

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND
TECHNOLOGY, KUMASI

Impact Assessment of Small Scale and Illegal Mining Activities – A Case Study of
Birim River in Kyebi, East Akim Municipality.

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MASTER OF SCIENCE (ENVIRONMENTAL SCIENCE)

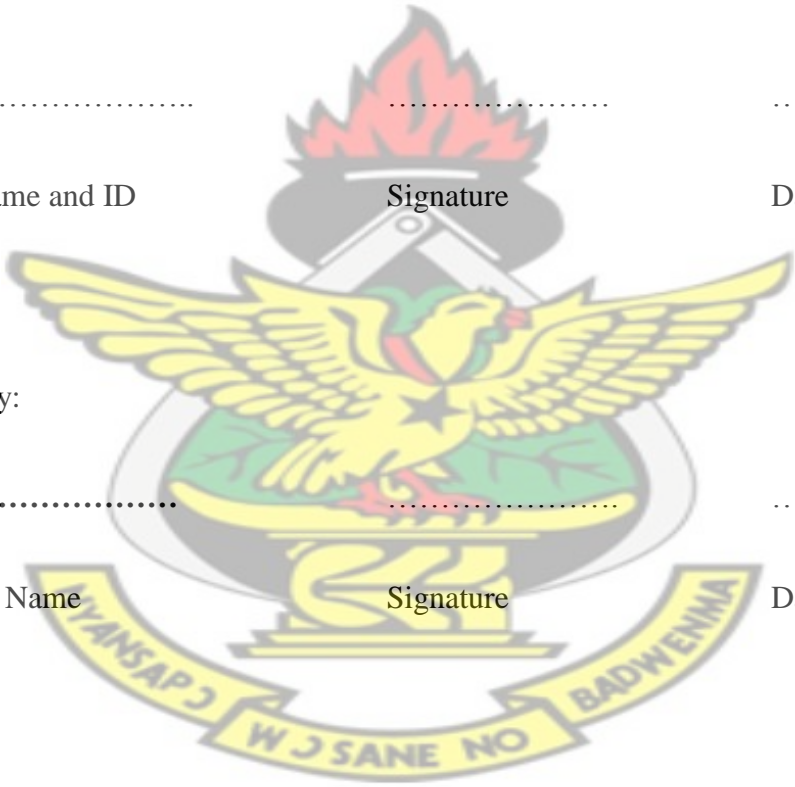
Faculty of Bioscience, College of Science

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DECLARATION

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

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Head of Dept. Name	Signature	Date

DEDICATION

This work is dedicated to my mother Mrs. Gladys Adobea Gyampoh and my late father Mr. Guggisberg Kwasi Gyampoh.

GOD blesses you all for your support and suggestions.

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ABSTRACT

Birim River is a prominent river in the Kyebi municipality in the eastern region of Ghana. It runs through several communities in the municipality including the area under study and serves as the main source of drinking water and for other domestic purposes. An assessment of the quality of water for drinking and other domestic purposes as well as the level of pollution was conducted by determining the levels of some physicochemical parameters (pH, colour, total hardness, sodium, calcium, potassium, fluoride, phosphate, nitrite, nitrate, turbidity, conductivity, temperature, etc), and trace metals (iron, mercury, zinc, nickel, lead, copper, arsenic and manganese) in both water and sediment samples from the river. Samples were taken from the point of main activity at Kyebi as well as upstream at Apapam and downstream at Bunso. The physicochemical parameters were generally within the WHO guidelines and EPA-Ghana permissible limits for drinking water except turbidity at downstream (171NTU), colour at both mid and downstream (58.5-85.8colour unit) respectively, pH (7.70) at upstream, total dissolved solids up and midstream (64.90-72.13mg/l), chloride also at all the sampling points (5.8667-6.267mg/l). With respect to the trace metals, iron (0.494-4.640mg/l) at all the sites exceeded the WHO permissible limits for drinking water. Water from both midstream and downstream was unsuitable for drinking and other domestic purpose.

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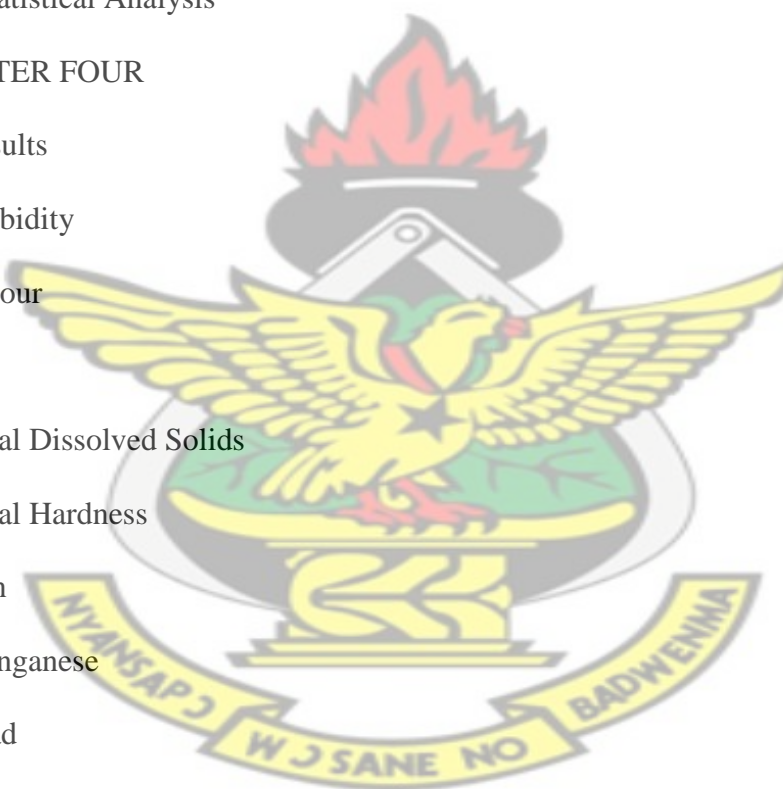
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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Small-scale gold mining is a crucial livelihood activity employing more than 13 million workers and sustaining 80-100 million people worldwide. It produces between 350-800 tonnes of gold per year contributing about 20-30% of global output. The people depending on small-scale gold mining are usually members of poor rural households in developing countries, (Heemskerk and Oliviera, 2003). Small-scale gold mining is viewed as a 'golden' opportunity for the poor, despite the social, environmental and health challenges. It is believed that more than a billion people still earn less than a dollar (US\$ 1) per day due to population increase, (Metcalf, 2008). Some rural populations depend on mining as a primary source of income or as a critical supplement to meagre farming revenues. The presence of gold deposits discovered in Kyebi in the Abuakwa traditional area in the eastern region has attracted a lot of unemployed youth and small-scale and illegal mining ventures to the area. The activities of illegal gold mining locally referred to as "galamsey" in the community and its environs is causing serious environmental havoc and destruction. Enormous quantities of the vegetation cover are gouged out, inverted and buried converting the natural terrain into raw, bare, lifeless spoil banks (Greenwood and Edwards, 1979). Greater portions of the vegetation cover in the mined areas lose its properties to be used for any other purpose (Charis, 1994). Water, a vital necessity of life is affected both in quality and quantity by activities of the galamsey operators. In Ghana, contaminations of surface and ground water bodies have particularly been experienced in gold mining communities (Davis et al., 1994), however, gold mining in recent times has become unpopular as it is regarded

