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POTABILITY OF SOME HAND DUG WELL WATER IN SOME SELECTED COMMUNITIES IN OBUASI

By

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DECLARATION

I hereby declare that this submission is my own work towards the M.Sc. and that, to the best of my knowledge, it contains no materials 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

This thesis is dedicated to God, my lovely husband Mr. Prince Peprah-Mensah and kids, Mishael and Audrey for their love and encouragements and also to my mother, Mrs. Mary Koomson who always encouraged me, saying 'you can make it' when the journey became tough.

Thanks a lot and God richly bless you all.

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It is my prayer that the Gracious Lord will open the flood gates of heaven and cause its rain to fall on you.

ABSTRACT

When water is talked of, its quality should not be undermined since it has great effects on man. Obuasi has been one of the towns whose water quality is always questioned due to the mining and other activities of theindigenes. It wastherefore necessary to ascertainhow potable some sources (precisely wellwater) of water for drinking were.In this work, a total of 27 well water samples were collected from three selected communities(Tutuka, Aboagyekrom, Kwabrafoso) in Obuasi township between February and April.The locations of the wells were considered during the choice of wells especially those close to waste water channels. The samples were analyzed formicrobiological parameters such as faecal coliform, total coliform, total heterotrophic bacteria and enterococci. The loads of total and faecal coliforns were as high as 9.5×10^5 and 2.2×10^5cfu100m/L respectively in some of the samples. Total heterotrophic bacteria were also present, with the least of 6.0×10^1cfu1m/L and the highest of 6.9×10^5cfu1m/L but enterococci were absent in all the water samples. Physicochemical parameters such as pH, Conductivity, Alkalinity, Total Dissolved solids, Total Suspended solids, Turbidity, Cyanide, Arsenic, Mercury, Cadmium and lead were analyzed. pH of the samples were mostly high and ranged between 4.16 and 6.97. The samples recorded turbidity and total suspended solids level between 0.00 and 79.50 and between 1.00 and 4.00 respectively. Total dissolved solids and conductivity levels were all below the WHO guideline values of 1000mg/L and 1500µS/cm respectively. Most of the samples had their alkalinity level below the WHO guideline value except samples from KWA7 which recorded the highest value of 2552.50mg/L.In terms of metals Lead concentration in the samples of well water ranged between 0.02mg/L and 0.18mg/L with the least exceeding the WHO guideline value for Lead (0.01mg/L).Cadmium also recorded some loads only within the first month (February) and ranged between 0.001mg/L and 0.020mg/L with most of its well waters exceeding the WHO standard value of 0.003mg/L. Concentration of Mercury were also high ranging from 0.00mg/L to 0.58mg/L exceeding the WHO guideline value of 0.01mg/L. As and CN were absent in all the samples.Considering the results it observed thatthe well waters were contaminated by microbes, trace metals and other suspended and dissolved solids. The accumulative nature of these metals could be very harmful to individuals who use these

waters as potable water. In conclusion, all the water samples could be recommended for washing and flushing of toilets but not for potable water.

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CHAPTER ONE

1.0 INTRODUCTION

Water is the common name applied to the liquid form (state) of the hydrogen and oxygen compound H_2O. Pure water is an odourless, tasteless, clear liquid. Water is one of nature's most important gifts to mankind. Essential to life, a person's survival depends on drinking water. Water is one of the most essential requirements to good health and it is necessary for the digestion and absorption of food; helps maintain proper muscle tone; supplies oxygen and nutrients to the cells; rids the body of wastes; and serves as a natural air conditioning system. Health officials emphasize the importance of drinking at least eight glasses of clean water each and every day to maintain good health(Wikipedia 2005).

Since water contains no calories and can serve as an appetite suppressant and helps the body metabolize stored fat, it may possibly be one of the most significant factors in losing weight (admin 2011). In his book, titled "The Snowbird Diet" Dr. Donald Robertson says the body will not function properly without enough water and discusses the importance of drinking plenty of water for permanent weight loss: “Drinking enough water is the best treatment for fluid retention; the overweight person needs more water than the thin one, water helps to maintain proper muscle tone and can help relieve constipation”(Robertson and Robertson 1986).

Water is a key component in determining the quality of our lives. Although water covers more than 70% of the Earth, only 1% of the Earth's water is available as a source of drinking (Wikipedia 2005), yet, our society continues to contaminate this precious resource. Water is known as a natural solvent because, before it reaches the consumer's tap, it comes into contact with many different substances, including organic and inorganic matter, chemicals, and other contaminants which it dissolves. Many public water systems treat water with chlorine to destroy disease-producing contaminants that may be present in the water. Although disinfection is an important step in the treatment of potable water, the taste and odour of chlorine is objectionable. The disinfectants that are used to prevent disease, can create byproducts which may pose significant health risks. Today, drinking water treatment at the point-of-use is a necessity and individuals are now determining the quality of the water they will drink by installing a drinking water system that will give them clean, refreshing, and healthier water. The freezing point of water is 0° C (32° F), and its boiling point is 100° C (212° F). Water reaches its maximum density at 4° C (39° F) and expands upon freezing. Water combines with salts to form hydrates and reacts with metal oxides to form acids. Water is the only substance that occurs at ordinary temperatures in all three states of matter: solid, liquid, and gas. As a solid(ice), it forms glaciers, frozen lakes and rivers, snow, hail, and frost. It is liquid as rain and dew, and it covers three-quarters of the earth's surface in swamps, lakes, rivers, and oceans. Water also occurs in the soil and beneath the earth's surface as a vast groundwater reservoir. As gas, or water vapour, it occurs as fog, steam, and clouds(Wikipedia 2005).

Water makes up 50 to 90 percent of the weight of living things. Protoplasm is a solution of water and fats, carbohydrates, proteins, and salts. Water transports, combines, and chemically breaks down these substances. Water also aids the metabolic breakdown of proteins and carbohydrates(Robertson and Robertson1986).

The continuous movement of water between the earth and the atmosphere is the hydrological cycle. Water vapour from water and land surfaces and from living cells circulates through the atmosphere and falls as rain or snow. When it reaches the earth, water either flows into streams and then into oceans or lakes, or it enters, or infiltrates the soil. Some water becomes soil moisture, which may evaporate directly or move up through the roots of plants and be released by leaves. Some water percolates downward, accumulating in the so-called zone of saturation to form the groundwater reservoir, the upper surface of which is the water table. Under natural conditions, the water table rises in response to inflowing water and then declines as water drains into natural outlets such as wells and springs (Alpha Omega Marketing 1996).

Water dissolves numerous substances in large amounts, pure water rarely occurs in nature. Precipitation absorbs carbon dioxide and other gases, as well as traces of organic and inorganic material from the atmosphere. It also reacts with minerals in the soil and rocks, surface and groundwater may contain many different dissolved substances such as heavy metals and salts. Surface waters may also contain domestic sewage and industrial wastes. Groundwater from shallow wells may contain nitrogen compounds and chlorides, but water from deep wells generally contains only dissolved minerals. Seawater contains many soluble compounds in addition to salt(Alpha Omega Marketing 1996).

Impurities in water are removed by screening, sedimentation, filtration, chlorination, or irradiation. Aeration saturates water with air, usually by spraying fountains of water into the air. Aeration removes odours and tastes caused by decomposing organic matter, industrial wastes, and some gases. Various salts and metals cause hardness in water. Hardness may be removed by boiling, by adding sodium carbonate and lime, or by filtering through natural or artificial zeolites(Alpha Omega Marketing1996).

1.1 UNDERGROUND WATER IN OBUASI

Most often, individuals located in polluted environments turn to complain or worry about pollution but tend to forget about it when its physical impact reduces. Unfortunately, some pollutants could stay in the environment for several days to years and in the process either get transformed to other more harmful forms or get transferred to other places especially when they find themselves in air or underground or surface water (Appiah 2008). The UN suggest that each person needs 20-50 litres of water a day to ensure his/her basic needs for drinking, cooking and cleaning. It continues to say that, developing countries have 70% of their untreated industrial wastes dumped into waters and pollute them. According to Wikipedia (2005), it was observed that by 2025, more than half of the worlds' population will be facing water-based vulnerability.

Mining is of fundamental importance to the economies of a number of countries including Ghana. The industry is however associated with serious environmental and health impacts. According to Agyapong (2005), the International Labour Organization describes mining as one of the world's most hazardous sectors, and is associated with about 15,000 deaths each year. In South Africa for instance, each tone of gold mined costs one life and 12 serious injuries (Agyapong, 2005).

In 2001, tailings dam burst at the Tarkwa gold mine in the Waasa West District of Ghana sent thousands of cubic meters of mine waste into the Asuman River contaminating it with cyanide and heavy metals. The disaster left more than one thousand people without access to drinking water. Eventually almost all the life forms in the river and its tributary were killed. Hundreds of dead fish, crabs and birds lied on the bank of the river and floated to the surface (Asad, 2003; Owusu-Koranteng, 2004).

According to the Friends of Earth Ghana Report (1995) the Kwabrafo River at Obuasi (runs through one of the selected communities, Kwabrafoso) in the Ashanti region has 38 times more arsenic than World Health Organization's (WHO) permissible levels whilst the Jimi river at Akrofrom also in the Ashanti region has 36 times more Arsenic. The Kwabrafo River is no more in use by indigenes of Obuasi town due to the improper application of Mercury in the processing of gold by illegal small scale miners known in the local parlance as "galamsey". The pollutants in these rivers seep into underground water resulting in its pollution.

Economic development, which has its ultimate goal as improving human welfare, is crucially dependent on the environment and its natural resources to provide goods and services which go a long way to either directly or indirectly generate socio-economic benefits. However, this economic growth is often accompanied by significant adverse impacts which can result in real losses in long-term potential and further, undermine the basic objective of development – the sustainable improvement of human welfare (ADB, 1986) cited in Obiri (2005)

1.2 PROBLEM STATEMENT

The mining industry has long been recognized as causing major environmental problems but never has there been such a public outcry against mining companies like what we are experiencing today(Allan, 1999).

Toxic chemicals such as Sodium Cyanide and Mercury are used to process the ore in order to extract metallic gold and they pose substantial hazard to human life. People living in and around the mines are exposed to harmful chemicals used in operations. All chemicals are toxic when absorbed at certain dosage. All chemicals are capable of altering some biological function or producing negative effects in some organisms or can succeed in destroying certain functions in the ecosystem.

Realizing the damage and effect of environmental pollution associated with mining in March 1998, the Government of Ghana initiated a major effort to put environmental issues on priority agenda with the initiation of the Environmental Action Plan (E.A.P) cited in Obiri (2005).

As the chemicals used in mining find themselves in water bodies or underground water, they begin to cause harm to indigenes after a long exposure. The most pronounced effect of mine waste on the environment has been on the quality of water in the principal river systems.

The above problem and those that have not been made public necessitates the essence of accessing the portability of some wells in Obuasi township i.e. a mining community)

1.3 OBJECTIVES OF THE STUDY

The main objective of the study was to access the microbiological and physico-chemical quality of water from wells in some selected communities in Obuasi township.

The specific objectives were to;

- analyze the total coliform, faecal coliform, total heterotrophic coliform in the samples of water.
- assess the pH, alkalinity, total dissolved solids, total suspended solids and conductivity of the water samples.
- assess the metallic levels of the samples of water(ie Mercury, Lead, Arsenic and Cadmium) and the presence of Cyanide.
- determine whether the closeness of some of the wells to waste water channels will influence its level of contamination.
- compare the quality of the samples with the EPA and WHO water quality standards.

1.4 JUSTIFICATION OF THE STUDY

The findings of the study will help the communities and mining companies to;

- become aware of the level of toxic chemical contamination that is present in the mining environs.
- become aware of the extent to which toxic chemicals released into the environment in the course of their operations affect the environs.
- improve on their mode of operation so as to minimize or avoid the release of harmful chemicals into the environment.

- speed up their fight to restore the degraded environment.
- obtain a blue print for effective monitoring and risk assessment of toxic chemicals from mining operations.

CHAPTER TWO

LITERATURE REVIEW

Africa's share of global fresh water resources is at 10% and this closely matches its share of world population of 12%. The tropical belt of mid-Africa has been characterised by abundant and in some cases, excessive sources of water (UN, 2003). Unfortunately, the freshwater situation in Africa is not encouraging. Presently, it is estimated that more than 300 million people in Africa live in a water-scarce environment and by 2025, 18 African countries are expected to experience water deficit. The amount of freshwater available for each person in Africa is about one-quarter of what it was in 1950 (Obasi, 2003).

The Ghanaian Chronicle issue of July 25, 2003, reported at a durbar of chiefs to mark the launching of World Environmental Day celebrations that, Ghana is listed among countries that would experience water deficit of 1700 cubic metres or less per person annually by 2025. Ghanaians establish their communities along rivers, forests and places where they could have access to agricultural lands or water bodies because of the nature of income generating activities of these communities. For this reason, many communities in Ghana are named after Rivers, Trees or Hills such as Subriso, Goaso, Praso, Bonsaso, Mangoase, Abekoase, Beposo, Kwabrafoso etc. Individuals have good reasons to live along natural resources especially in a developing economy as ours where provision of potable water and income generating activities are an illusion even for many urban communities. People perceive rivers, hills and forests as pure and revered as they play important roles in traditional customs and rituals. Rivers and Streams provide communities with water for cooking, drinking, farming, building and as a protector against potential calamities in addition to the aesthetic and recreational values they provide. Water is life, is a simple statement which embodies the importance of water to individuals, families, communities, nations and regions. Without adequate water, the human body cannot survive and when droughts surface, they create famine. In modern times, sustainable socio-economic progress is seldom possible without adequate development of water resources to support food production, industry, the environment and other human needs (Appiah 2008).

2.1 QUALITY OF WATER IN THE STUDY AREA

Availability of water is very crucial for sustaining life. In Ghana, many rural communities and some urban dwellers depend on underground water to meet their basic water needs. Just as water is very important, its quality is equally important. Some wells in Ghana are prone to high levels of infection and contamination by heavy metal contaminants due to poor management of waste, industrial activities, floods and natural causes such as rock formation. In Ghana, contaminations of surface andground water bodies have particularly been experienced in gold mining communities (Davies*et al*. 1994; Manu *et al.,* 2004; Kuma and Younger, 2004; Obiri, 2007). Gold

mining in recent times has become unpopular as it is regarded as a significant source of Hg, Pb and heavy metal contamination of the environment owing to activities such as mineral exploitation, ore transportation, smelting and refining, disposal of the tailings and waste waters around mines (Essuman *et al.*, 2007; Hanson *et al.*, 2007; Obiri, 2007; Singh, *et al.*, 2007)

The introduction of open cast gold mining in Obuasi since 1980s has had a lot of implications on fresh water protection because it introduces contaminants into the water bodies. The Obuasi and Tarkwa areas of Ghana have undulating topography and many writers {Amonoo-Neiser and Busari, (1980); Jetuah, (1997); Carbo and Sarfo-Armah, (1997); Clement *et al*., (1997)} believe that the development of extensive mining operations in ecologically sensitive areas with undulating topography would certainly give rise to environmental problems. The writers argued that government's intention to permit large scale surface mining in the country had devastating impact on water bodies in mining areas and mining has destroyed many communities' sources of water bringing with it unfathomable hardships. Very early in the history of surface mining in Ghana, Acquah, (1995) recounted freshwater resource depletion linking it to increased marginal cost of providing potable water, increased burden on women's time and hastening climate change. He stated that industries, including mining looked at fresh water as a free good which is exploited with lack of effective regulatory framework and had deforested headwaters because there was no incentive to conserve water.

According to Acquah (1995) degraded quality of fresh water had health implications and reduced labour productivity. He believed that the harm caused by surface mining transcends just the mere lack of access to potable water since there are other benefits that can never be quantified. Akabzaa *et al*., (2003) in hydro chemical analytical results of water bodies in Obuasi showed that streams in the study area are more polluted than groundwater, with the groundwater iron and arsenic values exceeding the maximum permissible WHO guidelines in some of the samples. Mining is an activity classified as most polluting as well as a drain on the dwindling water resources in the World. A study conducted by the Economic Commission for Africa (ECA)(1999) on the water situation in African countries specifically cited Ghana as being one of the most water-stressed countries. In Ghana, the effects of the activities of mining companies on our water bodies through dewatering, ground water pollution, the free use of water for mining operations, pollution of streams through cyanide and other waste spillages, are contributing enormously to impoverishing the communities who live around these areas. Pollution and destruction of water bodies in some cases has effects on community livelihoods and health status.

In June 1996, a spill at Teberebie Goldfields sent 36 million litres of cyanide solution into the Angonaben stream, a tributary of the Bonsa River. The spillage destroyed Cocoa trees and fishponds while the local people complained of skin rashes (Mining Watch, 2000). Since 1989, Ghana has recorded eight accidental cyanide spillages by mining companies and four of these which occurred in Wassa West District (Cyanide Investigative Committee, 2002) affected major water bodies. WACAM (2004) made a statement on a cyanide spillage of Bogoso Gold Limited (BGL), from a new tailings dam of the company into river Aprepre which links other rivers including Egya Nsiah, Benya and Manse. These rivers also flow into a bigger River Ankobra which in the long run affected Dumase town, and other communities like Goloto, Juaben, Kokofu and Egyabroni. The Environmental Protection Agency (EPA) investigation into the spillage confirmed WACAM's statement and the Executive Director of EPA, said the source of the sodium cyanide discharge was traced to a newly constructed tailings storage facility. WACAM's investigations indicatedthat the number of officially reported cyanide spillages had increased from eight between 1989 and 2002(Cyanide Investigative Committee's report) to about 13 cyanide spillages as at 2006 (Action Aid report, 2007).Evidence of water degradation due to mining is from the fact that while there is augmented concentrations of major and trace ions in water samples from Kwabrafoso, Tutuka, Dokyiwa and Sansu, all proximal to mine facilities, there is attenuation of the concentration of the parameters in streams further away from, and upstream of mining and processing facilities. The concentration of major and trace ions in samples from Amaamo, Fenaase and Adaase, all upstream of mining and processing facilities, are highly low and rarely exceed the WHO guideline values of the measured ions in waters from these communities. Similarly, a sample from the Jimi river, which also takes drainage from other streams far from mining activities, are relatively low due to dilution and sequestering of these elements in sediments. The spatial correlation between augmented metal concentrations and mining and processing facilities, and mine spoil sites suggest that mine waste sites constituent sources of these metals in drainage water. Microprobe analysis of rock samples taken from rock waste dumps and exposed outcrops in the area showed that the waste rocks contain a variety of base metal and metalloid bearing sulphides, together with carbonates (calcite, dolomite, ankerite, siderite), silicates and oxides. The analysis showed that sulphides content in waste rock samples ranged between 0.01% and 3.86% while carbonates ranged from 0.01% to 15%. This study put emphasis on the analysis of sulphide because they constitute the principal custodians of the toxic metals analysed in water samples. The probe results showed that sulphides exhibit strong compositional variation defined by their relative trace element content. Fe, As, Cu, Ni, Zn, Sb and Co-bearing varieties constitute the dominant sulphides(Obiri, 2005). According to Larocque and Rasmussen (1998), mine spoil, especially tailings environments are the sites of metal flux from the geosphere to the hydrosphere through dissolution of minerals. The exposure of rock strata to the atmosphere (air and water) promotes oxidation of the sulphides, leading to the discharge of the contained metals into local drainage.

2.2 MINING AS A PROCESS IN OBUASI

Mining is the removal of minerals from the earth's crust for the benefit of man (Down and Stock, 1977 cited in Acheampong, 2004). The Encarta encyclopaedia alsodefines mining as the selective recovery of minerals and materials, other than recently formed organic materials from the crust of the earth (Encarta, 2005).

Mining has also been defined as the extraction of valuable minerals or other geological materials from the earth, usually (but not always) from an ore body, vein, or (coal) seam. Materials recovered by mining include bauxite, coal, diamonds, iron, precious metals, lead, limestone, nickel, phosphate, rock salt, tin, uranium, and molybdenum. Mining in a wider sense can also include extraction of petroleum, natural gas, and even water (Wikipedia, 2006).

According to Obiri (2005), the gold bearing quartz rocks contains the ore. These rocks are found either on the surface or underground and are classified as;

Underground ore; this consist mostly of sulphides-pyrites (FeS_2) and arsenopyrites ($FeAsS$).

Surface ore; this consist of;

- oxides – mainly as iron oxides-hematite (α- Fe_2O_3) and Magnetite (Fe_3O_4)
- sulphides- mainly as pyrites &arsenopyrites.
- transition ore- partially oxidized sulphide forms a transition between the above 2 types of surface ore.
- old tailings; these are low- grade ores, which consist of dumped tailings from the processing of gold.

The gold is trapped in the crystal structure of the sulphides and the oxides (William and Burson, 1985). Underground mining could be put into 2 main forms, which are:

1. those that require some form of support such as pillars, these include open stopping and cut and fill.
2. those that require no support. These include long wall mining, sub level caving and block caving mining. In all these, the gold bearing ore is transported to the surface of the earth for processing.

Surface mining involves the development of physical structures to provide access to the mineralized zone. The liberation of the ore from the gold bearing rocks involves the blasting of the gold bearing rocks or open pit mining. The separated ore is then transported to processing plants for processing.

AGA (Obuasi) has five treatment plants (Coakley, 1996; Harvey *et.al.*, 1999) namely;

1. Pompora Treatment plant (PTP); processes refractory sulphide and carbonaceous ore and consists of crushing, milling, flotation, and roasting of the flotation concentrate.
2. Oxide Treatment plant (OTP) treats high grade surface oxide ore and consist of crushing, milling, and Carbon-in-Leach (CIL) facilities.
3. Heap Leach Plant (HLP, now idled) treats gold from old tailings. Oxide ores that are below the cut off grade for OTP are also processed here. The flexibility in managing the processing of ores at AGA has enabled concentrates from one plant to be treated in other plant. For example, the pregnant solution (concentrate) from the HLP is pumped to the OTP for further processing (Obiri 2005).
4. Carbon-in-Leach section; Leaches concentrates from old tailing plants.
5. Sulphides treatment plant (STP) that treats the sulphides and transition ore from the ore body and 15% of underground ore. At the STP, sulphide and transition ores from the surface and 15% of the underground ores are processed.

The stages involved in the sulphide treatment plant are; crushing, milling, gravity separation, floatation, bio-oxidation, leaching, adsorption and elution, electro winning, calcimining and smelting. At STP, the bigger lumps of ore are crushed in a jaw crusher to reduce the size of the ore to less than 150mm.A weight meter fitted to a conveyor belt measures and controls the discharge of the crushed product into the mills. Water is added to the ore and grounded by balls into pulp. The pulp product from the crusher is discharged into a set of classified cyclones (Obiri 2005). The overflow feed two flash floatation cells where concentrates are collected and the underflow is discharged into a ball mill for further milling. About 10% of the underflow is fed to a concentrating machine where free gold is trapped and sent to the smelting furnace. The cyclone overflows goes into a condition tank where floatation reagents like

(i) Copper sulphate, activates the surface of the mineral to make them amenable for collection. It also acts as modifier and activator and thus intensifies the amenability of the ore to float.

(ii) Sodium hydrogen sulphide (NaHS) modifies the pH of the slurry.

Flotation separates the pulp into a stable froth which is skimmed off, from the top of the cell to produce a sulphide concentrate containing most of the gold and tailings. The tailings are sent to the carbon-in-leach (CIL) tank for gold leaching. The flotation concentrate is sent into a BIOX reactor. The BIOX (Bio-oxidation) is an innovative technology that utilizes micro-organisms (bacterial) to oxidize the arsenopyrites and oxides into forms that can easily form complexes with NaCN. These complexes make the gold readily available for electro wining process. In the BIOX reactor, bacteria and pH modifiers such as sulphuric acid and potassium phosphate are added to the concentrate. The sulphuric acid changes the PH from 5 to about 2 (Harvey, *et al,* 1999.).The potassium phosphate serves as a nutrient for the bacteria to enable them to thrive. The bacteria oxidize sulphur and iron in the flotation concentrate. In addition to sulphur and iron, bacteria in the reactor also oxidize the pyrite arsenopyrite and pyrrhotite in the concentrate, freeing the microscopic gold particle occluded in these minerals and thereby rendering the gold accessible in subsequent cyanidation. The oxidation process takes approximately 4 days; the soluble salt is decanted and pumped to CIL tanks for carbon adsorption. The flotation tailings and

BIOX product are leached in tanks. The gold is leached from the floatation tailings and BIOX product using sodium cyanide, lime and oxygen. Adsorption occurs on the surface of the activated carbon. Passing a hot cyanide solution through the carbon beds does the elution. The gold solution is pumped into the gold house whereby electrolysis takes place, the gold is deposited into steel wool, calcined and smelted into gold bars (Obiri 2005).

2.3 SMALL SCALE MINING IN OBUASI

"Galamsey" is the name given to the activity of non-professional small-scale miners in Ghana. Galamsey operations are normally carried out at the gold and diamond mining areas. 'Galamseys' involved in illegal mining activities also create challenges for monitoring and regulating small-scale mining activities in the country. A UN study on artisanal mining and poverty reduction reports that there may be between 50,000 and 80,000 people engaged in illegal small-scale mining activities in Ghana (Carnegie, *et al*, 2000).

In Ghana, the gold bearing ores are dug from the ground or sometimes the tailings from the gold treatment plants are washed several times with clean water in a bucket or a pan to remove the slime. An inclined table is set up and the surface is covered with an old jute sack or even a piece of woollen carpet or any woollen material that can hold heavy particles. The gold bearing material in the pan is then poured into the covered table and further washed to remove the light materials. The heavy materials are trapped in the sack covering the table .This operation is repeated until the sack is saturated with the concentrate and the initial material is reduced to a very small quantity very rich in gold.

The gold on the piece of sack/cloth is then washed off into a pan. The water is decanted and mercury is added to the very small volume of concentrate obtained. The mercury is rubbed hard into the concentrate until an amalgam (Au/Hg), a solution of gold is formed leaving behind the gangue. The Au/Hg is put in a clean white handkerchief and tied. The mercury is then squeezed off the gold and comes out through the handkerchief. The gold, white in colour because of the mercury contamination, is then roasted in fire. The mercury vaporizes into the atmosphere leaving behind the impure gold. They either refined it in hot concentrated HNO_3 solution or sell it to buyers called "dealers"(Obiri 2005).

2.4 MININIG AND ITS EFFECTS ON THE COMMUNITY

Mining makes a large portion of the gross domestic product (GDP) and plays a significant role in the economic recovery programme of the country. However, the gains were achieved at a great environmental cost as the exploitation of gold puts stress on water, soil, vegetation and poses health hazards to humans (Amonoo-Neizer and Amekor, 1993). The main prospects in Ghana occur at Obuasi, Tarkwa and Prestea.

Many streams and rivers in Obuasi have been polluted as a result of spillage and leakage from tailing dams, denying thousands of local people access to adequate clean water supplies (Action Aid Report, 2006). For example, the River Fena, which flows through many communities in Obuasi, has been polluted by open-pit and 'heap leach' methods. Cyanide leakage due to flooding and dams failure such as incidents in nearby south and north Dokyiwa in 1996 and 1998 – further compounded an already pressing problem, leading to the abandonment of villages such as Badukrom and Attakrom (Action Aid

Report, 2006). An effluent discharge in November 2005 from AGA's Pompora Treatment Plant into the Kwabrafo River, a tributary of the Jimi river, contaminated these rivers and deprived villages and towns such as Sansu, Odumase, Akofuom, Jimiso, Kakraba of their once-fresh water, according to Third World Network(TWN) Africa.TWN Africa conducted a study on the effects of gold mining on local water sources in the area, 93% of respondents in a survey by TWN Africa expressed the view that mining had polluted water in their communities.Some 71% of respondents also said they could not drink from their age-old water sources due to pollution.

2.5 KOKOTEASUA/ ABOMPEKROM SPILLAGE, NOVEMBER 2005

Abompekrom is a village of about 10,000 people situatednext to one of AGA's gold processing plants. Many houses and a village school were flooded by toxic water from the 'containment lake' at the plant, believed to contain cyanide and other pollutants from ore processing on November 2005(Action Aid Report 2006). Beyond the lake is a massive waste dump, about 500 metres long, which dominates the skyline overlooking the village school, the Steadfast Academy. Contrary to AGA's position, TWN Africa researchers heard allegations from local people that the pipes from the containment lake are sometimes opened after heavy rain.

