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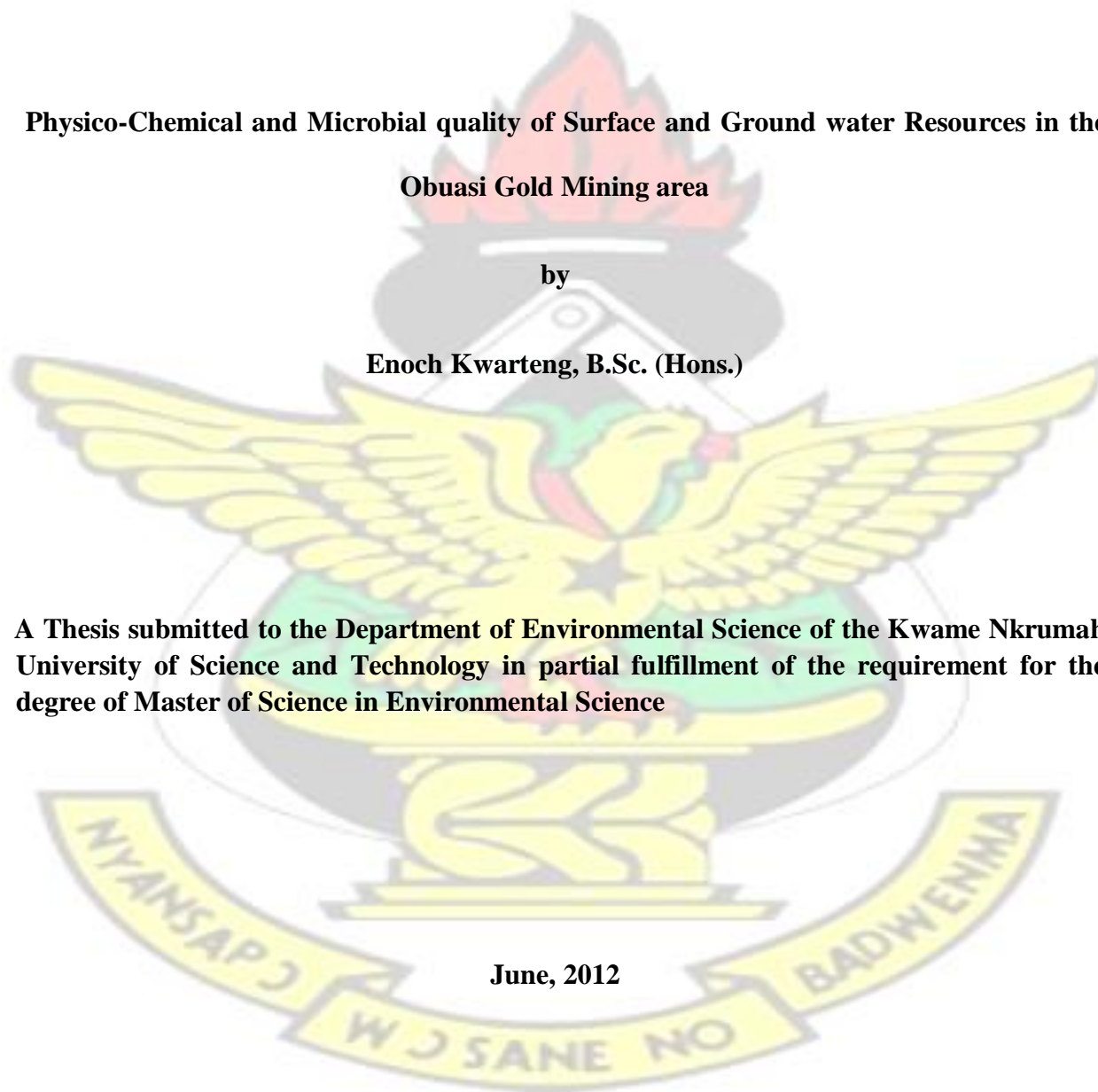
**Physico-Chemical and Microbial quality of Surface and Ground water Resources in the
Obuasi Gold Mining area**

by

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**A Thesis submitted to the Department of Environmental Science of the Kwame Nkrumah
University of Science and Technology in partial fulfillment of the requirement for the
degree of Master of Science in Environmental Science**

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CERTIFICATION

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

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DEDICATION

I dedicate this piece of Work to my dear Pastor, Rev. Prophet Silas Ankrah of the Lighthouse Chapel International, Bibiani for being a Father, a source of inspiration and encouragement throughout these challenging times.

Also to my dear mum, Mrs. Mercy Asieduah, Thank you so much for your unceasing prayers and financial support that has brought me this far.



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ABSTRACT

In most mining towns in Ghana, access to clean and potable water is a great challenge, resulting in waterborne diseases. The aim of this study was to assess the levels of some physical, chemical and microbial water quality parameters in 18 rivers and streams, 15 boreholes and 3 hand-dug wells at Obuasi, a gold mining town in southern Ghana. Parameters were determined using standard procedures. Statistical comparison was made between the levels of various water quality parameters with respect to the distance of the water source from the mining or hotspots areas. This was done by performing mean comparison test for the water quality parameters under study. The results showed that ground water pH ranged between 4.91–6.31 with a mean value of 5.38 ± 0.35 pH unit, which was acidic than surface water (pH range 6.02–7.45 and mean 6.59 ± 0.32 pH unit). Surface water which recorded a conductivity range of 48.99–1141.9 $\mu\text{S}/\text{cm}$ and a mean value of 439.94 ± 410.84 $\mu\text{S}/\text{cm}$ in the study area which were, more mineralized than ground waters (with conductivity range of 34.46–742.11 $\mu\text{S}/\text{cm}$ and mean value of 186.62 ± 188.00 $\mu\text{S}/\text{cm}$). The quality of surface water samples close to the mines was found to be generally poorer than for samples outside the mines. Significant differences were found between, Conductivity, TDS, Hardness, Sulphate and Arsenic levels for the surface water samples close to the mines compared to the water samples outside the mine. However, parameters such as pH, NO_3^- , Fe, Pb, Cu and Cd levels showed no significant locational variation. Moreover, Coliform population, NO_3^- , As, Fe, Pb and Cd levels in most cases, exceeded the World Health Organization recommended thresholds for potable water. In conclusion, the quality of most of the streams, boreholes and hand-dug wells were not suitable for human consumption without adequate treatment.

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LIST OF ABBREVIATIONS AND ACRONYMS

Acronym	Definition
AAOL	AngloGold Ashanti Obuasi Limited
AG	Ashanti Goldfields Company
AMD	Acid Mine Drainage
As	Arsenic
BRRI	Building and Road Research Institute
Cd	Cadmium
Cu	Copper
CN	Cyanide
CWQRB	California Water Quality Resources Board,
CSIR	Council for scientific and Industrial research
DWAF	Department of Water Affairs and Forestry, South-Africa
ERP	Economic Recovery Programme
EMS	Environmental Management System
EIS	Environmental Impact Statement
EC	Electrical Conductivity
Fe	Iron
FC	Feacal Coliform
GW	Ground Water
GEPA	Ghana Environmental Protection Agency
IMF	International Monetary Fund
ISO	International Standardization Organization
IARC	International Arsenic Research Center
MDGs	Millennium Development Goals
Ph	Potential of Hydrogen
Pb	Lead
PTP	Pompora Treatment Plant

PTD	Pompura Tailing Dam
SABS	South African Bureau of Standards
SW	Surface Water
STP	Sansu Treatment Plant
STD	Sansu Tailing Dam
SPSS	Statistical Package for Social Scientist
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
TC	Total coliform
TWN -Africa	Third World Network- Africa
USEPA	United States Environmental Protection Agency
UNO	United Nations Organization
UN	United Nations
WHO	World Health Organization
WACAM	Wassa Association of Communities Affected by Mining
Zn	Zinc



CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Water is an important natural resource in the world. It is often said that where no water exists, no life also exists. The link between Water and life can be seen in the fact that about 50-97% of the weight of all plants and animals and about 70% of the human body is made up of water (Buchholz, 1998). Water has no substitute for many of its uses and it is an essential prerequisite for the establishment of any permanent community. A general goal therefore is to make certain that adequate supplies of water of good quality is made available to all people, the ones living today and future generations, while preserving the required quantity and quality of water flow to sustain crucial functions of ecosystems (Tay, 2001).

Water-related diseases account for over 80 per cent of all deaths in developing countries. Infectious and parasitic diseases are the major cause of morbidity in developing countries and cause important outbreaks worldwide (WHO, 1996).

Due to the crucial importance ascribed to water, the desire of every government and nations at large is to ensure that communities around the globe have access to safe drinking water. The UNO had for example designated the period 1981-1990 as an international drinking water supply and sanitation decade (Tebutt, 1983). At the same time, the UN-MDG aims at halving the number of people around the world without access to safe drinking water by 2015 (The MDG Report- UN, 2010).

Mining and other human activities, natural geochemical and biochemical process may affect the achievement of these goals by impacting on the quality and quantity of water available for use. Ghana, a developing country has been producing gold since the 15th century. At present, it is second only to South Africa as the leading producer of gold in the sub-Sahara Africa region. Apart from generating employment to a sizeable proportion of the population, revenues and foreign exchange earnings from the export of gold amounts to several millions of cedi. Gold export has been pivotal to the recovery of the economy fortunes of Ghana since 1981. About 90 percent of the bulk of all gold produced in the country is through large scale operations, while the remaining 10 percent is through the activities of small scale miners also called galamsey operators (Aryee, 2002; Hilson, 2001).

1.2 Problem Statement

The Obuasi and its environs, the focus of this research, is one of the historic mining towns in Ghana with mining activities spanning more than 110 years. It is home to the AngloGold Ashanti (Obuasi) Mine which operates the over 200 km² Obuasi mine. It currently practices the underground system of Gold-mining after phasing out surface mining practices in 2004. In addition, several illegal miners also operate on the concessions belonging to the company. While mining has brought many varied benefits to the people of Obuasi and its environs which include providing employment, mining activities still continue to affect the water resources found within their catchment area. In recent times, the cost of allowing mining activities in the area has become overbearing (Amonoo-Neizer & Amekor, 1993). Many reports have indicated the considerable

pollution of surface and ground water sources in some communities near the center of the gold-mining activities in the area (Amasa, 1975; Smedley *et al.*, 1995; Akabzaa, 2004). Accordingly, the inhabitants of the affected communities in some cases have been barred by the mine authorities from using their traditional water sources such as streams and rivers for domestic and other economic purposes. Near some of these rivers, signpost bearing inscriptions such as ‘do not drink, fish or swim’ have been erected as a warning signal. In worse cases, alternative water sources such as boreholes have also been abandoned amidst the fear that they may also be contaminated.

While many people believe that gold mining activities indicated by the inadequate management of mine tailings and waste rocks, seepage of cyanide and processing chemical solution from defective tailing dams and processing facilities, acid mine drainage from exposed surface and underground mines as well as run-offs from the general mine area to water courses, are the major cause of the poor surface and groundwater quality conditions in the area. Others are of the view that, much blame should be put on illegal miners who operate in the area (Smedley, 1996; Hilson, 2001; Aryee, 2002; Smedley and Kinniburgh, 2002; Armah *et al.*, 2010).

It is against this backdrop that this research is called for; to ascertain the current drinking water quality conditions in the area and to determine the impact that gold mining activities exert on the quality of surface and ground water sources in the area.

1.3 Main Objective

The main objective of the study was to assess the physico-chemical and microbial quality of streams, boreholes and hand-dug well drinking water sources in the Obuasi gold mining area.

1.3.1 Specific objectives

1. To determine the levels of selected physico-chemical parameters (pH, Conductivity, Alkalinity, Hardness, Nitrates, Sulphate, Phosphate, Chloride, Cyanide) content for selected surface and ground water samples within the mining area.
2. To determine the levels of trace metals (As, Fe, Cd, Pb, Zn, and Cu), in streams and borehole water sources in the area.
3. To determine the level of total and faecal coliform in the identified water sources.
4. To identify the sources of contaminant input in stream and borehole drinking water sources in the area
5. To compare water quality trends found in samples close to the mines with those outside the mines.
6. To determine the seasonal variation in the quality of the water sources in the area.

1.4 Significance of the Study

The result of this study will provide current baseline information on surface and groundwater quality within the Obuasi gold belt. This baseline information will be used

to assess the suitability of ground and surface water sources in the area for domestic usage.

The study will also provide information that will help to sensitize the government, stakeholders and players in the mining sector on the need to seriously address water pollution issues at the Obuasi gold-belt and other mining areas in the country.



CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Environmental impacts at Obuasi due to Gold mining activities

The Ashanti Goldfields Company (AGC) Obuasi mining project has been in operation since 1897 after the Economy Recovery Programme (ERP) of the late 1980 (Jonah, 1987). Since its inception, Ashanti has gained tremendous economic significance in the Obuasi town, and the country as a whole. The mine for example was the largest contributor to Ghana's foreign exchange earnings to the year ending 2000. In 2002, mineral exports were raised from 20% in the 1980's to 38% out of gross foreign exchange earnings. Export earnings during this period rose from \$107.9 million in 1992 to \$717.8m in 1998 which further increased to 757 million dollars in 2002 (Jonah, 1987; Keatly, 1992).

On the global Scale, AGC, now AGA is a global player and is the only African multinational company with equities listed in the Ghana, London, Australian and Johannesburg Stock exchanges consecutively. The mine is also the oldest, largest and richest single mine which constitute the prime center of mining activity in Ghana and Sub-Saharan Africa as a whole.

As anticipated of most companies, AGA has also had its fair share of setbacks despite its numerous successes. One of the key set back centers on environmental issues associated with the mines, particularly as related to water quality issues within its catchment.

Since it received the ISO 14001 certification in 2004, the Obuasi mine have been on the nerve trying to mitigate the negative environmental consequences arising from its past,

present and future operations. In the year 2010 ending, the company recorded some significant improvement in its environmental performance but was still handed a red rating by EPA- Ghana Annual Environmental Performance Assessment Program (AKOBEN) alongside other prominent companies in the Ghanaian mining sector (Jonah, 1987; AngloGold Ashanti report, 2010; Sekyi, 2011)

Akabzaa, *et al.* (2007) and others have pointed out that AGC now (AGA) environmental woes did not begin until 1989, when the Ashanti Mine Expansion or Sansu Project began. This project sought to overcome the limitations of deep underground mines and resulted in the opening up of new surface mines at various locations within the gold-belt. It was anticipated that tremendous gains will be obtained from the surface mines. However, their wider coverage resulted in less land for the local dwellers. This spurred a lot of conflict between the host communities and the mines for the subsequent years thereafter (AGC, 1992; Akabzaa *et al.*, 2007).

Again, the technological advancement associated with the surface mine projects made it possible to recover low-grade ore by open pit and heap leach (cyanide) methods. Processing chemicals used in this method were Sodium cyanide, lime, Zinc oxide, Hydrochloric acid, and various floatation reagents.

Surface mining operations in addition also compounded the problem of acid mine drainage by exposing Sulphide mineral locked in the rock complexes to the abrasive action of the environment. Akabzaa, *et al* (2007) noted that acid mine drainage problems in the area is directly linked to surface mining activities in the area to some extent.

While some of the negative effects of surface mine operations were reduced by the use of tailing dams as a mine waste management tool. On some occasions, dam-failures with catastrophe consequence have been reported. For instance, between 1997 and 1998, two of such dam failures occurred in the minor south and north of the Dokyiwaa dam (Amegbey and Adimado, 2003). This compounded the water quality problem in the area and led to the relocation of villages such as Badukrom, Attakrom and Kronko downstream to the Dokyiwaa dam. These villages were served by the river Fena from akatakyieso hills. But the interception of the river by the dam and spillage problem resulted in the pollution of the river, thus making it difficult for the people to access water (Akabzaa *et al.*, 2007).

An earlier research done by Akabzaa *et al* (2007) for TWN-Africa also revealed that about 71 percent of all the respondents could no longer access portable water from the streams in the area because of pollution, while 3 percent were forced to drink the polluted water out of necessity.

The processing plant at Sansu and Kwabrafosso also emits foul smoke consisting of Sulphur dioxide and NO_x compounds into the atmosphere, and contribute significantly to airborne arsenic due to the roasting of the gold ore. In addition, the effluent discharge from the Pompora treatment plant to the Kwabrafosso River which runs into the Jimi River also resulted in the contamination of these rivers which served several communities downstream in the Kwabrafosso region (Akabzaa *et al.*, 2007).

2.2 Beneficiation of gold ores and its impact on water bodies

Gold extraction process depends on the ore mineralogy of the mined material. This in turn determines the type of environmental impact and management plan to be initiated. For gold ores, classification is solely based on the gold winning technique used in processing the ore. For example in alluvial ores, gold particles may exist as discrete or free entities in the form of nuggets or fine particles. Gold particles may also exist freely among siliceous material with no physical or chemical bond between them. Where the gold occurs in this form, it is separated using procedures which involve, gravity separation, amalgamation and smelting of the sponge gold (Aryee, 2002).

Amalgamation involves the use of mercury to extract gold in its free state. In this process, the gold ore is repeatedly washed with water along an inclined surface lined with jute sacks until a gold concentrate is obtained. Mercury is then added to the gold concentrate. This causes the gangue material in the concentrate to float on the mercury surface while the gold reacts with the mercury. The amalgam formed is then separated from the gangue through physical means. It is then roasted in an open fire. The mercury thus vaporizes to the atmosphere leaving behind the impure gold. The crude gold resulting from the process is either refined by smelting or dipping in hot concentrated nitric acid solution (Wacam, 2008). Under galamsey workings, the contaminated water used in washing the gold which contains mercury and other heavy metals are discharged into the nearby water bodies and vegetation causing pollution problems (Akosa, 2002).

Another type of ore is gold bearing quartz. The gold particles in this type of ore are physically associated with the gangue material. The gold particles are found along the sheared zones of the gangue rock. Such ores are also called free milling ores or

nonsulphidic ores. For these ores, processing techniques used is mainly by comminution processes. The process essentially involves crushing, grinding, gravity separation, followed by either amalgamation or cyanidation (Aryee, 2002).

In cyanidation technique, gold which is naturally insoluble in water is dissolved with cyanide in the presence of dissolved oxygen. It essentially involves drilling to reach the gold ore, blasting, haulage of the ore, crushing and screening, agglomeration, haulage and stacking. Lime (CaO) is then applied to the ore to raise the pH to between 10.5 and 11.0 followed by the addition of Sodium cyanide solution (NaCN) to dissolve the gold. The prepared ore is finally heaped into plastic lined pads but records show that on average between 45-450 l/day of Sodium Cyanide solution per hectare possibly leaks out into the environment which may affect water sources (Kuma & Younger, 2004). Finally, the gold is recovered using electro-winning process in which the gold is deposited on carbon electrodes (Akosa *et al.*, 2002).

For sulphidic ores, roasting is the preferred approach used in separating the gold from the sulphur mineral complex before extraction (Akabzaa, 2004 and Kortatsi, 2004). Roasting of gold ore in the past in Obuasi area have been noted for the considerable pollution with sulphide dioxide, and arsenic in air, land and water media within the gold belt (Asiam, 1996).

Currently, Sulphate abatement plant (BIOX reactor) has been installed at the Sansu treatment and processing plant (STP) to reduce sulphide pollution in the area significantly (Akabzaa, 2004 and Kortatsi, 2004).

2.3 Gold Processing Method in use at the AngloGold Ashanti Obuasi mine

2.3.1 Crushing

Ore from the mine site is hauled directly to the new crushing plant near Sansu for crushing and further processing. The Product from the crushing plant is then fed into the milling circuit.

2.3.2 Milling

A dual reclaim apron feeder, conveyor tunnel system is used to deliver the crushed ore to two SAG mills operating in parallel (CSIR-BRRI, 2010)

2.3.3 Gravity Separation and In- Line leach reaction

A gravity circuit which is part of the milling circuit comprising of a centrifugal (Knelson) concentrator and an In-line Leach Reactor (ILR) recovers free gold (gravity gold) from the milling circuit. Product of the milling circuit feeds the leaching and adsorption circuits (CSIR-BRRI, 2010).

2.3.4 Leaching and Adsorption

There are four leach tanks and seven adsorption tanks in the CIP circuit. Oxygen and Cyanide are added to the feed for gold dissolution at a pH of 10.5 (CSIR-BRRI, 2010).

Carbon is used in the adsorption tanks to recover the gold cyanide complex ions out of solution as the carbon moves in counter current direction to the flow of the ground feed.

Carbon is continuously moved from tank to tank via recessed impeller pumps accumulating higher gold values in the process. Carbon is recovered from adsorption tank number 1 for elution (CSIR-BRRI, 2010).

2.3.5 Elution and Gold Recovery

The Anglo American Research Laboratory (AARL) method is employed to get the adsorbed gold on the carbon back into solution using about 3-5% caustic solution. The gold is then electroplated onto steel wool cathodes. The steel wool cathodes are removed, calcined and smelted into Gold bullion (CSIR-BRRI, 2010).

2.3.6 Disposal of tailings and left over waste

Tailings from the plant are currently deposited at the Sansu tailing dam at a Relative Density of around 1.32 to 1.45 t/m³ (CSIR-BRRI, 2010).

2.4. Sources of metal pollution in water bodies

Mining is one of the most important sources of heavy metals in the environment. Mining- metallurgy and milling operations with the disposal of the resulting tailings causes significant metal pollution in the environment. For example, Nriagu and Pacyna (1988) estimated that, more than 635×10^6 kg/yr lead and 35×10^6 kg/yr arsenic that entered various environmental media were from the mining and metallurgy industry alone. This was about 35% and 22%, respectively, of the total Pb and As released into the environment (Nriagu and Pacyna, 1988).

The second prominent source of metallic elements in environmental media such as water is from natural geological conditions found in an area. Geological weathering is basically the weathering of various rock formations. It is usually the source of baseline or background metal levels found in many soils and water bodies. However in areas characterized by metal bearing formations, natural concentrations of these metals may exceed the background concentration resulting in significant metal enrichment (Tay, 2001).

In mineralized zones, where it's economically feasible, some of these minerals in rock complexes are mined to retrieve and process the target metal from the ore. This also leads to the disposal of tailings, discharge of effluents and possible smelting operations which result in environmental pollution (Tay, 2001).

2.4.1 Acid mine drainage and metal enrichment in the environment

Acid mine drainage (AMD) is one of the prominent source of metal pollution in the environment. It involves the exposure of pyrite (FeS_2) and other sulphide minerals to atmospheric oxygen and moisture conditions. This leads to the production of Sulphuric acid which then attacks and leaches the minerals constituent in the rock (Akcil & Koldas, 2006; Wacam, 2008).

It usually occurs when large quantities of rock containing sulphide minerals are excavated from open pits or are opened up in underground mines. The Sulphur in these minerals reacts with water and oxygen to create sulphuric acid (H_2SO_4). When the water

reaches a certain level of acidity, a natural occurring type of bacteria called Thiobacillus Ferroxidans kicks in and accelerate the oxidation and acidification process.

This acidic condition causes the release of metals tied in the rock complex such as Fe, Pb, As, Cu and Zn (Akcil & Koldas, 2006). The uncontrolled release of these metals can drift to Surface and Groundwater sources to cause immense pollution. Streams affected by mine drainage have a characteristics low pH, with high sulphate content and elevated concentrations of metal such as As, Fe, Pb, Cu and Zn (Förstner & Wittman, 1983).

2.5 Water bodies; Surface water and Groundwater

All freshwater bodies are inter-connected, from the atmosphere to the sea, via the hydrological cycle. Thus water constitutes a continuum, with different stages ranging from rainwater to marine salt waters. Also, inland freshwaters such as rivers, lakes or groundwater's are closely inter-connected and may influence each other directly (Chapman, 1996).

Surface water flow over land into Streams and River channels. It may also create temporary water storage and reservoirs such as lake and ponds. Surface water is the water which has been left over from local precipitation after evaporation. In some cases, it arises from intrusions such as from the groundwater beneath to the earth surface (Tay, 2001).

Rivers and streams are characterized by uni-directional flow with a relatively high, average flow velocity ranging from 0.1 to 1 ms⁻¹. The river flow is variable in time, and depends on the climatic situation and the drainage pattern in the area. However in some

cases, a more thorough and continuous vertical mixing can be achieved in rivers due to the prevailing currents and turbulence. Lateral mixing may also take place only over considerable distances downstream of major confluences (Chapman, 1996).

Lakes are different from Streams as they are characterized by low, average current velocity of 0.001 to 0.01 ms⁻¹. Currents within lakes are more multi-directional compared to Streams and Rivers. Many lakes usually have alternating periods of stratification and vertical mixing; the periodicity of which is regulated by climatic conditions and lake depth (Chapman, 1996).

Groundwater on the other hand is water held in pores and cracks of rocks and superficial deposits which is free to move under gravity (Todd, 1980). They are characterized by a rather steady flow pattern in terms of direction and velocity. The average flow velocities commonly found in aquifers range from 10⁻¹⁰ to 10⁻³ ms⁻¹ and are largely governed by the porosity and permeability of the geological material in the aquifer. As a consequence, mixing is rather poor and, depending on the local hydrogeological features, the groundwater dynamics can be highly diverse (Chapman, 1996).

2.5.1 Groundwater pollution and quality

Ground water especially that found close to underground and surface mines is not secluded from pollution problems contrary to popular belief. This is because both surface and underground mines extend below the water table. This makes underground water vulnerable to pollution problems associated with the mines such as Acid Mine

Drainage, direct infiltration of mine waste from defective storage dams etc. Also, pollution problems in Groundwater may emanate from the leaching of old mine tailings and settling ponds of both active and abandoned mines. Notable signs of groundwater polluted near mining centers include extremely low pH, high Iron and Sulphate content (Asklund and Eldvall, 2005).

Asklund and Eldvall (2005) have also linked groundwater quality to the prevailing natural geological conditions in the area. The composition of groundwater can vary widely and is in most cases a function of the composition of the water entering the groundwater reservoir and the reactions with minerals present in the rock. While some minerals such as Carbonates dissolve quickly and significantly change the water composition; others like Silicates dissolve slowly with less pronounced effect on the water composition (Asklund and Eldvall, 2005).

The retention time is also important in determining the groundwater water chemistry. Long residence times, allow more reactions which in turn can increase the concentration of major ions in the water compared to groundwater having short residence times (Appelo and Postma, 1999; Fianko *et al.*, 2010). Usually in unaffected environments, the concentration of most metals is very low and is mostly determined by the mineralogy and the weathering conditions in the area. To this end, there are a few examples of local metal pollution through natural weathering. Thus in many cases, metals become an environmental and health issue because of anthropogenic activity.

Soil concentration of adsorbing surfaces (oxide surfaces, clay mineral and humic substances) and pH also play a very important role in affecting the transportation of metals in the Groundwater system (Asklund and Eldvall, 2005).

2.6 Assessing the palatability of a water source

For a water supply system to be declared as safe for human consumption and use there is a need for it to pass various local, national and international standards in terms of taste, odour, and appearance as well as for the presence of various chemical and microbiological agents (Tebutt, 1983). Potable water is therefore defined as water that is free from diseases producing microorganisms and chemical substances deleterious to health (Ihekoronye and Ngoddy, 1985).

The palatability of surface and ground water sources are determined by the use of various variables or indicators ranging from physico-chemical to microbiological.

These include pH, conductivity, total dissolved solids (TDS), turbidity, anions (chlorides, nitrates, phosphates and sulphates), hardness, metals and microbiological factors such as the presence of faecal and total coliform organisms.

2.6.1 Physico-Chemical Indicators of water quality

These include pH, conductivity, total dissolved solids (TDS), turbidity, anions (chlorides, nitrates, phosphates and sulphates), hardness, and trace metals levels

2.6.1.1 pH pH is the negative logarithm of the concentration of hydrogen ion in a solution. It expresses the intensity of the acid or alkaline condition of a solution. The nominal pH value has a scale of 0-14. A solution is neutral if its pH value is 7, acidic if its pH value is less than 7 and basic if its pH value is greater than 7. The pH is an important variable in water quality assessment because it alone affects many

biochemical processes within a water body and all processes which affect the supply and treatment of water. In water pollution studies, the pH plays an important role in helping to determine the extent of an effluent or plume in a water body. It also affects the solubility and toxicity of most metals present in the water source (DWAF, 1996). Extreme pH values may also have pronounced effects on the taste of the water; Low pH will give the water source a sour taste, while high pH may result in soapy taste. Directly, very low or high pH values can cause irritation or burning of the mucous membranes of the intestinal mucosa (Fatoki and Muyima, 2003). Acceptable pH range for palatable water is therefore set from 6.0-9.0 (Ghana EPA, 1997).

2.6.1.2 Electrical conductivity (EC)

Conductivity is a measure of the ability of water to pass an electrical current. It gives a useful indicator of the mineralization and the pollution status in a water sample (Jain *et al.*, 2005). It depends on the amount, of dissolved ions present in a solution. Principal ions involved are chlorides, nitrate, sulfate, and phosphate and cations such as sodium, magnesium, calcium, iron, and aluminum. Conductivity is temperature dependent and is measured in ($\mu\text{S}/\text{cm}$) at 25 °C. Natural background concentrations found in many fresh waters ranges from 10.0 – 300.0 $\mu\text{S}/\text{cm}$.

Health effect associated with EC in drinking water can occur at levels as low as 370 $\mu\text{S}/\text{cm}$. However, water sources with electrical conductivity levels' exceeding 1000 $\mu\text{S}/\text{cm}$ generally are regarded as polluted (Fatoki and Muyima, 2003).

2.6.1.3 Total Solids

Total solids include both dissolved and suspended solids. The presence of solids both dissolved and particulate is partially responsible for both the apparent colour and cloudiness or turbidity of a water source. These may be organic impurities and may lend odor and taste to the water. They may also be inorganic in nature and may be responsible for high conductivity values of the water

Measuring Total dissolved solids gives a very good indication of the suitability of a water source for domestic use. High TDS values makes the water salty and less palatable compared with one moderate mineral content. TDS has no health-based guideline value. The WHO has recommended a guideline value of 1000 mg/l for TDS based on taste and other aesthetic effect rather than health effects (WHO, 1996).

2.6.1.4 Alkalinity

Alkalinity is a measure of the ability of a source of water to neutralize excess acid. It acts as a buffer and prevents the water from abrupt changes in pH which can be detrimental to the desired use of the water. Alkalinity indicates a solution's power to react with acid and neutralize it (USEPA, 1986). This ability to neutralize acid, or H^+ ions, is particularly important in regions where acid rain is a problem. Thus with waters obtained from aquifers with low buffering capacity, acidity is more prominent. Principal sources of alkalinity in natural waters are from carbonates, bicarbonates and hydroxides compounds tied in the underlying rock mineral. Anions such as, borates, the silicates, and phosphates may also contribute considerable alkalinity in natural waters (USEPA, 1986).

2.6.1.5 Total Hardness

Hardness in water is a measure of the ability of the water to lather or foam with soap. Hardness is caused primarily by calcium and magnesium ions. However, it is often expressed as mg/L equivalent of Calcium Carbonate (CaCO_3). Hardness in water causes excessive soap consumption and scaling in, kettles, piping systems, as well as causing graying problems in laundry. Water can be classified on the basis of hardness into the following categories, soft water which has between 0-75 mg CaCO_3 per litre, moderately hard water (75-150 mg/l), hard water with about 150-300 mg CaCO_3 per litre and very hard water with over 300 mg/l of CaCO_3 per litre of water (Shelton, 2000).

2.6.1.6 Sulphates

Sources of sulphate in natural water systems can be from industrial wastes such as mining, from wood preservation and through atmospheric deposition as acid rain.

However, the highest levels that occur in groundwater are from natural sources (Wacam, 2008)

The presence of sulphate in drinking water results in a noticeable change of taste. The lowest taste threshold concentration for sulphate is therefore set to be approximately 250 mg/l, while the aesthetic objective for Sulphates in drinking water is set at 500 mg/l (Shelton, 2000). At levels above 600 mg/l, it may acts as a purgative in humans. Drinking water should therefore not have sulphate levels exceeding 500 mg/l. However,

natural background levels of sulphates in most water sources are always very small and vary between 0.1 to 10 mg/l.

The physiological effects resulting from the intake of large quantities of sulphate in water may vary from catharsis, dehydration, and gastrointestinal irritation. In addition, excess Sulfate may also contribute to hardness of water and cause corrosion of drinking water distribution systems. Under anaerobic conditions, sulphate in water may be reduced to H_2S and this can give the water source an unpleasant or rotten egg smell (Shelton, 2000).

2.6.1.7 Nitrate and Nitrite

Nitrate is one of the most commonly identified groundwater contaminants. Nitrate (NO_3^-) and Nitrites (NO_2^-) are naturally occurring ions that are part of the N-cycle. The nitrate ion (NO_3^-) is the most stable form and it can be reduced by microbial action to the nitrite ion (NO_2^-), which constitutes the primary toxicity to humans. It is involved in the oxidation of normal hemoglobin to methaemoglobin. This disrupts the blood's ability to transport oxygen to the body tissues. More serious conditions due to nitrate intoxication are cyanosis, asphyxia, gastric and colo-rectal cancer (Uba and Aghogho, 2001). The WHO Safety guideline for nitrate-nitrogen in drinking water supplies is therefore 10 mg/l (WHO, 1996).

2.6.1.8 Phosphates

Phosphorus occurs chiefly in apatite which is a Calcium Phosphate mineral with variable amounts of OH^- , Cl^- and F^- and various impurities (Rao and prassad, 2004).

It's found in the form of phosphates in minerals such as Apatite, Pyroxene, Plagioclase, Garnet, Amphibole and Biotite (Handa, 1981).

During the natural process of weathering, the rocks gradually release the phosphorus as phosphate ions which are soluble in water. Total Phosphates exist in three forms: orthophosphate, metaphosphate (or polyphosphate) and organically bound phosphates which occur in plant and animal remains. However these minerals are not very common in the study area and may not contribute much in phosphate mobilization in the ground water sources.

2.6.1.9 Chlorides

Chlorides are relatively harmless to organisms except when converted to Cl_2 , ClO^- and ClO_3^- forms. High chloride content can also impact taste and cause corrosion problems in drinking water supplies (WHO, 1990).

2.6.1.10 Cyanide

Compounds of cyanide occur in water in the ionic form as weakly dissociated hydrocyanic acid. Some may also combine with metals to form various metallic complexes. Compounds of cyanide enter fresh water systems mainly as a result of industrial waste water discharge. Cyanide compounds are highly toxic, causing harm by

interfering with the body's use of oxygen, essentially causing suffocation (Shelton, 2000).

The toxicity of cyanide depends on its form and on its speciation. Most ionic forms of cyanide and species such as hydrogen cyanide are highly toxic. Moreover, cyanide complexes formed with metals such as zinc; lead and cadmium are extremely toxic. Complexes formed with copper, iron and cobalt behaves as weak toxicants. In view of the high toxicity of cyanide, the WHO has recommended a maximum concentration of 0.1 mg/l free cyanide in drinking water (WHO, 2004)

2.7 Sources, toxicity and established health effect of As, Pb, Cu, Fe, Zn and Cd in portable water

The accumulation of heavy metals in aquatic environment has a direct health consequences to man. Interest in metals like Fe, Mn, Zn and Cu mostly which are required for metabolic activity in organisms, lie in the narrow window between their essentiality and toxicity (Skidmore, 1964; Spear, 1981) but metal elements like Pb, Cd and Hg have no nutritional effect and exhibit toxicity even at trace levels (Borgmann, 1983).

The toxicity of metals depends entirely on their solubility, pH of the solution and also the type of speciation such as the presence of different types of anions and cations present in the water (Abulude *et al.*, 2007). Some of the Sources and potential health effects of trace metals analyzed in the study include the following

2.7.1 Copper (Cu)

Copper is an essential element and adverse health effects are related to both deficiency and excesses. Deficiency of copper in the diet can cause symptoms such as anaemia, neutropenia and bone abnormalities and menkes disease. In excess, it may lead to the development of Wilson disease, but extremely high doses can cause stomach and intestinal distress, liver and kidney damage, (Shelton, 2000; USEPA, 1986).