as a significant source of Hg, Pb and heavy metal contamination to the environment owing to activities such as mineral exploitation, ore transportation, smelting and refining, disposal of the tailings and waste waters around mines (Hilson, 2001a; Hilson, 2002d; Aryee et al., 2003; Essumang et al., 2007; Paruchuri et al., 2010). The principal environmental problems caused by small-scale and illegal mining activities are mercury pollution from gold processing and land degradation (World Bank, 1995). In recent times there has been reported cases of waterlogged pits, soil erosion (Hilson, 2002d), pollution of fresh vegetables and food items (Essumang et al., 2007), rivers and other water bodies that served as a source of drinking water (Obiri et al., 2010; Paruchuri et al., 2010) for communities in mining areas. Communities downstream are seriously affected with water pollution because of the activities of small scale and illegal gold mining. Generally mineral exploitation creates environmental damage on a scale matched by only few other human activities. It is responsible for deforestation, soil erosion, water pollution and significant air pollution. The environmental impacts are particularly very severe in developing countries, which produce a large portion of the world's minerals. Surface mining scars large areas and creates enormous quantities of waste that erode into streams and lakes (Charis, 1994).

1.2 Mining and water pollution

Water is essential to life on our planet. A prerequisite of sustainable development must be to ensure uncontaminated streams, rivers, lakes and oceans. Water is essential for growing food; for household water uses, including drinking, cooking and sanitation; as a critical input into industry; for tourism and cultural purposes; and for its role in sustaining the earth's ecosystems. However, this essential resource is

under threat. Growing national, regional and seasonal water scarcities in much of the world pose severe challenges for national governments and international development and environmental communities. The challenges of growing water scarcity are heightened by the increasing costs of developing new water treatment systems, degradation of soil in irrigated areas, depletion of groundwater, water pollution and degradation of water-related ecosystems, and wasteful use of already developed water supplies, often encouraged by the subsidies and distorted incentives that influence water use. Mining affects fresh water through heavy use of water in processing ore and through water pollution from discharged mine effluent and seepage from tailings and waste rock impoundments. Increasingly, human activities such as mining threaten the water sources on which we all depend. Mining by its nature consumes, diverts and can seriously pollute water resources. Water pollution from mine waste rock and tailings may need to be managed for decades, if not centuries, after closure. These impacts depend on a variety of factors, such as the sensitivity of local terrain, the composition of minerals being mined, the type of technology employed, the skill, knowledge and environmental commitment of the company, and finally, our ability to monitor and enforce compliance with environmental regulations. There are four main ways in which mining impact on water quality negatively. These are:

- Acid Mine Drainage (AMD).
- Heavy metal pollution.
- Processing chemicals pollution.
- Erosion and sedimentation of rivers and streams in mining communities occurs during mineral development.

For the sake of current and future generations, we need to safeguard the purity and quantity of our water against pollution. We need to ensure the best pollution prevention strategies are employed in cases where the risks can be managed.

1.3 Statement of Problem

In Ghana, most communities are established along rivers, forest and places where they could have access to water bodies because of the nature of income generating activities of these communities. Communities like Kyebi, Apapam and Bunso are established along the Birim River. People have good reasons to live along rivers/streams especially in developing economy such as Ghana, where provision of potable water is an illusion even for many urban communities not to talk about communities, which are rural and remote. For this reason, rivers and streams are revered in most Ghanaian communities such as Kyebi, as they perceive the rivers/streams to protect them in times of calamities. Rivers and streams provide communities with water for cooking, drinking, farming, building, recreation and aesthetic. It is children that are most affected by water problems, one child under the age of five dies every 20 seconds from water-related diseases, according to the UN Environment Program (UNEP). This is due to the pollution of water bodies. Water pollution can be defined as anything human beings do to cause harmful effects to water bodies. This occurs because of the introduction of toxic chemicals from the effluents of mining operations, domestic wastes and municipal wastes; run-off of agricultural activities (fertiliser application).

Mining is an activity classified as most polluting as well as draining the dwindling water resources in the world. In Ghana, the effects of the activities of mining on our water bodies through dewatering, the virtually free use of water for mining

operations and other waste spillages, are affecting the health status of residents of mining communities. A study by Duker A. A, Carranza E. J. M, and Hale M. (2005) has shown a positive relationship between exposure to arsenic in contaminated water bodies, soil and food crops to the occurrence of Buruli Ulcer disease. The Birim River as a source of drinking water for majority of inhabitants from Kyebi, Apapam and Bunso has now become so polluted that people do not want to even use it for washing not to talk of drinking and other domestic purposes. The socio-cultural and agricultural importance of River Birim to the Akyem people is paramount. There is therefore the need to assess and identify the level of heavy metal pollution and contamination associated with mining activities in the area.

1.4 Objectives of the Study

Main Objective

- To assess the impact of small scale and illegal mining activities on the Birim River in Kyebi, East Akim Municipality.

Specific Objectives

- To determine the presence and the concentration of heavy metals in water and sediment of the Birim River.
- To determine the presence and the concentration of Physico-chemical parameters of the Birim River

1.5 Significance of the Study

1. The study will provide up-date information to add to the existing data on quality of the Birim River at Kyebi and its environs.