Public water pumps on which villagers now rely for clean water, often built by the company (AGA or AGC) to replace contaminated streams, in many cases provide polluted water, according to villagers. In short, it appears AGA is failing to address villagers' rights to adequate and alternative safe water supplies. The district Director of Health Services for

Obuasi, Dr Samuel Somuah said in an interview with TWN Africathat "We've had circumstances wherewe've seen that water that people are drinking from standpipes is coloured and leaves silver stain on the surface. When we raised the concern" They [AGA] say it is iron. Most of these pipes were made in the1940s and 1950s when PVC was not available, so they used iron in the pipes and this has led to the colouring of the water. But some of the tests that we did with TWN Africa prove that the levels of arsenic in these waters are high" (Action aid report 2006)

Akabzaa *et al*. (2003) observed high levels of Mg, Ca, SO_4, and HCO_3 ions in samples from streams immediately downstream of mining and processing facilities at Kwabrafoso, Binsere and Dokyiwa. These studies have indicated the immense pollution of streams and groundwater, hence the need to resort to other sources of potable water supply to satisfy the day to day domestic water needs of the inhabitants of Obuasi and other communities around.

2.6 MICROBIOLOGICAL PARAMETERS

2.6.1 Faecal and Total Coliform

Coliforms (indicator' organisms) are bacteria that are always present in the digestive tracts and waste of animals, including humans. They are also found in plant and soil materials. Water pollution caused by faecal contamination is a serious problem due to the potential for contracting diseases from pathogens (disease causing organisms). Frequently, concentrations of pathogens from faecal contamination are small, and the number of different possible pathogens is large. As a result, it is not practical to test for pathogens in every water sample collected. Instead, the presence of pathogens is determined with indirect evidence by testing for an "indicator" organism such as coliform bacteria. Coliforms come from the same sources as pathogenic organisms. Coliforms are relatively easy to identify, and are usually present in larger numbers than more dangerous pathogens, and respond to the environment, wastewater treatment, and water treatment similarly to many pathogens. As a result, testing for coliform bacteria can be a reasonable indication of whether other pathogenic bacteria are present. Total coliform counts give a general indication of the sanitary condition of a water supply. Total coliforms include bacteria that are found in the soil, in water that has been influenced by surface water, and in human or animal waste. To ascertain the presence of coliform in a well, the samples should be analysed in the late dry season or early wet season, when the probability of the inflow of contamination by water is high (Waskom and Bauder, 2009).

If coliform bacteria are present in a drinking water, then the risk of contracting a water-borne illness is increased. Although total coliforms can come from sources other than fecal matter, a positive total coliform sample should be considered an indication of pollution in your well. Positive faecal coliform results, especially positive E. Coli results, should be considered indication of fecal pollution in a well (Waskom and Bauder, 2009).

According to Water Well Construction Rules, Colorado (2003), the number of coliform bacteria present in a specific volume of water is a measurement of the amount of sewage which has been discharged into the water. If large numbers of coliform bacteria are present, then a large amount of sewage has entered the water, so the water is probably unsafe for drinking or swimming. A smaller number of coliform bacteria indicate a lower concentration of sewage pollution.

When coliforms have been detected, repairs or modifications of the water system may be required. Boiling the water is advised until disinfection and retesting can confirm that contamination has been eliminated. A defective well is often the cause when coliform bacteria are found in well water.Bacterial contamination can be controlled by well chlorination, proper septic system and well maintenance, and good sanitation practices.
Coliforms and other bacteria in drinking or swimming water will not necessarily cause harm to the user. However, since these organisms are present, other disease-causing organisms may also be present. Health symptoms related to drinking or swallowing water contaminated with bacteria generally range from no ill effects to cramps and diarrhoea (gastrointestinal distress).

Two common waterborne diseases, giardiasis and cryptosporidiosis; both cause intestinal illness. *E. coli* 0157:H7 has also been associated with contaminated drinking water and can cause intestinal illness. In very rare cases, it can cause haemolytic uremic syndrome, a serious kidney condition (Murrary, 1998).
Public drinking water supplies are required, by law, to be free from microbial pathogens. However, private water systems, while also vulnerable to contamination from bacteria, usually have no governmental oversight. If one relies on a private well, it is one's responsibility to ensure the water is safe to drink(Waskom and Bauder 2009)

According Waskom and Bauder (2009), one must protect a well by;

- periodic inspection of exposed parts of the well for problems such as:

  - a cracked, corroded, or damaged well casing.

  - a broken or missing well cap

  - settling and cracking of surface seals.

- Sloping the area around the well to drain surface runoff away from it.
- Keeping accurate records of well maintenance and water quality analysis.
- Hiring a licensed well contractor for new well construction, modification, or abandonment and closure.
- Avoiding mixing or using pesticides, fertilizers, weed killers, fuels degreasers, and other pollutants near the well.
- Not disposing of wastes in dry wells, abandoned wells or sinkholes.
- Not cutting off the well casing below 12 inches above the ground's surface.
- Pumping and inspect septic systems as often as recommended by your local health department.
- Not disposing of hazardous materials in a septic system.

2.6.2 Disinfection ofContaminated Wells

There are several options for private water supply disinfection. These include continuous chlorination, shock chlorination, ultraviolet radiation (UV), ozonation, boiling and pasteurization. Each of these methods has advantages and limitations, but they are all intended for use on clean, clear water. Water supplies must be sealed and protected from sources of bacterial contamination for disinfection methods to function properly.

Chlorination

According to Waskom and Bauder (2009) chlorination is the standard method for disinfecting wells because it is highly effective against bacteria. However, the drawbacks include: safety issues in handling concentrated chlorine; the taste it gives the water; the required contact time; its effectiveness against other microorganisms; and chlorine's reaction with organic matter to form trihalomethanes, THM (THMs are known carcinogens). Continuous chlorination is accomplished a chemical feed pump that dispenses chlorine directly into the well or into a baffled tank. The contact time required to kill microbes varies depending on the chlorine concentration, water temperature and pH. Simple chlorination maintains a low level of chlorine at a concentration of 0.2 to 0.5 ppm for at least 30 minutes of contact time. Super chlorination produces a chlorine residue of 3 to 5 ppm for approximately 5 minutes of contact time. Chlorine odour and taste can be removed with an activated carbon filter at the point of use. Shock chlorination is recommended for newly installed wells, whenever a well is serviced or flooded, or when a test shows the presence of coliform bacteria. Unlike continuous chlorination, shock chlorination is a onetime treatment designed to kill bacteria in the well and water system. Shock chlorination is the preferred disinfection treatment for private well systems because it is simple, cheap and effective for most situations. The amount of chlorine used in well treatment is determined by the well's diameter and depth of water(Waskom and Bauder 2009).

2.6.3 Enterococcus

Enterococcus species are hardy, facultative anaerobic organisms that can survive and grow in many environments. In the laboratory, enterococci are distinguished by their morphologic appearance on Gram stain and culture (gram-positive cocci that grow in chains) and their ability to:

(1) hydrolyzeesculin in the presence of bile.

(2) grow in 6.5% sodium chloride,

(3) demonstrate pyrrolidonylarylamidase and leucineaminopeptidase, and

(4) react with group D antiserum. Before they were assigned their own genus, they were known as group D streptococci.

Enterococcus faecalis and *Enterococcus faecium* are the most prevalent species cultured from humans, accounting for more than 90% of clinical isolates. Other enterococcal species known to cause human infection include *Enterococcus avium, Enterococcus gallinarum, Enterococcus casseliflavus, Enterococcus durans, Enterococcus raffinosus* and *Enterococcus mundtii. E. Faecium*re presents most vancomycin-resistant enterococci (VRE) (Murrary 1998).

Isolation of enterococci resistant to multiple antibiotics has become increasingly common in the hospital setting. According to National Nosocomial Infections Surveillance (NNIS) (2003) data from January 2003 to December 2003, more than 28% of enterococcal isolates in ICUs of the more than 300 participating hospitals were vancomycin-resistant. Clonal spread is the dominant factor in the dissemination of multidrug-resistant enterococci in

North America and Europe. Virulence and pathogenicity factors have been described using molecular techniques. Several genes isolated from resistant enterococci (agg, gelE, ace, cylLLS, esp, cpd, fsrB) encode virulence factors such as the production of gelatinase and hemolysin, adherence to caco-2 and hep-2 cells, and capacity for biofilm formation.Enterococci have both an intrinsic and acquired resistance to antibiotics, making them important nosocomial pathogens. Intrinsically, enterococci tolerate or resist beta-lactam antibiotics because they contain penicillin-binding proteins (PBPs); therefore, they are still able to synthesize some cell-wall components.

Unlike streptococcal species, enterococci are relatively resistant to penicillin, with minimum inhibitory concentrations (MICs) that generally range from 1-8 mcg/mL for E faecalis and 16-64 mcg/mL for E faecium. Therefore, exposure to these antibiotic agents inhibits but does not kill these species. Combining a cell wall–active agent such as ampicillin or vancomycin with an aminoglycoside may result in synergistic bactericidal activity against enterococci (Murrary 1998).

2.6.4 Total Heterotrophic Bacteria

Heterotrophs are those microorganisms that use organic compounds for most or all of their carbon requirements. Most bacteria, including many of the bacteria associated with drinking water systems, are heterotrophs (Abaidoo and Obiri-Danso,2008).

2.7 PHYSICOCHEMICAL PARAMETERS OF WATER

2.7.1 pH of Water

The pH of water represents the concentration of the free hydrogen ions in it. On private water systems, one of the most common causes of corrosion is acidic water. Water that has a pH value of less than 7.0 is considered to be acidic. When acid waters come into contact with certain chemicals and metals, they often make them more toxic. Signs of acid water are corrosion of fixtures, pinhole leaks in plumbing, and blue staining (from copper pipes) or rust staining (from iron pipes) (Wikipedia 2005). Often these waters are good for drinking or household use, but are low in buffering calcium minerals, and contain dissolved carbon-dioxide gas, which can cause a low pH and acid condition. Without treatment, these waters can be contaminated with copper, lead and other metals from piping, fixtures and appliances, turning good water into contaminated drinking water. When acid waters come into contact with certain chemicals and metals, they often make them more toxic. For example, fish that can tolerate pH values as low as 4.8 will die at pH 5.5 if the water contains 0.9 mg/L of iron (USEPA, 2006). Dissolved carbon dioxide and mineral acids, either by natural or from mining or other industrial waste cause low pH or acidity, and often the pH is less than 5.0. Treating this type of water requires the use of soda ash feeder, and in some cases injection of sodium hydroxide.

2.7.2 Turbidity

The American Public Health Association (APHA,2005) defines turbidity as "the optical property of a water sample that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample." Light's ability to pass through water depends on how much suspended material is present. Turbidity may be caused when light is blocked by large amounts of silt, microorganisms, plant fibres, sawdust, wood ashes, chemicals and coal dust. These suspended particles can be an indicator of bacterial activity in the water and cause problems with disinfection processes. Turbidity is measured in NTU's, (nephelometric turbidity units). The turbidity of drinking water should always be less than 1 NTU. Most treated city water is less than 2 NTUs. While it is possible to filter water containing colloidal particles, and/or water that has a colour to it, generally filtration is the last step in the process of treating this type of water. To remove turbidity, often the first step is to inject a flocculant, or coagulant aid, which allows these microscopic suspended particles to lose their positive charge and "floc" together into larger clumps. This is easily done on small scale systems by using a metering pump and injecting 2 -5 ppm of "Cat-Floc" (one of the many types of flocculant aids used for this purpose) into the water as it flows into a holding tank or storage tank. The water is allowed to settle, and is then followed by filtration to remove any suspended floc. In some cases the water must be gently stirred or agitated in order for the floc to form. A very effective method to remove turbidity is with reverse osmosis ("RO") or ultrafiltration ("UF") membrane systems. RO and UF systems can be used by homeowners, small communities and commercial sites to reduce turbidity and produce crystal clear water less than 0.1 NTUs. Turbidity can be measured by filtering a water sample and comparing the filter's colour (how light or dark it is) to a standard turbidity color chart(Shelton,2000).

In addition to RO and UF membrane systems, direct filtration can be used. Depending on the nature of the turbidity, a backwashing sediment filter using a special type of zeolite filter media is efficient at clarifying water. Sediments from 5 to 10 micron range can be removed, and then backwashed out periodically by the automatic control valve.

2.7.3 Alkalinity

It is the measure of substances in water that have "acid-neutralizing" ability. Alkalinity should not be confused with pH. pH measures the strength of an acid or base; alkalinity indicates a solution’s power to react with acid and neutralize it (USEPA, 2006). The main sources of natural alkalinity are rocks, which contain carbonate, bicarbonate, and hydroxide compounds. Borates, silicates, and phosphates may also contribute to alkalinity (CWQRB, 2005).

2.7.4 Electrical Conductivity

According to the California Water Quality Resources Board (CWQRB, 2005), Conductivity is a measure of the ability of water to pass an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulphate, and phosphate anions or sodium, magnesium, calcium, iron, and aluminum cations. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity. For this reason, conductivity is reported as conductivity at 25 °C. Conductivity is measured in microsiemens per centimeter (µs/cm). Distilled water has conductivity in the range of 0.5 to 3 µs/cm. Industrial waters can range as high as 10,000 µs/cm (Pushard, 2005).

2.7.5 Total Dissolved Solids

While salinity or salty water, is generally used to describe and measure seawater or certain industrial wastes, the term total dissolved solids ("TDS") is typically used to describe water high in various salt compounds and dissolved minerals. Total Dissolved Solids (TDS) refers to the amount of dissolved solids (typically various compounds of salts, minerals and metals) in a given volume of water. It is expressed in parts per million (also known as milligrams per liter) and is determined by evaporating a small amount of water in the lab, and weighing the remaining solids. Another way to approximately determine TDS is by measuring the conductivity of a water sample and converting the resistance (in micromhos) to TDS. The most common range in city water is 200 - 400 ppm. The maximum contaminant level set by USEPA is 500 ppm. Over many years, United States Environmental Protection Agency has added to and revised a set of standards for drinking water quality. The higher the TDS, the less palatable the water is considered to be. Sea water ranges from 30,000 to 40,000 ppm. Many brackish ground water supplies contain private well water with a TDS of 1500 - 5000 ppm. In some cases the levels exceed 7000 ppm. When the levels start to exceed 1500 ppm, one could experience dry skin, stiff laundry, and rapid corrosion of piping and fixtures. White spotting and films on surfaces and fixtures is also common at these levels and can be very difficult or impossible to remove. TDS affects taste, and waters over 500 - 600 ppm can have an alkaline taste.TDS is removed by distillation, reverse-osmosis or electrodialysis. Increasingly most desalination projects, both large and small are accomplished with reverse-osmosis. Depending on the water chemistry, reverse osmosis systems are the most popular, given their low cost and ease of use (Appiah 2008).

2.7.6 Lead

Lead has many useful industrial applications; in water lead is a toxic metal, and can cause damage to the brain and blood cells over time. Lead occurs naturally in ground waters throughout the world, but most contamination of lead in drinking water comes from lead leaching from service pipes, fixtures, valves and other materials containing lead. The United States Environmental Protection Agency (USEPA) estimates that approximately 20% of human exposure to lead is attributable to lead in drinking water. Lead is commonly used in household plumbing materials and water service lines. The greatest exposure to lead is swallowing or breathing in lead paint chips and dust. Lead in drinking water can cause a variety of serious health effects. In babies and children, exposure to lead in drinking water can result in delays in physical and mental development, along with slight deficits in attention span and learning abilities. In adults, it can cause increases in blood pressure. Adults who drink this water over many years can develop kidney problems or high blood pressure. Lead is rarely found, but enters tap water through corrosion of plumbing materials. Homes built before 1986 world are more likely to have lead pipes, fixtures and solder. However, new homes are also at risk: even legally "lead-free" plumbing may contain up to 8 percent lead. The most common problem is with brass or chrome-plated brass faucets and fixtures which can leach significant amounts of lead into the water, especially hot water and instant hots unless they use lead-free fixtures. Lead is strictly regulated in public water supplies, and the USEPA sets a maximum allowable level of 15 parts per billion, or .015 milligrams per liter. Generally, water that is first drawn, after sitting for several hours in piping that contains lead, is much higher in lead, than after the pipes have been flushed. For this reason, when one is testing for lead, the water should be allowed to sit in the pipes overnight, so a first draw, or worst case scenario can be determined. Often lead problems can be corrected by replacing the lead service pipes with new piping, by replacing lead-leaching brass fixtures with new non-leaded brass, and/or by treating for corrosive water conditions to prevent the water from leaching lead from the piping or fixtures(http://water,epa.gov/drink/info/lead/index.cfm 22/07/12 11:00pm)

2.7.7 Arsenic

Arsenic occurs naturally in rocks and soil, water, air, and plants and animals and it is odourless and tasteless. According to the USEPA, it can be further released into the environment through natural activities such as volcanic action, erosion of rocks and forest fires, or through human actions. Industry practices such as copper smelting, mining and coal burning also contribute to arsenic in our environment. Arsenic is well known for the catastrophic mass poisoning it has caused in Bangladeshi tube wells (Bissen and Frimnel, 2003) Higher levels of arsenic tend to be found more in ground water sources than in surface water sources (i.e., lakes and rivers) of drinking water. Non-cancer effects can include thickening and discoloration of the skin, stomach pain, nausea, vomiting; diarrhoea; numbness in hands and feet; partial paralysis; and blindness. Arsenic has been linked to cancer of the bladder, lungs, skin, kidney, nasal passages, liver, and prostate. Arsenic has been found in the mining areas in Ghana (Smedley and Kinniburg, 2002). EPA has set the arsenic standard for drinking water at .010 parts per million (10 parts per billion) to protect consumers served by public water systems from the effects of long-term, chronic exposure to arsenic. It is found in two forms or species: Arsenic III & Arsenic V. For drinking water high in arsenic, distillers can provide a reliable and consistent method to remove both of these species. Reverse osmosis is also used, but works better when the water has been pre-chlorinated or ozonated, so that any Arsenic III in water has been converted to Arsenic V before the reverse osmosis system. According to the Geological Society (1996) cited in Kumi-Boateng (2007).Arsenic in drinking water from streams, shallow wells and boreholes in the Obuasi gold-mining area of Ghana range between < 2 and 175 μgl−1. The main sources are mine pollution and natural oxidation of sulphide minerals, predominantly arsenopyrite (FeAsS). Deep mine exploration boreholes (70–100 m) have relatively low As contents of 5–17 μgl−1, possibly due to As sorption onto precipitating ferric oxyhydroxides or to localized low As concentrations of sulphide mineral. Amoono-Neizer*et al*., (1995) found significant distribution of As and Hg in the top soils, plantain, water fern, elephant grass, cassava and mud fish at Obuasi and its environs. Other studies have made various findings regarding presence of trace elements in water sources, soils and foodstuffs at Obuasi and surrounding areas (Amasa, 1975; Bamford*et al*., 1990; Golow*et al*., 1995). So far, it appears that As constitutes the major trace element problem in the Obuasi area. This has been linked to the considerable level of naturally occurring arsenic at Obuasi, as well as liberations from arsenic bearing gold ores during gold extraction (Amonoo-Neizer *et al*., 1995, Asiam,1996; Ahmad and Carboo,2000; Kumi-Boateng,2007). Obuasi, for instance, contain very high amount of As, averagely 8305 mg/kg (Ahmad and Carboo, 2000). Clinical symptoms similar to arsenic poisoning have been observed in patients in AGC hospital at Obuasi and have been associated with aerial pollution from mineral procession by the AGC (Awudi, 2002).

2.7.8 Cyanide

Cyanide is a singly charged anion containing equal atoms of Carbon and Nitrogen triply bonded. Cyanide has strong ability to attract metals. Mining companies have made huge profit from the use of Cyanide in extracting gold from its ore, even from low grade ores. Bogoso Gold Limited (BGL), has adopted the use of cyanide solution in extracting metallic gold from its ores. The ores include surface ores (Iron oxides-haematiteα-Fe_2O_3 and Magnetite Fe2O4), sulfide ores and transition ores. Effluent from BGL treatment plants contains high concentration of Cyanide (Amegbey and Adimado, 2003). Cyanide is a toxic chemicalfound in effluents of mining companies. For example a teaspoonful of cyanide solution containing 50-200mg of cyanide ingested by an adult human being will result in his premature death. Cyanide exerts its toxic effects by forming a complex with Ferric ion(Fe3+) of mitochondrial cytochrome oxidase, the enzyme that catalyzes the terminal step in the electron transport chain thereby preventing the use of oxygen by cells. Since cytochrome oxidase occupies a central role in the use of oxygen in all cells, its inhibition leads to the disruption of cellular respiration producing cytoxic hypoxia (Obiri*etal* cited Cromptom *et al.*, 1979).

Cyanide (potassium cyanide), a poisonous chemical, is used to recover gold from the ore, and in the process some spillages occur resulting in drainage (of cyanide) into the nearby streams. This causes aquatic life loss, as these chemicals are highly toxic. It also seeps down into the soil causing plant roots to die. For instance, there was a tailing treatment dam failure at Kokoteasua in 2005 alledged to have been caused by illegal activities of 'galamseyers' two years earlier. This resulted in the spillage of tailing materials into the external environment, thereby, affecting surrounding downstream communities of Kokoteasua, Abompekrom and Nkamprom (Obuasi Mine Report, 2005). Undoubtedly, it is evident that streams and rivers where these chemicals and toxic materials drain into serve the villages and towns along them. Consequently, their drinking water is poisoned, causing morbidity and mortality conditions among residents. Skin rashes are widespread particularly among communities living along rivers and streams which regularly receive leaked cyanide waste waters and other mining wastes within their concessions (Akabzaa and Darimani, 2001).

2.7.9 Mercury

The modern chemical symbol for mercury is Hg. It comes from hydrargyrum, a Latinized form of the Greek word Ύδραργυρος (hydrargyros), which is a compound word meaning "water-silver" (hydr- = water, argyros = silver) — since it is liquid like water and shiny like silver. The element was named after the Roman god Mercury, known for speed and mobility. It is associated with the planet Mercury; the astrological symbol for the planet is also one of the alchemical symbols for the metal; At room temperature, metallic mercury is an odourless liquid that can slowly evaporate into the air and can combine with other elements to form inorganic and organic compounds. Mercury is used for a wide variety of purposes such as thermometers, pressure gauges, electric switches, fluorescent lamps, and dental fillings. Mercury is used to prevent mildew in outdoor paints. It was also used in the past in indoor paints and Agricultural pesticides. Mercury, carried by wind and rain, is found throughout the environment mostly due to the release of naturally occurring mercury from rock and soil; burning of coal and oil that contains small amounts of mercury; release of mercury from metal smelters (wikipedia 2006).

In Africa and Latin America, most studies concentrate on mercury exposure and intoxication incurred in the extraction and processing stage of mining (Camara, *et a*l., 1997; Malm, 1998; Harada *et al*., 1999; Tirado *et al*., 2000; van Straaten, 2000; Rojas, *et al*., 2001). Results of studies indicate patterns of mercury intoxication during the gold amalgamation process (Camara, *et al*., 1997; Tirado, *et al*., 2000; van Straaten 2000; Drasch, *et al*., 2001). For example, in one site in the Philippines a study of 102 workers (occupationally Hg burdened ball-millers and amalgam- smelters), 63 other inhabitants (exposed from the environment), 100 persons living downstream of the mine, and 42 inhabitants of another site (serving as controls) was undertaken using their bio-monitors and medical scores. The authors report that "by this method, 0% of the controls, 38% downstream, 27% from Mt. Diwata non-occupational exposed and 71.6% of the workers were classified as Hg intoxicated" (Drasch, *et al*., 2001). Another study in Tanzania with a similar design found lower levels of intoxication and a more complex mix of mining-related and environmental exposures to mercury through household items such as soap (Harada,*et al*., 1999). One study in Ecuador reports higher levels of intoxication in children involved in "gold washing" (Harari, *et al*.,1997) and another in Venezuela found no mercury intoxication, despite occupational and community exposures (Rojas,*et al*., 2001). People may be exposed to mercury from a variety of sources, including drinking water. Too much mercury in the human body can cause serious damage to the brain, nervous system and kidneys depending upon the form and amount of mercury that one is exposed to and how much mercury has built up in the body over time. Young children and developing foetuses are at greatest risk of the harmful effects of mercury. In animals, it has been shown that small amounts of inorganic mercury can pass from the mother's body into the developing foetus. Other health effects, such as kidney damage, certain types of tumours, and changes in the immune system, have been seen in animals exposed to very high levels of inorganic mercury. Organic mercury compounds are the most harmful forms of mercury. They are easily absorbed into the blood through the digestive tract and, at high levels, can damage the nervous system and kidneys and are especially harmful to young children since it can easily enter their nervous system and interfere with brain development. In order to prevent or reduce the chances of health effects from occurring due to drinking water contamination (http://atsdr.cdc.gov/tfacts46.html 23/07/12 10:00pm)

2.7.10 Cadmium

Cadmium is found in very low concentrations in most rocks, as well as in coal and petroleum. Mostly cadmium is found in combination with zinc (WHO, 1992). Cadmium uses include electroplating, nickel-cadmium batteries, paint and pigments, and plastic stabilizers (WHO, 1992). It is introduced into the environment from mining, smelting and industrial operations, including electroplating, reprocessing cadmium scrap, and incineration of cadmium containing plastics. The remaining cadmium emissions are from fossil fuel use, fertilizer application, and sewage sludge disposal. Cadmium may enter drinking water as a result of corrosion of galvanized pipe. Landfill leachates are also an important source of cadmium in the environment (Wester, *et al.*, 1992). Acute and chronic exposure to cadmium in animals and humans results in kidney dysfunction, hypertension, anemia, and liver damage (Wester*et al*., 1992). The kidney is considered to be the critical target organ in humans who are chronically exposed to cadmium by ingestion. Cadmium has been classified in EPA's Group B1 (probable human carcinogen), based upon evidence of carcinogenicity in humans through inhalation exposure. However, since cadmium has not been shown to be carcinogenic through ingestion exposure, the metal is regulated based upon chronic toxicity data. Because of cadmium's potential adverse health effects and widespread occurrence in raw waters, it is regulated (Weast, 1974).

CHAPTER THREE

MATERIALS AND METHODS

3.1 STUDY SITE

Obuasi means “under the rock”. It is now part of AngloGold Ashanti Group. It started operation as a mine since 1897. It has yielded 28 million ounces of gold since 1897, with 7.5 million oz. in the past 10 years (Obuasi Mines Presentation, 2006).

Obuasi is the capital of Adansi West Municipality. It is the administrative headquarters of Ashanti Goldfields Company, now AngloGold Ashanti-Obuasi Mine. Obuasi is located on latitude 6^{0}15N and on longitude 1^{0}40W and lies in a valley surrounded by hills and mountains made up of igneous and sedimentary rocks which are rich in gold ore. The municipality experiences semi-equatorial climatic conditions with a double maximum rainfall regime. Mean annual rainfall ranges between 125 cm and 175 cm. Temperatures are uniformly high all year with the hottest month being March when 30 °C is usually recorded. Mean average annual temperature is 25.5 °C. Relative humidity is 75 % - 80 %.The area has a population of over 100 000 scattered over many small to large villages. Most of the local residents are engaged in farming and mining (Appiah, 2008). It is also located within the tropical evergreen rainforest belt and the soil is very good for producing food and cash crops such as cocoa, coffee etc. The municipality is drained by streams such as; Jimi, Kwabrafo, Pompo, Nyame, Akapori, Wheaseammo, and Kunka. All these streams are almost polluted by mining and other human activities (Obuasi Municipality Development Plan, 2006).