At Obuasi, high levels of copper in the water bodies have on many cases been linked to the occasional accidental cyanide processing solution spillages as well as leaching of toxic metals from waste rocks, which are dumped very close to some of the water bodies identified (Wacam, 2008). Also, the use of copper in the gold extraction process can also account significantly for copper drift into the aquatic environment (Penn, 1999).

It can also be released through the weathering and leaching of the metal from waste rocks dumps (AGC, 2001). Other sources of copper are from the weathering of the Birimian and Tarkwain rocks, which contains high levels of the element (Wacam, 2008).

2.7.2 Lead (Pb)

Lead is the most abundant heavy metal. It account for about 13 mg/kg of the earth's crust. It is found in a variety of minerals but the principal ores are Galena (PbS), Cerussite (PbCO₃), Anglesite (PbSO₄) and Jamesonite (Pb₄FeSb₆S₁₄) which occurs in many geological formations e.g. veins in the Cambrian clay, slates in bed or nests within the sandstones and limestone (Watkins *et al.*, (1983).

Lead is of no value to plants and animals even as a micronutrient. It is therefore regarded as a neurotoxic metal. Children exposed to high levels of lead in drinking water develop low intelligent quotients (IQs). At high doses; it can cause damage to the kidneys, and the nervous system. It may also impair the uptake of Iodine by the thyroid gland and causes brain damage, behavioral disorders and impaired hearing (Abulude *et al.*, 2007). Lead (Pb) at concentration of > 0.1 mg/l, is detrimental to foetuses and leads to premature abortion (USEPA, 1986).

2.7.3 Zinc (Zn)

Zinc metal does not occur naturally in the environment but exist as Zn^{2+} ions. It's concentration in the Soil, Sediments and Fresh water is mostly determined by the local geological and anthropogenic conditions of an area. Natural background total concentrations of Zn are usually between 0.1-50 $\mu\text{g/l}$ in fresh water and from 0.0020.1 $\mu\text{g/l}$ in sea water. However, in contaminated samples, Zinc levels of up to 4 mg/l in water have been reported (Environmental Health criteria, 2001).

The distribution and transport of Zinc in Water and Sediments depends upon the species of Zn present and the characteristics of the environment. Factors such as lower pH favor the dissolution of Zinc from the parent mineral. On the other hand, higher pH greater than 8.0 will cause Zn to precipitate out of solution (Environmental Health criteria, 2001).

2.7.4 Cadmium (Cd)

Cadmium (Cd) is chemically similar to Zn, except that it is more toxic and carcinogenic compared to Zn (Goering *et al.*, 1994). It is widely distributed in the earth's crust and natural background concentrations in soils typically range between 0.1 and 0.4 mg/kg (Page *et al.*, 1982).

However, sources of Cadmium in water bodies is chiefly from non-ferrous metal mines, where contamination usually arise from mine drainage water, wastewater from the processing of ores, overflow of the tailing ponds and also from rainwater run-off from the general mine area (Johnson & Eaton, 1980).

Cd derives its toxicological properties from its chemical similarity to Zn an essential micronutrient for plants, animals and humans. It replaces Zn in some enzymes, and thus affects the catalytic ability of the enzyme. It is also bio-persistent and accumulates in soft tissues of human. Long term exposure to cadmium has been associated with renal dysfunction, obstructive lung disease and lung cancer in humans (Friberg *et al.*, 1986). Cadmium may also produce painful bone defects (osteomalacia, osteoporosis) increased blood pressure and cadmium pneumonitis in humans and animals (Woodworth & Pascoe, 1982).

2.7.5 Arsenic (As)

Arsenic is a naturally occurring element in the earth's crust. It is less abundant than Cu and Zn but more abundant than Hg, Cd, Au, Ag, Sb, and Se.

Natural sources of arsenic are related to various types of rocks especially with sulfide minerals. The most important arsenic bearing minerals have been identified as Orpiment (As_2S_3), Realgar (AsS), Mispickel (FeAsS), Loellingite (FeAs_2), Niccolite (NiAs), Cobaltite (CoAsS), Tennantite ($\text{Cu}_{12}\text{As}_4\text{S}_{13}$), and Enargite (Cu_3AsS_4), (Matschullat, 2000), but it is commonly found alongside the gold ores such as Arsenopyrite (FeAsS), (Coakley, 1996).

Arsenic is usually present in the environment in inorganic form, which easily dissolves and enters underground and surface waters. Apart from natural sources, the presence of arsenic in environmental media such as soil, water and air can be sourced from pesticides use, smelter emission from ores of gold such as Arsenopyrite in sulphur treatment plants etc (Obiri *et al.*, 2006).

The toxicity of arsenic depends on its binding form. Organic arsenic compounds are less toxic than inorganic arsenic compounds (Shelton, 2000).

Arsenic can cause both acute and chronic poisoning. Chronic arsenic poisoning involves non-specific symptoms such as chronic weakness, loss of reflexes, weariness, gastritis, colitis, anorexia, weight loss, and hair loss. Long-term exposure through food or air may also cause hyperkeratosis, hyper-pigmentation, cardiovascular diseases, disturbance in the peripheral, vascular and nervous systems, circulatory disorders, Mee's lines, eczema, liver and kidney disorder etc. Arsenic is deposited in hair, skin, nails, and bones (Shelton, 2000).

In addition, withdrawal symptoms such as peripheral neuropathy have also been reported in some individuals even after cessation of the arsenic intake (USEPA, 1986; Petrusevski *et al.*, 2007).

2.7.6 Iron (Fe)

Iron is a metallic element that is present in many types of rock. The most common sources of iron in groundwater are naturally occurring, for example from weathering of iron bearing minerals and rocks (Wacam, 2008).

Concentrations of iron in groundwater are often higher than those measured in surface waters. At the study area, the presence of iron in drinking water is mainly from the weathering of the Birimian and Tarkwain rock system. At Obuasi, Arsenopyrite, the dominant mineral in the area, may be the chief source for higher concentrations in aquifers. Other sources of iron includes mining waste, acid mine drainage, sewage and landfill leachates which may increase iron levels in the surface water (AGC, 2001).

The presence of iron in water is usually not of health concern but may affect the taste, colour and smell of the drinking water source. High concentration of iron will tend to give the water a rusty colour and a metallic taste which may be objectionable to the consumer. In addition, it may also stain cooking utensils and laundry (Tahir, 2004).

The toxicity of inorganic iron is rare, but at higher doses, it may cause various health problems such as: anorexia, oliguria, diarrhea, hypothermia, metabolic acidosis to some extent death (Wacam, 2008).

2.8 Microbiological water quality

Microbiological indicators commonly used to determine the microbiology quality of a water source for domestic usage include measuring the levels of faecal and total coliform organism. These coliform organisms are used as an indication of the general hygienic quality of the water and of potential risk of infectious diseases from consuming the water.

2.8.1 Total Coliform and faecal Coliform

They represent the most useful indicators of the bacteriological quality of water. Coliforms are useful indicators of the possible presence of pathogenic bacteria in drinking water. *Escherichia coli* or faecal coliform is a member of the total coliform group of bacteria and is only found in the intestines and faeces of humans and other warm blooded animals. Faecal coliforms usually do not survive long in water; hence their presence in fresh water sources can be used as an indication of recent fecal contamination. Their presence in a water body gives an indication of the presence of other disease-causing organisms carried in the human intestine such as *vibrio cholerae*, *E. coli*, streptococcal organisms, enteric viruses and protozoan parasites (Fatoki and Muyima, 2003).

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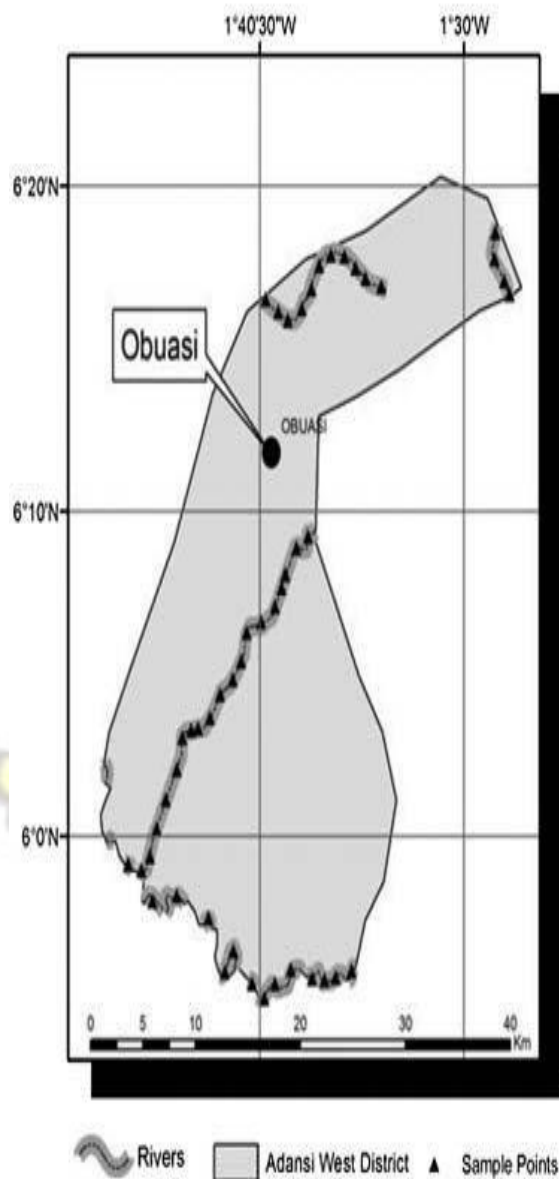
CHAPTER THREE

3.0 METHODOLOGY

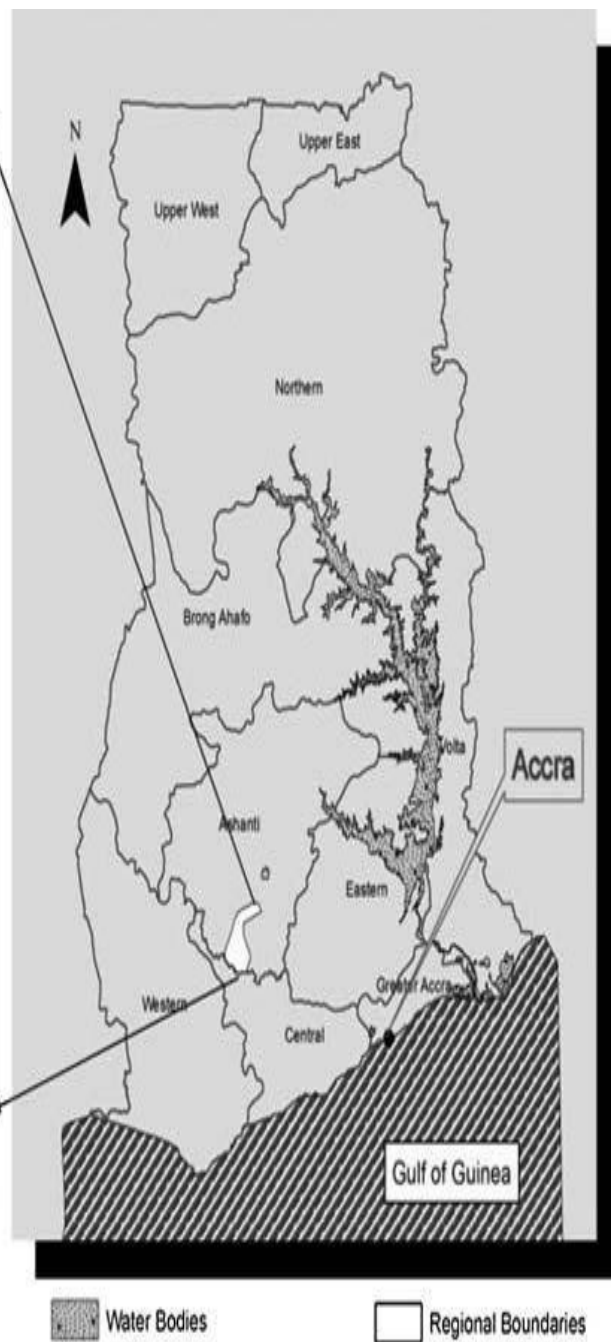
3.1 Description of Study area

The Obuasi Municipality lies in the southern part of Ashanti Region of Ghana between latitudes $5^{\circ} 35' \text{ N}$ and $5^{\circ} 65' \text{ N}$, and longitudes $6^{\circ} 35' \text{ W}$ and $6^{\circ} 90' \text{ W}$. It covers a land

area of about 162.4 square km . It is bounded to the south by Upper Denkyira District of the Central Region, east by Adansi South, west by Amansie Central, and north by Adansi North. There are 52 communities in the municipality. Generally, the Municipality has an undulating terrain with more of the hills higher than 500 meters above sea level. The Municipality is drained by streams and rivers which include; Pompo, Nyam, Akapori, Kwabrafo and Jimi, all within the catchment of the AngloGold Ashanti mine concession (Armah *et al.*, 2010b). Soils in the municipality are predominantly forest ochrosols developed under forest vegetation with rainfall between 90 cm and 165 cm. Rocks in the Municipality are mostly of Tarkwain (PreCambrian) and Upper Birimian formation that are noted for their rich mineral bearing potentials (Armah *et al.*, 2010a). Areas around the contacts of the Birimian and Tarkwaian zones known as reefs are noted for gold deposits. The Obuasi mine (AngloGold Ashanti), which works on steeply dipping quartz veins over a strike length of 8 km, has since 1898 produced over 600 tons (18 million ounces) of gold from ore averaging about 0.65 ounces per ton (Armah *et al.*, 2010b).



(a) Obuasi Municipality



(b) Ghana

Fig 3.1 Map of the study area (modified from Armah *et al.*, 2010b)

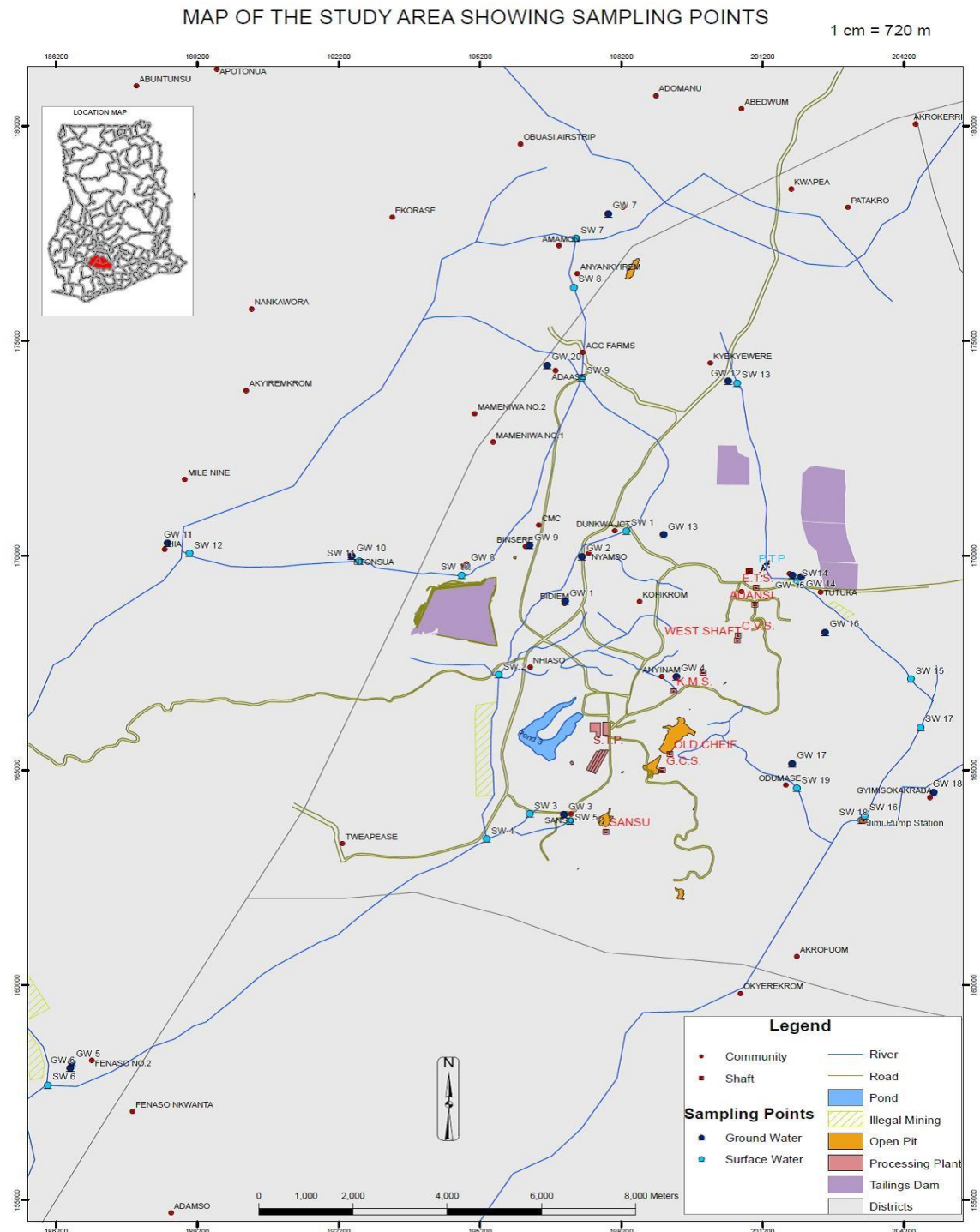


Fig 3.2 Map of Project area showing Sampling locations and communities- Field survey, 2012

3.2. Site description and selection of sampling points

The study area was visited and sampling points were selected with reference to work done earlier by Akabzaa *et al.*, (2004). Sampling points and locations were carefully chosen in line with the objectives of the study.

At each sampling point, direct visual observations were made for signs of nearby pollution sources and the GPS co-ordinates were taken which was then used to plot a base map as seen in Fig 3.2 above.

In all, 36 water samples were taken from 15 boreholes, 3 hand- dug wells and 18 streams serving the following communities; Dokyiwaa, Binsere, Sansu, New Bidiem, Kwabrafoso, Jimiso Kakraba, Adaase, Ntonsoa, Hia No 1 and 2, Nyameso, Odumase, Anyinam, kyekyewere, Amamon, Fenaaso No 3, Akatakyieso and Obuasi main town.

Out of the 36 water samples, 18 water samples were from sampling location close to mines; within a 0-500 m radius, while the remaining was from communities outside or distant to the center of mining activity or hot spot area (>500m radius). The hotspot areas were defined by the presence of mining activities such as tailing dams both active and inactive, gold-ore crushing and processing facilities, underground and surface mine operation and galamsey operations.

Notable rivers sampled include the Fena River, which serves communities around dokyiwaa, the river Nyam at Sansu and river Kwabrafo at Kwabrafoso.

The Fena River takes its source from the akatakyieso hills and runs downstream through dokyiwaa serving several communities along the terrain. It is intercepted when it reach

Dokyiwaa by waste dumps and cyanide containment dam of the mine. The stream has a turbid brownish colour with a rotten leaf smell and is used by the inhabitants for various domestic purposes and for oil palm processing (AGC, EIS-Baseline flora environment, 2001)

Table 4.1 Surface water samples close to the mines

Sample	Description	Latitude	Longitude
SW2	River Nyam close to the STD -	6 ° 10 43.61 N	1 ° 42 41.05 W
SW3	River Asuakor, it's close to the STP at Sansu	6 ° 08 57.86 N	1 ° 42 19.47 W
SW5	Stream at Sansu community close to abandoned Surface mines	6 ° 08 52.72 N	1 ° 41 55.55 W
SW7	River Buama near the abandoned mine at Amamon	6 ° 16 14.56 N	1 ° 41 48.70 W
SW10	River Kwame Tawia, close to the dokyiwaa tailing	6 ° 11 55.16 N	1 ° 43 06.77 W
SW11	River Ntonsoa, about 250m downstream to the dam at dokyiwaa	6 ° 12 14.82 N	1 ° 44 17.90 W
SW14	Kwabrafo at Amasa very close to the PTP.	6 ° 11 54.91 N	1 ° 39 15.20 W
SW15	River Kwabrafo further downstream	6 ° 10 50.86 N	1 ° 37 38.84 W
SW19	River Kaw	6 ° 09 17.64 N	1 ° 39 06.83 W

Table 4.2 Surface water samples outside the mines

Sample	Description	Latitude	Longitude
SW1	River Nyam Upstream of the Sansu mines	6 ° 12 31.27 N	1 ° 41 13.48 W
SW4	River Nyam at the midstream position to the dam	6 ° 08 39.16 N	1 ° 42 49.18 W
SW6	River Fena downstream to the Sansu		

	mines just before it joins river Offin	6 ° 05 32.59 N 1 ° 47 52.44 W
SW8	River Fena at Amamon, upstream of the Dokyiwaa	6 ° 16 42.76 N 1 ° 40 47.83 W
SW9	River Fena at Adaase, upstream to mines	6 ° 14 28.45 N 1 ° 41 43.93 W
SW12	River Fena at Hia far from the dokyiwaa mines	6 ° 12 14.82 N 1 ° 46 14.77 W
SW13	Kwabrafo river upstream to the PTP and PTD	6 ° 13 21.67 N 1 ° 41 04.52 W
SW16	River Pompo and Kwabrafoso mixed together	6 ° 08 57.07 N 1 ° 38 28.04 W
SW17	River Pompo alone unaffected by Kwabrafo	6 ° 10 23.66 N 1 ° 37 41.55 W
SW18	River Jimi	6 ° 08 52.93 N 1 ° 38 30.47 W

Table 4.3 Groundwater samples close to the mines

Sample	Description	Latitude	Longitude
GW1	Borehole at Bidiem near the Sansu Dam	6 ° 11 39.28 N	1 ° 42 19.47 W
GW2	Borehole at Nyameso	6 ° 12 13.30 N	1 ° 41 41.05 W
GW3	Borehole at Sansu village	6 ° 08 57.67 N	1 ° 41 56.02 W
GW4	Borehole at Anyinam village in center of the Underground mines	6 ° 10 41.82 N	1 ° 40 37.80 W
GW8	Borehole at Dokyiwaa near the tailing dam	6 ° 12 05.36 N	1 ° 43 03.68 W
GW9	Borehole at Binsere near the tailing dam	6 ° 12 24.98 N	1 ° 42 19.75 W
GW10	Borehole at Ntonsoa	6 ° 12 13.22 N	1 ° 44 22.78 W
GW14	Hand dug well very close to PTD	6 ° 11 58.08 N	1 ° 39 12.27 W
GW15	Hand dug well close to the PTP	6 ° 11 59.10 N	1 ° 39 18.58 W

Table 4.4 Groundwater samples outside the mines

Sample	Description	Latitude	Longitude
GW5	Abandoned borehole at Fenaaso No 3	6 ° 05 49.37 N	1 ° 47 35.67 W
GW6	Active borehole in use at the Fenaaso community	6 ° 05 44.97N	1 ° 47 36.69 W
GW7	Borehole at Amamon village	6 ° 16 32.93N	1 ° 41 26.31 W
GW11	Borehole at Hia	6 ° 12 22.81N	1 ° 46 29.85 W
GW13	Borehole at Obuasi town	6 ° 12 29.36 N	1 ° 40 47.50 W
GW12	Borehole at kyekyewere outside the mines	6 ° 14 25.75 N	1 ° 40 02.45 W
GW16	Borehole at Aboagyekrom	6 ° 11 16.18 N	1 ° 38 55.95 W
GW17	Hand dug well at Odumase village	6 ° 09 36.07 N	1 ° 39 17.75 W
GW18	Borehole at Jimiso Kakraba	6 ° 09 14.90 N	1 ° 37 40. 30W

3.3 Sample collection procedure

In order to obtain accurate results from the sampling, the following procedures were adopted to minimize potential contamination of the samples.

3.3.1 Preparation of sampling containers

Sample containers used were 500 ml plastic containers. The containers were soaked in 10% nitric acid overnight, washed with detergent, rinsed twice with distilled water and dried in a drying cabinet overnight (Claasen *et al.*, 1982). The Sample containers were then labeled to enhance good record keeping.

3.3.2 Duration and frequency of sampling

Sampling was on monthly basis for six months to cover both the wet season (October-December, 2010) and dry season (January-March, 2011). At each site, duplicate samples were taken from the same water source during each sampling trip. In all, a total of 36 samples were collected, from 15 boreholes, 3 hand-dug wells, and 18 streams.

3.3.3 Sampling of Surface and Groundwater

The sampling protocols prescribed by Claasen (1982) and Barcelona *et al* (1985) were strictly adhered to. Samples for microbiological analysis were collected into sterile screw capped plastic containers, while those for physico-chemical, heavy metal and cyanide analysis were collected in dark bottles to prevent entry of light. At each sampling point, sampling containers were first rinsed three times with some of the stream or borehole water. Stream water was collected midstream by dipping the container at a depth of 20-30 cm against the stream flow. Borehole samples were also collected after pumping the water for at least 10 minutes using the hand pump attached. For hand dug wells with no pump, a sterilized bailer was used to draw some water out and poured into the sample bottles. The bottles were covered immediately with a lid and properly labeled with the date and sample code.

3.3.4 Quality control during sampling collection

To minimize errors and possible contamination associated with the field sampling, a trip blank prepared from distilled water was put among one of the prepared sampling containers and labeled. The purpose of the trip blank was to help measure the degree of

contamination from external factors during each sampling trip. In the field, while collecting the samples and with the hand gloves still on, one of the cleaned empty bottles was also filled with distilled water and covered tightly. This helped to assess the degree of contamination associated with collecting and filling the sampling bottles at the field. The result of the field and trip blank recorded very minimal or negligible amounts of the analyte substance. This shows that no or minimal re-contamination occurred during sampling period. On this basis, the results presented in this study are very representative and reliable.

3.3.5 Sample preservation technique

Samples for trace metal analysis were preserved with 3-ml of concentrated HNO_3 acid per litre in the field. All the collected water samples including the field and trip blanks were put in an ice chest at a temperature of 4°C . They were immediately transported to the Environmental Laboratory of the AngloGold Ashanti (Obuasi) mine Ltd for analysis. Where immediate analysis was not possible, the samples were refrigerated, upon receipt in the laboratory, to avoid external contamination or deterioration, until the time of the analysis

3.4 Method of determination of physicochemical parameters

The pH, temperature and electrical conductivity were determined on site.

3.4.1 Determination of pH

The pH of the sample was measured using the pH 72 HANNA pH meter. The pH meter was first calibrated using a buffer solution with pH of 4 and 7 respectively. The asymmetry potential control of the pH meter was altered until it read the known pH value. The pH of the samples was then determined by pouring 100 ml of each sample into a 250 ml beaker. The probe of the pH meter was immersed into the sample and allowed to stand for some time, until a stable pH value was obtained. The pH value was then recorded. The probe was rinsed with distilled water after each sample measurement and again rinsed with the next sample whose pH was to be determined.

3.4.2 Determination of Electrical Conductivity (EC) and Total Dissolved Solids

The Electrical conductivity and Total Dissolved Solids of the water samples were measured using the Eu-TECH WP COND 610 Bench conductivity / TDS meter. The Conductivity probe was immersed into the 100 ml sample in the 250 ml beaker. The conductivity of the sample was then measured by pressing the COND key that displayed the conductivity measurement mode. The reading was recorded. The TDS key was pressed to display the TDS measurement mode. The total Dissolved Solid was recorded after waiting for some time until a constant value was shown. The procedure was repeated for all the samples. The probe was rinsed with distilled water after each sample measurement.

3.4.3 Determination of Total Suspended Solids (TSS)

Total Suspended Solids (TSS) was measured by employing a DR 500 spectrophotometer. The favourite program (TSS) was chosen after the system check. Calibration was done 100 ml of distilled water in a cell tube. The sample was well shaken and poured into the cell tube to the 10 ml mark. The cell tube was placed in the DR 500 spectrophotometer and the suspended solids present in the sample measured at the appropriate wavelength.

3.4.4 Determination of Total Hardness

Total Hardness was determined by the method of titration where 0.02 M EDTA was titrated against the 100 ml of the buffered sample using Erichrome Black T as the indicator.

100 ml of the sample was measured into a 250 ml conical flask using a measuring cylinder. 10 ml of ammonia buffer was then added solution followed by the addition of 2 drops of the Erichrome Black T indicator. The content in the flask was titrated against the EDTA solution until the solution in the flask changed from wine to purple blue at the end point. The calculation for total hardness was done using the equation below.

Titre Value = Final volume - Initial volume

Total Hardness, CaCO_3 (mg/l) = Titre Value \times 20

3.4.5 Determination of Total Alkalinity

Alkalinity was determined by the titrimetric method using 0.01 M HCl solution and methyl orange as indicator. 100 ml of the sample was measured into a 250 ml conical flask. 2 drops of methyl orange was added to the sample and titrated against the 0.01M HCl in the burette. The end point was marked by the change in colour of the sample solution from yellow to pink.

Calculation

Titre Value = Final volume - Initial volume

Alkalinity (mg/l) = Titre Value \times 20

3.4.6 Determination of Nitrate (NO_3^-) and Nitrite (NO_2^-) -N

The concentration of the nitrate was measured using the PF-11 photometer and the visocolor nitrate test kit/ reagents. Nitrate was determined in the range between 1-50 mg/l. The comparator cell (test tube) was first rinsed both with distilled water and with small portion of the sample after which it was filled with the sample to the 10 ml mark. 10 drops of the nitrate-1 reagent provided in the test kit was added to the sample and mixed followed by 1 spoonful of the nitrate-2 reagent. The resulting mixture swirled briskly for 30 seconds. After 10 min, the prepared solution containing the analyte was placed in the holder of the PF-11 meter and the nitrate content was read off when M button of the meter was pressed. This was repeated for the remaining samples.

The determination of nitrite followed the same procedure for nitrate except that 10 drops of nitrite-2 was used; while 9 mls of the sample was used instead of the 10 ml used for nitrate determination.

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

The concentration of the sulfate was measured using the PF-11 photometer. The photometer functions by placing the test tube containing the sample in the hole found in the photometer. The system reads from 20-200 mg/l. The photometer was calibrated by placing a test tube containing 10 ml of distilled water and adjusting the photometer to read 0 mg/l. 10 drops of sulphate-1 re-agent was added to the sample and swirled to mix. A spoonful of sulphate-2 reagent was then added and the resulting mixture was shaken for 30 seconds. The sample was allowed to stand for 5 minutes, before the sulphate reading was taken. The procedure was repeated for the rest of the samples.

3.4.8 Determination of Phosphate (PO_4^{3-})

This was done by using the visocolor phosphate test kit provided (Cat. No. 914223). The Kit is for the determination of phosphate content within the range of 0.02-25 mg/L. The test kit consists of 30 ml phosphate-1 reagent which contains 25% sulphuric acid and phosphate 2 reagent made up of about 25% sodium disulphide.

The reagent Phosphate-1 and Phosphate- 2 and the PF-11 photometer were used. The test tube was rinsed and filled with the sample up to the 9 ml mark. 10 drops of

Phosphate-1 was added to the sample and mixed. After 30 seconds, another 10 drops of the phosphate-2 was added and mixed. The content was allowed to stand for 5 minutes. The amount of phosphate in the sample was measured using PF-11 photometer in mg/l. The procedure was repeated for the remaining samples.

3.4.9 Chloride determination

Chloride was determined by the Silver-Argentometric method using a standard direct reading titrator. 15 ml of the sample was pipetted into a test tube and one drop of 1% of phenolphthalein indicator was added until the resulting solution turns pink. About 0.5 mls of sulfuric acid was added to the solution in the test tube in drops. After each drop, the test tube was swirled until the pink colour disappears. 3 drops of 5% potassium chromate was added again and the test tube was capped and swirled again to get a resulting yellow solution. About 2% of the silver nitrate reagent in a direct reading titrator was then added to the prepared solution in drops via the small hole at the center of the capped test tube while swirling gently. The end point is reached when the solution in the test tube changes from yellow to orange brown. The resulting chloride level in the sample in mg/l is measured from the amount of silver nitrate used in the reaction by reading directly from the titrator.

3.4.10 Free cyanide (CN⁻) determination

Six (6) ml of the decanted water sample was filled into a 10 mm cuvette and place into the fume chamber. Using the micro spoon provided in the CN kit, a spoonful each of

CN-1A and CN-2A reagent was added to each of the content of the sample in the cuvette one after the other. Three drops of CN-3A reagent was finally added and the resulting mixture was shaken gently. A period of 5 minutes is allowed, for the reaction to complete and the colour which develops is compared using the standard colour chart provided, to find the concentration of free cyanide in mg/l.

3.5 Method of determination of dissolved Arsenic (As), Iron (Fe), Copper (Cu), Lead (Pb) and Zinc (Zn)

The heavy metals; As, Fe, Cu, Pb and Zn were determined using Spectra AA220 Atomic Absorption Spectrophotometer. The series of calibration was made using distilled water as (blank) and three standard solutions containing 1 ppm, 5 ppm and 10 ppm of the target metal. The responses recorded was use to draw a calibration curve as a prelude to the actual analysis of the target metal.

100 ml of the sample was first decanted. The decanted sample containing the target metal was then atomized and its concentration was read from the results displayed on the computer screen. The procedure was repeated three times and the average reading of the target metal was taken. The lamp was then changed for the next metal to be analyzed and the same procedure was repeated.

3.6 Bacteriological Analysis

The membrane filtration was used in the determination of the Total Coliform count and fecal coliform counts.

3.6.1 Preparation of culture media for total Coliform

Four and half (4.5) g of M-ENDO AGAR LES powder was weighed into a beaker. 100 ml of distilled water was added and mixed. 10% volume of basic fusion (BR 50) was dissolved in 50 ml distilled water. 10 ml of the solution was then added to the medium and heated with frequent agitation. The medium was allowed to cool at 45° C and dispensed into Petri dishes.

3.6.2 Media preparation for faecal Coliform

Five (5.2) g of M-FC Agar powder was weighed into a beaker containing 100 ml of distilled water and mixed thoroughly. 10 ml of Rosaline acid was dissolved in 0.2 M NaOH. The solution was added to the medium. The content in the beaker was heated to boil for 1 minute. The medium was cooled at a temperature of 45°C and then dispensed into Petri dishes.

3.6.3 Procedure for bacteriological analyses

A vacuum filtration apparatus which consist of a vacuum pump connected to a vacuum flask, with the help of a clamp was set up. A pair of sterilized flat ended forceps was also provided in the set-up. Using the sterilized forceps in the water bath, a 47 mm

membrane filter of 0.45 μ m pore size was transferred from its cover onto the filter support with the grid side facing upwards. 100 ml of the water sample was poured onto the filter paper and the vacuum filtration was applied. The membrane filter was removed and placed in the Petri dish containing the MFC Agar. It was then incubated for 24 hours in an oven at 44.5°C. Feacal Coliform was detected as blue colonies on the M-FC Agar. The total number of colonies formed on each plate was then counted using a colony counter. The same procedure was repeated for Total Coliform but using the M-Endo Agar at an incubation of 39°C for 24 hours. The number of Total Coliform units which appears as dark-red colonies with a metallic (golden) sheen on the M-Endo Agar was counted.

3.7 Statistical Analysis

Descriptive statistics; minimum, maximum, mean values and standard deviation were performed using Statistix 9.0 for windows. Mean comparisons were also performed using both Statistix 9.0 for windows for significant variations and inter-element relationships at the various locations and sub –location.

CHAPTER FOUR

4.0 RESULTS

The average physical, chemical and microbiological properties of the surface and ground water samples including pH, conductivity, TDS, TSS, Alkalinity, hardness, sulphates, nitrates, metal concentrations, faecal and total Coliform for both the wet and dry season during the sampling period are presented in Fig 4.1 to Fig 4.21 alongside the Ghana EPA, 1997 and WHO, 2004 recommended limits for various parameters in portable water.