2. This study will also provide a useful data on sediment contamination of river Birim.

1.6 Justification of the Study

Small scale and illegal (galamsey) mining had sprung up at Kyebi and surrounding villages. In the Eastern Region, Water Treatment Plants at Osino, Bunso, Kyebi and Anyinam that drew raw water from the Birim River had to be shut down on several occasions as a result of pollution. These Plants were not designed and built to process the rapidly deteriorating raw water quality characteristics caused mainly by mining activities. Shutting down of water treatment plants denied the people of regular supply of water. The miners use toxic chemicals for their operations and had even diverted the course of the river. It was, however, the only necessary precautionary measure applied to avoid supplying communities with unsafe drinking water (Balaara Y, 2011).

The statements made by both Nana Yentumi Boaman, Abodeesahene, of Kyebi and the chief of Bunso, Barima Adjabeng Nti II underscore the urgent need to save the Birim River and the community dwellers from water borne diseases as a result of pollution. Abugre and Akabzaa (1997) have stated that, the process of mining and processing of minerals involve various activities which give rise to environmentally related diseases. In Ghana, these diseases include: Respiratory tract diseases such as Tuberculosis, Pulmonary diseases and Silicosis, Water - borne diseases such as Shistosomiasis and Onchocerchiasis, Skin diseases of all types, eye diseases and mental illness (Adu-Yeboah et al, 2008).

Based on the justifications made, the researcher has decided to undertake this study.

CHAPTER TWO

2.0 LITEARTURE REVIEW

2.1 Historical background

West Africa has for centuries been one of the world's most important gold mining regions. Today the most significant gold producing country in this area is Ghana. The gold deposits enhanced the development of many successful ancient West African civilizations, and attracted both Arabic and European merchants. The country of Ghana has taken its name from the Ancient Kingdom of Ghana, which was located about 800 km north of present Accra. Ghana was first mentioned in an Arabic source 788-93 when the trans-Saharan trade with the western savannah started. The gold trade brought increased wealth to West Africa but ancient Ghanaian society was already in an advanced economical and political state (Hilson 2002a).

Pre-colonial gold mining operations were extremely simple. Alluvial mining was most widespread and practised along rivers. Sediment was scooped from the shores, stored in canoes or bowls and washed repeatedly to separate gold particles. Shallow-pit surface mining and deep shaft mining also occurred. At the beginning of the Trans Saharan trade, gold was collected as dust or nuggets by rural inhabitants, but increasing demand from Arabic traders intensified gold production. Because of acute gold shortage during the 15th and 16th centuries, Europe's interest in West Africa increased. In 1471 the Portuguese reached present day Ghana and gained control of the West African gold trade. The arrival of the Europeans simulated a shift in activity towards the Gulf of Guinea coastlines. The Portuguese settlement in West Africa lasted for some 100 years. They constructed a number of forts along the coast facilitating transcontinental gold trade and preventing other Europeans from being

engaged in the trade. In 1595 the Dutch landed in the Gold Coast and the overtaking of fort Elmina in 1642 signified the end of the Portuguese occupation. The English soon challenged the Dutch.

During the 17th and 18th centuries the Dutch West India Company and the British African Company of Merchants were extremely active in gold mining and trade in West Africa. Trading of gold decreased but was not abandoned though no advancements and improvements of mine design and extraction were made. Britain finally got control of Ghana in the mid-1800s, establishing the Gold Coast Colony in 1874 (Hilson 2002a). The gold production fluctuated until Second World War. After Ghana gained independence in 1957 the industry collapsed (Hilson 2002a). The drastic decrease in gold production was due to the many problems resulting of the economic, financial, institutional and legal framework within which the sector operated (Aryee 2001).

In the 1960s and 1970s Ghana developed one of the most centrally controlled economies outside Eastern Europe (Hilson 2002a). This resulted in a rise of illegal and uncontrolled artisanal mineral production and smuggling as well as declining mineral sector performance (Addy 1998). In 1972 the Government endorsed a new law emphasizing that 55% of equity capital of each company to be held by the government and payment of fair compensation, based on 55% of the company's total assets also to be made to the government. It became extremely difficult for companies to become profitable. By 1976, gold mine production was about 60% compared to 1960 and a 50-years low record was reached in 1982 (Hilson 2002a).

In 1981, a military coup lead by Rawlings overthrew the existing government and formed the Provisional National Defence Council (PNDC). The PNDC government soon sought help from IMF (international money fund) to prepare a plan for economic recovery (Hilson, 2002a).

In 1983 the government started the Economic Recovery Program (ERP) under guidance of IMF (Hilson 2002a). The objective of the program was to quickly attract investors to the mining sector and other key sectors, which had export potential, to turn around the general economy of the country (Aryee 2001). After the implementation of the ERP the mining industry has seen a phenomenal growth, which mainly can be attributed to the adoption of World Bank recommendations in a new national mineral policy through the 1986 Minerals and Mining Law. This law basically means that the government leaves the mine operation, management and ownership to the private sector (Addy 1998). In 1989 the Small Scale Gold Mining Law legalized small-scale gold mining as an industry in Ghana (Hilson 2002b). Records from the Minerals Commission show that US\$4 billion of private investment capital was injected in the mining sector between 1983 and 1998. The gold production increased from 8.87 MT 1983 to 74.1 MT 1998 (Aryee 2001). Both large and small-scale projects have developed during the 1990s and a wide range of companies from Australia, Canada, the Netherlands, South Africa, the United Kingdom and the United States now hold controlling interest in most of the gold mines currently in operation (Addy 1998). From 1992 the mineral industry became the single largest foreign exchange earner and gold accounts for 95 % of this. Other big key sectors in Ghana are cocoa and forestry (Aryee 2001).

2.1.2 Small-scale mining

Small-scale mining in Ghana is defined as “mining by any method not involving substantial expenditure by any individual or group of persons not exceeding nine in number or by a cooperative society made up of ten or more persons” (Government of Ghana 1989). They are estimated to number over 150,000 in Ghana, of which many operate illegally on concessions belonging to large scale operators, or in restricted areas (Ghana academy of arts and sciences 2003). These are locally referred to as *galamsey* (Hilson 2002c). The technique mostly used for small-scale mining is amalgamation (Akosa 2002). In this process mercury is mixed with gold concentrate to form gold amalgam, which is heated to separate the gold (Ntibery et al. 2003). In the Kyebi area small-scale mining is found all around, both in the forest and along the rivers.