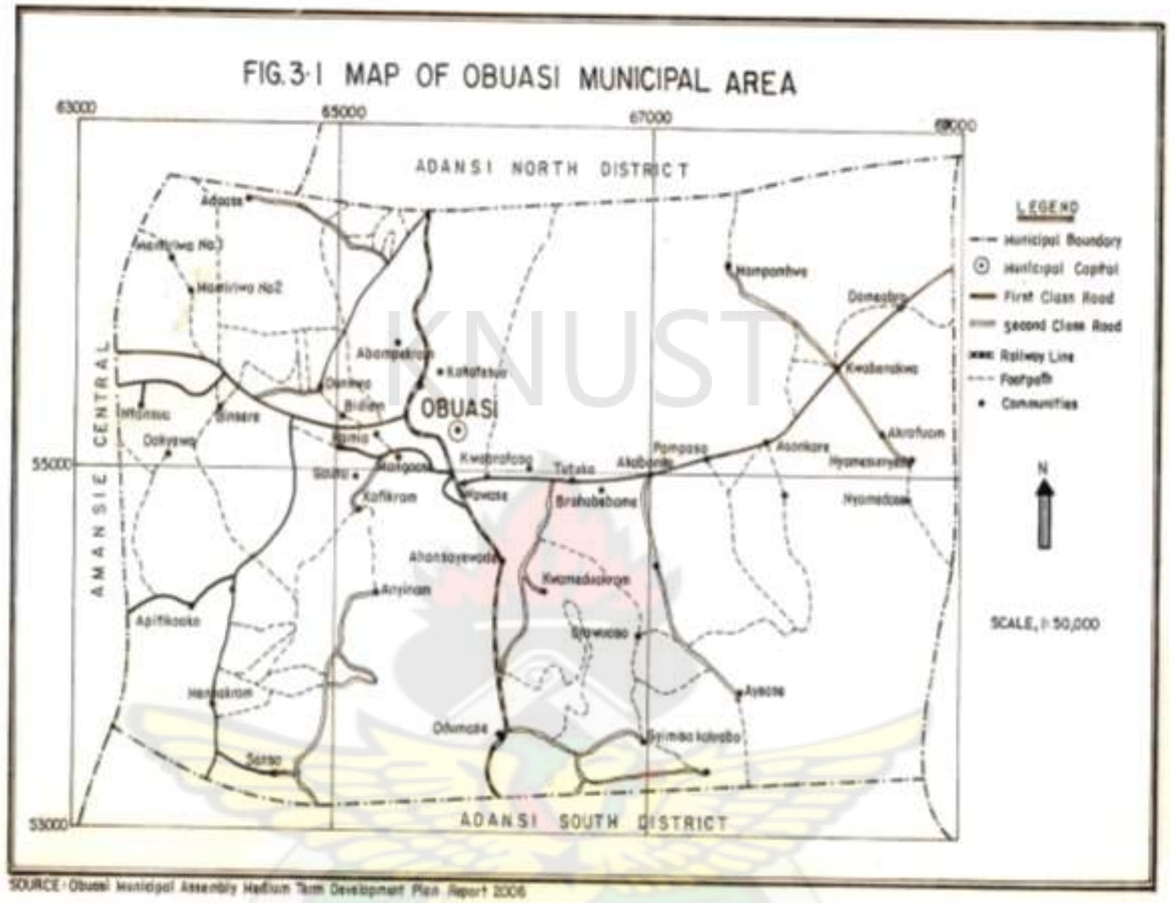

Fig1:Map of Study Area (Obuasi Municipal Assembly)

3.2 SAMPLING AREAS

The sampling areas were selected based on the availability of hand dug wells under the study, and the probability of seepage of chemicals (such as mercury, sodium cyanide) used during mining processes both legal and illegal was also taken into consideration. Consideration was also given to the closeness of the wells to the mining tailing dams and waste water channels. The communities studied were Kwabrafoso, Tutuka and Aboagyekrom.

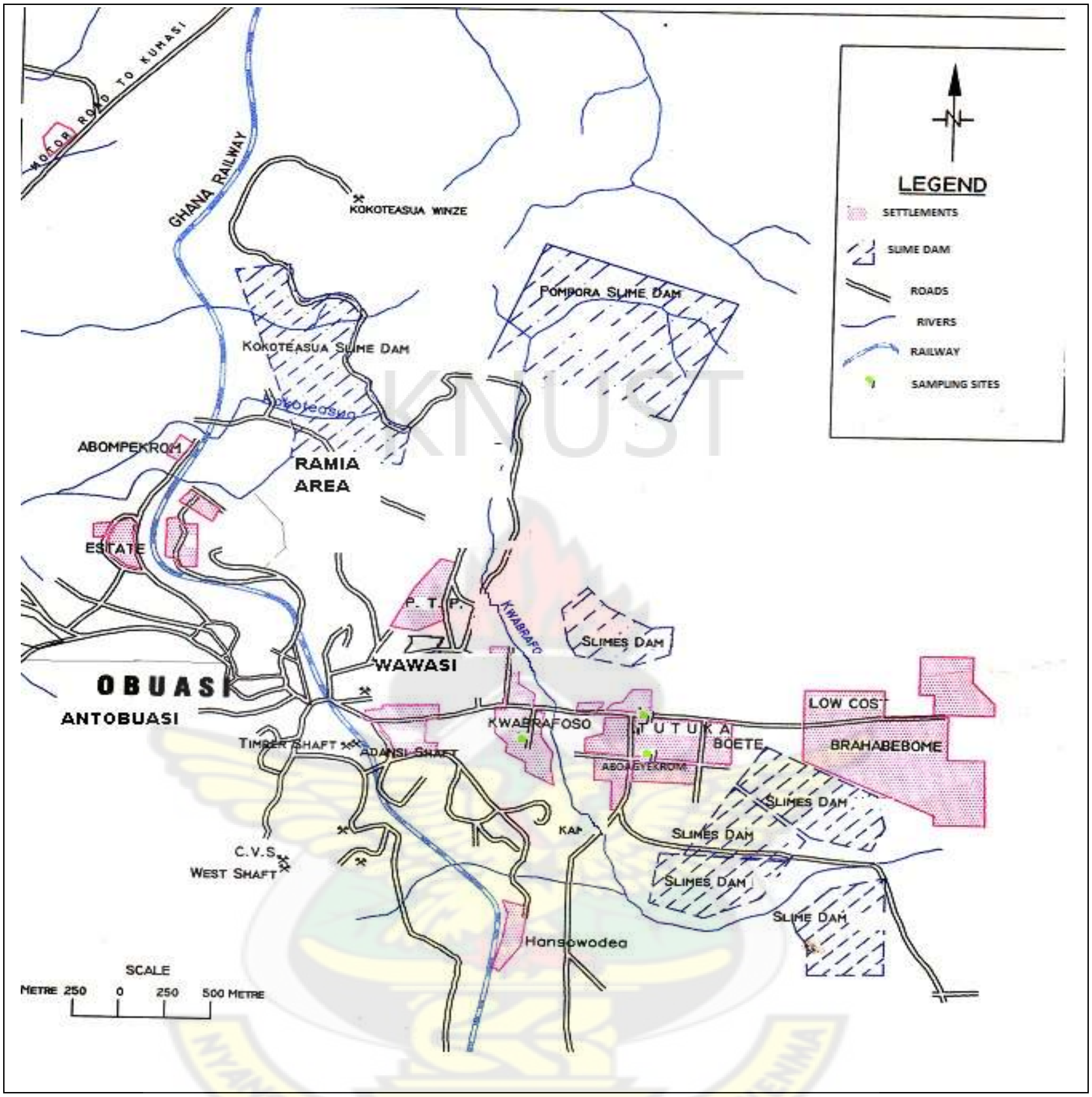

Fig2: Map of Sampling Sites

Photographs of Sampling Sites

Plate1 [TU 1 (Tutuka well 1)]

Plate2[TU2 (Tutuka well2)

Plate3 [TU3 (Tutuka well 3)]

Plate 4 [AB 4(Aboagyekrom well 4)]

Plate 5 [AB 5 (Aboagyekrom well 5)]

Plate 6 [AB 6 (Aboagyekrom well 6)]

Plate 7 [KWA7 (Kwabrafoso well 7)]

Plate 8[KWA8 (Kwabrafoso well 8)]

Plate 9KWA 9 (Kwabrafoso well 9)

3.3 PREPARATION OF SAMPLING BOTTLES

During the sampling, measures taken were; the bottles used were sterilized ones [i.e. distilled water bottles with their content (1.5L voltic water and special ice water bottles)] .The bottles were labelled sample 1-9 taking the sampling area into consideration. Samples 1-3 were collected at Tutuka and labelled Tu1, Tu2, Tu3. Samples 4-6 were sampled from Aboagyekrom and labelled AB4, AB5, AB6. Samples 7-9 were sampled from Kwabrafoso and labelled Kwa7, Kwa8, Kwa9. Translucent bottles were used to sample water from the various wells under study for Cyanide analysis since it degenerates under sun rays and were labelled accordingly.

3.4 SAMPLING

Sampling was done at different locations within the various communities chosen in Obuasi. Sampling was done monthly [February -April 2012] and three hand dug wells were sampled from different locations within the selected communities (9 samples at each sampling period with a total of 27 samples being collected from 3 events within the selected communities). During sampling, the bottles filled with distilled water were emptied and immediately rinsed with the well water and then filled. The translucent bottles were also rinsed and filled.

3.5 ACIDIFICATION OF THE SAMPLES

Acidification of the water samples was done just after 50ml had been taken for the pH determination and some taken for microbiological analysis. A 3ml concentrated HNO_3 was added to 300ml of the samples. This was done to preserve the water samples and as an initial step to bring the particulate metals into solution (APHA, 1992).

The collected samples were stored on iced cubes to prevent growth of microbes and the precipitation of metals (Anon, 1992; APHA, 1992). They were then transported to the laboratory (KNUST Microbiological and Natural Resource laboratory) for analysis.

3.6 MICROBIOLOGICAL ANALYSIS

Upon reaching the laboratory, the samples were stored in a refrigerator at 4^oC to prevent excessive increase in temperature which could result in either growth or death of the microbes. The working surface was cleansed with methylated spirit to prevent contamination during the analysis.

3.6.1 Preparation of Media

M-Endo Broth

4.8 g of dehydrated Endo medium was suspended in 100ml distilled water containing 2.0ml of 95% Ethanol. The medium was covered with aluminium foil and heated whilst stirring for 5 minutes. It was done on hot plate with a magnetic stirrer. It was removed from the hot plate when the medium began to boil. It was then allowed to cool to room temperature.

M-Fc Broth

3.7g of dehydrated FC medium was suspended in 100ml of distilled water in a volumetric flask. 1ml of 1% solution of Rosalic acid was added to 0.2N Sodium Hydroxide (NaOH). It was then covered with Aluminium foil and heated whilst stirring. It was removed from the hot plate immediately when the medium began to boil, and allowed to cool to room temperature.

3.6.2 Procedure for Serial Dilution

To achieve a 10^{-1} dilution, the samples were thoroughly mixed by inverting the sample bottles several times to prepare them for the serial dilutions. An automatic pipette and sterile 1ml pipette tip were used to take a 1ml aliquot from an inch below the surface of the water. It was then added to 3 test tubes containing 9ml of the MacConkey broth (a 10^{-1} dilution had been prepared). The pipette tip was dropped into a disinfectant to reduce contamination.

In preparing 10^{-2} dilution, the 10^{-1} dilution solution was mixed thoroughly and using a fresh sterile pipette tip to draw the suspension up and down several times. 1ml of the 10-1 dilution was drawn into another 3 tubes containing 9ml of MacConkey. The procedure was repeated four times to achieve the 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6} dilutions. It was ensured that no gas was trapped in the inverted Durham tubes in the test tubes containing the MacConky broth. The diluted samples were incubated at $37^{o}C$ for enterococci, total coliform and heterotrophic bacteria and at $44^{0}C$ for faecal coliform for 48 hours. The tubes were observed for any colour change. The Most Probable Number Index Table was used to calculate the number of coliforms in the water samples.

3.6.3 Procedure for Total Viable Count (TVC) or Plate Count

For each dilution a fresh sterile pipette tip was used to aseptically add 1ml of each of the dilutions of the water samples to test tubes containing molten plate count agar at 400C. The samples and agar were mixed by rotating the test tubes between the palms, taking care not to form bubbles. The mixtures were aseptically poured into clean Petri dishes. The mixtures were allowed to solidify. The solidified agar plates were incubated in an inverted position at $37^{0}C$ for enterococci, total coliform and heterotrophic bacteria and at $44^{0}C$ for faecal coliform. After 48 hours the numbers of microorganisms on the countable plate were counted using the Colony counter.

3.7 DETERMINATION OF PHYSICOCHEMICAL PARAMETERS

The physicochemical parameters assessed during the study were; pH, Turbidity, Total Dissolved Substances, Total Suspended Substances, Conductivity, Lead, Arsenic, Cadmium, Cyanide, Mercury.

3.7.1 Determination of Total Suspended Solids (TSS)

50ml of a well-mixed sample was filtered through a weighed standard glass-fibre filter paper. The residue retained on the filter was then dried in an oven at 103 to 105°C for 1 hour. It was then cooled in a desiccator and weighed. The increase in weight of the filter represents the total suspended solids.

Calculation

The T.S.S was computed using the formula below:

$$\text{mg total suspended solids/L} = \frac{(A - B) \times 1000}{\text{sample volume, mL}}$$

where

A = weight of filter + dried residue, mg, and

B = weight of filter, mg

3.7.2 Determination of Alkalinity

Titrimetric analysis was employed in the determination of alkalinity with reference to (APHA, 1992). The following procedures were followed;

A volume of 100 ml of the sample was measured into a volumetric flask.

Three drops of phenolphthalein indicator were added

The samples were titrated with 0.1 N acid until a red colour appeared indicating the endpoint, and the volumes were recorded.

Alkalinity (mg/ L $CaCO_3$) = ("V x N ")" × 1000" /"sample volume, mL x 2" x 100

V = titration volume in mL

N = normality of the acid solution

100 = molecular mass of $CaCO_3$

61 = molecular mass of HCO_3

3.7.3 Determination of Turbidity

The turbidity of samples was measured using a turbidimeter as follows;

25mL of the samples were measured with a measuring cylinder and poured into a clean cell. The sample cells were carefully cleaned with tissue paper. The sample cell was placed in the instrument light cabinet and covered with the light shield. The turbidity read were then recorded in NTU (Nephelometric Turbidity Units).

3.7.4 Determination of pH

The pH was measured with a pH meter immediately after collecting the water sample. This is because the values of the parameter can change rapidly. Samples were collected in a plastic container. Enough samples were collected so that the tip of the probe could be fully submerged. The probe was rinsed with distilled water before placing it in the sample. The probe was placed in the sample and left in it for the meter to stand at equilibrium before taking the reading. The equilibrium state was determined when the signal became steady and the pH of the sample was recorded.

3.7.5 Determination of Total Dissolved Solids and Conductivity.

The instrument was calibrated before the measurements were started. The TDS key was pressed to display "TDS" to confirm the measurement mode. The meter automatically defaulted the TDS factor value to 0.5. The TDS factor was changed to the value of the solution, by pressing the FTR key. The TDS factor value started blinking on the screen. The desired value was obtained by pressing the numeric keys and then the ENTER key to confirm the value. The stored value was displayed and it stopped blinking. The measurement reading stabilized and the measurement was complete. The conductivity button on the instrument was pressed to display its value which was then recorded on the data sheet.

3.8 DETERMINATION OF METALS

3.8.1 Digestion of Samples

The samples were thoroughly mixed by shaking and 100 ml transferred into a conical flask. A 5 ml concentrated HNO_3 and a few boiling chips were added (APHA, 1992). The mixture was then heated until the volume was reduced to about 15 ml and complete digestion was indicated by a clear solution. Contents were washed down with double distilled water and then filtered. The filtrate was transferred into 100 ml previously washed volumetric plastic containers and the volume finally adjusted to 100 ml with distilled water and stored at 4^0C, ready for AAS analysis (APHA, 1992) and mercury determination.

3.8.2 Determination of Cyanide

6ml of sample (analyte) each were pipetted into test tubes. A spatula full of Chloro-T-amine powder [CN-A1] was added, shaken and allowed to settle for about 5 seconds.

A spatula full of Dimethyl 1, 1, 3 barbituric acid [CN-A2] was also added, shaken and allowed to settle for about 5 seconds. 3 drops of Pyridine [CN-A3] were added and allowed to settle for about 3 minutes. The comparator was then used to take the readings.

NB: Detection limit of this procedure was 0.01.

3.8.3 Determination of Mercury

Determination of mercury in all the digests was carried out by Cold Vapour Atomic Absorption Spectrophotometer using an Automatic Mercury Analyser model HG-5000 (Sanso Seisakusho Co., Ltd, Japan) developed at National Institute for Minamata Disease (NIMD). During the determination, 5 ml was introduced into the reaction vessel using a micropipette (1-5 ml). The reaction vessel was immediately stoppered tightly and 0.5 ml of 10% (w/v) $SnCl_2 2H_2O$ in 1M HCl was added from a dispenser for the reduction reaction. Air was circulated through the four-way stopcock at the same time to allow the mercury vapour to come to equilibrium and the acidic gases produced by the reaction also swept into the sodium hydroxide solution. After 30 seconds the four-way stopcock was rotated through 90^0 and the mercury vapour was swept into the absorption cell. Response was recorded on the strip chart recorder as very sharp peaks. Peaks heights were used for computations. Standards used for calibration of the analyser included solutions containing 25 and 50 ng Hg.

3.8.4 Determination of Metals by Atomic Absorption Spectrophotometer 220 (AAS)

The metals analysed with the AAS were; lead, cadmium, arsenic

The AAS has a light source used to generate light at the wavelength which is characteristic of the analyte element. This is often a hollow cathode lamp, with intense narrow line source. The source of energy for free atom production is usually heat, most commonly in the form of an air/acetylene or nitrous-oxide/acetylene flame.

A sample was mixed thoroughly by shaking and a portion filtered through 0.45μM pore size membrane filter paper, using vacuum filtration.

The filtered sample was acidified with concentrated nitric acid to pH 2 or lower and aspirated and the concentration of the samples calculated.

Analytical Procedure for Spectra 220 Atomic Absorption Spectrophotometer

Fundamentally, quantitative analysis by atomic absorption spectroscopy is a matter of converting samples and standards into solutions, comparing the instrumental responses of standards and samples, and using these comparative responses to establish accurate concentration values for the element of interest. Solution which contained no analyte element was prepared (the analytical blank). A series of calibration solutions containing known amounts of analyte element were also prepared (the standards). The blank and standard were atomized in turn and the response for each solution was measured. A calibration graph showing the response obtained for each solution was plotted. The sample solutions were atomized and the response measured. The concentrations of the sample from the calibration, based on the absorbance obtained for the unknown were determined.

3.9 DATA ANALYSIS

Data were presented in tables as means ± SD and ranges. Data obtained in this study for the levels of the studied physicochemical parameter, heavy metal concentrations and microbial loads were analysed using one-way analysis of variance (ANOVA) to determine the variability in levels recorded at the various sampling stations over the sampling period. The Tukey's Multiple Comparison post-test was used to further test for significant differences among the sampling stations. All descriptive statistics and graphs were executed using the GraphPad Prism 5 Software. In all cases, standard error difference (s.e.d) at 5% was used to compare treatment means.

CHAPTER FOUR

RESULTS

4.1.1 HEAVY METAL CONCENTRATIONS IN THE SAMPLED WATER

Lead

In February, Lead concentration ranged from 0.02±0.00 to 0.13±0.00. KWA8 recorded the maximum while TU1 recorded the least (Fig 3).

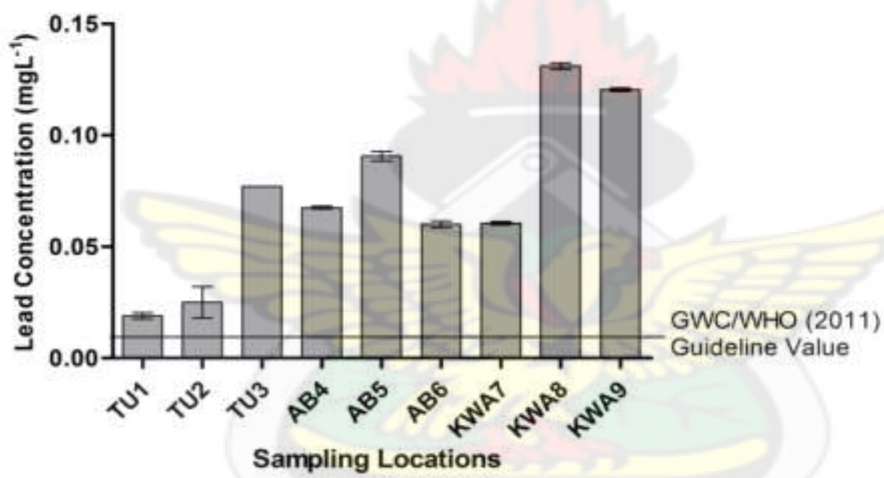

Fig3:Lead Concentrations in the Water Samples from the Sampling Locations(February 2012)

In March, the concentration of Lead ranged from 0.07±0.00 to 0.18±0.00. KWA9 recorded the least while AB4 recorded the highest concentration at (Fig 4).

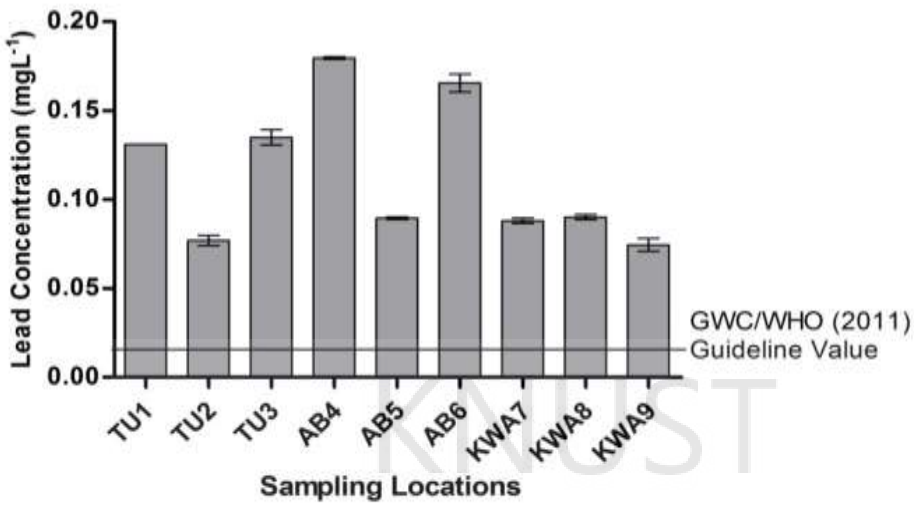

Fig4:Lead Concentrations in the Water Samples from the Sampling Locations(March 2012)

In April, the least concentration of 0.04mg/L was recorded in AB5 while the highest of 0.16mg/L was recorded in AB6 (Fig 5)

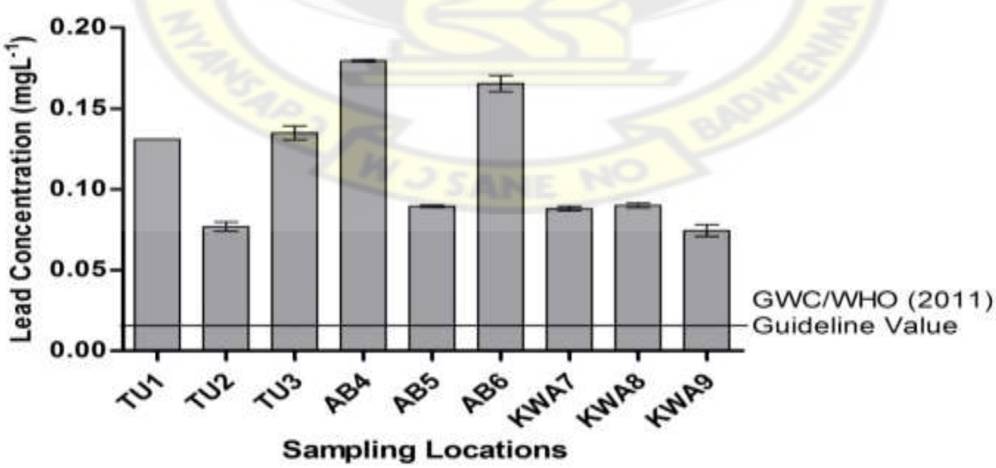

Fig5: Lead Concentrations in the Water Samples from the Sampling Locations(April 2012)

The ANOVA analysis revealed significant differences ($p<0.05$) in the lead concentration recorded at the different sampling stations over the study period. The Tukey's Multiple Comparison Test in Table 7 in the Appendix further revealed specifically where the differences in lead levels were among the sampling stations.

Cadmium

In February, Cadmium (Cd) was present in high concentrations in all the samples ranging from 0.005mg/L at TU1 and TU2 to 0.020mg/L at AB6 except KWA7 which had a concentrations of 0.001mg/L. All the other samples recorded very high concentrations of Cd with AB6 recording the largest concentration of 0.020mg/L(Fig. 6)

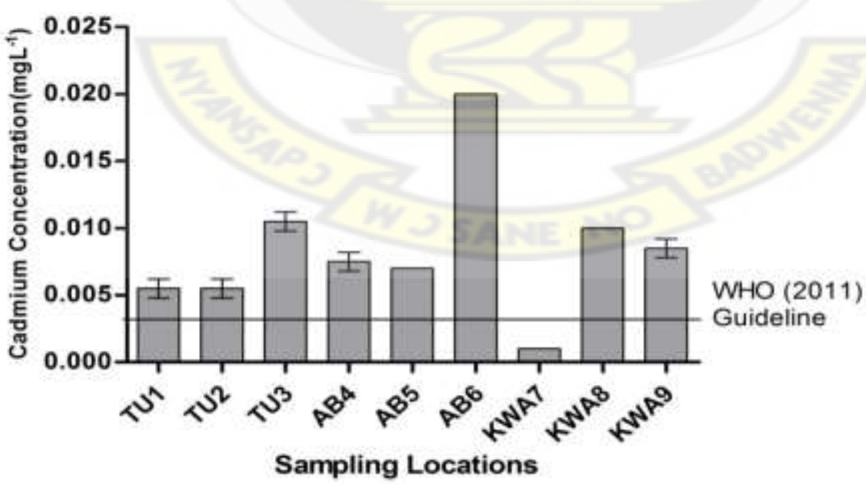

Fig6:Cadmium Concentrations in the Water Samples from the Sampling Locations(February 2012).

The ANOVA analysis revealed no significant differences ($p>0.05$) in the Cadmium concentration recorded at the various stations over the sampling period(table 8).

Mercury

In February, all the samples had some level of Mercury with the exception of TU2 and AB6, had Mercury concentrations below the detection level of the instrument used. Mercury concentration ranged from 0.00mg/L at TU1 and AB6 to 0.19mg/L at KWA7 (Fig 7)

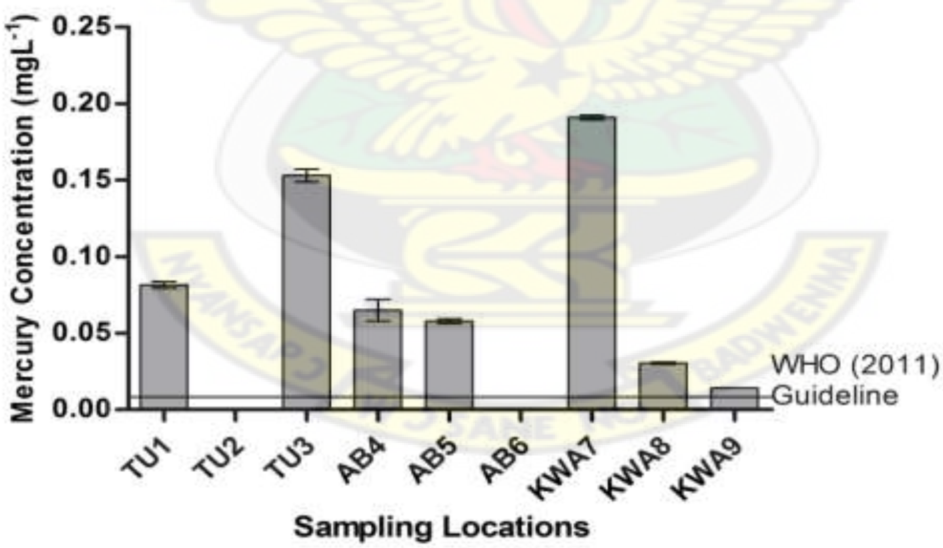

Fig7:Concentrations Mercury of in the Water Samples from the Sampling Locations (February 2012).

In March, all the samples had some levels of Mercury and their concentrations ranged from 0.02 mg/L at KWA7 to 0.312mg/L at TU2(Fig 8).

