of water quality

Measurement of the physical attribute of a stream can serve as indicators of some form of pollution. For example changes in pH may indicate the presence of certain effluents like metals, while changes in turbidity may indicate dredging in the area (Kortatsi, 2007). Other commonly physical characteristics of a stream include temperature, colour, and total dissolved solids. Svobodova et *al*., (1993) added that alteration of waters physical chemistry includes acidity, conductivity, temperature, and eutrophication.

2.9.1 pH

pH is the most commonly measured attribute of water. The concentration of hydrogen ion (H^+) activity in a solution determines the pH. Thus, it is a measure of the acidity or alkalinity of a solution. pH is measured on a scale of 0 to 14. Acidic water has pH values less than 7, with 0 being the most acidic. Basic water has value likewise greater than 7, with 14 being the most basic. The pH of most streams ranges from neutral (6.5) to slightly basic (8.5). If a stream water has a pH less than 5.5, it may be too acidic for fish to survive in, while stream water with pH greater than 8.5 may be too basic (WHO, 2004). Water with high or extremely high or low pH is deadly as it has been established thatpH below 4 or above 10 will kill most fish and very few animals can tolerate water with a pH of 3 or above 11 (Mensner et *al*., 2010).

The ideal pH level of drinking water should be between 6 and 8.5. Water with pH less than 6.5 could be acidic, soft and corrosive. Acidic water could contain metal ions such as iron, manganese, copper, lead, and zinc (Freedrinkingwater.com).pH of water determines the solubility (amount that can be dissolve in water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc) Michand (1991). No health-based guide is proposed for pH, although eye irritation and exacerbation of skin disorders have been associated with pH values greater the 11 (WHO, 2004).

2.9.2 Turbidity

Water that is highly coloured or has an objectionable taste may be regarded by consumers as unsafe and may be rejected for drinking purposes (Anon, 1993). Turbidity is the amount of particulate matter suspended in water. It measures the scattering effect that suspended solids have on light. It is widely agreed that the higher the intensity of scattered light, the higher the turbidity. Clay, silt, finely divided organic and inorganic matter, soluble coloured organic compounds, plankton and microscopic organisms make water opaque. Different particles have significantly different effects on perceived turbidity. The particulate matter suspended making drinking water turbid could either be organic or inorganic, or both (Boxall et *al*., 2003).

Turbidity is used to indicate water quality and filtration effectiveness (e.g. whether disease causing organisms are present). Higher turbidity levels are often associated with higher levels of disease causing microorganisms such as virus, parasites and some bacteria. These organisms cause symptoms such nausea, cramps, diarrhoea, and associated headaches (USEPA, 2009). According to the WHO (2011), although the turbidity is not necessarily a threat to health, it is an important indicator of the presence of the possible presence of contaminants that would be of concern for health, especially from inadequately treated or unfiltered surface water.

2.9.3 Conductivity

Conductivity is the ability of water to carry electrical charges. It indicates the presence of ions in the water. Conductivity relates to the amount of dissolved substances in water, but it, however, does not give an indication of which mineral is present. Changes in conductivity over time may indicate changing water quality. With regards to acceptable results, there is no health standard. A normal conductivity value is roughly twice the hardness in unsoftened water. Conductivity source may be natural or human-made dissolved substances. The presence of inorganic compounds makes water exhibit high conductivity (Ntengwe, 2006). For typically unpolluted stream, the average conductivity value is approximately 350µS/cm (Koning and Roos, 1999). The presence of inorganic dissolved solids such as chlorides, nitrate, and phosphate anions or sodium, magnesium, calcium and aluminium cations affect conductivity. Temperature on the other hand affects the conductance of water as the warmer the water, the higher the conductivity. For this reason, conductivity is reported as conductivity at 25^0C.

A failing sewage system would raise the conductivity because of the presence of chloride, phosphate, and nitrate; oil spill would however lower the conductivity (APHA, 1992). Industrial pollution or urban runoff (water running of streets, building, and parking lots may results high conductance reading.Conductivity in streams and rivers is affected by the geology of the area through which the water flows. Streams that run through granite bedrock will have lower conductivity, and those that flow through limestone and clay soils will have higher conductivity values. Extended dry periods and low flow conditions

also contribute to higher specific conductance readings (www.lcra.org/water/quality/crwn/indicators.html).

2.10 Chemical parameters

2.10.1 Total Dissolved Solids (TDS)

Dissolve solids refer to any minerals, salts, metals, cation, or anions in water. Total dissolve solids comprise inorganic salts (principally calcium, magnesium, potassium, sodium, carbonates, chlorides and sulphates) and some small amount of organic matter that are dissolved in water (USEPA, 1997). TDS in drinking water originate from natural sources, sewage, urban runoff, industrial waste water, and chemical used in the water treatment process and the nature of the piping or hardware used to convey the water. There is no primary drinking water standard for TDS but the secondary standard for TDS is 500mg/L (USEPA, 1997).

Elevated TDS can result in water having a bitter or salty taste, encrustations, films or precipitates on fixtures, corrosion of fixtures, and reduced efficiency of water filter and equipment (Oram, 2011). High TDS interfere with the taste of foods and beverages, and makes them less desirable to consumers (Freedrinkingwater.com).

2.10.2 Nitrates

Nitrogen is typically present in groundwater in three forms; ammonia (NH_3), nitrate (NO_3^-) and nitrite (NO_2^{2-}). Nitrate comes into water supplies through the nitrogen cycle rather than through dissolved minerals. Other secondary sources of nitrogen compounds

include fertilizers, manure and urine from feedlots and pastures, sewage, and landfills (ODNR, 2011).

Increasing nitrate levels in water resources are a potential source of severe environmental stress to aquatic organisms, because nitrate is known to be toxic to crustaceans (Muir et *al*., 1990), insects (Camargo and Ward, 1992), amphibians (Baker and Waights 1993; 1994) and fish (Tomass and Carnicheal, 1986). Nitrates are especially toxic to children less than six months of age. The condition known as "blue baby syndrome" (methemoglobinemia) may occur (Spalding and Exner 1993; ODNR, 2011). Water moving down through soil after rainfall or irrigation carries dissolved nitrate with it to ground water. In this way, nitrate enters the water supplies of many home-owners who use wells or spring (Jennings et *al*., 1996).

Water quality standards for human consumption have been set at ten milligrams of nitrate –nitrogen per litre or water (10mg/L NO_3-N) (Jennings et *al*., 1997). This level of nitrate-nitrogen is equivalent to 45mg/L of nitrate (NO_3^-). Shallow wells are susceptible to nitrate contamination because there is less soil and rock to serve as filter between the soil source and the groundwater supply.

Pregnant women may be less able to tolerate nitrate, and nitrate in the milk of nursing mothers may affect infants directly. These persons should not consume water containing more than 10ppm nitrate directly added to food products, or beverages especially in baby formula (DEQ, 2011). High nitrate level in surface water contribute to algae blooms and may result in elevated levels of disinfection by-product in treated drinking water which is

linked to increased cancer and reproductive health risk in humans as well as liver, kidney and central nervous system problems (Stewart, 2011).

2.11 Effects of some metals in water

Problems associated with chemical constituents of drinking water arise primarily from their ability to cause adverse health effect after prolong periods of exposure. Of particular concern are contaminants that have cumulative toxic properties, such as heavy metals (Anon, 1993).

Metals are inorganic substances that occur naturally in geological formations. Some metals are essential for life and are naturally available in our food and water. In addition to metals essential for life, drinking water may contain metals which cause chronic or acute poisoning (Pedersen, 1997). Consumption of heavy metals is linked to many serious health concerns (Benham et *al*., 2011). Severe effects include reduced growth and development, cancer, organ damage, nervous system damage and in extreme cases, death.

Contaminations of our water resources by poisonous metal occur largely due to human activities such as industrial processes, agricultural activities, and discarding of wastes in landfills (Pedersen, 1997). Heavy metals such as lead and copper for example most commonly leached into water supplies through corrosion of household plumbing fixtures, pipes, fittings, and solder. However, many heavy metals enter the water supply as groundwater dissolves rocks or soil from runoff due to environmental contamination.

2.11.1 Lead

The most ubiquitous of toxic metals in drinking water is lead. Lead can leach from water pipes and soldered joints which deliver water to our tap especially in older homes. The toxic effect of lead can lead to nerve and brain damage. Children are specifically sensitive. Exposure to lead has been shown to be associated with wide range of effects, including neurological and behavioural effects, mortality (mainly due to cardiovascular disease), impaired renal function, hypertension, impaired fertility and adverse pregnancy outcomes, delayed sexual maturation and impaired dental health (WHO, 2011).

Lead is generally immobile in soil and accumulates in the upper layers (Pate et *al*., 2006). The primary rout of entry into surface waters include surface erosion of lead contaminated soils, airborne drift of fine dust, and contamination of other sources of discharge into surface waters such as cooling water steam or wastewater treatment plant effluents (Illinois Environmental Protection Agency (IEPA), 2007). The solubility of lead increases as the pH is reduced below 8 as there is substantial decrease in the equilibrium concentration (Anon, 1993). The USEPA maximum control level (MCL) for lead is 0.005mg/L in water (Pedersen, 1997).

2.11.2 Iron

One of the most troublesome elements in water supplies is iron. It makes up at least 5% of the earth's crust and it is one of the earth's most plentiful resources (IDPH, 1999). It is found in natural fresh waters at levels ranging from 0.5 to 50mg/L. Anaerobic groundwater may contain ferrous iron at concentrations of up to several milligrams per litre without discolouration or turbidity in the water when directly pumped from a well, exposure to the atmosphere, however, the ferrous iron oxidizes to ferric iron, given an objectionable reddish-brown colour to the water.

The combination of naturally occurring organic material 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, 1999). Iron is not hazardous to health but it is considered a secondary or aesthetic contaminant as it stains laundry and plumbing fixtures at levels above 0.3mg/L. It is essential for good health and also helps in oxygen transport in the blood (Nartey et *al*., 2005).

2.11.3 Arsenic

Arsenic is widely distributed throughout the earth's crust and is used commercially, primarily in alloying agents. It is introduced into water through the dissolution of minerals and ore, from industrial effluents, and atmospheric deposition. Concentrations in groundwater in some areas are sometimes elevated as a result of erosion from natural sources. Besides, Blaylock (2006) maintains that environmental arsenic is still produced as a result of various mining, industrial and manufacturing operations. Contamination of

surface water and ground water by arsenic poses significant health risk to humans and animals that depend on such water resources. Arsenic is known carcinogen and mutagen (Smedley et, *al*., 1995). It is an immune system depressant and contributes to skin, bladder and other cancers (WHO, 2004). With the view to reducing the concentration of this carcinogenic contaminant in drinking water, a provisional guideline value for arsenic in drinking water of 0.01mg/L is established (WHO, 2004).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study was carried out within Wamfie Town in Dormaa East District of the Brong Ahafo Region. Dormaa East District lies between 7°.08´ North and 7°.25´ North and Longitude 2°.35´ West and 2º.48´. The District has a total land area of 456 square kilometres with Wamfie as District Capital. The land area of the District is about 1.18 percent of the total land area of Brong Ahafo Region that is 38,557 square kilometres. The district shares common boundaries with Dormaa Municipal to the West, Berekum to the North, Sunyani to the East and South by the Asunafo North Municipal and Asutifi District (Fig. 1)

The topography of the District is generally undulating and rises between 180m and 375m above sea level. The drainage pattern of Dormaa East District is basically dendrite and flows in the North–South direction. The District is located within the East semi-equatorial climate region with double maxima rainfall regime. The mean annual rainfall is between 1240mm and 1750mm. The first rainy season is from March to June and the second rainy season is from September to October. Most part of the town rely on hand-dug wells to meet their domestic and daily needs; and some others fetch water directly from River Asuotia for drinking. The rocks underlying the soil of the study area are of Birimian formation which covers more than three quarters of the close forest zone. Associated with the Birimian formation are extensive masses of granite. Under varying atmospheric

pressure, the granites weather into soils with varying characteristics at different localities (Dearman, 1974).