2.2 Environmental impact of small-scale and illegal mining activities

2.2 Small-scale mining

Illegal miners account for the most significant part of the environmental damage of the small-scale miners. Legal small-scale miners must have environmental permits and are monitored regularly by field officers. Amalgamation is the technique mostly used (Ntibery et al. 2003). The main environmental problems are mainly; Ntibery et al. (2003):

- Land degradation
 - Pollution of rivers and streams by mercury
 - Atmospheric impacts from mercury fumes during gold recovery and dust
 - Mercury in groundwater from accidental spillage during gold processing
- (Akosa et al. 2002)

- AMD from solid waste from sulphidic ore leaching heavy metal and acidity into water and soil (Akosa et al. 2002)
- Siltation of surface waters (Akosa et al. 2002)
- Deforestation due to wood used for stabilizing mining shafts
- Damage to infrastructure due to undermining of roads and houses

The management of waste on small-scale mines particularly illegal ones does not have a waste management plan but simply leave the waste. Estimated 5 tonnes mercury is released from small-scale mining operations in Ghana each year (Hilson 2001). High concentrations of mercury have been found in sediments and fish in the vicinity of small-scale mining activities using amalgamation as their main technique. The concentration in most fish fillets in these areas exceeds the recommendations of the United States Food and Drug Agency (Babut et al. 2003).

2.2.3 Acid mine drainage (AMD)

Acid Mine Drainage (AMD) is a natural process whereby sulphuric acid is produced when sulphides in rocks are exposed to air and water. Acid Mine Drainage (AMD) is essentially the same process, greatly magnified. When large quantities of rock containing sulphide minerals are excavated from an open pit or opened up in an underground mine, it reacts with water and oxygen to create sulphuric acid (Akosa et al. 2002). When the water reaches a certain level of acidity, a naturally occurring type of bacteria called *Thiobacillus ferrooxidans* may kick in, accelerating the oxidation and acidification processes, leaching even more trace metals from the wastes. The acid will leach from the rock as long as its source rock is exposed to air and water and until the sulphides are leached out – a process that can last hundreds, even thousands of years. Acid is carried off the mine site by rainwater or surface

drainage and deposited into nearby streams, rivers, lakes and groundwater. AMD severely degrades water quality, and can kill aquatic life and make water virtually unusable.

2.3 Factors Affecting the Mobility of Heavy Metals in the Environment

Besides the metals, man has created through nuclear reactions the rest have been on earth since the planet was formed (Walker and Sibly, 2001). The metals exist naturally in the bedrock and are released through weathering. In water, metals exist in different forms, both dissolved and suspended, depending on a number of different parameters. The solubility, transportation and toxicity differ between different metal species. The transportation of metals with groundwater is normally affected by sorption to solid aquifer material (Appelo and Postma, 1999). The most important chemical retention mechanisms are sorption processes and precipitation (Espeby and Gustafsson, 2001). Other chemical processes of importance are redox reactions and complexation. An increased aqueous complexation often makes an element more soluble, but the form is often less toxic. The redox status decides the speciation of some redox-sensitive elements. Different redox species have different retention capacity and the redox status is important for transport (Espeby and Gustafsson, 2001). These mechanisms and the mobility of metals are affected by a number of different parameters e.g. the oxidation state of the metal ion, pH and EC-electrical conductivity (Appelo and Postma, 1999). Determining the mobility of heavy metals is a very complex matter.

2.3.1 Sorption Processes

The pH is crucial for the extent of sorption. Anions adsorb more strongly with decreasing pH while the reverse is true for cations (Espeby and Gustafsson, 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. Sorption processes is a generic term for a number of different mechanisms. Adsorption indicates that a chemical adheres to the surface of the solid, absorption suggest that the chemical is taken up into the solid and exchange involves the replacement of one chemical for another at the solid surface. The major difference between adsorption and ion exchange is that ion exchange considers the concentration of two chemicals and adsorption considers one (Appelo and Postma, 1999). Ion Exchange: An ion in solution can be electrostatically attracted to a charged surface, and is adsorbed (Fetter 2001). Only electrostatic forces cause the adsorption and the ion is situated at a certain distance from the surface and can easily be substituted by competing ions. Soil particles are mostly negatively charged and ion exchange is most important for cations but Fe and Al oxides have positive charge, and adsorption of anions can occur (Espeby and Gustafsson, 2001). Ion exchange sites are found primarily on clay and organic materials, however, all soils and sediments have some ion-exchange capacity (Fetter, 2001) A general order of cation exchangeability in groundwater is (Fetter, 2001; Appelo and Postma, 1999): $Na > K > Fe > Mn > Mg > Ca$

Adsorption and absorption: Ions have different tendencies to form complexes with different substances. Many cations can form complexes with hydroxyl groups (OH), or carboxyl groups (COOH) and therefore these ions easily are adsorbed to surfaces with these groups. Many anions form complexes with surfaces containing Fe or Al and can be adsorbed by them (Espeby and Gustafsson, 2001). In soils, only particles

with large specific surface have the ability to adsorb ions significantly. Coarser particles have much smaller surface and are therefore insignificant for sorption processes. Examples of soils with large specific surface are clay-minerals and oxides (Espeby and Gustafsson, 2001). The charge of clay minerals varies depending on protonation of surface oxygen and deprotonation of surface hydroxyls. The surface charge and capacity of sorption is therefore pH-dependent (Appelo and Postma, 1999).

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2.3.2 Precipitation

The most important precipitations are different oxides/hydroxides and carbonates. Concerning Manganese, Aluminium, Chromium and Iron, formation of oxides/hydroxides are important throughout the natural range of pH, but also for other elements when they occur in high concentrations. Some elements form carbonates and hydroxycarbonates but only at high pH > 7- 8. During reducing conditions sulphides can be very important for precipitation (Espeby and Gustafsson, 2001).

2.3.3 Redox potential

Redox reactions imply an electron transfer from one atom to another. Redox processes are generally very slow (Appelo and Postma, 1999). The solubility of many substances is governed by the redox state. Some examples of metals greatly affected by the redox state are: Manganese, Chromium, Arsenic, Selenium and Iron. Sulfate ions can be reduced to sulfide and react with metals and form complexes which often have very low solubility. This can considerably decrease the mobility of metals such as, Iron, Copper, Lead, Zinc, Mercury, Cadmium and Nickel (Espeby

and Gustafsson, 2001). Different species are reduced in a specific sequence. O₂ is reduced first, followed by reduction of nitrate, followed by reduction of Mn(IV) to Mn(II), followed by reduction of Fe(III) to Fe(II), followed by reduction of organic matter, SO₄²⁻ reduction etc. (Appelo and Postma, 1999).