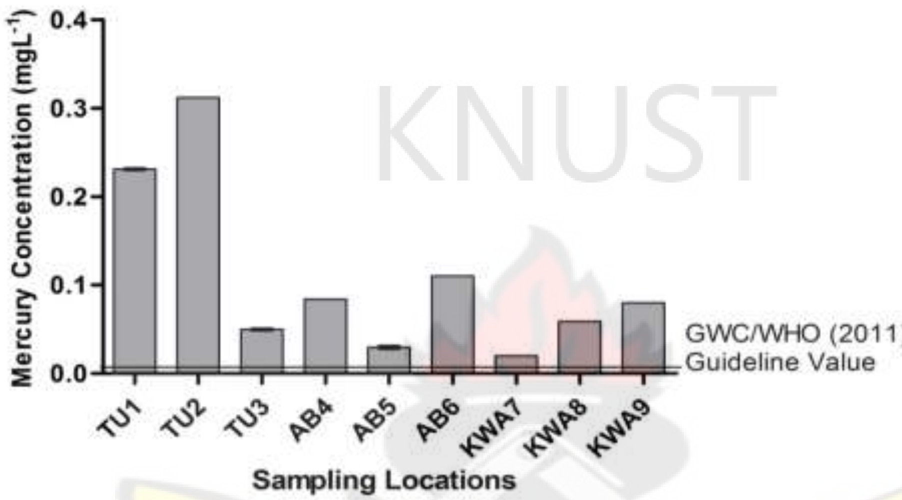

Fig8:Mercury Concentrations in the Water Samples from the Sampling Locations (March 2012)

April also recorded concentrations of Mercury in all the samples and it ranged from 0.01mg/L at KWA9 to 0.192±0.00 at TU2(Fig 9).

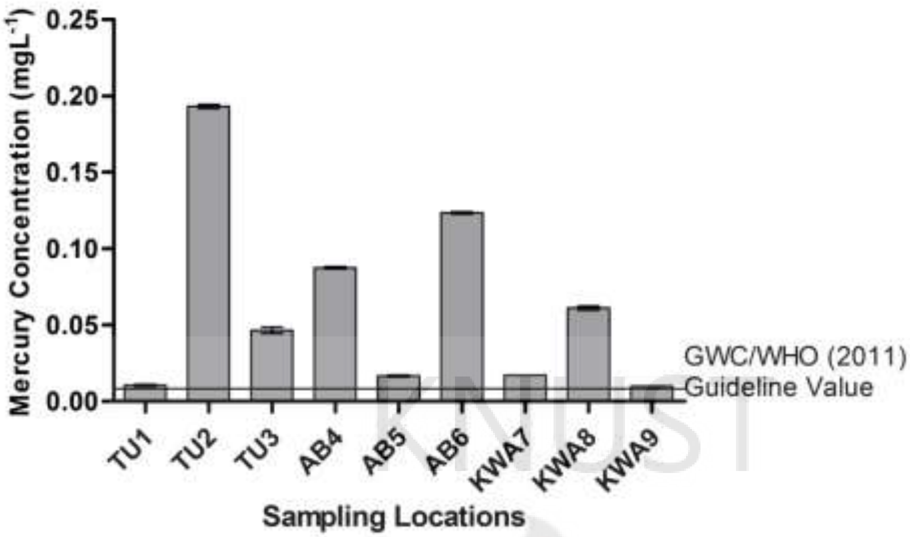

Fig9: Mercury Concentrations in the Water Samples from the Sampling Locations (April 2012)

The ANOVA analysis revealed no significant differences ($p>0.05$) in the Mercury levels recorded at the various stations over the sampling period(table 9).

Arsenic

All the samples collected from February to April had their Arsenic level below the detection level of 0.01mg/L of the instrument used.

Cyanide

Cyanide levels from February to April were below detection level of 0.07mg/L.

Microbial Loads in the Water

Total Coliforms.

Total coliform was present in all the samples in the February but in low levels as compared to the subsequent months. The levels ranged from as low as $9.0\times10^0\pm0.00\times10^0$ to $4.2\times10^3\pm2.1\times10^2$.

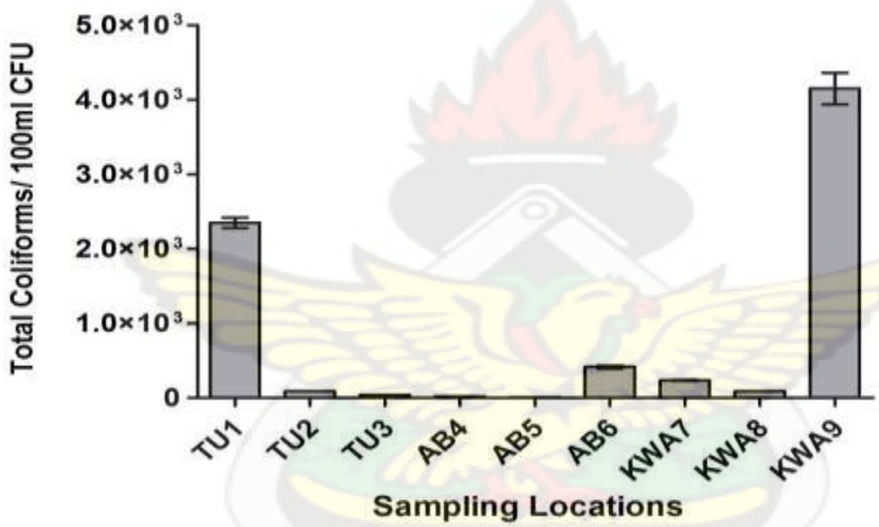

Fig10:Total Coliform loads in the Water Samples from the Sampling Locations(February 2012)

The Total coliform level in March had a great rise with the least of $9.0\times10^4\pm0.0\times10^0$ and the highest being $9.5\times10^4\pm0.00\times10^0$.

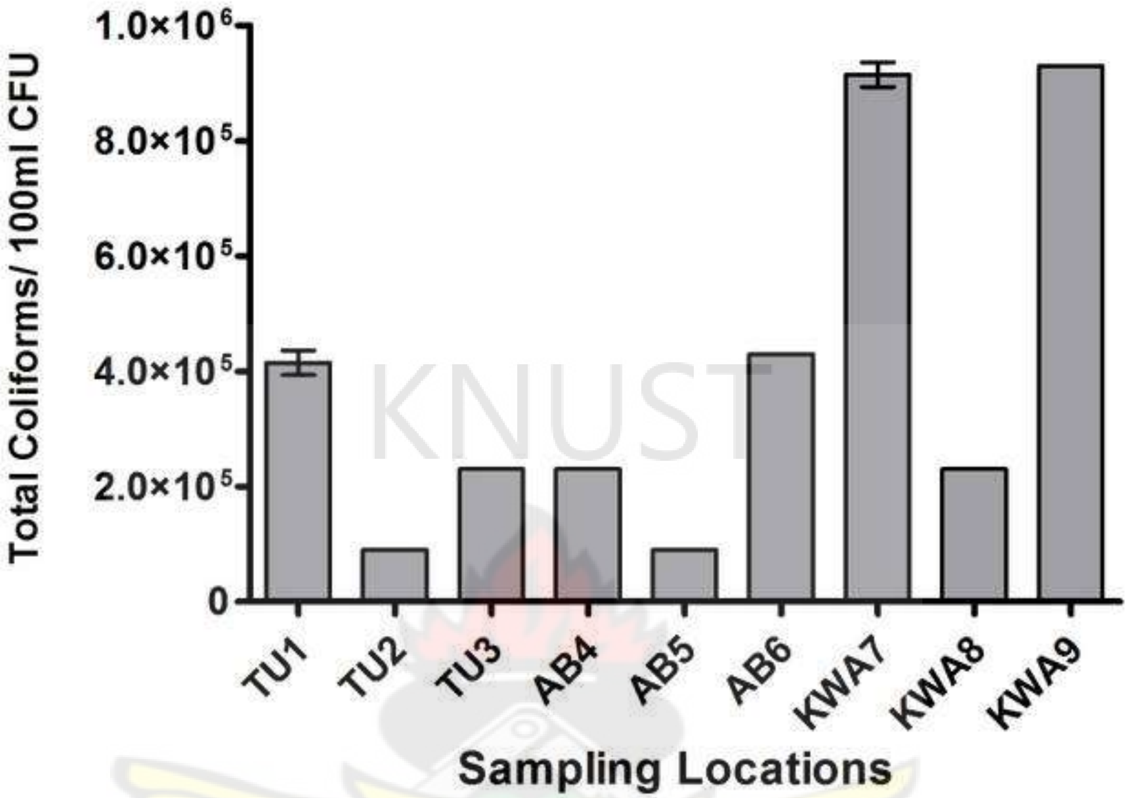

Fig11:Mean March Total Coliform loads in the Water Samples from the Sampling Locations(March 2012).

The Total Coliform level decreased in all the samples in April ranging from $4.0\times10^{4}\pm 0.0\times10^{0}$ to $4.2\times10^{5}\pm2.1\times10^{4}$.

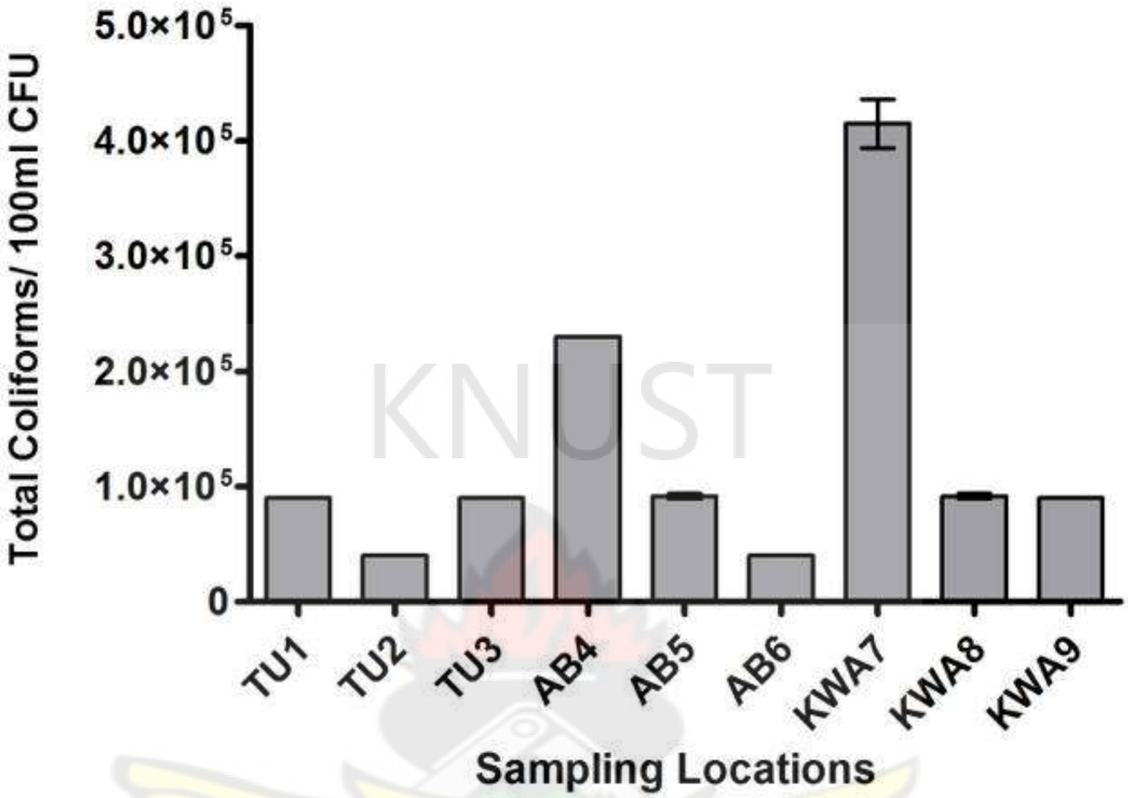

Fig12:Total Coliform loads in the Water Samples from the Sampling Locations(April 2012)

The ANOVA analysis revealed no significant differences ($p>0.05$) in the Total heterotrophic bacteria loads recorded at the various stations over the sampling period(table 6).

Faecal Coliform

In February, water samples from TU1, TU2, TU3, AB6, KWA7 and KWA8 had a few level of Faecal Coliform present, ranging from a mean value $9.0\times10^0\pm0.0\times10^0$ to 2.3×10^1 to0.0×10^0. AB4 and AB5 had no coliforms present but there was a shoot up in the number of coliforms in KWA9 with a mean value of $9.1\times10^1\pm 0.0\times10^0$.

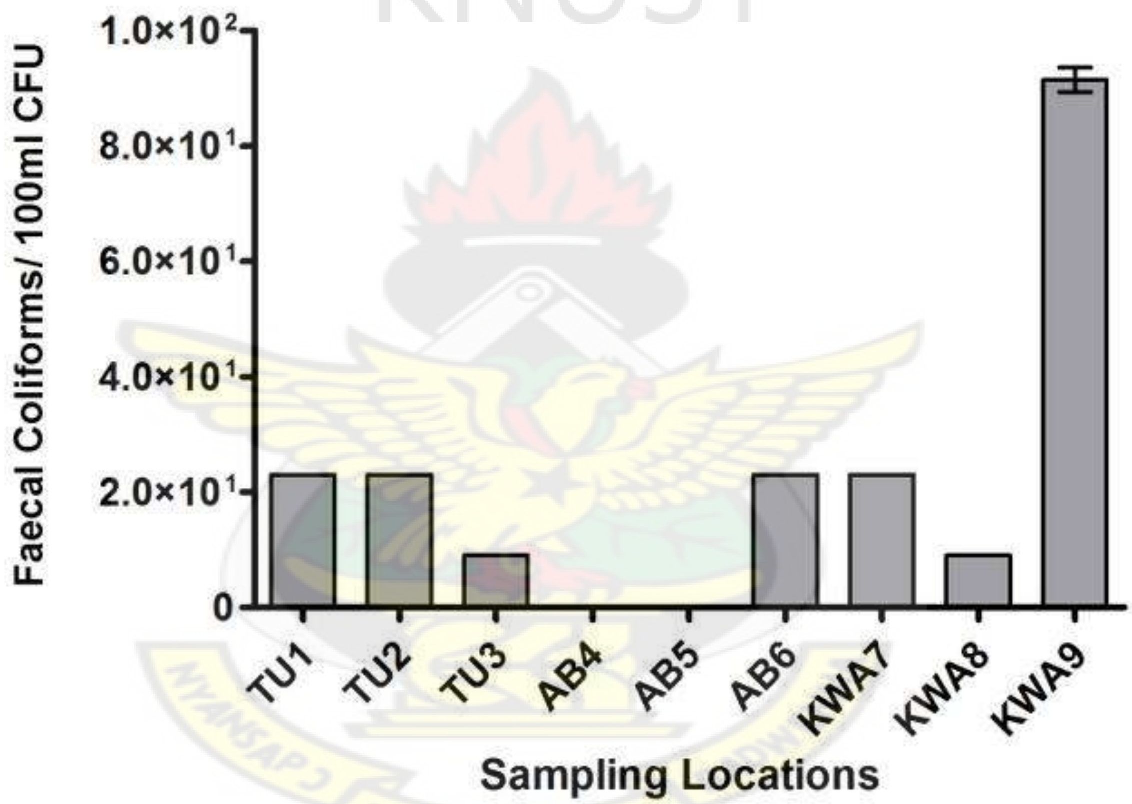

Fig13:Mean Faecal Coliform loads in the Water Samples from the Sampling Locations(February 2012)

In March, there was high loads of coliforms even to the thousands and this might be due to the onset of rain that might have washed coliforms into the wells (especially those close to waste water channels i.e. plate7 and 9). Faecal coliform in TU1 had shot from $2.3\times10^{1}\pm0.0\times10^{0}$ to $9.0\times10^{4}\pm0.0\times10^{0}$ in March.TU2 and KWA9 all had their coliform level high. KWA7 had an incredible rise in Faecal coliform with a mean value of $2.2\times10^{5}\pm2.1\times10^{4}$

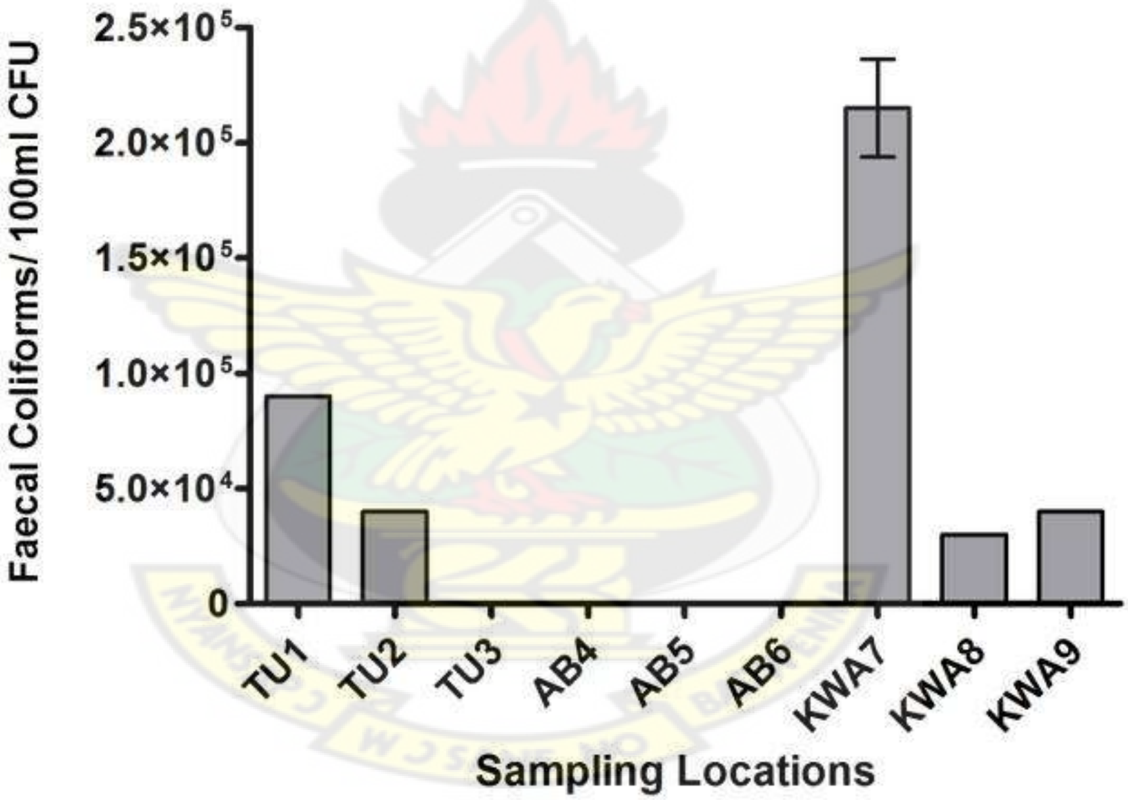

Fig14:Total Coliform loads in the Water Samples from the Sampling Locations (March 2012)

In April faecal coliform was absent in TU1, TU2, TU3, AB4, AB5, AB6, KWA9 and decreased in KWA7 and KWA8.

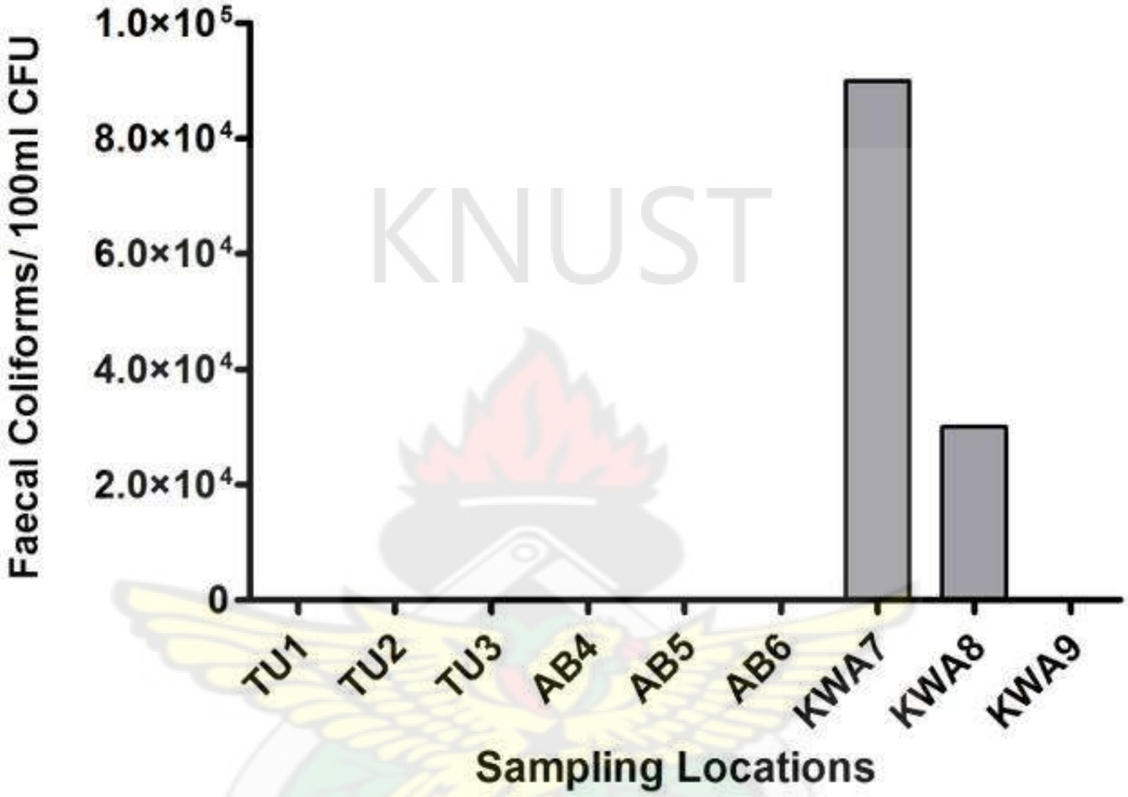

Fig15:Faecal Coliform loads in the Water Samples from the Sampling Locations(April 2012)

The ANOVA analysis revealed significant differences ($p<0.05$) in the faecal coliform loads recorded at the different sampling stations over the study period. The Tukey's Multiple Comparison Test in Table 5 in the Appendix further revealed specifically where the differences in faecal coliform loads were among the sampling stations.

Total Heterotrophic Bacteria

Total Heterotrophic Bacteria were in very high loads in February ranging from $1.1 \times 10^3 \pm 0.0 \times 10^0$ to $9.0 \times 10^4 \pm 0.00 \times 10^0$, with AB4 having the least and KWA 9 having the highest.

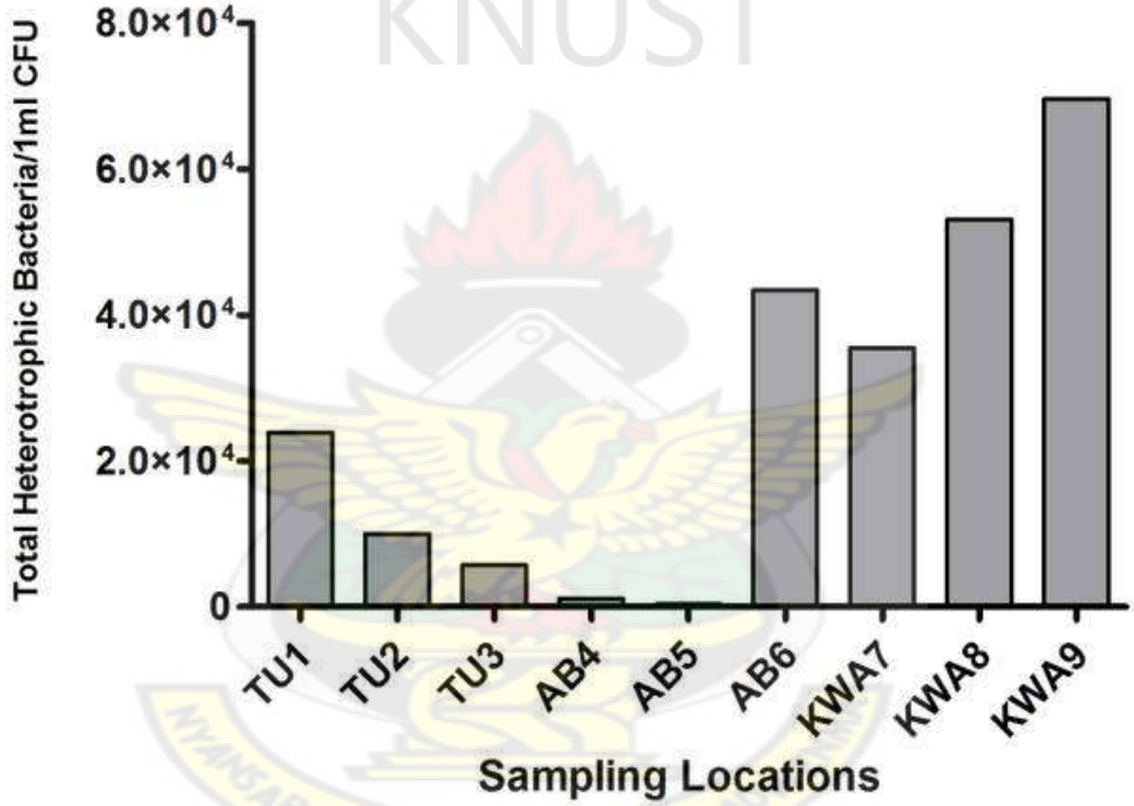

Fig16: Total Heterotrophic Bacteria loads in the Water Samples from the Sampling Locations(February 2012)

There was a decrease in the number of Total Heterotrophic bacteria in March ranging from 1.4×10^{3}(1mlcfu) at TU1 to 3.5×10^{4}(1mlcfu) at KWA

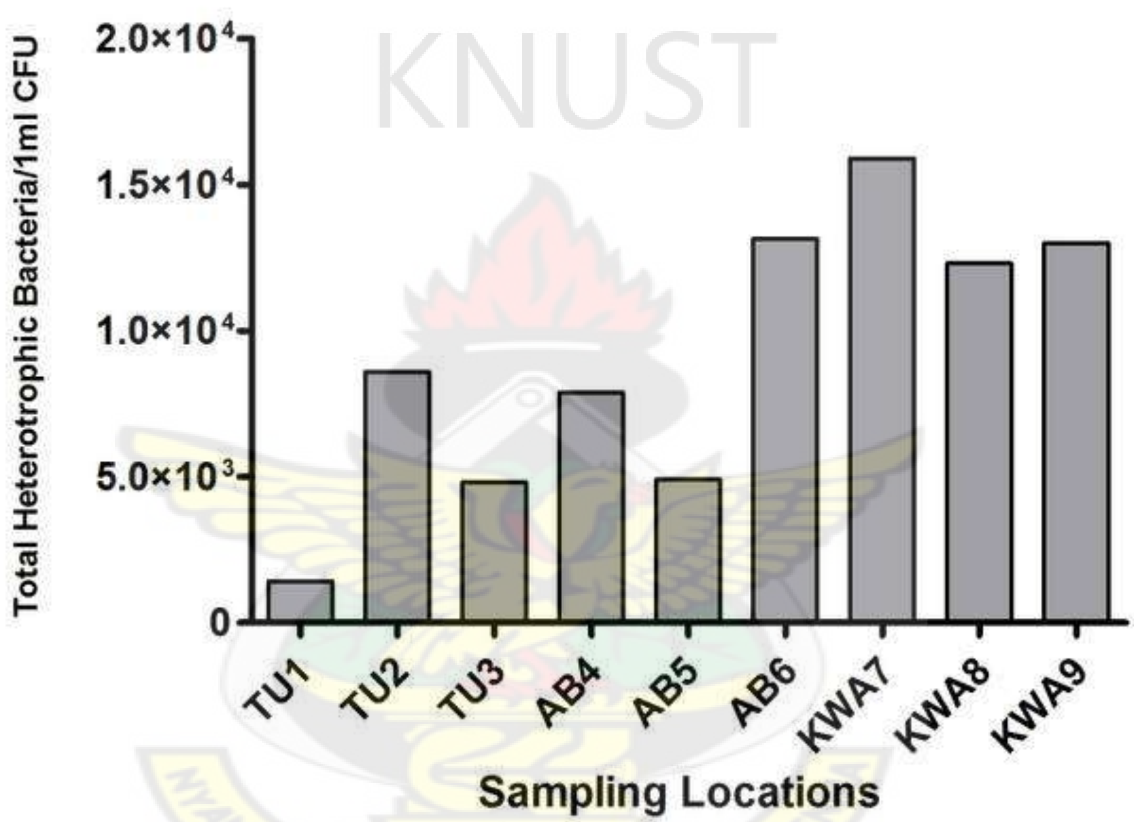

Fig17:Mean Total Heterotrophic Bacteria loads in the Water Samples from the Sampling Locations(March 2012)

Total Heterotrophic loads in April had the least recorded in TU1 and highest in KWA7 with values $6.0\times10^{1}\pm0.0\times10^{0}$ and $9.5\times10^{2}\pm0.00\times10^{0}$ respectively.