4.1 Levels of the physicochemical parameters in the Ground and Surface water sources

The mean levels of the physical and chemical parameters measured in the ground and surface water sources in the Obuasi mining area are presented below

4.1.1 pH

In general, pH levels in the surface water samples varied from 6.02 to 7.45 pH units during the wet season with a mean of 6.59 ± 0.323 pH units and from 7.03 to 8.78 pH units with an average value of 7.92 ± 0.417 pH units in the dry season as can be seen in Fig. 4.1 below.

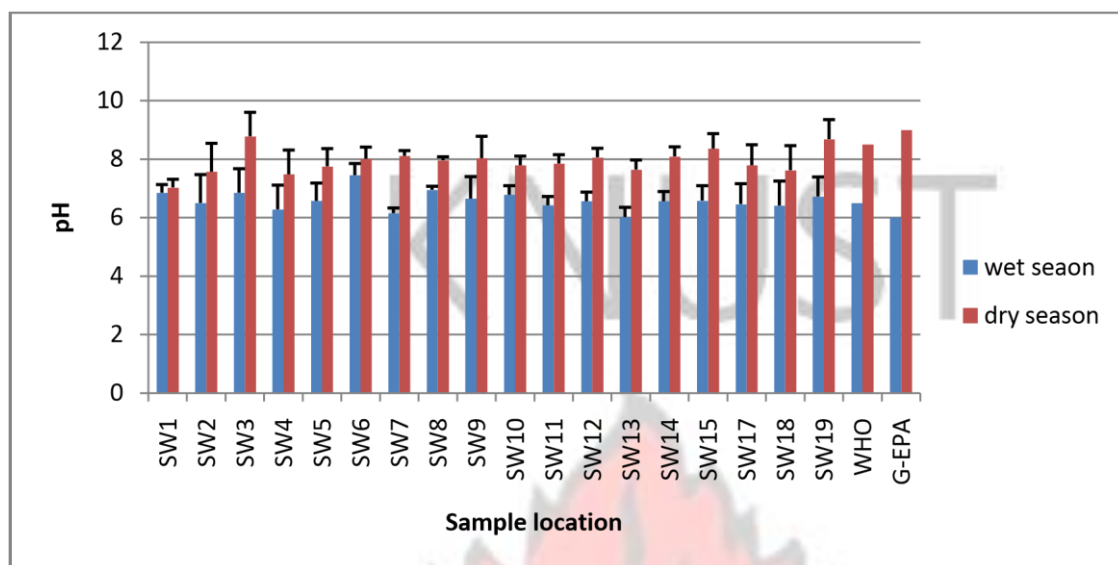


Fig 4.1 Mean levels of pH in the surface water samples

Throughout the period, the lowest pH for surface water was in SW13 during the wet season, while SW3 recorded the highest pH as in Fig. 4.1 above.

The proportion of surface water samples with pH outside the WHO, guideline value were 33.33% for the wet season and 11.11% for the dry season respectively (Fig 4.1).

For ground water, pH levels were observed from 4.91 to 6.31 units during the wet season and from 6.28 to 7.94 units in the dry season. The mean pH for all the groundwater samples during the period were 5.38 ± 0.350 and 7.21 ± 0.425 pH units for the wet and dry season respectively. The minimum groundwater pH was observed in GW14, while the maximum pH was also from GW 6 (Fig. 4.2)

The pH for groundwater samples taking in the wet season all fell below the recommended W.H.O limits except GW6 (Fig 4.2). In the dry season, all the groundwater samples had pH levels within the limit.

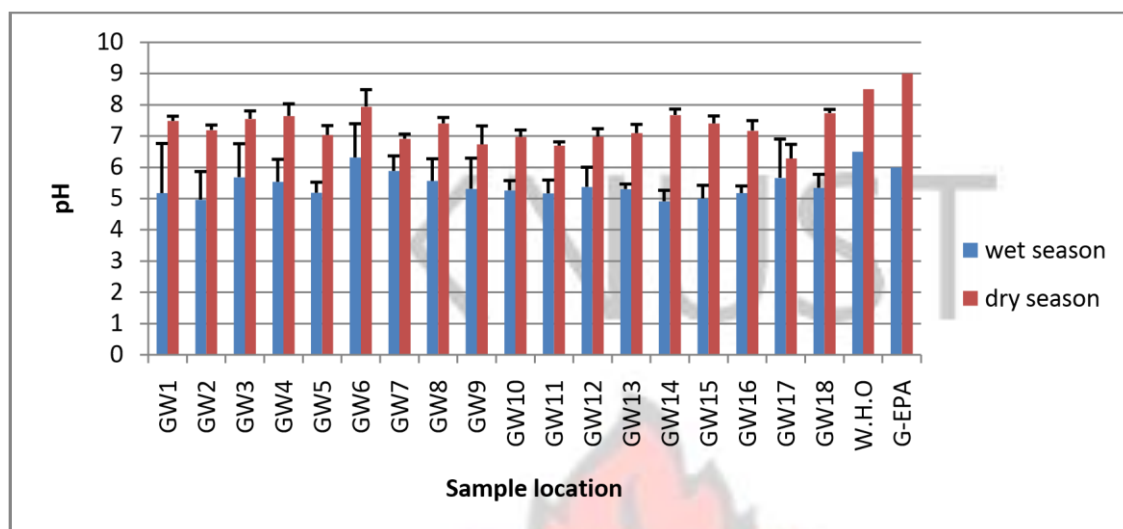


Fig 4.2 Mean levels of pH in the groundwater samples

This suggests that in the wet season, the water sources are acidic while in the dry season they become generally alkaline. Acidity problems in the groundwater samples witnessed in the wet season can be solely attributed to the oxidation of sulphide minerals present in the rock aquifer leading to acid mine drainage (Smedley, 1996; Tay, 2001). Groundwater sources are thus likely to be rejected by the average consumer on the basis of taste problems due to their acidic nature.

The mean pH of the surface water samples (6.59 pH unit) was significantly higher than the average ground water pH (5.38 pH unit) at $p=0.000$. Seasonal variation in pH was also very significant with fig. 4.1 and 4.2 depicting, lower pH values for both the ground and surface water samples compared to the higher pH levels in the dry season.

The average pH of all surface and ground water sources sampled close to the mines were not significantly different from the mean pH for samples collected outside the mines; [(6.57 pH unit against 6.63 pH unit for surface water in the wet season at ($p=$

0.73) and (5.26 pH unit against 5.49 pH unit for groundwater, wet season at (p=0.188)].

4.1.2 Conductivity levels in the Surface and Ground water samples

Conductivity is a direct measure of the ability of an aqueous solution to conduct current. It depends on the amount of dissolved ionic contaminants in the water. It can therefore give a fair indication of the extent of chemical pollution in a water body.

Generally, Conductivity levels in surface water samples varied between 48.99-1141.9 $\mu\text{S/cm}$ with a mean of 439.4 ± 410.84 $\mu\text{S/cm}$ and from 543.83-1731.3 $\mu\text{S/cm}$ with a mean of 556.58 ± 543.83 $\mu\text{S/cm}$ during the wet and dry season respectively. However, lower values were observed in the ground water samples and varied between 34.46 742.11 $\mu\text{S/cm}$ with a mean of 186.62 ± 188.00 $\mu\text{S/cm}$ in the wet season and from 35.54–1016.1 $\mu\text{S/cm}$ with a mean of 254.66 ± 254.80 $\mu\text{S/cm}$ in the dry season (Fig. 4.3 & 4.4). The highest conductivity was from samples such as SW15, GW14 and GW15 (Fig. 4.3 & 4.4).

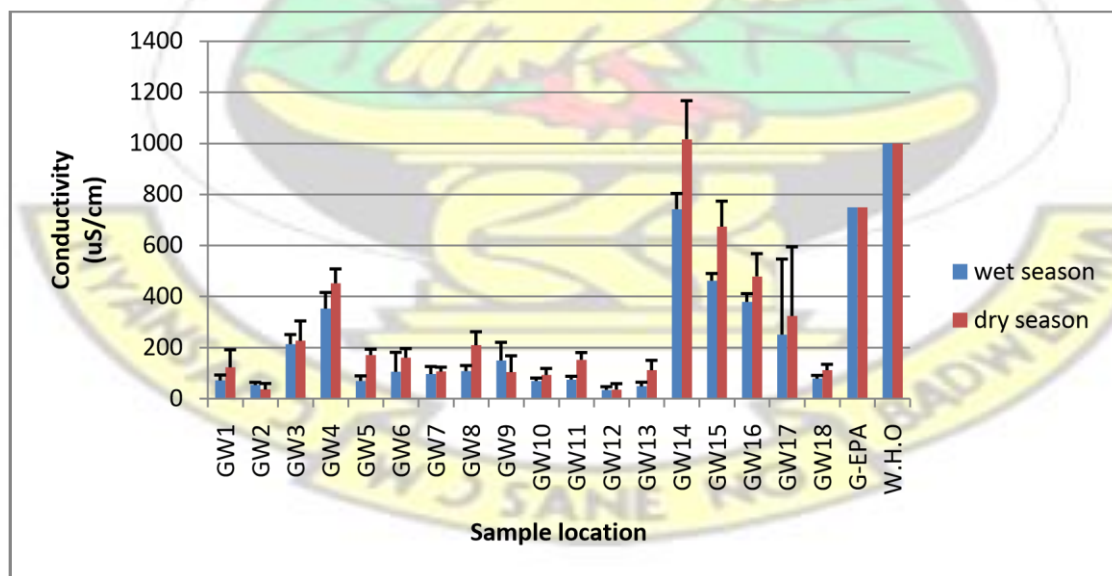


Fig. 4.3 Mean Conductivity levels in the groundwater samples.

Surface water Conductivity levels were generally higher than groundwater conductivity levels during the period of study viz; [(439.94 $\mu\text{S}/\text{cm}$ against 186.62 $\mu\text{S}/\text{cm}$ at $p=0.023$ for the wet season), (556.58 $\mu\text{S}/\text{cm}$ against 254.66 $\mu\text{S}/\text{cm}$ at $p=0.040$ for the dry season).

Seasonally, higher Conductivity levels in both water samples were more noticeable during the dry season compared to the wet season but this was not significant at $p<0.05$.

The conductivity levels in surface water samples close to the mines were generally high and varied from 242 to 1141.9 $\mu\text{S}/\text{cm}$ with a mean of $733.55 \pm 382.77 \mu\text{S}/\text{cm}$ during the wet season. For the surface water samples outside the mines, lower Conductivity levels were observed from 48.99 – 689.00 $\mu\text{S}/\text{cm}$ with a mean value of $168.55 \pm 204.65 \mu\text{S}/\text{cm}$ (Fig. 4.4).

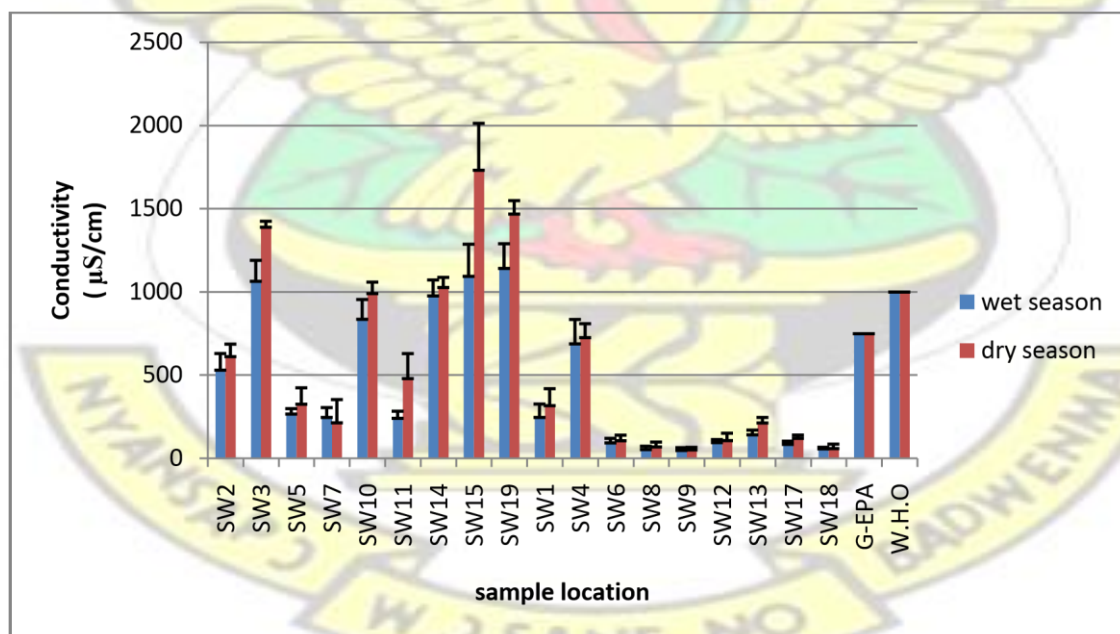


Fig. 4.4 Mean Conductivity levels in the surface water samples within the mine

(SW2 to SW19) and outside the mine (SW1 to SW18)

In the dry season, the surface water samples close to the mines recorded Conductivity levels ranging from 215.03-1731.3 with a mean value of $915.77 \pm 539.99 \mu\text{S/cm}$. Surface water samples outside the mines also recorded Conductivities' between 52.30-726.33 $\mu\text{S/cm}$ with an average value of $197.39 \pm 215.84 \mu\text{S/cm}$ (Fig 4.4).

This generally suggest significantly higher Conductivities for Streams near the mines compared to Streams at the extreme of the mines; [(711.33 $\mu\text{S/cm}$ against 168.55 $\mu\text{S/cm}$ in the wet season, $p=0.002$) and (915.8 $\mu\text{S/cm}$ against 197.4 $\mu\text{S/cm}$) in the dry season at $p= 0.002$).

Moreover, a higher proportion of the surface water samples taking close to the mines (55.56 %) had conductivity levels in excess of the Ghana EPA, 1997 guideline value of 750 $\mu\text{S/cm}$. In contrast, none of the surface water samples taking outside the general mining concession had conductivities above the Ghana EPA Permissible limit (Fig. 4.4).

On this basis, we conclude that the higher conductivity levels, in streams serving the mining regions compared to those outside the mines is introduced from the mining and other ancillary activities in the area.

However, for the ground water samples, no significant differences were observed between the mean conductivity of samples collected close to mining region compared to those outside the mines.

4.1.3. TDS levels in the water samples

TDS levels observed for the samples were similar to that for Conductivity. The amount of Total Dissolved Solids in the water samples during the period generally varied from 28.07 to 785.33 mg/l with a mean value of 271.55 ± 274.29 mg/l for the Surface water samples (fig 4.5) and from 17.91 to 426.06 mg/l with a mean value of 108.25 ± 117.23 mg/l for the groundwater samples during the wet season (Fig. 4.6).

In the dry season, surface and the groundwater samples exhibited higher TDS. This was from 30.57-1102.3 mg/l with a mean value of 362.94 ± 371.04 mg/l and $24.38661.67$ mg/l with a mean value of 158.44 ± 161.90 mg/l respectively (Fig. 4.5 & 4.6).

Similarly, Fig. 4.5 below also depicts TDS variations between, 129.43-785.33 mg/l for the surface water samples taking close to the mines compared to the samples outside the mines (28.07 - 352 mg/l) for the wet season.

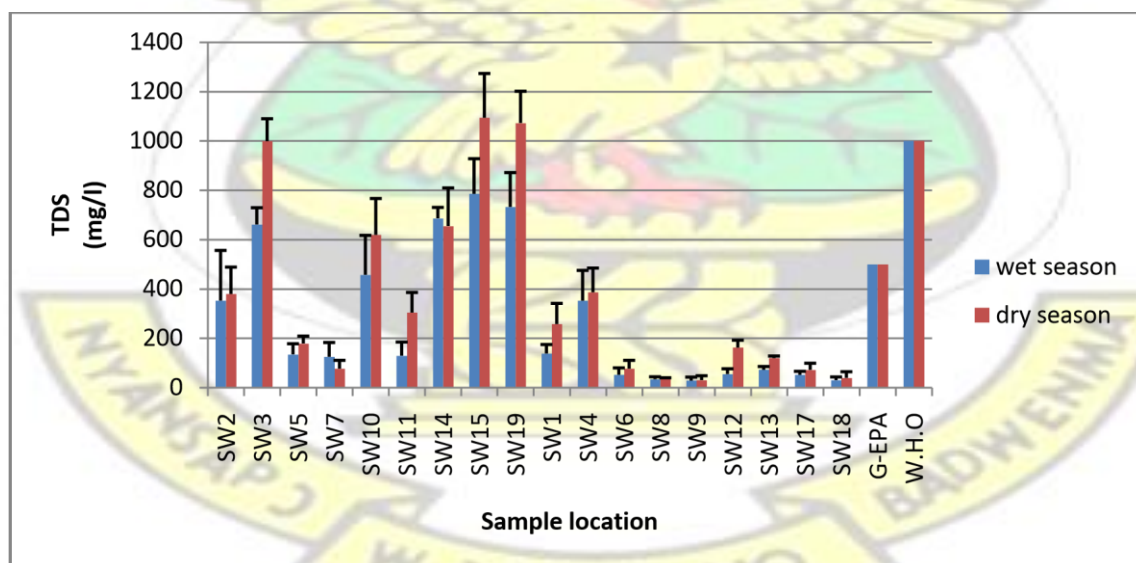


Fig 4.5 TDS levels in surface water samples close to the mines (SW2 to SW19) vrs outside the mines (SW1 to SW18)

In the drier periods of sampling, the surface water samples outside the mining region exhibited TDS concentrations varying from 30.57 to 386.40 mg/l which was lower than that recorded for the surface water sample taking close to the mines (Fig. 4.5).

The average groundwater TDS for samples close to the mines was significantly greater than that for samples outside the mine concession: (452.8 mg/l versus 90.34 mg/l, $p=0.019$; wet season and (605.30 mg/l versus 120.50 mg/l at $p=0.022$), dry season.

The result of the study suggest that the mean TDS levels for the surface water was statistically higher than the average groundwater TDS; [(271.55mg/l vs. 108.25mg/l at $p=0.026$ for the wet season) and (362.94 mg/l versus 158.44mg/l at $p=0.039$ for the dry season).

The slight Seasonal variations in TDS levels as depicted by Fig 4.5 and 4.6 was however not significant. [(271.55 mg/l versus 362.94 mg/l at $p=0.407$ for surface water) and (108.25 mg/l against 158.44 mg/l and at $p=0.294$) for groundwater)]. This suggests that the impact of rainfall on TDS levels on both water sources during the period of study was minimal within the Obuasi gold belt.

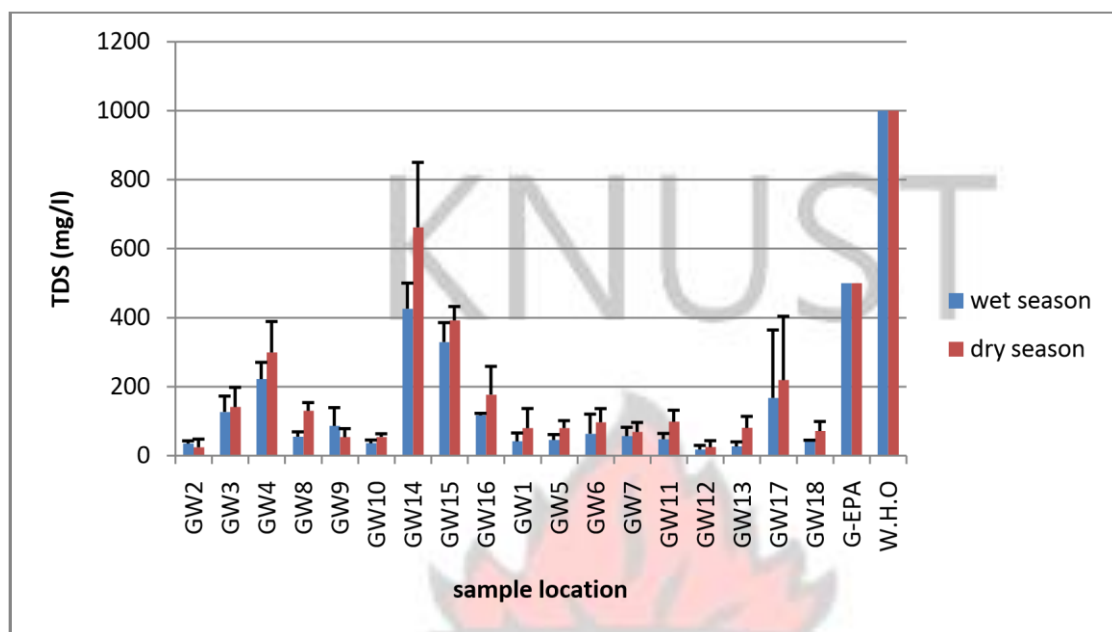


Fig 4.6 Mean TDS levels in the groundwater samples within the mines (GW2 to GW16) versus outside the mines (GW1 to GW18)

SW9 and GW12 which were samples outside the mines recorded the lowest TDS. However, samples such as SW15, SW19 and GW14 found close to the Kwabrafoso mining zone had the highest TDS (Fig. 4.5 & 4.6) and were in excess of the WHO 1000 mg/l threshold. This means most ground and surface water sources in the Obuasi gold mining area will be suitable for use as domestic water sources. The high TDS recorded in SW14 and 15, (Kwabrafoso River), in Fig. 4.5, may be due to their proximity to illegal mining as well as mine processing and tailing facilities.

4.1.4. TSS

The amount of TSS detected in all the surface water samples varied from 12.33 to 132.33 mg/l with a mean of 40.19 ± 32.06 mg/l during the wet season and from 6.33 to 555.0 mg/l with a mean of 62.44 ± 124.55 mg/l in the dry season. Ground water recorded

lower TSS levels which were from 9.33 to 82.67 mg/l with a mean of 26.86 ± 16.51 mg/l in the wet season and from 12.00 to 35.00 mg/l with a mean of 25.33 ± 7.28 mg/l in the dry season.

The lowest TSS levels recorded in the surface water sample were from SW13 during the dry season while the maximum TSS was from SW14 at Kwabrafosu. In contrast, the lowest TSS for the groundwater samples was found in GW16 sampled at Aboagyekrom outside the mines while the highest level of suspended solids (TSS) was also obtained from GW3 near Sansu close to the mining zone during the wet period.

Again, comparing our results with the standard levels of suspended solids allowable in portable drinking water, it was discovered that, only 16.67 percent of all surface water samples had TSS levels in excess of the WHO guideline value of 50 mg/l.

However, most groundwater samples TSS levels were within recommended WHO threshold except GW3 for which higher TSS (82.67 mg/l) was recorded above the limit. This suggests that groundwater sources in the Obuasi area can be used for domestic purposes without any need for filtration.

In terms of the location of the water sample, more surface water samples within the mines (44.44%) recorded TSS levels above the 50 mg/l limit set by the Ghana EPA, 1997. However, none of the samples outside the general mining region exceeded the Ghana EPA limit

In conclusion, our findings show that the variation in TSS due to change in season, location and change in water source from surface to ground were not well defined and were found to be insignificant.

4.1.5. Levels of Total Alkalinity observed in the water samples

Alkalinity levels observed in the surface water samples during the period were in the ranges of 32.67- 181.0 ppm with a mean value of 76.96 ± 38.56 ppm and from 50.02-84.10 ppm with a mean value of 155.98 ± 74.18 ppm for the wet and dry periods respectively.

For the groundwater samples, alkalinity levels recorded varied from 14.33-119.0 ppm with a mean value of 57.19 ± 35.55 ppm during the wet season and from 27.0- 200.0 ppm with a mean value of 112.91 ± 61.45 ppm in the drier period. The highest alkalinity which was witnessed in the dry season was from SW15 in the Kwabrafosso zone while the lowest alkalinity was also recorded in GW2 within the Sansu zone.

Significant differences were also found between the following alkalinity means for water samples close to the mines as against samples outside the general mine: (102.3 ppm versus 51.64 ppm at $p= 0.0021$ for surface water samples in the wet season and 80.03 ppm versus 34.36 ppm at $p=0.004$ for the groundwater samples in the wet season as well as 148.0 ppm for the groundwater samples within the mine compared with the mean alkalinity of 83.7 ppm for samples outside the mine, dry season, $p= 0.021$)

4.1.6. Total Hardness levels in the Water Samples

Total Hardness levels in surface water in the Obuasi gold-belt during this study varied from 24.0-554.67 mg/l with a mean of 169.16 ± 168.70 mg/l for the wet season and from 56.00-896.04 mg/l with a mean value of 278.99 ± 240.07 mg/l for the dry season

as seen in Fig. 4.7 below. The seasonal difference between the mean hardness in the surface water samples from wet to dry season was however not significant at ($P=0.121$; 169.16 mg/l against 278.99 mg/l),

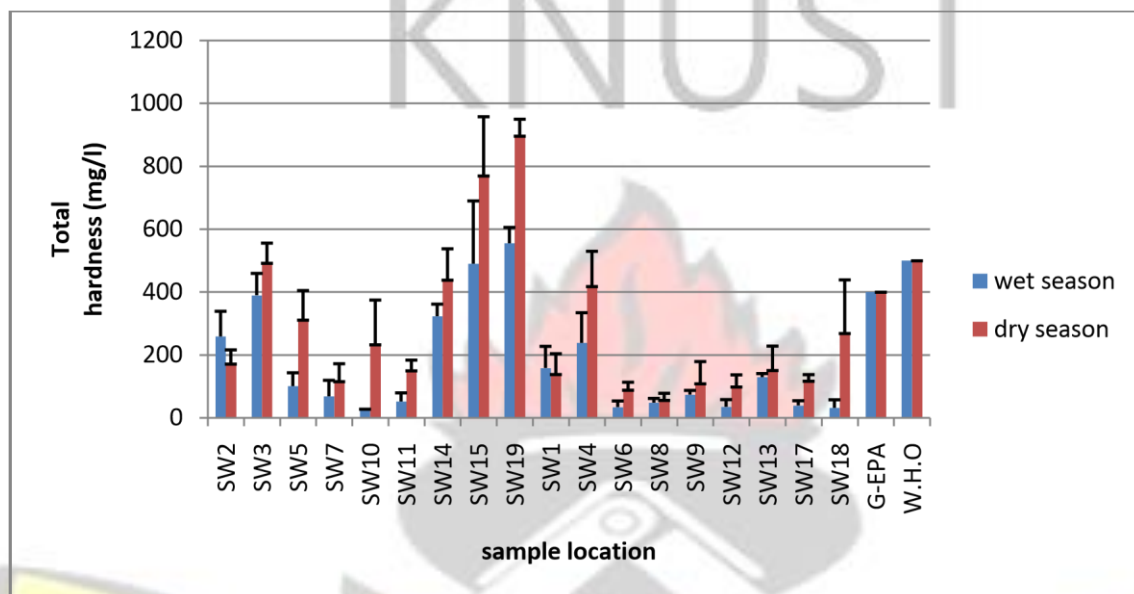


Fig 4.7 Mean levels of Total hardness in surface water samples within (SW2-SW19) and outside the mines (SW1-18)

Total hardness levels for the surface water samples close to the mines, varied between 24.0-554.67 mg/l with a mean value of 251.01 ± 200.27 mg/l compared to samples taking outside the mining zone, which recorded values between 31.33-238.0 mg/l with a mean value of 87.30 ± 72.73 mg/l during the wet season. In the dry season, the surface water samples, close to the mines exhibited total hardness levels between 115.67 to 896.04 mg/l compared to the samples outside the mining region (56.00 to 418 mg/l), (Fig. 4.7).

The difference in the mean hardness levels between the two locations of the surface water; water samples within the mines (251.01 mg/l) and surface water samples outside the mines (87.30 mg/l) during the wet period was significant at $p=0.035$.

Similarly, the average hardness of all the surface water samples within the mines (397.5 mg/l) and those outside the mines (160.5 mg/l) was also significant for the dry period of sampling at $p=0.032$. Also 22.22% of surface water samples close to the mines had hardness levels above the 400 mg/l limit of the Ghana EPA as opposed to 0 % for the samples outside the mines.

From Fig 4.7, the highest hardness levels were all from SW3, SW14, SW15 and SW19. These were samples taking immediate downstream of the STP and PTP at the Sansu and Kwabrafosso mining zone respectively.

As expected, the level of total hardness recorded in these stream samples were above the WHO, 2004 and the Ghana EPA, 1997 general guideline value of 400-500 mg/l (CaCO_3). On this basis, these water sources are unsuitable for domestic use especially for laundry purposes. The high hardness recorded in these surface water samples attest to the complaints given by the local dwellers concerning the inability of their stream water sources to foam or lather adequately with soap.

Similarly, for the groundwater samples, levels of total hardness varied between 14.33 mg/l to 283.33 mg/l in the wet season and from 80.33 mg/l to 470 mg/l in the dry season. The mean hardness of all the Groundwater samples in the dry season (169.62 mg/l) was very significantly greater than that recorded in the wet season (69.74 mg/l) at $p=0.001$.

For the groundwater samples within the mines, hardness levels also varied from 22.0-

283.33 mg/l with a mean of 98.07 ± 86.47 mg/l in the wet season and from 81.00470.0 mg/l with a mean value of 209.89 ± 136.75 mg/l in the dry season. However, for samples collected outside the mines, values obtained were between 14.33-70.33 mg/l with a mean value of 35.41 ± 18.19 mg/l and from 80.33-185.82 mg/l with a mean value of 119.01 ± 31.30 mg/l during the wet and dry season respectively

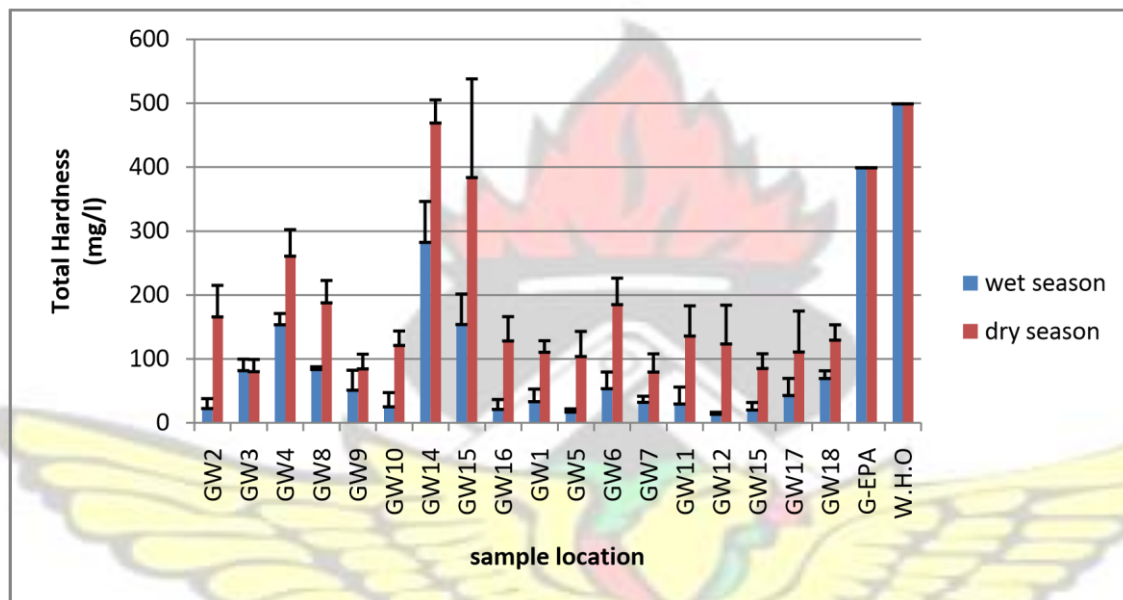


Fig 4.8 Mean levels of Total hardness in ground water samples within (GW2 to GW16) and outside the mines (GW1 to GW18)

From Fig 4.8, the highest hardness levels were all from the well samples GW14 and GW15 close to the abandoned tailing dam at Kwabrafoso. The result of this study also suggest that the mean hardness in the ground water samples from the mining zone were significantly greater than that recorded in the groundwater samples outside the mining zone; (104.07 mg/l against 35.41 mg/l at $p=0.027$, during the wet season and 220.2 mg/l against 119.0 mg/l at $p=0.041$, in the dry season).

As seen from fig 4.8, the hardness levels in groundwater were moderate compared to surface water (Fig 4.7) and were all well below the WHO, 2004 limit except GW14 which recorded average hardness levels exceeding the Ghana EPA, 1997 limit of 400 mg/l for drinking water. Higher hardness level observed in GW14 may probably emanate from contaminant influx from the tailing dam at Pompora because of its proximity to the dam.

4.1.7 Chlorides

Chlorides (Cl⁻) currently do not have a health-based guideline, but may cause taste problems, if found at high levels. The WHO, 2004 suggests that, Chloride levels above 250 mg/l will make a portable water source increasingly unpalatable while causing appreciable corrosion in cooking hardware.

Chloride concentration in surface water sources varied from 0.8 to 48.67 mg/l during the wet season with a mean value of 23.93 ± 15.62 mg/l, and from 0.8 to 48.45 mg/l with a mean value of 12.27 ± 13.69 mg/l during the dry season.

This suggests that chloride levels in the surface water samples depend on season. The average chloride difference between the season (23.93 mg/l; wet season versus 12.27 mg/l; dry season) was significant at $p= 0.023$).

On the other hand, Chloride concentration observed in groundwater were extremely lower and were in the range of 8.67 to 42.0 mg/l with a mean value of 17.06 ± 11.16 mg/l during the wet season. In the dry season, Chloride levels decreased significantly and varied between 0.20 to 8.67 mg/l with a mean value of 2.15 ± 2.29 mg/l.

However, in all, chloride levels observed in this study were found at very low concentrations below the 250 mg/l taste threshold. It will therefore present no serious problem to the use of the water samples for domestic purposes.

4.1.8 Levels of Nitrate and Nitrite-Nitrogen and Phosphates

Nitrate and nitrite pollution was a common problem for groundwater sources than for surface water sources in the Obuasi area during the period of study.

Nitrate levels varied between 0.014 to 4.80 mg/l with a mean value of 1.44 ± 1.38 mg/l for the surface water samples and from 0.30 to 19.30 mg/l with a mean value of 2.24 ± 4.33 mg/l for groundwater samples for the rainy periods. In the dry season, nitrate concentration of both surface and ground water samples increased significantly and recorded values from 1.32 to 11.63 mg/l with a mean value of 5.83 ± 2.78 mg/l and 3.75 to 31.33 mg/l with a mean value of 8.97 ± 7.01 mg/l for surface and groundwater samples respectively.

Nitrate levels recorded for both surface and groundwater samples within the mine region were similar to that observed for the samples taking outside the mines. No significant difference was observed in this respect. However, Nitrate levels were abnormally high for samples such as GW11, GW12, GW13 and GW14.

Concentrations of nitrite in the surface and ground water samples varied from 0.003 to 0.10 mg/l and from 0.006 to 32.33 mg/l respectively in the wet season. In the dry season, it varied from 0.01- 0.097 mg/l with a mean of 0.032 ± 0.023 mg/l for the surface water samples and from 0.01 to 37.67 mg/L with a mean of 2.31 ± 8.86 mg/l for the

groundwater samples. GW11 sampled at Hia recorded the highest nitrate concentration of 37.67 mg/l and may thus present a significant health risk to the users. It can cause methaemoglobinaemia or blue baby syndrome in pregnant women and infants who use the water for drinking and other domestic purposes. Methaemoglobinaemia (blue-baby syndrome), is a disease condition which limits the ability of the blood to transport oxygen to the cells of the body. At higher concentrations, excess nitrate and nitrites in drinking water can also cause cyanosis, asphyxia and even death (Weier *et al.*, 1994). On this basis, ground water samples such as GW11, GW12, GW13, GW14 and GW17 will be unfit for use as portable water.