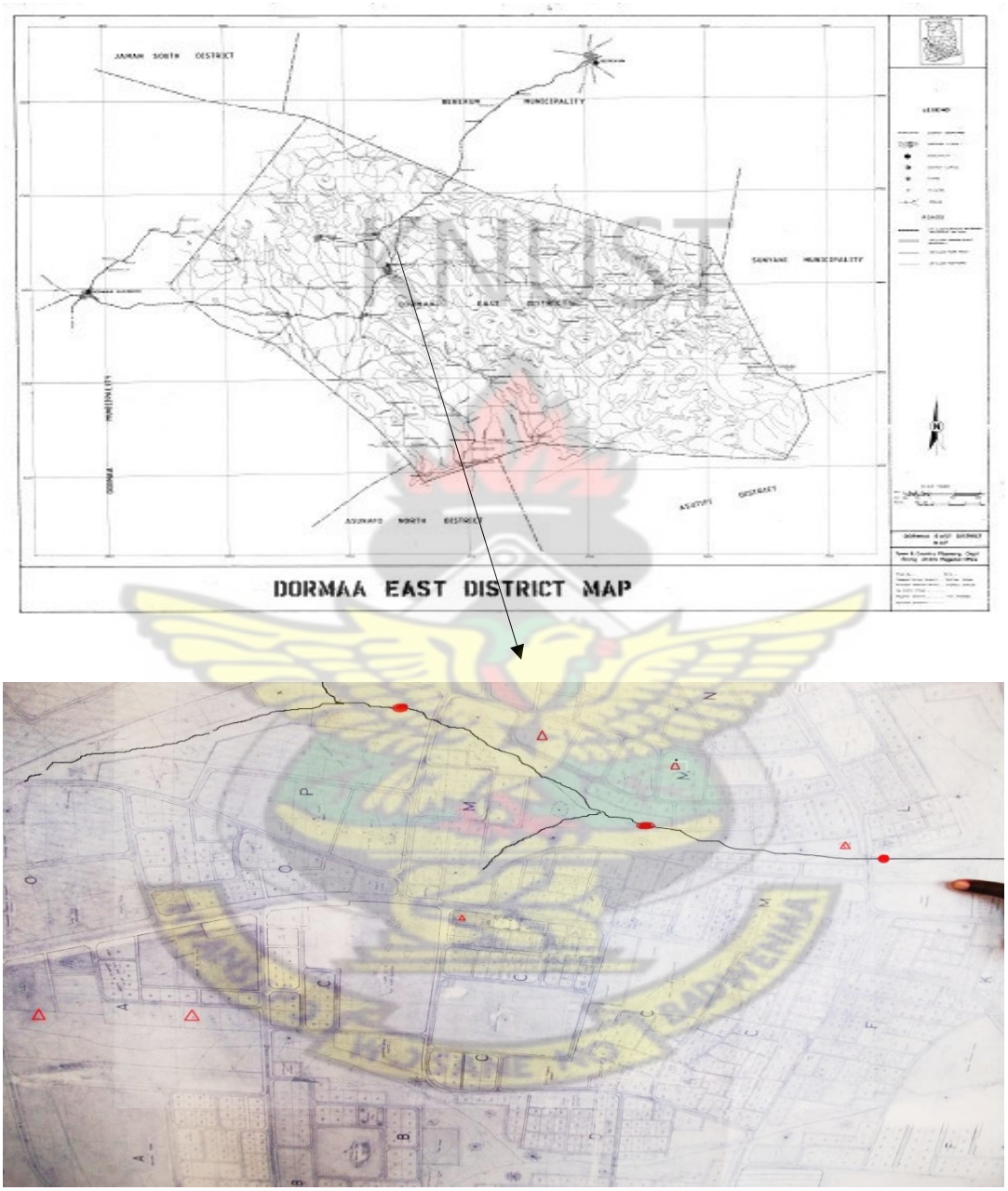

Fig1.Map of Wamfie Township showing the sampling sites of the study area

3.2 Sampling procedure

Monthly water samples were collected from River Asuotia, and also from the respective wells at Anopabosuo, Sawmill, Estate, Bonsuom and Poultry from December 2011 to March 2012. Triplicate samples were taken from each site/point of the river (Plates 1-3) at every sampling period. Triplicate samples were also taken from the respective wells. A total of 27 samples were taken each time. In all, a total of 108 samples from both the river and the wells were taken for the analysis in this study. Water samples were collected in the morning between the hours of 03:00 GMT and 06:00 GMT.

Sterile bottles were used to collect samples for microbiological analysis. Sample containers and lids were rinsed with some of the sampled water except for microbiological analysis and then filled to the rim leaving an air space of at least 2.5cm to ensure homogenize sample for laboratory analysis and the lids were carefully tightened or sealed. They were then labelled and immediately placed in a cold ice chest at temperature of 4^{o}C to prevent possible alteration of parameters and also to ensure that micro-organisms remain viable though dormant. Samples were then transported to laboratory for analysis. All the physico-chemical and heavy metals were done at Anglogold Ashanti, Obuasi, and the microbiological analysis were also performed in the microbiological laboratory in the Theoretical and Applied Biology Department, KNUST, Kumasi.

Plate 1: Asuotia River showing sampling site A

Plate 2: Asuotia River showing sampling site B

Plate 3: River Asuotia showing sampling site C

3.3 Determination of pH, turbidity, conductivity and TDS

The sample containers of volume 500ml were thoroughly washed with detergent and tap water. The plastic containers were then rinsed with distilled water and left to dry. Upon reaching the sampling site, each bottle was rinsed with water from the river and the respective wells, thrice (3×), before actual sample collection was undertaken.

The pH meter was calibrated by immersing the electrode in two buffer solutions of pH 4.01 and 7.00 prepared from capsules of BDH buffer. The pH meter was adjusted to the standard buffers (4.01 and 7). The water sample was placed in a beaker and the electrode was rinsed with distilled water and lowered into the sample in the beaker. The Yokogawa model PH 82 pH meter was used. The pH meter was allowed to stabilize and the pH of the sample read.

The conductivity and TDS were measured using Hanna instruments HI 9032 microcomputer conductivity meter. The conductivity meter was calibrated by immersing the electrode in a reference buffer of 12,880µS/cm. The water sample was put in a beaker and the electrode rinsed with distilled water and lowered into the sample in the beaker. The conductivity in µS/cm of the sample was displaced on the screen and recorded. TDS was also measured by selecting the TDS key while the electrode remained in the water sample used to measure the conductivity, and the TDS value in mg/L displayed on the screen was recorded.

The turbidity values were taken using a Cybercan IR TB 100 Turbidimeter. The Turbidity was calibrated with the 1000 NTU, 100 NTU, 10 NTU and 0.02 NTU calibration standards. The cuvette was rinsed three times with the sample to be tested. The light shield cap was replaced and all outside surfaces were cleaned and made dry. The cuvette was pushed firmly into the optical well and index to the lowest reading. The NTU values were measured by pressing and releasing the arrow button and the value was recorded after the display has stopped flashing

3.4 Determination of heavy metals (iron, lead and arsenic)

An aliquot of 5ml of concentrated nitric acid was added to 50ml of sample collected in a 100ml beaker. The mixture was heated slowly to evaporate to a lower volume of 20ml. Five millilitre of concentrated nitric acid (HNO_3) was again added to the 20ml and heating continued for 10 more minutes. A final 5ml of nitric acid was used to rinse the sides of the beaker. The solution was poured into a 50ml volumetric flask and topped with distilled water to the mark. A blank solution was similarly prepared to serve as control for analyses. Heavy metal analyses were performed on Atomic Absorption Spectrophotometer (Unicam 969) using acetylene gas as a fuel and air as oxidizer. Calibration curves were prepared separately for all the metals by running suitable concentrations of the standard solutions. The digested samples were aspirated in the fuel rich air-acetylene flame and the concentrations of metal were determined from the calibration curves. Average values of three replicates were taken for each determination. The blank absorbance was taken before the testing of the samples.

3.5 Nitrate Concentration

The Wagtech photometer method was used. Nitrate from the sample aliquot was reduced to nitrite and the resulting nitrite was then determined by a diazonium reaction to form reddish dye. Unique zinc-based Nitratest Powder and Nitratest Tablet were used in the reduction stage to aid rapid flocculation. The nitrite resulting from the reduction stage was determined by reaction with sulphanilic acid in the presence of N-(1-naphthyl) ethylene diamine to form a reddish dye. The intensity of colour produced in the test is proportional to the nitrate concentration and was measured using the wagtech photometer 7100.

3.6 Determination of total and faecal coliforms

Sample bottles of volume 500ml for bacteriological analyses were thoroughly washed with soap and water and then rinsed with hot water to remove possible traces of washing compound and finally rinsed with distilled water. The bottles were then sterilized in the Gallenkamp autoclave at a temperature of 170^{o}C for three hours, with an Aluminium foil placed around the cover. An indicator tape was placed across the foil. A black strip on the indicator tape connoted proper sterilization of the bottle.

The Most Probable Number (MPN) method was used to determine total and faecal coliform according to standard methods (Anon, 1992). Serial dilutions of 10^{-1} to 10^{-5} were prepared by picking 1ml of the sample into 9ml sterile distilled water. One millilitre aliquots from each of the dilutions were inoculated into 5ml of the MacConkey Broth with inverted Durham tubes and 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 and gas collected in the Durham Tubes after 24 hours were identified as positive for both total and faecal coliforms. Counts per 100ml were calculated from most probable number table.

3.6.1 Determination of *E. coli* (Thermotolerant coliform)

From each of the positive tubes identified a drop was transferred into a 5ml test tube of trypton water and incubated at 44ºC for 24 hours. A drop Kovac's regent was then added to the tube of trypton water. All tubes showing 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 number table as used by Feng et *al.* (2002).

3.7 Statistical analysis

The Kruskall-Wallis non-parametric test was used to test for significant differences ($p<0.05$) in the heavy metal concentrations of different sampling of the wells and the River. ANOVA and Dunn's Multiple Comparison post-test were used to further test for significant differences among the different sampling stations at a significant level of 0.05.

CHAPTER FOUR

RESULTS

4.1 Quality of wells

The wells were sampled between December and March. Effa's well was given the label A, Agya's well was labelled B, Estate well was marked C, Bonsuom well was branded D, Abrewa's well was marked E, and F (Plates 4-9) for that of Afia's well.

Plate 4: Effa's well sampling site at Anopabosuo (A)

Plate 5: Agya's well sampling site at sawmill (B)

Plate 6: Well sampling site at Estate (C)

Plate 7: Well sampling site at Bonsuom (D)

Plate 8: Abrewa's well sampling site at Poultry (E)

Plate 9: Afia's well sampling site at Poultry (F)

4.1.1 Bacteriological concentration

4.1.1.1 Total coliform concentration

The total coliform numbers recorded over the sampling period is shown in Fig 2. The mean numbers of total coliform in the wells were 1689.00±151.10, 640.00±37.20, 1490.00±162.50, 260.80±22.76, 158.30±10.83, and 299.10±16.80 for Effa's well (A) at Anopabosuo, Agya's well (B) at Sawmill, Estate well (C), Bonsuom well (D), Abrewa's well (E) and Afia's well (F) both at Poultry respectively. Effa's well had the highest mean total coliform number of 1689.00±151.10 whilst Abrewa's well recorded the least number per 100ml coliform forming unit (158.30±10.83cfu).