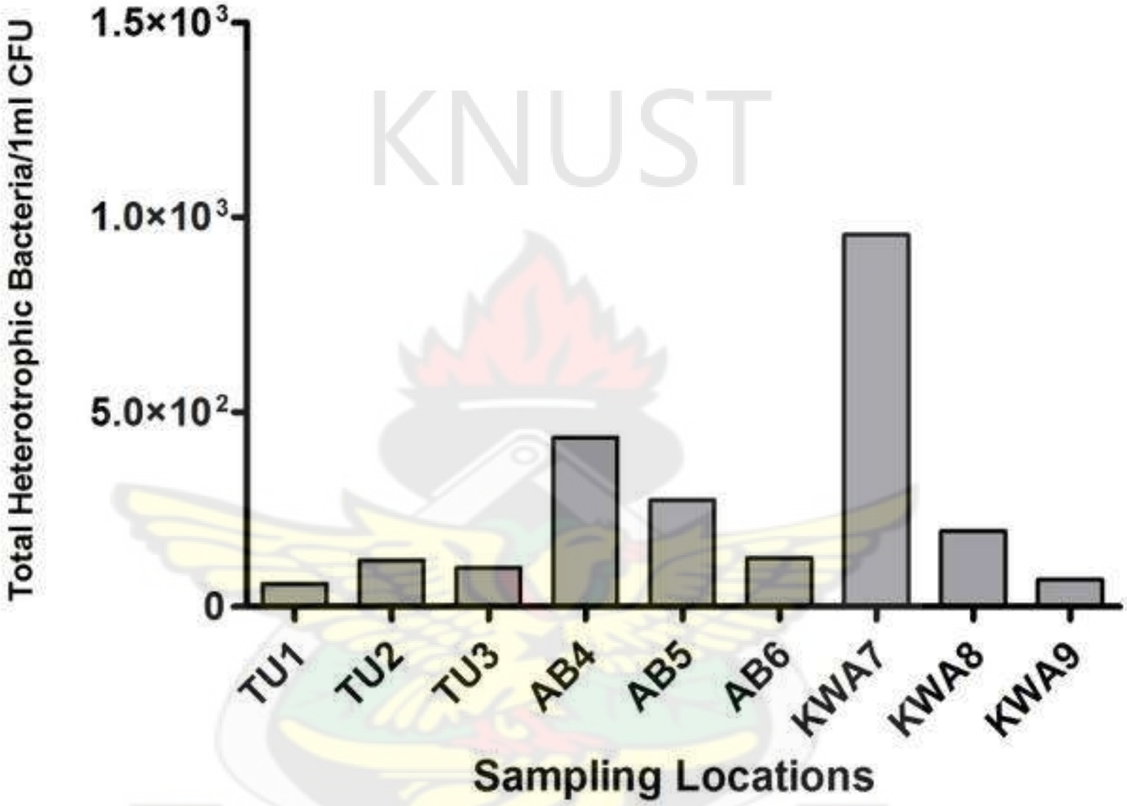

Fig18: Total Heterotrophic Bacteria loads in the Water Samples from the Sampling locations (April 2012).

The ANOVA analysis revealed no significant differences ($p>0.05$) in the Total heterotrophic loads recorded at the various stations over the sampling period(table 6).

Enterococci

All the samples collected from February to April had no enterococci in them.

Physicochemical Parameters of the Water

pH

All the wells but one (KWA7) were acidic. Well TU2, AB5, and AB6 recorded the least pH and with values, 4.16 and 4.76(Fig 19, 20, 21)

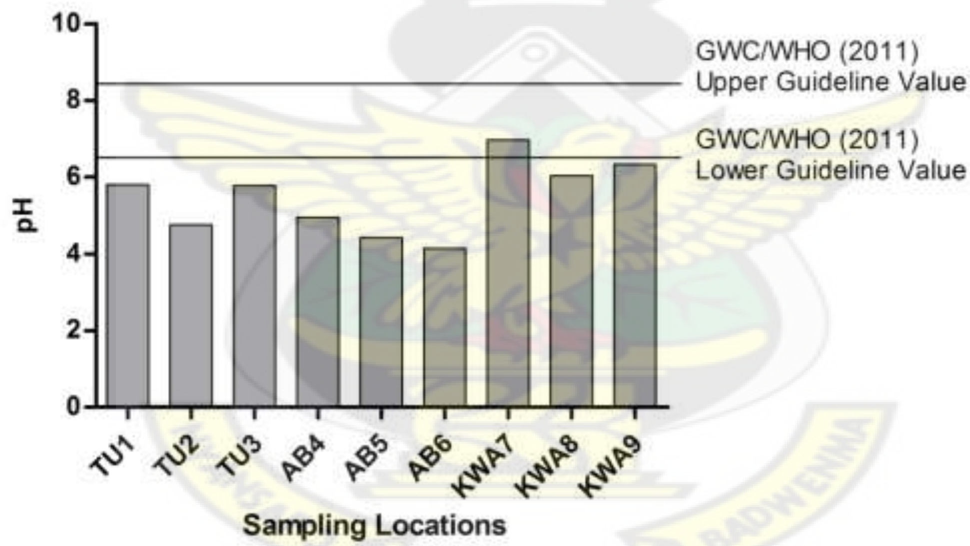

Fig19: pH Levels in the Water Samples from the Sampling Locations(February 2012)

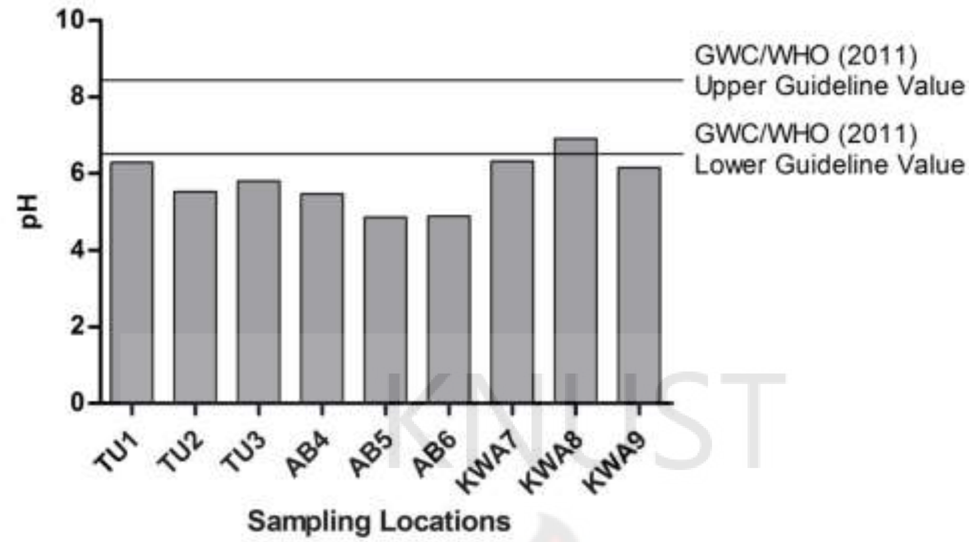

Fig20: pH Levels in the Water Samples from the Sampling Locations(March 2012)

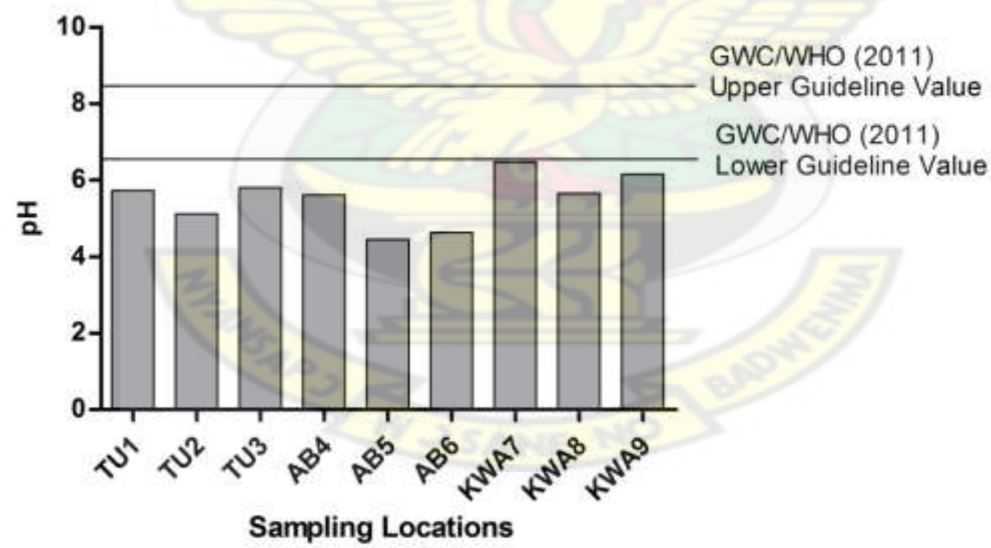

Fig21:pH Levels in the Water Samples from the Sampling Locations(April 2012)

The ANOVA analysis revealed significant differences ($p<0.05$) in the pH levels recorded at the different sampling stations over the study period. The Tukey's Multiple Comparison Test in Table12 in the Appendix further revealed specifically where the differences in pH levels were among the sampling stations.

Total Suspended Solids

In February, all the samples had their concentrations below the GWC/WHO guideline values with the exception of TU1, TU3, and AB5 which had concentrations of 3.50mg/L, 3.5mg/L and 4.00mg/L respectively. AB4 and KWA recorded the least concentrations of 1.00mg/L and the largest 4.00 was recorded in AB5 (Fig 22).

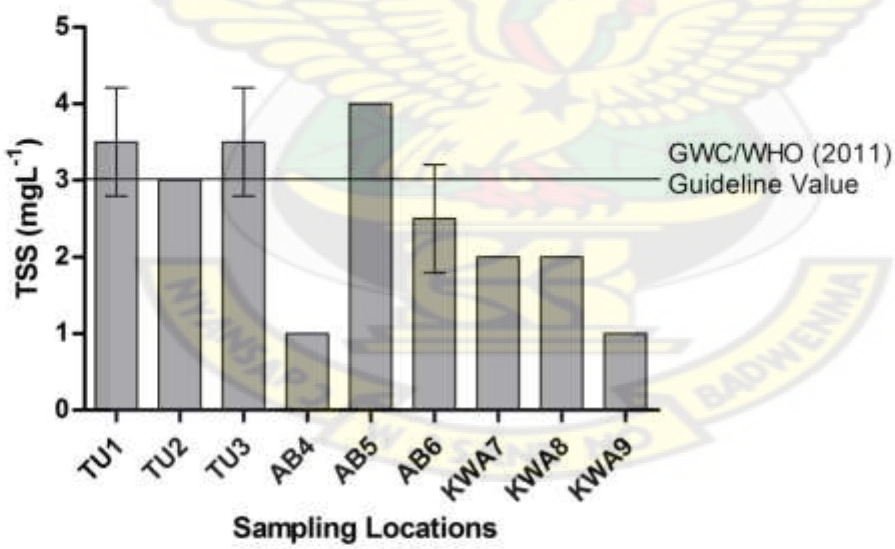

Fig22:Levels of Total Suspended Solids in the Water Samples from the Sampling Locations(February 2012)

March had TU1 having its concentrations reduced to 1.00mg/L and AB4 and KWA8 rising above the WHO guideline with concentrations of 4.00mg/L(Fig 23).

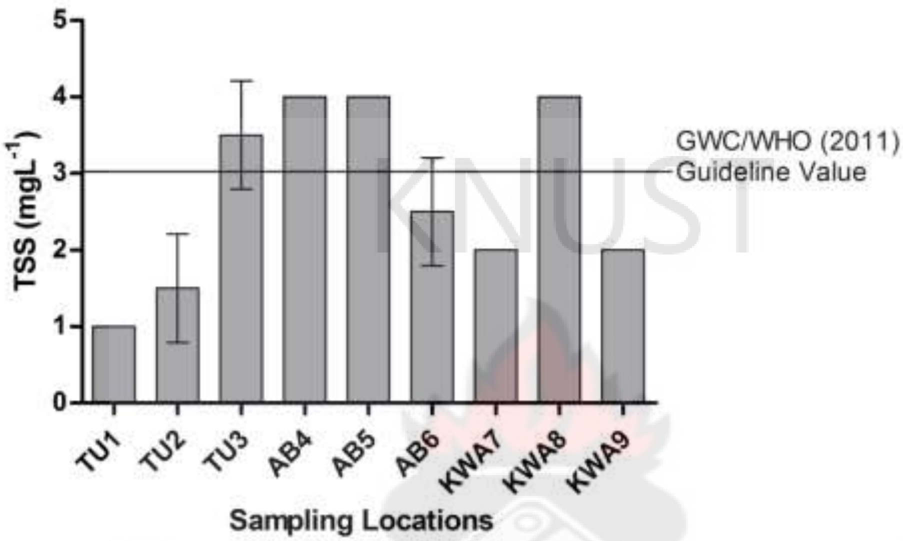

Fig 23:Levels of Total Suspended Solids in the Water Samples from the Sampling Locations(March 2012)

April had all the samples falling below the WHO maximum guideline value with the exception of AB4 which was above, with a concentration of 3.50mg/L. The least concentration of 1.00mg/L was recorded in AB6 and TU2 (Fig 24).

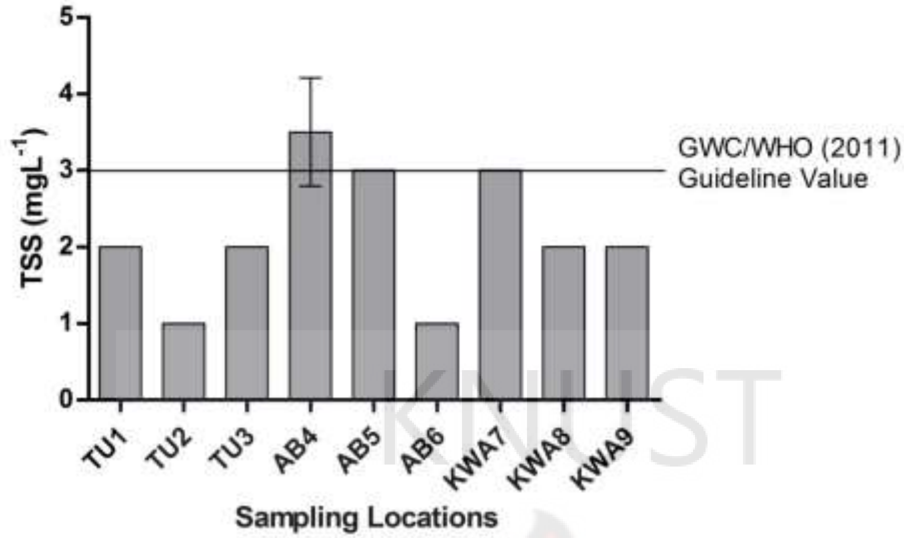

Fig24:Levels of Total Suspended Solids in the Water Samples from the Sampling Locations(April 2012)

The ANOVA analysis revealed significant differences (p<0.05) in the Total suspended solids(TSS) levels recorded at the different sampling stations over the study period. The Tukey's Multiple Comparison Test in Table 10 in the Appendix further revealed specifically where the differences in TSS levels were among the sampling stations.

Total Dissolved solids

All the water samples had their TDS concentrations below the WHO maximum limit (1000mg/L) ranging from 89.50mg/L at AB4 to 363.50mg/L (Fig 25).

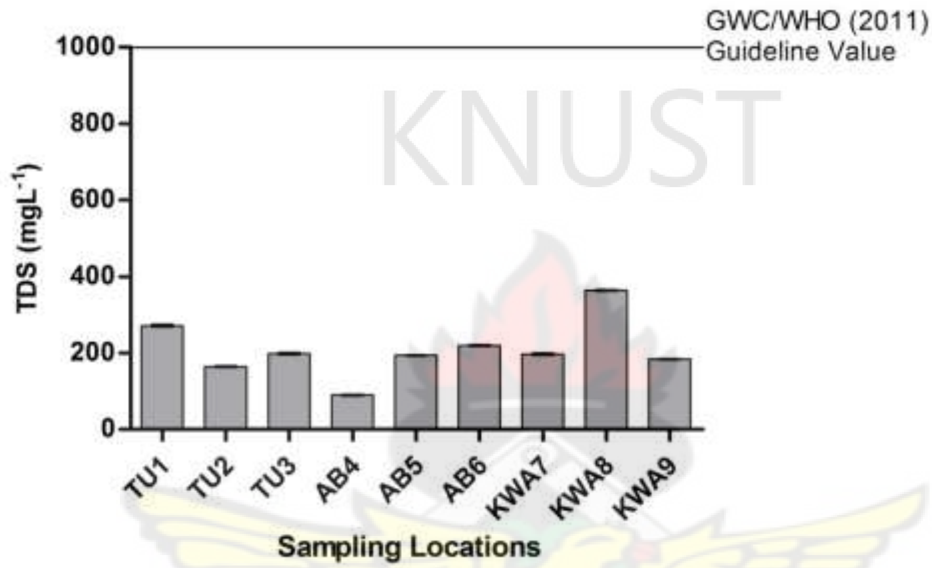

Fig25:Levels of Total Dissolved Solids in the Water Samples from the Sampling Locations (February 2012).

All the water samples had their TDS concentrations below the WHO maximum limit (1000mg/L) ranging from 66.00mg/L at AB4 to 364.00mg/L at AB6 (Fig 26).

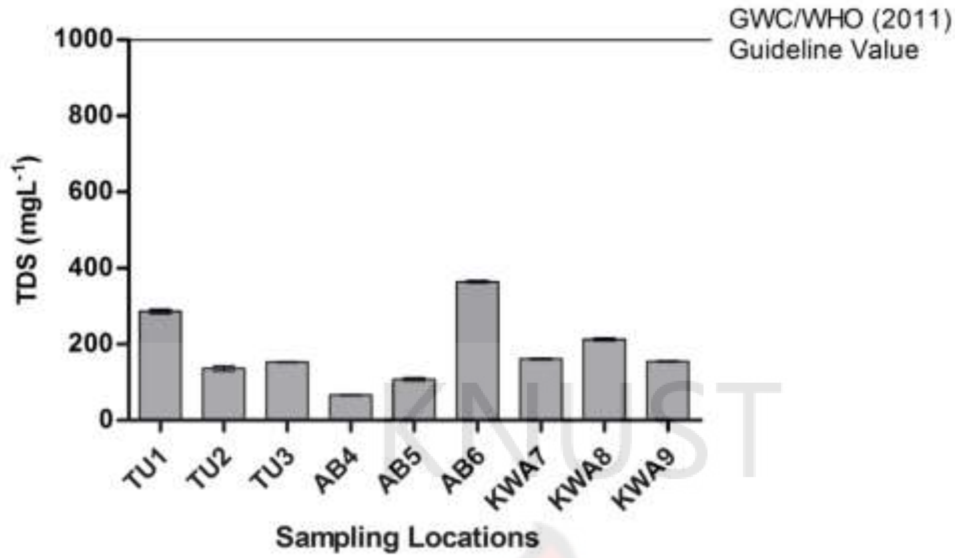

Fig26:Levels of Total Dissolved Solids in the Water Samples from the Sampling Locations (March 2012).

All the water samples had their TDS concentrations below the WHO maximum limit (1000mg/L) ranging from 68.00mg/L at AB4 to 369.00mg/L (Fig 27). This implies the samples had less dissolved salts.

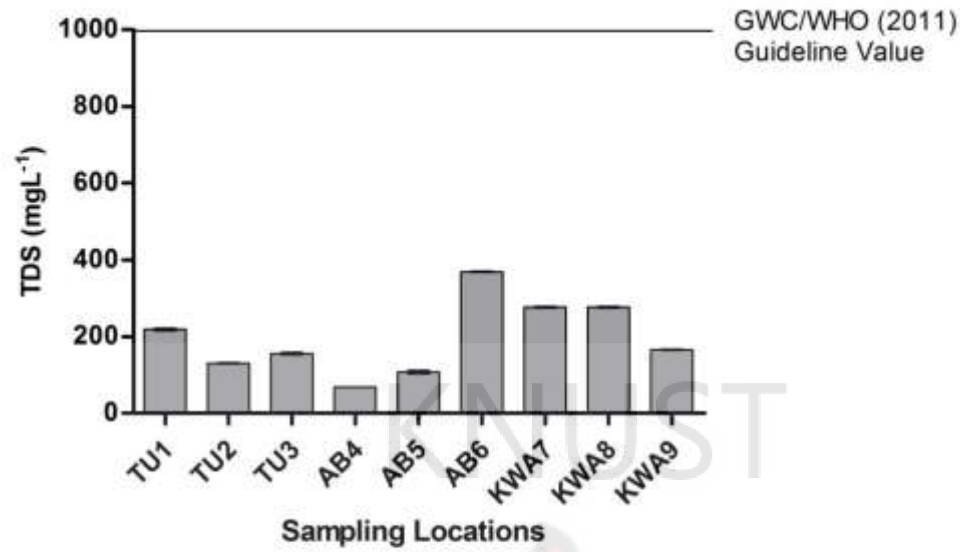

Fig27: Levels of Total Dissolved Solids in the Water Samples from the Sampling Locations (April 2012).

The ANOVA analysis revealed significant differences ($p<0.05$) in the total dissolved solids (TDS) levels recorded at the different sampling stations over the study period. The Tukey's Multiple Comparison Test in Table 11 in the Appendix further revealed specifically where the differences in TDS levels were among the sampling stations.

Alkalinity

February had all its concentrations ranging from 6.30mg/L at AB6 and 40.50mg/L at KWA8 with the exception of KWA7 and KWA9 which had their concentrations 146.70mg/L and 60.00mg/L respectively within the WHO guideline (Fig 28).

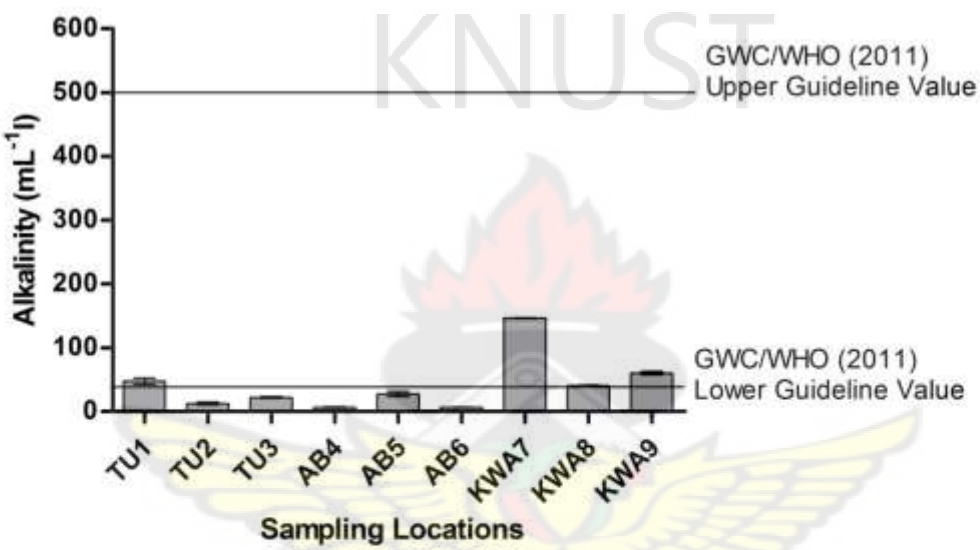

Fig28: Alkalinity in the Water Samples from the Sampling Locations (February 2012)

In March, the concentrations of samples from KWA7 (148.20mg/L) was within the WHO guideline, with KWA9 almost on the lower guideline value with a concentration of 43.05mg/L. AB4 recorded the least concentration of 6.10mg/L(Fig 29).

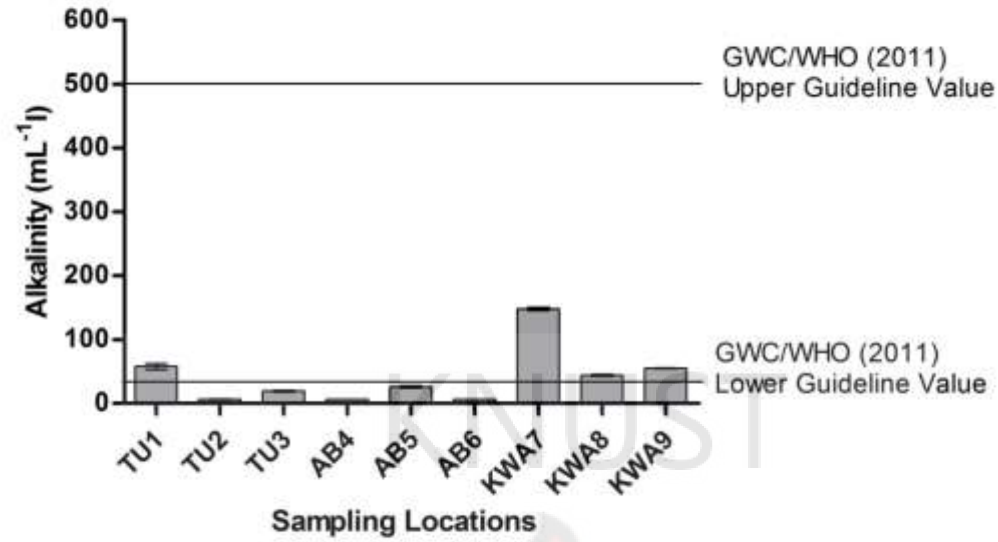

Fig29:Mean Alkalinity in the Water Samples from the Sampling Locations (March 2012)

Alkalinities of samples in April were strikingly low with the exception of KWA7 which recorded a concentration of 2552.50mg/L. The lowest alkalinity 6.10mg/L was recorded at AB4 (Fig 30).

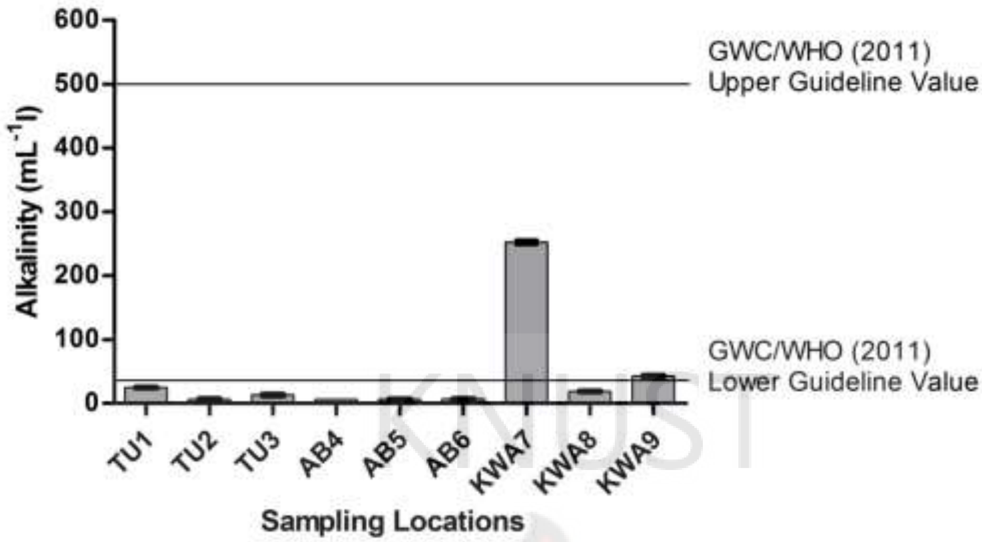

Fig30:Alkalinity in the Water Samples from the Sampling Locations (April 2012)

The ANOVA analysis revealed significant differences ($p<0.05$) in the alkalinity levels recorded at the different sampling stations over the study period. The Tukey's Multiple Comparison Test in Table 13 in the Appendix further revealed specifically where the differences in alkalinity levels were among the sampling stations.