Nitrate contamination in the groundwater water samples can be mainly attributed to seepages from pit latrines which are common in rural communities in the area. These wells should therefore be avoided in order to safeguard public health. Moreover, the construction of pit latrines close to some of these groundwater sources should be discouraged.

4.1.9 Sulphates levels in the Water Sample

The presence of sulphates in the water samples especially in the streams in the area may emanate from a variety of sources; from natural to anthropogenic.

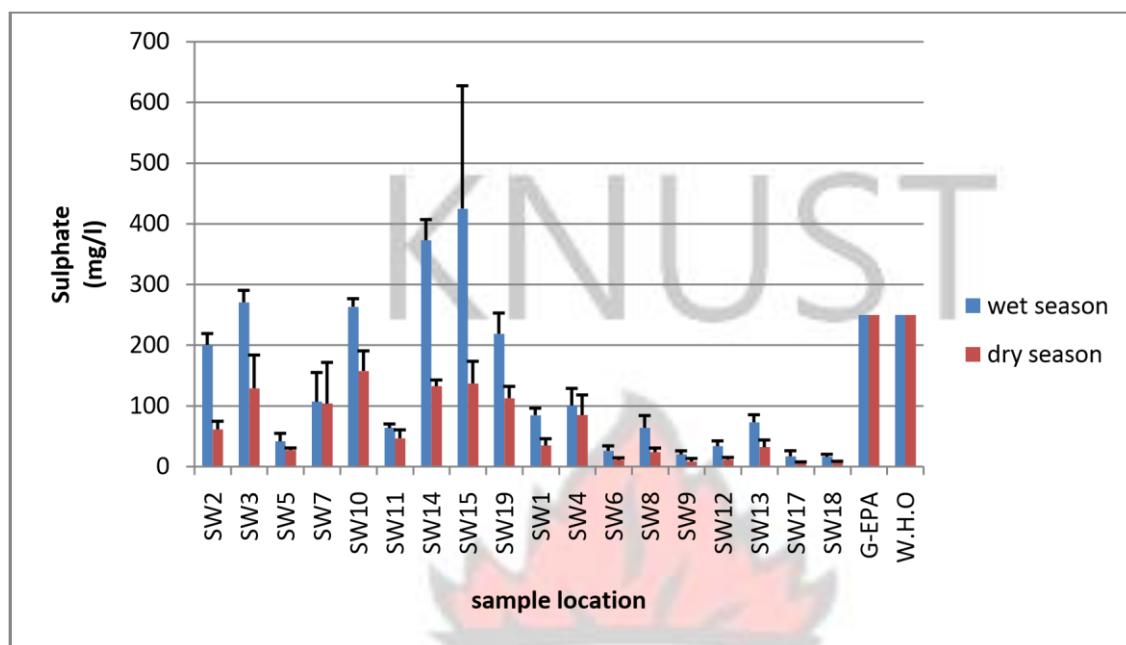


Fig. 4.9 Mean sulphate concentration in surface water samples within the mines (SW2-19) and outside the mines (SW1-18)

As can be seen in Fig 4.9 above, sulphate levels recorded in surface water samples varied from 16.33 to 425.00 mg/l during the wet season with a mean value of 127.74 ± 118.56 mg/l. In the dry season, there was a drastic drop in sulphate levels from 6.17 to 157.64 mg/l with a mean value of 62.71 ± 53.02 mg/l.

Throughout the period, the lowest sulphate level for surface water was from SW9 which is from the dokyiwaa area and which falls outside the mine, while the highest value was obtained from SW15 at Kwabrafosso close to the PTP and abandoned tailing dam during the wet season.

Sulphate ions are particularly released in the oxidation of sulphide to release gold and also from the bio-oxidation of pyrites or Arsenopyrite using bacteria (Penn, 1999). It

may also be produced from acid mine drainage from abandoned tailings and surface mines in the area (Appelo & Postma 1999, Smedley, 1996).

Again, the concentration of sulphates present in the surface water samples close to the mines, varied from 41.6- 425.0 mg/l with a mean value of 218.9 ± 131.94 mg/l as compared to samples taking outside the mining zone, which were between 16.33- 100.80 mg/l with a mean value of 48.39 ± 32.50 mg/l during the wet season (Fig. 4.9).

In the dry season, the surface water samples, close to the mines exhibited concentrations of sulphates varying from 27.33 to 157.64 mg/l with a mean value of 100.94 ± 45.27 mg/l compared to the surface water samples outside the mining region which varied from 6.17 to 85.0 mg/l with a mean value of 24.47 ± 25.14 mg/l, (Fig 4.9).

The results above also suggest that, the average sulphate concentrations for the surface water samples which drain the mining region (218.9 mg/l) was about 5 times the average sulphate concentrations for the samples outside the general mining region (48.39 mg/l) in the wet season. Similarly, the difference between the two sulphate means (218.9 mg/l and 48.39 mg/l) was found to be very significant at $p= 0.002$.

At the same time, from Fig 4.9, 4 out of 9 (44.4%) surface water samples taken from the mines had sulphate levels above the W.H.O guideline value of 250 mg/l; but none of the samples taken outside the mine confluence outwitted the WHO thresholds for sulphate. Higher Sulphate levels for stream water samples such as SW2, SW3, SW4, SW7, SW10, SW14, and GW4 can be linked to factors such as mine drainage problems in the area (Asklund & Eldvall, 2005, Penn, 1999; Akabzaa, 2004).

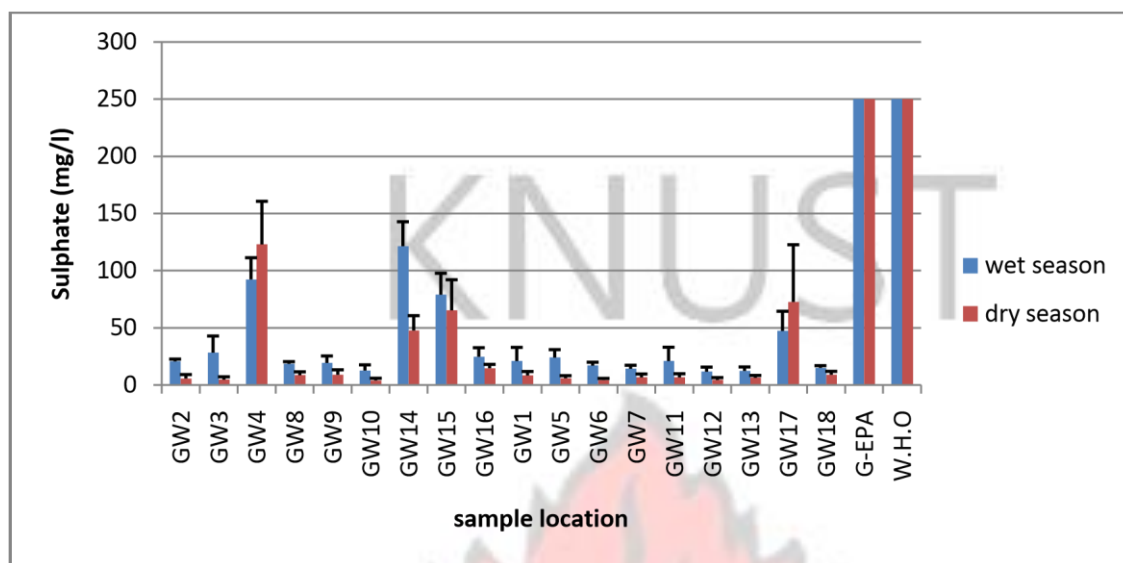


Fig. 4.10 Mean sulphate levels in the groundwater samples within (GW2 to GW16) and outside the mines (GW1 to GW18)

Sulphate concentrations obtained in groundwater was rather lower and varied from 11.67 to 121.40 mg/l for the wet season and from 4.0 to 123.0 mg/l for the dry season (fig 4.10). The mean levels of sulphates in groundwater for the wet season and for the dry season were 34.47 mg/l and 22.62 mg/l respectively.

Sulphate levels in all the ground water samples were however found to be below the 250mg/l threshold set by the WHO, 2004 and Ghana, EPA, 1997 as seen in Fig 4.10. Groundwater samples in the Obuasi mining area will thus be suitable for various domestic uses without any anticipated effects. The minimum groundwater concentration was also found from GW13 as compared to the maximum concentration which was found in GW4 near the Anyinam underground mine (Fig. 4.10 & 3.2).

Seasonal variations in sulphate level were also more evident in the surface water samples (Fig. 4.9 and 4.10). The average sulphate level in surface water for wet season

(127.7 mg/l) was significantly greater than that recorded for the dry period (62.70 mg/l) at $p=0.041$.

4.1.10 Levels of Free Cyanide in the Water samples at Obuasi.

From our results, all the surface and groundwater bodies sampled had free cyanide values less than the WHO permissible levels of 0.01 mg/l allowed in portable water. This was also less than 0.1 mg/l threshold set by the Ghana EPA, 1997 guideline and will thus present no significant risk to the users in the area.

4.2 Levels of dissolved As, Fe, Pb, Cu, Zn and Cd in the ground and surface water samples

Levels of dissolved metals such as As, Fe, Pb, Cu, Zn and Cd generally varied from below detection limits (0.004) to levels above the W.H.O 2004 thresholds for portable water. These are presented below.

4.2.1 Levels of dissolved Arsenic (As) in the Water Samples

In general, dissolved arsenic levels in surface water ranged from 0.004-1.595 with a mean value of 0.407 ± 0.489 mg/l in the wet season and from 0.004-1.470 mg/l with a mean value of 0.277 ± 0.461 mg/l in the dry season. The highest arsenic levels for surface water sources found during the period was from SW15 in the wet season and SW4 in the dry season (Fig. 4.11). These were also samples from streams that directly drain the Kwabrafoso mining confluence (Fig. 3.2).

Similarly, in the mining region, surface water samples recorded dissolved arsenic levels varying from 0.112-1.595 mg/l with a mean value of 0.560 ± 0.568 mg/l in the wet season and 0.008-1.126 mg/l with a mean value of 0.352 ± 0.457 mg/l in the dry season

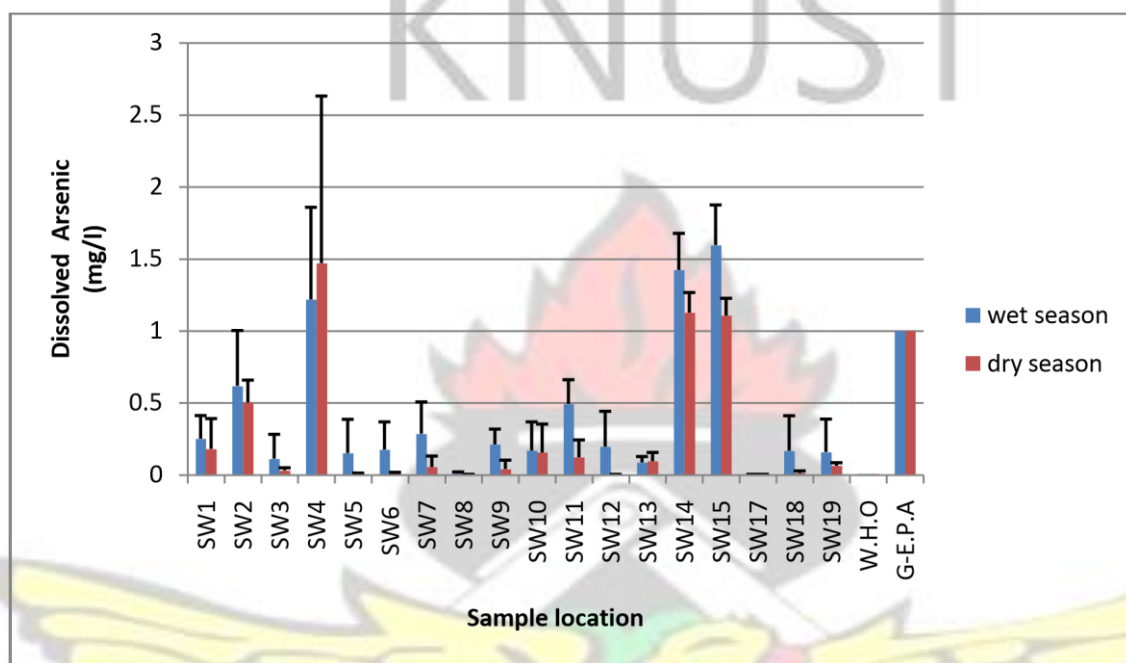


Fig 4.11 Arsenic levels in surface water samples

This was higher but not significant at ($p < 0.05$) compared to values recorded for samples outside the mining region which ranged from 0.004-1.218 mg/l with a mean value of 0.258 ± 0.307 mg/l during the wet season and from 0.004-1.47 mg/l with a mean value of 0.203 ± 0.479 mg/l in the dry season respectively (Fig 4.12).

Moreover as can be seen in Fig. 4.12 below, while 2 out of the 9 surface water samples close to the mines had arsenic levels above the Ghana EPA limit of 1.0 mg/l, all surface water samples outside the mines had arsenic levels well below this limit.

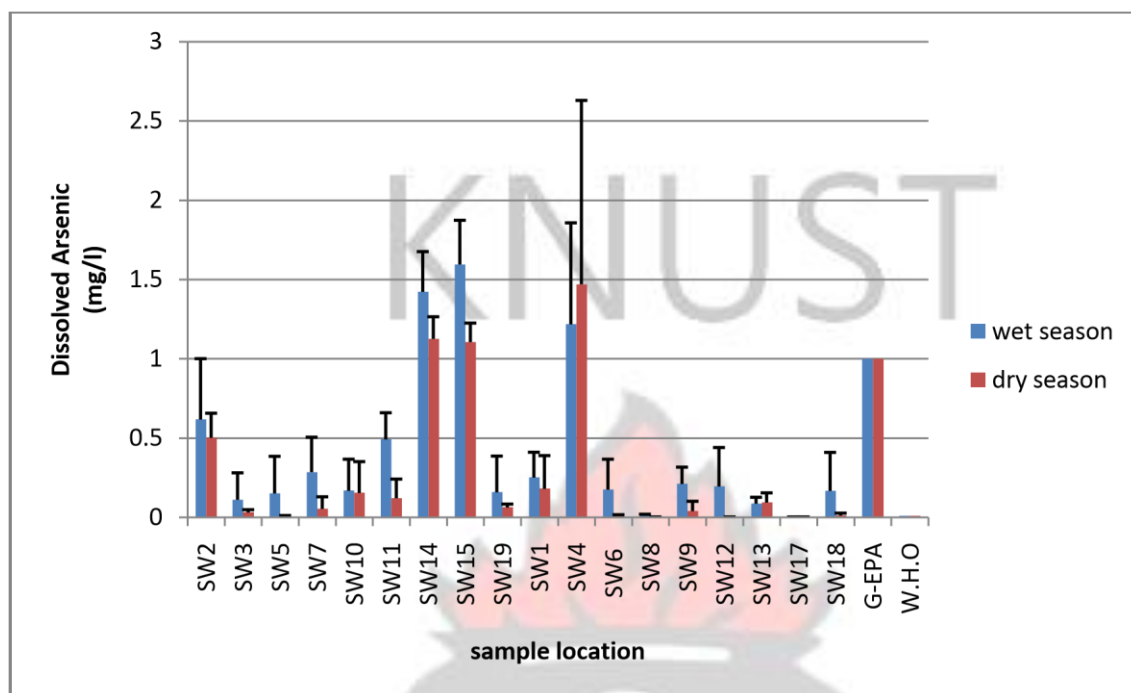


Fig 4.12 Mean dissolved arsenic in surface water within (SW2-SW19) and outside the mines (SW1-SW18)

Lower arsenic levels were however detected in groundwater and varied from 0.004 - 0.297 mg/l with a mean value of 0.101 ± 0.281 mg/l and from 0.04 - 0.112 mg/l with a mean value of 0.019 ± 0.034 mg/l for the wet and dry season respectively (Fig 4.13).

Negligible arsenic levels well, below the WHO recommended levels were detected in GW10, GW16, GW5, GW12, GW13 and GW18. These represented samples outside the mining zone. Conversely samples such as GW2, GW3, GW4, GW8, GW14, GW15 (samples within the mining zone) and GW6, GW7 (samples outside the mining zone) had arsenic levels well above the WHO threshold and will thus pose tremendous risk to the users (Fig 4.13).

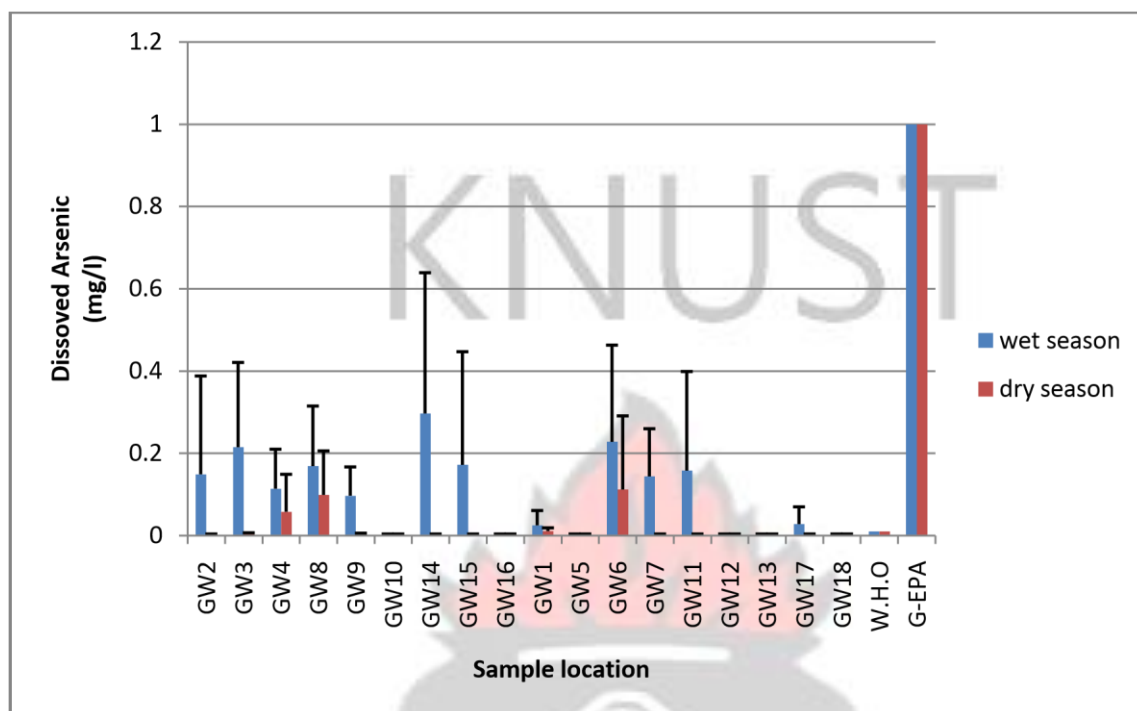


Fig 4.13 Mean dissolved arsenic levels in groundwater samples within the mines

(GW2 to GW16) compared to samples outside the mine (GW1 to GW18) While many groundwater samples had arsenic levels above the WHO 0.01 mg/l health guideline threshold, the average arsenic levels for the ground water samples taking within the mining area was statistically insignificant from that recorded for ground water samples outside the general mine region; 0.138 mg/l versus 0.067 mg/l at $p < 0.05$, wet season and 0.021 mg/l versus 0.017 mg/l at $p < 0.05$, dry season.

Also, dissolved arsenic concentrations in surface water were significantly higher than arsenic levels in groundwater at all locations and throughout the season. This may suggest that surface water sources in the area are more prone to arsenic pollution problems due to mining activities compared to groundwater.

4.2.2 Levels of dissolved Iron (Fe) in the surface and groundwater Samples

Iron is one of the few elements which are naturally present in the environment. Its presence

in drinking water is perceived to be safe except that at concentrations above the WHO limit of 0.3 mg/l, it can discolor the water sources and cause taste problems.

Out of the total samples, 55.6% of the surface water samples recorded values higher than the WHO aesthetic limit (0.3 mg/l) during the wet season. On the other hand, only 11.11% of groundwater samples were above the WHO aesthetic limit for iron during the wet season (Fig. 4.14 &15).

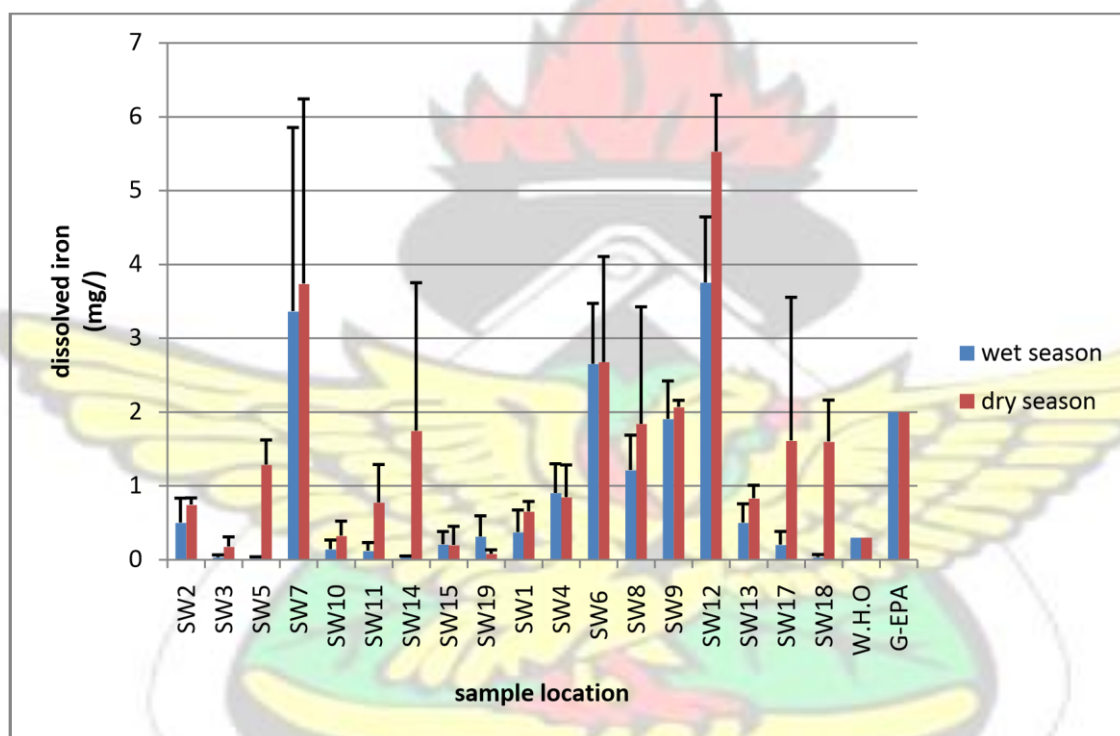


Fig. 4.14 Mean Levels of dissolved Iron in the surface water sample close to the mines (SW2 to SW19) and outside the mine (SW1 to SW18)

This may suggest that surface waters in the area are more enriched in natural iron content than groundwater. The highest iron level was observed in SW12 near Hia, which has a myriad of galamsey activities along the banks of the Fena River. The extremely high

iron content in the river can therefore be due to direct dissolution and erosion of iron minerals from the disturbed soil around the river.

The average iron concentration for surface water samples taking close to the mines (SW2 to SW 19) varied between 0.019-3.363 mg/l and recorded a mean value of 0.556 ± 0.568 mg/l in the wet season. This was lower compared to samples outside the mines (SW1-SW18) which recorded values between 0.031- 3.750 mg/l with a mean value of 1.279 ± 1.259 mg/l (Fig. 4.14). Similarly, in the dry season, levels of dissolved iron observed, also varied from 0.076-3.736 mg/l with a mean value of 1.0058 ± 1.166 mg/l for the samples within the mines in contrast to 0.65-5.526 mg/l and a mean value of 1.959 ± 1.489 mg/l for surface water samples outside the mines during the period (Fig 4.14).

Like arsenic, lower dissolved iron levels were recorded in the groundwater samples and varied from 0.004-0.090 mg/l with a mean value of 0.029 ± 0.028 mg/l for wet season and from 0.021-0.423 mg/l with a mean value 0.119 ± 0.127 mg/l in the dry season for the samples close to the mines. Groundwater samples taking outside the mines also recorded dissolved iron concentrations from 0.004-1.194 mg/l with a mean value of 0.194 ± 0.389 mg/l in the wet season and from 0.019-2.146 mg/l with a mean value of 0.362 ± 0.695 mg/l in the dry season (Fig 4.15)

From Fig. 4.15, the maximum dissolved Fe was from GW5. GW5 is located at Fenaaso and is far from the Sansu mining center. The high Iron content recorded in the sample can therefore be solely attributed to iron enrichment from natural sources.

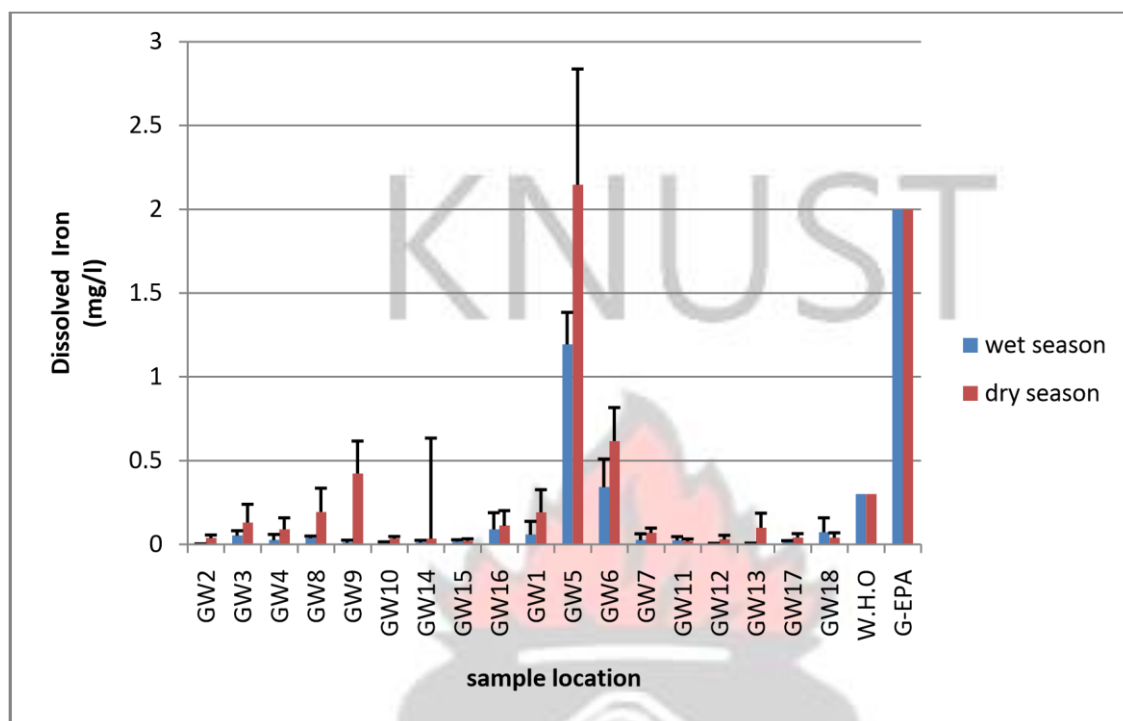


Fig 4.15 Mean dissolved Iron levels in the ground water samples within the mines (GW2-GW16) compared to samples outside the mines (GW1-GW18)

Iron levels in the water samples from this study, when compared with WHO, 2004 general guideline value of 0.3 mg/l reveals that, about 66.67 percent of all surface water and 33.33% of all the groundwater samples were in excess of the limit.

This may be the reason for the rusty colour, observed for the wells such as GW5 and GW9 and may partly explain why the wells have been abandoned by the users.

Generally, higher iron levels were found in the samples outside the mining region compared to samples closer to the mining centers. However the difference was not significant. For instance, while about 50.0% of the surface water samples and 22.22% of groundwater samples taking outside the mine recorded iron levels above the 0.3mg/l taste threshold set by the WHO, 2004 and Ghana EPA, 1997, only 33.33 % and 11.11%

of the surface and groundwater samples close to mines had iron concentrations exceeding the limit (Fig. 4.14 & 4.15).

The fact that more surface and groundwater samples outside the mine recorded iron levels higher than for samples close to or within the general mining area, is an indication that most dissolved iron that enters the surface water pathways are directly from natural sources such as from the dissolution and oxidation of pyrites and Arsenopyrite mineral complexes in the area. Ironically, these iron enriched minerals, such as pyrites (FeS) and Arsenopyrite (FeAsS) are a major component of most Birimian and Tarkwain rock systems found in most gold mining belts in a Ghana.

4.2.3 Levels of dissolved Lead (Pb) in the Water Samples levels of dissolved lead when compared with the 0.01 mg/l threshold of the WHO. 2004, revealed that all Groundwater (100%) and 77.78% of Surface water were above this threshold in the wet season. While in the dry season, 100% of both the surface and ground water samples had lead levels above this limit (Fig. 4.16 & 17). Thus majority of the water samples will be unsuitable for domestic use.

In general, lead concentrations in surface water during the period varied from 0.006 mg/l to 0.057 mg/l in the wet season and from 0.011 to 0.083 mg/l in the dry season.

For ground water sources, Lead concentrations were in the range of 0.013 mg/l- 0.092 mg/l during the wet season compared to the range of 0.026 to 0.15 mg/l during the dry season As can be seen in Fig 4.20 and 4.21, the highest lead values in the Sansu area,

were from SW2, and SW4 which were samples close to the mines. However, higher lead levels were also noticeable in some streams distant to the mining zone as in SW6.

At dokiya, excessive contamination of the water samples with inorganic lead was more noticeable in samples such as SW7 and GW10 respectively during the dry season (Fig. 4.20 & 21). SW7 is close to an abandoned surface mine at the Akatakyieso hills and may thus be affected. Similarly, the proximity of GW10 to the tailing dam at Dokiya can also explain the high dissolved inorganic lead present.

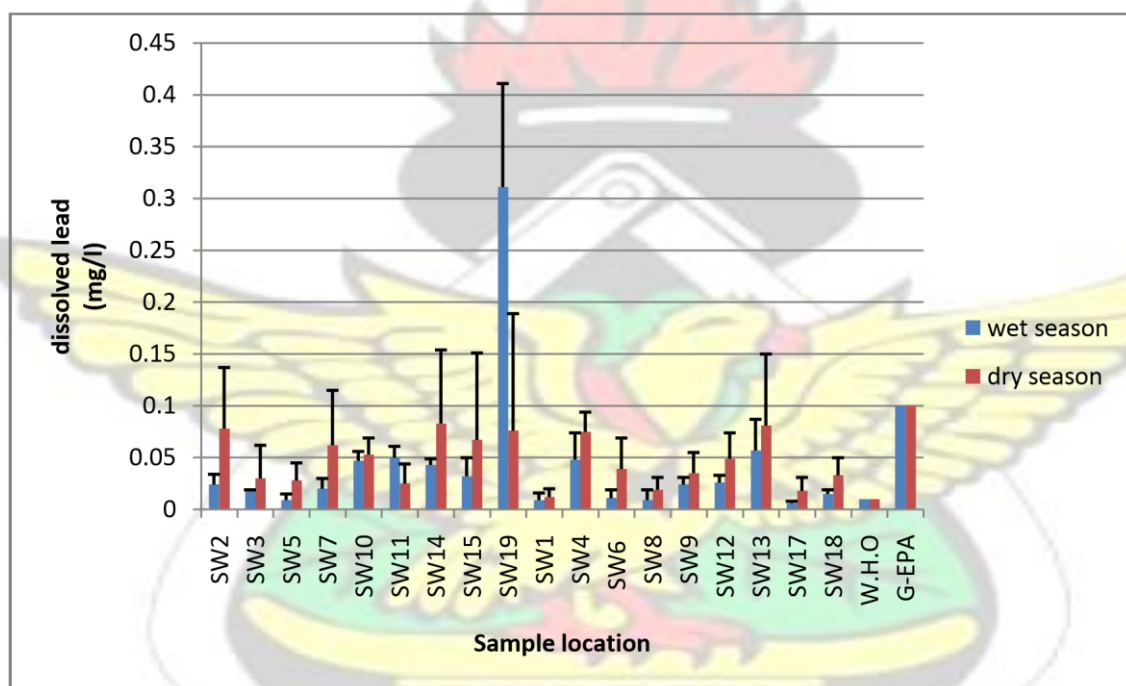


Fig 4.16 Mean levels of dissolved lead in surface water samples within the mines (SW2 to SW19) compared to outside the mine (SW1 to SW18)

The highest Pb level in the Surface and Ground water samples was recorded in the Kwabrafos area and was from SW19 and GW14 respectively as shown in (Fig 4.16 & 17). These represented samples taking very close to the abandoned tailings dam and PTP at Pompora. The result of the study revealed that dissolved lead concentration in surface

water and groundwater samples were low in the wet season compared to the dry season (Fig 4.16 & 4.17).

In general, the average lead concentration of all surface water samples in the dry season (0.044 mg/l) was significantly higher than the average value of 0.026 mg/l recorded in the wet season at $p = 0.05$.

Similarly, the mean dissolved lead concentrations in all the ground water samples were found to be statistically greater than mean lead concentration in surface water especially during the dry season (0.079 mg/l vs 0.044 mg/l, $p=0.05$,) but no significant differences were recorded in the wet season.

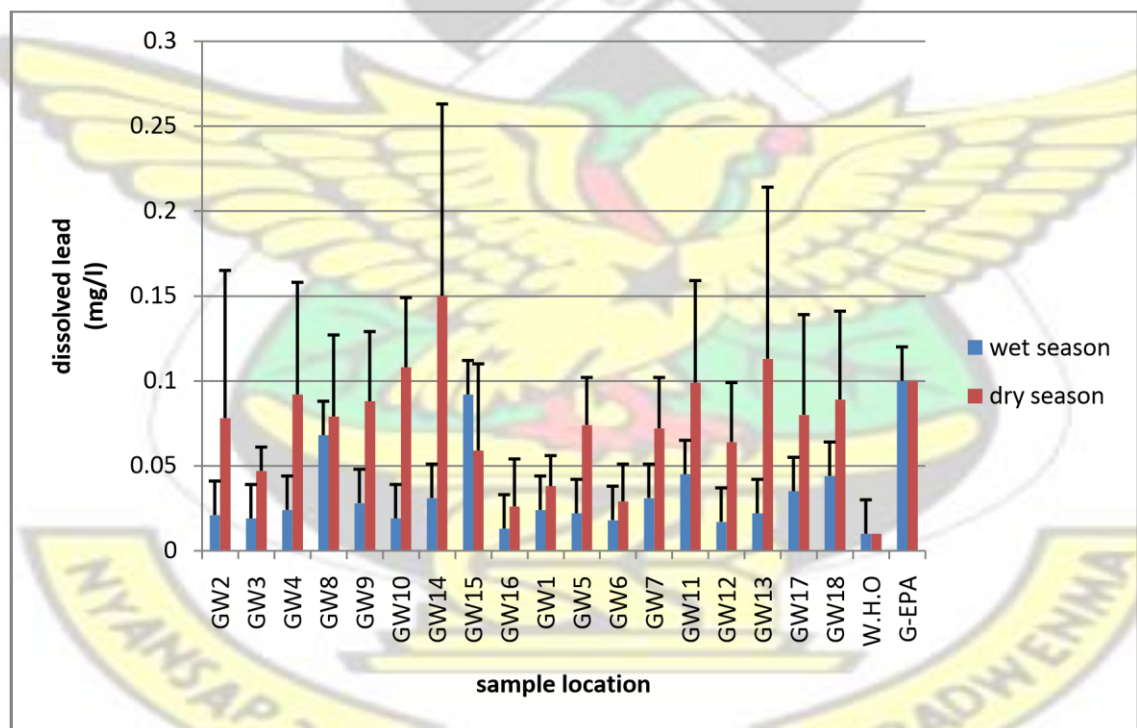


Fig 4.17 Mean levels of dissolved lead in the ground-water samples within the mine (GW2-GW16) compared to samples outside the mines (GW1-GW18)

4.2.4 Levels of Copper (Cu), Zinc (Zn) and Cadmium (Cd) in the surface and ground water samples in the area.

The results of this study revealed that, dissolved copper levels were relatively low in most of the samples. Copper levels were at below detection limits (0.004 mg/l) in nearly all the surface and groundwater samples except GW2, GW3, GW12 and GW17 for which trace amounts of the metal were recorded in the wet season.

