

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

KUMASI

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ASSESSMENT OF GROUNDWATER QUALITY IN BOGOSO,

A MINING COMMUNITY IN THE WESTERN REGION OF GHANA

BY

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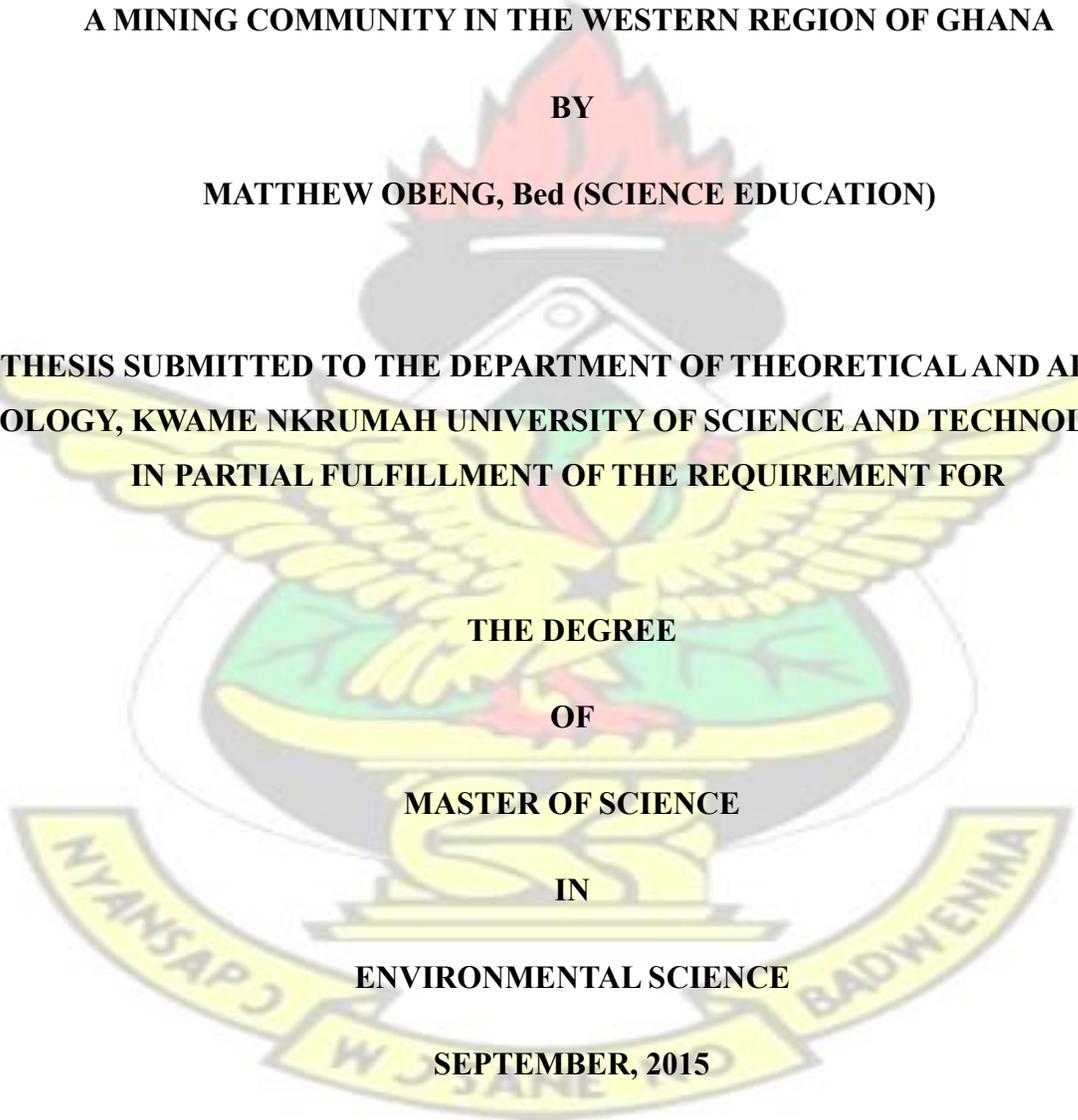
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DECLARATION

It is hereby declared that this thesis is the outcome of research work undertaken by the author, any assistance obtained has been duly acknowledged. It is neither in part nor whole been presented for another degree elsewhere.

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DEDICATION

This work is dedicated to my mother Mrs. Emelia Obeng and all my good friends whose encouragement and prayers made the completion of this work a success

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ACKNOWLEDGEMENT

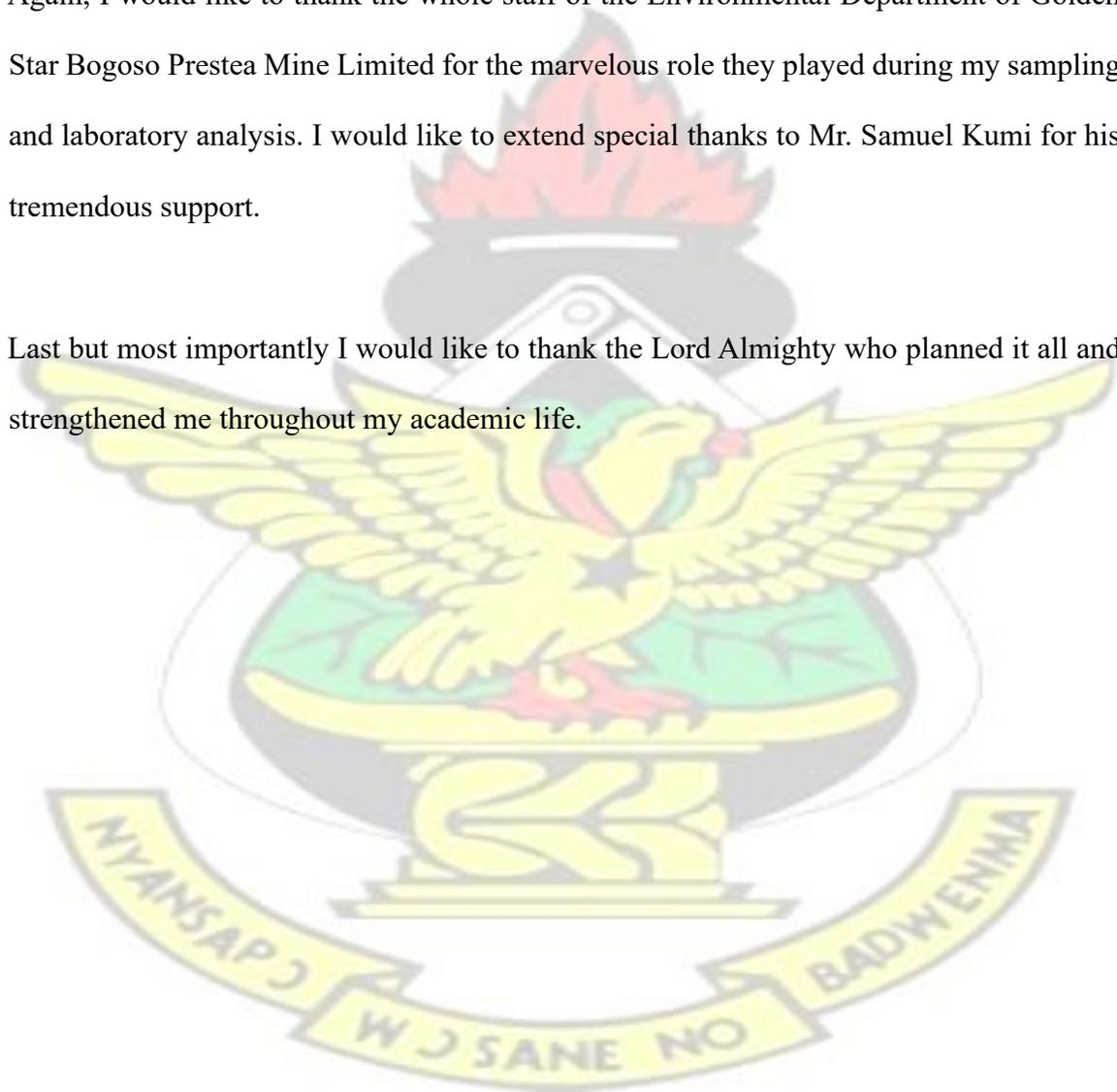
I would like to acknowledge the profound influence that my supervisor exerted on me throughout this study. From him I have learned a great deal about groundwater quality and, by his example, much about research work in general and discipline. He is consistently my

best and most thorough critic. His encouragement and suggestions have contributed in many ways to my work.

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ABSTRACT

There is the general perception that mining activities have severe adverse effects on the environment, particularly groundwater quality. Based on this, groundwater quality in the Bogoso area was studied because the area has experienced mining activities over a long period. It is believed that the mining activities have imparted negatively on the quality of ground water. This study aimed at assessing the quality of groundwater in Bogoso, focusing on pollution from heavy metals. Groundwater samples from ten (10) boreholes were collected and analysed for their quality using recommended techniques. The concentrations obtained for the parameters were compared with WHO guidelines for water quality. The results showed wide variations in the parameters investigated. pH values ranged from 5.10 at BB4 to 6.32 at BB2, which was lower than the WHO standard. The EC ranged from the lowest of 393.33 μ s/cm at BB1 to the highest of 863.33 μ s/cm indicating a higher EC value than the recommended standard. Heavy metal concentrations in boreholes were generally low. Results obtained for Zn, Cu, As, Cd and Pb were below the recommended limit by WHO. The concentration of Mn and Fe in the samples were found to be higher than the recommended limit for drinking water by WHO. Result obtained for Fe in the study ranged from 0.016mg/l to 1.285mg/l. Sample points BB1, BB2, BB9 and BB10 recorded values above the WHO standards of 0.03mg/l for drinking water. Concentration of Manganese also ranged from 0.079mg/l to 0.377mg/l. This significant difference was observed at samples points BB4 and BB10. In summary, the concentrations obtained for the parameters

studied showed that the sampled boreholes in Bogoso have characteristics that correspond to fresh ground water.

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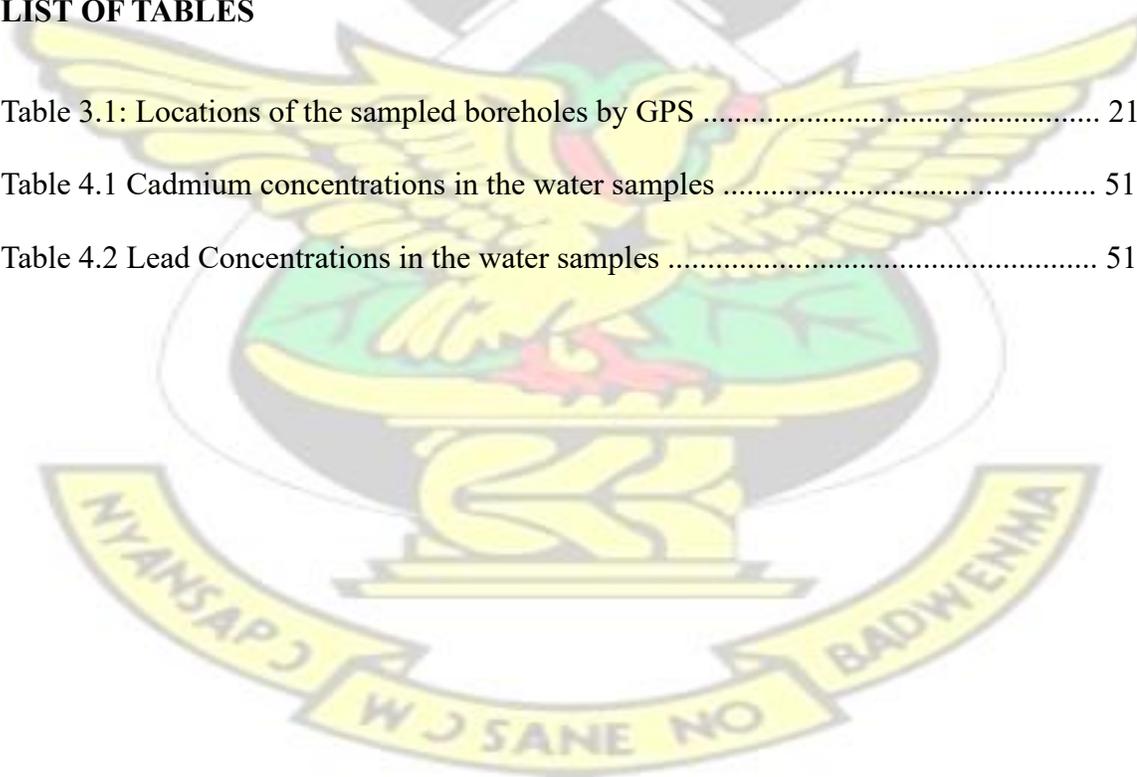
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CHAPTER ONE

INTRODUCTION

1.1 Background

Rivers and streams were the main sources of water used in Bogoso and its environs. Studies from (Kuma, 2003) has revealed that the intense minig activities in Bogoso have polluted the surface waters and thereby rendered them unsafe for use. River Ankobra one the major sources of water in the district has been rendered dead due to pollution from minig waste (Kuma, 2003). Realising that the major sources of water in the area are polluted, the district assembly with the support of Ghana government and some mining companies in the area collaborated to provide a number of boreholes to supply good drinking water for the people of Bogoso and its environs. With time the number of boreholes keep on increasing and have become the major sources of water for the people in the area.

In mining areas, ground water in rock aquifers are known to have problems regarding quality and this may impart seriously on health of users. Poorly buffered water may produce from carbonate deficient rocks (Smedley *et al.* 1995). Dissolution of Elements such as Al, Mn, Be and Fe which are contained in rocks may also dissolve as a result of acid rain and released into groundwater. In Zimbabwe, William and Smith (1994) reported that drainage in gold mining areas have high As levels of 72 mg/l. Sulphide aquifered rocks was reported by Smedley *et al.* (1995) to contain harmful metals such as AS, Sb, Pb and Ba and oxidation of such mineral rocks releases the metals into ground water making it toxic when used. They continued that Arsenic in high concentrations may be due to Manganese and Iron ore found in the Sulphide mineral, example pyrites.

Refractory quartz-Fe/As sulphide lode gold is the major gold ore found in Birimian (Marston *et al.* 1993). Junner *et al.* (1942) stated that there are a lot of pyrites found in the igneous rocks and quartz that run through the Birimian and Tarkwaian rocks in the area. There is therefore the high rate of metal pollution of the groundwater in Bogoso from the Birimian rocks.

Golden Star Bogoso Prestea Limited, a large scale mining company is located in the study area- Bogoso. It is possible that these mining activities may impact on the groundwater quality. From these assertions that the researcher finds it necessary to assess the quality of the borehole water in Bogoso and its environs. The study will also provide a source of information to the mining industries for proactive environmental interventions to protect the quality of the natural groundwater. Also people living in the mining communities will be informed about the risk of groundwater contamination or pollution.

1.2 Problem Statement

Mining operations may cause adverse changes in the environment of surrounding communities. Such changes do not only affect the inhabitants in terms of life-threatening illnesses, but also the destruction of vital natural resources such as groundwater. According to the WHO, about five million people die every year from drinking polluted water (Anon, 2001). There is therefore the need to assess groundwater quality in these mining communities.

One of the major assets of any nation is its water resources, of which groundwater is a major component. It is therefore important to assess and/or monitor the quality and identify the extent of groundwater contamination/pollution resulting from anthropogenic activities,

including mining. The assessment will enable preventive measures to be taken, while the knowledge of extent of pollution will inform on the level of treatment, if any, required to make the water potable.

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1.3 Justification

Water resources are of paramount importance to life and other economic activities of man so there is the need to protect them. Groundwater constitute about 20% of fresh water supply in the world (Columbia Water Center, 2009). Todd (1980) stated that about 90% of the water used in USA are supplied from groundwater. In Asia groundwater provides about half of the drinking water supply. The percentage is even much higher in Europe as 98% in Denmark and 94% in Portugal (Chapman, 1996). Africa has a large percentage of rural communities, which are dispersed. In Ghana about 70% of the populations live in rural areas. A centralized water supply system for such places is not practical and would be too expensive. There is availability of groundwater in many places in Africa. It can be cheaply developed to meet demands with simple techniques and lower capital compared to other sources like rivers and streams. It is therefore not surprising that most African countries rely extensively on groundwater systems. In several countries in Africa, groundwater is produced from boreholes and hand-dug wells for drinking and irrigation. Xu and Usher (2006) pointed out that most ground water sources are polluted and their use has led to increased health problems. They further stated that sources of groundwater pollution are numerous including uncontrolled expansion of human settlement, high levels of effluent and sewage leakage, mining operations and indiscriminate waste disposal.

The intensity of groundwater pollution depends on the volume of waste, composition, rate of release of contamination and concentration of components among others. Major pollutants of ground water are from mining operations. This is because underground and surface mining operations extends beyond the water table. Also the water used in such operations may be pumped from constructed borehole or the mine site and may contain high levels of minerals, Iron, Aluminium, Sulphate which can lead to low pH (Chilton *et al.*, 1995).

Users of surface or ground water that contains effluent of mine drainage can have serious health implications. In Bogoso and its surrounding communities, operations of the mine are the main sources of both surface and ground water pollution. Around the plants of the mining concessions are heap of mine waste, waste rocks and ore stockpiles (Armah *et al.*, 2010). Cadmium, Arsenic, Mercury and Lead are toxic metals that are released from mine tailings. These chemicals constitute the major pollutants of groundwater (Akabzaa and Darimani, 2001). Notwithstanding this, information on the impact of mining operations on groundwater quality, especially the extent and trend is inadequate within the Bogoso mining area (Kuma and Ewusi, 2009).

1.4 Objectives of the Study

This study is aimed at assessing the groundwater quality in Bogoso

1.4.1 Specific Objective

To determine the concentrations of some heavy metals (Fe, Mn, Pb, Cu, Cd and As) in the groundwater (boreholes)

To determine some physico-chemical parameters –e.g. Temp, pH, TDS, EC, THD, DO in the groundwater (boreholes).

To compare the concentrations with the WHO guidelines in order to determine its suitability for consumption.

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CHAPTER TWO

LITERATURE REVIEW

2.1 Hydrogeology

The major source of water supply in the study area is groundwater. There has been a rapid increase in the number of boreholes to match the demand for potable water in the area (Kortatsi, 2004). Direct seepage or infiltration is the recharge process by which groundwater recharges in the area. Recharge of the groundwater occur from rivers since they are both in hydraulic contact (Kortatsi, 2004). In the study area ground water circulation is localized due to the hills tha serve as groundwater divides. Circulation is done through the quartz veins and fissures- fault-brecciated zones. The speed at which the groundwater circulate is not known and it might happened that the domestic wells have not received pollutants yet (Kortatsi, 2004). The area recorded low values of conductivity indicating that reactivity with rock matrix is low and that also shows short resident period (Kortatsi, 2004). The study area is prone to pollution from mining waste which may impart negatively on the health of users. Oxidation of sulphide in areas of mining operations leads to low pH in water. This normally results in dissolution of metals which occur in groundwater (Kortatsi, 2004)

2.2 Occurrence of Groundwater Contamination

The path through which groundwater takes determines its chemical constituents. This explains why groundwater contains a wide range of inorganic materials (Freeze *et al.* 1985). Indeed, the composition of the ground water reflects the path it flows. As the path of flow is altered the chemical makes up also changes (Focazio *et al.* 2000). Human

activities can alter the chemical composition of groundwater and can result in groundwater contamination. The activities could be direct (spills or leakages of liquid) or indirect (changing the water path). In some cases the change can increase the concentration of chemicals that are already dissolved in it. Sometimes the change may result in the introduction of new chemical materials that are not already found in the natural ground water (Freeze *et al.* 1985). Groundwater contamination causes degradation of water quality. The quality of groundwater can therefore be attributed to both internal and external factors and also on the soils ability to change the contaminants (Kinniburgh and Edmunds, 1986).

2.2.1 Contaminants Migration in Groundwater

Contaminants found in groundwater result from both point sources (e.g. mining spills) and non-point sources (e.g. waste from agricultural fields). These contaminants enter the groundwater by percolation through the unsaturated soil zone to the water table (USGS, 2008). This zone determines the amount of material (contaminants) that should enter the groundwater from the soil surface (Freeze *et al.* 1985). Some of the contaminants enter the ground in a dry state but requires further dissolution by moisture in the soil before percolation from the force of infiltration. The time taken for contaminants to migrate into groundwater therefore depends on the contaminant type, namely groundwater soluble contaminants, those lighter than water or heavier than water but insoluble (Freeze *et al.* 1985). Most inorganic and many organic chemical constituents are soluble. After dissolving in groundwater they form a chain of plumes of contaminant that moves out in the path of flow of the groundwater. Contaminants with solubility greater than 1000 mg/l are increasingly soluble but those with solubility less than 100 mg/l are insoluble. If an

insoluble contaminant has specific gravity less than 1.0 it is referred to as “floater” and if specific gravity is greater than 1.0 is also a “sinker” (Freeze *et al.* 1985).