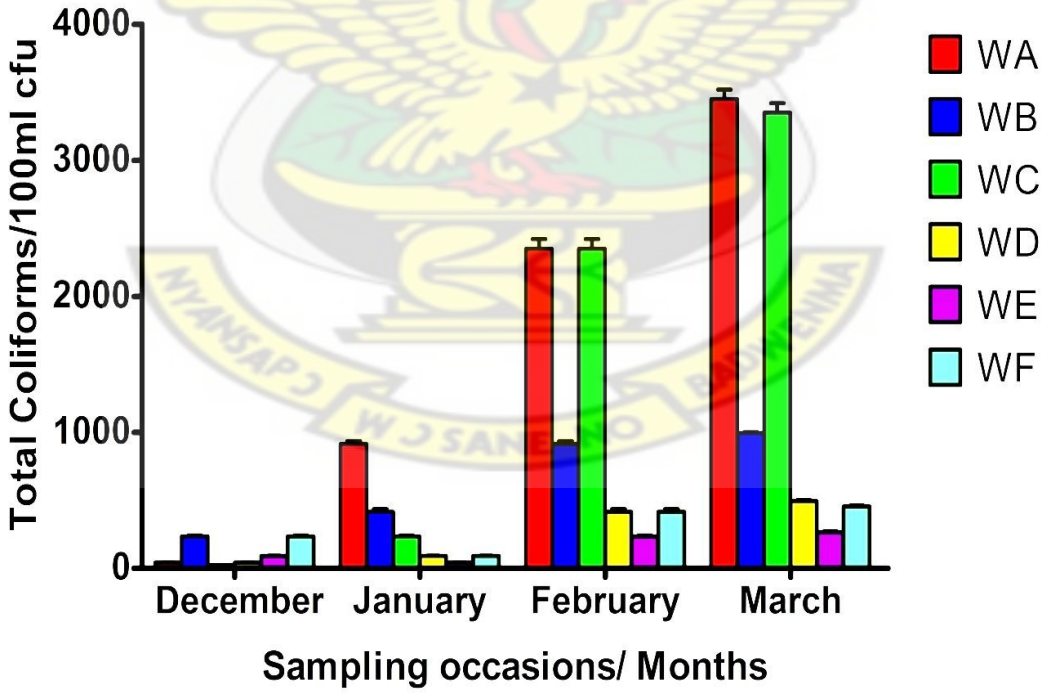

Fig.2: Mean total coliform concentration in the sampled wells

4.1.1.2Faecal coliform concentration

The mean concentration of faecal coliform numbers in the wells were 59.88±42.20, 37.75±9.97,45.25±36.89, 54.50±4.80, 24.75±21.21, 18.25±9.50 respectively for Effa's well (A) at Anopabosuo, Agya's well (B) at Sawmill, Estate well (C), Bonsuom well (D), Abrewa's well (E) and Afia's well (F) both at Poultry (Fig.3). Averagely, the faecal coliform numbers were 18 times lower than that of the total coliform.

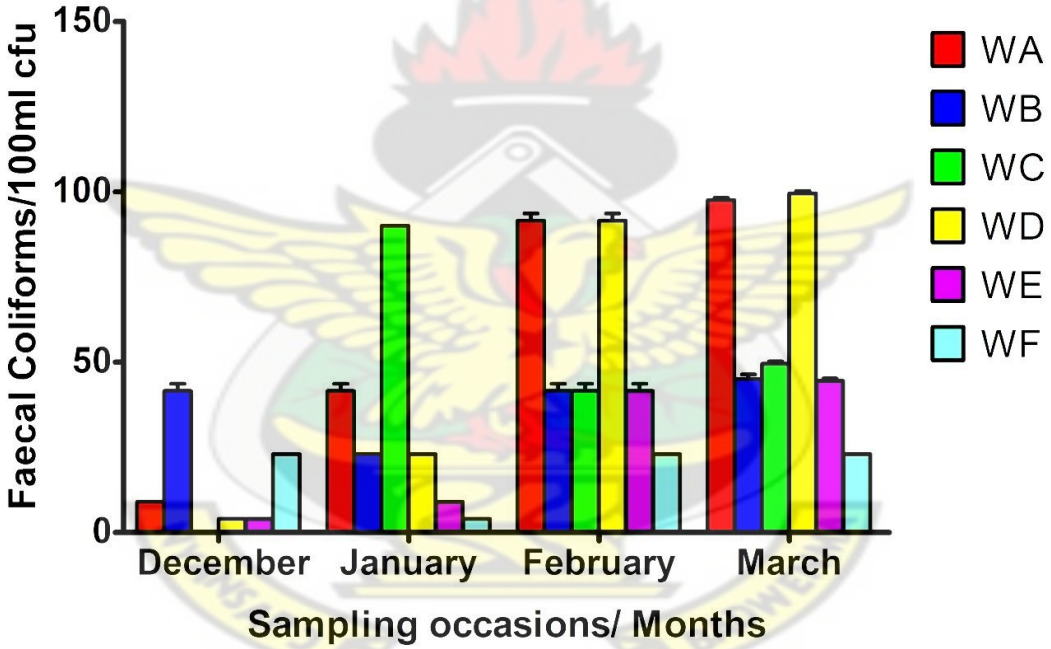

Fig. 3: Faecal coliform numbers in the sampled wells.

4.1.1.3 Amount of *E. coli*

The mean highest value of 20.50±7.90 per 100ml coliform forming unit of *E. coli* was recorded in Effa's well(A) whilst Afia's well recorded non (Fig 4). The mean *E. coli* numbers were four times lower than that of the faecal coliform and 81 times lower than total coliform numbers in the wells. With the exception of Effa and Afia's wells, and that of Agya and Afia's well, the differences between the *E.coli* numbers in the other wells were not statistically significant.

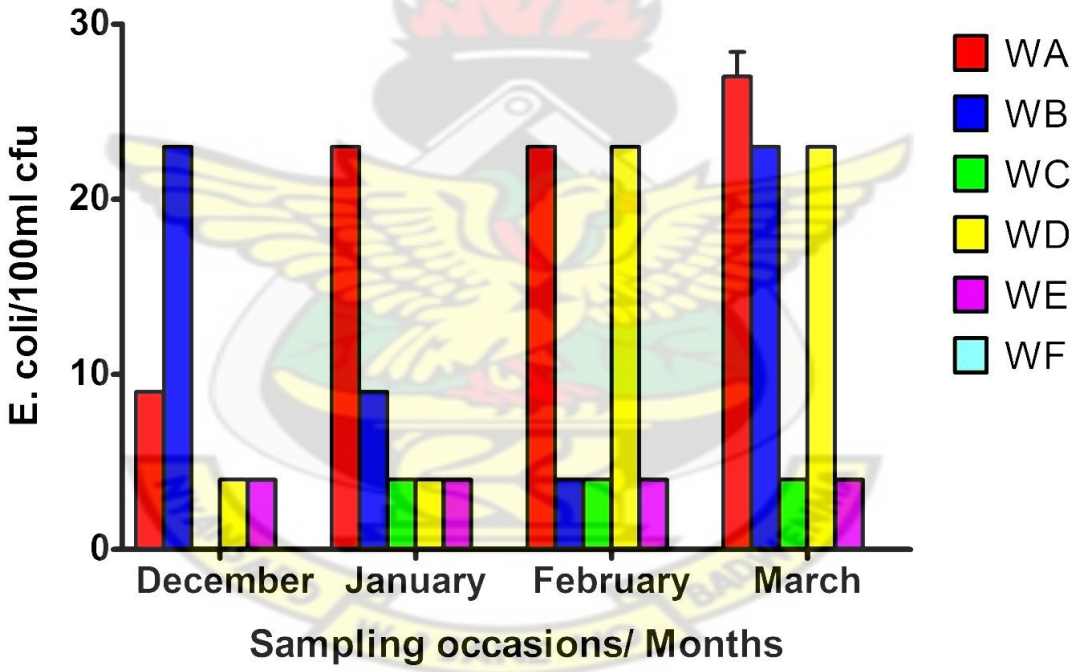

Fig.4: *E. coli* numbers over the sampling period in the wells

4.2 Quality of river

4.2.1 Total coliform

The microbial indicator numbers in the river were quite higher compared to that in the wells. The mean total coliform numbers were 2107.00±241.70 at River station A (RSA), 26184.00±447.06 at River station B (RSB) and 11599.00±200.14 at site C (Fig.5). The differences in the river stations in terms of total coliform numbers were not statistically significant.

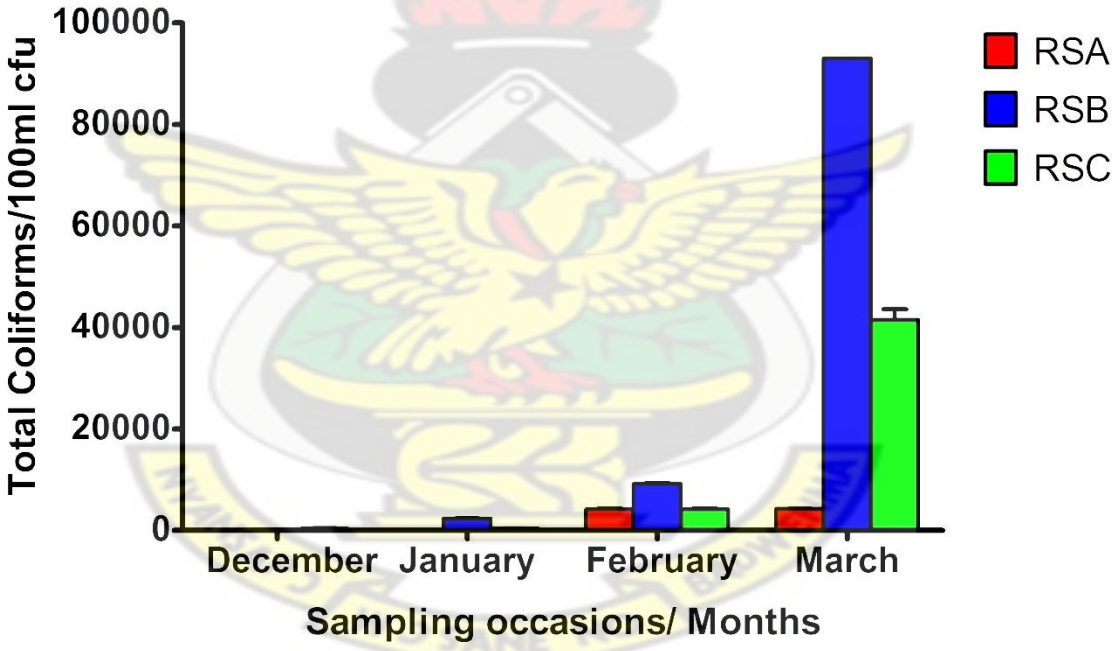

Fig.5: Total coliform numbers in the river over the sampling period

4.2.2 Faecal coliform

The highest value of 217.00±23.76 per 100ml coliform forming unit was recorded at station A while the least value of 49.75±29.28 coliform forming unit was recorded at station B (Fig.6). The average total coliform numbers in the river were ninety nine times more than the number in the wells.

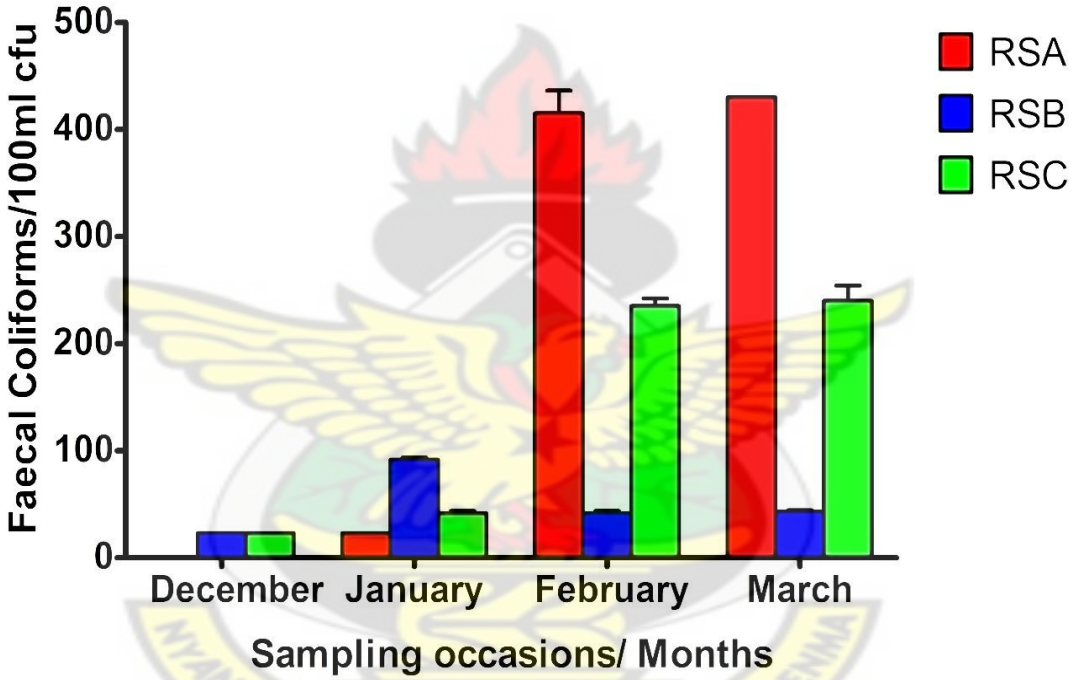

Fig.6: Faecal coliform numbers in the river over the sampling period.