In the dry season, a greater proportion of the samples exhibited trace amounts of copper ranging from below detection limits to 0.06 mg/l with a mean value of $0.008 \pm$

0.013 mg/l for surface water and from below detection limit to 0.098 mg/l with a mean value of 0.016 ± 0.026 mg/l for the ground water samples

However, the values obtained for copper were insignificant to pose any hazard to the users of the water sources when compared with the WHO guideline value of 2.0 mg/l. This suggests that, all the surface and groundwater samples have copper levels below the recommended thresholds.

Zinc and cadmium showed a similar trend to copper and were below detection limit in almost all the samples during the wet season except the borehole at kyekyewere (GW12). In the dry season, Zinc levels in the water samples also increased slightly and recorded values from 0.004 to 0.228 mg/l with a mean value of 0.034 ± 0.052 mg/l for the groundwater samples. For surface water, levels of Zinc were observed from 0.004 to 0.035 mg/l with an average value of 0.011 ± 0.009 mg/l.

Cadmium levels were also below detection limit (0.002) in all samples analyzed in the wet season. However about 50% and 78% of all the surface and groundwater sampled in the area recorded levels above the WHO general guideline value of 0.01 mg/l during the dry season.

Significant risk from the use of these boreholes during the dry periods is therefore very much anticipated. This is because Cadmium is a very powerful neurotoxin that can have several negative effects on the users (Anawara *et al.*, 2002).

4.3 Levels of Total and Faecal coliform in the Surface and Ground water samples

The results of this study revealed that majority of the surface water samples were poorer in microbial quality compared to groundwater. Very highly significant differences were therefore observed between the surface and groundwater samples for both faecal and total coliform counts per 100 ml of the water sample. For example, in the wet season, only 55.56% of all groundwater samples had Coliform levels exceeding the WHO limit of 0 CFU/100 ml while about 95% of all surface waters were above the WHO threshold.

The average level of total coliform in the surface water samples during the wet season was between 0.0 to > 200 CFU/100 ml. In the dry season, the total counts of Coliform in the surface water samples were also from 0 CFU/100 ml to > 200 CFU/100 ml. Faecal Coliform population in the surface water sample were also between 0 to > 200 CFU/100 ml in both the wet and dry season.

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CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Physical and chemical water quality patterns in the Obuasi mining area

Generally, from the results of the study, the physicochemical quality of ground and surface water sources in the Obuasi mining area can be regarded as poor. Excessive amount of some of these parameters like pH, TDS, Sulphates, etc in the water source may impact taste problems, discoloration and odour problems to the water source. This will in turn affect the average consumer's judgment on the sanity and acceptability of the water sources for domestic usage. This can be seen from the discussion presented below

5.1.1 pH

The ground water and surface water sources in the Obuasi mining area are characterized by varying degrees of acidity during the rainy season but generally become alkaline in the dry season. However, ground water was also more acidic than surface waters. The

result of this work compares favorably with work published earlier by (Tay, 2001; Akabzaa *et al.*, 2004). Acidic problems in the wet season may emanate from the oxidation of sulphide minerals in the area which produces acid mine drainage in the area. The low pH witnessed in the wet season will give the water a sharp sour taste while the alkaline pH in the dry season will give the water a bitter taste causing consumers to reject it. In addition, the low pH in groundwater will increase the concentration and toxicity of trace metals in the groundwater (Fatoki and Muyima, 2003).

5.1.2 Conductivity and TDS

The result obtained for conductivity and TDS suggest that surface water sources are more mineralized than groundwater. Higher conductivity levels in surface water sources close to the mines compared with samples outside the general mine suggests possible contamination from the mining and related activities in the area. This corroborates with Akabzaa *et al.*, (2004) but contrast with Tay (2001) who reported higher conductivity for ground water than for surface water in the Obuasi gold belt.

Koning and Roos (1999) have suggested an average conductivity value of 350 $\mu\text{S}/\text{cm}$ for a typical unpolluted river. On this basis, surface water samples such as SW4, SW10, SW12, SW19 and groundwater samples such as GW14 can be regarded as polluted and will therefore be unsuitable for domestic use. However, majority of the water samples identified will present no obvious problem to domestic users as their average conductivity levels were lower than 350 $\mu\text{S}/\text{cm}$ during both seasons.

The WHO currently does not have any health based guideline for TDS but values above 1000 mg/l have been noted to cause taste problems which can cause consumers to reject a water supply source. MacCutcheon *et al.*, (1983) have pointed out that, the palatability of water with TDS level less than 600 mg/l is generally good whereas above 1200 mg/l, the water becomes unpalatable. The TDS range, of most ground water samples in the Obuasi gold belt is thus optimal for their use for domestic purposes but taste problems may be noticeable in few surface water samples especially for samples close to the mining regions. Notable Rivers such as Kwame Tawia (SW10), Kwabrafos (SW14 and 15) as well as River Kaw sampled at Odumase (SW19) will present taste problems when consumed domestically.

5.1.3 Hardness and Alkalinity

Alkalinity Levels in streams and borehole sources in the Obuasi-gold belt were generally low. Thus both surface and ground water sources are poorly buffered (Smedley *et al.*, 1995). This will affect the ability of the water sources to resist abrupt changes in pH. The drastic seasonal change in pH may buttress this point. Similarly, the significantly higher alkalinity levels in stream samples from the mines compared to samples outside the mines can be due to the use of various limy and ammonium chemicals in the gold milling and extraction process (Armah *et al.*, 1998). Higher hardness in groundwater may be due to the carbonaceous material, which has been reported in aquifers in the area but that of surface water is likely to be introduced.

The higher hardness value recorded for river Kwame-Tawia and Kaw in particular confirms complaints by the inhabitants of these villages concerning the extreme difficulty in using their water for laundry purposes because of the streams inability to lather with soap when used for washing.

5.1.4 Sulphates

The South African Bureau of standards (SABS, 1984), regards the presence of Sulphate (SO_4^{2-}) ions in drinking water as non-toxic within the limit of 0.0-200.0 mg/l. Kempster *et al* (1997) have pointed out that, the intake of SO_4^{2-} ions at elevated concentrations can cause diarrhoea problems for the users. It is therefore important to regulate the levels of sulphate in portable water sources in order to safeguard the health of users.

From the results of the study, there were significant variations in the sulphate levels of streams near the mining centers compared to samples outside the mining region. This may be an indication that, the mining activities affects the sulphate concentration of surface water. This can be due to acid mine drainage problems associated with the mining and processing of sulphuric ores in the area. Stream samples near the mines are therefore unsuitable for domestic use.

5.1.5 Nitrates and nitrites

Nitrate can cause a lot of health problems if it occurs above 10mg/l in drinking water (WHO, 2004). Health problems such as methaemoglobinaemia in infants, Cyanosis and Asphyxia, and in serious cases death have been reported (Groen *et al.*, 1988; Burkhart *et al.*, 1993; Weier *et al.*, 1994; Adekunle *et al.*, 2007; Groen *et al.*, 1988; Burkhart *et al.*, 1993). Ground water samples such as GW17 and GW15 recorded nitrate and nitrite levels, at concentrations about 10 and 2 times higher than the WHO recommended limit and should be avoided. Measures such as improving general sanitation around the boreholes and avoiding the construction of septic tank, pit latrines, municipal refuse dumps, open defecation sites etc around the boreholes will help to curb nitrate contamination in boreholes in the area.

5.2 Sources, Levels and potential risk of Pb, As, Fe, Cu, Zn and Cd in the water sources in the study area

The widespread prevalence of heavy metals in surface and groundwater sources in this study can be attributed primarily to the weathering of sulphide-bearing rocks in the area. According to the geology of the Ashanti Gold belt, (Dzigbordi-Adjimah, 1988), rock mineral types present chiefly include, Arsenopyrite (FeAsS), Magnetite (Fe_2O_3), Pyrite (FeS_2), Chalcopyrite (CuFeS_2), Marcasite, Sphalerite (ZnS), Bornite (Cu_3FeS_4) and Galena (PbS).

All these primary minerals when weathered can lend trace and heavy metals into both the surface and ground water sources. However, elevated concentrations of the metals

in the water samples may also be enhanced by the mining-metallurgy activities in the area. Johnson and Eaton (1980), for instance, have observed that mine spoil, especially from tailing environments account for a significant metal flux from the geosphere to the hydrosphere through various leaching and sediment erosion processes.

The risk of poisoning or adverse health impacts due to heavy metal concentration in the water samples have already been cited by many other works in the area. Akabzaa *et al* (2004), have noted that the presence of disease as such as acute respiratory infection, eye infections, skin diseases and diarrhea among users have a strong link to heavy metal pollution of drinking water sources in the area. The presence of trace metals especially As, Pb, Fe and Cd above the recommended WHO and the Ghana EPA limit may further confirm this assertion to some degree. There is a need to carefully monitor levels of heavy metals in the identified drinking water sources periodically.

5.2.1 Toxicity and potential risk due to Lead (Pb) in the Water samples

Lead is known to produce health effects such as impaired growth, increased blood pressure, and anemia and kidney damage. In women, it can cause premature abortion while for males exposed to increasing concentration of the metal, sterility can arise (Da Rosa and Lyon, 1997).

The result of this Study revealed that Lead concentration in Streams and Groundwater samples in the Obuasi area is abnormally high and in most cases was above the WHO Permissible limit of 0.01 mg/l.

The detection of lead at such high concentrations suggests that lead is very persistent and widespread in the area. It may have long term negative effect on the population especially, if it becomes bio-present and is passed on to humans through the food chain. Notable pathways will be from the consumption of fish products in the affected rivers and streams.

The widespread occurrence of lead in both surface and ground water sources can be from the dissolution of minerals such as, galena (PbS) which is widespread in the Obuasi gold belt (Junner *et al.*, 1932). However, pH will be the main factor that will favor lead dissolution and mobilization in the identified water sources. Extremely lower pH recorded for groundwater samples in contrast to the neutral to alkaline pH recorded for Surface water samples can explain the elevated concentrations in the Groundwater samples compared to the Surface water samples.

Also, higher concentration of lead in Ground and Surface water were more peculiar to samples near the tailing and processing facilities around Dokyiwaa and the Kwabrafosso mining zone. Such an occurrence will probably be introduced from windblown dust from the abandoned tailings during the dry season and from intrusions from defective tailing dams to the groundwater. Consumers of Groundwater sources at Dokyiwaa, Binsere and Kwabrafosso are at a greater risk of facing lead poisoning problems. Health problems such as hypertension and kidney problems are also expected to develop among consumers in the long-run.

Pb levels in water sources, (SW15 and GW14) were found to exceed 0.1mg/l in the dry period. Pregnant and expectant women who use the water sources are at a serious risk.

This is because high levels of lead in drinking water can be detrimental to developing fetus, and, may cause abortion in some cases. The risk of children and babies in the area developing neurological problems and hearing impairment is anticipated for prolonged use of the affected water samples (USEPA 1986; Abulude *et al.* 2007).

5.2.2 Arsenic exposure in drinking water and associated risk in the area

Arsenic concentration in this study was generally high and widespread especially during the rainy season. Higher dissolved arsenic levels above the W.H.O and EPAGhana guideline values of 0.01 mg/l and 1 mg/l respectively were more pronounced for the stream water samples compared to groundwater. This agrees consistently with findings from Amasa (1975); Smedley (1996); Asiam (2010) and Rossiter *et al* (2010) that attributed this trend to airborne contamination of the stream with arsenic from the mining activities in the area.

The highest arsenic concentrations were mostly concentrated in stream water samples where some level of mining activity especially illegal mining has been practiced. Notable streams serving the Kwabrafosso, Dokyiwaa, Ntonsoa and the Sansu area are severely impacted. In view of this, stream water sources such as Kwame Tawia, Supu, etc are no longer in use as domestic water supply for these communities. The affected communities now depend on groundwater sources from the boreholes constructed for them, but analytical results for this study has also confirmed that some of the boreholes, such as the one at dokyiwaa and Binsere (GW9 and GW10) are also contaminated, with dissolved arsenic levels exceeding the 0.01mg limit of the WHO, (2004). The decision of AGA to resettle the inhabitants of Dokyiwaa and allied communities is therefore timely and laudable. This will help to forestall any serious health concern among the

people in the long run. Akabzaa *et al* (2004) also discovered a similar trend of arsenic pollution in the streams serving these communities. However, tremendous improvement in the quality of the streams in this work is noticeable and fishes and other aquatic lives were noticed in the once reported lifeless streams.

Smedley (1996) work on arsenic geochemistry and mobility attributed the occurrence of inorganic arsenic in both surface and ground water samples in the Obuasi area to flooding of exposed land surface, from the reduction and mobilization of As-containing Fe oxides, or by oxidation of Arsenopyrite, which is the predominant mineral in most Birimian gold basement in Ghana. At the same time, researchers such as Asiam (1996); Smedley (1996); Smedley *et al* (1996) and Kumi-Boateng (2007) have attributed Arsenic (As) pollution in soils and river bodies in the Obuasi area to ore-roasting activities and from seepage from nearby mine tailings.

However, the increasing spate of land degradation due to loss of natural vegetative cover from illegal and surface mining activities in the area should be the main contributory factor to arsenic mobilization in the streams during the study. Illegal mining activities (Galamsey) should thus be closely monitored in the area to forestall further degradation of residual water quality in the region.

Dissolved arsenic levels recorded in the streams in this study were also found to be higher than levels reported in the literature in areas such as, Bibiani; Bolgatanga and Tarkwa which has similar geology and mining presence (Kuma, 2007; Smedley *et al.*, 1995). However, it was lower than values reported in Mexico, Bangladesh and India

where chronic arsenic intoxication problems have been reported (Smedley and Kinniburgh, 2002).

Arsenic at high doses has been the poison of choice since medieval times, while chronic exposure to extreme lower doses in drinking water may also be cancerous on body organs such as the bladder, lungs, skin, kidney, liver and the prostate (Smedley *et al.*, 1995). Apart from causing inflammation of the eye, it may also cause various cardiovascular diseases such as, diabetes and anemia. Reproductive, immunological and neurological responses may also develop in the exposed population at Obuasi in the long run.

Wang and Huang (1994) have pointed out that, significant morbidity could arise through consumption of water supplies with arsenic levels higher than 0.1 mg/l. From our results, approximately, 83.33% of surface water and 50.0% of groundwater samples recorded arsenic levels above this limit.

Thus a higher morbidity rate is expected from the use of the ground and surface water sources in the Obuasi area for drinking and other domestic purposes. There is a need for stream and borehole samples to be monitored closely and screened regularly for abnormally higher concentration of dissolved arsenic.

5.2.3 Iron (Fe) and its effect on the acceptability of the water sources

The importance of iron (Fe) on water quality analysis is solely based on its aesthetic effect on a water source. It may not have any health effect, but will affect consumer's

judgment on the sanity of a water source and cause consumers to opt for less colourless but dangerous water sources. Iron levels above 0.3 mg/l will give the water an apprehensive rusty-yellowish colour. Rositer *et al* (2010) have reported significantly higher iron levels in stream water than in groundwater samples in the Obuasi area. Stream water samples in this study also contained appreciable levels of iron that gives them a turbid yellowish colour. Ironically, some groundwater sources in areas where little or no mining activities are practiced also contained high levels of the metal in excess of the 0.3 mg/l aesthetic limit. Iron and manganese are elements which are widespread in most geological settings. Thus the widespread distribution of iron in the ground water sources in the area is solely natural and bears a linkage to the natural geochemistry of the Obuasi gold-belt where primary mineral such as Arsenopyrite, FeAsS), are widespread (Smedley, 1996; Tay, 2001; Rossiter *et al.*, 2010).

The extreme higher iron values in surface water such as River Fena at Hia (SW12) is from galamsey activities and the abandoned surface mines found close to the river.

5.3 Microbiological water quality in the area

For water to be considered of no risk to human health, the total and faecal Coliform counts/100 ml should be zero (WHO, 1993; Shelton, 2000). However, most surface and ground water samples analyzed in this study had varying degree of Coliform populations which suggest that they are dangerous for human consumption.

During the study, it was observed that surface water sample close to the mines (urban communities) like Kwabrafosso and Sansu were more affected with microbial contamination compared to surface water samples at the extremes. This suggest that the conditions within the urban mining towns, characterized by the very high population densities and inadequate sanitary and waste disposal systems have a serious bearing on the microbial quality of streams and rivers within their catchment compared to those at the rural settings with less mining presences and which are characterized by lower population densities.

The Poor microbiological quality recorded for streams in the area is due to direct defecation into these streams, while that of groundwater samples, may emanate from direct seepage from septic tanks and pit latrines which are very common in the rural communities in the area. The risk of contracting diarrhoea disease from the consumption of some of these water sources identified will be particularly high under the prevailing conditions. There is a need for inhabitants in the area to boil their water sources before drinking to prevent the outbreak of cholera and diarrhoea diseases in the area. Strict sanitation especially around the borehole sources should be enforced. Moreover, the use of pit latrines in the area should be discouraged. Simple treatment technologies such as the addition of chlorine may also help in ensuring that the water sources are safe for drinking and other domestic uses.

5.4 Ground water quality versus surface water quality

The result of this study also revealed that contamination of ground water sources were only benign for most physical, chemical and microbiological parameters except pH and heavy metallic content. This suggests that surface water sources in the Obuasi mining area are more affected by the presence of mining and other ancillary activities than groundwater. Stringent measures towards the use of streams in the area should be enforced. However, the potential risk associated with the consumption of fish and other products from these rivers may remain a great concern. This can be worsened by the high cost of fish products in the area as stressed by Akabzaa (2004). In the end, the situation can force the deprived and marginalized in the area to fish directly from these polluted rivers. Even when this does not happen, the possibility of stray fishes running into other adjacent tributaries or rivers in the area such as River Offin to the south is very high. Under such conditions, it may lead to the consumption of contaminated fish which can affect the health of people in the area (Kelly, 1999)

5.5 Comparing water quality trends for samples within the mines and samples outside the mines

From the result of this study, it appears that general surface and ground water quality for samples taking outside the mines were far better than those within the mining region. Significant differences were observed in the water quality of samples within the mines and outside the mines for parameters such Conductivity, TDS, Total alkalinity and hardness, chlorides, sulphates, Faecal Coliform and Total Coliform but no significant

differences were observed for metallic contaminants viz As, Fe, Pb, Cu, Zn and Cd. The results show that the mining activities in the area exert some significant influence on the physico- chemical and microbial quality of the water sources especially for surface water. This also corroborates with findings of Akabzaa *et al.*, (2004). The regulation of mining activities with better waste disposal regime can go a long way to improve water quality patterns in the area to a substantial degree.

5.6 Seasonal trends in water quality in the area and implications for water use and management

Seasonal changes in surface and ground water quality within the Obuasi gold belt were very noticeable. The concentrations of most analyte substance were higher during the dry season than in the wet season (Von der Heyden and New, 2004). This trend is partly due to dilution in the wet season, which reduces the levels of the identified contaminants in both the surface and ground water samples (Fianko *et al.*, 2010).

Parameters which showed significant variation with season were pH, Alkalinity, Hardness, Chlorides, SO_4^{2-} and Nitrates. For most of these parameters, such as pH, Nitrates, Hardness and Alkalinity and metal concentrations such as Lead and Cadmium, elevated concentrations were observed in the dry season compared to the wet season.

However, for parameters such as, arsenic, phosphates and sulphates, higher concentration were more obvious in the wet season than in the dry season. Conductivity and TDS levels were also found to be high during the dry season over the wet season but the difference was not significant.

In the wet season, the use of both water sources may present serious problems considering the acidic nature of the water sources which may affect the solubility, toxicity and bioavailability of some of the identified metallic contaminants. Caution with the use of the water resources should be instilled in the wet season and followed up to the dry season.

5.7 Current water quality trends against previous water quality trends in the area

The average Conductivity, TDS, Sulphate, Alkalinity, Hardness, Lead and Cadmium concentration reported for the water sources in this study were significantly higher than those reported in previous studies by (Akabzaa, 2004 and Penn, 1999). On the other hand, levels of arsenic and iron values were extremely lower than values reported earlier in the literature.

These suggest that some of the recommendations suggested earlier by researchers such as Akabzaa (2004) and Wacam (2008) were not implemented. It may also be the result of new pollution trends developing in the area. Similarly, the higher Conductivity, TDS, Total hardness, Sulphate levels in stream such as River Kwame Tawia (SW10), River Kwabrafosso (SW14) and River San (SW3) compared to the values reported in earlier studies by Akabzaa, 2004 can be attributed to the continual erosion and build up of minerals and mined waste from the abandoned surface mines and tailings to these streams. It may also be due cumulative effect of acid mine drainage patterns over the years especially during the wet season.

Notwithstanding, tremendous improvement in arsenic and iron levels in the Surface water sources are evident compared to values reported earlier for these streams. For instance, the highest arsenic content found in streams such as San (SW3), Kwame Tawia (SW10), and Kwabrafos (SW14) during the period of study were only 11.2, 49.3, 159.3, times higher than WHO limits respectively as opposed to the 27.1, 307.1, 1800 times high values recorded earlier at these locations (Akabzaa *et al.*, 2004). The improvement in current water quality in the area may be partly attributed to the implementation of ISO 1401 EMS by the company since 2004. This EMS stresses on high environmental performance standards. It may also be due to the less frequent attacks on the pipelines that link mine effluents from the processing plants to the dams by illegal miners in the area. Furthermore, in areas where surface mining were practiced before such as near the Sansu river (SW5) and Buama river (SW7), improvement in the quality of the water may be due to the cessation of surface mining operations in the area. Re-vegetation of the mining strips and abandoned lands may also be a factor to the considerable improvement in the quality of the water at these locations during the periods compared to that reported earlier by Akabzaa *et al.*, 2004) **CHAPTER SIX**

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Following the discussions in this study, it can be concluded that, mining activities in the Obuasi gold belt has affected water quality patterns of ground and surface water sources.

Average levels of Conductivity, TDS, Hardness, sulphate, Arsenic (As), lead (Pb) for stream and ground water source within the mines were significantly higher than those taking outside the mines.

Galamsey operations along the banks of major streams and rivers in the area were in most cases the cause of high dissolved iron and arsenic levels in surface water sources in the area.

The levels of parameters such as Arsenic, Lead, Cadmium, Iron, pH, Conductivity, TDS, Total Hardness were found to exceed the WHO levels in both the Surface and Ground water samples during the wet and dry season. However, Phosphate, Nitrite, Cyanide, Copper and Zinc levels were all found within the permissible limit in all the samples irrespective of their source, the season or location of the sample.

Parameters such as pH, Conductivity, TDS, Alkalinity, Hardness, Sulphates and trace metal concentration such as As, Fe, Cu, Pb and Cadmium in the surface and ground water samples were also affected greatly by seasonal changes. TSS, Phosphate, Nitrite and Coliform concentrations were however independent of season.

6.2 Recommendations

During the study, it was discovered that galamsey activities involving the use of mercury in the gold extraction process were widespread in the Obuasi mining area.

Future works should seek to quantify mercury and where possible manganese contamination in the stream water sources close to these galamsey workings.

Geological mapping of the distribution of rock types at the study area may also help to explain some of the variations in the water quality parameters not accounted for in this work.

In the future, the construction of tailing dams and mine processing plants near community water sources especially surface water should not be allowed.

Similarly, the granting of mining lease for commencement of mining activities in fragile ecosystems such as the one at Obuasi should be followed with the appropriate pollution prevention and control measures.

The logo of KNUST (Kwame Nkrumah University of Science and Technology) is a large, faint watermark in the background. It features a yellow eagle with spread wings perched on a green shield. Above the eagle is a red torch with a flame. The shield has a yellow border with the text 'KNUST' at the top and 'BADWANA' at the bottom. The eagle's chest is decorated with a green and yellow pattern.

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APPENDIX A. DESCRIPTIVE STATISTICS FOR FIELD MEASURED PARAMETERS.

Table A-1: GENERAL SURFACE WATER QUALITY- WET SEASON

(All parameters are in mg/l unless otherwise stated)

Parameter	N	Mean	SD	Minimum	Maximum	Percent outwit	Guideline
G-EPA,1997 WHO, 2004							
PH	18	6.5978	0.3220	6.0200	7.4500	-	33.33
Cond. (μ S/cm)		439.94	410.84	48.990	1141.9	27.8	16.67
TDS	18	271.55	274.29	28.070	785.33	-	22.25
TSS	18	40.196	32.063	12.330	132.33	-	5.56
ALK. (ppm)	18	76.959	38.559	32.670	181.00		
HARD	18	169.16	168.70	24.000	554.67	5.56	-
CL	18	23.926	15.615	0.8000	48.670	-	-
SO4	18	127.74	118.56	16.330	425.00	-	
NO3	18	1.4386	1.3570	0.0140	4.8000	-	
NO2	18	0.0198	0.0216	0.003	0.1000	-	-
PO4	18	0.1960	0.7830	0.004	3.3300	-	-
TC (CFU/100ml)		131.28	89.918	0.0000	200.00	94.4	77.78
FC (CFU/100ml)		68.333	86.176	0.0000	200.00	94.4	77.78 As
18	0.4073	0.4897	0.004	1.5950	16.67	100	
Fe	18	0.9021	1.2006	0.0190	3.7500	16.67	55.56 Cu
18	0.0054	0.0061	0.004	0.0300	-	-	
Pb	18	0.0256	0.0166	0.006	0.0570	-	77.78
Zn	18	0.0040	0.0000	0.004	0.0040	-	-
Cd	18	0.0020	0.0000	0.002	0.0020	-	- CN
18	0.0011	0.0024	0.0010	0.0020	-	-	

Table A-2: GENERAL SURFACE WATER QUALITY-DRY SEASON

(All parameters are in mg/l unless otherwise stated)

Parameter	N	Mean	SD	Minimum	Maximum	percent outwit guideline	
						G-EPA,1997	WHO, 2004
PH	18	7.9222	0.4174	7.0300	8.7800		11.11
Cond (µS/cm)		556.58	543.83	2.300	1731.3	44.44	22.22
TDS	18	362.94	371.04	30.570	1102.3	27.70	11.11
TSS	18	62.438	124.54	6.3300	555.00	-	-
ALK (ppm)		155.98	74.181	50.000	284.10	-	-
HARD	18	278.99	240.07	56.000	896.04	27.70	11.11
CL	18	12.268	13.688	0.8000	48.450	-	- SO ₄
	18	62.705	53.002	6.1700	157.64	-	-
NO ₃	18	5.8311	2.7827	1.3200	11.630	5.55	-
NO ₂	18	0.0301	0.0227	0.0100	0.097	-	-
PO ₄	18	1.1888	1.2651	0.0040	4.2000	77.77	33.33
TC	18	133.94	75.961	0.0000	200.00	94.44	94.44
FC	18	106.54	80.474	0.0000	200.00	94.44	94.44
As	18	0.2774	0.4608	0.004	1.4700	16.67	77.78
Fe	18	1.4826	1.3872	0.0760	5.5260	22.22	88.88
Cu	18	0.0078	0.0130	0.004	0.0600	-	-
Pb	18	0.0443	0.0248	0.0110	0.0830	-	100.0
Zn	18	0.0108	0.0093	0.0040	0.0350	-	-
Cd	18	0.005	0.0027	0.0002	0.0100	-	50.0
	18	0.0027	0.0044	0.0001	0.0160	-	-

TABLE A-3 GENERAL GROUND WATER QUALITY- WET SEASON

(All parameters are in mg/l unless otherwise stated)

Parameter	N	Mean	SD	Minimum	Maximum	percent outwit guideline	
						G-EPA,1997	WHO ,2004
PH	18	5.3750	0.3501	4.9100	6.3100	94.4	94.4
Cond (µS/cm)		186.62	188.00	34.460	742.11	-	-
TDS	18	108.25	117.23	17.910	426.06	-	-
TSS	18	26.86	16.51	9.330	82.670	5.56	-
ALK (ppm)		57.198	35.55	14.33	119.00	-	-
HARD	18	69.738	67.76	14.33	283.33	-	-
CL	18	17.057	11.16	8.670	42.00	-	-
SO ₄	18	34.469	31.55	11.67	121.40	-	-
NO ₃	18	2.237	4.33	0.300	19.30	-	5.56
NO ₂	18	1.828	7.61	0.006	32.33	-	5.56
PO ₄	18	0.004	0.0000	0.004	0.0040	-	-
TC (CFU/100ml)		35.222	53.28	0.000	180.00	-	55.56
FC (CFU/100ml)		18.722	36.19	0.000	117.00	-	50.00
As	18	0.101	0.095	0.004	0.2970	-	66.67
Fe	18	0.111	0.281	0.004	1.1940	-	11.11
Cu	18	0.005	0.0026	0.004	0.0120	-	-
Pb	18	0.032	0.0199	0.013	0.0920	-	100
Zn	18	0.007	0.0055	0.004	0.0240	-	-
Cd	18	0.0002	0.0000	0.002	0.0020	-	-
	18	0.0001	0.0000	0.001	0.0010	-	-

Table A-4: GENERAL GROUND WATER QUALITY-DRY SEASON

(All parameters are in mg/l unless otherwise stated)

Parameter	N	Mean	SD	Minimum	Maximum	percent outwit guideline G-EPA 1997	WHO,2004
pH	18	7.2139	0.4253	6.2800	7.9400	-	5.56
Cond (μS/cm)		254.66	254.80	35.540	1016.1	5.56	5.56
TDS	18	158.44	161.90	24.380	661.67	5.56	-
TSS	18	25.325	7.2787	12.000	35.000	-	-
ALK (ppm)		112.91	61.445	27.000	200.00	-	-
HARD	18	169.62	106.99	80.330	470.00	5.56	-
CL	18	2.1456	2.2949	0.2000	8.6700	-	5.56
SO4	18	22.619	33.021	4.0000	123.00	-	-
NO3	18	8.9672	7.0096	3.7500	31.330	-	-
NO2	18	2.3102	8.8574	0.0130	37.670	-	22.2
PO4	18	0.2140	0.1762	0.0040	0.6800	-	-
TC (CFU/100ml)		40.315	56.197	0.0000	200.00	55.56	44.44
FC (CFU/100ml)		10.784	28.314	0.0000	117.00	55.56	44.44 As
18	0.0188	0.0341	0.004	0.1120	-	22.22	-
Fe	18	0.2407	0.5005	0.0190	2.1460	-	16.67 Cu
18	0.0156	0.0261	0.004	0.0980	-	-	-
Pb	18	0.0769	0.0311	0.0260	0.1500	16.67	100.0 Zn
18	0.0344	0.0519	0.004	0.2280	-	-	-
Cd	18	0.0570	0.0023	0.0020	0.0100	-	77.77
CN	18	0.0011	0.0024	0.0010	0.0020	-	- NOTE

0.004 MEANS BELOW DETECTION LIMIT

TABLE A-5: SURFACE WATER QUALITY WITHIN THE MINES - WET SEASON

(All parameters are in mg/l unless otherwise stated)

Parameter	N	Mean	SD	Minimum	Maximum	percent outwit guideline G-EPA,1997	WHO,2004
PH	9	6.5700	0.2089	6.1500	6.8500	-	22.22
Cond (μS/cm)		733.55	382.77	242.00	1141.9	55.56	33.33
TDS	9	465.01	271.65	129.43	785.33	44.44	-
TSS	9	53.814	40.540	17.670	132.33	33.33	-
ALK (ppm)		102.28	36.865	64.500	181.00	-	-
HARD	9	251.01	200.27	24.000	554.67	22.22	11.11
CL	9	31.866	14.132	10.000	48.670	-	-
SO4	9	218.19	131.94	41.600	425.00	44.44	44.44
NO3	9	1.9200	1.6586	0.2800	4.8000	-	-
NO2	9	0.0140	0.0068	0.006	0.0260	-	-
PO4	9	0.3890	1.1038	0.004	3.3300	-	-

TC (CFU/100ml	178.22	65.333	4.0000	200.00	88.89	88.89
FC (CFU/100ml	118.44	98.562	0.0000	200.00	77.78	77.78
As	9	0.5563	0.5679	0.1120	1.5950	22.22
Fe	9	0.5244	1.0758	0.0190	3.3630	11.11
9	0.069	0.0087	0.0040	0.0300	-	-
Pb	9	0.0284	0.0152	0.0090	0.0500	-
Zn	9	0.004	0.0000	0.0040	0.0004	-
Cd	9	0.002	0.0000	0.0020	0.0020	-
CN	9	0.011	0.0033	0.0010	0.0020	-

NOTE- 0.004 MEANS BELOW DETECTION LIMIT

TABLE A -6: SURFACE WATER QUALITY OUTSIDE THE MINES, - WET SEASON

(All parameters are in mg/l unless otherwise stated)

Parameter	N	Mean	SD	Minimum	Maximum	percent outwit guideline	
						G-EPA,1997	W.H.O,2004 pH
9	6.6256	0.4184	6.0200	7.4500	-	44.44	Cond (µS/cm)
168.55	204.65	48.990	689.00	-	-	-	-
TDS	9	90.301	103.68	28.070	352.00	-	-
TSS	9	26.578	11.127	12.330	44.330	-	-
ALK (ppm)		51.638	18.915	32.670	84.00	-	-
HARD	9	87.303	72.728	31.330	238.00	-	-
CL	9	15.986	13.288	0.8000	47.000	-	-
SO4	9	48.392	32.502	16.330	100.80	-	-
NO3	9	0.9571	0.8005	0.0140	2.7000	-	-
NO2	9	0.0257	0.0294	0.003	0.1000	-	-
PO4	9	0.2504	0.7363	0.004	2.2140	-	-
TC (CFU/100ml	84.333	89.187	0.000	200.00	-	-	-
FC (CFU/100ml	18.222	20.407	0.000	55.000	-	-	-
As	9	0.2583	0.3703	0.004	1.2180	11.11	88.89
Fe	9	1.2798	1.2588	0.031	3.7500	22.22	77.78 Cu
9	0.0040	0.0000	0.004	0.0040	-	-	-
Pb	9	0.0228	0.0183	0.006	0.0570	-	55.56
Zn	9	0.0040	0.0000	0.004	0.0040	-	-
Cd	9	0.0020	0.0000	0.002	0.0020	-	-
CN	9	0.0011	0.0033	0.001	0.0020	-	-

NOTE 0.004 MEANS BELOW DETECTION LIMIT

TABLE A-7: SURFACE WATER QUALITY WITHIN THE MINES- DRY SEASON

(All parameters are in mg/l unless otherwise stated)