2.4.1 Water

Water samples are normally used in almost all pollution research on water bodies to quantify the various pollutants in such waters especially heavy metal studies. For instance, using water samples (Aksoy et al., 2005) demonstrated high concentrations of heavy metals in waters of Sultan Marsh and its environs of Turkey. Through water sample analysis, (Awofolu et al., 2005) reported the occurrence of toxic metals in Tyme river of South Africa. (Aksoy et al., 2005) and (Liua et al., 2002) reported that through atmospheric pollution, effluent discharges (from both domestic and industrial sources), use of agricultural chemicals, eroded soils, and domestic and industrial waste, water bodies have been the recipient of toxic substances including heavy metals.

2.4.2 Sediments

Heavy metals discharge into a river system by natural or anthropogenic sources are distributed between the aqueous phase and bed sediments (Sin et al., 2001). Sediment can provide a deeper insight into the long term pollution state of a water body (Awofolu et al., 2005). The analysis of river sediments is a useful method to study the metal pollution in an area (Sin et al., 2001)

2.5.1 Major metallic contaminants related to mining

Several of the heavy metals are essential to the human body. These metals are mainly utilised in enzymes to make them function properly. But we only need the metals in small quantities (WHO, 1996). Some of them we need as trace elements and some are non-essential for us. Calcium, sodium and magnesium are essential metals and cobalt, molybdenum, selenium, chromium, nickel, vanadium and silicon are added as trace metals. Mercury and cadmium are examples of non-essential metals (Walker and Sibly, 2001). The term heavy metals are used for metals with a density which is more than 5 g/cm^3 , (Walker and Sibly, 2001). Heavy metals which are of importance in environmental and health issues are Arsenic, Lead, Cadmium, Copper, Chromium, Mercury, Zinc, Cobalt, Nickel, Tin and Vanadium (SEPA, 2003). These are not normally a part of the human body and are more poisonous to us than other metals (WHO, 1996).

2.5.2 Arsenic

The results of available studies indicate that arsenic may be an essential element for several animal species, but there is no evidence that it is essential for humans. The level of arsenic in natural waters generally varies between 1 and $2 \mu\text{g/l}$. Concentrations may be elevated, however, in areas containing natural sources; values as high as 12 mg/l have been reported. Inorganic arsenic compounds are classified as carcinogenic to humans. Lethal doses in humans range from 1.5 mg/kg to 500 mg/kg of body with early clinical symptoms of acute intoxication include abdominal pain, vomiting, diarrhoea, muscular pain, and weakness, with flushing of the skin. These symptoms are often followed by numbness and tingling of the extremities, muscular cramping, and the appearance of a papular erythematous rash. Within a month,

symptoms may include burning paraesthesias of the extremities, palmoplantar hyperkeratosis, Mee's lines on fingernails, and progressive deterioration in motor and sensory responses. Signs of chronic arsenicalism, including dermal lesions, peripheral neuropathy, skin cancer, and peripheral vascular disease, have been observed in populations ingesting arsenic-contaminated drinking-water. In view of reducing the concentration of arsenic in drinking-water, a provisional guideline value of 0.01 mg/l is recommended but 0.137 mg/l in surface water has been reported (Kuma, 2004) at Tarkwa. The guideline value has been derived on the basis of estimated lifetime cancer risk (WHO, 1996).

2.5.3 Cadmium

Cadmium is chemically similar to zinc and occurs naturally with zinc and lead in sulphide ores. Cadmium concentrations in unpolluted natural waters are usually below 1µg/l. Median concentrations of dissolved cadmium measured at 110 stations around the world were less than 1µg/l. The maximum value recorded being 100µg/l in the Rio Rimao in Peru. Maximum levels to be <0.05mg/l has been reported in surface water at Tarkwa (Kuma, 2004).

Acute oral exposure to 20-30g of Cd has caused fatalities in humans (Young, 2005b). Exposure to lower amounts may cause gastrointestinal irritation, vomiting, abdominal pain, and diarrhea (Young, 2005b). Long term exposure to cadmium primarily affects the kidneys, resulting in tubular proteinosis. Inhalation exposure to cadmium and its compounds may result in effects including headache, chest pains, muscular weakness, pulmonary edema, and death (USAF, 1990). The estimated lethal oral dose for humans is 350-3500mg of cadmium; a dose of 3mg of cadmium

has no effects on adults. A guideline value for cadmium is calculated to 0.003mg/l drinking-water (WHO, 1996).

2.5.4 Iron

Iron is an essential element in human nutrition. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability and range from about 10 to 50mg/day. In drinking-water supplies, iron (II) salts are unstable and are precipitated as insoluble iron (III) hydroxide, which settles out as a rust-coloured silt. As a precaution against storage of excessive iron in the body a provisional maximum tolerable daily intake was calculated to about 2mg/l drinking water, however, a maximum levels of 4.01mg/l has been recorded in surface water at Tarkwa (Kuma, 2004). That level does not present a hazard to health. The taste and appearance of drinking water will usually be affected below this level, although iron concentrations of 1-3mg/l can be acceptable for people drinking anaerobic well-water. No health-based guideline value for iron is proposed (WHO, 1996).

2.5.5 Lead

Lead is the most common of the heavy elements, accounting for 13mg/kg of the earth's crust. More than 80% of the daily intake of lead is derived from the ingestion of food, dirt, and dust. That means that an average of 5µg/l lead intake from water forms a relatively small proportion of the total daily intake for children and adults, but a significant one for bottle-fed infants. Lead is possible human carcinogen (evidence inadequate in humans, sufficient in animals) and it is also a cumulative poison (bioaccumulation) so that any increase in the body burden of lead should be avoided. A provisional tolerable daily intake is set to 3.5µg of lead per kg of body

weight for infants lead to a calculated guideline value of 0.01mg/l. As infants are considered to be the most sensitive subgroup of the population, this guideline value will also be protective for other age groups (WHO, 1996). Previous studies show maximum levels in surface water at Tarkwa to be <0.05mg/l (Kuma, 2004). Some of the symptoms of acute lead poisoning are tiredness, slight abdominal discomfort, irritability, anaemia and, in the case of children, behavioural changes (WHO, 1996).