2.2.2. Sorption and Precipitation as Factors of Contaminants Migration

The transportation of metal contaminants in groundwater is influenced by sorption (adsorption or absorption) to aquifer solid material (Appelo and Postma, 1999).

According to Charest (1998), precipitation and sorption are the major processes through which chemical retention occurs. The processes and transportation of metals are influenced by several parameters. The parameters include pH, Eh and oxidation state of metal ion, notwithstanding toxicity levels of different species of metals, solubility and transportation (Asklund and Eldvall, 2005).

Sorption is a term generally used to express different several processes such as adsorption and absorption.

Adsorption process involves the attraction of molecules of substances such as gas or liquid on the surface of solid (sorber) so as to remove it from solution (McCarty, 1996). The adherence of the molecule is caused by electrostatic force found on the mineral grain surface formed by the phase of the aquifer that is solid (Charest, 1998). The sorber may be driven by thermodynamic gradient as in hydrophobic solute in water (Charest, 1998).

Absorption on the other hand suggest the permeation of one substance (liquid chemical contaminant) into another (solid). Absorption occurs when contaminants enter the absorbing material-mineral (Charest, 1998).

The Precipitation can reduce the movement and concentration of contaminants that are inorganic in groundwater. This process can only occur when the organic contaminant is

oversaturated (Charest, 1998). Solubility of inorganic contaminants in aquifers is affected by different factors, example, ion pairing- increasing the carrying capacity for cation in solution as a result of the interaction between an anion and a cation in the solution (Charest, 1998). Precipitation removes inorganic contaminant from solution in aquifer environment by increasing solubility (Brady *et al.* 1997).

2.2.3. Environmental Geochemistry of Mine Water

Groundwater in mining districts is mostly severely polluted and have low pH resulting from pyrite oxidation and other sulphide minerals contained in the mine tailings (Dinelli *et al.* 2002). In most cases, these tailings are characterised with elevated concentrations of heavy metals. Mining waste contains sulphide minerals such as pyrite. When pyrite is oxidized in the presence of water and oxygen, acid is produced which dissolves in water to form acid mine water and leads to Acid Mine Drainage (AMD). Acid Mine Drainage can persist and travel over 10 km from the source (Naicker *et al.* 2003). The introduction of such contaminants from mine water could be dangerous to health and sometimes very destructive to the ecosystem. It is worth mentioning that mining activities form an integral part of the metal pollution in our environment, though few pollution occur by weathering (Asklund and Eldvall, 2005).

2.2.4. Reactive Minerals in Mine

Sulphide minerals such as arsenopyrite, bournonite, chalcopyrite, galena, pyrite, sphalerite and tennalite are stable in reducing environments (Zeelie and Hodgson, 2007). Mining exposes these minerals to atmospheric conditions (air and water); an environment in which they are unstable. They react to form oxidic phases that are in equilibrium in the new

environment. In doing so, sulphur is released and reacts with the water to form sulphuric acid. This may lower the pH of mine waters to around two. At pH below five, many toxic metals go into solution in the acid water so the concentration of metals in solution increases (Kortatsi, 2004).

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2.2.5. Acid Mine Drainage (AMD)

When mine waste (metal mines) that contains acid water outflows from abandoned pit is referred to as acid mine drainage or acid rock drainage. This phenomenon occurs when sulphide rich rocks comes in contact with groundwater. The oxidation of this sulphide rich rock in the presence of oxygen and water result in the production of highly acidic sulphaterich drainage (Fripp *et al.* 2000). Indeed, both surface and underground mining can accelerate oxidizing conditions (Fripp *et al.* 2000). In order to prevent flooding of mine water that contains high levels of acid, water must be pumped out of the abandoned pit constantly (Fripp *et al.* 2000). On the parts of Asklund and Eldvall (2005), they stated oxidation of sulphide mineral passes through some processes namely: micro-organism catalyzed oxidation, Fe^{3+} oxidation and oxidation with oxygen. At low pH these reactions accelerate. In the area however, the problem of AMD should be expected. This is due to the fact that Bogoso abound in defunct (closed) underground mine pits which have been illegally taken over by Galamsey operators who on daily basis pump out (though unspecified) but very high quantity of water to land surface. The abandoned underground mine pits are also most likely to serve as an underground point source for groundwater recharge. Unfortunately, water from abandoned underground mine pits are characterised with low pH down to about three. This phenomenon coincides with the findings of Kuma

(2004), who found out that, levels of pH in water including groundwater in mining areas is constantly low.

2.2.6. Major Inorganic Contaminants Related to Mining

Inorganic contaminants (e.g., metals, metalloids, and ions) enter the hydrologic cycle as a result of mining activities, groundwater pumping, and other industrial activities, all of which are prevalent in the mining area. These inorganic contaminants cause water alkalinity, salinity or acidity to change thereby making the water harmful to animal and plant life. It could also have very serious effect on human (Dawson, 2004). Notwithstanding this, ions of Potassium, Chlorine, Calcium, sulphate, Sodium which are major ions and Fluoride ions a minor ion as well as some trace elements are good for metabolism in human (Safe drinking Water Comm, 1980). Again, (Freeze and Cherry, 1979) found out that the high intake of some major ions such as: sodium, sulphate and chloride are not harmful even beyond recommended limits. Water will only taste salty when the Sodium ions exceeds the recommended limit of 200 mg/l. The recommended limit for Chloride in drinking water is 250 mg/l and this is allowed because of taste (Kortatsi, 2004). On the other hand some minor ions and trace metals can become harmful to human health when they exceed the recommended limit in water (Kortatsi, 2004). In the study area previous work on water quality has been conducted mainly by Kuma and Ewusi (2009), Kortatsi (2004), and Asklund and Eldvall (2005).

2.2.6.1. Sulphate

Sulphate level in drinking water should not exceed 500 mg/l (WHO, 1996). Studies done previously in the area by Kuma (2004) revealed that the groundwater has a minimum level of sulphate to be 21.0 mg/l and a maximum levels of 490mg/l in surface water. Sulphate in water result in a change in taste. Approximately 250 mg/l is the lowest taste threshold. Large quantities of sulphate in drinking water can result in dehydration, and irritation of the intestine. Water distribution systems may corrode due to high sulphate levels in water. When magnesium sulphate level in the water exceeds 600 mg/l, it works in human as purgative

2.2.6.2. Sodium and Potassium

Previous study in the area showed that Sodium concentration in the ground water is excellent (Kortatsi, 2004). By WHO standard sodium in drinking water should not exceed 200 mg/l. The water will taste salty when the 200 mg/l recommended limit is exceeded. Potassium and Sodium occur naturally and are released when rocks containing them are weathered (Singh *et al.* 1999). Cation exchange mechanism can influence the concentration of Potassium and Sodiun aside industrial and sewage pollutants.

2.2.6.3. Calcium and Magnesium

To determine the quality of water for industrial and domestic purposes total hardness should be considered (Karanth, 1994). Magnesium and Calcium salt dissolved in water determines the hardness. Hardness is related to a reaction of water with soap when used domestically. Mg^{2+} and Ca^{2+} precipitate soap, hardness is the sum of concentration of Ca^{2+} and Mg^{2+} expressed as mg/l of $CaCO_3$. Water hardness in the range 0-60 mg/l is soft, 61120 mg/l is

moderately hard, 121-180 mg/l hard and greater than 180 is very hard (Kortatsi, 2004). Previous studies in the area shows that there was variation in hardness of groundwater ranging from 10mg/l to 358 mg/l (Kortatsi, 2004).

2.2.6.4. pH

The acidity or alkalinity of water measure its pH. Water acidity leads to the ability to dissolve rock minerals to release harmful trace metals into water making it toxic for consumption by human. High levels of acidity in groundwater can expose it to trace metal pollution if the percolation path is a metal rich rock. The sour taste of water is due to acidity. For water potability, the WHO (1993) recommended pH range is 6.5-8.5. Earlier study by Kortatsi (2004) showed a highest pH range in groundwater from 5 to 6.9.

2.2.6.5. Electrical Conductivity (EC)

Electrical Conductivity measures the salinity of the water which influences the taste and has an impact on the potability of the water (Pradeep, 1998). The EC defines the ability of the water to conduct. The conducting ability is determined by the presence of ions and solids that are dissolved in the water. The more the solids that ionizes, the higher the conducting capacity. The recommended limit for EC in water by WHO is 600 mS/cm (Jameel and Sirajudeen, 2002). Previous studies in the area shows that the groundwater varies largely in total hardness from 10 mg/l to 358 mg/l (Kortatsi, 2004).

2.2.6.6. Total Dissolved Solids (TDS)

Amount of material that is dissolved in the water column is measured as TDS. The unit for recording is mg/l. Naturally, the values in water ranges from 0-1000 mg/l. WHO (2003) reported that high values of TDS are as a result of sodium, chloride, magnesium and sulphate salt dissolved in the water. If TDS value is above 500 mg/l, the water suitability is affected and its use as irrigation is also limited. Increased TDS value of water affect its colour, taste and clarity (WHO, 2003).

2.2.6.7. Hardness

Magnesium and Calcium present in the water determines the water hardness. Ions of metals such as Fe and Mn also cause water hardness (USEPA, 1997). Hardness is defined in terms of Magnesium and Calcium Carbonate in the unit mg/l. Water hardness reflect the geology of the area and also provides a measure of the influence of human activities on the area. These reasons make hardness a useful water quality indicator (Akpabli and Drah, 2001). Hard water also has the ability to reduce the toxic effect of some metals including Lead, zinc and Copper. Water which is soft may corrode metal plumbing, while hard water may form scale deposits in pipes.

2.2.7. Trace and Heavy Metal Contamination Related to Mining

Some of the metals are useful to human and for proper functioning of body parts. These metals are needed in small portions (WHO, 1996). Some of the metals are non-essential (mercury and cadmium), trace metals (nickel, cobalt, selenium, vanadium, molybdenum, silicon and chromium), others essential (calcium, magnesium and sodium) (Walker and

Sibly, 2001). Metals with density greater than 5 g/cm^3 are referred to as heavy metals (Walker and Sibly, 2001). Heavy metals such as Cd, Hg, Ni, Cr, Cu, Pb, As, Zn and Sn are of more concern to health and environment (SEPA, 2003). These metals are not needed by the human body because they are poisonous (WHO, 1996). The living tissue can store some metals and they can be there for a longer time (SEPA, 2003). The property of a metal and the environment it is stored makes it harmful. Animals and plants show characteristics or reaction for the need of essential and non-essential metals. Some metals are toxic to plants while others to animals (Pettersson, 1994). Earlier study in the area recorded the metal levels in the groundwater are within the WHO recommended limit (Kuma, 2003) and (Kortatsi, 2004).

2.2.7.1. Mercury

When mercury is found in drinking water it causes a lot of physiological problems. Mercury in drinking water accumulates in the kidney and affect the gastrointestinal tract. Inorganic mercury is toxic to the nervous system (WHO, 1993). Previous study in the area by Kortatsi (2004) reveal high value of mercury in groundwater to be 0.037 mg/l .

2.2.7.2. Cadmium

In natural water which is not polluted the concentration of Cadmium is below $1 \mu\text{g/l}$. The chemical characteristics of Cadmium is similar to that of Zinc. Improper disposal of waste or corrosion of galvanized pipes releases Cadmium into drinking water (Florida dept. of environment, 2008). When one is exposed to this chemical for a long time, it can result in kidney damage. Previous study in the area by Kortatsi (2004) reveal high value of Cadmium in groundwater to be 0.003 mg/l .

2.2.7.3. Nickel

This inorganic metal enter groundwater through mining activities and refining of Nickel containing ore (Florida Dept. of Env., 2008). When ferrosulphide which contain Nickel is oxidized, the concentration of nickel ion in groundwater increases (Florida Dept. of Env., 2008). The concentration of Nickel in drinking water worldwide is lower than 20 µg/l (Asklund and Eldvall, 2005). To protect the risk of Nickel effect in drinking water the WHO (1993) guideline maximum value set for drinking water for nickel is 0.02 mg/l. Previous study in the area by Kortatsi (2004) reveal high value of Nickel in groundwater to be 0.076 mg/l.

2.2.7.4. Arsenic

In groundwater the presence of Arsenic result from dissolved minerals through weathering of rock over time (Florida Dept. of Env., 2008). Naturally, Arsenic concentration in groundwater ranges from 1 µg/l to 2 µg/l. High values as 12 µg/l have been reported in areas where it occurs naturally (Asklund and Eldvall, 2005). Insoluble Arsenic compound can be obtained and co- precipitated with Iron and Manganese hydroxide at some conditions (Smedley and Kinniburgh, 2001). 0.01 mg/l is the recommended provisional guideline. This value is estimated base on cancer lifetime risk (WHO, 1996). Previous study in the area by Kortatsi (2004) reveal high value in groundwater to be 0.046mg/l. and Kuma (2004) also reported high values in surface water to be 0.137mg/l.

2.2.7.5. Zinc

Zinc is a natural essential mineral element found in drinking water. It aids the metabolism in human. Insufficient intake of the element can result in loss of appetite, slow healing of wounds, and defect in birth (Kortatsi, 2004). High intake result in gastrointestinal problems (Kortatsi, 2004). In water large quantities result in metallic taste so the WHO (1993) approved a limit 3.0 mg/l for water potability. Previous studies in the area show that concentration of the metal has no problem with groundwater quality and only 1% of the boreholes exceeded WHO recommended limit (Kortatsi, 2004).

2.2.7.6. Manganese

The taste of drinking water is affected when concentration of this metal exceeds 0.1 mg/l. It produces coating in pipes and fall off as black precipitate when levels are at 0.02 mg/l (Asklund and Eldvall, 2005). In solution it precipitate by oxidation. At 20 mg/l consumption, it has no negative effects on human (Asklund and Eldvall, 2005). To protect the health of human, a provisional value of 0.5 mg/l has been proposed (WHO, 1996). Previous study in the area by Kortatsi (2004) reveal high value in groundwater to be 1.3 mg/l. and Kuma (2004) also reported high values in surface water to be 2.43 mg/l.

2.2.7.7. Lead

One of the commonest metal in the earth crust and amount to 13 mg/kg. Food indigestion dust and dirt produces above 80% Lead daily (Florida Dept. of Env., 2008). It is carcinogenic so its intake must be avoided. 3.5 μg is the daily provisional intake per Kg of infant body weight. 0.01 mg/l in potable water is recommended in infants. This recommended value is proposed for age groups (WHO, 1996). Previous study in the area

by Kortatsi (2004) reveal high value in groundwater to be 0.026 mg/l. and Kuma (2004) also reported high values in surface water to be <0.05 mg/l.

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CHAPTER THREE

MATERIALS AND METHODS

3.1. The Study Area

The study area, Bogoso is the administrative capital of Prestea Huni-Valley District. The area has a long history of gold mining activities. Currently, Golden Star Bogoso Prestea Limited (GSBPL) a large scale mining company is mining gold in the area. The area lies within the main gold belt of Ghana that stretches from Axim in the southwest, to Konongo in the northeast (Kortatsi, 2004). Figure 3.1 shows the location of Bogoso.



Fig.3.1 Location of the study area (Source: Anon, 2001)

3.1.1 Geology and Soil

Bogoso is found between Tarkwaian rocks in the west and older Birimian super-group of Ghana to the east. The Tarkwaian system has less heavy metals compared with the upper and lower Birimian series. For instance, Dzigbodi-Adjimah, (1993) found out that the veins of the Birimian in the area has of quartz which contain carbonate minerals, green sericite, carbonaceous partings and metallic sulphides. The quartz also contains arsenides of Iron, Arsenic, Zinc, Silver, Copper and Lead. The upper series of the Birimian also consist of volcanic and pyroclastic origin. This part also contains bedded groups of green lava. The Tarkwaian system rock on the other hand is made up of the Kawere group, the banket series, the Tarkwa phyllite and the Huni sandstone (Kuma and Younger, 2001).

The soils in the study area consist mainly of silty-sands with less patches of laterite mostly on hilly areas which belong to the forest oxysol group of soils (Kuma and Younger, 2001).

3.1.2 Climate and Vegetation

The area is very humid and warm with daily temperatures ranging from 28 to 30⁰C during the wet season and 31 to 33⁰C during the dry season (Dickson and Benneh, 1980). Sunshine duration for most part of the year averages 7 hours per day. The relative humidity is generally high throughout the year and ranges from 70 to 90% (Armah *et al.* 2010). The area experiences high rainfall with an average value of 1576 mm from 1994 to 2002 (Obiri, 2007). Kuma and Ewusi (2009) also indicated an annual rainfall mean of 1900 mm/yr, using rainfall figures from 1939 to 2008. Seasonal weather patterns characterizes the climate of the area. This consist of two wet season in April to June and October to

November and a major dry season from December to February (Armah *et al.* 2010). In the area, the vegetation is made up of partly tropical rain forest and moist semi-deciduous forest.

3.2.1 SAMPLING

Ten sampling sites were selected using the global positioning system, GPS as shown in table 3.1. A map of the sampling site is shown in figure 3.2

Table 3.1: Locations of the sampled boreholes by GPS

GPS DATA			
Location	Sample ID	X (N)	Y (UTM)
Adjei krom	BB 1	0610883	0615968
Kokoase	BB 2	0610447	0615741
Atechem	BB 3	0609531	0615466
Nyamekyekrom	BB 4	0609444	0614951
Town Hall	BB 5	0609212	0615508
Old cemetery	BB 6	0609659	0616038
Star Line	BB 7	0609210	0615900
Atobrakrom	BB 8	0608789	0615943
Hospital	BB 9	0608604	0615731
Golden Star	BB 10	0607858	0616309

GROUND WATER SAMPLING POINTS WITHIN THE STUDY COMMUNITIES

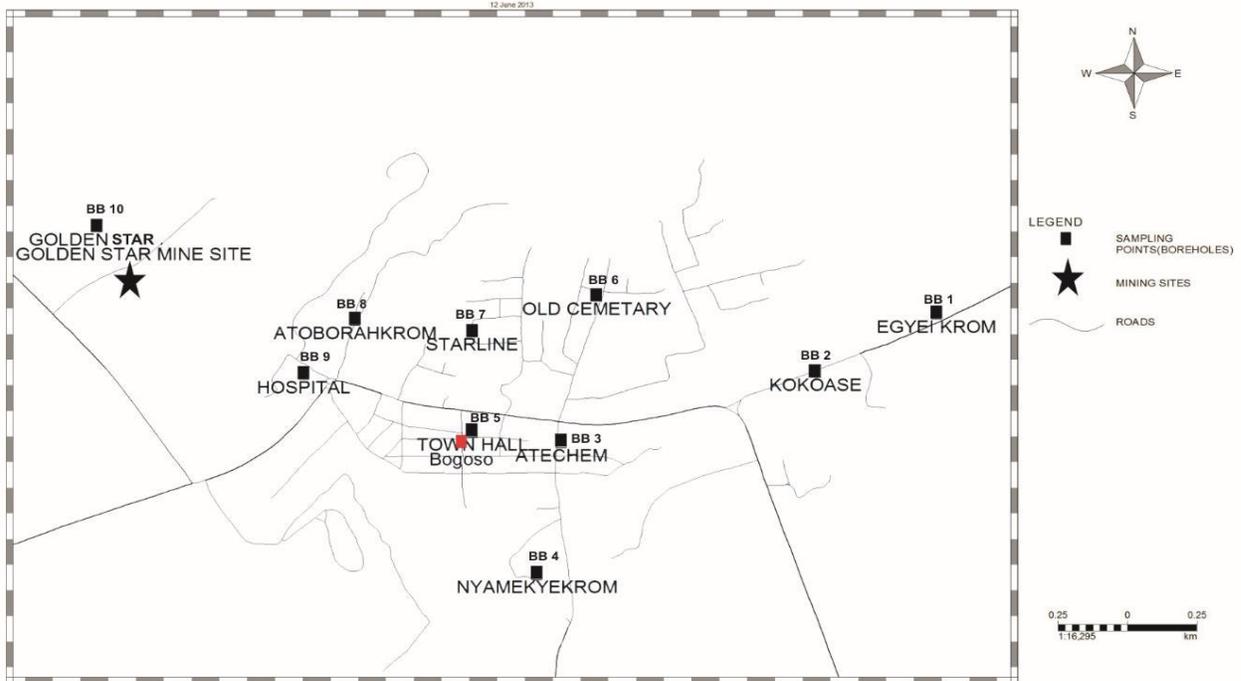


Figure 3.2: Groundwater sampling points within the study community (Bogoso)

3.2.3 Groundwater Sampling

Ten groundwater point sources (boreholes) used for drinking were selected. Each point was sampled three times within each month (March, May and July). The sampling points were assigned names and serial numbers based on the area in Bogoso they were situated. All the samples were collected from boreholes which are in active use. The first set of samples were taken in March. On each day of sampling, two samples were collected at each point to analyze for heavy metals and physico-chemical parameters. The samples were collected in 500 ml acid-washed, high density plastic containers.

To prevent any external contamination during the process of sampling, the following steps were taken:

- The samples were obtained directly from the boreholes after allowing the water to run for at least 5 min (Reimann *et al.* 2003).
- All the sampling containers were rinsed three times with the very water to be sampled before every sample is collected.
- Changing of hand gloves after each event to avoid cross contamination.
- The sample bottles were completely filled so that no air space is left before capping (This was to avoid mixing the water with air during sampling).