Parameter	N	Mean	SD	Minimum	Maximum	percent outwit guideline
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G-EPA, 1997 WHO,2004 pH							
9	8.1089	0.4225	7.5700	8.7800			
Cond (µS/cm)	915.77	539.99	215.03	1731.3	55.56	44.44	
TDS	9	605.34	381.49	138.83	1102.3	55.56	22.22
TSS	9	94.333	173.34	20.000	555.00	11.11	-
ALK (ppm)		181.70	74.467	50.000	284.10	-	-
HARD	9	397.45	279.30	115.67	896.04	44.44	22.22
CL	9	16.339	15.629	1.8700	48.450	-	-
SO4	9	100.94	45.265	27.330	157.64	-	-
NO3	9	6.0056	2.7805	2.7600	11.630	11.11	-
NO2	9	0.0240	0.00068	0.0160	0.0330	-	-
PO4	9	1.6667	1.4547	0.0004	4.2000	-	-
TC	9	161.89	58.345	34.000	200.00	100	100
FC	9	116.74	78.090	3.0000	200.00	100	100
As	9	0.3523	0.4574	0.008	1.1260	22.22	100
Fe	9	1.0058	1.1659	0.0760	3.7360	11.11	66.67
Cu	9	0.0118	0.0183	0.0004	0.0600	-	-
Pb	9	0.0486	0.0258	0.0110	0.0830	-	100
Zn	9	0.0109	0.0106	0.004	0.0350	-	-
Cd	9	0.0056	0.0027	0.002	0.0100	-	77.78
CN	9	0.0028	0.0044	0.001	0.0130	-	-

NOTE- 0.004 MEANS BELOW DETECTION LIMIT

TABLE A-8: SURFACE WATER QUALITY OUTSIDE THE MINES, - DRY SEASON

(All parameters are in mg/l unless otherwise stated)

Parameter	N	Mean	SD	Minimum	Maximum	percent outwit guideline	
						G-EPA,1997	WHO,2004
pH	9	7.7356	0.3366	7.0300	8.0600	-	-
Con (µS/cm)		197.39	215.84	52.300	726.33	-	-
TDS	9	120.54	121.68	30.570	386.40	-	-
TSS	9	30.543	24.999	6.3300	86.670	11.11	-
ALK (ppm)		130.25	68.255	54.000	277.70	-	-
HARD	9	160.53	113.53	56.000	418.00	11.11	-
CL	9	8.1967	10.797	0.8000	33.330	-	-
SO4	9	24.474	25.143	6.1700	85.000	-	-
NO3	9	5.6567	2.9420	1.3200	9.6700	-	-
NO2	9	0.0361	0.0311	0.0100	0.0970	-	-
TC (CFU/100ml)		106.00	84.263	0.0000	200.00	88.89	88.89
FC (CFU/100ml)		96.333	86.193	0.0000	200.00	100	100
As	9	0.2026	0.4790	0.0040	1.4700	11.11	66.67
Fe	9	1.9594	1.4894	0.6500	5.5260	33.33	100 Cu
9	0.0056	0.0187	0.0040	0.0090	-	-	-
Pb	9	0.0401	0.0244	0.0120	0.0810	-	100 Zn
9	0.0108	0.0089	0.0040	0.0310	-	-	-
Cd	9	0.0044	0.0028	0.0020	0.0100	-	55.56
CN	9	0.0027	0.0050	0.0010	0.0160	-	-

NOTE- 0.004 MEANS BELOW DETECTION LIMIT

TABLE A-9: GROUND WATER QUALITY WITHIN THE MINES- WET SEASON

(All parameters are in mg/l unless otherwise stated)

Parameter	N	Mean	SD	Minimum	Maximum	percent outwit guideline	
						G-EPA,1997	WHO,2004
Ph	9	5.2644	0.2806	4.9100	5.6800	100.00	100.00
Cond(μ S/cm)		269.93	222.94	53.670	742.11	-	-
TDS	9	148.90	144.72	33.330	426.06	-	-
TSS	9	31.764	21.163	9.3300	82.670	-	-
ALK (ppm)		74.479	36.804	14.330	119.00	-	-
HARD	9	98.068	86.466	22.000	283.33	-	-
CL	9	20.036	12.645	9.6700	42.000	-	-
SO4	9	46.322	40.167	12.670	121.40	-	-
NO3	9	1.2167	0.7953	0.3300	2.8000	-	-
NO2	9	0.0408	0.0528	0.0140	0.1810	-	-
TC(CFU/100ml)		32.444	44.108	0.0000	142.00	66.67	66.67
FC(CFU/100ml)		17.444	37.617	0.0000	117.00	55.55	55.55
As	9	0.1357	0.0946	0.0040	0.2970	-	77.78
Fe	9	0.0290	0.0277	0.0040	0.0900	-	-
Cu	9	0.0577	0.0027	0.0040	0.0120	-	-
Pb	9	0.0352	0.0266	0.0130	0.0920	-	100.00
Zn	9	0.0051	0.0026	0.0040	0.0120	-	-
Cd	9	0.0020	0.0000	0.0020	0.0020	-	-
CN	9	0.0010	0.0000	0.0010	0.0000	-	-
PO4	9	0.0040	0.0000	0.0040	0.0040	-	-

TABLE A-1: GROUND WATER QUALITY OUTSIDE THE MINES - WET SEASON

(All parameters are in mg/l unless otherwise stated)

Parameter	N	Mean	SD	Minimum	Maximum	percent outwit guideline	
						G-EPA,1997	WHO,2004
Ph	9	5.4856	0.3927	5.1600	6.3100	88.89	100.00
Cond(μ S/cm)		92.204	63.339	34.460	251.04	-	-
TDS	9	56.479	43.844	17.910	167.37	-	-
TSS	9	21.964	8.7819	10.330	41.670	-	-
ALK (ppm)		34.362	20.835	15.600	71.330	-	-
HARD	9	35.408	18.186	14.330	70.330	-	-
CL	9	13.406	8.2929	8.6700	35.300	-	-
SO4	9	20.394	10.938	11.670	47.300	-	-
NO3	9	3.2578	6.0708	0.3000	19.300	-	-
NO2	9	3.6147	10.768	0.0060	32.330	-	11.11
PO4	9	0.0040	0.0000	0.0040	-	-	-
TC(CFU/100ml)		38.000	63.795	0.0000	180.00	33.33	33.33
FC(CFU/100ml)		20.000	36.936	0.0000	92.000	33.33	33.33
As	9	0.0666	0.0861	0.0040	0.2280	-	66.67
Fe	9	0.1936	0.3898	0.0040	1.1940	-	22.22
Cu	9	0.0056	0.0027	0.0040	0.0110	-	-
Pb	9	0.0289	0.0105	0.0170	0.0450	-	100.0
Zn	9	0.0081	0.0072	0.0040	0.0240	-	-
Cd	9	0.0020	0.0000	0.0020	0.0020	-	-
CN	9	0.0020	0.0015	0.0010	0.0040	-	-

NOTE: 0.004 MEANS BELOW DETECTION LIMIT

TABLE A-11: GROUND WATER QUALITY WITHIN THE MINES- DRY SEASON

(All parameters are in mg/l unless otherwise stated)

Parameter	N	Mean	SD	Minimum	Maximum	percent outwit guideline G-EPA,1997	WHO,2004
pH	9	7.2678	0.3207	6.7300	7.6700	-	-
Cond(μ S/cm)		351.87	320.02	36.150	1016.1	11.11	11.11
TDS	9	214.76	206.26	24.380	661.67	11.11	-
TSS	9	26.976	6.4002	16.670	35.000	-	-
ALK (ppm)		142.12	42.615	81.670	200.00	-	-
HARD	9	209.89	136.75	81.000	470.00	11.11	-
CL	9	2.6922	2.9905	0.4900	8.6700	-	-
SO4	9	31.413	40.666	4.0000	123.00	-	-
NO3	9	7.5422	4.4975	3.7500	15.670	22.22	22.22
NO2	9	0.3882	1.0807	0.0130	3.2700	-	-
PO4	9	0.1438	0.0923	0.0040	0.2530	-	-
TC(CFU/100ml)		60.778	69.548	0.0000	200.00	66.67	66.67
FC(CFU/100ml)		40.889	70.410	0.0000	200.00	55.56	55.56
As	9	0.0208	0.0343	0.0040	0.0990	-	22.22
Fe	9	0.1199	0.1272	0.0210	0.4230	-	11.11
Cu	9	0.0189	0.0321	0.0040	0.0980	-	-
Pb	9	0.0808	0.0359	0.0260	0.1500	22.22	100.0 Zn
9	0.0456	0.0721	0.0040	0.2280	-	-	-
Cd	9	0.0050	0.0020	0.0020	0.0080	-	66.67 CN
9	0.0010	0.0000	0.0010	0.0010	-	-	-

TABLE A-12: GROUND WATER QUALITY OUTSIDE THE MINES, - DRY SEASON

(All parameters are in mg/l unless otherwise stated)

Parameter	N	Mean	SD	Minimum	Maximum	percent outwit guideline G-EPA,1997	WHO,2004
pH	9	7.1600	0.5245	6.2800	7.9400	-	-
Cond(μ S/cm)		143.90	78.350	35.540	323.77	-	-
TDS	9	91.008	52.571	24.770	219.07	-	-
TSS	9	23.674	8.0926	12.000	34.000	-	-
ALK (ppm)		83.711	65.496	27.000	184.70	-	-
HARD	9	119.01	31.297	80.330	185.82	-	-
CL	9	1.5989	1.2554	0.2000	3.6000	-	-
SO4	9	13.826	22.121	4.3300	72.670	-	-

NO3	9	10.392	8.9227	4.0300	31.330	33.33	33.33
NO2	9	4.2321	12.539	0.0150	37.670	-	11.11
PO4	9	0.2842	0.2154	0.0040	0.6800	-	-
TC (CFU/100ml)	19.852	30.529	0.0000	90.670	44.44	44.44	
FC (CFU/100ml)	1.7033	2.9643	0.0000	8.0000	33.33	33.33	
As	9	0.0168	0.0358	0.0040	0.1120	-	22.22
Fe	9	0.3616	0.6951	0.0190	2.1460	-	22.22
Cu	9	0.0123	0.0198	0.0040	0.0650	-	-
Pb	9	0.0731	0.0270	0.0290	0.1130	11.11	100.0
Zn	9	0.0233	0.0157	0.0040	0.0490	-	-
Cd	9	0.0064	0.0027	0.0020	0.0100	-	88.89
CN	9	0.0011	0.0033	0.0010	0.0000	-	- NOTE

0.004 MEANS BELOW DETECTION LIMIT

APPENDIX B: MEAN COMPARISON TABLES FOR SIGNIFICANT VARIATION WATER QUALITY PARAMETERS

Table B-1: Mean Comparison table on the effect of water source on trace metal levels;

(Surface against Groundwater)

Source of variation	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						CN
	As	Fe	Cu	Pb	Zn	Cd	
source	wet season						
Surface	0.407 ^a	0.902 ^a	0.004 ^a	0.026 ^a	0.004 ^a	0.002 ^a	0.001 ^a
Ground	0.101 ^b	0.111 ^b	0.004 ^a	0.032 ^a	0.004 ^a	0.002 ^a	0.001 ^a
LSD	0.239	0.591	-	0.012	-	-	-
	dry season						
Surface	0.277 ^a	1.483 ^a	0.004 ^b	0.044 ^b	0.011 ^a	0.002 ^a	0.001 ^a
Ground	0.019 ^b	0.241 ^b	0.018 ^a	0.079 ^a	0.033 ^a	0.002 ^a	0.001 ^a
LSD	0.221	0.706	0.014	0.019	0.025	-	-
	wet season in-mine						
Surface	0.556 ^a	0.524 ^a	0.004 ^a	0.028 ^a	0.004 ^a	0.002 ^a	0.001 ^a
Ground	0.138 ^b	0.029 ^a	0.004 ^a	0.035 ^a	0.004 ^a	0.002 ^a	0.001 ^a
LSD	0.407	0.761	-	0.022	-	-	-
	wet season-out mine						
Surface	0.258 ^a	1.279 ^a	0.004 ^a	0.023 ^a	0.004 ^a	0.002 ^a	0.001 ^a
Ground	0.067 ^b	0.194 ^b	0.004 ^a	0.029 ^a	0.004 ^a	0.002 ^a	0.001 ^a
LSD	0.269	0.931	-	0.015	-	-	-
	dry season, in-mine						
Surface	0.352 ^a	1.006 ^a	0.012 ^a	0.049 ^b	0.011 ^a	0.002 ^a	0.001 ^a

Ground	0.021 ^b	0.129 ^b	0.019 ^a	0.087 ^a	0.048 ^a	0.002 ^a	0.001 ^a
LSD	0.324	0.828	0.026	0.032	0.051	-	-
	dry season, out-mine						
Surface	0.203 ^a	1.959 ^a	0.004 ^a	0.040 ^b	0.011 ^a	0.002 ^a	0.001 ^a
Ground	0.017 ^a	0.353 ^b	0.016 ^a	0.072 ^a	0.018 ^a	0.002 ^a	0.001 ^a
LSD	0.339	1.163		0.025	0.011	-	-

Note – means with the same letters are not significant at the 0.05 level

Table B-2: Mean comparison table of the effect of season on trace metal level;

(Wet season against dry season)

Source of variation	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						
	As	Fe	Cu	Pb	Zn	Cd	CN ⁻
source	all surface, wet vrs dry						
wet	0.407 ^a	1.483 ^a	0.0054 ^a	0.026 ^b	0.004 ^b	0.002 ^b	0.0011 ^a
dry	0.277 ^a	0.902 ^a	0.0087 ^a	0.044 ^a	0.011 ^a	0.005 ^a	0.0027 ^a
LSD	0.322	0.879	0.0069	0.014	0.004	0.0013	0.0021
	all groundwater						
wet	0.101 ^a	0.111 ^a	0.005 ^a	0.032 ^b	0.006 ^b	0.0020 ^a	0.0010 ^a
dry	0.019 ^b	0.241 ^a	0.018 ^a	0.079 ^a	0.033 ^a	0.0059 ^a	0.0011 ^a
LSD	0.048	0.275	0.013	0.018	0.025	0.0011	0.0011
	surface water in mine						
wet	0.556 ^a	0.524 ^a	0.007 ^a	0.028 ^a	0.004 ^a	0.002 ^b	0.001 ^a
dry	0.352 ^a	1.006 ^a	0.018 ^a	0.049 ^a	0.011 ^a	0.006 ^a	0.0027 ^a
LSD	0.515	1.121	0.014	0.021	0.008	0.0019	0.0028
	groundwater in mine						
wet	0.136 ^a	0.029 ^b	0.006 ^b	0.035 ^b	0.005 ^a	0.002 ^b	0.001
dry	0.021 ^b	0.129 ^a	0.019 ^a	0.087 ^a	0.048 ^a	0.006 ^a	0.001
LSD	0.071	0.089	0.023	0.032	0.050	0.0012	-
	surface water- outside the mine						
Wet	0.258 ^a	1.279 ^a	0.0040 ^b	0.023 ^a	0.004 ^b	0.002 ^b	0.001 ^a

dry	0.203 ^a	1.959 ^a	0.0057 ^a	0.040 ^a	0.011 ^a	0.044 ^a	0.003 ^a
LSD	0.428	1.378	0.0013	0.022	0.006	0.002	0.0035
ground water-outside mines							
Wet	0.067 ^a	0.194 ^a	0.0056 ^a	0.029 ^b	0.008 ^a	0.0020 ^b	0.0011
dry	0.017 ^a	0.353 ^a	0.016 ^a	0.072 ^a	0.018 ^a	0.0058 ^a	0.0019
	0.066	0.566	0.015	0.020	0.011	0.0021	0.0002

Note – means with the same letters are not significant at the 0.05 level

Table B-3: Variation in trace metal levels due to the location of sample.

(Mean comparison: within the mines vrs outside the mines)

Source of variation	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						CN ⁻
	As	Fe	Cu	Pb	Zn	Cd	
source	surface water, wet season						
in-mine	0.556 ^a	1.279 ^a	0.007 ^a	0.0284 ^a	-	-	0.0011 ^a
out-mine	0.258 ^a	0.524 ^a	0.004 ^a	0.0228 ^a	-	-	0.0010 ^a
LSD	0.479	1.170	0.006	0.017	-	-	2.355
	Surface water, dry- season						
in mine	0.352 ^a	1.006 ^a	0.012 ^a	0.049 ^a	0.011 ^a	0.0056 ^a	0.003 ^a
out mine	0.203 ^a	1.959 ^a	0.006 ^a	0.040 ^a	0.011 ^a	0.0044 ^a	0.003 ^a
LSD	0.468	1.337	0.013	0.025	0.009	0.0027	0.005
	ground water, wet season						
in mine	0.136 ^a	0.194 ^a	0.006 ^a	0.035 ^a	0.005 ^a	-	-
out mine	0.067 ^a	0.029 ^a	0.006 ^a	0.029 ^a	0.008 ^a	-	-
LSD	0.090	0.276	0.003	0.02	0.005	-	-
	groundwater, dry season						
in-mine	0.021 ^a	0.129 ^a	0.019 ^a	0.086 ^a	0.048 ^a	0.0058 ^a	0.0011 ^a
out -mine	0.017 ^a	0.353 ^a	0.016 ^a	0.072 ^a	0.018 ^a	0.0057 ^a	0.0010 ^a

LSD	0.035	0.501	0.027	0.032	0.051	0.0025	0.0026
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Note – means with the same letters are not significant at the 0.05 level

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Table B-4: Mean Comparison table of the effect of water source on quality: Surface against Groundwater

source of variatn	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (mg/l)	HARD. (mg/l)	CL- (mg/)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/)	P0 ₄ ³⁻ (mg/l)	T.coli counts/10 0ml	F. coli counts/10 0ml
source	wet season												
S.W	6.59 ^a	439.94 ^a	271.55 ^a	40.19 ^a	76.96 ^a	169.16 ^a	23.9 ^a	127.7 ^a		1.83 ^a	0.32 ^a	131.3 ^a	68.33 ^a
G.W	5.38 ^b	186.62 ^b	108.24 ^b	26.86 ^a	57.19 ^a	69.74 ^b	16.7 ^a	34.47 ^b		0.02 ^a	0.004 ^a	35.22 ^b	18.72 ^b
LSD	0.23	216.42	142.89	17.27	25.45	87.08	9.13	58.77		3.65	0.44	50.07	48.77
	dry season												
S.W	7.92 ^a	556.58 ^a	362.94 ^a	62.44 ^a	155.98 ^a	278.99 ^a	12.27 ^a	62.71 ^a	8.97 ^a	2.31 ^a	1.19 ^a	133.9 ^a	106.5 ^a
G.W	7.21 ^b	254.66 ^b	158.44 ^b	25.30 ^a	115.85 ^a	169.62 ^a	2.15 ^b	22.62 ^b	5.83 ^a	0.03 ^a	0.19 ^a	40.32 ^b	21.29 ^b
LSD	0.29	287.67	193.91	59.76	46.16	125.98	6.65	29.91	3.61	4.24	0.613	45.26	45.99
	wet season -in mine												
S.W	6.57 ^a	711.33 ^a	452.79 ^a	53.81 ^a	102.28 ^a	251.01 ^a	31.87 ^a	207.1 ^a	1.92 ^a	0.01 ^a	0.389 ^a	178.2 ^a	118.4 ^a
G.W	5.26 ^b	281.04 ^b	160.01 ^b	31.76 ^a	80.03 ^a	104.07 ^a	20.04 ^a	48.54 ^b	1.22 ^a	0.04 ^a	0.150 ^a	32.44 ^b	17.4 ^b
LSD	0.25	317.69	219.48	32.32	35.96	153.00	13.40	89.93	1.30	0.038	0.780	55.70	74.55
	wet season-out mine												
S.W	6.63 ^a	168.55 ^a	90.30 ^a	26.58 ^a	51.64 ^a	87.30 ^a	15.99 ^a	48.39 ^a	3.26 ^a	3.61 ^a	0.25 ^a	84.33 ^a	20.0 ^a
G.W	5.49 ^b	92.20 ^a	56.48 ^a	21.96 ^a	34.36 ^a	35.41 ^a	13.41 ^a	20.39 ^b	0.96 ^a	0.03 ^a	0.04 ^a	38.00 ^a	18.2 ^a
LSD	0.41	151.38	79.54	10.02	19.89	52.97	11.07	24.23	4.33	7.61	0.52	77.49	29.82

	dry season-in mine												
S.W	8.11 ^a	915.77 ^a	605.34 ^a	94.33 ^a	187.70 ^a	397.45 ^a	16.34 ^a	100.9 ^a	6.00 ^a	0.39 ^a	1.67 ^a	161.8 ^a	116.74 ^a
G.W	7.27 ^b	365.42 ^a	225.87 ^b	26.93 ^a	148.00 ^a	220.22 ^a	2.69 ^b	31.4 ^a	7.54 ^a	0.02 ^a	0.13 ^b	60.78 ^b	40.89 ^b
LSD	0.38	444.57	306.59	122.56	59.01	218.70	11.25	42.99	3.74	0.76	1.03	64.15	74.30
	dry season out mine												
S.W	7.74 ^a	197.39 ^a	120.54 ^a	30.54 ^a	130.25 ^a	160.53 ^a	8.19 ^a	24.47 ^a	5.66 ^a	4.23 ^a	0.71 ^a	106.0 ^a	96.33 ^a
GW	7.16 ^b	143.90 ^a	91.0 ^a	23.67 ^a	83.70 ^a	119.01 ^a	1.60 ^a	13.83 ^a	10.4 ^a	0.04 ^a	0.260 ^a	19.85 ^b	1.70 ^a
LSD	0.44	162.26	93.66	18.57	66.84	83.22	7.68	23.66	6.64	8.86	0.64	63.33	60.94

Note – means with the same letters are not significant at the 0.05 level

Table B-5: Effect of season on the water quality; (mean comparison: wet season against dry season)

source of variatn	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (mg/l)	HARD. (mg/l)	CL. (mg/)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	P0 ₄ ³⁻ (mg/l)	T.coli counts/10 0ml	F. coli counts/100 ml
source	all surface water												
Wet	6.60 ^b	439.94 ^a	271.55 ^a	40.19 ^a	76.96 ^b	169.16 ^a	23.93 ^a	127.7 ^a	1.44 ^b	0.019 ^a	0.319 ^b	131.3 ^a	68.33 ^a
Dry	7.92 ^a	556.58 ^a	362.94 ^a	62.44 ^a	155.98 ^a	278.99 ^a	12.26 ^b	62.70 ^b	5.83 ^a	0.030 ^a	1.189 ^a	133.9 ^a	106.5 ^a
LSD	0.25	326.48	221.02	61.60	40.05	140.55	9.95	62.21	1.48	0.015	0.747	56.38	56.48
	all ground water												
Wet	5.37 ^b	186.62 ^a	108.25 ^a	26.86 ^a	57.19 ^b	69.74 ^b	16.72 ^a	34.47 ^a	2.24 ^b	1.83 ^a	0.004 ^b	35.22 ^a	18.72 ^a
Dry	7.21 ^a	254.66 ^a	158.44 ^a	25.30 ^a	115.85 ^a	169.62 ^a	2.15 ^b	22.62 ^a	8.97 ^a	2.31 ^a	0.195 ^a	40.32 ^a	21.29 ^a
LSD	0.27	151.68	95.75	8.65	34.28	60.84	5.35	21.88	3.95	5.59	0.092	37.09	30.49
	surface water in- mine												
Wet	6.57 ^b	711.33 ^a	452.79 ^a	94.33 ^a	102.28 ^b	251.01 ^a	31.87 ^a	207.1 ^a	1.92 ^b	0.014 ^b	0.389 ^a	178.2 ^a	118.4 ^a
Dry	8.11 ^a	915.77 ^a	605.34 ^a	53.81 ^a	181.70 ^a	397.45 ^a	16.34 ^b	100.9 ^b	6.01 ^a	0.024 ^a	1.667 ^a	161.9 ^a	116.7 ^a

LSD	0.33	470.15	332.01	125.80	58.72	242.86	14.89	91.31	2.29	0.007	1.290	61.89	88.86
	groundwater in-mine												
Wet	5.26 ^b	281.04 ^a	160.01 ^a	31.76 ^a	80.03 ^b	20.04 ^a	104.07 ^b	48.54 ^a	1.22 ^b	0.04 ^b	0.004 ^b	32.44 ^a	17.44
Dry	7.27 ^a	365.42 ^a	225.87 ^a	26.93 ^a	148.00 ^a	2.69 ^b	220.22 ^a	31.41 ^a	7.54 ^a	0.39 ^a	0.129 ^a	60.78 ^a	40.89
LSD	0.30	278.44	178.71	15.64	36.44	9.18	110.73	39.99	3.23	0.76	0.072	58.19	56.41
	surface water –outside the mine												
Wet	6.63 ^b	168.55 ^a	90.30 ^a	26.58 ^a	51.6 ^b	87.30 ^a	15.99 ^a	48.39	0.96 ^b	0.03 ^a	0.25 ^a	84.3 ^a	18.22 ^a
Dry	7.74 ^a	197.39 ^a	120.54 ^a	30.54 ^a	130.3 ^a	160.53 ^a	8.19 ^a	24.47	5.66 ^a	0.04 ^a	0.71 ^a	106 ^a	96.33 ^a
LSD	0.38	210.18	19.34	19.34	50.05	95.28	12.09	29.04	2.15	0.03	0.81	86.70	62.59
	ground water outside the mine												
Wet	5.49 ^b	92.20 ^a	56.48 ^a	21.96 ^a	34.36 ^b	35.41 ^b	13.41 ^a	20.39 ^a	3.26 ^a	3.61 ^a	0.004 ^a	38.0 ^a	20.00 ^a
Dry	7.16 ^a	143.90 ^a	91.01 ^a	23.67 ^a	83.70 ^a	119.01 ^a	1.59 ^b	13.83 ^a	10.4 ^a	4.23 ^a	0.260 ^a	19.85 ^a	1.700 ^a
LSD	0.46	71.19	22.82	8.44	48.56	25.58	5.93	17.44	7.63	11.68	0.169	49.98	26.18

Note – means or figures with the same letters are not significant at p=0.05

Table B-6 : Variation in the water quality due to location of sample; mean comparison: within the mines vrs outside the mines

source of variatn	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (mg/l)	HARD. (mg/l)	CL- (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	PO ₄ ³⁻ (mg/l)	T.coli counts/100ml	F. coli counts/100ml
location	surface water, wet season,												
in- mine	6.57 ^a	711.33 ^a	452.8 ^a	53.81 ^a	102.3 ^a	251.01 ^a	31.87 ^a	218.2 ^a	1.92	0.03 ^a	0.38 ^a	178.2 ^a	118.4 ^a

out mine	6.63 ^a	168.55 ^b	90.3 ^b	26.58 ^a	51.64 ^b	87.30 ^b	15.98 ^b	48.4 ^b	0.96	0.01 ^a	0.25 ^a	84.3 ^b	18.2 ^b
LSD	0.33	310.41	207.2	29.71	29.28	150.56	13.71	88.6 ^a	1.30	0.021	0.94	78.12	71.13
	surface water, dry season												
in mine	8.11 ^a	915.8 ^a	605.3 ^a	94.33 ^a	181.7 ^a	397.5 ^a	16.34 ^a	100.9 ^a	6.0 ^a	0.04 ^a	1.67 ^a	161.9 ^a	116.7 ^a
out mine	7.74 ^a	197.4 ^b	120.5 ^b	30.54 ^a	130.3 ^a	160.5 ^b	8.19 ^a	24.5 ^b	5.7 ^a	0.02 ^a	0.71 ^a	106.0 ^a	96.3 ^a
LSD	0.382	410.93	282.9	123.8	71.38	213.05	13.42	36.6	2.9	0.02	1.20	72.42	82.19
	groundwater, wet season												
in-mine	5.26 ^a	281.04 ^a	160.01 ^a	31.76 ^a	80.03 ^a	104.07 ^a	20.04 ^a	48.54 ^a	1.22 ^a	0.04	-	32.4 ^a	17.4 ^a
out mine	5.49 ^a	92.20 ^b	56.48 ^a	21.96 ^a	34.36 ^b	35.41 ^b	13.41 ^a	20.39 ^a	3.26 ^a	3.62	-	38.0 ^a	20.0 ^a
LSD	0.34	165.80	107.57	16.19	28.83	59.56	10.69	28.87	4.33	7.61	-	54.81	37.25
	groundwater, dry season												
in-mine	7.27 ^a	365.42 ^a	225.87 ^a	26.93 ^a	148.0 ^a	220.2 ^a	2.69 ^a	31.41 ^a	10.4 ^a	4.23 ^a	0.26 ^a	60.78 ^a	40.89 ^a
out mine	7.16 ^a	143.90 ^a	91.01 ^a	23.64 ^a	83.7 ^b	119.0 ^b	1.59 ^a	13.83 ^a	7.54 ^a	0.39 ^a	0.13 ^a	18.52 ^a	1.70 ^a
LSD	0.43	234.75	150.68	7.32	53/43	96.78	2.29	32.71	7.06	8.89	0.18	53.67	49.79

Note – means with the same letters are not significant at p=0.05

A PPENDIX C: MEAN RESULTS FOR LEVELS OF PHYSICO-CHEMICAL AND MICROBIAL PARAMETERS IN THE WET AND DRY SEASON.

Table C-1: Field Results of the mean levels of physical, chemical and microbiological parameters in surface water sources (wet season, Oct-Dec, 2101)

Sample code	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (mg/l)	HARD. (mg/l)	CL- (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	P0 ₄ ³⁻ (mg/l)	T.coli counts/100 ml	F. coli counts/100 ml
SW1	6.85	247.90	138.00	16.00	84.00	158.30	18.50	84.70	1.32	0.034	0.004	56	20
SW2	6.50	531.00	352.00	17.67	138.5	258.33	35.00	200.67	3.65	0.016	0.004	>200	63
SW3	6.85	1064.67	660.90	52.67	108.5	389.33	42.00	270.67	1.65	0.026	0.143	>200	>200
SW4	6.28	689.00	352.00	14.20	78.50	238.00	24.00	100.80	0.90	0.028	0.004	63	35
SW5	6.57	267.29	134.57	35.67	90.00	100.67	20.67	41.60	0.50	0.022	0.004	>200	>200
SW6	7.45	94.27	51.92	38.67	53.00	34.00	11.00	26.00	0.014	0.012	0.004	>200	6
SW7	6.15	247.15	137.5	33.0	64.5	68.0	23.0	107.0	0.80	0.007	0.004	>200	0
SW8	6.95	54.00	34.00	28.00	54.00	48.00	0.80	64.00	2.70	0.015	0.012	200.00	55.00
SW9	6.65	48.99	28.07	30.67	35.0	73.33	11.33	20.0	0.43	0.01	0.004	>200	40
SW10	6.78	836.43	457.2	41.33	66.00	24.00	48.67	263.33	4.80	0.006	0.004	4	3
SW11	6.42	242.00	129.43	29.0	91.67	51.66	10.00	63.68	0.28	0.010	0.004	>200	0
SW12	6.56	96.20	54.89	44.33	54.0	34.67	47.0	33.70	0.78	0.015	0.004	12	0
SW13	6.02	142.80	72.30	32.0	37.9	129.1	12.9	73.0	1.50	0.003	0.004	0	0
SW14	6.56	977.13	686.00	132.33	93.68	322.8	18.67	273.0	0.90	0.017	0.004	>200	>200
SW15	6.58	1094.40	785.33	113.33	181.0	489.67	40.33	425.0	1.07	0.009	0.004	>200	>200
SW16	6.62	619.67	349.97	38.67	93.43	300.33	35.33	176.0	0.38	0.020	0.004	57	38
SW17	6.46	85.37	51.50	23.0	35.67	39.0	9.67	17.0	0.57	0.10	0.004	15	5
SW18	6.41	58.43	30.03	12.33	32.67	31.33	8.67	16.33	0.40	0.012	0.004	13	3
SW19	6.72	1141.86	732.19	29.33	86.67	554.67	48.45	218.78	3.63	0.013	3.33	>200	200
GEPA	6.0- 9.0	750.00	500.0	50.00		400.0	-	250	11.5	-	<0.3	0	0
WHO	6.5-8.5	1000.00	1000.0			500.0	250	250	10.00	3.0	2.00	0	0
percent outwit guideline value n=18													
GEPA	-	27.78	22.22	5.55		5.56	-	-	-	-	5.56	94.4	77.78
WHO	33.33	16.67	-			-	-	-	-	-	5.56	94.4	77.78

Table C-2 Mean levels of dissolved metals and cyanide in surface water sources for the wet season

Sample code	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						CN-(free)
	As	Fe	Cu	Pb	Zn	Cd	
SW1	0.252	0.370	0.004	0.009	0.004	0.002	0.001
SW2	0.618	0.500	0.030	0.024	0.004	0.002	0.001
SW3	0.112	0.029	0.004	0.018	0.004	0.002	0.001
SW4	1.218	0.900	0.004	0.048	0.004	0.002	0.002
SW5	0.152	0.019	0.004	0.009	0.004	0.002	0.001
SW6	0.176	2.650	0.004	0.011	0.004	0.002	0.001
SW7	0.286	3.363	0.004	0.020	0.004	0.002	0.001
SW8	0.012	1.212	0.004	0.009	0.004	0.002	0.001
SW9	0.212	1.904	0.004	0.024	0.004	0.002	0.001
SW10	0.169	0.140	0.004	0.047	0.004	0.002	0.001
SW11	0.493	0.119	0.004	0.050	0.004	0.002	0.001
SW12	0.196	3.750	0.004	0.026	0.004	0.002	0.001
SW13	0.087	0.500	0.004	0.057	0.004	0.002	0.001
SW14	1.423	0.033	0.004	0.043	0.004	0.002	0.001
SW15	1.595	0.206	0.004	0.032	0.004	0.002	0.001
SW16	0.543	0.261	0.004	0.006	0.004	0.002	0.001
SW17	0.004	0.201	0.004	0.006	0.004	0.002	0.001
SW18	0.168	0.031	0.004	0.015	0.004	0.002	0.001
SW19	0.159	0.311	0.004	0.013	0.004	0.002	0.001
GEPA	1.00	2.00	1.0	0.10	2.0	-	0.2
WHO	0.01	0.30	2.0	0.01	3.0	0.003	-

Table C-3: Results of the mean levels of physical, chemical and microbiological parameters in ground water sources sampled in the wet season (mid Oct. - mid Dec, 2010)

Sample code	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (mg/l)	HARD. (mg/l)	CL. (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	P0 ₄ ³⁻ (mg/l)	T. coli counts/100ml	F. coli counts/100ml
GW1	5.17	71.30	41.46	19.0	34.67	34.00	11.00	21.00	2.83	0.010	0.004	0	0
GW2	4.96	53.67	34.96	37.33	14.33	23.33	11.00	20.67	0.63	0.027	0.004	24	6
GW3	5.68	213.43	126.73	33.33	73.33	82.58	9.67	28.33	1.13	0.026	0.004	36	4
GW4	5.53	352.60	221.93	22.33	116.0	154.33	42.0	92.33	0.37	0.181	0.004	21	7
GW5	5.18	69.67	45.58	10.33	15.60	17.67	12.67	24.0	1.27	0.006	0.004	0	0
GW6	6.31	105.13	63.6	20.67	71.33	54.33	10.0	17.0	0.70	0.007	0.004	0	0

GW7	5.88	96.49	56.75	23.67	66.34	33.0	10.67	14.25	0.51	0.025	0.004	85	77
GW8	5.56	107.95	55.29	14.55	84.32	84.34	21.34	18.50	1.98	0.022	0.004	2.00	0.00
GW9	5.31	149.58	86.37	34.67	67.00	52.00	12.00	19.33	1.07	0.014	0.004	0.00	0.00
GW10	5.26	69.30	35.92	30.33	43.00	26.00	11.33	12.67	0.33	0.030	0.004	46.00	10.00
GW11	5.16	74.67	47.68	20.34	24.33	30.34	10.34	21.0	0.75	0.053	0.004	77.00	11.0
GW12	5.37	34.46	17.91	25.67	18.00	14.33	10.00	11.67	1.56	32.33	0.004	0.00	0.00
GW13	5.30	48.53	26.59	22.33	17.66	21.00	8.67	12.33	0.30	0.013	0.004	0	0
GW14	4.91	742.11	426.06	30.67	111.0	283.33	39.67	121.40	1.51	0.024	0.004	142	117
GW15	5.00	461.83	329.41	24.0	119.0	154.70	22.00	79.0	2.8	0.019	0.004	0	0
GW16	5.17	378.90	216.83	9.33	92.33	76.00	11.31	44.67	1.13	0.024	0.004	21	13
GW17	5.66	251.04	167.37	41.67	25.33	43.67	35.30	47.30	19.30	0.04	0.004	180	92
GW18	5.34	78.55	41.37	14.00	36.00	70.33	12.00	15.00	2.10	0.048	0.004	0	0
B.grd	7.00	50-300	-		-	-	7.8	0.1-10	0.23	-	0.02	-	-
GEPA	6.0- 9.0	750.00	500.0	50.00		400.0	-	250	11.5	-	<0.3	0	0
WHO	6.5-8.5	1000.00	1000.0			500.0	250	250	10.00	3.0	2.00	0	0