2.5.6 Manganese

Manganese concentrations above 0.1mg/l impart an undesirable taste to drinking water. Even at about 0.02mg/l, manganese will form coatings on piping that may later tear off as a black precipitate. A study in Tarkwa has shown maximum levels to be 2.43mg/l in surface water (Kuma, 2004). When manganese (II) compounds in solution undergo oxidation, manganese is precipitated. Humans can consume as much as 20 mg/day without apparent ill effects. Manganese is believed to have a neurotoxic effect; a provisional health-based guideline value of 0.5mg/l is proposed to protect public health (WHO, 1996).

2.5.7 Mercury

Almost all mercury in uncontaminated drinking water is thought to be in the form of Hg^{2+} . It is only the carbon-mercury bond in organic mercury compounds that are chemically stable. The solubility of mercury compounds in water varies. Mercury (II) chloride is readily soluble, mercury (I) chloride much less soluble, mercury sulphide has a very low solubility and elemental mercury vapour is insoluble. Some anaerobic bacteria are capable of mercury methylation. Methyl mercury can then easily enter the food chain as a consequence of rapid diffusion and tight binding to proteins.

Environmental levels of methyl mercury depend on the balance between bacterial methylation and demethylation. Organic mercury, especially methyl mercury, rapidly enters the central nervous system resulting in behavioral and neuromotor disorders (ATSDR, 1989b). Exposure to organic mercury causes central nervous system effects, especially in the foetus and neonate (Marsh et al., 1987). Naturally occurring levels of mercury in groundwater and surface water is less than 0.5µg/l. In the gastrointestinal tract, acute poisoning by mercury produces a sloughing away of the mucosa to an extent where pieces of the intestinal mucosa can be found in the stools. Mercury also breaks down barriers in the capillaries resulting in edema throughout the body. A range of neurological toxicities are also common. These include lethargy and tremor (Hoekman, 2008). Inhalation of mercury vapour may cause irritation of the respiratory tract, renal disorders, renal toxicity and death (ATSDR, 1989b). The WHO guideline value for total mercury is 0.001mg/l. Previous studies at Tarkwa show maximum levels surface water to be 0.093mg/l (Kuma, 2004).

2.5.8 Copper

Most copper (Cu) compounds found in air, soil and water are strongly attached to dust or embedded in minerals (MDH, 2006). One may be exposed to Cu by breathing air, eating food, or drinking water containing Cu as well as through skin contact with soil, water or other copper-containing substances. Copper is an essential element for living organisms, including humans, and small amounts is necessary in diets to ensure good health (Vitosh et al., 1994; MDH, 2006). Copper has also been associated with liver damage and kidney disease (MDH, 2006).

2.5.9 Nickel

In aqueous solution, nickel occurs mostly as the green hexa-aquanickel(II) ion, $\text{Ni}(\text{H}_2\text{O})_6^{2+}$. The nickel ion content of groundwater may increase as a result of the oxidation of natural nickel containing ferrosulphide deposits. Oxidation can occur if the groundwater table is lowered or if nitrate has leached from the soil. Nickel concentrations in drinking water around the world are normally below $20\mu\text{g/l}$, although levels up to several hundred micrograms per litre in groundwater and drinking water have been reported. Leaching from nickel-chromium plated taps and fittings is also a factor. The nickel intake from food exceeds that from drinking water, even if a health-based guideline value for drinking water is calculated to 0.02mg/l . That should provide sufficient protection even if nickel is sensitive to an individual (WHO, 1996).

2.5.10 Nitrate and Nitrite

Nitrate and nitrite are naturally occurring ions that are part of the nitrogen cycle. The nitrate ion is the stable form and it can be reduced by microbial action to a nitrite ion which is a relatively unstable oxidation state for the ion. It is the nitrite ion that constitutes the toxicity to humans. It is involved in the oxidation of normal haemoglobin to methaemoglobin, which is unable to transport oxygen to the tissues. Therefore the health guideline for nitrate-nitrogen is set to 10mg/l but 60mg/l of (NO_3) has been recorded in surface water at Tarkwa (Kuma, 2004). This value should not be expressed in terms of nitrate-nitrogen but as nitrate itself which is the chemical entity of health concern, and the guideline value for nitrate alone is therefore 50mg/l (WHO, 1996).

2.5.11 Sulphate

The presence of sulphate in drinking water results in a noticeable change of taste. The lowest taste threshold concentration for sulphate is approximately 250mg/l. The physiological effects resulting from the intake of large quantities of sulphate are catharsis, dehydration, and gastrointestinal irritation. Water containing magnesium sulphate at levels above 600mg/l acts as a purgative in humans. Sulfate may also contribute to the corrosion of distribution systems. Drinking water should not have sulphate levels exceeding 500mg/l (WHO, 1996) however, Kuma (2004) reports of 490mg/l in surface water at Tarkwa.

2.6 pH Level

2.6.1 General Description

The pH of a solution is the negative logarithm of the hydrogen ion activity (α_{H^+})

$$pH = -\log_{10} (\alpha_{H^+})$$

In a dilute solution, the hydrogen ion activity is approximately equal to the concentration of hydrogen ion. The pH of an aqueous sample is usually measured electrometrically with a glass electrode.

2.6.2 Health Aspects

A direct relationship between human health and the pH of drinking water is impossible to ascertain because pH is so closely associated with other aspects of water quality.

In so far as pH affects the various processes in water treatment that contribute to the removal of viruses, bacteria and other harmful organisms, it could be claimed that pH has an indirect effect on health. The recommended guideline value for pH is 6.5-8.5,

although it is recognized that some problems could arise within a distribution system with pH levels below 7.

2.7 Total Dissolved Solids (TDS)

2.7.1 General Description

The TDS in water comprise inorganic salts and small amounts of organic matter. The principal ions contributing to TDS are carbonate, bicarbonate, chloride, sulphate, nitrates, sodium, potassium, calcium, and magnesium (US EPA, 1999). Total dissolved solids influence other qualities of drinking water, such as taste, hardness, corrosion properties and tendency to incrustation.

2.7.2 Health Aspects

There is no evidence of deleterious physiological reactions occurring in persons consuming drinking water supplies that have TDS levels in excess of 1000mg/litre. The results of certain epidemiological studies would appear to suggest that TDS in drinking water may even have beneficial health effects.

Water with extremely low TDS levels may also be unacceptable because of its flat, insipid taste. No deleterious physiological effect has been recorded with TDS in water above 1000mg/litre.