3.3 SAMPLE PRESERVATION

Water samples meant for metal analyses were acidified with 1 ml HNO₃ to achieve a pH of 2.0. The addition of acid to water sample was to keep the metal ions in the dissolved state, as well as to prevent microbial activities (APHA, 2005). The samples were kept in an ice chest loaded with ice blocks, transported to the laboratory and stored in a refrigerator at 4°C until they were analyzed. The samples were analyzed at the Environmental Laboratory of Golden Star Bogoso Prestea Limited, Prestea using the Agilent's 280FS Atomic Absorption Spectrometer.

3.3 LABORATORY AND ON-SITE ANALYSIS

3.3.1 On-Site Analyses

In-situ measurement of pH, temperature, electrical conductivity, DO and TDS were done using the Hanna Instrument (HI) water quality monitoring device Model HI991301. The on-site analysis was achieved by collecting the samples in a 500 ml container, after which

the cell of the HI water quality monitoring device was immersed in the water. Measurements for the parameters were taken (read) on-screen after stable values were achieved from the HI device. The device was rinsed with distilled water and cleaned with a tissue paper in between measurements.

3.3.3 Total Hardness

Total hardness was determined by titration using standard methods. A 100 ml portion of the water sample was put into a 250 ml conical flask and 10 ml of NH_4/NH_3 buffer was added to it. Two drops of Erichrome Black T indicator was added. The content of the conical flask was titrated against 0.02 M Ethylenediaminetetraacetic acid (EDTA) solution until the colour changed from the wine-red to the blue end point. Titration was repeated until a consistent titre was obtained and the average titre calculated (APHA, 1998). The concentration was then calculated as;

$$\text{Total Hardness} = \frac{\text{mL of EDTA used} \times B \times 1000}{\text{Volume of sample}}$$

Where B = mg of CaCO_3 equivalent to 1000 ml of EDTA titrant or by multiplying the end point by 10.

3.3.2 Heavy Metals

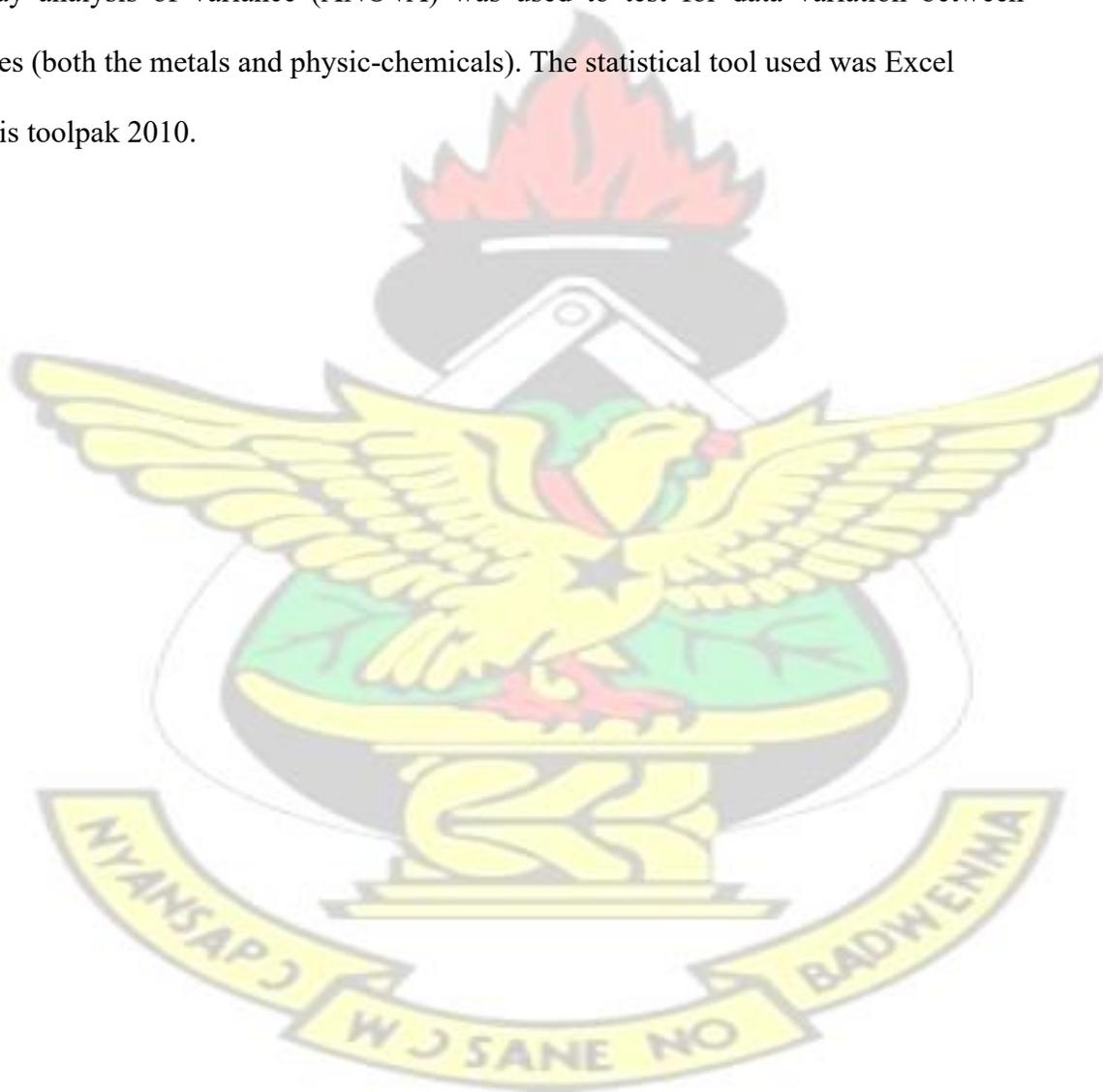
10 ml of the water sample each was taken with the pipette and filtered using 0.45 μm Whatman filter paper into clean polyethylene digestion tubes. It was then acidified to a pH less than 2 with 1 ml concentrated HNO_3 ultra-pure. The sample was shaken and allowed to stand for about an hour. After cooling the sample is pipetted into the vials in rack. The samples were then taken through a tube to the Nebulizer and into the spray chamber of the

Agilent's 280FS Atomic Absorption Spectrometer for analysis. The metals were determined by aspirating the solution of the sample into the flame of the instrument. The instrument was calibrated for the metals to be determined.

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3.4 Statistical Analysis

One-way analysis of variance (ANOVA) was used to test for data variation between variables (both the metals and physic-chemicals). The statistical tool used was Excel Analysis toolpak 2010.



CHAPTER FOUR

RESULTS

4.0 Physicochemical quality of the water during the whole study

There was variation in the values of pH recorded over the period of the study from one point to the other. pH values ranged from 5.10 at BB4 to 6.32 at BB2 (Figure 4.1). The variation in the results at a confidence interval of 95% using two-way ANOVA was significant ($p = < 0.0001$).

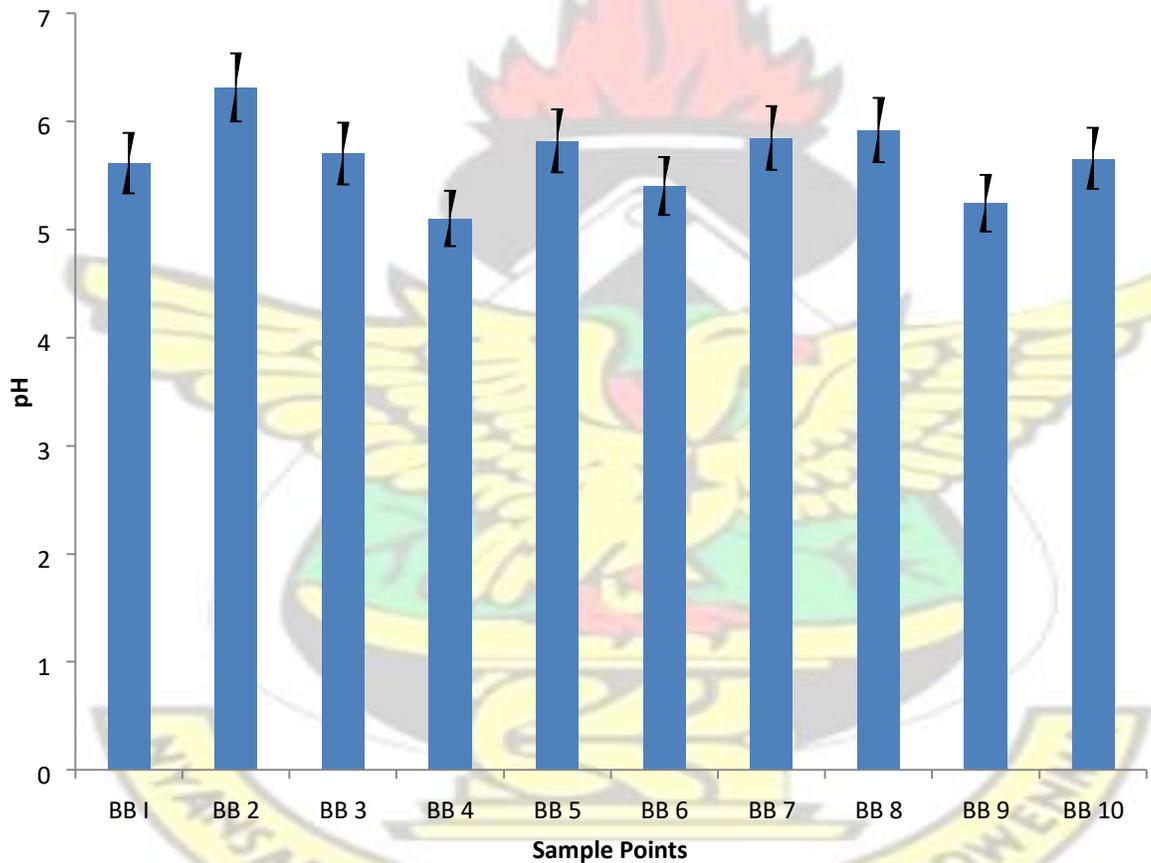


Fig. 4.1 pH of the water samples for the study area

The ability of the water samples to conduct electric current was also measured with values ranging from the lowest of 393.33 $\mu\text{s}/\text{cm}$ at BB1 to the highest of 863.33 $\mu\text{s}/\text{cm}$ at BB3

(Figure 4.2). Statistically the difference in the values of conductivity across the sampling points was significant ($p = < 0.0001$).

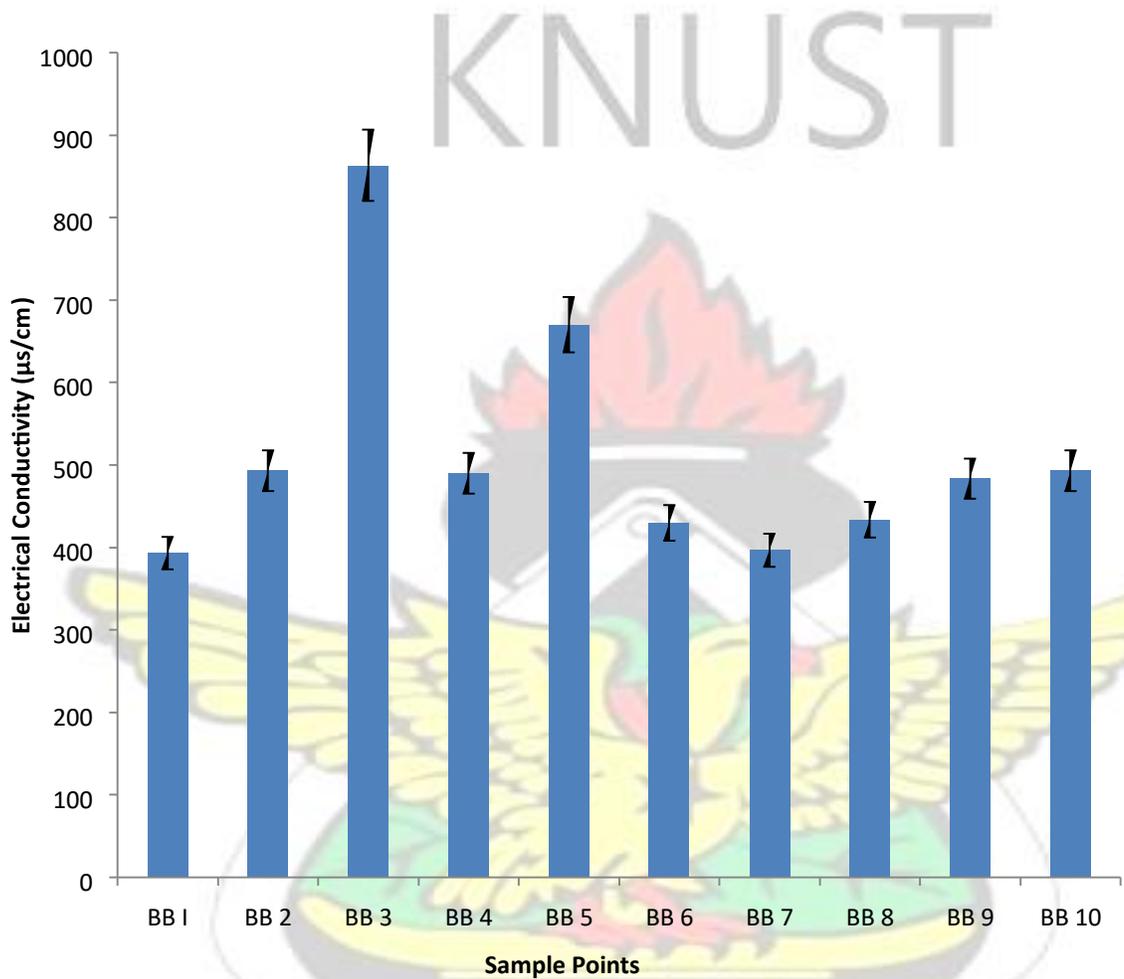


Fig. 4.2 Electrical conductivity of the water samples

Dissolved solids in the water samples recorded values ranging from 200.33 mg/l at BB1 to 414 mg/l at BB3 (Figure 4.3). Statistically there is significant difference between the values of TDS recorded. ($p = 0.0002$).

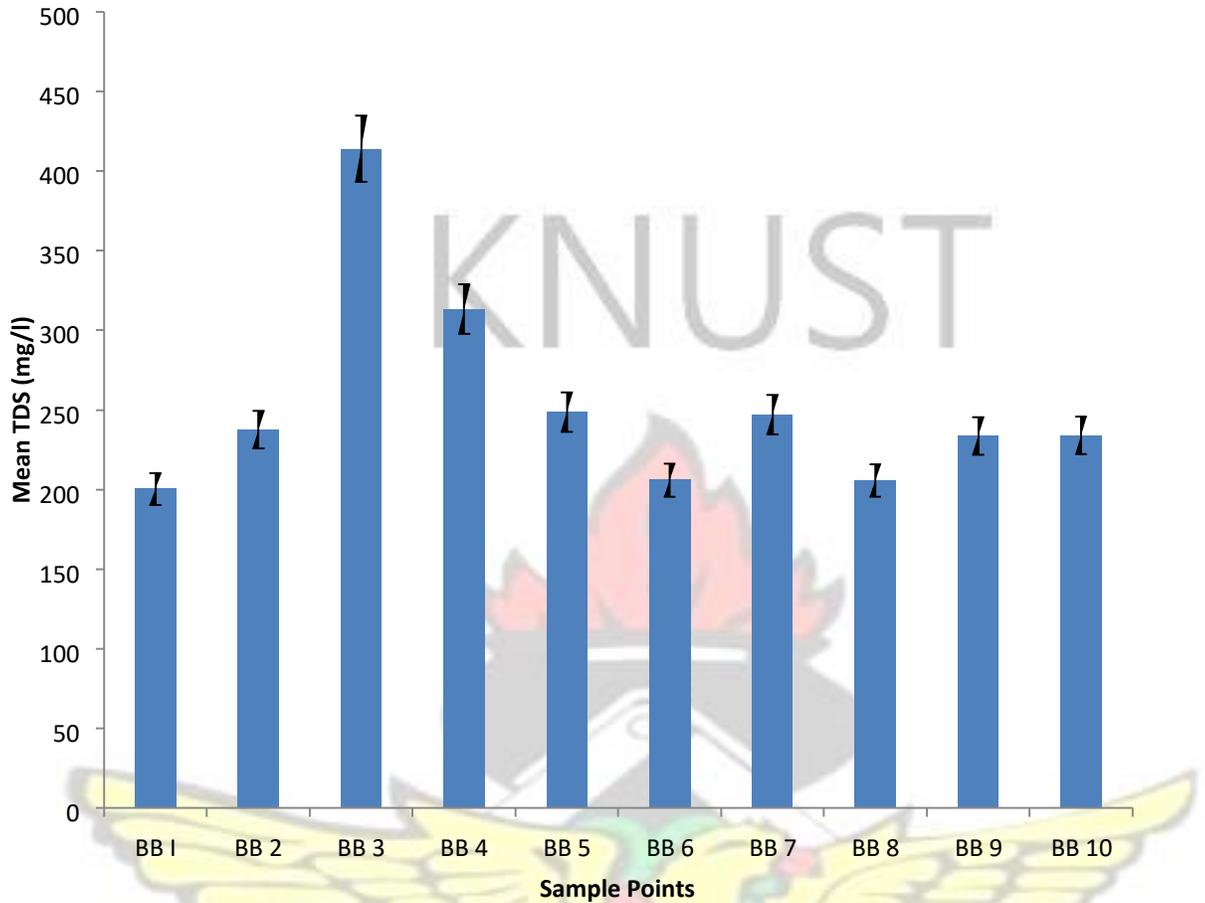


Fig 4.3 Total Dissolved Solids in the water samples.

The temperature of water bodies differ from point to point depending on the ambient temperature in the area. The lowest temperature recorded in this study were very close, the highest of 26.8 °C was recorded at six (6) points and the remaining four (4) points recorded temperatures of 26.7 °C (Figure 4.4). The difference in the temperature readings was not significant ($p = 0.678$).

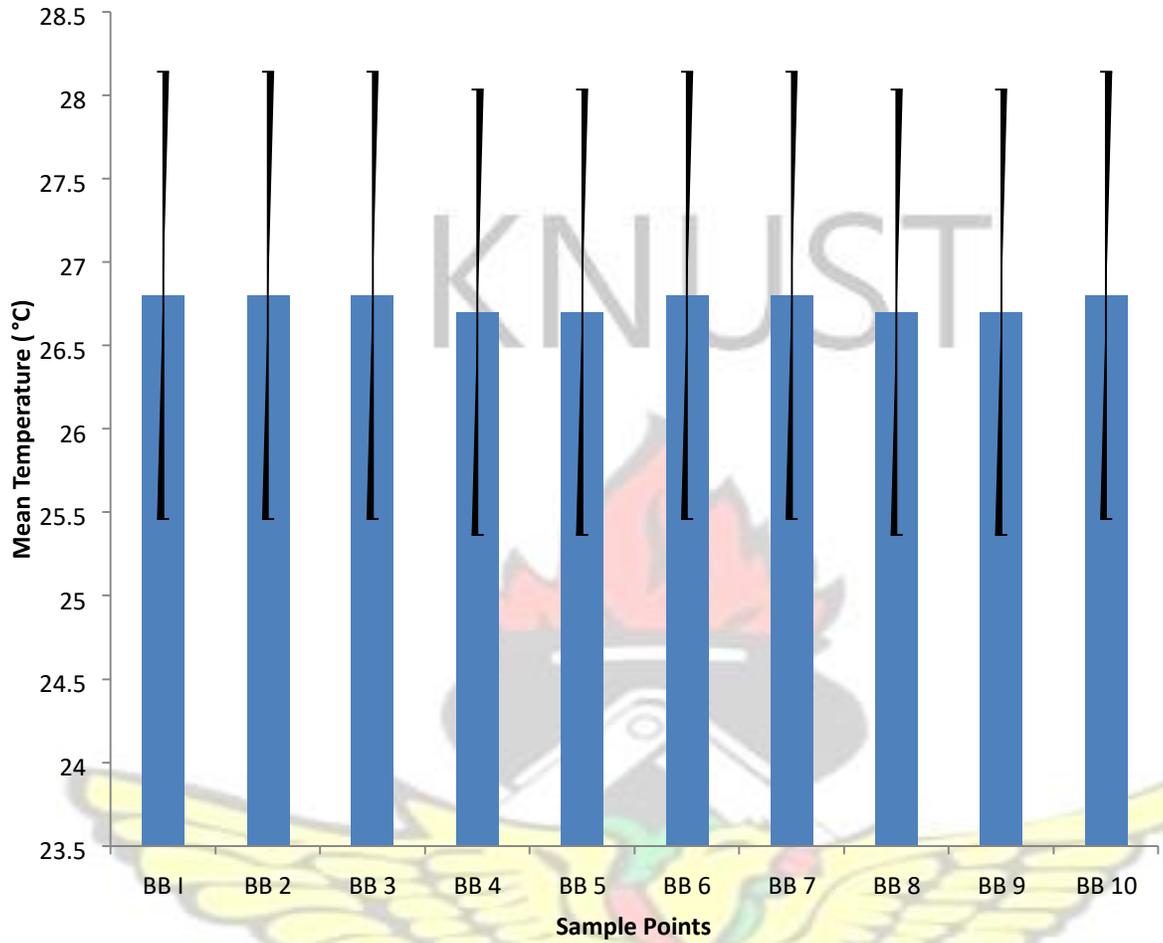


Fig. 4.4 Mean Temperature of the water samples

Dissolved oxygen as an essential component of water quality had mean values ranging from 1.32 mg/l at BB10 to 7.17 mg/l at BB5 (Figure 4.5). The difference in the D.O values were statistically significant ($p = < 0.0001$).