Conductivity

All well samples had their conductivity below the WHO maximum limit of 1500µscm-^{1}. A clear indication that the samples had optimum conductivity (Fig 31, 32, 33)

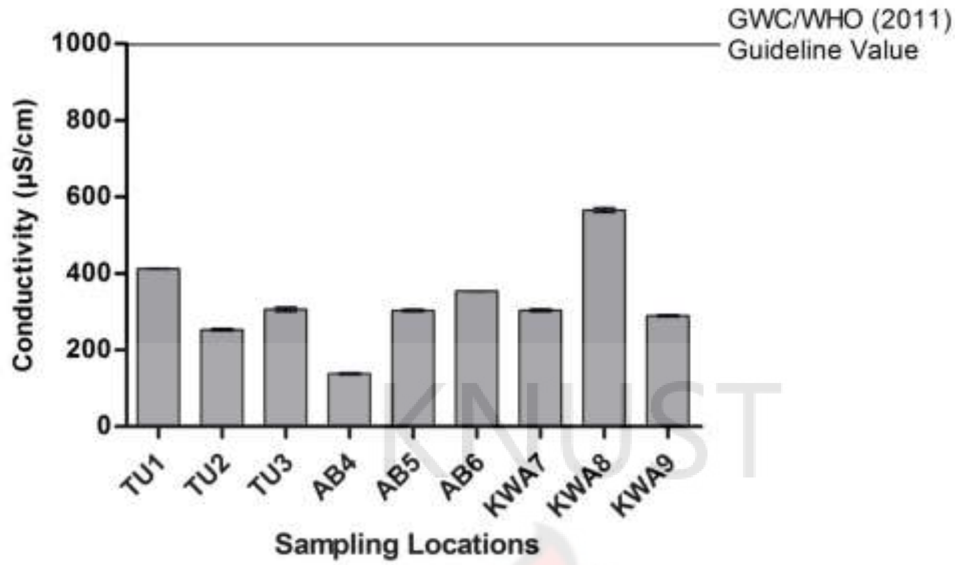

Fig31: Conductivity Levels in the Water Samples from the Sampling Locations (February 2012)

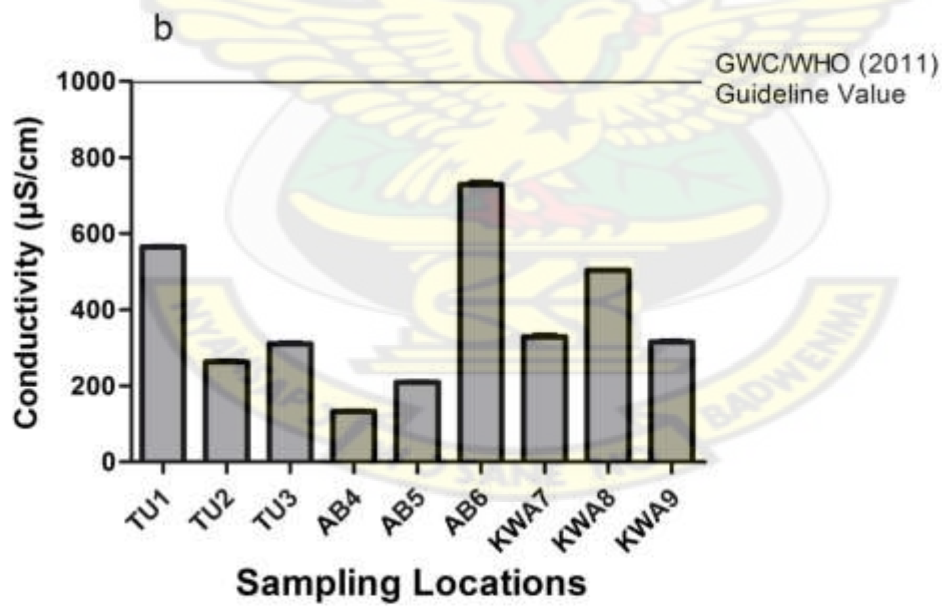

Fig32: Conductivity Levels in the Water Samples from the Sampling Locations (March 2012)

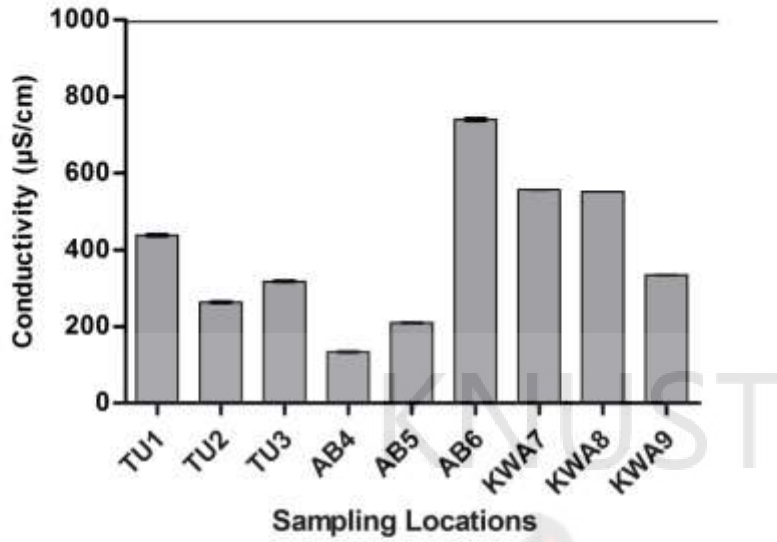

Fig33:Mean Conductivity Levels in the Water Samples from the Sampling Locations (April 2012)

The ANOVA analysis revealed significant differences ($p<0.05$) in the conductivity levels recorded at the different sampling stations over the study period. The Tukey's Multiple Comparison Test in Table 14 in the Appendix further revealed specifically where the differences in conductivity levels were among the sampling stations.

Turbidity

In February, AB5 had its sample very turbid with mean value of 38.00±1.41, while TU3 recorded the least with a mean value of 1.50±0.70 (Fig 34)

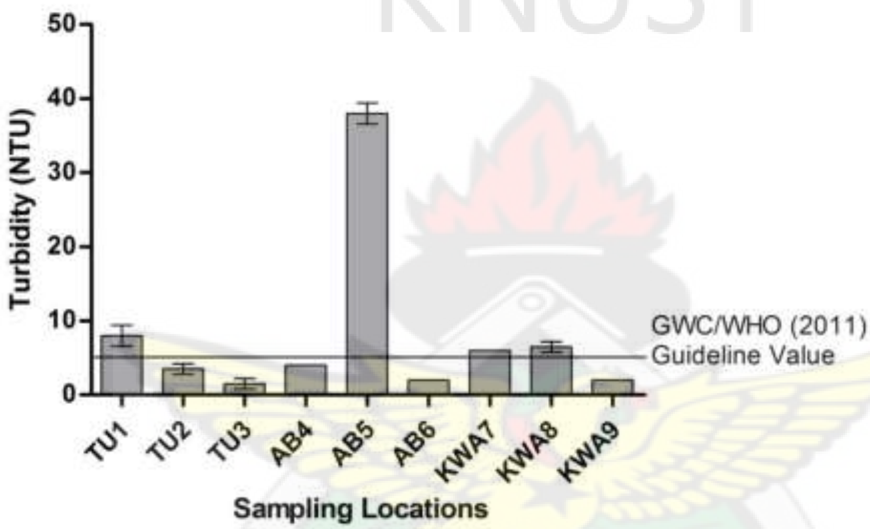

Fig34: Turbidity Levels in the Water Samples from the Sampling Locations (February 2012)

In March AB5 had its samples very turbid with mean value of 43.50±2.21 and the least recorded at AB4 and AB6 with mean value of 0.00± 0.00.

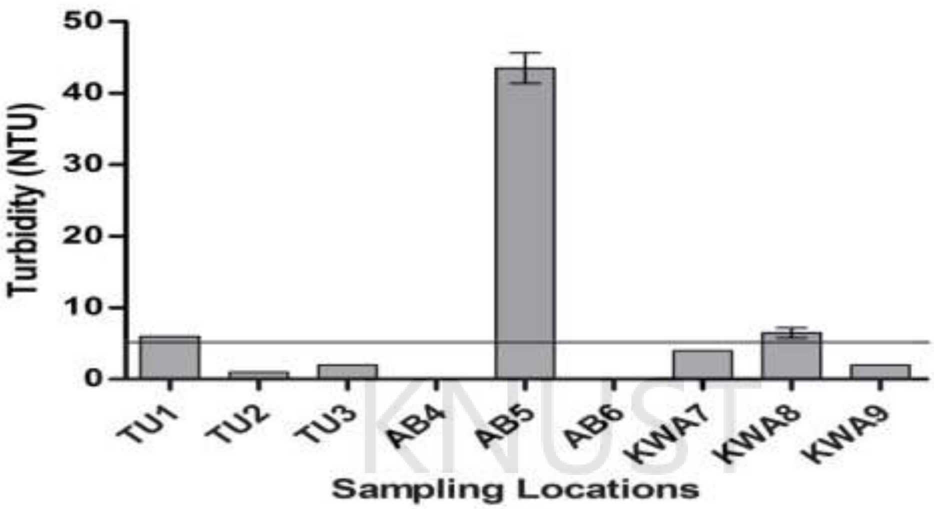

Fig35:Turbidity Levels in the Water Samples from the Sampling Locations (March 2012)

All the well samples were turbid in the month of April(ie were all above the WHO guideline) and the mean values were TU1;14.50±0.71, TU2;19.50±2.12, TU3;15.00±1.41, AB4;19.50±2.12, AB5;79.50±4.95, AB6;19.50±2.12, KWA7;20.50±0.71, KWA8;19.50±2.12, KWA8; 20.00±0.00, KWA9; 19.50±2.12.

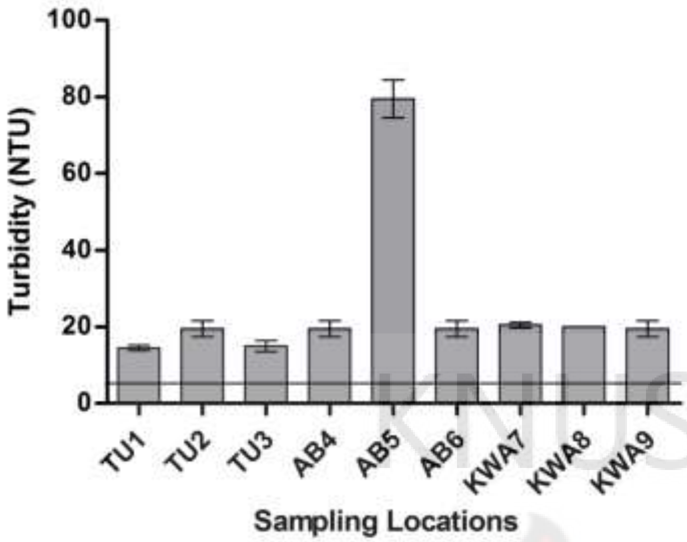

Fig36:Turbidity Levels in the Water Samples from the Sampling Locations (April 2012)

The ANOVA analysis revealed significant differences ($p<0.05$) in the turbidity levels recorded at the different sampling stations over the study period. The Tukey's Multiple Comparison Test in Table 15 in the Appendix further revealed specifically where the differences in turbidity levels were among the sampling stations.

CHAPTER FIVE

DISCUSSION

5.1 PHYSICOCHEMICAL PARAMETERS OF WATER

The sampling stations in the communities in Obuasi are within the mining lease of the Ashanti Goldfields (Obuasi) Limited. Currently, active artisanal mining is intense in the area, but conducted by illegal miners, since the entire area is covered by the concession of Ashanti Goldfields. The development of extensive mining operations in an area that can be described as ecologically sensitive zone(plate 1-9), covered by forested highlands rising up to 400 m above sea level in some places and well-developed drainage system would certainly give rise to environmental problems (Amonoo-Neizer andBusari, 1980; Jetuah, 1997; Carboo andSerfor-Armah, 1997; Clement *et al*., 1997). Gold mining in some areas in Ghana in recent times has become unpopular as it is regarded as a significant source of Arsenic, Mercury and Lead and heavy metal contamination of the environment owing to activities such as mineral exploitation, ore transportation, smelting and refining, disposal of the tailings and waste waters around mines (Essuman*et al*., 2007; Hanson *et al*., 2007; Obiri 2007; Singh, 2007). Heavy metal pollution within mining communities of Ghana has been extensively studied (Adimado and Amegbey, 2003; Akabzaa*et al*., 2005; Carboo and Serfor - Armah, 1997; Essumang,*et al* 2007; Hilson, 2002; Manu,*et a*l., 2004; Obiri, 2007; Yidana,*et al*., 2008).

Mining activities in Obuasi can be implicated in the released of high metal concentrations into the environment. Anthropogenic inputs, both point and non-point sources may also play a role in the high metal concentrations, although mining appears to be the main pollution source. The high levels of heavy metals in the groundwater could also be due to the inherent mineralogy of the ores of the study area. Arsenic for example, is a metal naturally associated with gold and may be released through processing into water bodies (Kumi-Boateng, 2007). Serfor-Armah *et al*. (2006) reported high levels of some heavy metals in some streams of Prestea, a gold mining town in the western part of Ghana. According Kumi-Boateng (2007), soil and sediment samples from major gold mining town in Ghana contained high arsenic concentrations, possibly implying the impact of mining activities. Mine tailings in the study area also represent a potential heavy metals source(Fig 2). The separation processes used for most metals do not extract all the minerals present and the tailings that accumulate in the environment may contain quantities of toxic metals and other minerals, as well as residues of the chemicals used for extraction. The finely ground minerals from processing makes contaminants such as arsenic, accessible to water (Beischer, 2006). The activities of galamsey operators in mining communities also contribute immensely to heavy metal pollution in the streams by increasing the mercury content(Plate 9). Galamsey operators combine significant volumes of water from the streams with mercury for gold processing (Akabzaa*et al*., 2001) which could seep into the groundwater resources of Obuasi.

The heavy metal composition of the groundwater in Obuasi varied widely and this probably is a combined result of the composition of the water entering the groundwater reservoir and the reactions with minerals present in the rock that may modify the water composition. A similar trend was reported by Asklund and Eldvall, (2005) who examined groundwater contamination in Tarkwa. The retention time of the heavy metals in the groundwater can also be implicated in the observed marked variations in monthly concentrations of the assayed heavy metals. According to Appelo andPostma, (1999), some metals dissolve quickly and significantly change the water composition; others dissolve slowly and have less effect on the water composition. The retention time is also important in determining the water chemistry and metal concentrations in groundwater. Long residence times allow reactions to take place and these waters are likely to have higher concentrations of ions than water with short residence times (Appelo andPostma, 1999).

Usually in unaffected environments the concentration of most metals is very low and is mostly determined by the mineralogy and weathering of rocks (Espeby andGustafsson, 2001). There are a few examples of local metal pollution through natural weathering but in most cases metals become an environmental and health issue because of anthropogenic activity. Mining and smelting plants release metals from the bedrock (Walker andSibly, 2001). The excessively high concentrations of Lead, Cadmium and Mercury in the sampled groundwater sources in Obuasi is most likely as a direct result of the mining activities carried out in the area.

Soil types(Plate 1-9) and the nature of adsorbing surfaces (oxide surfaces, clay mineral and humic substances) and the pH are also important parameters affecting the concentrations and transportation of heavy metals in the groundwater system (Espebyand Gustafsson, 2001). Although anthropogenic factors are the most likely causes of the observed concentrations of heavy metals in the groundwater, there are a number of reasons that can also explain the metal concentrations in the Obuasi groundwater. Sorption processes are also very important for metal concentrations of the groundwater in the area. Sorption can considerably lower the metal concentration in the groundwater, especially when the soil types of the location have clayey composition. The soil types all some of the sampling stations were observed to be clayey. These soils have a lot of adsorption and absorption sites due to their content of clay and abundance of Al/Fe oxides/hydroxides like goethite and montmorillonite. Heavy metals such as Arsenic and Cadmium as well as other metals usually have the tendency to be strongly bonded to these sites and thus may not be readily-available to the groundwater. This probably explains why some of the heavy metals recorded very low metal values in the water. According to Asklund and Eldvall, (2005), ion exchange in clays can remove heavy metal cations and provide some protection to groundwater supplies.

Arsenic concentrations in surface waters in Obuasi have been reported by researchers like Amonoo-Neizer*et al.* (1995), Smedley*et al.* (1996), Kumi-Boateng, (2007) to be very high. They concluded that Arsenic constitutes the major trace element problem in the Obuasi area and linked this to the considerable level of naturally occurring Arsenic at Obuasi, as well as its liberations from Arsenic-bearing gold ores during gold extraction. Around the town of Obuasi, high Arsenic concentrations have been noted in soils close to the mines and treatment works (Amasa, 1975; Bowell, 1991). High concentrations have also been reported in rivers waters close to the mining activity (Smedley *et al*., 1996). Arsenic contamination in Obuasi has been associated with gold mining in the area. According to Smedley*et al*., (1996), arsenopyrite (FeAsS) in the ore is the principal cause of Arsenic pollution in Obuasi, especially when they leach from into tailings into ground and surface waters. Gold ore smelters process arsenopyrites containing about 0.8% arsenic that is not recovered but is dispersed into the surrounding environment. Despite the presence of high Arsenic concentrations in the contaminated soils and in bedrocks close to the mines, Smedley,*et al*. (1996) found that many of the groundwaters of the Obuasi area had low Arsenic concentrations. The low Arsenic concentration recorded by this study is similar to the findings of Smedley,*et al*., (1996). The very low Arsenic concentrations in the sampled groundwater could well be due to the soil types in the areas which adsorb Arsenic and make it unavailable to the groundwater.

Another factor which affected the concentrations of heavy metals in groundwater is slope of the area and ultimately the retention time of the heavy metals in the groundwater. Obuasi is very hilly and there are a lot of water divides(plate7 and 9). This according to Asklund and Eldvall, (2005), gives rise to local groundwater systems with short residence times for heavy metals. Such groundwater systems will not be strongly affected by dissolution of heavy metals due to the short contact time. However, there is the possibility that local mining pollutants have not yet reached the wells and that the groundwater quality will deteriorate in some of the wells in the future. Rainfall might also have a diluting effect on the concentrations of contaminants in the groundwater. This could explain the low concentrations of some of the heavy metals(arsenic) recorded in the study area. The mechanisms and the mobility of metals in water are affected by a number of different parameters e.g. the oxidation state of the metal ion and pH (Appelo andPostma, 1999).pH is crucial for the extent of sorption. Anions adsorb more strongly with decreasing pH while the reverse is true for cations (Espeby andGustafsson, 2001). This is caused by the increase in H^+, which binds to charged surfaces instead of metals. Since binding sites are limited, metals will go into solution increasing concentrations in the groundwater. The low pH recorded in the Obuasi groundwater might have had an effect on the heavy metal concentrations.

Most of the pH values recorded in the Obuasi groundwater were found to be below the natural background level as prescribed by WHO (2011) as in fig 19-21. The low pH values could well be attributed to ground water acidification in those areas. Groundwater acidification in these areas could originate from different anthropogenic processes such as mining activities (Tay and Kortatsi, 2008). Large scale mines in the area use roasting of ore as processing method. This can give rise to acidified rain which might be infiltrated into the well waters in the sampled areas, although the low pH cannot solely be explained by acid rain.

The total dissolved solids (TDS) contents of drinking water have not been established in the WHO (2011) Guidelines for Drinking-water Quality. The reason for not establishing a guideline value is that TDS does not actually constitute health concern at levels found in drinking-water. Nkansah,*et al*. (2010) in their assessment of ground water quality in the Kwahu West District of Ghana, stated a TDS value of 1500 mgL-1 as the maximum permissible limit of TDS in drinking water. With reference to this value, it can be said that the TDS values of the entire well and borehole water samples(Fig 25-27) of Obuasi are wholesome for consumption. Reliable data on possible health effects associated with the ingestion of TDS in drinking-water are not available, and no health-based guideline value is proposed. However, the presence of high levels of TDS in drinking-water may be objectionable to consumers.

The conductivity levels of sampled groundwater in Obuasi could well be indication of the extent of mineralization, which is dependent on pH (Tay and Kortatsi, 2008), and, therefore, suggestive of human impacts and or natural geochemical and biochemical activities in these areas. Conductivity values(fig 31-33) of the groundwater samples were all however lower than the WHO (2011) Guideline for drinking-water quality.

5.2 MICROBIOLOGICAL PARAMETERS OF THE WATER

The observed microbiological loads in the water of the sampled wells is possibly as a direct result of contamination from external sources, especially from the pitcher used in drawing water from the wells. The presence of faecal indicators waters has been reported to be due to poor hygienic practices in some of the sampling areas(plate 7 and 9), failure to wash hands and illiteracy (Coroler,*et al*., 1996). In many developing countries, the use of dirty bucket and rope to fetch water from deep wells has led to the incidence of diseases (Ademoroti, 1996). The use of soak aways for the disposal of domestic and industrial effluents and even siting of refuse dumps for both domestic and industrial solid wastes may impair groundwater quality unless there is an impermeable stratum between the disposal area and the groundwater table. Ademoroti (1987) reported the contamination of well water by Vibrio cholera and coliform bacteria from many Nigerian cities and villages and recommended that a minimum of 30m must separate a well from a soak-away site.

Pit latrines have been identified as major sources of contamination of wells with microbial contaminants (Molard*et al*., 1994; Howard *et al*., 2002; Ayanlaja*et al*., 2005; Pritchard *et al*., 2007). Groundwater is often polluted because pit latrines are mostly located near water source such as shallow wells. In Obuasi some of the sampling areas were observed to have wells situated close to pit latrines. Bacteria, viruses and other contaminants such as nitrate can infiltrate the surrounding soil through leachate from pit latrines to groundwater and are transported by it. Leachates from human wastes can contain large numbers of enteric micro-organisms that have high concentration of nutrients and a high oxygen demand, all of which may have adverse impact on groundwater quality (Dillon, 1997) and could well represent a potential source of microbial contamination to groundwater.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

The well water samples compared to the WHO standards and works done by other researchers, proved that;

Samples collected from sample site TU1 was microbiologically not safe for domestic purposes (precisely drinking). It had its total coliform, Faecal coliform and total Heterotrophic counts to the tune of 4.2×105 ±2.1×104, 9.0×104±0.0×100 and 2.4×104±0.0×100 respectively in some of its sampling events. Enterococci was not detected in all the sampling events but the presence of these coliforms in the sample indicates a higher risk of infection since WHO requires that there should be no coliform present(0.0×100 100cfu/ml) APHA(2005). Physicochemically, (ie heavy metals) water from TU1 had some loads of Lead, Cadmium and Mercury but no Arsenic and Cyanide during all its sampling events. Lead and Mercury recorded higher concentrations and their accumulative effects on humans could be very harmful. In terms of pH, TU1 samples were acidic throughout the sampling events, turbidity was high and could also be due to the presence of microorganisms. Conductivity and TDS were below the WHO maximum standards throughout the sampling events with their maximum mean as 565.00±1.41 and 286.00±5.66 respectively. TU1 was turbid throughout the sampling events, with its total suspended solids decreasing in March and April. TU1 had its sample not meeting the WHO standards of the parameters assessed, thereby the conclusion that it is not safe for potable water.

Samples collected from sample site 2 (TU2) was observed to be microbiologically not safe for potable water. Its Total coliform, Faecal coliform and Total heterotrophic loads were at a particular point in time as high as 9.0×104± 2.1×100, 4.0×104±0.0×100 and 1.0×104±0.0×100 respectively. No enterococci was detected during all the sampling events, but the presence of the other microbes makes TU2 water not safe for drinking since it could cause other diseases.

Physicochemically (in terms of heavy metals), TU2 contained some loads of Mercury, Lead,Cadmium but no As and CN. These metals had their concentrations high above the WHO recommended maximum limit, thereby the risk of a faster accumulation in human when used for domestic purposes (especially drinking).The pH of TU2 water was also acidic, thereby the effect of dissolving more metals and also its ulcerous effect in the human alimentary canal. The water was turbid (i.e. above the WHO guideline value) at particular periods of sampling. Its TDS, TSS, conductivity and alkalinity were below the WHO standards which were signs of clean water to some extent. TU2 water had most of its parameters not meeting the WHO recommended guideline values, thereby making it unsafe for potable water.

Samples collected from sample site TU3 was also observed to be microbiologically unsafe, since it had some microbes like Faecal coliform, Total coliform and Total heterotrophic coliform to the load of 9.0×100±0.0×100, 2.3×105±0.0×100 and 5.7×103±0.0×100 respectively. Unfortunately the presence of these microbes poses the risk of a water borne disease.TU3 water had its physicochemical parameters such as TDS, conductivity and alkalinity below the WHO recommended standard , but its turbidity and TSS were above the standards recommended as safe. The pH was observed to be very low thereby it being acidic.

Heavy metals like Mercury, Lead and Cadmium were present in concentrations above the recommended standards (WHO). TU3 had no Arsenic and Cyanide present in it but fact that the water had most of its parameters not meeting the standards (WHO) makes it unsafe for drinking.

Sample water from AB4 was also observed to be microbiologically unsafe, because it had loads of Total coliform and Total heterotrophic bacteria to about 2.3×105±0.0×100and 7.9×103±0.0×100 respectively. Fortunately Faecal coliform and Enterococci bacteria were absent but the presence of the other bacteria still poses risk to users if not treated. Level of parameters such as alkalinity, TDS and conductivity were below the WHO standard guideline but the water was turbid and acidic in nature. Heavy metals such as Mercury, Cadmium, and Lead were present in concentrations far higher than the recommended standard. AS and CN were also absent but their absence do not reduce or positively change the accumulation effect of Pb, Hg and Cd, thereby the water from AB4 considered as not potable.

AB5 water samples were also observed to be microbiologically unsafe, since it had loads of Total heterotrophic bacteria and Total coliform of 4.9×103±0.0×100 and 9.2×104±2.1×103 respectively. Enterococci bacteria and Faecal coliforms were absent but that does not exempt the water from being unsafe. Heavy metals like Pb, Cd and Hg were present making the water harmful but As and CN were absent. pH of the sample water was very low (i.e. acidic), very turbid throughout all the sampling period and among all the samples AB5 was the most turbid. TDS, conductivity and alkalinity were all below the WHO standards with TSS above the WHO standard. The observations made after the analysis of this water aid to declare AB5 well water unsafe for drinking.

Samples collected from AB6 were also having loads of Faecal coliform, Total coliform and Total heterotrophic bacteria during all its sampling events to the tune of 2.3×105± 0.0×100, 4.3×105 ±0.0×100 and 4.3×102± 0.0×100 respectively. It had no Enterococci bacteria but the presences of the others make it unsafe since it could be a breeding site for other pathogens. Physiochemically, heavy metals such as Cadmium, Lead and Mercury were at very high concentrations as compared to the WHO standards. Arsenic and Cyanide were below the detection level of the instrument used. The pH were low (which is acidic) and could be harmful to users. Alkalinity was also much below the WHO standard range. TDS, conductivity, and TSS were all below the WHO maximum guideline which is a good idea. The sample was turbid which is harmful when used as potable water. The observations make it clear that the water is not microbiologically and physiochemically safe for potable water.

Samples collected from sampling site KWA7 were with high loads of microbes during some of the sampling events. Microbes like Total coliform, Total Heterotrophic bacteria and Faecal coliform had their loads as high as 9.2×105±7.1×100, 3.5×104±0.0×100 and

2.2×105±2.1 104 respectively. Enterococci was absent in the water sample during all the sampling events. KWA7 was the sample with the highest loads of microbes and this makes the water microbiologically not good for drinking. Conductivity, total dissolved solids and total suspended solids of the water were all below the maximum guideline of WHO standards. Its pH and alkalinity were averagely within the lower and upper guideline values. Heavy metals like Lead, Mercury and Cadmium were present, while Arsenic was not detected but the accumulative nature of the others could still put users at risk. Cyanide was also absent and all these characteristics of the water makes it unsafe for drinking.

KWA8 samples were also with loads of microbes though none was supposed to be detected in them. The loads of Total heterotrophic, Faecal coliform and Total coliform were as high as 5.3 104± 0.0 ×100, 4.0× 104± 0.0 ×100 and 9.5 ×105± 0.0× 100 respectively. Enterococci was absent in all the sampling events of this well water. KWA water sample averagely had its pH and alkalinity below the WHO lower guideline value. The Total Suspended solids, Total dissolved solids and Conductivity were below the WHO guideline value but was very turbid (ie above the WHO guideline value). Heavy metals such as Mercury, Cadmium and Lead were present and high above the WHO standard for drinking water. Cyanide and Arsenic were also absent in the water but the presence of Mercury, Cadmium, Lead and the coliforms in the water disqualifies it from being a safe water for drinking.