2.8 Total Hardness

2.8.1 General Description

Hardness of water is not a specific constituent but is a variable and complex mixture of cations and anions. Hardness is predominantly due to calcium and magnesium, although strontium, barium, and other polyvalent ions contribute. Hardness is

commonly expressed as mg of calcium carbonate equivalent per litre. Traditionally, hardness is a measure of the capacity of the water to react with soap. It is often divided into carbonate (temporal) and non-carbonate (permanent) types of hardness.

2.8.2 Health Aspect

There is no evidence of adverse health effects specifically attributed to high levels of calcium or magnesium in drinking water.

Apart from the domestic disadvantage resulting from the use of water possessing a high degree of hardness, another possible disadvantage may arise from the association of magnesium with the sulphate ion resulting in water possessing laxative properties. The taste threshold for the calcium ion in drinking water varies from 100 to 300mg/l, depending upon the ions present; for the magnesium ion the taste threshold is less than this value (Arthur, 1971). Guideline values are not proposed for calcium or magnesium in water as a guideline value is proposed for total hardness based on aesthetic consideration.

2.9 Alkalinity

The alkalinity of water is defined as its capacity to neutralize a strong acid to a designated pH value. Although many ions may contribute to the alkalinity, such as borates, phosphates and silicates, the major contributors are hydroxide, carbonate and bicarbonate. Alkalinity, therefore, is accepted universally as a measure of the concentration of these ions. By convention, alkalinity is reported as mg CaCO_3 /litre.

2.10 Temperature

2.10.1 General Description

In general, the rates of chemical reactions decrease with decreasing temperature. The relative concentration of reactants and products in chemical equilibrium can also change with temperature. Temperature can, therefore, affect every aspect of the treatment and delivery of safe drinking water.

2.11 Turbidity

2.11.1 General Description

Turbidity in water is caused by the presence of suspended matter, such as clay, silt, colloidal organic particles, plankton, and other microscopic organisms. Turbidity is an expression of certain light scattering and light-absorbing properties of the water sample. Five methods may be used in the measurement of water turbidity, but only two of these, nephelometry and turbidimetry, form the basis of present standard methods (American Water Society, 1980).

2.11.2 Health Aspects

Turbidity in excess of the guideline value of 5NTU is generally objectionable to consumers. The perception of higher turbidity in water at the consumer's tap than in that entering the distribution system may indicate post-treatment contamination, corrosion, or other distribution problems.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Experimental Methods

This chapter describes the various methods, other auxiliary materials employed and the reagents used in this work. All chemicals used were of the analytical grade and therefore need not to be purified unless otherwise stated. The determination of the trace metals in the samples was carried out at the Chemistry Laboratory of the Water Research Institute (WRI) of the Council for Scientific and Industrial Research (CSIR), Accra-Ghana. In this work, trace metal analysis was conducted applying Atomic Absorption Spectrometry (AAS) technique.

3.2 Study Area

This study covers Kyebi municipality and its environs of which the Birim River passes through; namely Kyebi, Apapam and Bunso all in the Eastern Region of Ghana. Water samples were collected from upstream, midstream and downstream of Birim River.

3.3 Location and Size

The East Akim Municipal is located in the central portion of Eastern Region with a total land area of approximately 725km². It used to be the second largest of the 15 districts in Eastern Region until 2004 when the Atiwa district was carved out of it. The Municipal is bounded by six districts namely Kwahu South District to the North, Atiwa District to the North-West, Kwaebibirem District to the South-West,

Fanteakwa District to the East and New Juaben Municipal and Suhum-Krabo-Coaltar Districts to the South. The Municipal capital, Kyebi, is 55km from Koforidua, 105km from Accra and 179km from Kumasi.

<http://eastakim.ghanadistricts.gov.gh/?arrow=dnf&=70&r=4&rlv=location>

3.4 Topography and Drainage

The land is generally undulating and rises about 240 metres to 300 metres above sea level with the highest point being the Atiwa ranges rising over 350 metres above sea level. There are several different types of rock formation giving the different relief features ranging from flat bottom valleys to steep-sided highlands which are usually covered with iron pans, bauxite and kaolin. This rock group contains several mineral deposits including gold, diamond, and bauxite. The district is drained by rivers such as the Birim, Pra, Densu, Kua, Adenchensu and Merepong etc.

<http://eastakim.ghanadistricts.gov.gh/?arrow=dnf&=70&r=4&rlv=topology>

3.5 Climate and Vegetation

The district lies within the moist semi-deciduous forest. There are few forest reserves covering about 108.8sq. kms, including part of the Atiwa Forest Reserve. The forest reserves constitute about 15% of the entire surface area of the district. Some commercial species of trees contained in the forest are Odum, Wawa, Ofram, Mahogany, Kyenkyen etc.

The district lies in the west semi-equatorial zone characterized by double rainfall maxima occurring in June and October; the first rainy season from May to June and the second from September to October.

The mean annual rainfall is between 125cm and 175cm. The dry seasons are really distinct with the main season commencing in November and ending in late February.

Temperature is found to be fairly uniform ranging between 26°C in August and 30°C in March. Relative humidity is generally high throughout the year, ranging between 70% - 80% in the dry season and 75% - 80% in the wet season.

http://eastakim.ghanadistricts.gov.gh/?arrow=dnf&_=70&r=4&rlv=climate

3.6 Sampling Sites

Feasibility study conducted for this work revealed that the major sources of drinking water and other household activities for the inhabitants was river Birim, boreholes and pipe borne water. The localities using the water sources include Kyebi, Apapam, and Bunso. The sampling sites were selected keeping in mind the need to assess possible deleterious effects of the illegal gold mining activities in the area on water quality. A total of three (3) sampling points were covered and these were:

- Apapam for the upstream (Elevation 381m; N 06.13845⁰; E 000.60069⁰)
- Kyebi for the mid stream (Elevation 303m; N 06.15602⁰; E 000.55835⁰)
- Bunso for the downstream (Elevation 209m; N 06.28206⁰; E 000.46447⁰)

Plastic ladles were used to scope the sediments from the bottom of the Birim River at the sampling sites.

3.7 Sample Collection, Preparation and Storage

The collection of water samples of the river was performed by wearing polyethylene gloves, and facing the direction of flow of the stream. The water samples were collected from the river into plastic bottles that has been pre – washed with detergent and tap water, and later rinsed with 1:1 conc. nitric acid and distilled water. At each sampling point, the bottles were rinsed three (3) times with the water before collection of the sample. Each bottle was immersed below the water surface. Identification labels were fixed on each sample collected.