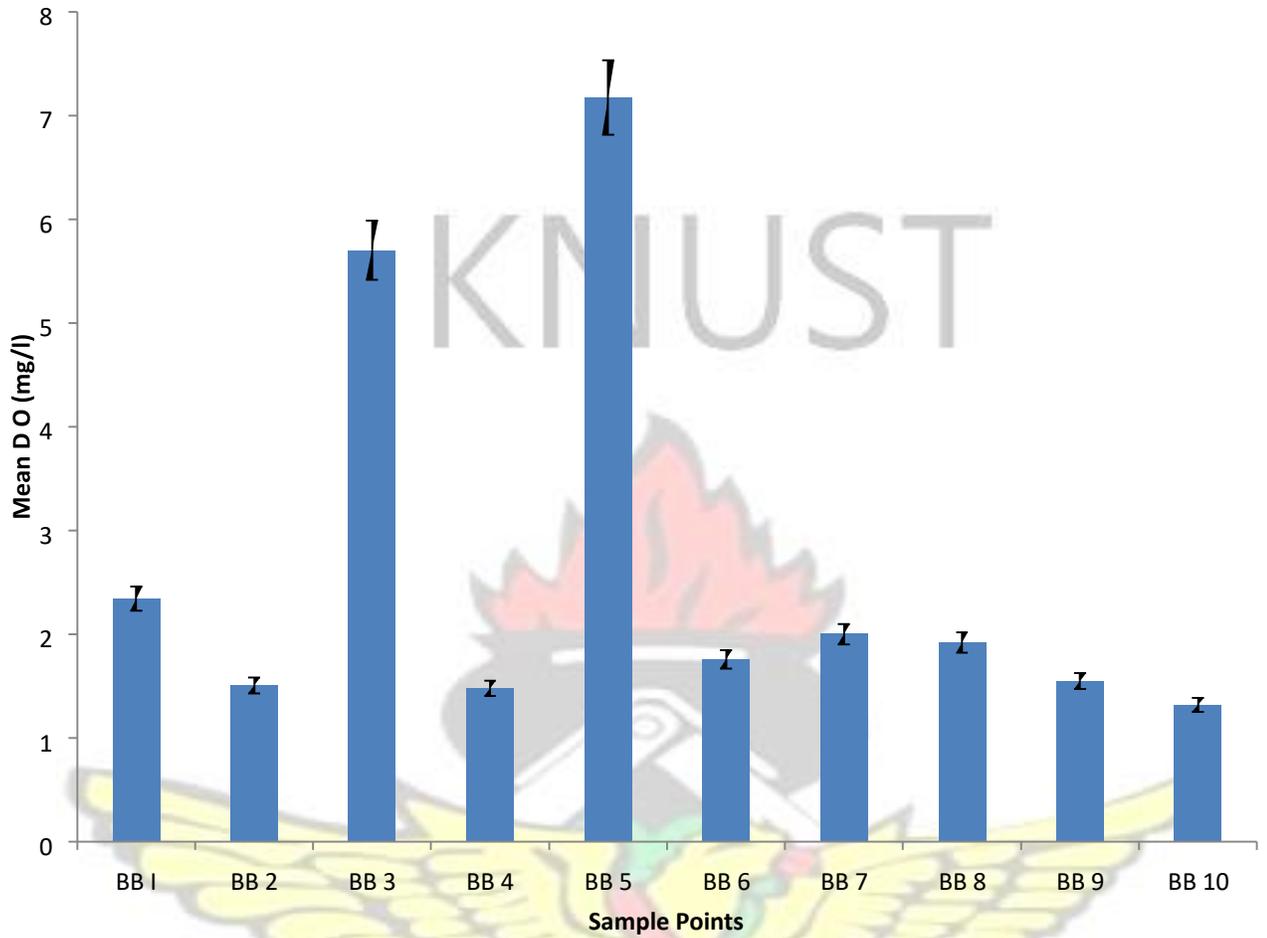


Fig. 4.5 Mean of Dissolved Oxygen in the water samples

Water hardness determines some of the uses of the water body. BB10 recorded the lowest mean value of hardness 42 mg CaCO₃/l and the highest of 217 mg CaCO₃/l was recorded at BB5 (Figure 4.6). This increase in the values of hardness recorded was statistically significant ($p < 0.0001$).

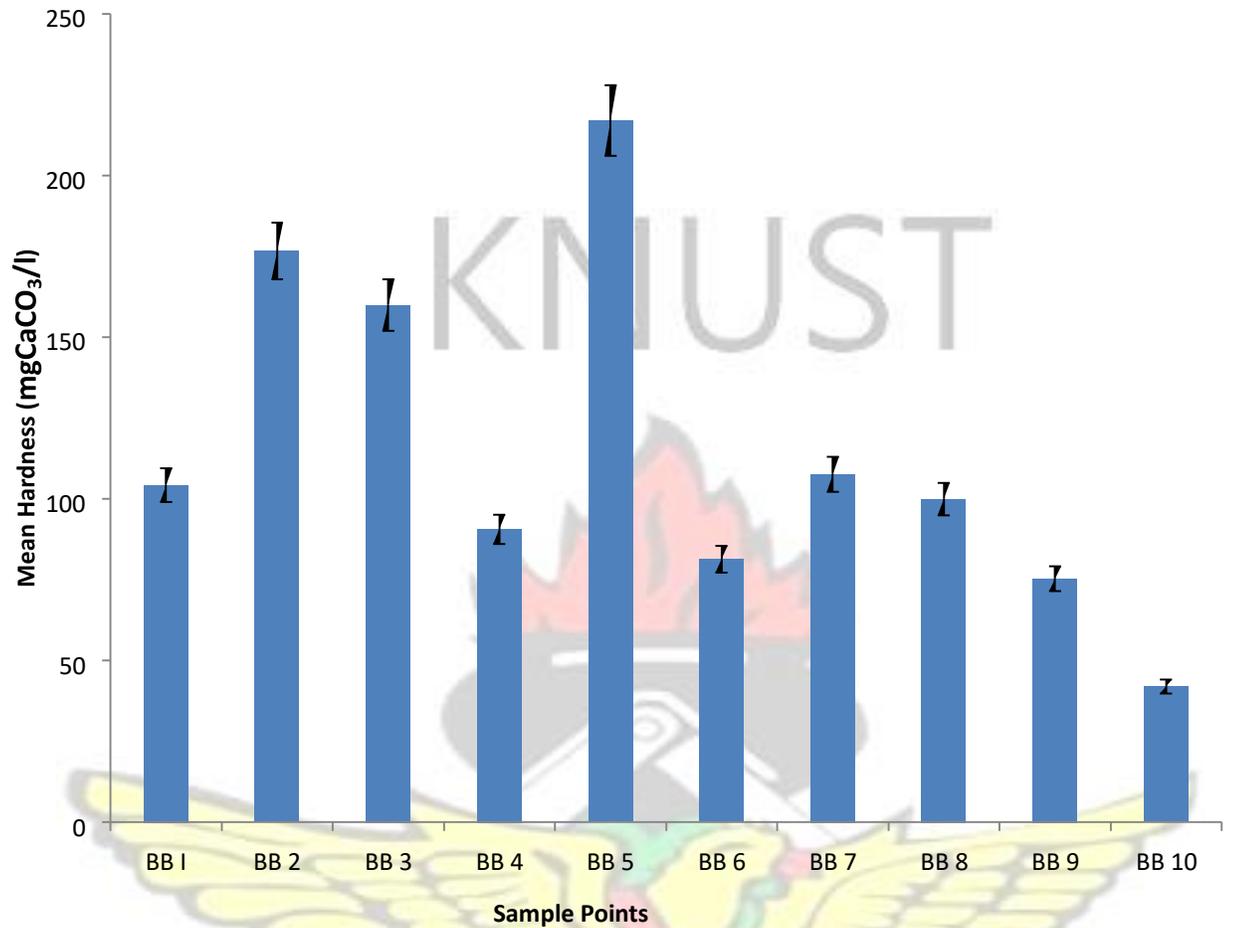


Fig. 4.6 Hardness of the water samples

4.1 Seasonality of the physicochemical quality of the water samples

The readings of pH varied slightly across the months, increasing steadily from March (5.62) to July (5.72) however statistically the variation was not significant ($p = 0.1431$) (Fig. 4.7a)

5.8

5.75

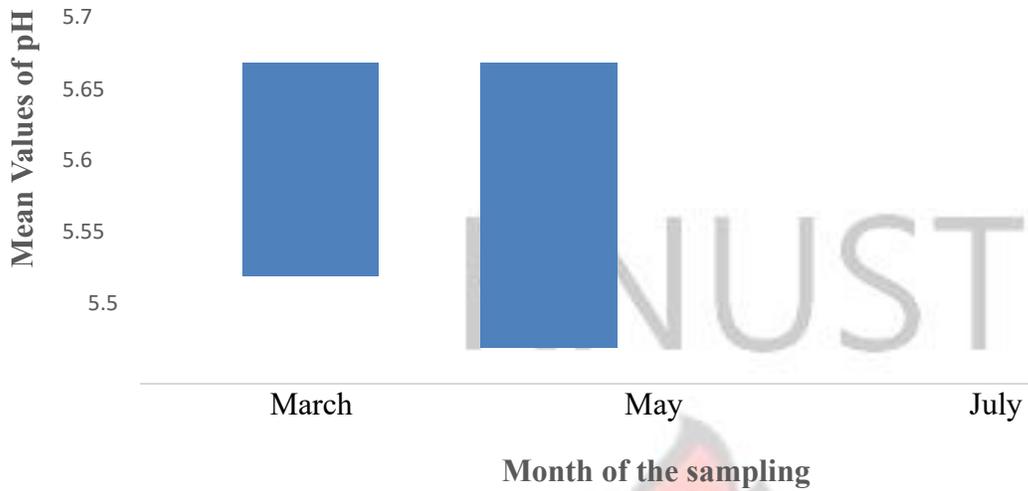


Fig. 4.7a Variation in the pH three months of sampling

Dissolved oxygen readings too varied, although marginally, from March (2.69 mg/l) to July (2.70 mg/l). The month of May saw a slight dip in the mean values of D.O (2.64 mg/l) (Figure 4.7b). Just as was the case for pH the difference in D.O values across the months was not statistically different.

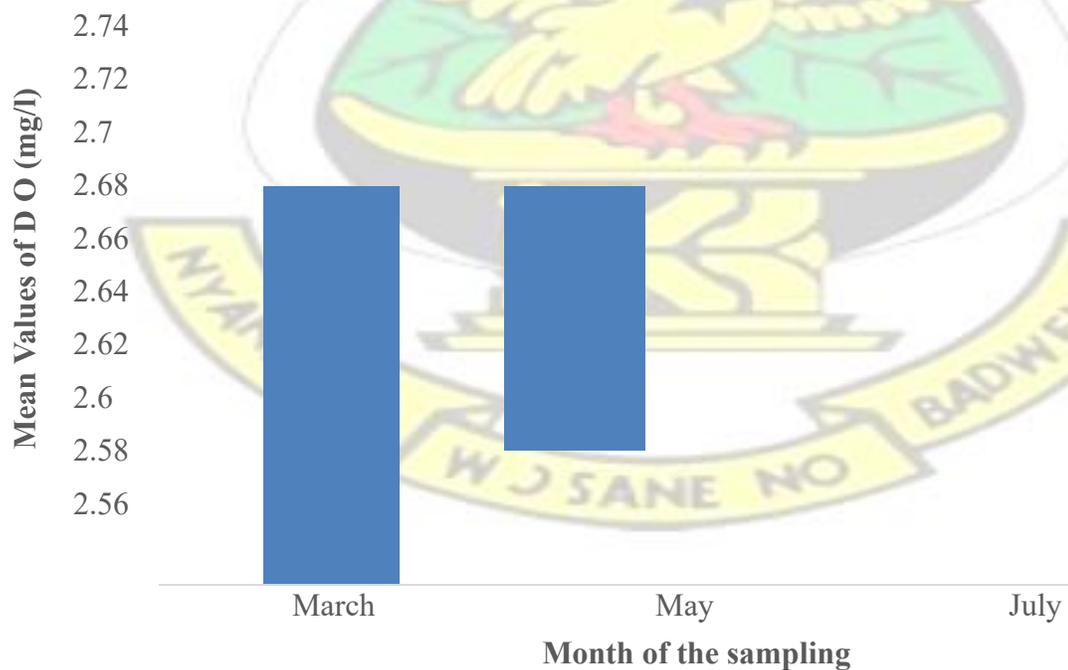


Fig. 4.7b Variation in the D.O three months of sampling

Electrical conductivity varied from one month to the other. There was an increase in the readings from March (514 $\mu\text{s}/\text{cm}$) to May (520 $\mu\text{s}/\text{cm}$). However, the month of July recorded the lowest mean value of 510 $\mu\text{s}/\text{cm}$ (Figure 4.8). This difference in conductivity of the water samples was not significant statistically ($p = 0.7005$)

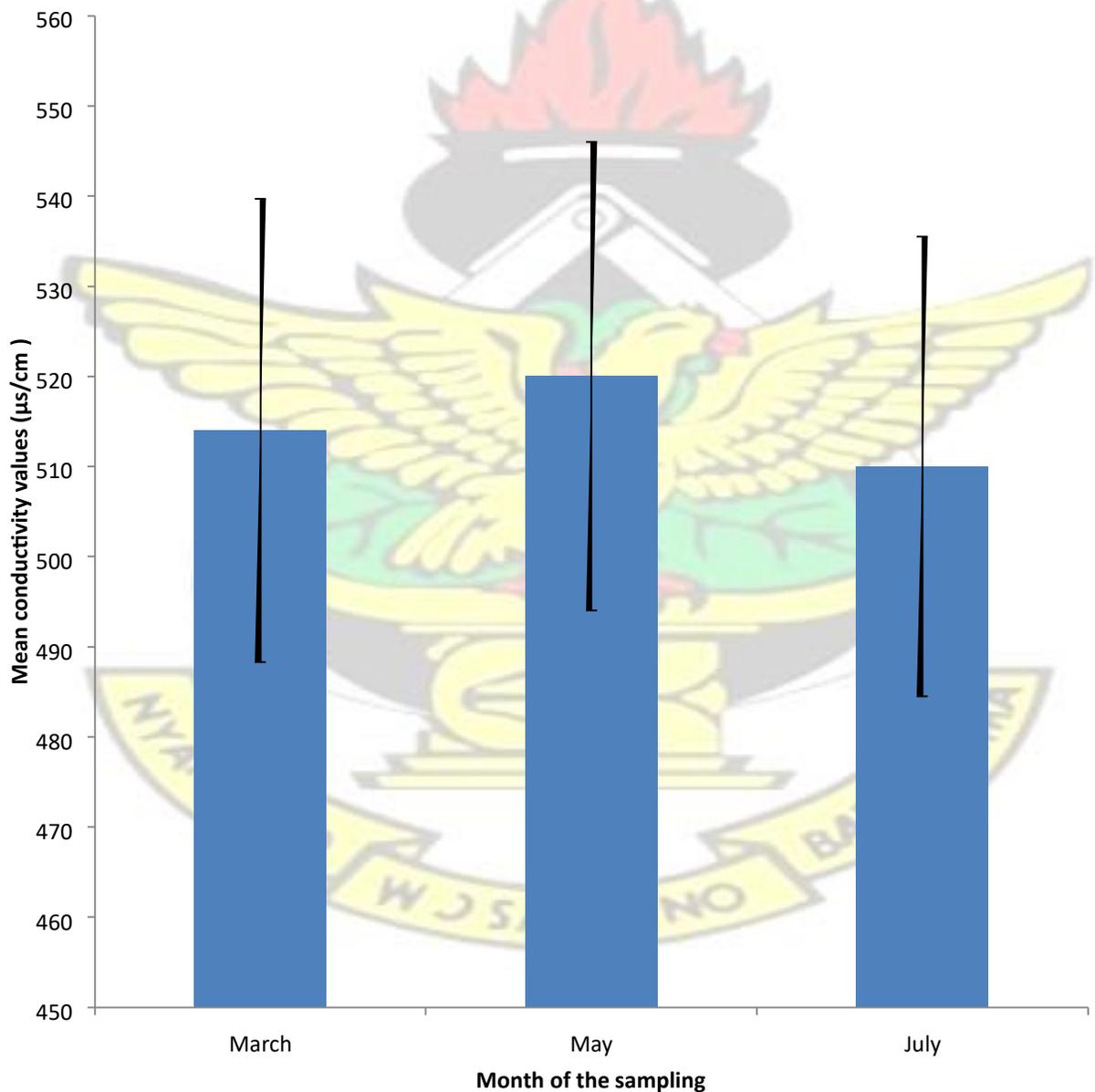


Fig. 4.8 Variation in the conductivity readings of the samples.

The mean values of TDS showed a trend similar to that recorded for conductivity (Fig. 4.9a). The month of March recorded a mean value of 254 mg/l, this rose to 256 mg/l in May and then dropped to 252.1 mg/l in July which was the lowest mean recorded. This fluctuation in the values was however not significant statistically ($p = 0.9788$).

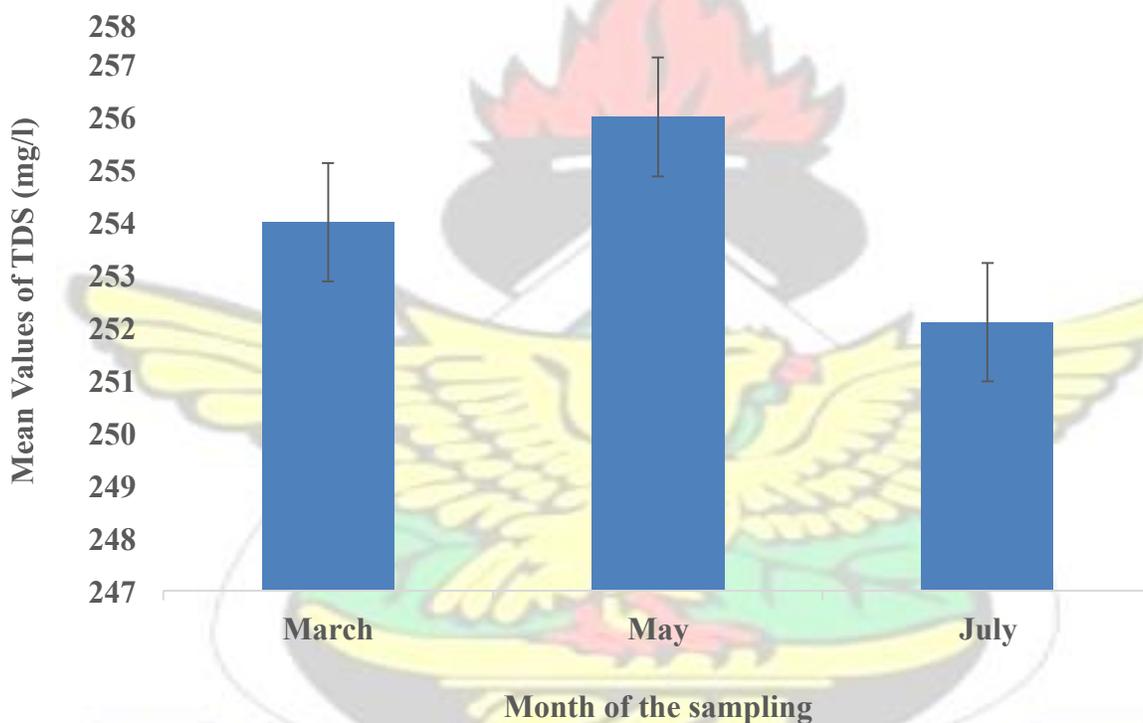


Fig. 4.9a Variation in the Total Dissolved Solids three months of sampling

The hardness level of the water however saw a steady rise from 109.4 mg CaCO₃/l in March to 122.4 mg CaCO₃/l in July (Figure 4.9b). There was a significant difference between these values recorded during the period of the study ($p = 0.0102$).