Last but not the least, KWA9 also had some loads of microbes (ie Total heterotrophic bacteria, Faecal and Total Coliform to the values of 6.9×105± 0.0× 100, 4.0× 104± 0.0

×100 and 9.5× 105 ±0.0 100 respectively). KWA9 under normal circumstances should not have had microbes in it. Therefore the presence of these coliforms disqualifies it from being microbiologically safe for drinking. Heavy metals like Pb, Cd and Hg were also present in high concentrations, but As was absent. CN was also absent in water sample KWA9 but unfortunately the presence of the others could still be harmful to consumers due to their accumulative effect. Physicochemically, KWA9 water had its TSS, TDS and conductivity below the WHO guideline value. Alkalinity of this sample was right within the WHO guideline range but pH was acidic (i.e. was below the WHO guideline range which could increase the rate of metal dissolution and could go a long way to affect the users after a period of time.

In summary, all the water samples analyzed (ie TU1, TU2, TU3, AB4, AB5, AB6, KWA7, KWA8, KWA9) were in one way or the other not safe for drinking and individuals should desist from using them as drinking water. KWA7 and KWA9 were highly contaminated among all the samples and have to be used for only bathing and flashing toilet or better still be decommissioned. The results of KWA7 and KWA9 were also influenced by their closeness to waste water channel which were carrying some of these contaminants analyzed.

6.2 RECOMMENDATIONS

Considering the conclusions made on all the water samples (i.e.TU1, TU2, TU3, AB4, AB5, AB6, KWA7,KWA8, and KWA9) the following recommendations should be effectively enforced by mining companies (i.e. AGA and galamesy operators), individual owners of well water and GEPA to help safeguard Obuasi indigenes. Some of the recommendations are:

- Much public education should be given to inhabitants of these communities (i.e. Kwabrafoso, Tutuka and Aboagyekrom) on the causes and effects of these contaminated wells, so that they will be in the position to make the right choice.
- Indigenes of Obuasi should try as much as possible to desist from using underground water as potable water especially those close to waste water channels.
- AGA and the government should provide indigenes with another source of potable water(precisely community tap water)
- Individual owners of these wells should try as much as possible to analyse their water samples at least once in two years.
- The Ghana Environmental Protection Agency (GEPA) should develop enforceable standards so as to effectively monitor the potability of underground water in mining areas.

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APPENDIX

Table 1: Means±SD of the Microbial loads of the various sampling locations over the sampling period

	TU1	TU2	TU3	AB4	AB5	AB6	KWA7	KWA8	KWA9
T. Coliforms									
Feb	$2.4x10^{3}\pm$ $7.0x10^{1}$	$9.2x10^{1}\pm$ $2.1x10^{0}$	$4.2x10^{1}\pm$ $2.1x10^{0}$	$2.3x10^{1}\pm$ $0.0x10^{0}$	$9.0x10^{0}\pm$ $0.00x10^{0}$	$4.2x10^{2}\pm$ $2.1x10^{1}$	$2.4x10^{2}\pm$ $7.1x10^{0}$	$9.2x10^{1}\pm$ $2.1x10^{0}$	$4.2x10^{3}\pm$ $2.1x10^{2}$
Mar	$4.2x10^{5}\pm$ $2.1x10^{4}$	$9.0x10^{4}\pm$ $0.0x10^{0}$	$2.3x10^{5}\pm$ $0.0x10^{0}$	$2.3x10^{5}\pm$ $0.0x10^{0}$	$9.0x10^{4}\pm$ $0.0x10^{0}$	$4.3x10^{5}\pm$ $0.0x10^{0}$	$9.2x10^{5}\pm$ $2.1x10^{4}$	$2.3x10^{5}\pm$ $0.0x10^{0}$	$9.5x10^{5}\pm$ $0.0x10^{0}$
Apr	$9.0x10^{4}\pm$ $0.0x10^{0}$	$4.0x10^{4}\pm$ $0.0x10^{0}$	$9.0x10^{4}\pm$ $0.0x10^{0}$	$2.3x10^{5}\pm$ $0.0x10^{0}$	$9.2x10^{4}\pm$ $2.1x10^{3}$	$4.0x10^{4}\pm$ $0.0x10^{0}$	$4.2x10^{5}\pm$ $2.1x10^{4}$	$9.2x10^{4}\pm$ $2.1x10^{3}$	$9.0x10^{4}\pm$ $0.0x10^{0}$
F. Coliform									
Feb	$2.3x10^{1}\pm$ $0.0x10^{0}$	$2.3x10^{1}\pm$ $0.0x10^{0}$	$9.0x10^{0}\pm$ $0.0x10^{0}$	$0.0x10^{0}\pm$ $0.0x10^{0}$	$0.0x10^{0}\pm$ $0.00x10^{0}$	$2.3x10^{1}\pm$ $0.0x10^{0}$	$2.3x10^{1}\pm$ $0.0x10^{0}$	$9.0x10^{0}\pm$ $0.0x10^{0}$	$9.1x10^{1}\pm$ $0.0x10^{0}$
Mar	$9.0x10^{4}\pm$	$4.0x10^{4}\pm$	$0.0x10^{0}\pm$	$0.0x10^{0}\pm$	$0.0x10^{0}\pm$	$0.0x10^{0}\pm$	$2.2x10^{5}\pm$	$3.0x10^{4}\pm$	$4.0x10^{4}\pm$

	$0.0x10^{0}$	$0.0x10^{0}$	$0.0x10^{0}$	$0.0x10^{0}$	$0.0x10^{0}$	$0.0x10^{0}$	$2.1x10^{4}$	$0.0x10^{0}$	$0.0x10^{0}$
Apr	$0.0x10^{0}\pm$ $0.0x10^{0}$	$0.0x10^{0}\pm$ $0.0x10^{0}$	$0.0x10^{0}\pm$ $0.0x10^{0}$	$0.0x10^{0}\pm$ $0.0x10^{0}$	$0.0x10^{0}\pm$ $0.0x10^{0}$	$0.0x10^{0}\pm$ $0.0x10^{0}$	$9.0x10^{4}\pm$ $0.0x10^{0}$	$3.0x10^{4}\pm$ $0.0x10^{0}$	$0.0x10^{0}\pm$ $0.0x10^{0}$
T. Heterotrophic									
Feb	$2.4x10^{4}\pm$ $0.0x10^{0}$	$1.0x10^{4}\pm$ $0.0x10^{0}$	$5.7x10^{3}\pm$ $0.0x10^{0}$	$1.1x10^{3}\pm$ $0.0x10^{0}$	$4.3x10^{2}\pm$ $0.00x10^{0}$	$4.3x10^{4}\pm$ $0.0x10^{0}$	$3.5x10^{4}\pm$ $0.0x10^{0}$	$5.3x10^{4}\pm$ $0.0x10^{0}$	$6.9x10^{5}\pm$ $0.0x10^{0}$
Mar	$1.4x10^{3}\pm$ $0.0x10^{0}$	$8.6x10^{3}\pm$ $0.0x10^{0}$	$4.8x10^{3}\pm$ $0.0x10^{0}$	$7.9x10^{3}\pm$ $0.0x10^{0}$	$4.9x10^{3}\pm$ $0.0x10^{0}$	$1.3x10^{4}\pm$ $0.0x10^{0}$	$1.6x10^{4}\pm$ $2.1x10^{4}$	$1.2x10^{4}\pm$ $0.0x10^{0}$	$1.3x10^{4}\pm$ $0.0x10^{0}$
Apr	$6.0x10^{1}\pm$ $0.0x10^{0}$	$1.2x10^{2}\pm$ $0.0x10^{0}$	$1.0x10^{2}\pm$ $0.0x10^{0}$	$4.3x10^{2}\pm$ $0.0x10^{0}$	$2.7x10^{2}\pm$ $0.0x10^{0}$	$1.2x10^{2}\pm$ $0.0x10^{0}$	$9.5x10^{2}\pm$ $0.0x10^{0}$	$1.9x10^{2}\pm$ $0.0x10^{0}$	$7.0x10^{1}\pm$ $0.0x10^{0}$

Table 2: Means±SD of the Heavy Metals at the various sampling locations over the sampling period

	TU1	TU2	TU3	AB4	AB5	AB6	KWA7	KWA8	KWA9
Lead									
Feb	0.02±0.00	0.03±0.01	0.08±0.00	0.07±0.00	0.09±0.00	0.06±0.00	0.06±0.00	0.13±0.00	0.12±0.00
Mar	0.13±0.00	0.08±0.00	0.14±0.00	0.18±0.00	0.09±0.00	0.17±0.00	0.09±0.00	0.09±0.00	0.07±0.00
Apr	0.08±0.00	0.04±0.00	0.10±0.00	0.10±0.00	0.04±0.00	0.16±0.00	0.09±0.00	0.05±0.00	0.07±0.00
Cadmium									
Feb	0.005±0.00	0.005±0.01	0.010±0.00	0.007±0.00	0.007±0.00	0.020±0.00	0.001±0.00	0.010±0.00	0.009±0.00
Mar	ND	ND	ND	ND	ND	ND	ND	ND	ND
Apr	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mercury									
Feb	0.08±0.00	0.00±0.00	0.07±0.00	0.07±0.00	0.06±0.00	0.00±0.00	0.19±0.00	0.03±0.00	0.01±0.00
Mar	0.23±0.00	0.31±0.00	0.05±0.00	0.08±0.00	0.03±0.00	0.11±0.00	0.02±0.00	0.58±0.00	0.08±0.00
Apr	0.010	0.0192	0.048	0.087	0.016	0.123	0.017	0.060	0.010

Arsenic									
Feb	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mar	ND	ND	ND	ND	ND	ND	ND	ND	ND
Apr	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cyanide									
Feb	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mar	ND	ND	ND	ND	ND	ND	ND	ND	ND
Apr	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 3: Means±SD of the physicochemical parameters at the various sampling locations over the sampling period

	TU1	TU2	TU3	AB4	AB5	AB6	KWA7	KWA8	KWA9
TSS									
Feb	3.50±0.70	3.00±0.00	3.50±0.70	1.00±0.00	4.00±0.00	2.50±0.70	2.00±0.00	2.00±0.00	1.00±0.00
Mar	1.00±0.00	1.50±0.70	3.50±0.70	4.00±0.00	4.00±0.00	2.50±0.70	2.00±0.00	4.00±0.00	2.00±0.00
Apr	2.00±0.00	1.00±0.00	2.00±0.00	3.50±0.70	3.00±0.00	1.00±0.00	3.00±0.00	2.00±0.00	2.00±0.00
TDS									
Feb	271.50±3.54	164.50±2.12	198.50±2.12	89.50±2.12	194.00±1.41	219.50±2.12	197.00±2.82	363.50±2.12	184.00±1.41
Mar	286.00±5.66	136.50±6.36	153.00±1.41	66.00±1.41	107.00±4.24	364.00±2.82	161.50±2.12	212.50±3.54	155.00±1.41
Apr	219.00±2.83	131.00±1.41	156.00±2.83	68.00±0.00	107.00±4.24	369.00±1.41	277.00±1.41	277.00±1.41	166.00±1.41
Alkalinity									
Feb	47.50±4.95	12.50±2.12	22.00±1.41	6.50±0.70	27.20±3.96	6.30±0.28	146.70±0.42	40.50±0.70	60.00±2.83
Mar	57.65±4.74	6.35±0.35	19.05±1.34	6.10±0.00	25.80±1.98	6.25±0.21	148.20±2.55	43.85±1.62	54.65±0.50
Apr	24.70±0.42	6.50±0.70	13.10±1.27	6.10±0.00	6.30±0.28	6.55±0.63	2552.50±3.54	18.65±0.49	43.05±0.91

Conductivity									
Feb	412.50±0.70	253.00±2.83	306.00±5.66	138.00±2.83	303.00±1.41	253.50±0.70	303.50±3.54	565.50±6.36	289.50±2.12
Mar	565.00±1.41	263.00±1.41	310.50±2.12	132.00±1.41	209.50±0.70	729.00±5.66	329.00±4.24	503.00±0.00	315.00±2.82
Apr	438.00±4.24	263.50±3.54	318.00±2.83	134.00±2.83	210.00±1.41	740.50±4.95	556.50±0.70	552.00±0.00	334.50±0.71
Turbidity									
Feb	8.00±1.41	3.50±0.71	1.50±0.70	4.00±0.00	38.00±1.41	2.00±0.00	6.00±0.00	6.50±0.71	2.00±0.00
Mar	6.00±0.00	1.00±0.00	2.00±0.00	0.00±0.00	43.50±2.12	0.00±0.00	4.00±0.00	6.50±0.71	2.00±0.00
Apr	14.50±0.71	19.50±2.12	15.00±1.41	19.50±2.12	79.50±4.95	19.50±2.12	20.50±0.71	20.00±0.00	19.50±2.12
pH									
Feb	5.80	4.76	5.78	4.95	4.42	4.16	6.97	6.04	6.33
Mar	6.29	5.53	5.80	5.47	4.86	4.88	6.32	6.91	6.15
Apr	5.73	5.12	5.80	5.61	4.45	4.63	6.48	5.65	6.15

Table 4 ANOVA and Tukey's analysis for total coliform in water samples

Table Analyzed	Total Coliforms				
One-way analysis of variance					
P value	0.0845				
P value summary	ns				
Are means signif. different? (P < 0.05)	No				
Number of groups	9				
F	1.894				
R squared	0.2519				
Bartlett's test for equal variances					
Bartlett's statistic (corrected)	44.58				
P value	P<0.0001				
P value summary	***				
Do the variances differ signif. (P < 0.05)	Yes				
ANOVA Table	SS	df	MS		
Treatment (between columns)	841600000000	8	105200000000		
Residual (within columns)	2499000000000	45	55530000000		
Total	3340000000000	53			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
TU1 vs TU2	125800	1.307	No	ns	-318100 to 569600
TU1 vs TU3	62440	0.6490	No	ns	-381400 to 506300
TU1 vs AB4	15780	0.1640	No	ns	-428100 to 459600
TU1 vs AB5	108600	1.129	No	ns	-335200 to 552500
TU1 vs AB6	12310	0.1280	No	ns	-431500 to 456200
TU1 vs KWA7	-274300	2.851	No	ns	-718100 to 169600
TU1 vs KWA8	61920	0.6436	No	ns	-381900 to 505800
TU1 vs KWA9	-172300	1.791	No	ns	-616100 to 271600
TU2 vs TU3	-63320	0.6582	No	ns	-507200 to 380500
TU2 vs AB4	-110000	1.143	No	ns	-553800 to 333900
TU2 vs AB5	-17140	0.1782	No	ns	-461000 to 426700
TU2 vs AB6	-113400	1.179	No	ns	-557300 to 330400
TU2 vs KWA7	-400000	4.158	No	ns	-843900 to 43810
TU2 vs KWA8	-63830	0.6635	No	ns	-507700 to 380000
TU2 vs KWA9	-298000	3.098	No	ns	-741900 to 145800
TU3 vs AB4	-46660	0.4850	No	ns	-490500 to 397200
TU3 vs AB5	46180	0.4800	No	ns	-397700 to 490000
TU3 vs AB6	-50120	0.5210	No	ns	-494000 to 393700
TU3 vs KWA7	-336700	3.500	No	ns	-780600 to 107100
TU3 vs KWA8	-516.7	0.005371	No	ns	-444400 to 443300
TU3 vs KWA9	-234700	2.440	No	ns	-678600 to 209200
AB4 vs AB5	92840	0.9650	No	ns	-351000 to 536700
AB4 vs AB6	-3464	0.03601	No	ns	-447300 to 440400
AB4 vs KWA7	-290100	3.015	No	ns	-733900 to 153800
AB4 vs KWA8	46140	0.4797	No	ns	-397700 to 490000
AB4 vs KWA9	-188000	1.955	No	ns	-631900 to 255800
AB5 vs AB6	-96300	1.001	No	ns	-540200 to 347600
AB5 vs KWA7	-382900	3.980	No	ns	-826800 to 60940
AB5 vs KWA8	-46690	0.4854	No	ns	-490500 to 397200
AB5 vs KWA9	-280900	2.920	No	ns	-724700 to 163000
AB6 vs KWA7	-286600	2.979	No	ns	-730500 to 157200
AB6 vs KWA8	49610	0.5157	No	ns	-394200 to 493500
AB6 vs KWA9	-184600	1.919	No	ns	-628400 to 259300
KWA7 vs KWA8	336200	3.495	No	ns	-107600 to 780100
KWA7 vs KWA9	102000	1.061	No	ns	-341800 to 545900
KWA8 vs KWA9	-234200	2.434	No	ns	-678000 to 209700

Table 5; ANOVA and Tukey's analysis for faecal coliform in water samples

Table Analyzed	Faecal Coliforms				
One-way analysis of variance					
P value	0.0004				
P value summary	***				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	9				
F	4.508				
R squared	0.4449				
Bartlett's test for equal variances					
Bartlett's statistic (corrected)					
P value					
P value summary	ns				
Do the variances differ signif. (P < 0.05)	No				
ANOVA Table	SS	df	MS		
Treatment (between columns)	50750000000	8	6344000000		
Residual (within columns)	63330000000	45	1407000000		
Total	114100000000	53			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
TU1 vs TU2	16670	1.088	No	ns	-53990 to 87330
TU1 vs TU3	30000	1.959	No	ns	-40660 to 100700
TU1 vs AB4	30010	1.959	No	ns	-40650 to 100700
TU1 vs AB5	30010	1.959	No	ns	-40650 to 100700
TU1 vs AB6	30000	1.959	No	ns	-40660 to 100700
TU1 vs KWA7	-71670	4.679	Yes	*	-142300 to -1006
TU1 vs KWA8	10000	0.6532	No	ns	-60660 to 80670
TU1 vs KWA9	16640	1.087	No	ns	-54020 to 87300
TU2 vs TU3	13340	0.8709	No	ns	-57320 to 84000
TU2 vs AB4	13340	0.8711	No	ns	-57320 to 84000
TU2 vs AB5	13340	0.8711	No	ns	-57320 to 84000
TU2 vs AB6	13330	0.8706	No	ns	-57330 to 83990
TU2 vs KWA7	-88330	5.768	Yes	**	-159000 to -17670
TU2 vs KWA8	-6662	0.4350	No	ns	-77320 to 64000
TU2 vs KWA9	-22.83	0.001491	No	ns	-70680 to 70640
TU3 vs AB4	3.000	0.0001959	No	ns	-70660 to 70660
TU3 vs AB5	3.000	0.0001959	No	ns	-70660 to 70660
TU3 vs AB6	-4.667	0.0003047	No	ns	-70670 to 70660
TU3 vs KWA7	-101700	6.639	Yes	***	-172300 to -31010
TU3 vs KWA8	-20000	1.306	No	ns	-90660 to 50660
TU3 vs KWA9	-13360	0.8724	No	ns	-84020 to 57300
AB4 vs AB5	0.0000	0.0000	No	ns	-70660 to 70660
AB4 vs AB6	-7.667	0.0005006	No	ns	-70670 to 70650
AB4 vs KWA7	-101700	6.639	Yes	***	-172300 to -31010
AB4 vs KWA8	-20000	1.306	No	ns	-90660 to 50660
AB4 vs KWA9	-13360	0.8726	No	ns	-84020 to 57300
AB5 vs AB6	-7.667	0.0005006	No	ns	-70670 to 70650
AB5 vs KWA7	-101700	6.639	Yes	***	-172300 to -31010
AB5 vs KWA8	-20000	1.306	No	ns	-90660 to 50660
AB5 vs KWA9	-13360	0.8726	No	ns	-84020 to 57300
AB6 vs KWA7	-101700	6.638	Yes	***	-172300 to -31010
AB6 vs KWA8	-20000	1.306	No	ns	-90660 to 50670
AB6 vs KWA9	-13360	0.8721	No	ns	-84020 to 57300
KWA7 vs KWA8	81670	5.333	Yes	*	11010 to 152300
KWA7 vs KWA9	88310	5.766	Yes	**	17650 to 159000
KWA8 vs KWA9	6639	0.4335	No	ns	-64020 to 77300

Table 6 ANOVA and Tukey's analysis for total heterotrophic bacteria in water samples

Table Analyzed	Total Heterotrophic Bacteria				
One-way analysis of variance					
P value	0.6403				
P value summary	ns				
Are means signif. different? (P < 0.05)	No				
Number of groups	9				
F	0.7609				
R squared	0.2527				
ANOVA Table	SS	df	MS		
Treatment (between columns)	2144000000	8	268000000		
Residual (within columns)	6340000000	18	352200000		
Total	8484000000	26			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
TU1 vs TU2	2223	0.2052	No	ns	-51480 to 55920
TU1 vs TU3	4910	0.4532	No	ns	-48790 to 58610
TU1 vs AB4	5322	0.4912	No	ns	-48380 to 59020
TU1 vs AB5	6588	0.6081	No	ns	-47110 to 60290
TU1 vs AB6	-10430	0.9625	No	ns	-64130 to 43270
TU1 vs KWA7	-8992	0.8299	No	ns	-62690 to 44710
TU1 vs KWA8	-13410	1.237	No	ns	-67100 to 40290
TU1 vs KWA9	-19100	1.762	No	ns	-72800 to 34600
TU2 vs TU3	2687	0.2480	No	ns	-51010 to 56390
TU2 vs AB4	3098	0.2860	No	ns	-50600 to 56800
TU2 vs AB5	4365	0.4029	No	ns	-49330 to 58060
TU2 vs AB6	-12650	1.168	No	ns	-66350 to 41050
TU2 vs KWA7	-11220	1.035	No	ns	-64910 to 42480
TU2 vs KWA8	-15630	1.442	No	ns	-69330 to 38070
TU2 vs KWA9	-21320	1.968	No	ns	-75020 to 32380
TU3 vs AB4	411.7	0.03799	No	ns	-53290 to 54110
TU3 vs AB5	1678	0.1549	No	ns	-52020 to 55380
TU3 vs AB6	-15340	1.416	No	ns	-69040 to 38360
TU3 vs KWA7	-13900	1.283	No	ns	-67600 to 39800
TU3 vs KWA8	-18320	1.690	No	ns	-72010 to 35380
TU3 vs KWA9	-24010	2.216	No	ns	-77710 to 29690
AB4 vs AB5	1267	0.1169	No	ns	-52430 to 54970
AB4 vs AB6	-15750	1.454	No	ns	-69450 to 37950
AB4 vs KWA7	-14310	1.321	No	ns	-68010 to 39390
AB4 vs KWA8	-18730	1.728	No	ns	-72430 to 34970
AB4 vs KWA9	-24420	2.254	No	ns	-78120 to 29280
AB5 vs AB6	-17020	1.571	No	ns	-70720 to 36680
AB5 vs KWA7	-15580	1.438	No	ns	-69280 to 38120
AB5 vs KWA8	-19990	1.845	No	ns	-73690 to 33710
AB5 vs KWA9	-25690	2.371	No	ns	-79380 to 28010
AB6 vs KWA7	1437	0.1326	No	ns	-52260 to 55140
AB6 vs KWA8	-2977	0.2747	No	ns	-56680 to 50720
AB6 vs KWA9	-8668	0.8000	No	ns	-62370 to 45030
KWA7 vs KWA8	-4413	0.4073	No	ns	-58110 to 49290
KWA7 vs KWA9	-10110	0.9326	No	ns	-63800 to 43590
KWA8 vs KWA9	-5692	0.5253	No	ns	-59390 to 48010

Table 7 ANOVA and Tukey's analysis for lead in water samples

Table Analyzed	Lead				
One-way analysis of variance					
P value	0.0193				
P value summary	*				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	9				
F	2.615				
R squared	0.3174				
Bartlett's test for equal variances					
Bartlett's statistic (corrected)	14.05				
P value	0.0805				
P value summary	ns				
Do the variances differ signif. (P < 0.05)	No				
ANOVA Table	SS	df	MS		
Treatment (between columns)	0.02811	8	0.003514		
Residual (within columns)	0.06046	45	0.001344		
Total	0.08857	53			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
TU1 vs TU2	0.0290	1.938	No	ns	-0.04004 to 0.09804
TU1 vs TU3	-0.02567	1.715	No	ns	-0.09471 to 0.04338
TU1 vs AB4	-0.03817	2.550	No	ns	-0.1072 to 0.03088
TU1 vs AB5	0.002333	0.1559	No	ns	-0.06671 to 0.07138
TU1 vs AB6	-0.0530	3.542	No	ns	-0.1220 to 0.01604
TU1 vs KWA7	-0.001833	0.1225	No	ns	-0.07088 to 0.06721
TU1 vs KWA8	-0.01317	0.8799	No	ns	-0.08221 to 0.05588
TU1 vs KWA9	-0.01283	0.8576	No	ns	-0.08188 to 0.05621
TU2 vs TU3	-0.05467	3.653	No	ns	-0.1237 to 0.01438
TU2 vs AB4	-0.06717	4.488	No	ns	-0.1362 to 0.001875
TU2 vs AB5	-0.02667	1.782	No	ns	-0.09571 to 0.04238
TU2 vs AB6	-0.08200	5.480	Yes	**	-0.1510 to -0.01296
TU2 vs KWA7	-0.03083	2.060	No	ns	-0.09988 to 0.03821
TU2 vs KWA8	-0.04217	2.818	No	ns	-0.1112 to 0.02688
TU2 vs KWA9	-0.04183	2.796	No	ns	-0.1109 to 0.02721
TU3 vs AB4	-0.0125	0.8353	No	ns	-0.08154 to 0.05654
TU3 vs AB5	0.0280	1.871	No	ns	-0.04104 to 0.09704
TU3 vs AB6	-0.02733	1.827	No	ns	-0.09638 to 0.04171
TU3 vs KWA7	0.02383	1.593	No	ns	-0.04521 to 0.09288
TU3 vs KWA8	0.0125	0.8353	No	ns	-0.05654 to 0.08154
TU3 vs KWA9	0.01283	0.8576	No	ns	-0.05621 to 0.08188
AB4 vs AB5	0.0405	2.706	No	ns	-0.02854 to 0.1095
AB4 vs AB6	-0.01483	0.9912	No	ns	-0.08388 to 0.05421
AB4 vs KWA7	0.03633	2.428	No	ns	-0.03271 to 0.1054
AB4 vs KWA8	0.02500	1.671	No	ns	-0.04404 to 0.09404
AB4 vs KWA9	0.02533	1.693	No	ns	-0.04371 to 0.09438
AB5 vs AB6	-0.05533	3.698	No	ns	-0.1244 to 0.01371
AB5 vs KWA7	-0.004167	0.2784	No	ns	-0.07321 to 0.06488
AB5 vs KWA8	-0.01550	1.036	No	ns	-0.08454 to 0.05354
AB5 vs KWA9	-0.01517	1.014	No	ns	-0.08421 to 0.05388
AB6 vs KWA7	0.05117	3.419	No	ns	-0.01788 to 0.1202
AB6 vs KWA8	0.03983	2.662	No	ns	-0.02921 to 0.1089
AB6 vs KWA9	0.04017	2.684	No	ns	-0.02888 to 0.1092
KWA7 vs KWA8	-0.01133	0.7574	No	ns	-0.08038 to 0.05771
KWA7 vs KWA9	-0.0110	0.7351	No	ns	-0.08004 to 0.05804
KWA8 vs KWA9	0.0003333	0.02227	No	ns	-0.06871 to 0.06938