4.2.3 *E. coli* concentration

The mean numbers of *E. coli* were 13.75±11.30cfu, 32.88±3.89cfu and 14.75±9.74cfu for the river stations A, B, and C respectively (Fig.7). The *E. coli* counts in the river were similar to that in the wells.

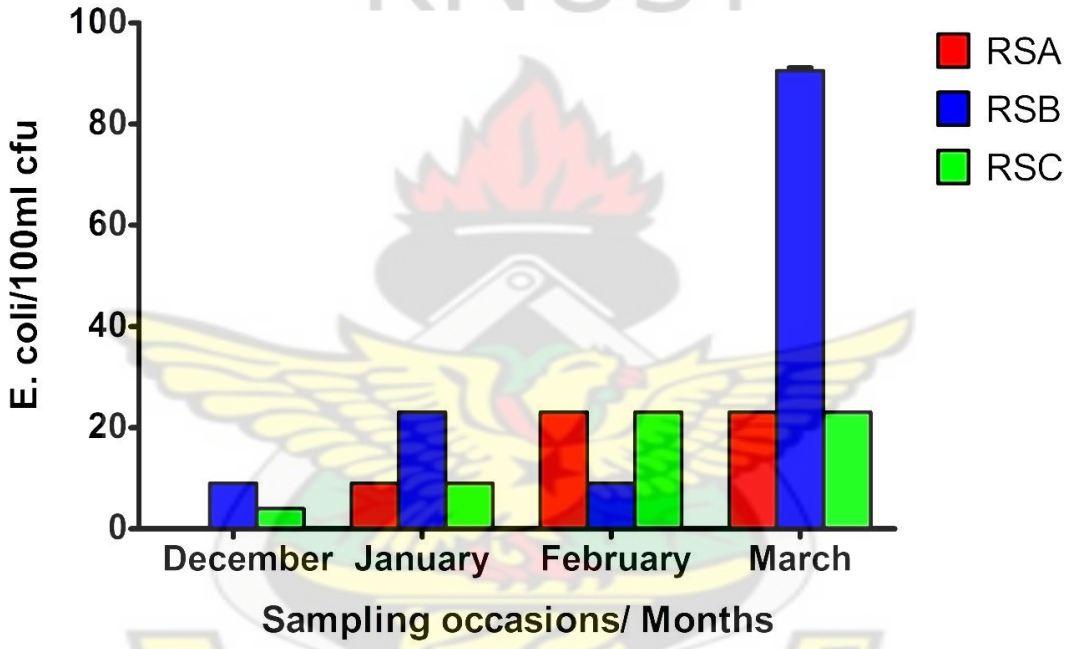

Fig.7: The mean *E. coli* counts during the sampling period

4.3 Physico-chemical parameters of the water samples from the wells and the river

4.3.1 Physico-chemical parameters for wells

4.3.1.1 pH measurement

The mean pH readings from all the wells were below the WHO guideline value (6.5- 8.5) for drinking water quality. Effa's well (A) recorded the highest mean pH of 5.91 whilst Agya's well (B) recorded the least pH of 5.14. The mean pH values were however similar in all the wells.

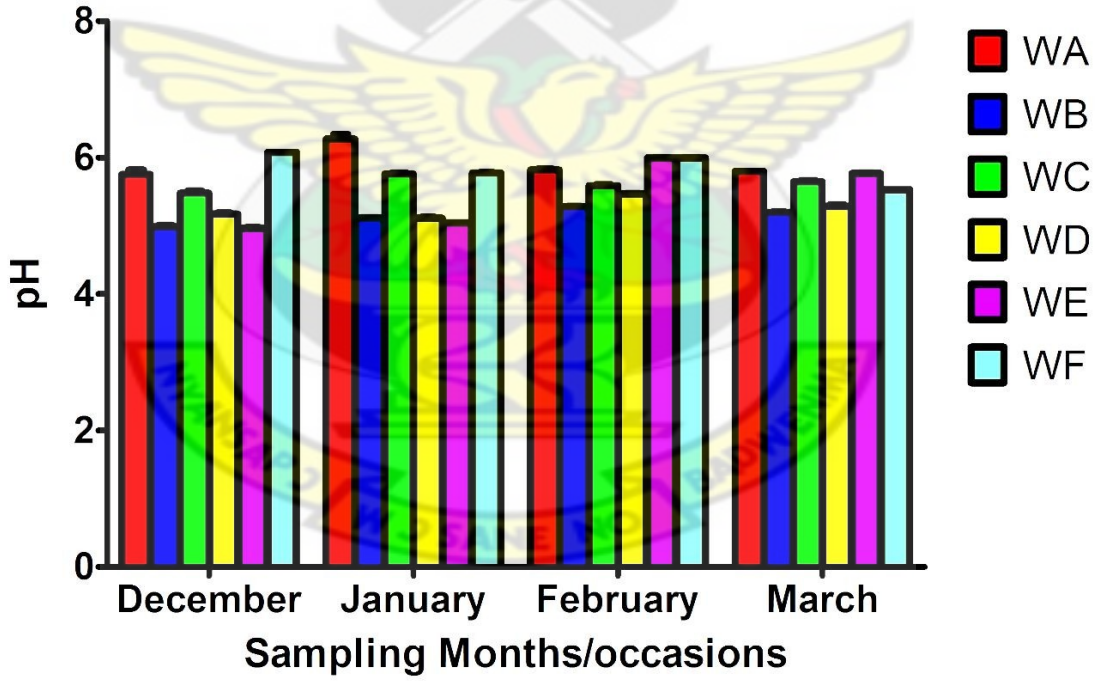

Fig.8: The mean pH in the wells over the sampling period.

4.3.1.2 Conductivity measurement

The mean highest conductivity level was recorded from Effa's well (0.09±0.03). The least mean values of 0.04±0.02 and 0.04±0.01 were found in both Abrewa and Effa's well respectively (Fig. 9). The differences between the conductivity levels from the wells were not statistically significant ($p<0.05$).

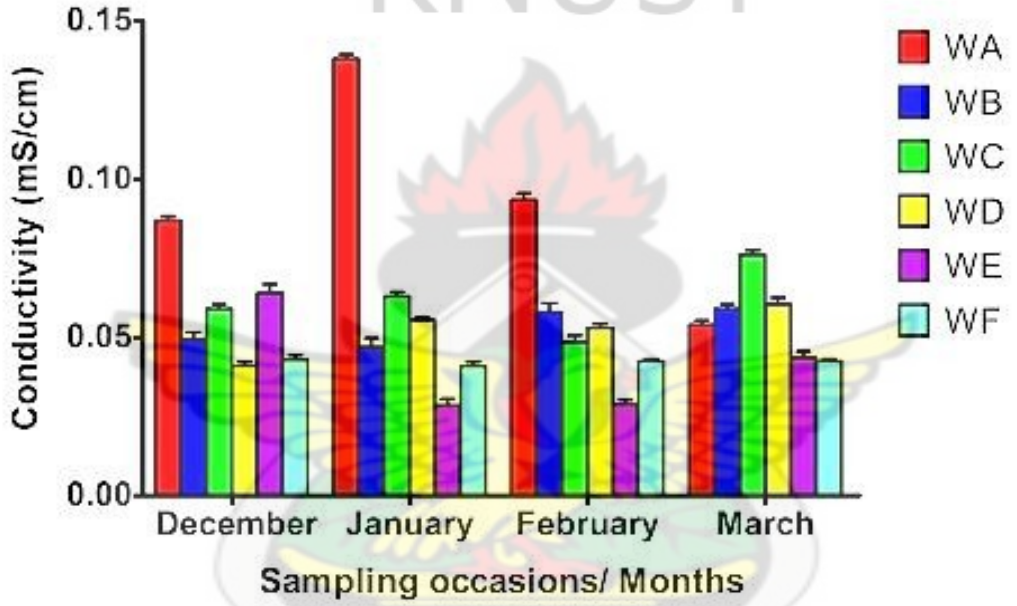

Fig.9: The mean electrical conductivity in the wells over the sampling period.

4.3.1.3Turbidity determination

The highest mean turbidity reading was recorded from Effa's well (A) 5.88±5.57NTU whilst the least mean value was found in Agya's well (1.25±0.63NTU) (Fig.10). The values were all within the WHO guideline limit for drinking water quality (0 - 10NTU). The differences within the turbidity values were not statistically significant.

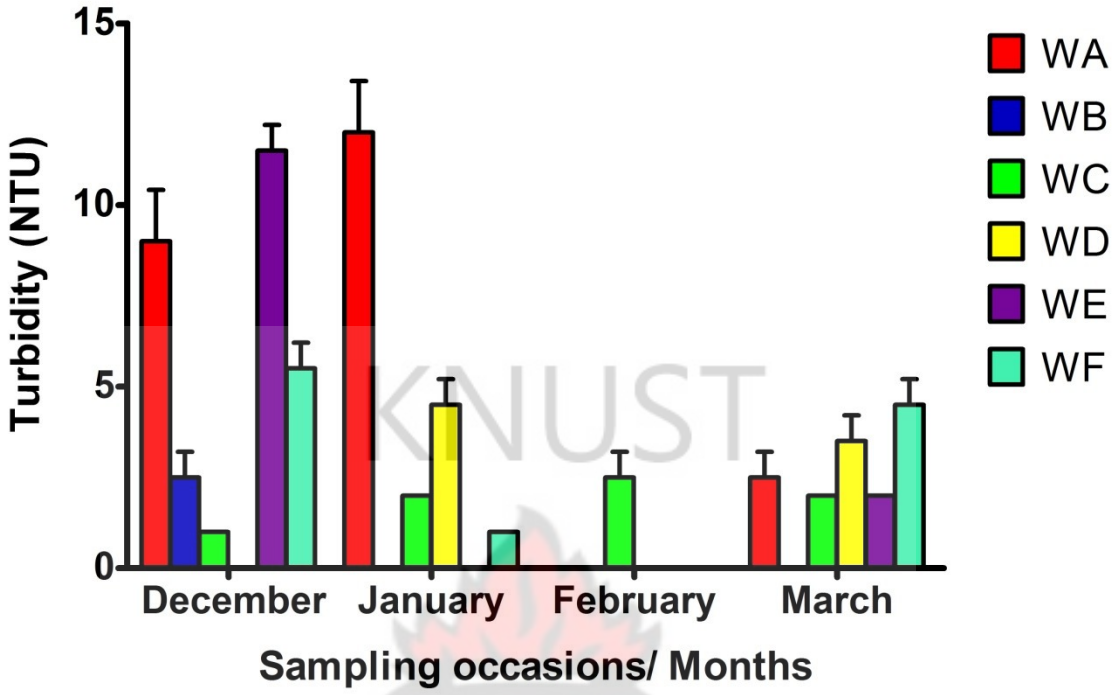

Fig.10: The mean turbidity levels in the wells over the period of sampling.

4.3.1.4 Determination of total dissolved solids (TDS)

The well which recorded the highest TDS concentration was Effa's well $0.06\pm0.02 mgL^{-1}$ whilst Abrewa's well had the least concentration of $0.02\pm0.01 mgL^{-1}$ (Fig.11). All the concentrations were far below the WHO guideline limit of $1000\ mgL^{-1}$ and that of EPA-Ghana recommended limit of $50 mgL^{-1}$. With the exception of Effa and Abrewa's well there was no significant difference in the total dissolved solid between the remaining wells.