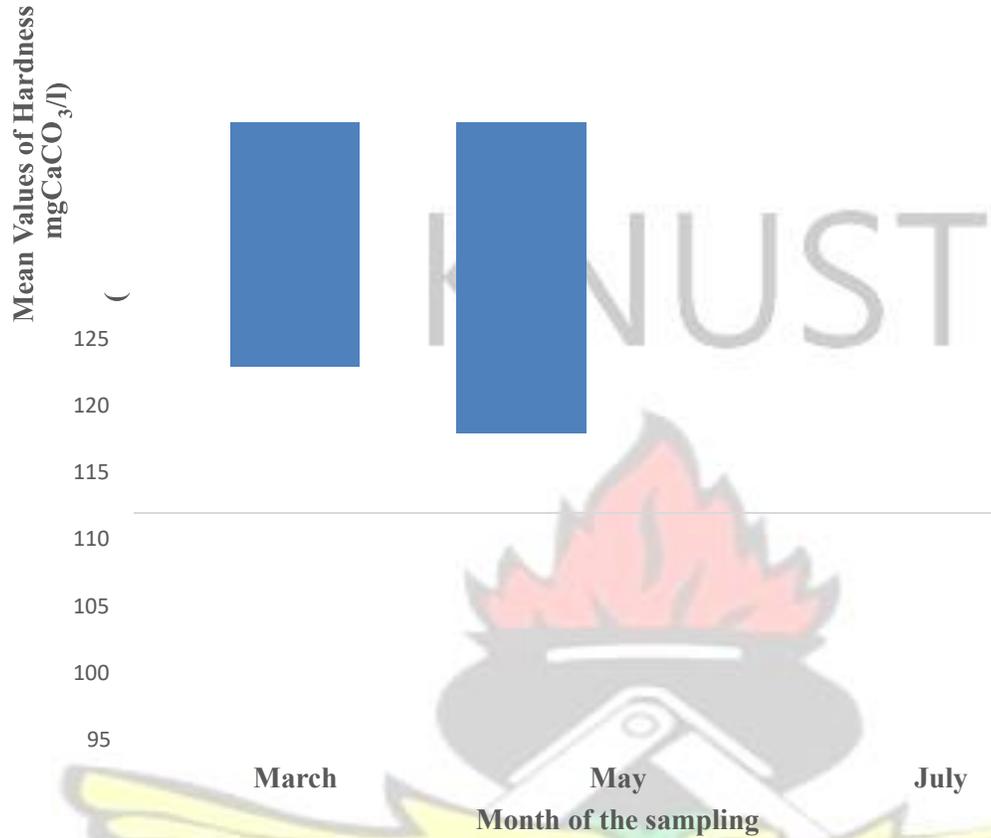


Fig. 4.9b Variation in the Hardness three months of sampling

The mean temperature during this study did not differ from month to month as was the case with the other parameters determined. A mean value of 26.76 °C was recorded across all the months (Figure 4.10), and statistically there was no difference between the temperature readings ($p = 1.00$)

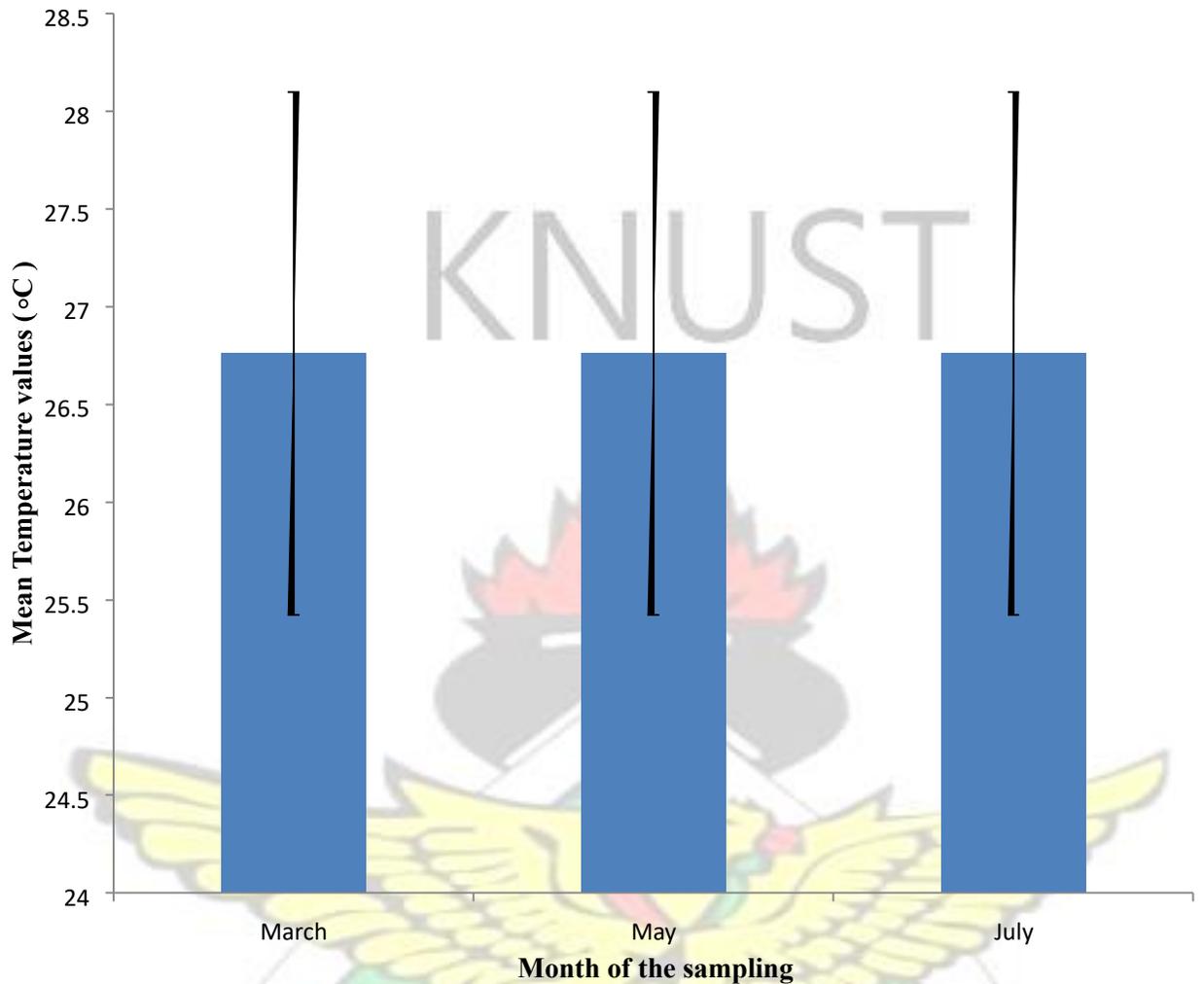


Fig. 4.10 Variation of the temperature readings for the whole study area.

4.3 Heavy metal levels in the water samples

The concentration of Zinc in the water samples varied from one point to the other, the highest mean value of 0.044 mg/l was recorded at BB10 while BB8 recorded the lowest of 0.0002 mg/l (Figure 4.11). These differences in the concentration of Zinc between the samples were significant statistically ($p = 0.0001$). Fig. 4.11 also shows the Concentration of Zinc at sampling points

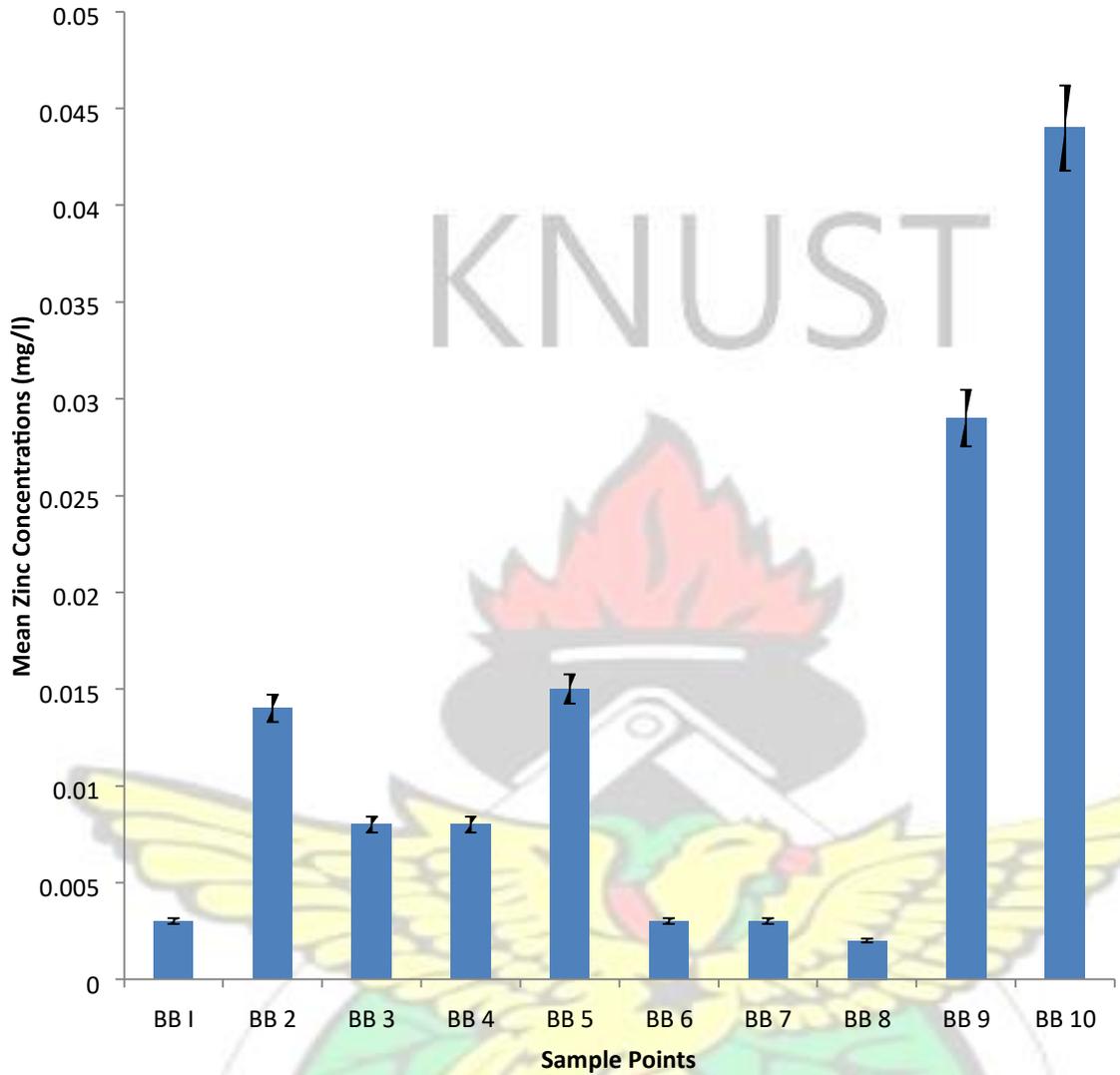


Fig. 4.11 Mean Zinc concentration in the water samples

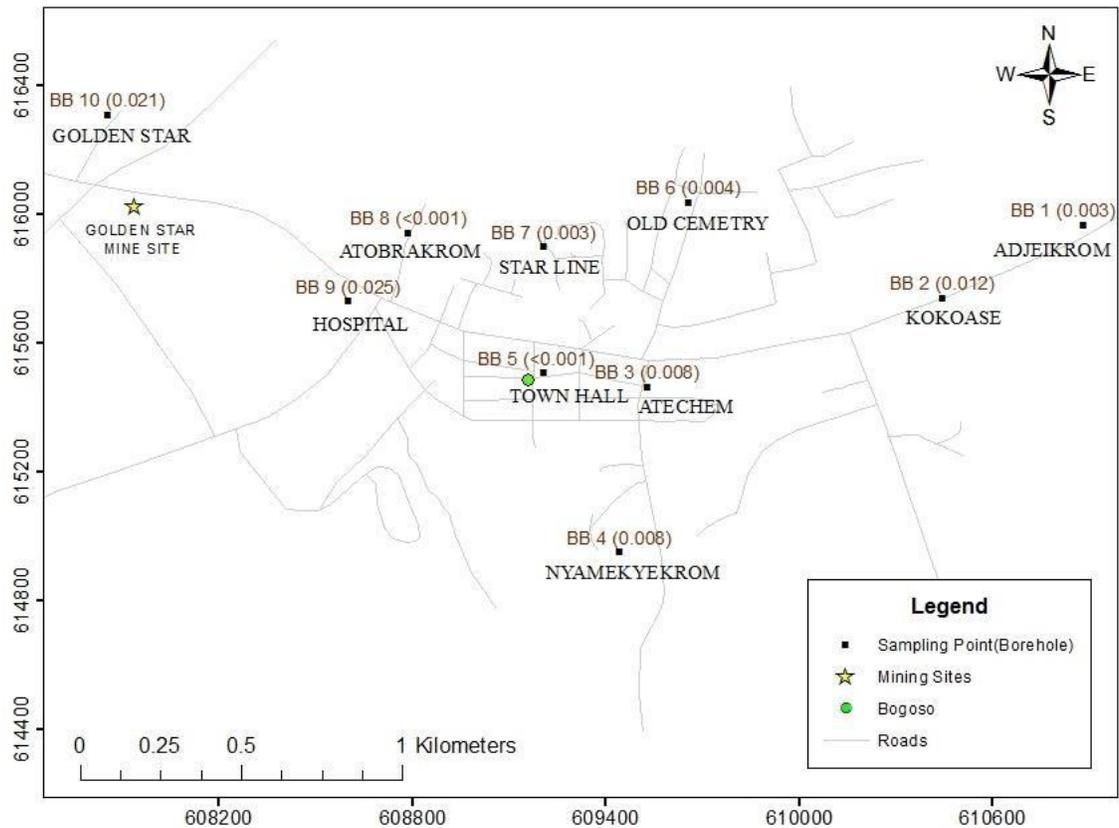


Fig. 4.11A. Concentration of Zinc mg/l at sampling points

Copper concentrations also varied across the sampling points. The highest mean value (0.066 mg/l) was recorded at BB9 and the lowest (0.014mg/l) at BB3 (Figure 4.12). This variation in the concentrations of the copper was significant ($p = 0.0003$). Fig. 4.12A shows the Concentration of Copper at sampling points

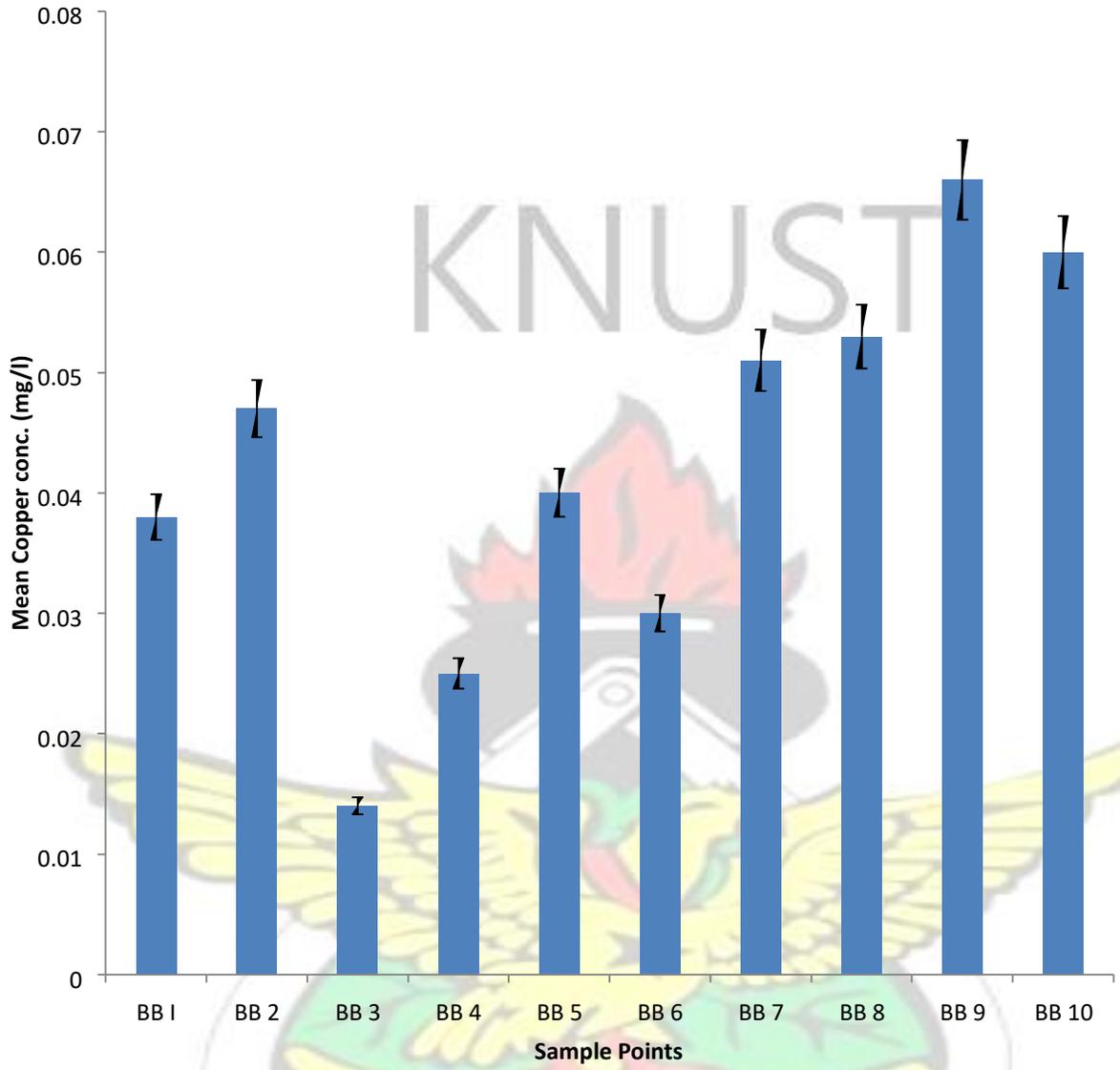


Fig 4.12 Mean Copper concentration levels in the water samples.

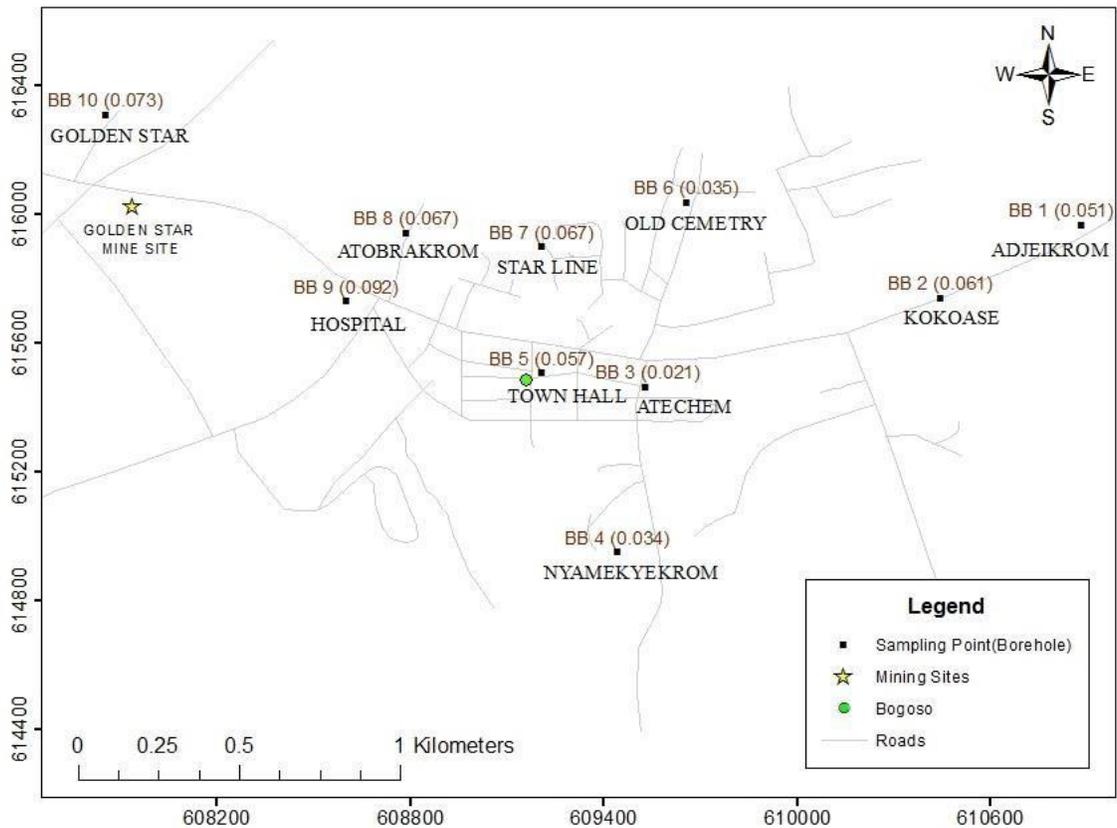


Fig. 4.12A. Concentration of Copper mg/l at sampling points

BB10 again recorded the highest mean concentration (0.377 mg/l) of manganese, with the lowest of 0.079 mg/l recorded at BB8 (Figure 4.13). This variation in the concentration of Manganese was significant ($p = < 0.0001$). Fig. 4.13A also shows the Concentration of Manganese at sampling points.