Table C-4: Mean levels of heavy metals in ground water sources for the wet season (mid october. -mid December, 2010)

Sample code	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						CN-(Free)
	As	Fe	Cu	Pb	Zn	Cd	
GW1	0.025	0.059	0.004	0.024	0.009	0.002	0.001
GW2	0.149	0.004	0.012	0.021	0.005	0.002	0.001
GW3	0.215	0.053	0.008	0.019	0.005	0.002	0.001
GW4	0.114	0.026	0.004	0.024	0.004	0.002	0.001
GW5	0.004	1.194	0.004	0.022	0.004	0.002	0.001
GW6	0.228	0.342	0.004	0.018	0.004	0.002	0.001
GW7	0.144	0.026	0.007	0.031	0.004	0.002	0.001
GW8	0.169	0.038	0.004	0.068	0.004	0.002	0.001
GW9	0.097	0.011	0.006	0.028	0.004	0.002	0.001
GW10	0.004	0.010	0.006	0.019	0.004	0.002	0.001
GW11	0.158	0.025	0.004	0.045	0.004	0.002	0.001

GW12	0.004	0.006	0.009	0.017	0.024	0.002	0.001
GW13	0.004	0.004	0.004	0.022	0.004	0.002	0.001
GW14	0.297	0.012	0.004	0.031	0.004	0.002	0.001
GW15	0.172	0.017	0.004	0.092	0.012	0.002	0.001
GW16	0.004	0.090	0.004	0.013	0.004	0.002	0.001
GW17	0.028	0.013	0.011	0.035	0.016	0.002	0.001
GW18	0.004	0.073	0.004	0.044	0.004	0.002	0.001
B.GRND	-	0.670	0.005	0.005	0.030	-	-
GEPA	1.00	2.00	1.0	0.10	2.0	-	0.2
WHO	0.01	0.30	2.0	0.01	3.0	0.003	-

Table C-5: Results of the mean levels of physical, chemical and microbiological parameters in surface water sources (dry season, January- March, 2011)

series	Sample code	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (mg/l)	HARD. (mg/l)	CL- (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	PO ₄ ³⁻ (mg/l)	T.coli counts/100ml	F. coli counts/100ml
Sansu	SW1	7.03	317.90	258.0	16.00	104.0	138.30	18.5	34.7	1.32	0.034	0.004	46	42
	SW2	7.57	612.33	379.33	20.00	246.6	171.33	7.90	61.33	5.20	0.027	2.27	>200	63
	SW3	8.78	1389.6	998.75	33.00	187.5	492.00	32.50	129.00	4.65	0.018	0.093	>200	39
	SW4	7.48	726.33	386.40	13.00	277.7	418.0	3.47	85.0	9.33	0.023	0.447	>200	>200
	SW5	7.75	326.67	178.67	69.00	174.7	311.33	4.83	27.33	5.00	0.030	0.100	118	53
	SW6	8.01	107.11	76.69	47.00	126.3	88.33	4.10	11.0	7.33	0.097	1.583	>200	>200
Dokyiwaa	SW7	8.11	215.03	138.83	29.67	82.33	115.67	3.43	104.0	4.47	0.018	0.004	180.00	158.67
	SW8	7.96	70.00	40.00	11.00	54.00	56.00	0.80	24.00	3.20	0.019	0.100	90.00	55.00
	SW9	8.03	52.30	30.57	33.33	131.3	108.67	2.23	8.33	7.63	0.018	0.367	157	129
	SW10	7.79	990.96	619.07	28.33	50.00	232.67	21.67	157.64	9.17	0.025	1.033	34	134
	SW11	7.85	480.23	303.83	29.0	223.3	150.00	1.87	46.67	2.76	0.016	2.200	125	3
	SW12	8.06	107.93	62.48	86.67	162	98.67	33.33	11.67	3.33	0.082	2.67	200	200
Kwabrafo	SW13	7.64	213.77	119.63	6.33	57.9	151.1	5.90	32.0	4.20	0.023	0.014	55	39
	SW14	8.09	1027.71	654.80	555.00	206.8	438.33	9.07	132.67	6.90	0.032	2.23	>200	>200
	SW15	8.36	1731.33	1102.3	37.00	284.1	769.67	17.33	137.0	4.27	0.017	2.87	>200	>200
	SW16	7.80	825.03	527.7	33.67	133.4	525.67	15.33	64.0	2.70	0.012	0.98	49	26
	SW17	7.79	121.27	71.93	37.23	92.33	117.0	2.87	6.17	4.90	0.019	0.633	0	0
	SW18	7.62	59.91	39.15	24.33	166.7	268.67	2.57	7.40	9.67	0.010	0.58	6	2
	SW19	8.68	1468.06	1072.5	48.00	180	896.04	48.45	112.78	11.63	0.033	4.20	>200	200
	GEPA	6.0- 9.0	750.00	500.0	50.00		400.0	-	250	10.0	-	<0.3	0	0
	WHO	6.5-8.5	1000.00	1000.0			500.0	250	250	50	3.0	2.00	0	0

Table C-6: Mean levels of dissolved metals and cyanide in surface water sources for the dry season (mid, Jan. - March, 2010)

Sample code	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						CN-(free)
	As	Fe	Cu	Pb	Zn	Cd	
SW1	0.181	0.650	0.004	0.012	0.004	0.002	0.001
SW2	0.503	0.743	0.060	0.078	0.035	0.008	0.013
SW3	0.032	0.175	0.004	0.030	0.004	0.004	0.005
SW4	1.470	0.844	0.004	0.075	0.031	0.010	0.016
SW5	0.008	1.285	0.004	0.028	0.017	0.002	0.001
SW6	0.011	2.674	0.005	0.039	0.014	0.006	0.001
SW7	0.055	3.736	0.006	0.062	0.004	0.005	0.001
SW8	0.004	1.837	0.009	0.019	0.004	0.004	0.001
SW9	0.041	2.066	0.008	0.035	0.004	0.002	0.001
SW10	0.155	0.323	0.005	0.053	0.004	0.008	0.001
SW11	0.122	0.773	0.007	0.025	0.018	0.006	0.001
SW12	0.004	5.526	0.005	0.049	0.014	0.007	0.001
SW13	0.095	0.829	0.004	0.081	0.004	0.002	0.001
SW14	1.126	1.744	0.012	0.083	0.006	0.005	0.001
SW15	1.106	0.197	0.004	0.067	0.006	0.010	0.001
SW16	0.371	0.078	0.004	0.004	0.004	0.002	0.001
SW17	0.004	1.611	0.005	0.018	0.007	0.005	0.001
SW18	0.013	1.598	0.007	0.033	0.015	0.002	0.001
SW19	0.064	0.076	0.004	0.011	0.004	0.002	0.001
B.GRND	-	0.670	0.005	0.005	0.030	-	-
GEPA	1.00	2.00	1.0	0.10	2.0	-	0.2
WHO	0.01	0.30	2.0	0.01	3.0	0.003	-

Table C-7: Results of the mean levels of physical, chemical and microbiological parameters in ground water sources sampled in the dry season (January. - March, 2011)

series	Sample code	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (ppm)	HARD. (mg/l)	CL. (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	PO ₄ ³⁻ (mg/l)	T. coli counts/100ml	F. coli counts/100ml
Sansu	GW1	7.48	122.86	79.70	15.07	27.67	111.33	2.50	8.33	10.83	0.031	0.50	0	0
	GW2	7.19	36.15	24.38	24.67	123.00	166.67	0.73	5.68	3.75	0.015	0.25	56	27
	GW3	7.55	226.70	140.94	16.67	177.67	81.00	0.67	4.70	6.00	0.013	0.071	62	11
	GW4	7.64	451.70	299.03	22.33	158.0	261.63	8.67	123.0	5.63	0.033	0.14	66	0
	GW5	7.03	170.60	80.14	34.00	162.0	104.67	0.20	6.00	5.27	0.020	0.40	0	0
	GW6	7.94	160.44	96.70	21.67	184.67	185.82	0.39	4.33	5.07	0.015	0.004	33	8
	GW7	6.91	106.10	68.72	23.33	162.67	80.33	0.53	6.70	4.80	0.021	0.68	37	0
	GW8	7.40	209.26	130.0	29.67	187.67	188.68	0.73	8.67	6.07	3.27	0.033	>200	>200

Dokyiwa	GW9	6.73	103.76	53.65	32.00	114.67	85.33	0.49	9.00	5.40	0.017	0.15	0	0
	GW10	6.97	92.50	54.23	29.33	81.67	122.00	1.70	4.00	4.23	0.036	0.253	0	0
	GW11	6.69	152.50	98.13	25.33	41.33	136.67	3.60	6.67	17.57	0.026	0.240	90.67	5.33
	GW12	6.98	35.54	24.77	12.00	48.00	124.30	2.430	4.40	6.43	37.67	0.337	0	0
Kwabrafo	GW15	7.09	1016.11	661.67	35.00	147.0	470.00	5.33	47.67	15.67	0.028	0.163	142	117
	GW14	7.67	673.73	392.13	33.33	200.0	384.67	0.60	65.33	15.00	0.038	0.23	0	0
	GW13	7.40	111.43	80.46	17.00	45.00	86.00	1.44	6.33	4.03	0.022	0.107	0	0
	GW16	7.17	478.90	276.83	19.78	89.33	129.00	5.31	14.67	6.13	0.044	0.004	21	13
	GW17	6.28	323.77	219.07	34.00	27.00	111.67	0.53	72.67	31.33	0.194	0.123	0	0
	GW18	7.73	111.83	71.38	30.67	55.00	130.33	2.77	9.00	8.20	0.09	0.167	18	2

Table C-8: Mean levels of heavy metals in ground water sources for the dry season (mid, Jan. - March, 2010)

Sample code	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						CN-(Free)
	As	Fe	Cu	Pb	Zn	Cd	
GW1	0.011	0.192	0.005	0.038	0.018	0.006	0.001
GW2	0.004	0.038	0.098	0.078	0.228	0.006	0.001
GW3	0.005	0.131	0.004	0.047	0.079	0.006	0.001
GW4	0.058	0.090	0.004	0.092	0.009	0.008	0.001
GW5	0.004	2.146	0.005	0.074	0.041	0.010	0.001
GW6	0.112	0.617	0.004	0.029	0.004	0.002	0.001
GW7	0.004	0.069	0.008	0.072	0.029	0.008	0.002
GW8	0.099	0.194	0.004	0.079	0.015	0.006	0.001
GW9	0.005	0.423	0.007	0.088	0.024	0.006	0.001
GW10	0.004	0.035	0.041	0.108	0.024	0.006	0.001
GW11	0.004	0.019	0.009	0.099	0.011	0.010	0.001
GW12	0.004	0.030	0.005	0.064	0.049	0.006	0.001
GW13	0.004	0.100	0.006	0.113	0.028	0.007	0.001
GW14	0.004	0.035	0.004	0.150	0.023	0.004	0.001
GW15	0.004	0.021	0.004	0.059	0.004	0.002	0.001
GW16	0.004	0.112	0.004	0.026	0.004	0.002	0.001

GW17	0.004	0.041	0.065	0.080	0.026	0.005	0.001
GW18	0.004	0.040	0.004	0.089	0.004	0.004	0.001
B.GRD	-	0.670	0.005	0.005	0.030	-	-
GEPA	1.0	2.00	1.0	0.10	2.0	-	0.2
WHO	0.01	0.30	2.0	0.01	3.0	0.003	-

APPENDIX D: MONTHLY RESULTS FOR THE FIELD MEASURED PARAMETERS (OCTOBER, 2010 TO MARCH, 2011)

Table D-1: Field measured results of the levels of physical, chemical and microbiological parameters in surface water sources (October, 2010)

Sample code	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (ppm)	HARD. (mg/l)	CL. (mg/l)	SO ₄₂₋ (mg/l)	NO ₃₋ (mg/l)	NO ₂₋ (mg/l)	P0 ₄₃₋ (mg/l)	T.coli counts/100 ml	F. coli counts/100 ml
SW1	6.52	243.75	149.7	12.0	72.0	96.0	16.3	74	3.77	0.019	0.004	93.0	34.0
SW2	6.07	536.8	416.9	18.0	109.0	252.0	45.0	220	2.68	0.009	0.004	200.0	46.0
SW3	6.92	1203	712.9	49.0	96.0	312	56.0	267	2.3	0.023	0.15	200.0	200.0
SW4	6.09	547	243.17	13.0	42.5	136	16.0	126	1.53	0.033	0.004	49.0	29.0
SW5	6.93	293.3	117.0	10.0	108.0	52.0	20.0	59.0	0.50	0.012	0.004	200.0	200.0
SW6	8.60	74.43	30.0	31.0	35.0	12.0	10.0	35.0	0.60	0.010	0.004	200.0	3.0
SW7	6.10	206.0	84.0	28.0	30.0	32.0	22.0	73.0	0.50	0.009	0.004	200.0	10.0
SW8	7.14	60.80	37.20	28.0	55.0	49.0	2.40	58.0	3.70	0.022	0.005	200.0	72.0
SW9	6.91	45.81	17.0	24.0	25.0	8.0	14.0	17.0	0.40	0.012	0.004	200.0	40.0
SW10	7.12	837.3	323	51.0	98.0	27.0	56.0	260.0	0.30	0.006	0.15	6.0	4.0
SW11	6.39	200.30	79	33.0	69.0	22.0	8.0	67.00	0.30	0.012	0.14	200	0.00
SW12	6.27	78.00	32.00	40.00	38.10	12.00	56.00	36.00	0.15	0.013	4.10	14.00	0.00

SW13	6.29	174.00	86.40	24.00	49.20	134.0	17.04	87.00	2.50	0.002	0.004	56.00	42.00
SW14	6.50	1080.00	723.00	130.00	98.00	298.0	18.00	236.00	0.80	0.021	0.004	200.00	200.00
SW15	6.73	1011.00	798.00	92.00	124.0	431.0	41.00	351.00	1.10	0.007	0.004	200.00	200.00
SW16	6.05	612.70	324.3	35.0	79.80	287.0	35.00	182.00	0.20	0.040	0.004	58.00	35.00
SW17	6.19	87.43	42.00	8.0	21.00	27.00	8.00	9.0	0.40	0.180	0.004	15.00	6.00
SW18	6.65	57.43	22.00	12.00	30.00	10.33	12.01	20.00	0.40	0.012	0.004	30.00	0.00
SW19	6.74	976.00	610.0	24.00	66.00	518.00	52.00	252.00	4.42	0.010	4.30	>200	>200

Table D-2: Field results of the levels of physical, chemical and microbiological parameters in surface water sources (November, 2010)

Sample code	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (mg/l)	HARD. (mg/l)	CL. (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	P0 ₄ ³⁻ (mg/l)	T.coli counts/100 ml	F. coli counts/100 ml
SW1	6.85	328.12	167.3	15.00	121.0	232.0	13.2	83.0	4.53	0.031	0.004	46.0	17.0
SW2	6.42	727.0	585	14.00	134.0	342.0	34.0	183.0	5.1	0.02	0.004	200.0	51.0
SW3	6.48	959.1	583.71	45.00	108.0	409.0	41.0	253.0	1.0	0.019	0.11	200.0	200.0
SW4	6.20	682.0	328.43	17.00	79.0	252.0	31.0	106.0	0.032	0.004	0.004	76.0	34.0
SW5	6.67	276.8	183.9	55.00	89.0	124.0	24.0	31.0	0.20	0.032	0.004	200.0	200
SW6	6.45	123.7	83.28	51.00	71.0	48.0	14.0	19.0	0.80	0.013	0.15	200.0	4.00
SW7	6.20	288.3	191.00	38.00	99.0	104.0	24.0	141.0	1.10	0.002	0.17	200.0	0.00
SW8	6.78	69.43	42.00	37.00	64.0	61.0	2.40	86.0	3.70	0.022	0.019	200.0	72.0
SW9	6.29	66.18	44.37	37.00	44.0	34.0	8.00	27.0	0.40	0.007	0.15	200.0	30.0
SW10	6.01	954.0	633.6	30.00	22.0	24.0	48.0	252.0	6.90	0.008	0.15	1.0	0.0
SW11	6.70	283.7	188.3	33.00	122.0	76.0	12.0	56.0	0.15	0.005	0.12	200.0	0.0
SW12	6.56	112.4	75.68	58.00	76.0	58.0	53.0	24.0	0.90	0.011	0.15	10.0	0.0
SW13	5.73	123.6	60.28	43.00	25.8	116.0	10.73	69.0	0.90	0.002	0.004	73.0	51.0
SW14	6.84	957.7	637.0	143.00	104.0	326.0	24.0	280.0	0.60	0.013	0.15	200.0	200.0
SW15	6.96	1314	921.0	105.00	315.0	712.0	56.0	654.0	1.60	0.011	0.15	200.0	200.0
SW16	6.47	728.3	412.6	49.00	132.5	402.0	48.0	234.0	0.65	0.012	0.15	70.0	49.0
SW17	6.68	102.5	68.14	24.00	42.00	56.0	13.2	15.0	0.90	0.070	0.004	18.0	10.0
SW18	6.45	67.45	45.29	21.00	44.00	24.0	8.00	12.0	0.20	0.006	0.007	1.0	0.0
SW19	7.31	1192.0	703.0	29.00	84.00	612.0	33.7	183.60	2.60	0.009	2.67	200.0	200.0

TABLE D-3: Field results of the levels of physical, chemical and microbiological parameters in surface water sources (December, 2010)

Sample code	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (mg/l)	HARD (mg/l)	CL. (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	PO ₄ ³⁻ (mg/l)	T.coli counts/100 ml	F. coli counts/100 ml
SW1	7.18	169.4	97.6	21.00	59.00	147.0	26.0	97.0	2.65	0.048	0.004	31	10
SW2	7.09	443.0	125.0	21.00	172.0	182.0	25.0	199.0	3.19	0.019	0.004	200	93
SW3	7.15	1034.0	686.3	64.00	121.0	447.0	29.0	292.0	1.70	0.035	0.17	200	200
SW4	6.54	838.0	485.1	12.00	114.0	326.0	25.0	70.5	0.97	0.032	0.004	64	43
SW5	6.12	231.79	102.8	42.00	73.0	126.0	18.0	34.8	0.80	0.021	0.15	200	200
SW6	7.31	84.68	42.5	34.00	53.0	42.0	9.0	24.0	1.20	0.016	0.12	200	12
SW7	6.36	189.6	99.70	25.00	67.0	85.0	16.0	83.6	1.40	0.011	0.12	200	50
SW8	6.95	32.16	23.0	19.00	43.0	34.0	0.086	47.0	2.80	0.010	0.019	200	47
SW9	6.76	35.0	22.8	31.00	36.0	28.0	12.0	16.0	0.50	0.011	0.12	200	50
SW10	7.32	718.0	415.0	43.00	78.0	21.0	42.0	278.0	7.20	0.005	0.11	5	64
SW11	6.15	237.6	121.0	21.00	84.0	57.0	10.0	68.0	0.40	0.014	0.09	200	0
SW12	6.84	98.2	57.0	35.00	48.0	34.0	32.0	41.0	1.30	0.021	2.5	12	0
SW13	6.03	130.9	70.0	29.00	38.7	137.0	11.0	63.0	1.20	0.004	0.004	36	24
SW14	6.34	893.7	698.0	124.00	79.0	374.0	14.0	303.0	1.30	0.018	0.004	200	200
SW15	6.05	958.2	637.0	143.00	104.0	326.0	24.0	270.0	0.60	0.007	0.004	200	200
SW16	6.89	518.0	313.0	32.00	68.0	212.0	23.0	112.0	0.3	0.009	0.120	42	30
SW17	6.36	66.18	44.37	24.00	42.0	56.0	13.0	15.0	0.90	0.07	0.004	12	0
SW18	6.12	50.41	22.80	4.00	24.0	60.0	6.0	17.0	0.6	0.019	0.090	10	0
SW19	6.10	1257.4	883.59	35.00	110.0	534.0	59.7	220.0	3.90	0.021	3.000	200	200

Table D-4: Field results of the levels of physical, chemical and microbiological parameters in surface water sources (January, 2011)

Sample code	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (mg/l)	HARD (mg/l)	CL. (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	PO ₄ ³⁻ (mg/l)	T.coli counts/100 ml	F. coli counts/100 ml
												ml	ml
SW1	7.06	203.15	161.0	22.0	74.0	78.5	22.0	25.00	2.15	0.009	0.004	55	26
SW2	6.50	567.0	356.0	29.0	283.0	178.0	6.00	48.00	3.40	0.04	2.80	200	200
SW3	7.43	1319.01	913.54	33.0	145.0	439.0	24.0	92.00	2.90	0.008	0.018	200	0
SW4	7.23	816.0	497.2	14.0	285.0	526.0	5.70	78.00	7.00	0.02	0.40	200	200
SW5	7.05	217.0	154.0	34.0	143.0	312.0	4.90	31.00	3.10	0.03	0.10	121	40
SW6	8.02	98.07	83.29	40.0	87.0	69.0	5.20	14.00	2.90	0.20	1.90	200	200
SW7	8.31	229.5	166.2	54.0	88.0	124.0	4.20	90.00	3.20	0.019	0.17	200	200
SW8	7.54	30.00	23.00	14.00	59.00	66.00	0.50	14.00	1.20	0.011	0.050	95.00	45.00
SW9	8.51	67.52	50.6	58.0	200.0	188	2.500	14.00	2.90	0.016	0.20	160	120
SW10	7.85	978.40	612.0	28.0	68.0	116	29.00	182.00	7.50	0.017	0.90	27	87
SW11	7.59	312.6	218.0	26.0	154.0	112	4.20	32.00	1.90	0.02	1.70	110	0
SW12	8.0	145.0	68.0	62.0	142.0	74	29.0	12.00	2.80	0.14	2.1	200	200
SW13	7.50	178.3	128.9	9.0	67.9	90	7.80	22.00	4.3	0.004	0.009	27	0

SW14	7.76	977.13	654.0	287.0	104.0	327	7.00	140.00	5.60	0.03	1.80	200	200
SW15	7.79	1426	990.0	23.0	218.2	569	24.00	112.00	2.60	0.018	2.52	200	200
SW16	7.05	612.8	427.9	29.0	104.0	327	10.00	43.00	2.9	0.011	0.39	34	18
SW17	7.12	127.0	64.0	38.7	79.0	112	2.4.00	8.00	2.5	0.012	0.40	0	0
SW18	6.8	78.0	54.0	16.0	94.0	182	1.80	6.20	4.0	0.013	0.52	10	0
SW19	7.95	1367.0	949.0	57.0	127.0	843	33.00	96.00	5.7	0.038	3.2	200	200

Table D-5: Field results of the levels of physical, chemical and microbiological parameters in surface water sources (February, 2011)

Sample code	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (ppm)	HARD. (mg/l)	CL. (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	P0 ₄ ³⁻ (mg/l)	T.coli counts/100 ml	F. coli counts/100 ml
SW1	6.74	358.67	296.0	15.0	116.0	128.0	14.4	47.00	1.08	0.053	0.004	46	59
SW2	7.81	698.00	498.0	17.0	183.0	212.0	12.0	75.00	5.02	0.02	2.40	200	200
SW3	8.52	1366.8	987.9	39.0	189.0	562.0	43.0	103.00	5.20	0.008	0.018	200	200
SW4	6.80	710.00	352.0	3.0	312.0	424.0	1.50	121.00	12.0	0.03	0.70	200	200
SW5	8.02	403.00	212.0	56.0	167.0	218.0	6.20	24.00	4.80	0.04	0.12	114	55
SW6	8.40	143.25	106.8	35.0	116.0	80.0	4.20	7.20	8.05	0.02	0.15	200	200
SW7	7.96	70.03	40.0	11.0	54.0	56.0	0.80	45.00	6.00	0.02	0.10	200	200
SW8	8.42	87.00	49.00	8.00	84.00	34.00	0.50	24.00	3.20	0.019	0.100	80.00	63.00
SW9	7.17	50.24	21.48	28.0	116.0	56.0	0.70	4.00	8.00	0.02	0.20	200	200
SW10	8.07	1064	769.9	49.0	68.0	116.0	29.0	182.00	7.50	0.017	1.20	27	87
SW11	8.18	517.8	380.9	55.0	280.0	160.0	0.90	60.00	2.40	0.019	2.70	110	0
SW12	8.40	118.8	89.45	52.0	160.0	80.0	40.0	8.00	3.20	0.016	2.10	200	200
SW13	8.02	242.00	118.0	8.00	48.0	126.0	4.32	45.00	5.10	0.037	0.024	0	0
SW14	8.42	1096.00	809.70	138.0	220.0	524.0	12.0	138.0	7.20	0.025	2.80	200	200
SW15	8.50	1788.00	1301.0	42.0	330.0	940.0	13.0	179.0	6.00	0.02	3.30	200	200
SW16	8.46	872.80	643.2	44.0	184.0	744.0	24.0	83.00	3.20	0.014	2.40	60	40
SW17	6.68	102.50	68.14	37.0	44.0	56.0	13.0	27.00	0.90	0.012	0.40	0	0
SW18	6.72	1141.86	732.19	29.33	86.67	554.67	48.45	218.78	3.63	0.013	3.33	200	200
SW19	8.81	1498.00	1062	39.0	182	896.0	48.45	112.78	11.63	0.033	4.20	200	200

TABLE D-6: Field results of the levels of physical, chemical and microbiological parameters in surface water sources

(March, 2011)

Sample code	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (ppm)	HARD. (mg/l)	CL. (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	P0 ₄ ³⁻ (mg/l)	T.coli counts/100 ml	F. coli counts/100 ml
SW1	7.29	391.98	315.0	12.00	123.0	208.0	19.33	32.0	0.73	0.042	0.004	37	41

SW2	8.40	572.00	284.0	14.00	274.0	124.0	5.62	61.0	7.00	0.020	1.60	200	200
SW3	9.03	1482.6	1094.7	27.00	229.0	476.0	30.0	92.0	5.86	0.032	0.24	64	43
SW4	8.41	653.00	310.0	22.00	236.0	304.0	5.70	121.0	11.8	0.030	0.70	200	200
SW5	8.18	360.00	170.0	117.00	214.0	404.0	3.40	27.0	7.00	0.020	0.10	120	65
SW6	7.60	80.00	40.0	66.00	176.0	116.0	2.90	12.0	11.0	0.070	2.70	200	200
SW7	8.05	345.60	210.3	24.00	105.0	167.0	5.30	178.0	4.20	0.014	0.40	140	76
SW8	7.15	108.00	75.00	17.00	42.00	73.00	1.40	19.00	5.20	0.027	0.100	85.00	5.00
SW9	8.41	39.14	19.6	14.00	78.0	82.0	3.50	7.05	12.0	0.019	0.50	112	67
SW10	7.45	930.48	475.3	8.00	42.0	192.0	24.0	120.10	11.0	0.030	1.04	45	200
SW11	7.78	610.30	312.6	6.00	236.0	178.0	0.50	48.0	4.0	0.010	2.20	120	10
SW12	7.77	60.00	30.00	146.0	184.0	142.0	31.0	15.0	3.60	0.090	3.10	200	200
SW13	7.40	221.00	112.0	13.0	57.80	237.0	5.60	28.0	3.20	0.029	0.01	22	8
SW14	8.08	1010.00	500.7	1240.0	294.0	464.0	8.00	120.0	8.00	0.040	2.10	200	200
SW15	8.78	1980.00	990.0	23.0	304.0	800.0	15.0	118.0	6.12	0.020	3.30	200	200
SW16	7.89	989.50	512.0	28.0	112.0	506.0	12.0	67.0	2.10	0.012	2.40	55	20
SW17	7.53	100.00	50.0	29.0	110.0	100.0	1.20	5.0	8.00	0.030	0.90	0	0
SW18	7.60	30.00	10.0	6.0	294.0	464.0	2.50	9.0	13.0	0.016	0.82	4	5
SW19	9.28	1512	1206	48.0	231.0	949.0	33.0	134.0	10.0	0.041	3.62	200	200

TABLE D-7: Field measured results of the levels of heavy metals in the Surface water sources (October, 2010)

Sample code	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						CN-(Free)
	As	Fe	Cu	Pb	Zn	Cd	
SW1	0.423	0.039	0.004	0.017	0.004	0.002	0.001
SW2	1.012	0.119	0.004	0.014	0.004	0.002	0.001
SW3	0.007	0.016	0.004	0.016	0.004	0.002	0.001
SW4	1.139	1.309	0.004	0.058	0.004	0.002	0.001
SW5	0.423	0.035	0.004	0.016	0.004	0.002	0.001
SW6	0.389	2.591	0.004	0.004	0.004	0.002	0.001
SW7	0.444	0.999	0.004	0.018	0.004	0.002	0.001
SW8	0.004	1.638	0.004	0.006	0.004	0.002	0.001
SW9	0.322	1.389	0.004	0.021	0.004	0.002	0.001
SW10	0.391	0.243	0.004	0.052	0.004	0.002	0.001
SW11	0.611	0.039	0.004	0.050	0.007	0.002	0.001
SW12	0.476	2.939	0.004	0.028	0.004	0.002	0.001
SW13	0.129	0.234	0.004	0.089	0.004	0.002	0.001
SW14	1.169	0.021	0.004	0.040	0.004	0.006	0.004
SW15	1.284	0.212	0.004	0.015	0.004	0.002	0.001
SW16	0.612	0.006	0.004	0.004	0.004	0.002	0.001

SW17	0.004	0.212	0.004	0.004	0.004	0.002	0.001
SW18	0.447	0.072	0.004	0.016	0.004	0.002	0.001
SW19	0.423	0.624	0.004	0.413	0.004	0.002	0.001

Table D-8: Field measured levels of heavy metals in the Surface water sources (November, 2010)

Sample code	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						CN-(Free)
	As	Fe	Cu	Pb	Zn	Cd	
SW1	0.216	0.438	0.004	0.006	0.004	0.002	0.001
SW2	0.599	0.625	0.004	0.034	0.004	0.002	0.001
SW3	0.021	0.006	0.004	0.009	0.004	0.002	0.001
SW4	1.894	0.870	0.004	0.018	0.004	0.002	0.001
SW5	0.012	0.004	0.004	0.008	0.004	0.002	0.001
SW6	0.119	3.506	0.004	0.019	0.004	0.002	0.001
SW7	0.131	5.727	0.004	0.022	0.004	0.002	0.001
SW8	0.004	1.293	0.004	0.001	0.004	0.002	0.001
SW9	0.110	1.905	0.004	0.032	0.004	0.002	0.001
SW10	0.004	0.004	0.004	0.049	0.004	0.002	0.001
SW11	0.374	0.243	0.004	0.060	0.004	0.002	0.001
SW12	0.101	4.701	0.004	0.033	0.004	0.002	0.001
SW13	0.086	0.712	0.004	0.057	0.004	0.002	0.001
SW14	1.676	0.031	0.004	0.050	0.004	0.002	0.001
SW15	1.825	0.374	0.004	0.028	0.004	0.002	0.001
SW16	0.812	0.007	0.004	0.017	0.004	0.002	0.001
SW17	0.007	0.374	0.004	0.004	0.004	0.002	0.001
SW18	0.004	0.004	0.004	0.018	0.004	0.002	0.001
SW19	0.025	0.225	0.004	0.212	0.004	0.002	0.001

Table D-9: Field results for levels of heavy metals in the Surface water sources (December, 2010)

Sample code	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						CN-(Free)
	As	Fe	Cu	Pb	Zn	Cd	
SW1	0.118	0.634	0.004	0.004	0.004	0.002	0.001
SW2	0.244	0.748	0.004	0.022	0.004	0.002	0.001
SW3	0.312	0.065	0.004	0.028	0.004	0.002	0.001
SW4	0.621	0.521	0.004	0.067	0.004	0.002	0.001
SW5	0.023	0.018	0.004	0.004	0.004	0.002	0.001

SW6	0.018	1.873	0.004	0.009	0.004	0.002	0.001
SW7	0.216	4.703	0.004	0.003	0.006	0.007	0.001
SW8	0.004	0.705	0.004	0.021	0.004	0.002	0.001
SW9	0.205	2.417	0.004	0.019	0.004	0.002	0.001
SW10	0.112	0.173	0.004	0.036	0.004	0.002	0.001
SW11	0.284	0.076	0.004	0.039	0.005	0.002	0.001
SW12	0.012	3.608	0.004	0.019	0.004	0.002	0.001
SW13	0.047	0.615	0.004	0.029	0.004	0.002	0.001
SW14	1.423	0.047	0.007	0.038	0.004	0.002	0.001
SW15	1.676	0.031	0.004	0.050	0.004	0.002	0.001
SW16	0.205	0.021	0.004	0.006	0.005	0.002	0.001
SW17	0.004	0.018	0.004	0.007	0.004	0.002	0.001
SW18	0.054	0.019	0.004	0.011	0.004	0.002	0.001
SW19	0.029	0.084	0.004	0.311	0.004	0.002	0.001

Table D-10: Mean levels of heavy metals in the Surface water sources (January, 2011)

Sample code	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						
	As	Fe	Cu	Pb	Zn	Cd	CN-(Free)
SW1	0.112	0.572	0.004	0.011	0.005	0.002	0.001
SW2	0.330	0.700	0.040	0.046	0.031	0.006	0.001
SW3	0.014	0.323	0.004	0.021	0.004	0.004	0.001
SW4	0.338	0.974	0.004	0.095	0.004	0.006	0.001
SW5	0.013	0.999	0.004	0.012	0.007	0.004	0.001
SW6	0.017	1.983	0.005	0.043	0.004	0.004	0.001
SW7	0.143	2.802	0.004	0.121	0.004	0.004	0.001
SW8	0.004	0.705	0.004	0.009	0.004	0.004	0.001
SW9	0.112	3.007	0.014	0.029	0.004	0.004	0.001
SW10	0.081	0.199	0.004	0.049	0.004	0.004	0.001
SW11	0.118	0.996	0.004	0.045	0.012	0.004	0.001
SW12	0.004	4.701	0.004	0.025	0.004	0.004	0.001
SW13	0.139	0.800	0.004	0.004	0.113	0.004	0.001
SW14	1.157	0.328	0.027	0.004	0.004	0.004	0.001
SW15	0.998	0.064	0.002	0.035	0.004	0.004	0.001
SW16	0.312	0.032	0.004	0.002	0.004	0.004	0.001
SW17	0.004	0.120	0.004	0.015	0.004	0.004	0.001
SW18	0.030	1.101	0.004	0.048	0.004	0.004	0.001
SW19	0.044	0.018	0.004	0.009	0.004	0.004	0.001

Table D-11: Mean levels of heavy metals in the Surface water sources (February, 2011)