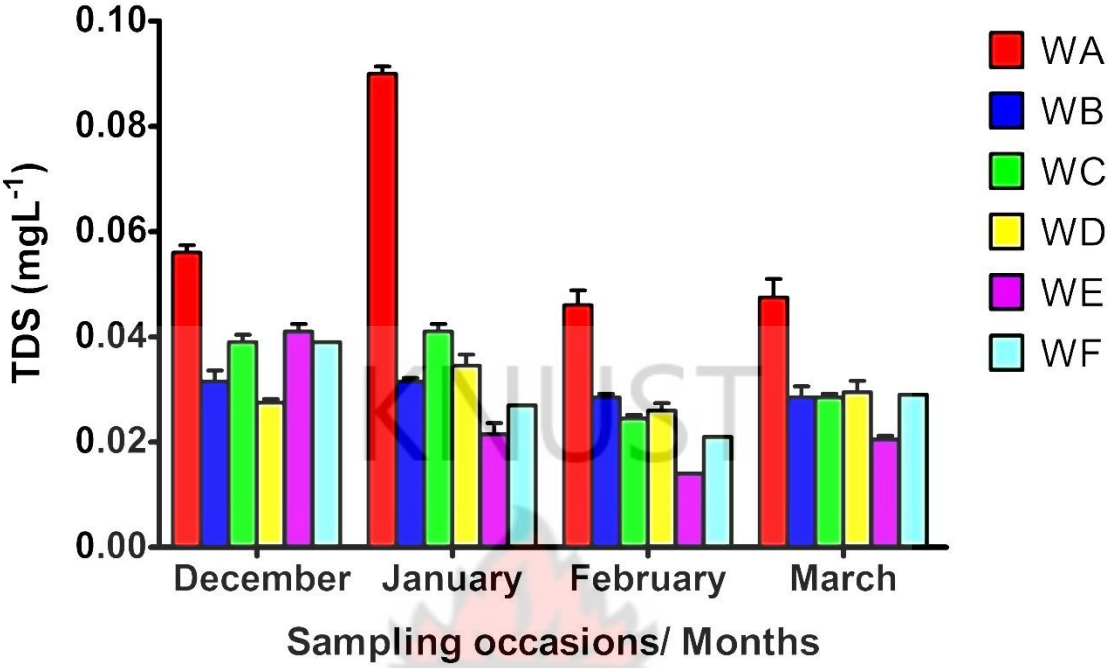

Fig.11: The mean TDS in the wells over the sampling period.

4.3.1.5 Concentration of metals

The concentration of arsenic (As) and lead (Pb) were both below the detection limit (<0.01 mgL^{-1}) (Fig.12). The recommended WHO guideline limit for both As and Pb is 0.01 mgL^{-1}.However, iron was detected with the highest mean value of 0.09±0.01mgL^{-1} from Effa's well. The least mean value was recorded at Abrewa's well (E) 0.02±0.01 mgL^{-1}. The differences between the concentration of iron in all the wells were statistically not significant ($p<0.05$).

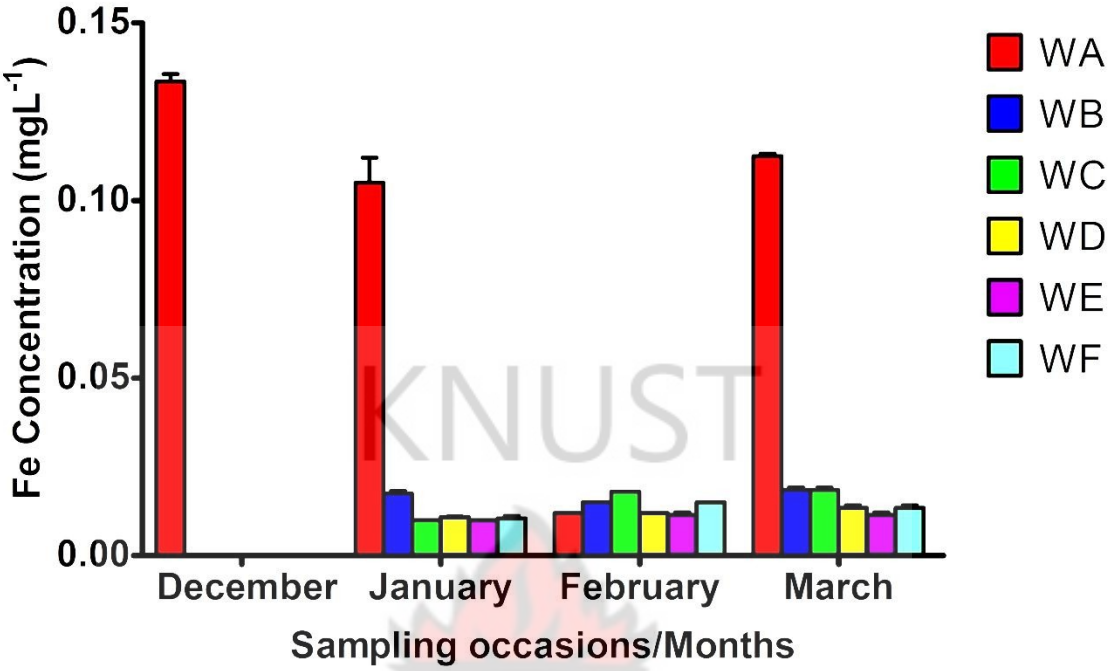

Fig.12: The concentration of iron in the wells over the sampling period.

4.3.2 Physico-chemical parameters of the river

4.3.2.1 pH measurement

The mean highest pH reading was recorded at station A of the river (RSA) i.e. 7.12 whilst the least was recorded from station C (6.79) at the downstream (Fig.13). The values were all within the WHO guideline limit for drinking water quality (6.5- 8.5). The differences between the pH values at the various stations of the river were statistically not significant.

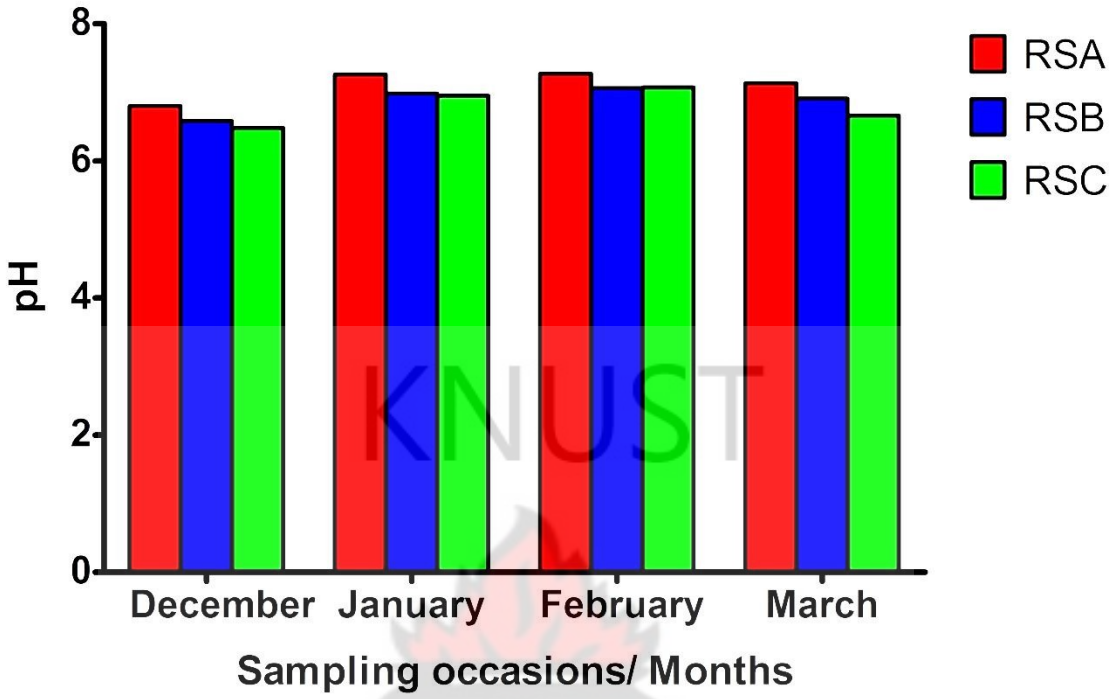

Fig.13: The mean pH levels in the river at the sampling sites.

4.3.2.2 Conductivity measurement

The least mean level of conductivity was recorded at station A (RSA) 0.08±0.03µs/cm which represents the upstream. The conductivity level at station B (midstream) and C (downstream) of the river were similar i.e. 0.12±0.04 µs/cm and 0.12±0.05 µs/cm respectively (Fig.14). The differences between the conductivity values were statistically not significant.

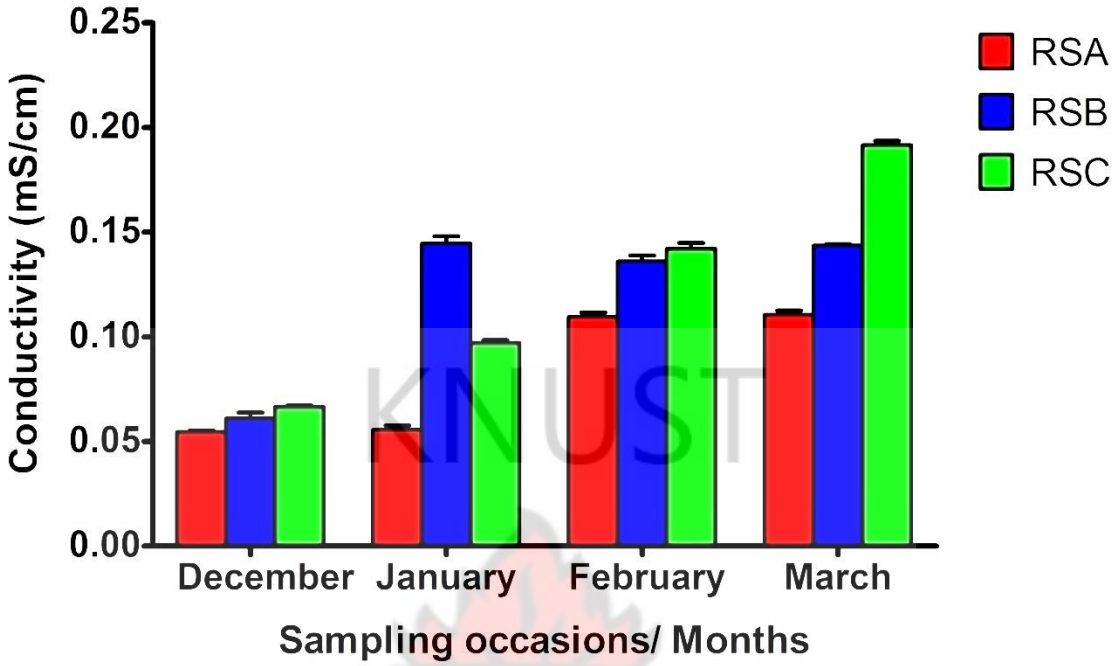

Fig.14: The mean conductivity of the river over the sampling period.

4.3.2.3Turbidity determination

The highest mean turbidity reading was recorded at station B of the river (mid-stream) 87.38±42.08 NTU. The least mean value of 27.50±6.75NTU was obtained at RSA (upstream) (Fig.15). The values were all above the WHO guideline limit for drinking water quality (0-10 NTU). There were no significant differences between the sampling values.

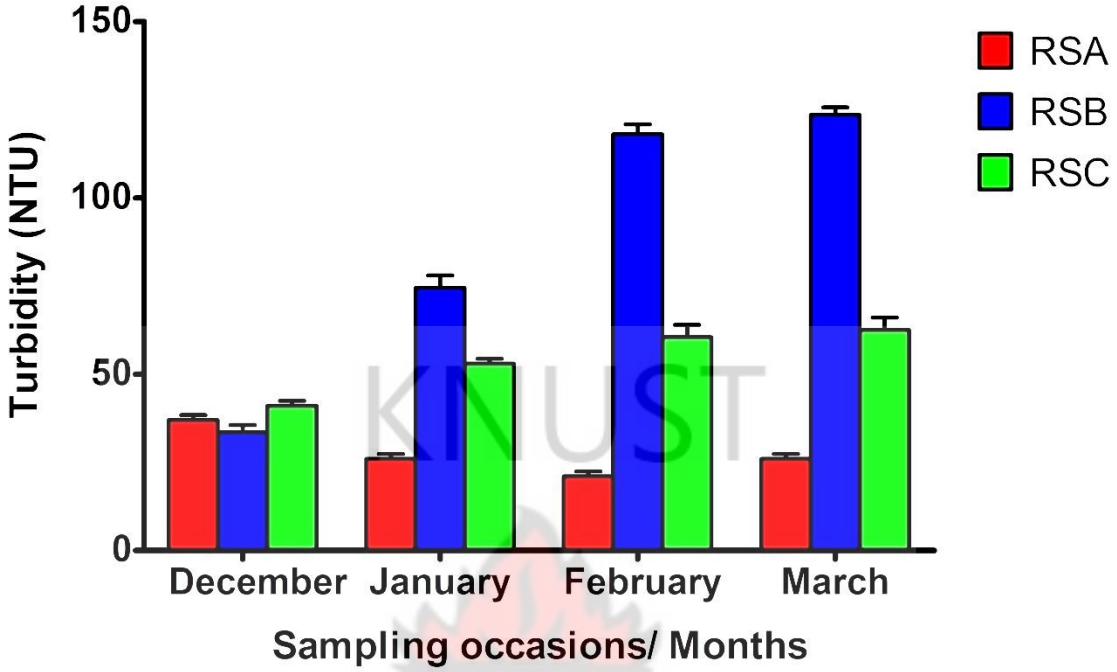

Fig.15: The mean turbidity readings of the river during the sampling period

4.3.2.4 Total dissolved solids (TDS)

The mean TDS concentration recorded were 0.06±0.05 mgL^{-1}, 0.06±0.02 $mgL^{-1}$and 0.06±0.01 mgL^{-1} for the river stations A, B and C respectively (Fig.16). All the sample stations of the river had values far below the WHO limit of 1000 mgL^{-1}. The differences between the TDS concentrations at the various stations were not statistically significant.