Table 8 ANOVA and Tukey's analysis for cadmium in water samples

Table Analyzed	Cadmium				
One-way analysis of variance					
P value	0.5643				
P value summary	ns				
Are means signif. different? (P < 0.05)	No				
Number of groups	9				
F	0.8554				
R squared	0.2022				
ANOVA Table	SS	df	MS		
Treatment (between columns)	0.0002159	8	0.00002699		
Residual (within columns)	0.0008518	27	0.00003155		
Total	0.001068	35			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
TU1 vs TU2	0.0000	0.0000	No	ns	-0.01338 to 0.01338
TU1 vs TU3	-0.0025	0.8902	No	ns	-0.01588 to 0.01088
TU1 vs AB4	-0.0010	0.3561	No	ns	-0.01438 to 0.01238
TU1 vs AB5	-0.0007500	0.2671	No	ns	-0.01413 to 0.01263
TU1 vs AB6	-0.00725	2.582	No	ns	-0.02063 to 0.006127
TU1 vs KWA7	0.00225	0.8012	No	ns	-0.01113 to 0.01563
TU1 vs KWA8	-0.00225	0.8012	No	ns	-0.01563 to 0.01113
TU1 vs KWA9	-0.0015	0.5341	No	ns	-0.01488 to 0.01188
TU2 vs TU3	-0.0025	0.8902	No	ns	-0.01588 to 0.01088
TU2 vs AB4	-0.0010	0.3561	No	ns	-0.01438 to 0.01238
TU2 vs AB5	-0.0007500	0.2671	No	ns	-0.01413 to 0.01263
TU2 vs AB6	-0.00725	2.582	No	ns	-0.02063 to 0.006127
TU2 vs KWA7	0.00225	0.8012	No	ns	-0.01113 to 0.01563
TU2 vs KWA8	-0.00225	0.8012	No	ns	-0.01563 to 0.01113
TU2 vs KWA9	-0.0015	0.5341	No	ns	-0.01488 to 0.01188
TU3 vs AB4	0.0015	0.5341	No	ns	-0.01188 to 0.01488
TU3 vs AB5	0.00175	0.6232	No	ns	-0.01163 to 0.01513
TU3 vs AB6	-0.00475	1.691	No	ns	-0.01813 to 0.008627
TU3 vs KWA7	0.00475	1.691	No	ns	-0.008627 to 0.01813
TU3 vs KWA8	0.00025	0.08902	No	ns	-0.01313 to 0.01363
TU3 vs KWA9	0.001000	0.3561	No	ns	-0.01238 to 0.01438
AB4 vs AB5	0.00025	0.08902	No	ns	-0.01313 to 0.01363
AB4 vs AB6	-0.00625	2.226	No	ns	-0.01963 to 0.007127
AB4 vs KWA7	0.00325	1.157	No	ns	-0.01013 to 0.01663
AB4 vs KWA8	-0.00125	0.4451	No	ns	-0.01463 to 0.01213
AB4 vs KWA9	-0.0005000	0.1780	No	ns	-0.01388 to 0.01288
AB5 vs AB6	-0.0065	2.315	No	ns	-0.01988 to 0.006877
AB5 vs KWA7	0.0030	1.068	No	ns	-0.01038 to 0.01638
AB5 vs KWA8	-0.0015	0.5341	No	ns	-0.01488 to 0.01188
AB5 vs KWA9	-0.0007500	0.2671	No	ns	-0.01413 to 0.01263
AB6 vs KWA7	0.0095	3.383	No	ns	-0.003877 to 0.02288
AB6 vs KWA8	0.0050	1.780	No	ns	-0.008377 to 0.01838
AB6 vs KWA9	0.00575	2.047	No	ns	-0.007627 to 0.01913
KWA7 vs KWA8	-0.0045	1.602	No	ns	-0.01788 to 0.008877
KWA7 vs KWA9	-0.00375	1.335	No	ns	-0.01713 to 0.009627
KWA8 vs KWA9	0.0007500	0.2671	No	ns	-0.01263 to 0.01413

Table 9 ANOVA and Tukey's analysis for mercury in water samples

Table Analyzed	Mercury				
One-way analysis of variance					
P value	0.1892				
P value summary	ns				
Are means signif. different? (P < 0.05)	No				
Number of groups	9				
F	1.543				
R squared	0.3137				
ANOVA Table	SS	df	MS		
Treatment (between columns)	0.2191	8	0.02739		
Residual (within columns)	0.4794	27	0.01776		
Total	0.6985	35			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
TU1 vs TU2	0.0002500	0.003752	No	ns	-0.3171 to 0.3176
TU1 vs TU3	0.05475	0.8218	No	ns	-0.2626 to 0.3721
TU1 vs AB4	0.08175	1.227	No	ns	-0.2356 to 0.3991
TU1 vs AB5	0.1125	1.689	No	ns	-0.2049 to 0.4299
TU1 vs AB6	0.1013	1.520	No	ns	-0.2161 to 0.4186
TU1 vs KWA7	0.05075	0.7617	No	ns	-0.2666 to 0.3681
TU1 vs KWA8	-0.1490	2.236	No	ns	-0.4664 to 0.1684
TU1 vs KWA9	0.1093	1.640	No	ns	-0.2081 to 0.4266
TU2 vs TU3	0.0545	0.8180	No	ns	-0.2629 to 0.3719
TU2 vs AB4	0.0815	1.223	No	ns	-0.2359 to 0.3989
TU2 vs AB5	0.1123	1.685	No	ns	-0.2051 to 0.4296
TU2 vs AB6	0.1010	1.516	No	ns	-0.2164 to 0.4184
TU2 vs KWA7	0.05050	0.7580	No	ns	-0.2669 to 0.3679
TU2 vs KWA8	-0.1493	2.240	No	ns	-0.4666 to 0.1681
TU2 vs KWA9	0.1090	1.636	No	ns	-0.2084 to 0.4264
TU3 vs AB4	0.0270	0.4052	No	ns	-0.2904 to 0.3444
TU3 vs AB5	0.05775	0.8668	No	ns	-0.2596 to 0.3751
TU3 vs AB6	0.0465	0.6979	No	ns	-0.2709 to 0.3639
TU3 vs KWA7	-0.004000	0.06004	No	ns	-0.3214 to 0.3134
TU3 vs KWA8	-0.2038	3.058	No	ns	-0.5211 to 0.1136
TU3 vs KWA9	0.05450	0.8180	No	ns	-0.2629 to 0.3719
AB4 vs AB5	0.03075	0.4615	No	ns	-0.2866 to 0.3481
AB4 vs AB6	0.0195	0.2927	No	ns	-0.2979 to 0.3369
AB4 vs KWA7	-0.0310	0.4653	No	ns	-0.3484 to 0.2864
AB4 vs KWA8	-0.2308	3.463	No	ns	-0.5481 to 0.08662
AB4 vs KWA9	0.0275	0.4128	No	ns	-0.2899 to 0.3449
AB5 vs AB6	-0.01125	0.1689	No	ns	-0.3286 to 0.3061
AB5 vs KWA7	-0.06175	0.9268	No	ns	-0.3791 to 0.2556
AB5 vs KWA8	-0.2615	3.925	No	ns	-0.5789 to 0.05587
AB5 vs KWA9	-0.003250	0.04878	No	ns	-0.3206 to 0.3141
AB6 vs KWA7	-0.0505	0.7580	No	ns	-0.3679 to 0.2669
AB6 vs KWA8	-0.2503	3.756	No	ns	-0.5676 to 0.06712
AB6 vs KWA9	0.008000	0.1201	No	ns	-0.3094 to 0.3254
KWA7 vs KWA8	-0.1998	2.998	No	ns	-0.5171 to 0.1176
KWA7 vs KWA9	0.0585	0.8780	No	ns	-0.2589 to 0.3759
KWA8 vs KWA9	0.2583	3.876	No	ns	-0.05912 to 0.5756

Table 10 ANOVA and Tukey's analysis for TSS in water samples

Table Analyzed	TSS				
One-way analysis of variance					
P value	0.0141				
P value summary	*				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	9				
F	2.767				
R squared	0.3297				
Bartlett's test for equal variances					
Bartlett's statistic (corrected)	10.23				
P value	0.2492				
P value summary	ns				
Do the variances differ signif. (P < 0.05)	No				
ANOVA Table	SS	df	MS		
Treatment (between columns)	19.59	8	2.449		
Residual (within columns)	39.83	45	0.8852		
Total	59.43	53			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
TU1 vs TU2	0.3333	0.8678	No	ns	-1.439 to 2.105
TU1 vs TU3	-0.8333	2.170	No	ns	-2.605 to 0.9388
TU1 vs AB4	-0.6667	1.736	No	ns	-2.439 to 1.105
TU1 vs AB5	-1.500	3.905	No	ns	-3.272 to 0.2721
TU1 vs AB6	0.1667	0.4339	No	ns	-1.605 to 1.939
TU1 vs KWA7	-0.1667	0.4339	No	ns	-1.939 to 1.605
TU1 vs KWA8	-0.5000	1.302	No	ns	-2.272 to 1.272
TU1 vs KWA9	0.5000	1.302	No	ns	-1.272 to 2.272
TU2 vs TU3	-1.167	3.037	No	ns	-2.939 to 0.6055
TU2 vs AB4	-1.000	2.604	No	ns	-2.772 to 0.7721
TU2 vs AB5	-1.833	4.773	Yes	*	-3.605 to -0.06120
TU2 vs AB6	-0.1667	0.4339	No	ns	-1.939 to 1.605
TU2 vs KWA7	-0.5000	1.302	No	ns	-2.272 to 1.272
TU2 vs KWA8	-0.8333	2.170	No	ns	-2.605 to 0.9388
TU2 vs KWA9	0.1667	0.4339	No	ns	-1.605 to 1.939
TU3 vs AB4	0.1667	0.4339	No	ns	-1.605 to 1.939
TU3 vs AB5	-0.6667	1.736	No	ns	-2.439 to 1.105
TU3 vs AB6	1.000	2.604	No	ns	-0.7721 to 2.772
TU3 vs KWA7	0.6667	1.736	No	ns	-1.105 to 2.439
TU3 vs KWA8	0.3333	0.8678	No	ns	-1.439 to 2.105
TU3 vs KWA9	1.333	3.471	No	ns	-0.4388 to 3.105
AB4 vs AB5	-0.8333	2.170	No	ns	-2.605 to 0.9388
AB4 vs AB6	0.8333	2.170	No	ns	-0.9388 to 2.605
AB4 vs KWA7	0.5000	1.302	No	ns	-1.272 to 2.272
AB4 vs KWA8	0.1667	0.4339	No	ns	-1.605 to 1.939
AB4 vs KWA9	1.167	3.037	No	ns	-0.6055 to 2.939
AB5 vs AB6	1.667	4.339	No	ns	-0.1055 to 3.439
AB5 vs KWA7	1.333	3.471	No	ns	-0.4388 to 3.105
AB5 vs KWA8	1.000	2.604	No	ns	-0.7721 to 2.772
AB5 vs KWA9	2.000	5.207	Yes	*	0.2279 to 3.772
AB6 vs KWA7	-0.3333	0.8678	No	ns	-2.105 to 1.439
AB6 vs KWA8	-0.6667	1.736	No	ns	-2.439 to 1.105
AB6 vs KWA9	0.3333	0.8678	No	ns	-1.439 to 2.105
KWA7 vs KWA8	-0.3333	0.8678	No	ns	-2.105 to 1.439
KWA7 vs KWA9	0.6667	1.736	No	ns	-1.105 to 2.439
KWA8 vs KWA9	1.000	2.604	No	ns	-0.7721 to 2.772

Table 11 ANOVA and Tukey's analysis for TDS in water samples

Table Analyzed	TDS				
One-way analysis of variance					
P value	P<0.0001				
P value summary	***				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	9				
F	19.24				
R squared	0.7738				
Bartlett's test for equal variances					
Bartlett's statistic (corrected)	30.60				
P value	0.0002				
P value summary	***				
Do the variances differ signif. (P < 0.05)	Yes				
ANOVA Table	SS	df	MS		
Treatment (between columns)	295900	8	36990		
Residual (within columns)	86500	45	1922		
Total	382400	53			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
TU1 vs TU2	114.8	6.416	Yes	**	32.25 to 197.4
TU1 vs TU3	89.67	5.010	Yes	*	7.086 to 172.2
TU1 vs AB4	184.3	10.30	Yes	***	101.8 to 266.9
TU1 vs AB5	122.8	6.863	Yes	***	40.25 to 205.4
TU1 vs AB6	-58.67	3.278	No	ns	-141.2 to 23.91
TU1 vs KWA7	47.00	2.626	No	ns	-35.58 to 129.6
TU1 vs KWA8	-25.50	1.425	No	ns	-108.1 to 57.08
TU1 vs KWA9	90.50	5.056	Yes	*	7.919 to 173.1
TU2 vs TU3	-25.17	1.406	No	ns	-107.7 to 57.41
TU2 vs AB4	69.50	3.883	No	ns	-13.08 to 152.1
TU2 vs AB5	8.000	0.4470	No	ns	-74.58 to 90.58
TU2 vs AB6	-173.5	9.693	Yes	***	-256.1 to -90.92
TU2 vs KWA7	-67.83	3.790	No	ns	-150.4 to 14.75
TU2 vs KWA8	-140.3	7.840	Yes	***	-222.9 to -57.75
TU2 vs KWA9	-24.33	1.359	No	ns	-106.9 to 58.25
TU3 vs AB4	94.67	5.289	Yes	*	12.09 to 177.2
TU3 vs AB5	33.17	1.853	No	ns	-49.41 to 115.7
TU3 vs AB6	-148.3	8.287	Yes	***	-230.9 to -65.75
TU3 vs KWA7	-42.67	2.384	No	ns	-125.2 to 39.91
TU3 vs KWA8	-115.2	6.434	Yes	**	-197.7 to -32.59
TU3 vs KWA9	0.8333	0.04656	No	ns	-81.75 to 83.41
AB4 vs AB5	-61.50	3.436	No	ns	-144.1 to 21.08
AB4 vs AB6	-243.0	13.58	Yes	***	-325.6 to -160.4
AB4 vs KWA7	-137.3	7.673	Yes	***	-219.9 to -54.75
AB4 vs KWA8	-209.8	11.72	Yes	***	-292.4 to -127.3
AB4 vs KWA9	-93.83	5.242	Yes	*	-176.4 to -11.25
AB5 vs AB6	-181.5	10.14	Yes	***	-264.1 to -98.92
AB5 vs KWA7	-75.83	4.237	No	ns	-158.4 to 6.748
AB5 vs KWA8	-148.3	8.287	Yes	***	-230.9 to -65.75
AB5 vs KWA9	-32.33	1.806	No	ns	-114.9 to 50.25
AB6 vs KWA7	105.7	5.904	Yes	**	23.09 to 188.2
AB6 vs KWA8	33.17	1.853	No	ns	-49.41 to 115.7
AB6 vs KWA9	149.2	8.334	Yes	***	66.59 to 231.7
KWA7 vs KWA8	-72.50	4.051	No	ns	-155.1 to 10.08
KWA7 vs KWA9	43.50	2.430	No	ns	-39.08 to 126.1
KWA8 vs KWA9	116.0	6.481	Yes	**	33.42 to 198.6

Table 12ANOVA and Tukey's analysis for pH in water samples

Table Analyzed	pH				
One-way analysis of variance					
P value	P<0.0001				
P value summary	***				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	9				
F	13.10				
R squared	0.8534				
ANOVA Table	SS	df	MS		
Treatment (between columns)	12.89	8	1.611		
Residual (within columns)	2.213	18	0.1229		
Total	15.10	26			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
TU1 vs TU2	0.8033	3.969	No	ns	-0.1999 to 1.807
TU1 vs TU3	0.1467	0.7246	No	ns	-0.8565 to 1.150
TU1 vs AB4	0.5967	2.948	No	ns	-0.4065 to 1.600
TU1 vs AB5	1.363	6.735	Yes	**	0.3601 to 2.367
TU1 vs AB6	1.390	6.867	Yes	**	0.3868 to 2.393
TU1 vs KWA7	-0.6500	3.211	No	ns	-1.653 to 0.3532
TU1 vs KWA8	-0.2600	1.284	No	ns	-1.263 to 0.7432
TU1 vs KWA9	-0.2700	1.334	No	ns	-1.273 to 0.7332
TU2 vs TU3	-0.6567	3.244	No	ns	-1.660 to 0.3465
TU2 vs AB4	-0.2067	1.021	No	ns	-1.210 to 0.7965
TU2 vs AB5	0.5600	2.766	No	ns	-0.4432 to 1.563
TU2 vs AB6	0.5867	2.898	No	ns	-0.4165 to 1.590
TU2 vs KWA7	-1.453	7.180	Yes	**	-2.457 to -0.4501
TU2 vs KWA8	-1.063	5.253	Yes	*	-2.067 to -0.06012
TU2 vs KWA9	-1.073	5.302	Yes	*	-2.077 to -0.07012
TU3 vs AB4	0.4500	2.223	No	ns	-0.5532 to 1.453
TU3 vs AB5	1.217	6.010	Yes	*	0.2135 to 2.220
TU3 vs AB6	1.243	6.142	Yes	**	0.2401 to 2.247
TU3 vs KWA7	-0.7967	3.936	No	ns	-1.800 to 0.2065
TU3 vs KWA8	-0.4067	2.009	No	ns	-1.410 to 0.5965
TU3 vs KWA9	-0.4167	2.058	No	ns	-1.420 to 0.5865
AB4 vs AB5	0.7667	3.787	No	ns	-0.2365 to 1.770
AB4 vs AB6	0.7933	3.919	No	ns	-0.2099 to 1.797
AB4 vs KWA7	-1.247	6.159	Yes	**	-2.250 to -0.2435
AB4 vs KWA8	-0.8567	4.232	No	ns	-1.860 to 0.1465
AB4 vs KWA9	-0.8667	4.281	No	ns	-1.870 to 0.1365
AB5 vs AB6	0.02667	0.1317	No	ns	-0.9765 to 1.030
AB5 vs KWA7	-2.013	9.946	Yes	***	-3.017 to -1.010
AB5 vs KWA8	-1.623	8.019	Yes	***	-2.627 to -0.6201
AB5 vs KWA9	-1.633	8.069	Yes	***	-2.637 to -0.6301
AB6 vs KWA7	-2.040	10.08	Yes	***	-3.043 to -1.037
AB6 vs KWA8	-1.650	8.151	Yes	***	-2.653 to -0.6468
AB6 vs KWA9	-1.660	8.201	Yes	***	-2.663 to -0.6568
KWA7 vs KWA8	0.3900	1.927	No	ns	-0.6132 to 1.393
KWA7 vs KWA9	0.3800	1.877	No	ns	-0.6232 to 1.383
KWA8 vs KWA9	-0.01000	0.04940	No	ns	-1.013 to 0.9932

Table 13 ANOVA and Tukey's analysis for Alkalinity in water samples

Table Analyzed	Alkalinity				
One-way analysis of variance					
P value	P<0.0001				
P value summary	***				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	9				
F	47.00				
R squared	0.8931				
Bartlett's test for equal variances					
Bartlett's statistic (corrected)	117.3				
P value	P<0.0001				
P value summary	***				
Do the variances differ signif. (P < 0.05)	Yes				
ANOVA Table	SS	df	MS		
Treatment (between columns)	147800	8	18480		
Residual (within columns)	17690	45	393.2		
Total	165500	53			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
TU1 vs TU2	34.83	4.303	No	ns	-2.515 to 72.18
TU1 vs TU3	25.23	3.117	No	ns	-12.11 to 62.58
TU1 vs AB4	37.05	4.577	No	ns	-0.2980 to 74.40
TU1 vs AB5	23.52	2.905	No	ns	-13.83 to 60.86
TU1 vs AB6	36.92	4.560	No	ns	-0.4313 to 74.26
TU1 vs KWA7	-139.2	17.19	Yes	***	-176.5 to -101.8
TU1 vs KWA8	8.950	1.106	No	ns	-28.40 to 46.30
TU1 vs KWA9	-9.283	1.147	No	ns	-46.63 to 28.06
TU2 vs TU3	-9.600	1.186	No	ns	-46.95 to 27.75
TU2 vs AB4	2.217	0.2738	No	ns	-35.13 to 39.56
TU2 vs AB5	-11.32	1.398	No	ns	-48.66 to 26.03
TU2 vs AB6	2.083	0.2574	No	ns	-35.26 to 39.43
TU2 vs KWA7	-174.0	21.50	Yes	***	-211.4 to -136.7
TU2 vs KWA8	-25.88	3.197	No	ns	-63.23 to 11.46
TU2 vs KWA9	-44.12	5.450	Yes	*	-81.46 to -6.769
TU3 vs AB4	11.82	1.460	No	ns	-25.53 to 49.16
TU3 vs AB5	-1.717	0.2121	No	ns	-39.06 to 35.63
TU3 vs AB6	11.68	1.443	No	ns	-25.66 to 49.03
TU3 vs KWA7	-164.4	20.31	Yes	***	-201.8 to -127.1
TU3 vs KWA8	-16.28	2.012	No	ns	-53.63 to 21.06
TU3 vs KWA9	-34.52	4.264	No	ns	-71.86 to 2.831
AB4 vs AB5	-13.53	1.672	No	ns	-50.88 to 23.81
AB4 vs AB6	-0.1333	0.01647	No	ns	-37.48 to 37.21
AB4 vs KWA7	-176.2	21.77	Yes	***	-213.6 to -138.9
AB4 vs KWA8	-28.10	3.471	No	ns	-65.45 to 9.248
AB4 vs KWA9	-46.33	5.724	Yes	**	-83.68 to -8.985
AB5 vs AB6	13.40	1.655	No	ns	-23.95 to 50.75
AB5 vs KWA7	-162.7	20.10	Yes	***	-200.0 to -125.4
AB5 vs KWA8	-14.57	1.799	No	ns	-51.91 to 22.78
AB5 vs KWA9	-32.80	4.052	No	ns	-70.15 to 4.548
AB6 vs KWA7	-176.1	21.75	Yes	***	-213.4 to -138.8
AB6 vs KWA8	-27.97	3.455	No	ns	-65.31 to 9.381
AB6 vs KWA9	-46.20	5.707	Yes	**	-83.55 to -8.852
KWA7 vs KWA8	148.1	18.30	Yes	***	110.8 to 185.5
KWA7 vs KWA9	129.9	16.05	Yes	***	92.55 to 167.2
KWA8 vs KWA9	-18.23	2.252	No	ns	-55.58 to 19.11

Table 14ANOVA and Tukey's analysis for conductivity in water samples

Table Analyzed	Conductivity				
One-way analysis of variance					
P value	P<0.0001				
P value summary	***				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	9				
F	19.93				
R squared	0.7799				
Bartlett's test for equal variances					
Bartlett's statistic (corrected)	97.12				
P value	P<0.0001				
P value summary	***				
Do the variances differ signif. (P < 0.05)	Yes				
ANOVA Table	SS	df	MS		
Treatment (between columns)	1122000	8	140300		
Residual (within columns)	316800	45	7039		
Total	1439000	53			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
TU1 vs TU2	212.0	6.189	Yes	**	53.97 to 370.0
TU1 vs TU3	160.3	4.681	Yes	*	2.300 to 318.4
TU1 vs AB4	337.2	9.844	Yes	***	179.1 to 495.2
TU1 vs AB5	231.0	6.744	Yes	***	72.97 to 389.0
TU1 vs AB6	-135.8	3.966	No	ns	-293.9 to 22.20
TU1 vs KWA7	75.50	2.204	No	ns	-82.53 to 233.5
TU1 vs KWA8	-68.33	1.995	No	ns	-226.4 to 89.70
TU1 vs KWA9	158.8	4.637	Yes	*	0.8004 to 316.9
TU2 vs TU3	-51.67	1.508	No	ns	-209.7 to 106.4
TU2 vs AB4	125.2	3.654	No	ns	-32.87 to 283.2
TU2 vs AB5	19.00	0.5547	No	ns	-139.0 to 177.0
TU2 vs AB6	-347.8	10.15	Yes	***	-505.9 to -189.8
TU2 vs KWA7	-136.5	3.985	No	ns	-294.5 to 21.53
TU2 vs KWA8	-280.3	8.184	Yes	***	-438.4 to -122.3
TU2 vs KWA9	-53.17	1.552	No	ns	-211.2 to 104.9
TU3 vs AB4	176.8	5.163	Yes	*	18.80 to 334.9
TU3 vs AB5	70.67	2.063	No	ns	-87.37 to 228.7
TU3 vs AB6	-296.2	8.647	Yes	***	-454.2 to -138.1
TU3 vs KWA7	-84.83	2.477	No	ns	-242.9 to 73.20
TU3 vs KWA8	-228.7	6.676	Yes	***	-386.7 to -70.63
TU3 vs KWA9	-1.500	0.04379	No	ns	-159.5 to 156.5
AB4 vs AB5	-106.2	3.100	No	ns	-264.2 to 51.87
AB4 vs AB6	-473.0	13.81	Yes	***	-631.0 to -315.0
AB4 vs KWA7	-261.7	7.639	Yes	***	-419.7 to -103.6
AB4 vs KWA8	-405.5	11.84	Yes	***	-563.5 to -247.5
AB4 vs KWA9	-178.3	5.206	Yes	*	-336.4 to -20.30
AB5 vs AB6	-366.8	10.71	Yes	***	-524.9 to -208.8
AB5 vs KWA7	-155.5	4.540	No	ns	-313.5 to 2.533
AB5 vs KWA8	-299.3	8.739	Yes	***	-457.4 to -141.3
AB5 vs KWA9	-72.17	2.107	No	ns	-230.2 to 85.87
AB6 vs KWA7	211.3	6.170	Yes	**	53.30 to 369.4
AB6 vs KWA8	67.50	1.971	No	ns	-90.53 to 225.5
AB6 vs KWA9	294.7	8.603	Yes	***	136.6 to 452.7
KWA7 vs KWA8	-143.8	4.199	No	ns	-301.9 to 14.20
KWA7 vs KWA9	83.33	2.433	No	ns	-74.70 to 241.4
KWA8 vs KWA9	227.2	6.632	Yes	***	69.13 to 385.2

Table 15ANOVA and Tukey's analysis for turbidity in water samples

Table Analyzed	Turbidity				
One-way analysis of variance					
P value	P<0.0001				
P value summary	***				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	9				
F	13.28				
R squared	0.7024				
Bartlett's test for equal variances					
Bartlett's statistic (corrected)	15.07				
P value	0.0577				
P value summary	ns				
Do the variances differ signif. (P < 0.05)	No				
ANOVA Table	SS	df	MS		
Treatment (between columns)	11010	8	1376		
Residual (within columns)	4665	45	103.7		
Total	15680	53			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
TU1 vs TU2	1.500	0.3609	No	ns	-17.68 to 20.68
TU1 vs TU3	3.333	0.8019	No	ns	-15.84 to 22.51
TU1 vs AB4	1.667	0.4010	No	ns	-17.51 to 20.84
TU1 vs AB5	-44.17	10.63	Yes	***	-63.34 to -24.99
TU1 vs AB6	2.333	0.5613	No	ns	-16.84 to 21.51
TU1 vs KWA7	-0.6667	0.1604	No	ns	-19.84 to 18.51
TU1 vs KWA8	-1.500	0.3609	No	ns	-20.68 to 17.68
TU1 vs KWA9	1.667	0.4010	No	ns	-17.51 to 20.84
TU2 vs TU3	1.833	0.4411	No	ns	-17.34 to 21.01
TU2 vs AB4	0.1667	0.04010	No	ns	-19.01 to 19.34
TU2 vs AB5	-45.67	10.99	Yes	***	-64.84 to -26.49
TU2 vs AB6	0.8333	0.2005	No	ns	-18.34 to 20.01
TU2 vs KWA7	-2.167	0.5213	No	ns	-21.34 to 17.01
TU2 vs KWA8	-3.000	0.7217	No	ns	-22.18 to 16.18
TU2 vs KWA9	0.1667	0.04010	No	ns	-19.01 to 19.34
TU3 vs AB4	-1.667	0.4010	No	ns	-20.84 to 17.51
TU3 vs AB5	-47.50	11.43	Yes	***	-66.68 to -28.32
TU3 vs AB6	-1.000	0.2406	No	ns	-20.18 to 18.18
TU3 vs KWA7	-4.000	0.9623	No	ns	-23.18 to 15.18
TU3 vs KWA8	-4.833	1.163	No	ns	-24.01 to 14.34
TU3 vs KWA9	-1.667	0.4010	No	ns	-20.84 to 17.51
AB4 vs AB5	-45.83	11.03	Yes	***	-65.01 to -26.66
AB4 vs AB6	0.6667	0.1604	No	ns	-18.51 to 19.84
AB4 vs KWA7	-2.333	0.5613	No	ns	-21.51 to 16.84
AB4 vs KWA8	-3.167	0.7618	No	ns	-22.34 to 16.01
AB4 vs KWA9	0.0000	0.0000	No	ns	-19.18 to 19.18
AB5 vs AB6	46.50	11.19	Yes	***	27.32 to 65.68
AB5 vs KWA7	43.50	10.47	Yes	***	24.32 to 62.68
AB5 vs KWA8	42.67	10.26	Yes	***	23.49 to 61.84
AB5 vs KWA9	45.83	11.03	Yes	***	26.66 to 65.01
AB6 vs KWA7	-3.000	0.7217	No	ns	-22.18 to 16.18
AB6 vs KWA8	-3.833	0.9222	No	ns	-23.01 to 15.34
AB6 vs KWA9	-0.6667	0.1604	No	ns	-19.84 to 18.51
KWA7 vs KWA8	-0.8333	0.2005	No	ns	-20.01 to 18.34
KWA7 vs KWA9	2.333	0.5613	No	ns	-16.84 to 21.51
KWA8 vs KWA9	3.167	0.7618	No	ns	-16.01 to 22.34