Sample code	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						CN-(Free)
	As	Fe	Cu	Pb	Zn	Cd	
SW1	0.416	0.771	0.004	0.021	0.003	0.002	0.001
SW2	0.628	0.848	0.030	0.147	0.028	0.008	0.001
SW3	0.049	0.127	0.004	0.045	0.004	0.004	0.001
SW4	1.423	1.200	0.004	0.056	0.050	0.016	0.001
SW5	0.009	1.205	0.004	0.027	0.018	0.004	0.001
SW6	0.004	1.722	0.004	0.005	0.004	0.004	0.001
SW7	0.004	1.837	0.009	0.019	0.004	0.004	0.001
SW8	0.004	3.202	0.004	0.032	0.004	0.004	0.001
SW9	0.004	2.002	0.014	0.056	0.004	0.004	0.001
SW10	0.380	0.548	0.007	0.073	0.004	0.015	0.001
SW11	0.245	0.186	0.004	0.007	0.004	0.004	0.001
SW12	0.004	6.209	0.004	0.046	0.004	0.004	0.001
SW13	0.026	1.016	0.004	0.102	0.088	0.004	0.001
SW14	0.969	0.866	0.004	0.102	0.004	0.004	0.001
SW15	1.236	0.039	0.073	0.004	0.004	0.004	0.001
SW16	0.470	0.075	0.004	0.004	0.004	0.004	0.001
SW17	0.007	0.374	0.004	0.008	0.004	0.004	0.001
SW18	0.004	2.072	0.004	0.015	0.004	0.004	0.001
SW19	0.067	0.086	0.004	0.012	0.004	0.004	0.001

Table D-12: Mean levels of heavy metals in the Surface water sources (March, 2011)

Sample code	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						CN-(Free)
	As	Fe	Cu	Pb	Zn	Cd	
SW1	0.031	0.512	0.004	0.006	0.004	0.002	0.001
SW2	0.550	0.681	0.110	0.041	0.028	0.008	0.001
SW3	0.034	0.075	0.004	0.030	0.004	0.006	0.001
SW4	2.650	0.357	0.004	0.073	0.040	0.016	0.001

SW5	0.004	1.651	0.004	0.045	0.027	0.004	0.001
SW6	0.012	4.317	0.006	0.070	0.033	0.012	0.001
SW7	0.019	6.570	0.006	0.046	0.004	0.007	0.001
SW8	0.004	0.004	0.004	0.016	0.004	0.004	0.001
SW9	0.006	1.219	0.006	0.018	0.006	0.037	0.001
SW10	0.004	0.218	0.007	0.043	0.004	0.015	0.001
SW11	0.004	1.136	0.014	0.022	0.038	0.010	0.001
SW12	0.004	5.668	0.006	0.075	0.034	0.011	0.001
SW13	0.121	0.667	0.005	0.138	0.043	0.004	0.001
SW14	1.160	4.037	0.003	0.142	0.011	0.009	0.001
SW15	1.086	0.488	0.003	0.163	0.012	0.023	0.001
SW16	0.543	0.026	0.004	0.006	0.004	0.004	0.001
SW17	0.004	3.846	0.008	0.034	0.014	0.006	0.001
SW18	0.004	2.072	0.004	0.035	0.004	0.004	0.001
SW19	0.063	0.126	0.004	0.206	0.004	0.002	0.001

Table D-13: Field results of the levels of physical, chemical and microbiological parameters in ground- water (October, 2010)

Sample code	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (mg/l)	HARD. (mg/l)	CL- (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	P0 ₄ ³⁻ (mg/l)	T. coli counts/100 ml	F. coli counts/100 ml
GW1	5.06	49.0	20.0	3.00	24.0	14.0	8.0	13.0	0.30	0.005	0.004	0.00	0.00
GW2	5.15	45.60	30.0	24.0	10.0	16	9.0	19.0	0.19	0.042	0.004	0.00	0.00
GW3	5.53	187.3	79.0	4.0	59.0	66	9.0	18.0	0.60	0.006	0.004	21.00	12.00
GW4	5.20	357.0	212.0	6.0	112	152	43	74	0.20	0.014	0.004	4.00	8.00
GW5	4.90	62.5	42.21	8.0	6.0	14.0	7.2	17.12	0.73	0.005	0.004	0.00	0.00
GW6	6.93	50.0	20.0	3.0	62.0	26.0	8.0	20.0	0.30	0.006	0.004	0.00	0.00
GW7	6.02	72.50	36.12	17.0	69.0	34.0	11.0	17.0	0.18	0.031	0.004	55.0	50.0
GW8	5.46	85.14	39.25	18.0	83.50	88.00	29.50	16.50	2.20	0.020	0.004	0.00	0.00
GW9	4.84	76.03	41.29	40.0	27.00	14.00	10.00	26.02	1.30	0.015	0.004	0.00	0.00
GW10	5.20	63.46	25.00	30.0	25.0	10.00	25.00	10.00	14.00	18.00	0.004	45.00	12.00
GW11	5.28	87.00	64.90	8.0	34.0	12.0	11.73	16.97	4.00	0.010	0.004	80.0	20.0
GW12	5.60	30.0	12.0	3.0	10.0	16.0	8.40	11.03	0.18	24.0	0.004	0.0	0.0
GW13	5.60	31.82	12.40	3.0	9.0	15.64	7.20	9.00	0.30	0.009	0.004	0.0	0.0
GW14	4.98	702.11	419.06	30.67	111.0	283.33	39.67	121.40	1.51	0.024	0.004	142	117
GW15	5.00	461.83	329.41	24.0	119.0	154.70	22.00	79.0	2.8	0.019	0.004	0	0
GW16	5.76	296.08	145.3	6.0	57.0	5.30	12.04	17.0	1.40	0.032	0.13	40.0	5.0
GW17	6.10	50.41	22.80	54.0	24.0	60.0	28.0	36.0	18.0	0.032	0.14	200	120

GW18	5.24	74.54	43.20	5.0	37.0	79.0	12.0	17.0	1.60	0.071	0.16	0.0	0.0
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Table D-14: Field results of the levels of physical, chemical and microbiological parameters in ground- water sources ,(November, 2010)

Sample code	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (mg/l)	HARD. (mg/l)	CL- (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	P0 ₄ ³⁻ (mg/l)	T. coli counts/100 ml	F. coli counts/100 ml
GW1	5.12	92.40	68.0	35.0	27.0	39.0	12.0	35.0	2.10	0.009	0.15	0	0
GW2	4.90	49.58	30.47	63.0	27.0	40.0	13.0	20.0	0.30	0.011	0.15	0	0
GW3	5.55	196.20	130.40	54.0	61.0	100.0	13.0	18.6	1.30	0.121	0.012	66.0	0
GW4	5.96	413.80	274.8	35.0	138	172.0	52.45	91.0	0.30	0.210	0.004	32.0	3.0
GW5	5.14	92.20	62.53	14.0	12.80	22.20	11.30	31.0	1.20	0.007	0.004	0.0	0.0
GW6	5.96	192.40	127.80	35.0	94.0	74.0	12.0	14.0	0.40	0.009	0.004	0.0	0.0
GW7	5.89	87.19	48.63	33.0	58.0	24.0	8.20	10.03	0.52	0.023	0.004	110.0	60.0
GW8	5.56	107.95	55.29	14.55	84.32	84.34	21.34	18.50	1.98	0.022	0.004	2.00	0.00
GW9	5.97	218.20	144.60	48.0	138.0	34.0	11.04	18.0	0.20	0.007	0.004	0.0	0.0
GW10	5.08	61.84	41.36	56.0	46.30	17.20	8.10	12.0	0.30	0.041	0.12	90.0	18.0
GW11	5.20	60.80	31.56	58.0	30.0	28.0	9.40	35.23	3.20	0.002	2.50	86	30
GW12	5.10	48.88	31.74	48.0	26.30	14.80	12.0	8.0	2.00	42.0	0.08	0	0
GW13	5.26	55.08	38.03	41.0	26.90	23.60	11.0	15.20	0.40	0.018	0.02	0	0
GW14	4.72	678.98	282.41	31.0	128.0	261	30.25	140.0	1.20	0.008	0.12	140	110
GW15	5.12	387.83	249.41	184.0	89.0	114.70	12.00	56.0	3.8	0.019	0.004	0	0
GW16	5.76	296.08	145.3	6.0	57.0	5.30	12.04	17.0	1.40	0.032	0.13	40.0	5.0
GW17	5.20	590.70	391.90	29.0	21.0	14.0	35.30	41.0	22.70	0.045	0.18	200.0	90.0
GW18	4.48	93.00	46.80	16.0	46	74	14.0	15.0	1.20	0.041	0.11	0.0	0.0

Table D-15: Field results of the levels of physical, chemical and microbiological parameters in ground- water sources

(December, 2010)

Sample code	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (mg/l)	HARD. (mg/l)	CL- (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	P0 ₄ ³⁻ (mg/l)	T. coli counts/100 ml	F. coli counts/100 ml
GW1	5.34	72.60	36.0	24.0	53.0	48.9	10.0	16.0	2.50	0.007	0.15	0.0	0.0
GW2	4.85	65.84	44.42	25.0	6.0	14.0	11.0	23.0	1.40	0.028	0.12	0.0	0.0
GW3	5.97	256.8	170.80	42.0	100.0	82.0	7.0	48.40	1.50	0.025	0.11	21.0	12.0
GW4	5.42	287.0	179.0	26.0	98.0	139	30.55	112.0	0.60	0.320	0.15	28.0	10.0
GW5	5.50	54.30	32.0	9.0	28.0	17.0	20.70	24.0	1.90	0.008		0.0	0.0
GW6	6.05	73.0	43.0	24.0	58.0	63.0	10.0	17.0	0.20	0.007		0.0	0.0
GW7	5.73	129.80	85.44	21.0	74.0	41.0	12.80	15.70	0.81	0.021		200.0	200.0

GW8	5.44	128.95	64.45	7.50	77.50	82.0	11.50	18.50	1.45	0.025	0.16	7.0	0.0
GW9	5.13	154.50	73.21	16.0	36.0	17.0	14.66	14.0	1.50	0.019	0.15	0.0	0.0
GW10	5.50	82.60	41.40	5.0	56.70	50.80	12.0	8.0	0.50	0.029	0.16	3.0	0.0
GW11	5.05	76.0	46.30	47.0	58.0	62.0	14.60	12.0	5.70	0.005	0.18	64.0	0.0
GW12	5.40	24.50	10.0	26.0	18.70	12.20	10.60	15.70	2.50	31.77	0.12	0.0	0.0
GW13	5.04	58.60	29.40	23.0	18.0	27.0	8.80	12.0	0.20	0.012	0.15	0.0	0.0
GW14	5.09	802.18	183.37	29.0	96.0	172.0	28.75	98.0	1.56	0.022	0.15	85.0	42.0
GW15	5.75	161.83	79.41	2.0	67.0	91.70	15.60	47.0	2.8	0.019	0.004	0	0
GW16	5.76	296.08	145.3	6.0	57.0	5.30	12.04	17.0	1.40	0.032	0.13	40.0	5.0
GW17	5.67	112.0	87.40	42.0	31.0	57.20	42.71	67.0	17.30	0.026		140.0	65.0
GW18	5.30	68.10	34.10	21.0	25.0	58.0	9.0	13.0	3.5	0.032	0.09	0.00	0.00

Table D-16: Field results of the levels of physical, chemical and microbiological parameters in ground- water sources

(January, 2011)

Sample code	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (mg/l)	HARD. (mg/l)	CL. (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	PO ₄ ³⁻ (mg/l)	T. coli counts/100ml	F. coli counts/100ml
GW1	7.52	112.0	67.0	12.0	21.0	94.0	5.0	12.0	6.70	0.020	0.004	0.0	0.0
GW2	7.30	42.60	28.30	20.0	43.0	112.0	0.70	6.20	2.50	0.008	0.004	45.0	5.0
GW3	7.45	312.21	193.12	12.0	53.0	79.0	0.90	6.40	7.90	0.013	0.004	31.0	8.0
GW4	7.53	512.0	376.0	24.0	128.0	245.0	6.0	139.0	8.70	0.041	0.004	12.0	0.0
GW5	7.18	174.0	74.40	36.0	130.0	110.0	0.20	8.10	3.90	0.01	0.40	0.0	0.0
GW6	7.89	124.74	68.00	14.0	174.0	217.0	0.18	4.00	7.0	0.009	0.004	0.00	0.00
GW7	7.03	107.0	65.22	12.0	89.0	53.0	0.2	9.0	4.2	0.02	0.90	55.0	0.0
GW8	7.74	167.0	104.0	29.5	98.37	152.0	1.20	7.90	10.20	0.021	0.205	125.0	5.0
GW9	6.90	170.0	80.0	16.0	156.0	108.0	0.40	14.0	7.00	0.01	0.10	0.0	0.0
GW10	7.21	112.3	65.0	33.0	99.0	98.0	4.20	6.0	2.70	0.052	0.11	0.0	0.0
GW11	6.81	171.0	110.0	26.0	43.0	87.0	7.50	9.0	17.0	0.032	0.31	12.0	0.0
GW12	7.45	40.0	27.0	5.0	46.0	102.0	2.80	6.20	7.30	32.01	0.33	0.0	0.0
GW13	7.28	132.70	98.99	34.0	48.0	74.0	2.00	8.0	4.20	0.018	0.12	0.0	0.0

GW14	6.69	998.32	612.0	11.0	99.0	430.0	9.0	58.40	14.0	0.020	0.19	53.0	12.0
GW15	7.80	573	345.63	21.0	112.0	338.0	0.40	53.0	23.0	0.029	0.17	200.0	200.0
GW16	7.03	551.70	336.90	14	89.0	154.0	4.1	27.0	11.6	0.041	0.004	26	17
GW17	6.78	80.0	45.0	33.0	45.0	67.0	0.40	70.0	61.0	0.312	0.15	112	22.0
GW18	8.05	86.0	43.0	10.0	57.0	123.0	8.0	9.40	9.40	5.20	0.17	0.0	0.0

Table D-17: Field results of the levels of physical, chemical and microbiological parameters in ground- water sources (February, 2011)

	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (mg/l)	HARD. (mg/l)	CL- (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	PO ₄ ³⁻ (mg/l)	T. coli counts/10 0ml	F. coli counts/1 00ml
GW1	9.04	196.57	142.1	14.0	34.0	112.0	1.60	8.00	12.80	0.034	0.20	0.00	0.00
GW2	8.03	55.87	38.83	49.0	276.0	204.0	1.20	9.00	2.80	0.026	0.20	0.00	0.00
GW3	8.66	207.89	149.70	34.0	280.0	100.0	0.30	5.20	5.50	0.016	0.02	40.0	25.0
GW4	8.41	443.10	321.1	38.0	172.0	232.0	12.0	150.0	3.20	0.029	0.12	43.0	0.00
GW5	6.64	192.0	104.0	18.0	100.0	64.0	0.40	3.70	6.30	0.040	0.10	24.0	0.00
GW6	9.04	196.57	142.10	34.0	256.0	203.0	0.70	6.00	2.80	0.018	0.12	30.0	22.0
GW7	7.31	124.10	97.95	52.0	221.0	80.0	0.90	7.10	3.20	0.024	0.70	23.00	0.00
GW8	7.91	192.0	134.85	38.50	255.0	195.0	0.66	11.92	3.78	0.028	0.29	100.00	17.00
GW9	7.61	41.29	30.95	69.0	68.0	86.0	0.39	6.03	5.00	0.020	0.15	0.00	0.00
GW10	7.09	63.51	47.68	39.0	34.0	140.0	0.50	4.00	3.20	0.036	0.25	0.00	0.00
GW11	7.05	166.50	124.40	41.0	28.0	188.0	3.10	10.70	30.01	0.022	0.30	60.00	0.00
GW12	7.22	56.63	42.31	24.0	52.0	78.0	4.20	3.60	5.10	81.02	0.28	0.00	0.00
GW13	7.34	134.90	100.60	5.0	56.0	121.0	0.90	6.98	3.20	0.019	0.16	0.00	0.00
GW14	7.27	1175.0	870.0	44.0	80.0	496.0	4.20	49.60	28.0	0.025	0.20	120.00	30.00
GW15	7.20	672.0	412.0	38.0	248.0	260.0	0.50	47.0	14.0	0.023	0.40	90.00	20.00
GW16	7.85	493.1	278.9	34.0	124.0	181	9.1	17.0	5.80	0.062	0.004	17	9
GW17	7.20	275.51	198.70	41.0	14.0	84.0	0.90	124.0	33.0	0.249	0.120	120.00	40.00
GW18	7.89	121.0	74.80	32.0	42.0	112.0	0.17	11.77	7.40	0.087	0.130	10.00	5.00

Table D-18: Field results of the levels of physical, chemical and microbiological parameters in ground- water sources (March, 2011)

Sample code	PH (units)	Cond (us/cm)	TDS (mg/l)	TSS (mg/l)	ALK. (ppm)	HARD. (mg/l)	CL. (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	P0 ₄₃ (mg/l)	T. coli counts/100ml	F. coli counts/100ml
GW1	5.87	60.00	30.00	21.0	28.0	128.0	0.90	5.0	13.0	0.040	1.200	0.0	0.0
GW2	6.24	10.08	6.02	5.0	50.0	184.0	0.30	1.80	6.00	0.010	0.40	74.0	10.0
GW3	6.53	160.0	80.00	4.0	100.0	64.0	0.80	2.38	4.00	0.010	0.012	115	0.0
GW4	6.98	402.10	198.07	5.0	174.0	308.0	8.00	80.0	5.00	0.030	0.20	142.0	0.0
GW5	7.28	146.0	62.0	48.0	256.0	140.0	0.30	6.20	5.60	0.014	0.28	0.0	0.0
GW6	6.88	160.0	80.0	17.0	124.0	137.20	0.38	3.00	5.40	0.020	0.30	0.0	0.0
GW7	6.38	87.42	43.0	6.0	178.0	108.0	0.50	3.90	7.00	0.018	0.40	34.0	0.0
GW8	6.60	269.0	151.32	21.0	209.60	219.0	0.34	6.19	4.25	0.040	0.20	116.0	19.5
GW9	5.68	100.0	50.0	11.0	120.07	64.0	0.70	6.97	4.20	0.020	0.20	0.0	0.0
GW10	6.62	102.7	50.01	16.0	98.0	128.0	0.40	2.00	6.80	0.016	0.40	0.0	0.0
GW11	6.22	112.40	60.00	9.00	53.0	129.0	0.20	3.00	5.10	0.025	0.10	200.0	16.0
GW12	6.26	10.0	4.8	7.0	46	192	0.30	3.4	7.05	0.010	0.40	0.0	0.0
GW13	7.58	66.70	41.80	12.0	31.0	63.0	1.42	4.12	4.70	0.029	0.04	0.0	0.0
GW14	7.33	875.0	503.0	49.0	262.0	484.0	2.80	35.0	4.70	0.040	0.10	0.0	0.0
GW15	8.02	781.0	418.80	41.0	248.0	556.0	0.90	96.0	23.0	0.062	0.40	55.0	45.0
GW16	6.64	392.0	214.0	11.0	55.0	52.0	2.70	6.0	6.20	0.032	0.004	20	15
GW17	4.88	615.80	413.50	28.0	22.0	184.0	0.30	24.0	30.0	0.02	0.10	67.0	0.0
GW18	7.24	128.50	98.14	50.0	66.0	156.0	0.13	6.03	12.0	0.14	0.20	0.0	0.0

Table D-19: Field measured results of the heavy metals in the Ground water sources (October, 2010)

Sample code	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						CN-(Free)
	As	Fe	Cu	Pb	Zn	Cd	
GW1	0.473	0.004	0.004	0.016	0.004	0.002	0.001
GW2	0.424	0.004	0.004	0.028	0.004	0.002	0.001
GW3	0.417	0.040	0.014	0.004	0.007	0.002	0.001
GW4	0.201	0.004	0.004	0.025	0.004	0.002	0.001
GW5	0.004	1.212	0.004	0.045	0.004	0.002	0.001
GW6	0.473	0.004	0.004	0.016	0.004	0.002	0.001
GW7	0.217	0.004	0.014	0.032	0.004	0.002	0.001
GW8	0.316	0.039	0.005	0.086	0.004	0.002	0.001
GW9	0.099	0.004	0.006	0.027	0.004	0.002	0.001
GW10	0.004	0.012	0.006	0.019	0.005	0.002	0.001
GW11	0.436	0.004	0.004	0.008	0.004	0.002	0.001
GW12	0.004	0.004	0.012	0.020	0.024	0.002	0.001

GW13	0.004	0.004	0.004	0.022	0.004	0.002	0.001
GW14	0.191	0.004	0.004	0.004	0.004	0.002	0.004
GW15	0.004	0.005	0.004	0.089	0.019	0.002	0.001
GW16	0.004	0.004	0.004	0.012	0.004	0.002	0.001
GW17	0.076	0.025	0.008	0.011	0.012	0.002	0.001
GW18	0.004	0.041	0.004	0.080	0.004	0.002	0.001

Table D-20: Field measured results of the heavy metals in the Ground water sources (November, 2010)

Sample code	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						
	As	Fe	Cu	Pb	Zn	Cd	CN-(Free)
GW1	0.004	0.104	0.004	0.026	0.004	0.002	0.001
GW2	0.004	0.004	0.014	0.011	0.005	0.002	0.001
GW3	0.004	0.086	0.006	0.037	0.004	0.002	0.001
GW4	0.130	0.004	0.004	0.025	0.004	0.002	0.001
GW5	0.004	0.998	0.004	0.018	0.004	0.002	0.001
GW6	0.473	0.004	0.004	0.016	0.004	0.002	0.001
GW7	0.011	0.004	0.004	0.004	0.004	0.002	0.001
GW8	0.024	0.050	0.005	0.053	0.004	0.002	0.001
GW9	0.026	0.024	0.009	0.048	0.004	0.002	0.001
GW10	0.004	0.004	0.009	0.026	0.008	0.002	0.001
GW11	0.033	0.050	0.004	0.023	0.004	0.005	0.001
GW12	0.004	0.004	0.008	0.015	0.018	0.002	0.001
GW13	0.004	0.004	0.004	0.033	0.004	0.002	0.001
GW14	0.379	0.028	0.004	0.059	0.004	0.006	0.004
GW15	0.458	0.032	0.004	0.156	0.009	0.002	0.001
GW16	0.004	0.195	0.004	0.018	0.004	0.002	0.001
GW17	0.004	0.004	0.018	0.062	0.021	0.002	0.001
GW18	0.004	0.170	0.004	0.041	0.004	0.002	0.001

Table D-21: Field measured results of the levels of heavy metals in the Ground water sources (December, 2010)

Sample code	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						
	As	Fe	Cu	Pb	Zn	Cd	CN-(Free)
GW1	0.208	0.019	0.004	0.016	0.004	0.002	0.001
GW2	0.018	0.004	0.017	0.024	0.007	0.002	0.001
GW3	0.224	0.032	0.004	0.022	0.004	0.002	0.001

GW4	0.011	0.071	0.004	0.018	0.004	0.004	0.001
GW5	0.004	1.378	0.004	0.009	0.004	0.002	0.001
GW6	0.208	0.019	0.004	0.018	0.004	0.002	0.001
GW7	0.206	0.070	0.004	0.056	0.004	0.002	0.001
GW8	0.168	0.026	0.004	0.066	0.004	0.002	0.001
GW9	0.166	0.004	0.004	0.008	0.004	0.002	0.001
GW10	0.004	0.015	0.004	0.011	0.006	0.002	0.001
GW11	0.004	0.020	0.006	0.062	0.004	0.002	0.001
GW12	0.004	0.006	0.009	0.018	0.031	0.002	0.001
GW13	0.004	0.004	0.004	0.011	0.004	0.002	0.001
GW14	0.021	0.006	0.004	0.032	0.004	0.006	0.004
GW15	0.018	0.016	0.004	0.029	0.004	0.002	0.001
GW16	0.004	0.072	0.004	0.011	0.004	0.002	0.001
GW17	0.004	0.011	0.006	0.032	0.017	0.002	0.001
GW18	0.004	0.007	0.004	0.012	0.004	0.002	0.001

Table D-22: Field measured results of the heavy metals in the Ground water sources (January, 2011)

Sample code	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						CN-(Free)
	As	Fe	Cu	Pb	Zn	Cd	
GW1	0.019	0.046	0.004	0.021	0.004	0.004	0.001
GW2	0.004	0.021	0.056	0.019	0.205	0.006	0.001
GW3	0.005	0.091	0.004	0.033	0.092	0.006	0.001
GW4	0.007	0.037	0.004	0.052	0.006	0.009	0.001
GW5	0.004	2.046	0.005	0.074	0.061	0.014	0.001
GW6	0.004	0.078	0.005	0.028	0.009	0.002	0.001
GW7	0.004	0.039	0.007	0.073	0.011	0.002	0.001
GW8	0.049	0.023	0.003	0.033	0.008	0.005	0.001
GW9	0.006	0.427	0.005	0.051	0.047	0.006	0.001
GW10	0.004	0.031	0.009	0.123	0.018	0.006	0.001
GW11	0.004	0.018	0.005	0.093	0.004	0.005	0.001
GW12	0.004	0.008	0.007	0.033	0.038	0.005	0.001
GW13	0.004	0.020	0.008	0.004	0.004	0.002	0.001
GW14	0.004	0.010	0.006	0.112	0.036	0.006	0.004
GW15	0.004	0.019	0.127	0.017	0.004	0.002	0.001
GW16	0.004	0.228	0.004	0.009	0.004	0.002	0.001
GW17	0.004	0.021	0.009	0.029	0.031	0.005	0.001
GW18	0.004	0.011	0.005	0.123	0.004	0.002	0.001

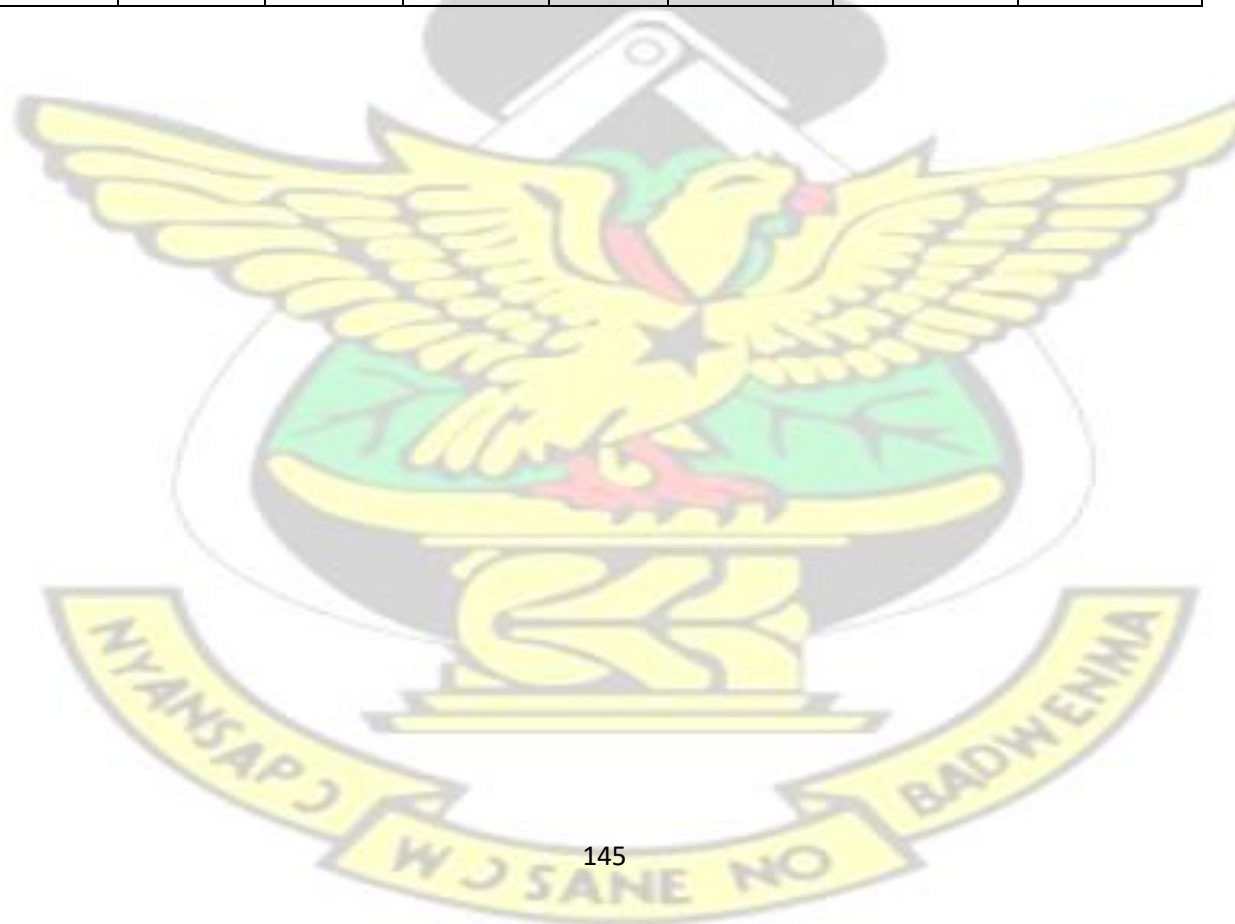
Table D-23: Field measured results of the levels heavy metals in the Ground water sources (February, 2011)

Sample code	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						
	As	Fe	Cu	Pb	Zn	Cd	CN-(Free)
GW1	0.009	0.312	0.005	0.038	0.019	0.003	0.001
GW2	0.004	0.060	0.164	0.178	0.401	0.002	0.001
GW3	0.004	0.047	0.004	0.047	0.140	0.005	0.001
GW4	0.164	0.065	0.004	0.151	0.004	0.002	0.001
GW5	0.004	1.032	0.007	0.046	0.024	0.007	0.001
GW6	0.004	0.063	0.017	0.004	0.352	0.002	0.001
GW7	0.004	0.067	0.006	0.102	0.024	0.002	0.001
GW8	0.189	0.129	0.005	0.129	0.004	0.002	0.001
GW9	0.004	0.228	0.007	0.132	0.004	0.002	0.001
GW10	0.004	0.025	0.113	0.139	0.014	0.002	0.001
GW11	0.004	0.034	0.007	0.162	0.026	0.002	0.001
GW12	0.004	0.025	0.004	0.102	0.071	0.002	0.001
GW13	0.004	0.036	0.004	0.125	0.004	0.002	0.001
GW14	0.004	0.052	0.004	0.147	0.021	0.006	0.004
GW15	0.004	0.035	0.004	0.186	0.013	0.002	0.001
GW16	0.004	0.009	0.004	0.011	0.004	0.006	0.001
GW17	0.004	0.034	0.169	0.145	0.026	0.002	0.001
GW18	0.004	0.038	0.004	0.029	0.004	0.002	0.001

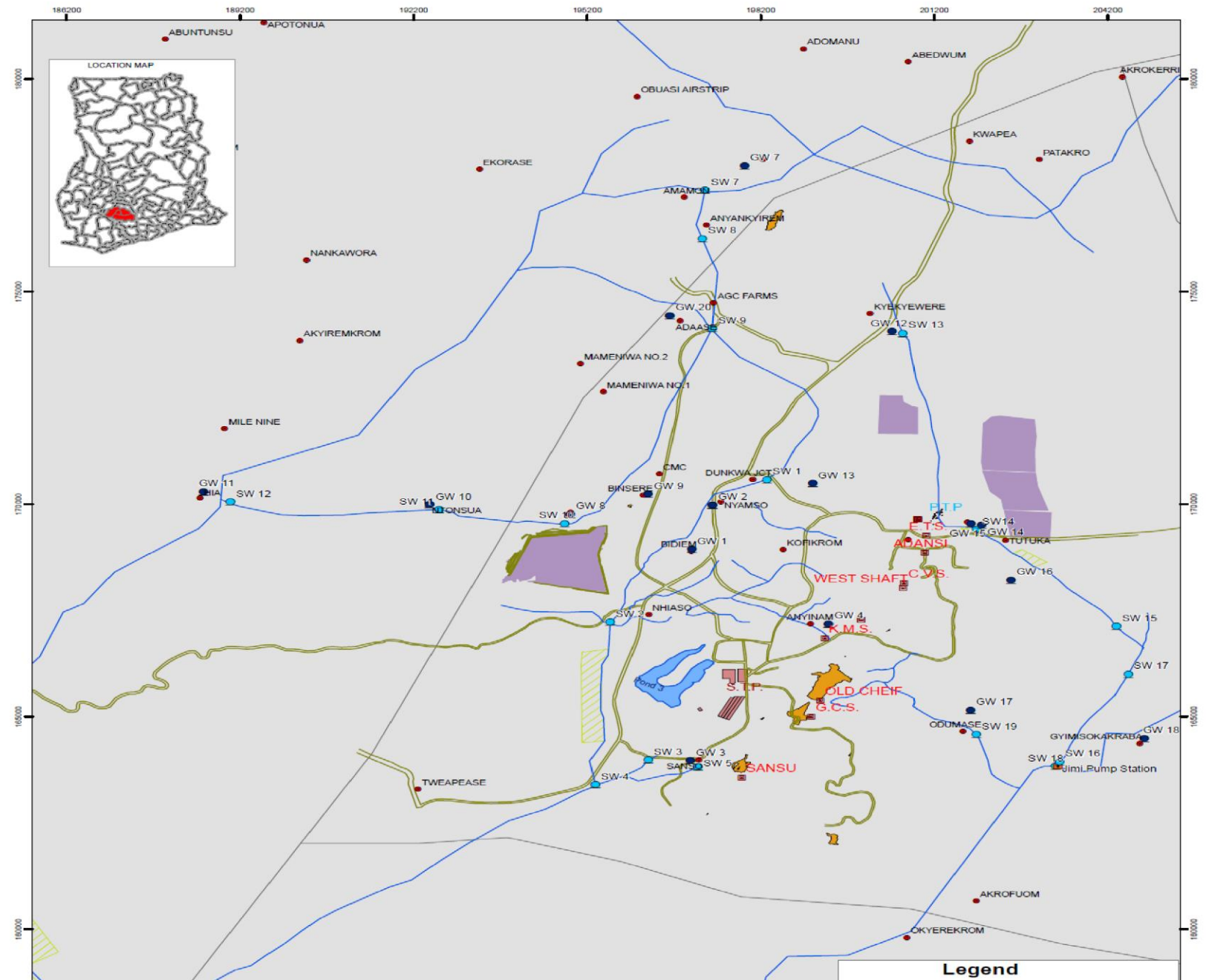
Table D-24: Field measured results of the heavy metals in the Groundwater sources (March, 2011)

Sample code	Concentration in mg/l for dissolved As, Fe, Pb, Cu, Zn and Cd						
	As	Fe	Cu	Pb	Zn	Cd	CN-(Free)
GW1	0.004	0.217	0.005	0.056	0.030	0.009	0.001
GW2	0.004	0.034	0.074	0.038	0.078	0.007	0.001
GW3	0.007	0.255	0.005	0.061	0.004	0.007	0.001
GW4	0.004	0.169	0.004	0.074	0.018	0.002	0.001
GW5	0.004	0.503	0.004	0.102	0.038	0.009	0.001
GW6	0.004	0.353	0.002	0.033	0.246	0.002	0.001

GW7	0.004	0.096	0.010	0.042	0.052	0.016	0.001
GW8	0.024	0.224	0.008	0.062	0.023	0.007	0.001
GW9	0.004	0.615	0.009	0.082	0.020	0.008	0.001
GW10	0.004	0.050	0.001	0.061	0.040	0.007	0.001
GW11	0.004	0.006	0.014	0.043	0.026	0.008	0.001
GW12	0.004	0.058	0.005	0.057	0.040	0.009	0.001
GW13	0.004	0.007	0.004	0.043	0.004	0.002	0.001
GW14	0.004	0.238	0.007	0.080	0.028	0.010	0.004
GW15	0.004	0.051	0.004	0.138	0.038	0.002	0.001
GW16	0.004	0.093	0.004	0.059	0.004	0.002	0.001
GW17	0.004	0.067	0.018	0.058	0.021	0.005	0.001
GW18	0.004	0.071	0.004	0.115	0.004	0.002	0.001



MAP OF THE STUDY AREA SHOWING SAMPLING POINTS

$$1 \text{ cm} = 720 \text{ m}$$


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