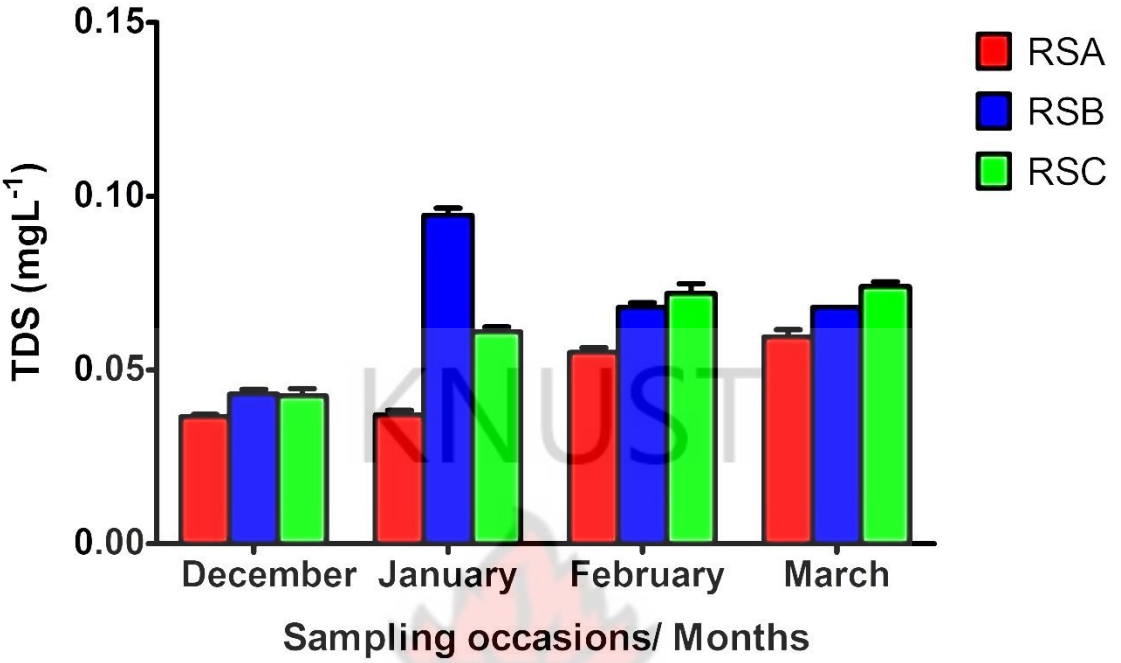

Fig.16: The mean TDS in the river over the sampling period.

4.3.2.5Determination of nitrate

The concentration of nitrate in the wells were below detection limit (< 0.01mgL^{-1}). However, there were traces detected in the river at mean concentrations between 0.05±0.03 mgL^{-1} at sampling site A to 0.12±0.11 mgL^{-1} at site B (Appendix 2). There was no significant difference in the nitrate concentrations between the sampling sites of the river ($p<0.05$).

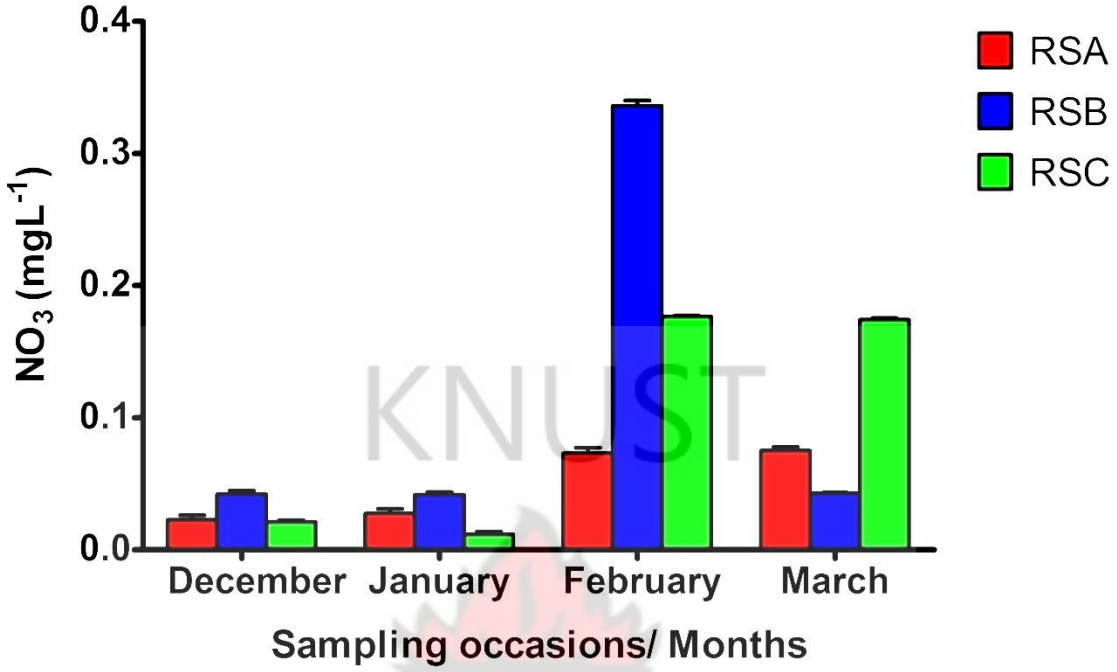

Fig.17: The mean nitrate concentration in the river during the sampling period.

4.3.2.6 Determination of metals

The concentrations of arsenic (As) and lead (Pb) were also below detection limit (< 0.01 mgL^{-1}). Iron was however detected at mean concentrations between 3.35±1.11 mgL^{-1} at the upstream and 10.69±2.74 mgL^{-1} in the mid stream (Fig 18). There was a significant difference between sample station A and B of the river.

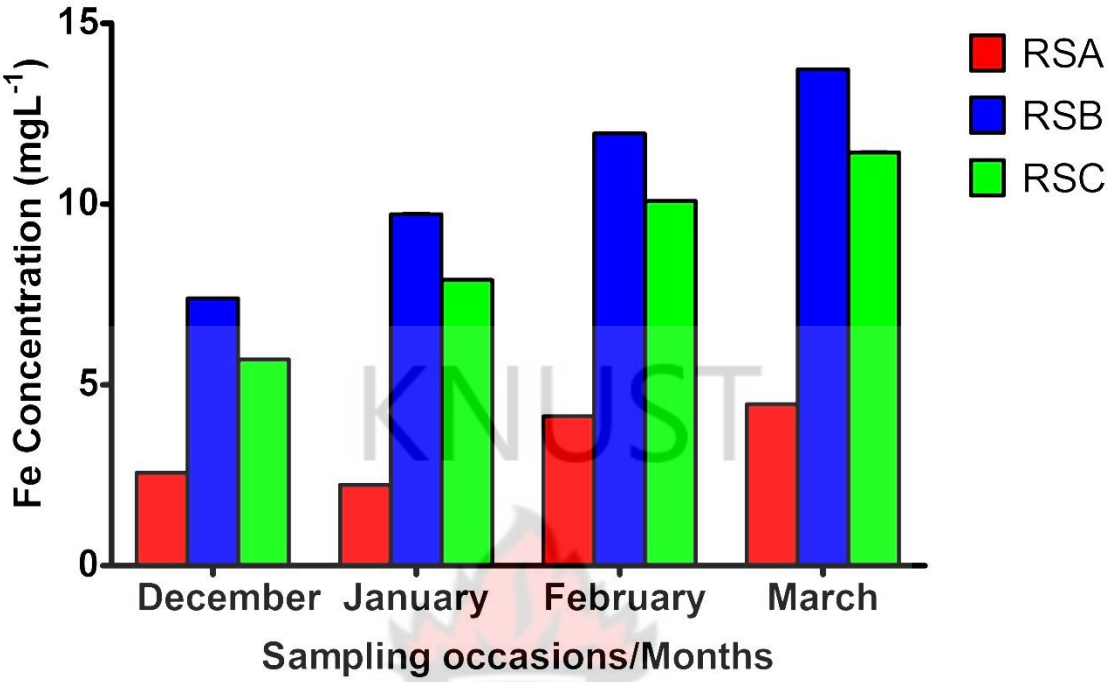

Fig.18: The mean iron concentration in the river during the sampling period.

CHAPTER FIVE

DISCUSSION

5.1 Physico-chemical parameters

5.1.1 pH

The mean pH of the water collected from the sampling sites of the river ranged from 6.79 to 7.12 indicating a balance between acid and alkalinity (Appendix.2). This signposts that the level is within the EPA-Ghana and WHO recommended guideline standard for drinking water (6.5 to 8.5) (WHO, 2011). There were no significant differences in the observed pH range at each site of the river. The pH of the river will thus not affect the health of its users for domestic purposes and that of aquatic life.

However, the observed mean pH recorded in the various wells ranged from 5.15 to 5.91(Appendix 1). It exhibited acidic characteristics. The values in all the samples from the wells were below the EPA-Ghana and WHO recommended pH range of 6.5 to 8.5. Agya's well at Sawmill recorded pH of 5.15 whilst Effa's well had 5.91. The low pH values might have come from the source of the water. Acidic or low pH of drinking water is usually a result of natural geological conditions at the site, possibly compounded by acid rain (www.watersystems council.org). Acidic water may be soft and corrosive and could contain metal ions. It could leach metals from pipes and fixtures such as copper, lead, and zinc. It could also damage metal pipes and cause aesthetic problems such as metallic or sour taste, laundry staining, or blue-green stains in sinks and drains. Low pH exposure may cause hair fibres to swell in sensitive individuals, gastrointestinal irritation

may occur just as high pH results in similar effects (pH in drinking -water @ www.who.int/water_sanitation_health/dwq/chemicals). Corrosion of metals and aggression of cement concrete is likely at low pH. The low pH of the well water may, therefore affect constructional works in the locality, and could be the cause of cracks and decay of the cement lining in the wells.

5.1.2 Turbidity

The mean turbidity recorded from the river varied between 27.50±6.75 to 87.38±42.08NTU at site A and B respectively (Appendix 2). The values were far beyond the background limit of between 0- 10NTU (Nephelometric turbidity unit). USEPA (2011) has indicated that at no time can turbidity go above 5NTU based under surface water treatment rule. There was significant difference ($p<0.05$) between sampling site A and B. The elevated level at site B could be due to the high inflow of waste water from the town into the river. Dead decaying organic matter from improper disposal of domestic waste along the river banks has also contributed to increase the level.

The value decreased at site C (54.25±9.73NTU) partly because of self- purification of the river as it flows downwards. Site B and C did not show any significant difference during the sampling period. On the other hand, the turbidity values recorded from the wells were within the WHO permissible limit of 0- 10NTU. The highest recorded level was 5.88±5.57NTU (Appendix 2) and this was found in Effa's well (A). The other wells had values ranging between 1.25 ±0.36 to 3.38±05.5NTU. None of the wells studied was cemented to the base. Dissolved clay particles and occasional drops of dirt from the

receptacles used to draw the water may be the source of the particulate matter suspended in the wells water studied. Ordinarily, finely divided organic and inorganic matters, like clay, silt, plankton and microscopic organisms make water opaque. Higher turbidity levels are often associated with disease causing organisms such as virus, parasites and some bacteria which cause symptoms such as nausea, cramps, diarrhoea, and associated headaches (USEPA, 2009). Turbidity can have negative impact on consumer acceptability of water as a result of visible cloudiness. Consumption of turbid water does not have any direct health effects. High turbidity implies a high concentration of suspended particles. These particles can shield bacteria and other micro-organisms from disinfection properties of treatment chemicals, for example chlorine, resulting in ineffective disinfection ((Physical and Organoleptic Parameters @www.wqms.co.za/ info pages/211). It is therefore important that the water from the river be filtered before it is used for drinking purposes.