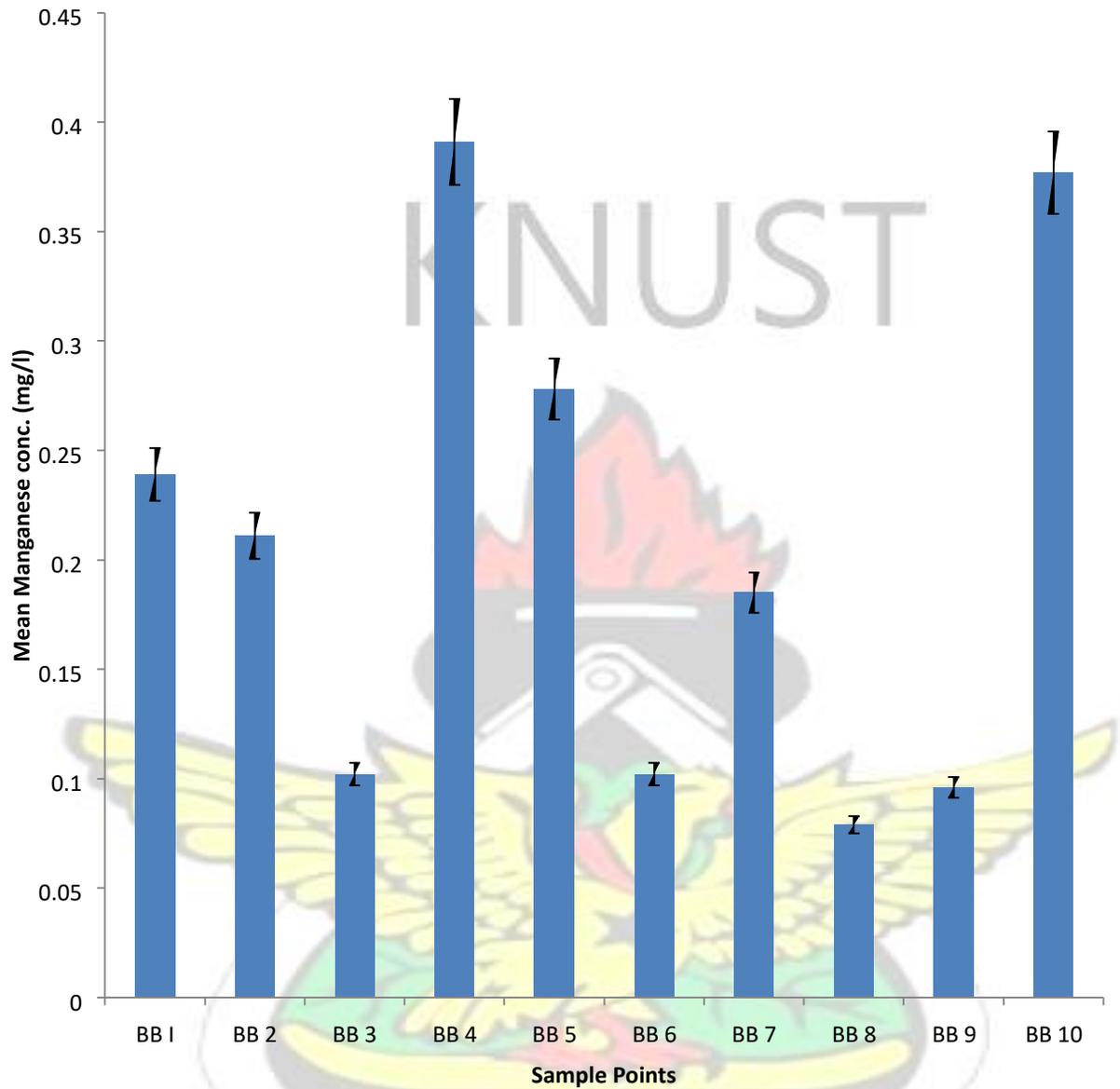


Fig. 4.13 Mean Manganese concentration in the water sample

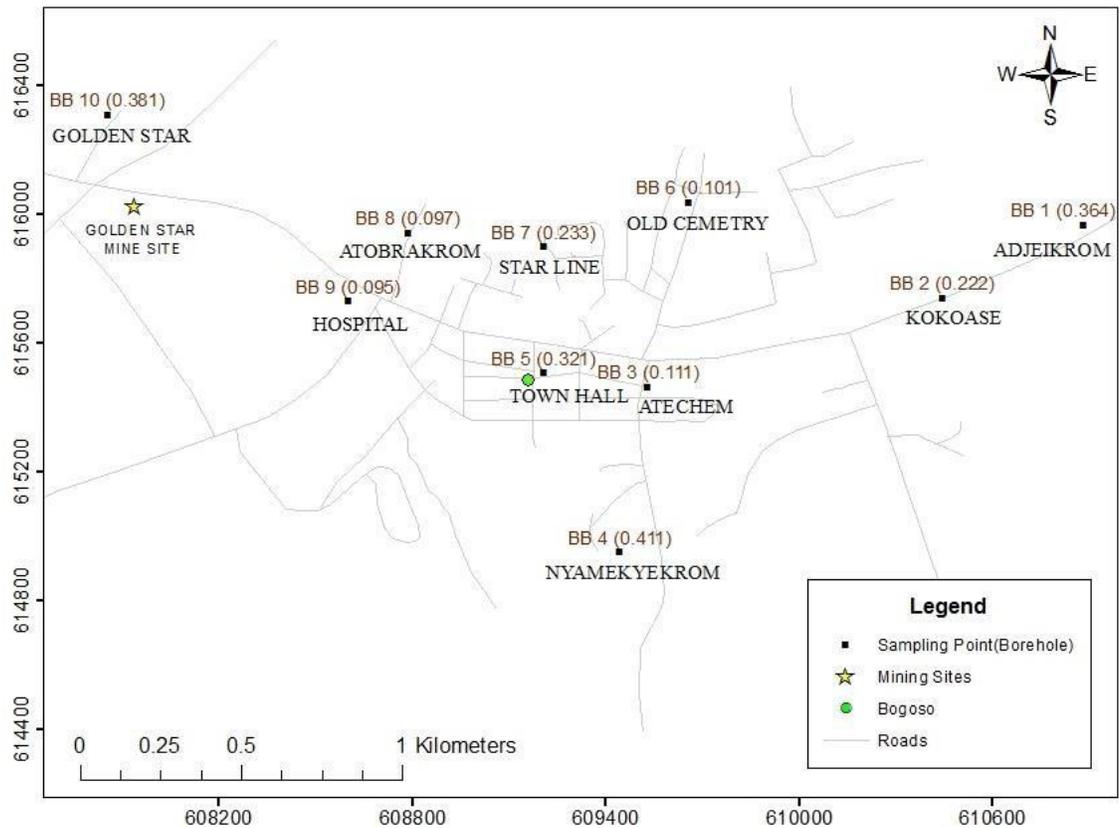


Fig. 4.13A. Concentration of Manganese mg/l at sampling points

The concentration of Iron in the water samples also recorded varying mean values with the highest (1.285 mg/l) at BB1 and the lowest of 0.016 mg/l at BB5 (Figure 4.14). Statistically this difference in the values was significant ($p = < 0.0001$). Fig. 4.14A also shows the Concentration of Iron at sampling points.

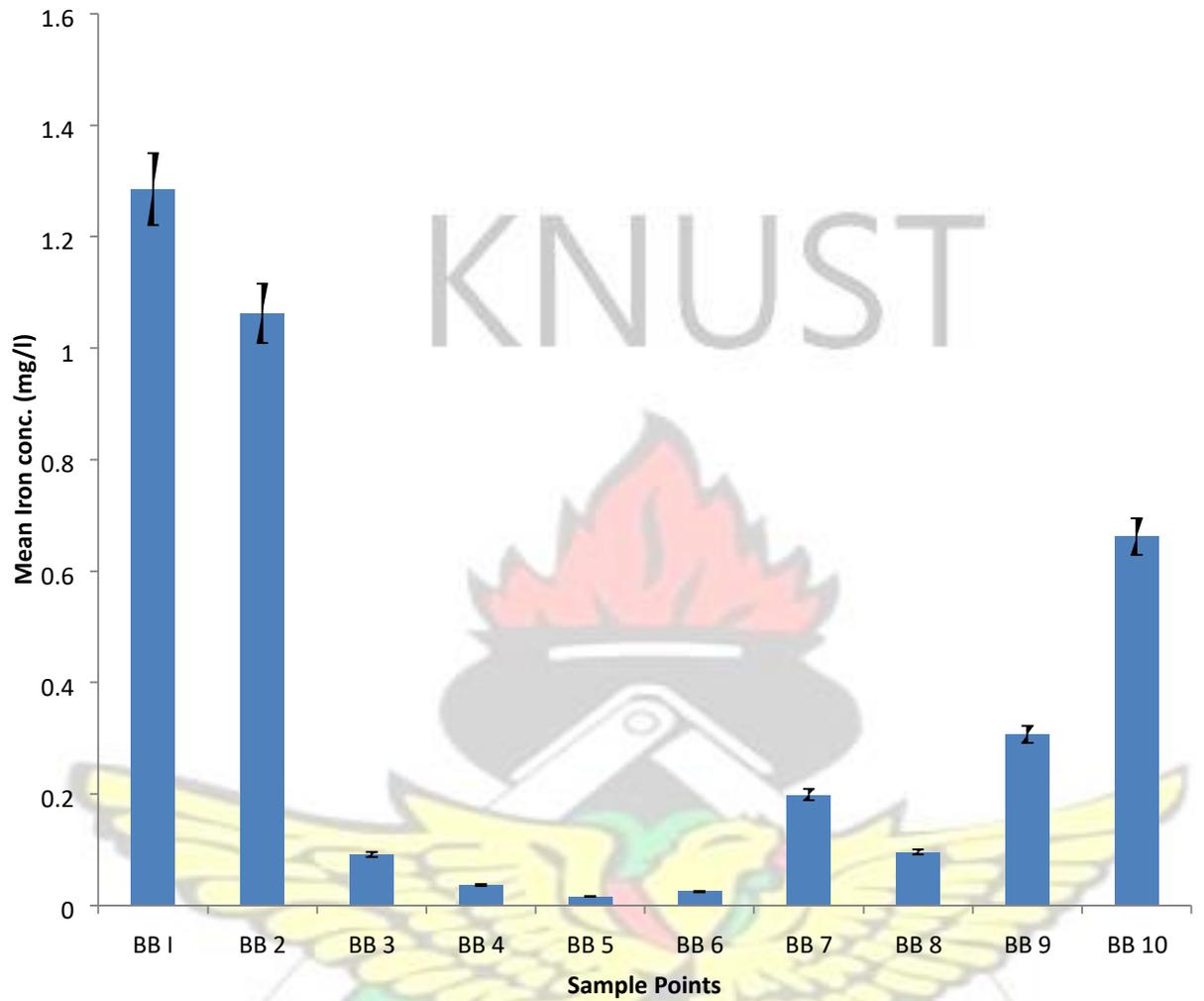


Fig. 4.14 Mean Iron concentration levels in the water samples.

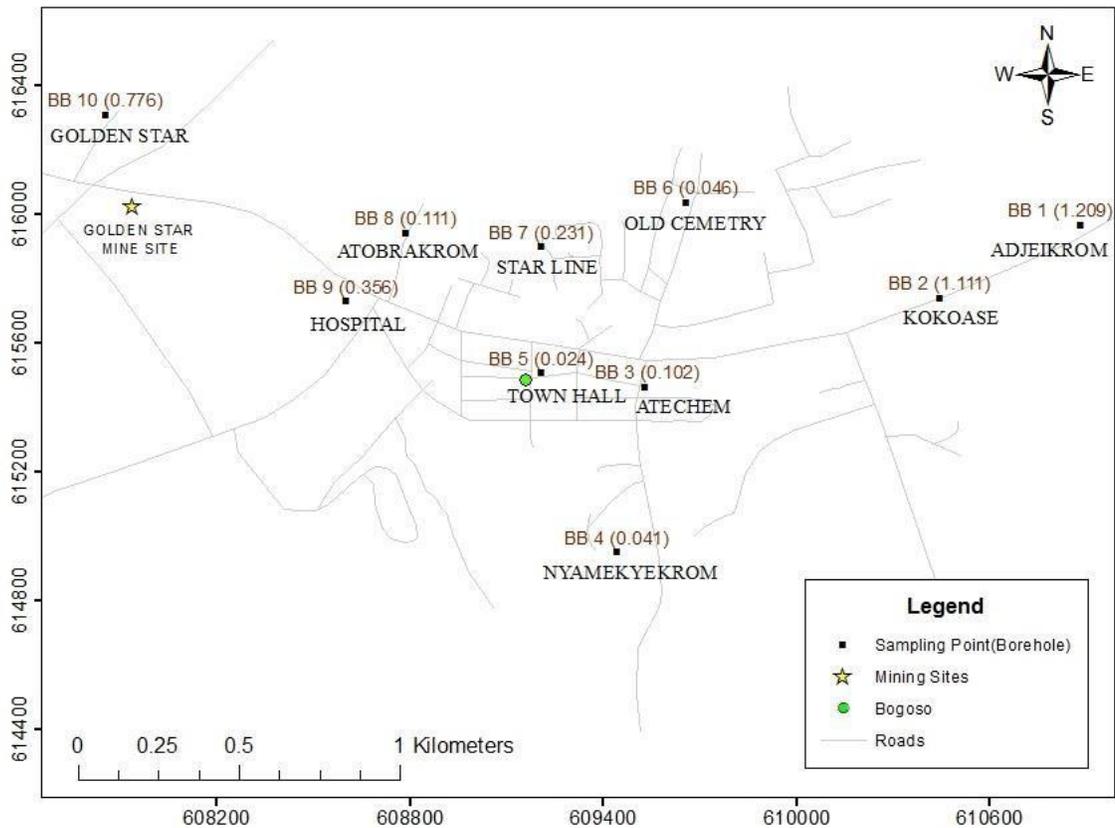


Fig. 4.14A. Concentration of Iron mg/l at sampling points

Arsenic concentrations also differed just as was the case for the other heavy metals. The highest mean value (0.006 mg/l) was recorded at BB2 and the lowest mean value of 0.001 mg/l was recorded at BB6 (Figure 4.15). This difference in the values was significant statistically ($p < 0.0001$). Fig. 4.15A also shows the Concentration of Arsenic at sampling points.

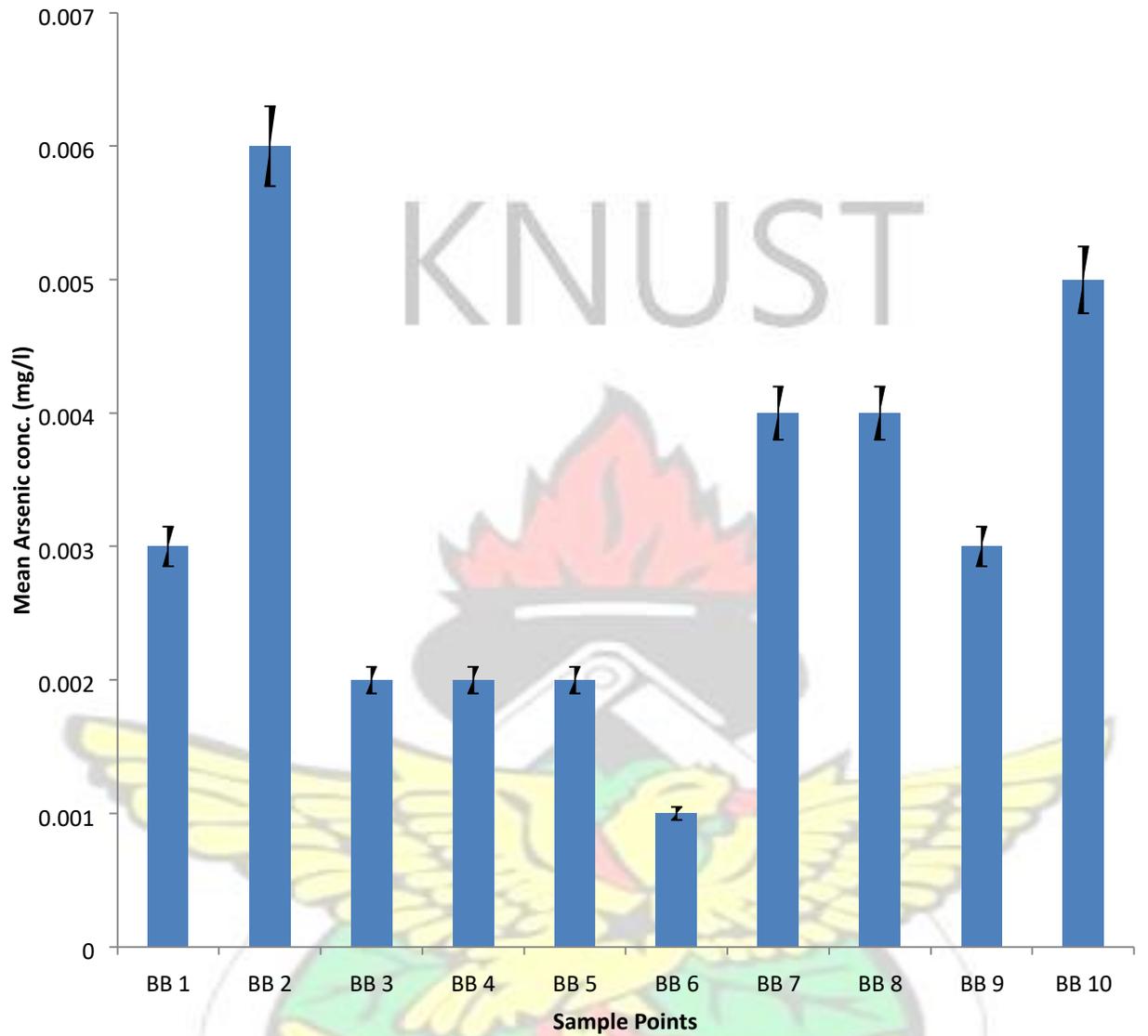


Fig. 4.15 Mean Arsenic concentration levels in the water samples.

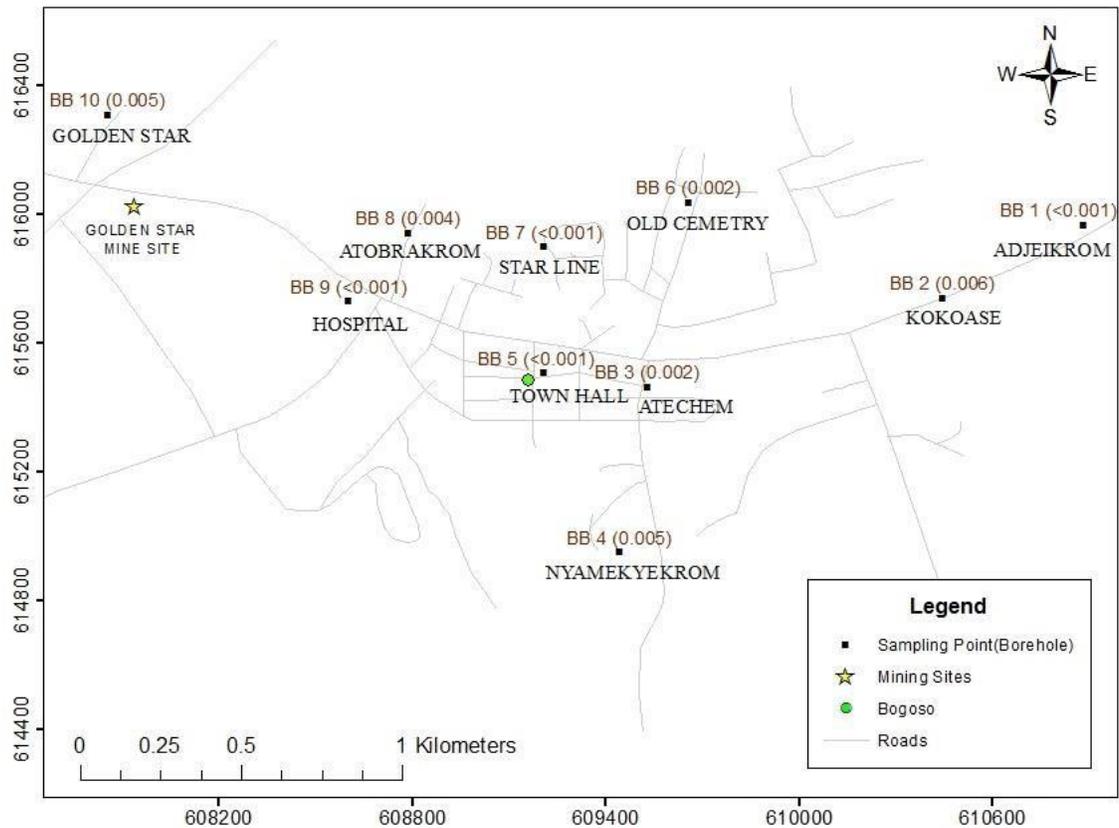


Fig. 4.15A. Concentration of Arsenic mg/l at sampling points

4.4 Seasonal variation in the Heavy metal levels of the water samples

The variation in the concentrations of the heavy metals during the period of this study indicated that, the concentration of Copper increased steadily from March (0.022 mg/l) to July (0.056 mg/l). This steady increase from one month to the other was significant statistically ($p < 0.0001$). However, the concentration of Zinc rather saw a steady decline from 0.018 mg/l in March to 0.009 mg/l in July (Figure 4.16). This decline in concentration was however not significant ($p = 0.0908$).