5.1.3 Electrical conductivity

The mean electrical conductivity values from both the river and the wells were all below the WHO /EU permissible limit of 250µS/cm (LENTECH, 1998-2009).The values obtained scaled between 0.04±0.01 to 0.12±0.05µS/cm for both river and the wells (Appendix 2). Conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows. Streams that run through areas with granite bedrock tend to have lower conductivity because granite is composed of more inert materials that do not ionize (dissolve into ionic components) when washed into the water. On the other hand, streams that run through areas with clay soils tend to have higher

conductivity because of the presence of materials that ionize when washed into the water. Ground water inflows can have the same effects depending on the bedrock they flow through (APHA, 1992). Adverse effects of high electrical conductivity may include disturbance of salt balance in infants, heart patients, individuals with high blood pressure, and renal disease. Aesthetic effects include a salty taste to the water (if conductivity >150 µS/cm) while water with conductivity >300 µS/cm does not slake thirst (Physical and Organoleptic Parameters @ www.wqms.co.za/infopages/211). No wonder the users claim that the well water taste good and quench thirst which could partly be attributed to low conductance of the well waters studied as the values obtained were far lesser than 300µS/cm (Appendix 2).

5.1.4 Total dissolved solids (TDS)

The average TDS ranged from 0.02±0.01mgL^{-1} to 0.06±0.02 mgL^{-1} in the wells sample water whilst a range of 0.06±0.05 to 0.06±0.01 mgL^{-1} was recorded in the river during the study period (Appendix 2). The values were not alarming when compared with WHO (2012) guideline value of 1000 mgL^{-1} and that of EPA-Ghana set limit of 50mgL^{-1}. USEPA (1997) on the other hand recommend a standard limit of 500mgL^{-1} in drinking water. These are indications that there is no primary drinking water standard for TDS. High TDS interfere with taste of foods and beverages, and makes them less desirable to consumers (Free drinking water.com). The values obtained therefore suggest that using such waters to prepare food and beverages will be more palatable to consumers because the recorded TDS levels were far below the three standards compared with.

5.1.5 Nitrate

Nitrate was below detection limit in the wells studied (< 0.01mgL^{-}). However, it was detected in the river at the mean level that ranged between 0.05±0.03 to 0.12±0.11 at site A and B respectively (Appendix 2). The values were below EPA-Ghana and WHO set limit of 50mgL^{-} .The traces of nitrate in the river could come from fertilizers used by farmers along the river bank, and also from sewage and feedlots of animals that drain into the river. Nitrate comes into water supplies through nitrogen cycle rather than dissolved minerals. Other secondary sources of nitrogen compounds include fertilizer, manure, sewage, and landfills (ODNR, 2011).

Increasing nitrate levels in water resources are a potential source of severe environmental stress to aquatic organisms, because nitrate is known to be toxic to insects, amphibians and fish (Tomass and Carnicheal, 1986). Nitrates are especially toxic to children less than six months of age. The condition called “blue baby syndrome” (methemoglobinemia) may occur. Pregnant women may be less able to tolerate, and nitrate in the milk of nursing mothers may affect infants directly. These persons should not consume water containing more than 10ppm nitrate added directly to food products of beverages especially in baby formula (DEQ, 2011).High nitrate level in surface water contribute to algae blooms and may result in elevated levels of disinfection by-product in treated drinking water which is linked to increased cancer and reproductive health risk in humans as well as liver, kidney and central nervous system problems (Stewart, 2011). Though the nitrate level in the river was far below WHO/EPA-Ghana standard limit and using it for drinking purposes may not be worrying to the health of the users, it would be more

advisable to use the well water for drinking and preparing food especially for infants and pregnant women because nitrate was not detected in the wells studied and therefore would have no negative impact on their health.

5.1.6 Heavy metals (arsenic, lead, iron)

Consumption of heavy metals is linked to many serious health concern (Benham et *al*., 2011). Severe effects may include reduced growth and development, cancer, organ damage, nervous system damage and in extreme cases, death. These metals are present in varying concentrations depending on prevailing factors such as temperature, pH, hardness and standing time of the water. Among the wells and the river studied, the concentration of both arsenic (As) and lead (Pb) were below limit of detection (<0.01mgL^{-1}) (Appendix 3). The maximum control level of these metals given by EPA-Ghana and WHO (2011) in drinking water is 0.01mgL^{-1}. Lead exposure is shown to be associated with wide range of effects including neurological and behavioral defects, mortality (mainly due to cardiovascular disease), impaired renal function, hypertension, impaired fertility and adverse pregnancy outcomes, delay sexual maturation and impaired dental health (WHO, 2011). Arsenic is however a known carcinogen and mutagen (Smedley et *al*., 1995). The International Programme on Chemical Safety (IPCS) has indicated that long-term exposure to arsenic is casually related to increased risks of cancer in the skin, lungs, bladder and kidney, as well as other skin changes such as hyperkeratosis an pigmentation changes (WHO, 2011). Using the source waters for drinking and other domestic purposes can be said to be safe and nontoxic to the health of the people as the level of arsenic and lead, if any were below detection limit (<0.01 mgL^{-1}).

Iron was however detected in both water sources. The mean concentration in the river varied between 3.35±1.11 to 10.69±2.74 mgL^{-1} at site A and B respectively (Appendix 3). There was a significant difference between site A and B. The change at site B could be a result of corrosion of steel and cast iron which were dumped in refuse along the river course by auto-mechanic activities. Mean concentrations ranging between 0.01±0.01 to 0.09±0.01mgL^{-1} were recorded in the wells (Appendix 3). There were no significant differences between the values obtained from the wells. No established guideline standard is proposed for iron in drinking water. It is not of health concern at levels found in drinking water. Iron is not hazardous to health but it is considered a secondary or aesthetic contaminant as it stains laundry and plumbing fixtures at levels above 0.3mgL^{-1}. USEPA (2011) recommends 0.3mgL^{-1} as a secondary drinking water regulation standard. EPA-Ghana recommends 2mg/L in drinking water. Iron is essential for good health and also helps in oxygen transport in the blood (Nartey et *al*., 2005). According to WHO (2011) report, iron is essential element in human nutrition, particularly in iron (ii) oxidation state. Estimate of minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability and range from about 10 to 50mg/day. The concentrations of iron in the water samples studied would therefore not pose any health threat to the users but would rather boost their daily iron requirement.

5.2 Micro-organisms

5.2.1 Total coliform, faecal coliform and *E. coli*

Drinking water standard requires that no coliform bacteria be present in it. The river and the wells studied showed the presence of high microbial indicator counts which is not acceptable in drinking water. Both the EPA-Ghana and WHO (2011) stipulate a recommended guideline limit of zero count of coliform bacteria per 100ml sample of drinking water. The mean total coliform counts in the river ranged between 2107.00±241.70cfu to 26184.00±447.06cfu per 100ml of the sample studied (Appendix 1). Whereas in the wells studied, the total coliform number varied between 158.30±10.83cfu to 1689.00±151.10cfu. The study recorded highest faecal coliform counts of 217.00±23.76, and *E. coli* counts of32.88±3.89cfu per 100ml sample of water at station A and B respectively in the river.

Also, among the six wells the highest faecal coliform number of 59.88±42.20 was recorded in Effa's well at Sawmill. The *E.coli* counts ranged between 4.00±0.00 to 20.50±7.90 (Appendix 1). Coliforms are used as indicator for indexing health hazards in drinking and recreational waters (Cobelli, 1977). The presence of faecal coliform bacteria in a well indicates that the well is contaminated with faeces or sewage, and it has the potential to cause disease (N.C DHHS, 2009). Faecal indicator bacteria are typically not disease causing but are correlated to the presence of several water borne disease-causing organisms. The concentration of faecal indicator bacteria is a measure of water safety for body contact recreation or for consumption. For bathing water the geometric mean concentration established for faecal bacteria is 200col/100ml (USEPA, 1976). *E. coli* is

generally not found growing and producing in the environment. A positive *E. coli* result is much serious than the coliform bacteria alone because it indicates that human or animal waste is entering the water supply and can cause diarrhoea, dysentery, hepatitis (Brauyan, et. *al*., 2007; CDC, 2010). The continuous use of the water both from the river and the wells without treatment is therefore a threat to the health of users because they could be susceptible to the risk of water borne infections.

The high microbial counts in the river is influenced by surface run-off from the town as such waters pick up many substances and become a perfect medium for the growth of all type of micro-organisms. The leachate from indiscriminate disposed waste very closed to the river and sometimes directly into it is another contributory factor. Byre and pig pens are situated closer to the river, faeces from such animals drain into the river during raining period. The users of the river also step into it with their foot wears which are a potential source of faecal pollution. Animals are freely allowed to roam in search of food (free range system). They drink from the river directly and defecate indiscriminately which finally land in the river from uphill.

Several factors might have accounted for microbial counts in the wells as well. Most of the wells were not covered while others have defective well caps. In situations where the caps meet the well casings, there were gaps and cracks which let in contamination. Insects could enter through these fissures to contaminate the water. Different vessels with varying degree of hygiene were used to draw water from the wells. The wells did not have windlass, or mechanized so the users had to come with their own rope and

receptacle to draw the water. Those wells with rope and receptacle are left in the surrounding wet soil by the well head. Stray animals drink from such containers and possibly infect them with their faecal matter and these are subsequently used to draw the water.

Septic tanks proximity to the wells is another potential source of contamination. Craun et *al*.(1989) established that contamination of groundwater by pathogenic organisms is common in situations where wells and poorly constructed septic tanks are in proximity. When wells are not geologically well located, natural flow of leachate, surface run-off and other contaminant migrate to the water table to pollute it. Ideally, wells should be constructed with concrete ring linings from the top to the basement to keep it open, and frequently repaired when cracks and other defects are detected. All the wells studied were not lined or cemented with concrete to the base. Cracks were detected in the upper layers that have been cemented and thus, allowing water that has not been filtered through the soil to enter the well.

CHAPTER SIX

CONCLUSIONAND RECOMMENDATION

6.1 CONCLUSION

In general, the sampled water from the wells in Wamfie would be classified as acidic. However, there was a balance between acid and alkalinity in the pH of Asuotia River.

Arsenic and lead were below detection (> 0.01mg/L). Iron levels in the wells were within EPA- Ghana recommended limit but high in the river. Electrical conductivity and TDS values were low in the wells and the river studied. Turbidity values were above WHO limit at all the sites of the river sampled. High turbidity is associated with disease causing organisms and has negative impact on consumer acceptability. Continuous use of the water for drinking poses a threat to the users. There were presence of total coliform, faecal coliform and *E.coli* in the wells and the river at levels above WHO/ EPA-Ghana limit which indicate contamination of the water source by human and animal waste.The greatest risk to public health from microbes in water is associated with consumption of drinking–water that is contaminated with human and animal excreta (WHO, 2011).

With reference to WHO/EPA-Ghana standards, the wells and River Asuotia could be considered not good for drinking purposes.

6.2 RECOMMENDATIONS

Based on the findings of the study, it is vital to integrally approach the issue of faecal pollution of water bodies that serve as drinking water source for people. It is recommended that:

1. Free range system of raising animals should be discouraged in the community to avoid indiscriminate defecating and direct access to the river by grazing and domestic animals.
2. There should be proper waste disposal facilities available and improved form of latrines for the people living along the river bank to prevent indiscriminate waste disposal and defecating in the river.
3. Access to the wells by domestic animals must be restricted by fencing.
4. Wells should be lined with concrete right down to the base.
5. Wells should be sited at higher elevations in order not to serve as a sink during rainfall to collect surface run-off.
6. Wells in houses should be sited away from septic tanks and at higher elevations.
7. Wells should be equipped with windlass and the receptacles for drawing the water should be on the windlass with the rope wrapped around the windlass when not in use.
8. Wells must be covered when not in use and cover slabs should be properly designed to prevent openings at joints and depressions that allow water, insects and dust into it.
9. There should be a routine program by the Health Ministry and District Assembly to educate well owners on the need to get their wells disinfected at least once a year.

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APPENDICES

Table 1: summary statistics of the analytical data of microbiological parameters in the wells and the river

	Total Coliform/ 100ml cfu	Faecal Coliform/ 100ml cfu	E. coli/100ml cfu
Sampling Stations			
Well A	1689.00±151.10	59.88±42.20	20.50±7.90
Well B	640.00±37.20	37.75±9.97	14.75±9.74
Well C	1490.00±162.50	45.25±36.89	3.00±2.00
Well D	260.80±22.76	54.50±4.80	13.50±10.97
Well E	158.30±10.83	24.75±21.21	4.00±0.00
Well F	299.10±16.80	18.25±9.50	0.00±0.00
RSA	2107.00±241.70	217.00±23.76	13.75±11.30
RSB	26184.00±447.06	49.75±29.28	32.88±3.89
RSC	11599.00±200.14	134.90±118.80	14.75±9.74
WHO (2011)*	0	0	0

**Guidelines for Drinking-water Quality*

Table 2: summary statistics of the analytical data of physico-chemical parameters in the wells and the river

pH	Conductivity	Turbidity (NTU)	TDS (mgL^{-1})	Nitrate (mgL^{-1})
Sampling Stations				
Well A	5.91	0.09±0.03	5.88±5.57	0.06±0.02	ND
Well B	5.14	0.05±0.01	1.25±0.63	0.03±0.00	ND
Well C	5.62	0.06±0.01	1.88±0.62	0.03±0.01	ND
Well D	5.25	0.05±0.01	2.25±2.00	0.03±0.01	ND
Well E	5.44	0.04±0.02	3.38±0.55	0.02±0.01	ND
Well F	5.84	0.04±0.01	2.75±2.66	0.03±0.01	ND
RSA	7.12	0.08±0.03	27.50±6.75	0.06±0.05	0.05±0.03
RSB	6.88	0.12±0.04	87.38±42.08	0.06±0.02	0.12±0.11
RSC	6.79	0.12±0.05	54.25±9.73	0.06±0.01	0.10±0.09
WHO (2011)*	6.5-8.50	250	0-10	1000

**Guidelines for Drinking-water Quality*

Table 3: summary statistics of the analytical data of heavy metal concentrations in the wells and the river

As (mgL^{-1})	Pb (mgL^{-1})	Fe (mgL^{-1})	
Sampling Stations			
Well A	<0.01	<0.01	0.09±0.01
Well B	<0.01	<0.01	0.01±0.01
Well C	<0.01	<0.01	0.01±0.01
Well D	<0.01	<0.01	0.03±0.05
Well E	<0.01	<0.01	0.01±0.01
Well F	<0.01	<0.01	0.01±0.01
RSA	<0.01	<0.01	3.35±1.11
RSB	<0.01	<0.01	10.69±2.74
RSC	<0.01	<0.01	8.78±2.52
WHO (2011)*	0.01	0.01	NG

**Guidelines for Drinking-water Quality NG: No guideline*

ANOVA of field results at $p<0.05$ significant level

parameter	p-value
pH	0.0198
Turbidity	0.5805
conductivity	0.0296
Total dissolved solids	0.0415
Arsenic	-
Lead	-
Iron	0.1915
Total coliform	0.4353
Faecal coliform	0.5352
E. coli	0.0033

WELL RIVER

parameter	p-value
pH	0.1672
Turbidity	0.0304
conductivity	0.2319
Total dissolved solids	0.1220
Arsenic	-
Lead	-
Iron	0.0210
Total coliform	0.5114
Faecal coliform	0.9112
E. coli	0.7686

Table 4: Mean monthly heavy metal Concentrations in the Water Samples from the Wells and River

Fe (mgL^{-1})	As (mgL^{-1})	Pb (mgL^{-1})
Sampling Stations		
Well A^1	<0.01	<0.01	0.134±0.002
Well A^2	<0.01	<0.01	0.105±0.007
Well A^3	<0.01	<0.01	0.012±0.000
Well A^4	<0.01	<0.01	0.112±0.007
Well B^1	<0.01	<0.01	0.000±0.000
Well B^2	<0.01	<0.01	0.018±0.001
Well B^3	<0.01	<0.01	0.018±0.000
Well B^4	<0.01	<0.01	0.019±0.001
Well C^1	<0.01	<0.01	0.000±0.000
Well C^2	<0.01	<0.01	0.010±0.000
Well C^3	<0.01	<0.01	0.018±0.000
Well C^4	<0.01	<0.01	0.019±0.001
Well D^1	<0.01	<0.01	0.000±0.000
Well D^2	<0.01	<0.01	0.109±0.000
Well D^3	<0.01	<0.01	0.012±0.000
Well D^4	<0.01	<0.01	0.014±0.001
Well E^1	<0.01	<0.01	0.000±0.000
Well E^2	<0.01	<0.01	0.010±0.000
Well E^3	<0.01	<0.01	0.012±0.001
Well E^4	<0.01	<0.01	0.014±0.001
Well F^1	<0.01	<0.01	0.000±0.000
Well F^2	<0.01	<0.01	0.010±0.001
Well F^3	<0.01	<0.01	0.015±0.000
Well F^4	<0.01	<0.01	0.014±0.001
RSA^1	<0.01	<0.01	2.569±0.002
RSA^2	<0.01	<0.01	2.234±0.002
RSA^3	<0.01	<0.01	4.132±0.001
RSA^4	<0.01	<0.01	4.462±0.001
RSB^1	<0.01	<0.01	7.391±0.003
RSB^2	<0.01	<0.01	9.719±0.001

RSB[3]	<0.01	<0.01	11.947±0.001
RSB[4]	<0.01	<0.01	13.719±0.001
RSC[1]	<0.01	<0.01	5.698±0.004
RSC[2]	<0.01	<0.01	7.896±0.001
RSC[3]	<0.01	<0.01	10.080±0.002
RSC[4]	<0.01	<0.01	11.430±0.002
WHO (2011)*	0.01	0.01	NG

[1]December sampling, [2]January sampling, [3]February sampling, [4]March sampling
**Guidelines for Drinking-water Quality NG: No guideline*

Table 5: Mean monthly physicochemical parameters of the Water Samples from the Wells and River

	pH	Conductivity (μS/cm)	Turbidity (NTU)	TDS (mgL^{-1})
Sampling Stations				
Well A[1]	5.75	0.087±0.001	9.00±1.41	0.056±0.001
Well A[2]	6.27	0.138±0.001	12.00±1.41	0.090±0.001
Well A[3]	5.82	0.094±0.002	0.00±0.00	0.046±0.003
Well A[4]	5.80	0.054±0.001	2.50±0.71	0.047±0.004
Well B[1]	4.99	0.049±0.002	2.50±0.71	0.032±0.002
Well B[2]	5.11	0.047±0.003	0.00±0.00	0.032±0.001
Well B[3]	5.28	0.058±0.003	0.00±0.00	0.029±0.001
Well B[4]	5.20	0.059±0.001	0.00±0.00	0.029±0.002
Well C[1]	5.48	0.059±0.001	1.00±0.00	0.039±0.001
Well C[2]	5.76	0.063±0.001	2.00±0.00	0.041±0.001
Well C[3]	5.59	0.049±0.002	2.50±0.71	0.025±0.001
Well C[4]	5.65	0.076±0.001	2.00±0.00	0.029±0.001
Well D[1]	5.17	0.041±0.001	0.00±0.00	0.027±0.001
Well D[2]	5.11	0.056±0.001	4.50±0.71	0.034±0.002
Well D[3]	5.46	0.053±0.001	0.00±0.00	0.026±0.001
Well D[4]	5.28	0.060±0.002	3.50±0.71	0.030±0.002
Well E[1]	4.96	0.064±0.003	11.50±0.71	0.041±0.001
Well E[2]	5.04	0.029±0.002	0.00±0.00	0.021±0.002
Well E[3]	5.99	0.029±0.002	0.00±0.00	0.014±0.000
Well E[4]	5.77	0.043±0.002	2.00±0.00	0.021±0.001
Well F[1]	6.08	0.043±0.001	5.50±0.71	0.039±0.000
Well F[2]	5.78	0.041±0.001	1.00±0.00	0.027±0.000
Well F[3]	5.99	0.043±0.001	0.00±0.00	0.021±0.000
Well F[4]	5.53	0.043±0.001	4.50±0.71	0.029±0.000
RSA[1]	6.80	0.054±0.001	37.00±1.41	0.036±0.001
RSA[2]	7.26	0.056±0.002	26.00±1.41	0.037±0.001
RSA[3]	7.27	0.110±0.002	21.00±1.41	0.055±0.001
RSA[4]	7.13	0.111±0.002	26.00±1.41	0.060±0.002
RSB[1]	6.58	0.061±0.003	33.50±2.12	0.043±0.001
RSB[2]	6.98	0.145±0.004	74.50±3.50	0.095±0.002

RSB[3]	7.06	0.136±0.003	118.00±2.82	0.068±0.001
RSB[4]	6.91	0.144±0.001	123.50±2.12	0.068±0.000
RSC[1]	6.48	0.067±0.001	41.00±1.41	0.043±0.002
RSC[2]	6.98	0.097±0.001	53.00±1.41	0.061±0.001
RSC[3]	7.06	0.142±0.002	60.50±3.54	0.072±0.001
RSC[4]	6.91	0.192±0.002	62.50±3.54	0.074±0.001
WHO (2011)*	6.5-8.5	250	0-10	1000

[1]*December sampling*, [2]*January sampling*, [3]*February sampling*, [4]*March sampling*
**Guidelines for Drinking-water Quality*

Table 6: Mean monthly microbiological parameters in the Water Samples from the Wells and River

	Total Coliforms/ 100ml cfu	Faecal Coliforms/ 100ml cfu	E. coli/100ml cfu
Sampling Stations			
Well A[1]	41.50±2.12	9.00±0.00	9.00±0.00
Well A[2]	915.00±21.21	41.50±2.12	23.00±0.00
Well A[3]	2350.00±70.71	91.50±2.12	23.00±0.00
Well A[4]	3450.00±70.71	97.50±0.70	27.00±1.41
Well B[1]	235.00±7.07	41.50±2.12	23.00±0.00
Well B[2]	415.00±21.21	23.00±0.00	9.00±0.00
Well B[3]	915.00±21.21	41.50±2.12	4.00±0.00
Well B[4]	995.00±7.07	45.00±1.41	23.00±0.00
Well C[1]	23.00±0.00	0.00±0.00	0.00±0.00
Well C[2]	235.00±7.07	90.00±0.00	4.00±0.00
Well C[3]	2350.00±70.71	41.50±2.12	4.00±0.00
Well C[4]	3350.00±70.71	49.50±0.71	4.00±0.00
Well D[1]	41.50±2.12	4.00±0.00	4.00±0.00
Well D[2]	91.50±2.12	23.00±0.00	4.00±0.00
Well D[3]	415.00±21.21	91.50±2.12	23.00±0.00
Well D[4]	495.00±7.07	99.50±0.71	23.00±0.00
Well E[1]	91.50±2.12	4.00±0.00	4.00±0.00
Well E[2]	41.50±2.12	9.00±0.00	4.00±0.00
Well E[3]	235.00±7.07	41.50±2.12	4.00±0.00
Well E[4]	265.00±7.07	44.50±0.71	4.00±0.00
Well F[1]	235.00±7.07	23.00±0.00	0.00±0.00
Well F[2]	91.50±2.12	4.00±0.00	0.00±0.00
Well F[3]	415.00±21.21	23.00±0.00	0.00±0.00
Well F[4]	455.00±7.07	23.00±0.00	0.00±0.00
RSA[1]	23.00±0.00	0.00±0.00	0.00±0.00
RSA[2]	4.00±0.00	23.00±0.00	9.00±0.00
RSA[3]	4150.00±212.13	415.00±21.20	23.00±0.00
RSA[4]	4250.00±70.71	430.00±0.00	23.00±0.00
RSB[1]	235.00±7.01	23.00±0.00	9.00±0.00
RSB[2]	2350.00±70.71	91.50±2.12	23.00±0.00
RSB[3]	9150.00±212.13	41.50±2.12	9.00±0.00
RSB[4]	93000.00±0.00	43.00±1.41	90.50±0.70
RSC[1]	330.00±141.42	23.00±0.00	4.00±0.00
RSC[2]	415.00±21.21	41.50±2.12	9.00±0.00

RSC[3]	4150.00±212.13	235.00±7.07	23.00±0.00
RSC[4]	41500.00±2121.23	240.00±14.14	23.00±0.00
WHO (2011)*	0	0	0

[1]*December sampling*, [2]*January sampling*, [3]*February sampling*, [4]*March sampling*
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