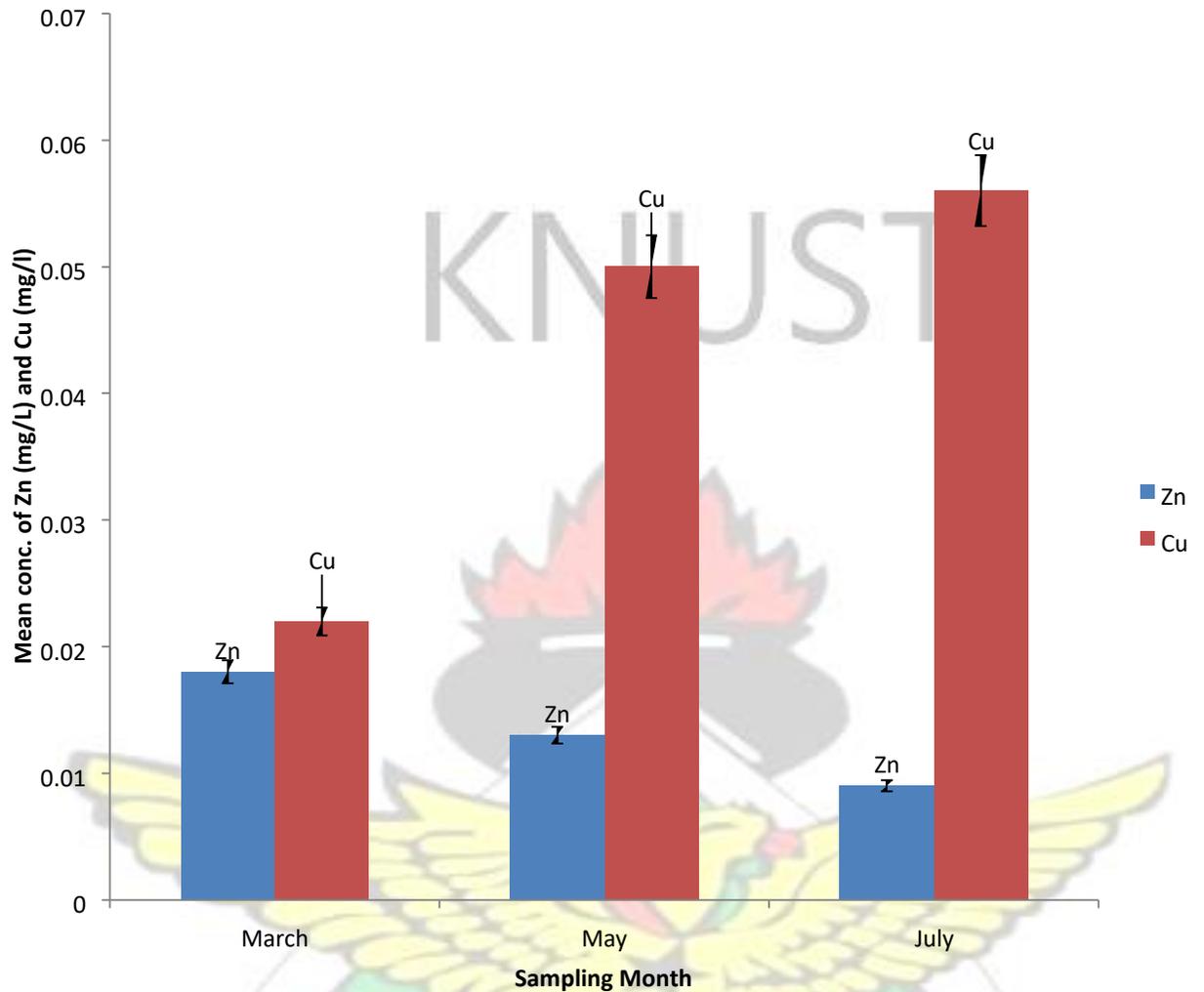


Fig. 4.16 Seasonal variation in the concentration of Zinc and Copper in the water samples

Manganese concentration during the period of study saw a rise from a low value of 0.168 mg/l in March to a high value of 0.234 mg/l in July, and this increase in the concentrations was significant ($p = 0.0482$).

Iron concentration also increased from 0.367 mg/l in March to 0.400 mg/l in July. (Figure 4.17). This difference was not significant statistically ($p = 0.2014$).

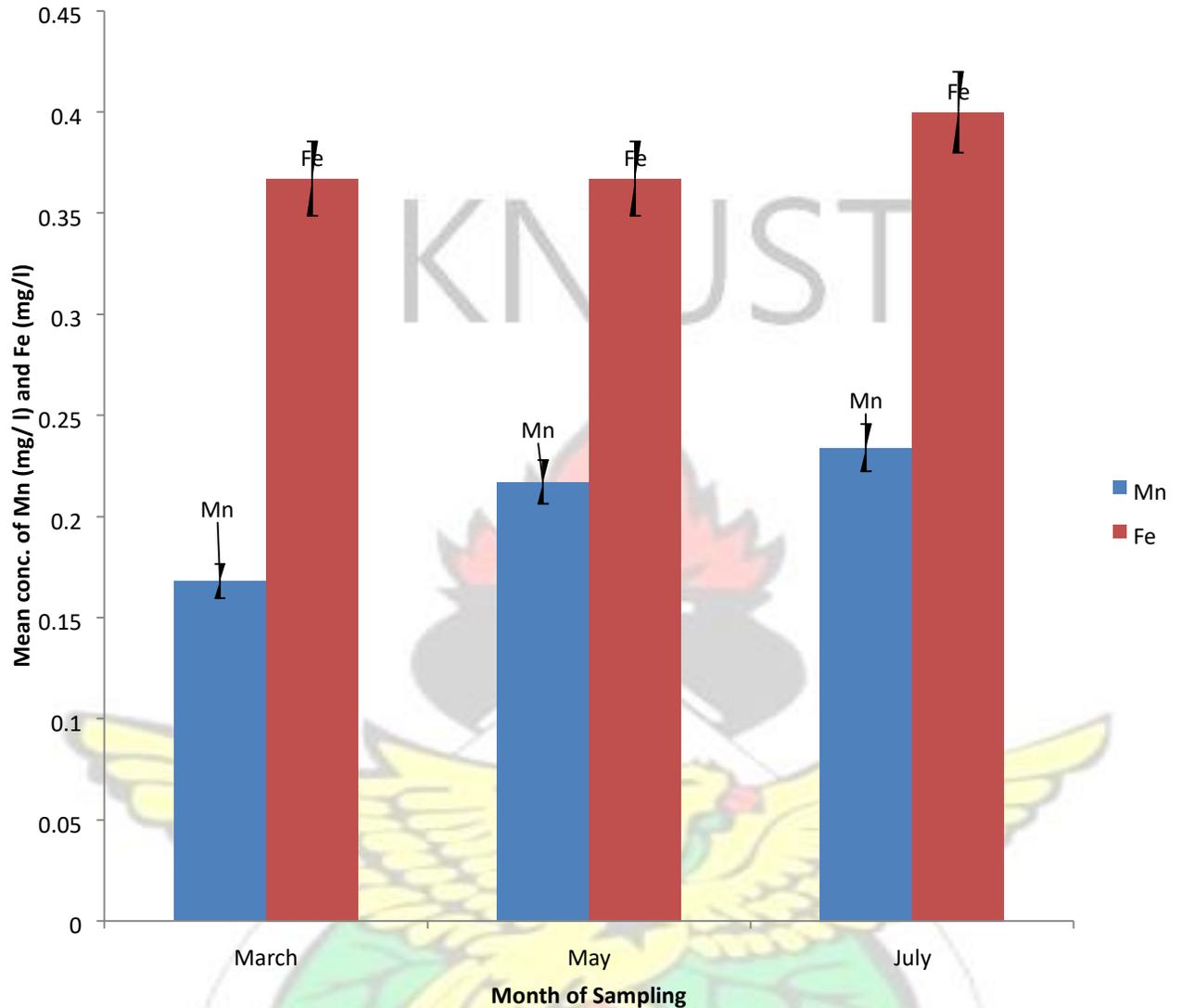


Fig. 4.17 Mean Manganese and Iron contamination of the water samples

Arsenic concentrations saw marginal change, decreasing from 0.004 mg/l in March to 0.003 mg/l in July. During the month of May there was no change from the mean values recorded in March (Figure 4.18). This slight downward change in the concentration was not significant ($p = 0.1649$).

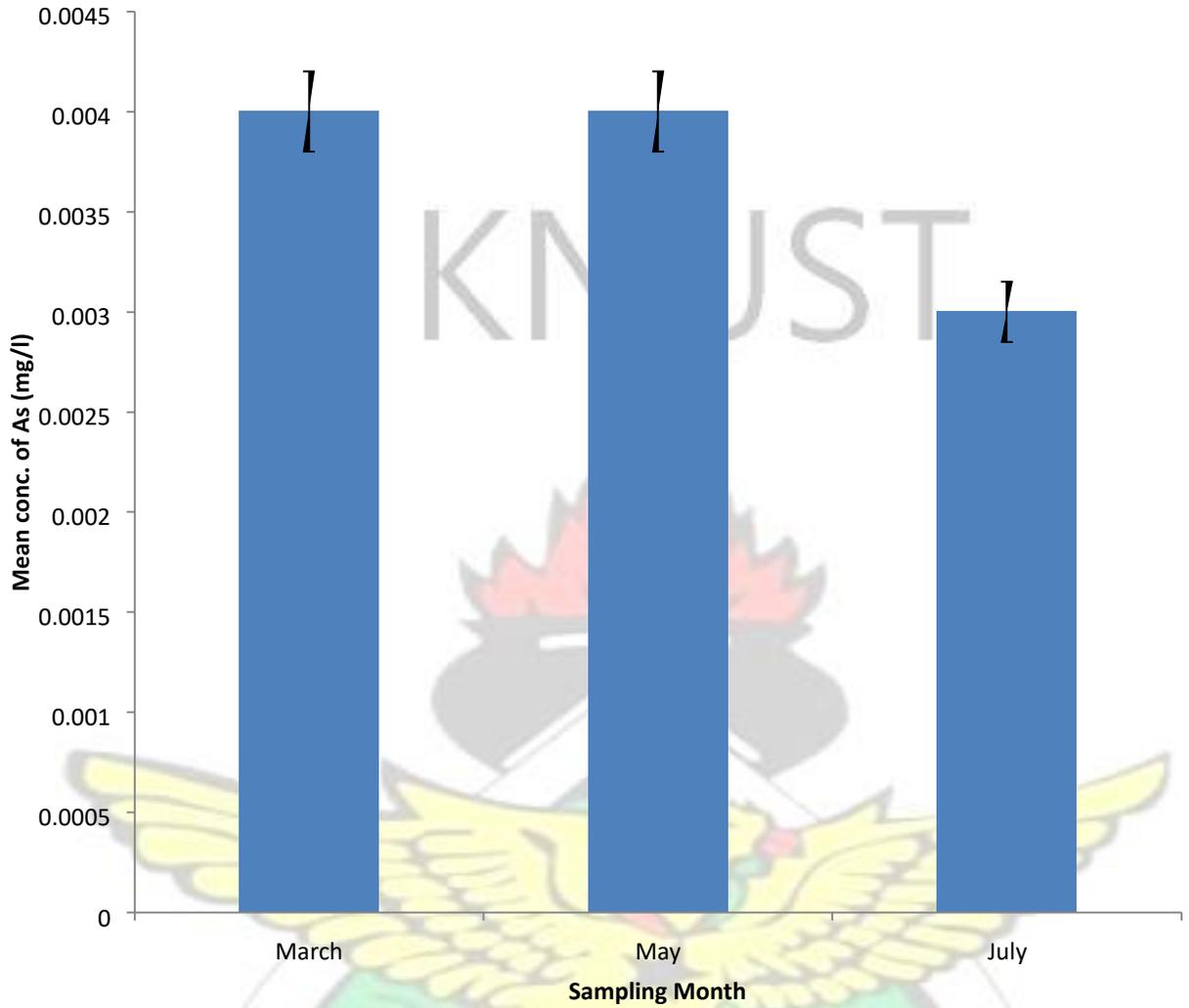


Fig. 4.18 Seasonal variation in the Arsenic concentration in the water samples

Cadmium and Lead concentrations did not differ from one sampling point to the other. Changes in date/month of sampling did not also affect the values recorded for the study, as shown in the tables below (Tables 4.1 and 4.2).

Table 4.1 Cadmium concentrations in the water samples

Sample ID	March	May	July
BB 1	<0.005	<0.005	<0.005

BB 2	<0.005	<0.005	<0.005
BB 3	<0.005	<0.005	<0.005
BB 4	<0.005	<0.005	<0.005
BB 5	<0.005	<0.005	<0.005
BB 6	<0.005	<0.005	<0.005
BB 7	<0.005	<0.005	<0.005
BB 8	<0.005	<0.005	<0.005
BB 9	<0.005	<0.005	<0.005
BB 10	<0.005	<0.005	<0.005

Table 4.2 Lead Concentrations in the water samples

Sample ID	March	May	July
BB 1	<0.010	<0.010	<0.010
BB 2	<0.010	<0.010	<0.010
BB 3	<0.010	<0.010	<0.010
BB 4	<0.010	<0.010	<0.010
BB 5	<0.010	<0.010	<0.010
BB 6	<0.010	<0.010	<0.010
BB 7	<0.010	<0.010	<0.010
BB 8	<0.010	<0.010	<0.010
BB 9	<0.010	<0.010	<0.010
BB 10	<0.010	<0.010	<0.010

CHAPTER FIVE

DISCUSSION

5.1 PHYSICOCHEMICAL QUALITY OF THE WATER SAMPLES

The pH of a water sample is an essential determiner of the acidity of the water. The WHO (2006) guideline for drinking water is between 6.5 and 8.5. However, the results obtained in this study were all lower (5.0 to 6.32) than the lower limit of the set standard, which indicates that the water samples were slightly acidic. The pH of the water may be attributed to the natural geology of the area, pollution from point and non-point sources and most especially from mining activities in the area which could contribute to acid drainage, considerably reducing the pH of the water. The level of pH obtained was significant from one point to the other indicating that the conditions that contribute to the pH differed for each point. These results differed from that obtained by Nartey *et al.* (2011), where the reported results ranged from 7.1 to 8.5 from studies conducted in Bibiani-Anwiaso-Bekwai District, a typical mining community as well as results obtained by Osafo (2011) from studies in the Birim river in the East Akim Municipality. Rainfall has an effect on the water quality of an area due to runoffs and washing of adjacent fields. In this study the samples were taken during the months of March to July with varying degrees of pH values. However, this difference was not significant. Washing and runoff from surrounding fields as mentioned earlier could wash ions into the water bodies, both surface and underground.

Water has the ability to conduct electricity which is also a factor in determining water quality. The WHO has a standard of 300 $\mu\text{S}/\text{cm}$. In this study the EC values ranged from 393.33 $\mu\text{S}/\text{cm}$ to 863.33 $\mu\text{S}/\text{cm}$ indicating a higher EC value than the recommended standard. The values were high in all the borehole water samples. Based on this electrical

conductivity, the borehole water sources are not suitable for domestic use in terms of EC. When EC is high it has health implications such as salt disturbance and water balance. It also has severe effect on heart patients and others with high blood pressure (Fatoki and Awofolu, 2003). This also support the record by WAPDA (1993) and Koehn *et al.* (2002). There was no marked variation in the electrical conductivity values recorded for the months of March to July, where there was a slight increase from March to May and then a decrease in the month of July (Figure 4.8). The magnitude of variation was not significant.

Dissolved solids content in water is another component in determining water quality. The TDS content ranged from 200.33 mg/l to 414 mg/l which is far below the WHO set standard of 1000 mg/l. This indicates that the amount of dissolved solids in the water are far below the standard. Therefore, wholesome for human consumption as far as TDS is concerned.

The level of TDS recorded in the current study agrees to the studies conducted in Karachi (Chandio *et al.*, 1998) and Hyderabad city (Jakhrani *et al.*, 2009). As was the case for electrical conductivity above, there was an increase in TDS concentration from March to May and then a marginal drop in July which the difference was statistically not significant. Although there might be an increase in rainfall from March to July this could not affect the TDS concentration of the groundwater probably due to protection of these water sources from surface runoffs as would have been seen in surface water bodies such as rivers and streams.

Water temperature plays an important role in determining the quality of life it could support. The temperature of groundwater is generally equal to the mean air temperature above the land surface. This usually stays within a narrow range all year-round (Norris and Spieker, 1996). Groundwater temperatures in the shallow subsurface are dominantly affected by the solar radiation (Lee *et al.*, 2000). Hence the results obtained in this study for mean

temperature was not surprising as the results obtained (Figure 4.4) were similar to the ambient temperature of the Bogoso environment.

The D.O content of the boreholes within the study area ranged from 1.32 mg/l to 7.17mg/l, indicating that the degree of contamination by organic matter is small. The DO concentration obtained is also enough to categorised the groundwater in the study area as being of good quality. The concentration also indicates that the water has high level of selfpurification. Water which has D.O concentration less than 0.2 mg/l has less selfpurification (WHO, 2003).

The presence of some ions in the water body does not only affect the pH and electrical conductivity but also the hardness of the water body. Calcium and Magnesium mainly determines the hardness. Hard water used in laundry requires the use of a large amount of detergents in addition to several other adverse effects of hard water. The average hardness values recorded in this study ranged from 42 mg CaCO₃/l to 217 mg CaCO₃/l, indicating that BB5 which recorded the highest mean value exceeded the WHO standard of 200 mg CaCO₃/l. Carbonates in water are some of the major contributory factors to hardness of water. Increase in rainfall might lead to dissolution of materials that contain these carbonates thereby increasing the hardness of the water. In this study, the water hardness increased from March (which is in the dry season) to July (in the main rainy season), thereby indicating that the increase in rainfall increased these carbonates in the water. This is so due to the statistical significance of the results obtained for the period of the study.

5.2 HEAVY METAL LEVELS IN THE WATER SAMPLES

Heavy metal concentration in water is essential to determine the role of mining activities on water quality. Metals are essential components of human physiology; however, some are needed in minute quantities. Higher concentrations of these metals can lead to a plethora of health issues. Therefore, it is recommended to consume only minute quantities.

Heavy metals are the common pollutants, which are widely distributed in the environment. These are produced from the weathering of minerals. However, level of these metals in the area has increased in the past decades as a result of human activities (O'Neil, 1993). Heavy metals are a major source of Acid Rock Drainage (ARD) indicators in natural waters due to mining and industrial waste disposal and considered highly toxic to aquatic organisms. The compounds of these elements are non-biodegradable and hence remain suspended or partially dissolved in water columns and get accumulated in many aquatic organisms (Singh *et al.*, 2001). The average range of zinc concentration in the water samples were from 0.0002 mg/l to 0.044 mg/l which is far below the WHO standard of 3.0 mg/ for drinking water. There is therefore, no detrimental effect when the water is used for domestic and other purposes at the level obtained in this study for Zn. Results obtained in this study are similar to reports by Ankomah-Appiah (2011). They are however much lower than the results obtained by Osafo (2011) from surface water in the East Akim Municipality. Sample points BB9 and BB10 recorded the highest mean values, probably because these two sampling points are located close to each other and are down slope. The high concentration could therefore be as a result of contamination from either anthropogenic or natural processes in the area. The difference in the values recorded at the sampling points was significant inferring that the conditions that contribute to the concentration of zinc in the study area differed greatly. Seasonal variation in terms of amount of rainfall affects the

level of runoffs which has the potential to increase the level of contaminants in a water body. However, in this study the increase in rainfall did not increase the concentration of zinc, but there was a marginal reduction in its concentration from March through May to July. This difference was however not significant (p -value= 0.0908).

Copper concentration was also lower than the WHO limit of 2.0 mg/l, as was the case for zinc. Consumption of this water would therefore not cause adverse effect on the health of the consumers. Osafo (2011) reported similar results from studies in the East Akim Municipality. Once again sampling points BB9 and BB10 recorded the highest mean values, suggesting that the proximity of these two sampling points made it easier for them to be influenced by the same conditions leading to similar levels of copper concentrations. This difference in the copper concentrations was significant attesting to the difference in factors that affect the concentration of heavy metals such as copper. Copper can be released into the environment by both natural sources and human activities. These include mining, metal production, wood production and phosphate fertilizer production. Because copper is released both naturally and through human activity, it is very widespread in the environment especially near mines, industrial settings, landfills and waste disposals (Kegley *et al.*, 2009; MDH, 2006). Increase in rainfall as observed in this study affected the concentration of copper in the water samples evident in a slight increase in their concentrations. This increase in the concentrations from March to July was statistically significant. Therefore, an increase in the rainfall would result in an increase in erosion or runoffs contaminating the water affecting the concentrations significantly.

Although Manganese does not play a major role when it comes to heavy metals that affect adversely the health of consumers, it is an important element to monitor due to its indicative

role. Manganese concentrations in this study ranged from 0.079 mg/l to 0.377 mg/l. Significant difference in concentrations were observed. BB4 and BB10 sampling points recording the highest mean concentrations. Natural geological structure of these areas as well as pollution from anthropogenic activities could contribute significantly to the contamination of water bodies with manganese and many other metals, however these concentrations did not exceed the WHO standard for drinking water. Manganese concentration increased from March to July, though this increase was only marginal and not significant

Iron concentration in water is also essential to the quality of the water. Iron may be found on surfaces of suspended solids and settle as sediments. Iron or manganese oxides can hydrolyse or co-precipitated with Iron when it is absorbed in it (Helms and Heinrich, 1997).

In this study the average Iron concentration ranged from 0.016 mg/l to 1.285 mg/l, and sample points BB1, BB2, BB9 and BB10 recorded mean values above the WHO standard of 0.03 mg/l for drinking water. This difference in Iron concentrations was significant, probably due to difference in the conditions pertaining at this sampling points. It is worth noting that sample points BB1 and BB2 are close to each other while BB9 and BB10 are also close to each other. Based on the results it is realized that the first two sampling points (BB1 and BB2) recorded values above 1mg/l indicating a higher source of Iron contamination there. The presence of high Fe concentration in the groundwater may be due to the natural geology of the area (Blarasin *et al.* 1999). The concentrations increased from the month of March through May to July. Although this increase was not significant, it could be attributed to the increase in the rainfall within the area and which has the potential of resulting from increased runoffs and subsequent contamination.

Long-term exposure to low levels of arsenic through drinking water can result in skin cancer (WHO, 2004), and there is also an evidence of increasing risk of bladder, kidney, liver and lung tumours. Arsenic concentration in this study ranged from 0.001 mg/L to 0.006 mg/L indicating lower concentrations than the WHO standard of 0.01 mg/L. Therefore, the water samples contain insignificant arsenic concentrations. There may not be mortality cases from using water from these sources for domestic purposes including drinking with regards to Arsenic poisoning. The increase in rains from March through May to July did not increase the concentration of arsenic in the water samples. There was rather a decrease in the concentrations though not significant.

The concentration of Cadmium was same throughout the study irrespective of the sample point and the time (month) of sampling. Cadmium concentration in the water samples were below the detection limit of 0.005 mg/l, therefore it was not possible to compare the concentration between the points and the months of sampling to ascertain the influence of the rains on the concentration.

The situation reported for Cadmium was also observed for lead. In this case all samples recorded values below 0.01 mg/l which is the detection limit as well as the WHO recommended limit for Lead in drinking water. In terms of lead and Cadmium contamination, mining and other factors such as natural geology did not increase their concentrations. Therefore, the water is wholesome for human consumption as far as Lead and Cadmium are concerned.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The study revealed that water sampled from the boreholes were slightly acidic. The results obtained for pH from this study were all lower (5.0 to 6.32) than the lower limit of the WHO standard. There were also significant variations in the pH from one borehole to the other.

The EC values ranged from 393.33 $\mu\text{S}/\text{cm}$ to 863.33 $\mu\text{S}/\text{cm}$ indicating a higher EC value than the recommended standard. These levels were exceeded in all the borehole water samples.

The TDS determined for the boreholes water samples within the study area were below permissible limits. There was an increase in TDS concentration from March to May and then a marginal drop in July which statistically was not significant.

In general, concentrations of the various metals for the boreholes in the study area were low. The values were below WHO guidelines for Cu, As, Mn and Zn. Cadmium and lead were below detection limit in the samples.

Results from most samples agree to the characteristics of relatively fresh groundwater. However, there is a possibility that local mining pollutants have not yet reached the boreholes.

6.2 RECOMMENDATIONS

Based on the findings of this study it is therefore recommended that a continuous water resources monitoring programme is developed to check and ensure that appropriate actions

are determined timely and implemented during alarming changing trends in both physicochemical and metal concentrations of the ground water in the area.

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APPENDIX

Appendix 1: Physico-chemical parameters (March Sampling)

Samlpe ID	pH	Cond	TDS	Temp	DO	T.Hardnes				
	μs/cm	mg/l	mgCaCO ₃ /l	BB I	5.63	380	190	26.8	2.17	98
BB 2	6.12	490	240	26.8	1.3	170				
BB 3	5.66	860	430	26.8	6.07	172				
BB 4	5.08	490	240	26.7	1.34	70				
BB 5	5.88	680	340	26.7	7.82	218				
BB 6	5.24	430	210	26.8	1.68	73				
BB 7	5.89	400	200	26.8	1.98	103				
BB 8	5.93	420	210	26.7	1.84	96				
BB 9	5.14	470	230	26.7	1.44	61				

BB 10	5.58	520	250	26,8	1.22	33
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Appendix 2: Physico-chemical parameters (May Sampling)

Samlpe ID	pH	Cond	TDS	Temp	DO	T.Hardness	$\mu\text{s/cm}$	$\text{mg/l } ^\circ\text{C}$	mg/l
BB I	5.65	390	200	26.8	2.18	104			
BB 2	6.17	500	250	26.8	1.41	173			
BB 3	5.71	870	420	26.8	5.13	152			
BB 4	5.11	480	350	26.7	1.43	92			
BB 5	5.78	670	220	26.7	7.72	220			
BB 6	5.42	440	210	26.8	1.78	84			
BB 7	5.87	390	220	26.8	2.01	108			
BB 8	5.92	430	210	26.7	1.91	100			
BB 9	5.25	480	240	26.7	1.56	76			
BB 10	5.68	550	240	26.8	1.31	38			

Appendix 3: Physico-chemical parameters (July Sampling)

Samlpe ID	pH	Cond	TDS	Temp	DO	T.Hardness	$\mu\text{s/cm}$	$\text{mg/l } ^\circ\text{C}$	mg/l
BB I	5.56	410	211	26.8	2.68	111			
BB 2	6.66	490	223	26.8	1.81	187			
BB 3	5.74	860	392	26.8	5.91	156			
BB 4	5.12	500	350	26.7	1.67	110			
BB 5	5.81	660	186	26.7	5.98	213			
BB 6	5.55	420	198	26.8	1.81	87	BB 7	5.78	400
	321	26.8	2.01	112					
BB 8	5.91	450	197	26.7	2.01	104	BB 9	5.34	500
	231	26.7	1.65	89					
BB 10	5.71	410	212	26.8	1.42	55			

Appendix 4: Heavy metal parameters (March Sampling)

Sample ID	Zn	Cd	Cu	Mn	Fe	Pb	As
	mg/l						
BB I	0.003	<0.005	0.015	0.115	1.328	<0.010	0.004

BB 2 0.019 <0.005 0.021 0.23 1.042 <0.010 0.006 BB 3 0.009 <0.005 0.009 0.086 0.078
<0.010 <0.001
BB 4 0.008 <0.005 0.017 0.369 0.034 <0.010 0.005 BB 5 0.021 <0.005 0.019 0.121
<0.010 <0.010 0.003
BB 6 0.003 <0.005 0.023 0.095 0.015 <0.010 0.002 BB 7 0.003 <0.005 0.031 0.111
0.183 <0.010 <0.001
BB 8 0.002 <0.005 0.019 0.072 0.085 <0.010 0.004
BB 9 0.036 <0.005 0.024 0.099 0.242 <0.010 0.004
BB 10 0.071 <0.005 0.042 0.378 0.655 <0.010 0.005

Appendix 5: Heavy metal parameters (May Sampling)

Sample ID	Zn mg/l	Cd mg/l	Cu mg/l	mMn mg/l	Fe mg/l	Pb mg/l	As mg/l
BB 1	0.004	<0.005	0.049	0.238	1.317	<0.010	0.005
BB 2	0.012	<0.005	0.059	0.181	1.034	<0.010	0.006
BB 3	0.008	<0.005	0.013	0.109	0.097	<0.010	0.002
BB 4	0.008	<0.005	0.023	0.392	0.037	<0.010	0.005
BB 5	0.045	0.391	0.014	<0.010	<0.001	0.023	<0.005
BB 6	0.004	<0.005	0.033	0.111	0.015	<0.010	0.002
BB 7	0.054	0.211	0.183	<0.010	<0.001	0.003	<0.005
BB 8	0.002	<0.005	0.073	0.067	0.091	<0.010	0.004
BB 9	0.025	<0.005	0.081	0.095	0.324	<0.010	0.004
BB 10	0.039	<0.005	0.065	0.371	0.556	<0.010	0.005

Appendix 6 : Heavy metal parameters (July Sampling)

Sample ID	Zn mg/l	Cd mg/l	Cu mg/l	Mn mg/l	Fe mg/l	Pb mg/l	As mg/l
BB 1	0.003	<0.005	0.051	0.364	1.209	<0.010	<0.001
BB 2	0.012	<0.005	0.061	0.222	1.111	<0.010	0.006
BB 3	0.008	<0.005	0.021	0.111	0.102	<0.010	0.002
BB 4	0.008	<0.005	0.034	0.411	0.041	<0.010	0.005
BB 5	<0.001	<0.005	0.057	0.321	0.024	<0.010	<0.001
BB 6	0.004	<0.005	0.035	0.101	0.046	<0.010	0.002
BB 7	0.003	<0.005	0.067	0.233	0.231	<0.010	<0.001
BB 8	<0.001	<0.005	0.067	0.097	0.111	<0.010	0.004

BB 9	0.025	<0.005	0.092	0.095	0.356	<0.010	<0.001
BB 10	0.021	<0.005	0.073	0.381	0.776	<0.010	0.005

APPENDIX 7: Statistical Analysis

Table Analyzed	pH			
Two-way ANOVA				
Source of Variation	% of total variation	P value		
Column Factor	1.49	0.1431		
Row Factor	92.35	< 0.0001		
Source of Variation	P value summary	Significant?		
Column Factor	ns	No		
Row Factor	***	Yes		
Source of Variation	Df	Sum-of-squares	Mean square	F
Column Factor	2	0.05378	0.02689	2.170
Row Factor	9	3.341	0.3712	29.96
Residual	18	0.2230	0.01239	
Number of missing values	0			

Table Analyzed	Conductivity			
Two-way ANOVA				

Source of Variation	% of total variation	P value		
Column Factor	0.09	0.7005		
Row Factor	97.77	< 0.0001		
Source of Variation	P value summary	Significant?		
Column Factor	ns	No		
Row Factor	***	Yes		
Source of Variation	Df	Sum-of-squares	Mean square	F
Column Factor	2	506.7	253.3	0.3631
Row Factor	9	571900	63540	91.06
Residual	18	12560	697.8	
Number of missing values	0			
Bonferroni posttests				
March vs May				

Row Factor	March	May	Difference	95% CI of diff.
BB1	380.0	390.0	10.00	-121.1 to 141.1
BB2	490.0	500.0	10.00	-121.1 to 141.1
BB3	860.0	870.0	10.00	-121.1 to 141.1
BB4	490.0	480.0	-10.00	-141.1 to 121.1
BB5	680.0	670.0	-10.00	-141.1 to 121.1
BB6	430.0	440.0	10.00	-121.1 to 141.1
BB7	400.0	390.0	-10.00	-141.1 to 121.1

BB8	420.0	430.0	10.00	-121.1 to 141.1
BB8	470.0	480.0	10.00	-121.1 to 141.1
BB10	520.0	550.0	30.00	-101.1 to 161.1
Row Factor	Difference	t	P value	Summary
BB1	10.00	0.2677	P > 0.05	ns
BB2	10.00	0.2677	P > 0.05	ns
BB3	10.00	0.2677	P > 0.05	ns
BB4	-10.00	0.2677	P > 0.05	ns
BB5	-10.00	0.2677	P > 0.05	ns
BB6	10.00	0.2677	P > 0.05	ns
BB7	-10.00	0.2677	P > 0.05	ns
BB8	10.00	0.2677	P > 0.05	ns
BB8	10.00	0.2677	P > 0.05	ns
BB10	30.00	0.8031	P > 0.05	ns
March vs July				
Row Factor	March	July	Difference	95% CI of diff.
BB1	380.0	410.0	30.00	-101.1 to 161.1
BB2	490.0	490.0	0.0000	-131.1 to 131.1
BB3	860.0	860.0	0.0000	-131.1 to 131.1
BB4	490.0	500.0	10.00	-121.1 to 141.1
BB5	680.0	660.0	-20.00	-151.1 to 111.1
BB6	430.0	420.0	-10.00	-141.1 to 121.1
BB7	400.0	400.0	0.0000	-131.1 to 131.1
BB8	420.0	450.0	30.00	-101.1 to 161.1
BB8	470.0	500.0	30.00	-101.1 to 161.1

BB10	520.0	410.0	-110.0	-241.1 to 21.13
Row Factor	Difference	t	P value	Summary
BB1	30.00	0.8031	P > 0.05	ns
BB2	0.0000	0.0000	P > 0.05	ns
BB3	0.0000	0.0000	P > 0.05	ns
BB4	10.00	0.2677	P > 0.05	ns
BB5	-20.00	0.5354	P > 0.05	ns
BB6	-10.00	0.2677	P > 0.05	ns
BB7	0.0000	0.0000	P > 0.05	ns
BB8	30.00	0.8031	P > 0.05	ns
BB8	30.00	0.8031	P > 0.05	ns
BB10	-110.0	2.945	P > 0.05	ns

Table Analyzed	TDS			
Two-way ANOVA				
Source of Variation	% of total variation	P value		
Column Factor	0.05	0.9788		
Row Factor	78.00	0.0002		
Source of Variation	P value summary	Significant?		

Column Factor	ns	No		
Row Factor	***	Yes		

Source of Variation	Df	Sum-of-squares	Mean square	F
Column Factor	2	76.07	38.03	0.02145
Row Factor	9	113400	12600	7.107
Residual	18	31910	1773	
Number of missing values	0			
Bonferroni posttests				
March vs May				
Row Factor	March	May	Difference	95% CI of diff.
BB1	190.0	200.0	10.00	-199.0 to 219.0
BB2	240.0	250.0	10.00	-199.0 to 219.0
BB3	430.0	420.0	-10.00	-219.0 to 199.0
BB4	240.0	350.0	110.0	-99.01 to 319.0
BB5	340.0	220.0	-120.0	-329.0 to 89.01
BB6	210.0	210.0	0.0000	-209.0 to 209.0
BB7	200.0	220.0	20.00	-189.0 to 229.0
BB8	210.0	210.0	0.0000	-209.0 to 209.0
BB8	230.0	240.0	10.00	-199.0 to 219.0
BB10	250.0	240.0	-10.00	-219.0 to 199.0
Row Factor	Difference	t	P value	Summary
BB1	10.00	0.1679	P > 0.05	ns
BB2	10.00	0.1679	P > 0.05	ns
BB3	-10.00	0.1679	P > 0.05	ns

BB4	110.0	1.847	P > 0.05	ns
BB5	-120.0	2.015	P > 0.05	ns
BB6	0.0000	0.0000	P > 0.05	ns
BB7	20.00	0.3359	P > 0.05	ns
BB8	0.0000	0.0000	P > 0.05	ns
BB8	10.00	0.1679	P > 0.05	ns
BB10	-10.00	0.1679	P > 0.05	ns
March vs July				
Row Factor	March	July	Difference	95% CI of diff.
BB1	190.0	211.0	21.00	-188.0 to 230.0
BB2	240.0	223.0	-17.00	-226.0 to 192.0
BB3	430.0	392.0	-38.00	-247.0 to 171.0
BB4	240.0	350.0	110.0	-99.01 to 319.0
BB5	340.0	186.0	-154.0	-363.0 to 55.01
BB6	210.0	198.0	-12.00	-221.0 to 197.0
BB7	200.0	321.0	121.0	-88.01 to 330.0
BB8	210.0	197.0	-13.00	-222.0 to 196.0
BB8	230.0	231.0	1.000	-208.0 to 210.0
BB10	250.0	212.0	-38.00	-247.0 to 171.0
Row Factor	Difference	t	P value	Summary
BB1	21.00	0.3527	P > 0.05	ns
BB2	-17.00	0.2855	P > 0.05	ns
BB3	-38.00	0.6382	P > 0.05	ns
BB4	110.0	1.847	P > 0.05	ns
BB5	-154.0	2.586	P > 0.05	ns

BB6	-12.00	0.2015	P > 0.05	ns
BB7	121.0	2.032	P > 0.05	ns
BB8	-13.00	0.2183	P > 0.05	ns
BB8	1.000	0.01679	P > 0.05	ns
BB10	-38.00	0.6382	P > 0.05	ns

Table Analyzed	Temperature			
Two-way ANOVA				
Source of Variation	% of total variation	P value		
Column Factor	0.00	1.0000		
Row Factor	100.00	< 0.0001		
Source of Variation	P value summary	Significant?		
Column Factor	ns	No		
Row Factor	***	Yes		
Source of Variation	Df	Sum-of-squares	Mean square	F
Column Factor	2	0.0000	0.0000	
Row Factor	9	0.07200	0.008000	0.0000
Residual	18	0.0000	0.0000	
Number of missing values	0			

Table Analyzed	D.O			

Two-way ANOVA				
Source of Variation	% of total variation	P value		
Column Factor	0.01	0.9576		
Row Factor	97.32	< 0.0001		
Source of Variation	P value summary	Significant?		
Column Factor	ns	No		
Row Factor	***	Yes		
Source of Variation	Df	Sum-of-squares	Mean square	F
Column Factor	2	0.01482	0.007410	0.04343
Row Factor	9	111.9	12.43	72.85
Residual	18	3.071	0.1706	
Number of missing values	0			

Table Analyzed	Hardness			
Two-way ANOVA				
Source of Variation	% of total variation	P value		
Column Factor	1.10	0.0102		
Row Factor	97.25	< 0.0001		
Source of Variation	P value summary	Significant?		
Column Factor	*	Yes		

Row Factor	***	Yes		
Source of Variation	Df	Sum-of-squares	Mean square	F
Column Factor	2	854.6	427.3	5.974
Row Factor	9	75750	8417	117.7
Residual	18	1287	71.52	
Number of missing values	0			

Table Analyzed	Zinc			
Two-way ANOVA				
Source of Variation	% of total variation	P value		
Column Factor	5.97	0.0908		
Row Factor	74.47	0.0001		
Source of Variation	P value summary	Significant?		
Column Factor	ns	No		
Row Factor	***	Yes		
Source of Variation	Df	Sum-of-squares	Mean square	F
Column Factor	2	0.0003965	0.0001982	2.749
Row Factor	9	0.004942	0.0005491	7.614
Residual	18	0.001298	0.00007212	
Number of missing values	0			

Table Analyzed	Copper			
Two-way ANOVA				
Source of Variation	% of total variation	P value		
Column Factor	41.80	< 0.0001		
Row Factor	45.05	0.0003		
Source of Variation	P value summary	Significant?		
Column Factor	***	Yes		
Row Factor	***	Yes		
Source of Variation	Df	Sum-of-squares	Mean square	F
Column Factor	2	0.006461	0.003231	28.60
Row Factor	9	0.006965	0.0007739	6.850
Residual	18	0.002033	0.0001130	
Number of missing values	0			

Table Analyzed	Manganese			
Two-way ANOVA				
Source of Variation	% of total variation	P value		
Column Factor	5.32	0.0482		

Row Factor	81.40	< 0.0001		
Source of Variation	P value summary	Significant?		
Column Factor	*	Yes		
Row Factor	***	Yes		
Source of Variation	Df	Sum-of-squares	Mean square	F
Column Factor	2	0.02349	0.01174	3.607
Row Factor	9	0.3592	0.03991	12.26
Residual	18	0.05860	0.003256	
Number of missing values	0			

Table Analyzed	Iron			
Two-way ANOVA				
Source of Variation	% of total variation	P value		
Column Factor	0.13	0.2014		
Row Factor	99.21	< 0.0001		
Source of Variation	P value summary	Significant?		
Column Factor	ns	No		
Row Factor	***	Yes		
Source of Variation	Df	Sum-of-squares	Mean square	F
Column Factor	2	0.007572	0.003786	1.754

Row Factor	9	5.823	0.6470	299.7
Residual	18	0.03885	0.002159	
Number of missing values	0			

Table Analyzed	Arsenic			
Two-way ANOVA				
Source of Variation	% of total variation	P value		
Column Factor	3.41	0.1649		
Row Factor	81.22	< 0.0001		
Source of Variation	P value summary	Significant?		
Column Factor	ns	No		
Row Factor	***	Yes		
		Sum-ofsquares		
Source of Variation	Df		Mean square	F
Column Factor	2	0.000003267	0.000001633	1.995
Row Factor	9	0.00007787	0.000008652	10.57
			0.000000818	
Residual	18	0.00001473	5	
Number of missing values	0			