Sediment samples were collected with a pre-cleaned plastic shovel. The plastic shovel was used to scoop the sediment. The sediment samples were transferred into pre-cleaned polyethylene bags. The samples were stored in an ice – chest at 4°C and later conveyed to the laboratory for analysis. In the laboratory, the acidified samples were filtered using Whatman's no. 0.45µm filter paper. The 0.45µm membrane filter paper was used because the analyte of interest in this work is the total dissolved metals. The filtered samples and the unfiltered samples were stored in the refrigerator at 4°C for further analysis (APHA – AWWA, 1998).

3.8 Treatment of Samples

Two containers of the samples were stabilized by acidifying on site each container with 2ml 5M HCl per litre of sample for the determination of levels of heavy metals to stabilize the ions in the solution. This is to prevent adsorption of metal ions on the sides of the container and minimize precipitation of metal ions. The containers were not filled to the brim so that the content can easily be mixed. Samples for mercury digestion were stored in glass bottles. This is because mercury ions readily react with many organic materials (Arnold et al., 1992). The other container was filled with

samples to the brim and not stabilized with acid as it would affect the determination of physicochemical analysis. Samples were stored in a refrigerator. The pH, Electrical conductivity and temperature of samples were measured in-situ (immediately on site after collecting them) before transporting to the laboratory.

3.9 Parameters Determined

The parameters determined include trace metals (Mercury, Lead, Zinc, Iron, Nickel, Arsenic, Cadmium, Copper), pH, Temperature, Electrical conductivity (EC), Total Dissolved Solids (TDS), Turbidity and Colour (apparent), Total Hardness (calcium, magnesium), Calcium hardness, Magnesium hardness, Sodium, Magnesium, Calcium, Potassium, Total Alkalinity (carbonates and bicarbonates), Total suspended solids, Chloride, Ammonium ion, Sulphate (SO_4^{2-}), Phosphate ($\text{PO}_4\text{-P}$), Nitrite ($\text{NO}_2\text{-N}$), Nitrate ($\text{NO}_3\text{-N}$), and Fluoride were determined.

3.10 Drying

Sediment Samples were allowed to dry in batches of six at 40°C in an electric oven for a minimum of forty-eight (48) hours in coated metal pans to simulate air-drying. Once dry, the sediment were ground into a fine powder using a ceramic mortar and pestle and sieved using a 2mm plastic sieve to remove any large organic matter such as reeds or grass, roots etc. The sieved material was then placed in sterilized plastic bags and labelled for storage at room temperature.

3.11 Digestion of samples

3.11.1 Sediment digestion and analysis

After filtering with 0.45 μm membrane filter, the sediment samples were digested by weighing 0.4g of the sample in Teflon tubes. Exactly 4ml of concentrated nitric acid (HNO_3) was slowly added to the content. The tubes were closed and placed in stainless steel bombs. The bombs were placed on a hot plate and heated at 150°C for seven (7) hours and then allowed to cool to room temperature before carefully opening the bombs to release pressure. The samples were transferred into the graduated polypropylene tubes and the Teflon tubes rinsed three (3) times with distilled water and added to the content of the polypropylene tube. The content was diluted to the 50ml mark of the tube with distilled water and mixed thoroughly. Analysis of sediment for the determination of heavy metals was carried out using AAS according to Whiteside and Milner, Ghana EPA, (1997)

3.11.2 Digestion and Determination Procedures for trace Metals (As, Fe, Ni, Cu, Mn, Cd, Pb and Zn)

Procedure

A 100ml of sample (analyte- aliquot) was transferred into a 250ml conical flask. 5ml of conc. HNO_3 was added to the measured sample, followed by a few boiling chips. Content of the conical flask was boiled slowly and evaporated on a hot plate to a volume of about 10ml (before precipitation could occur). Also, complete digestion was ensured and this was shown by light-coloured clear solution. The sample was not allowed to dry during the digestion process. The walls of the flask were washed down with de-ionized water and filtered to remove insoluble material that could clog the nebulizer. Filtrate was then transferred into a 50ml volumetric flask and rinsed with 5ml portions of deionized water. Content of the volumetric flask was cooled and diluted to the mark and mixed thoroughly to obtain a homogeneous solution and

portions of this solution were taken for the required metal determinations using the AAS.

NOTE: For Pb level determination, a large volume of 100ml of sample was pre-concentrated, going through the above digestion procedure and the final metal level was divided by the appropriate factor.

3.11.2 Digestion of Mercury (Hg)

Procedure

A 100.0ml aliquot of each water sample was transferred to a 250ml volumetric flask in duplicates. 5.0ml of conc. H_2SO_4 was added to each flask from a burette, followed by addition of 2.5ml conc. HNO_3 from another burette containing the conc. HNO_3 . 15.0ml of freshly prepared 5% KMnO_4 was also added to each aliquot of the water sample taken and made to stand for at least 15.0minutes. 8.0ml of 5% $\text{K}_2\text{S}_2\text{O}_8$ solution was then added to each beaker and heated for two (2) hours in a water bath 95.0°C . The digested samples were then cooled, covered and left to stay overnight. The next day, 10.0% hydroxylamine hydrochloride solution was prepared fresh and used to reduce excess KMnO_4 . Enough hydroxylamine hydrochloride solution was added to each digested sample until it became colourless, indicating the absence of KMnO_4 . A blank and 20.0 μg , 40.0 μg , 60.0 μg and 80.0 μg Hg solutions were prepared and treated as above. On the day of determination, 1.1% SnCl_2 in 3% HCl was prepared together with 3.0% HCl. The 1.1 SnCl_2 in 3% HCl and the 3% HCl were used to reduce Hg^{2+} . The elemental mercury produced was determined by cold vapour Atomic Absorption at 253.7nm.

3.12.1 Determination of Nitrate/Nitrite ($\text{NO}_3^-/\text{NO}_2^-$ -N) – Using Phenoldisulphonic Acid

Phenol – 2, 4 – disulphonic acid is nitrated by nitrates to 6 – nitrophenol – 2, 4 – disulphonic acid, which gives rise to an intense yellow colour on addition of alkali. The intensity of this colour, which is proportional to the nitrate concentration, is determined by spectrophotometric method at a wavelength of 410nm.

Procedure

10ml of the analyte solution was placed in a small porcelain dish and evaporated to dryness on a boiling water-bath. To the cooled residue, 1ml of the phenol-disulphonic acid solution was added, ensuring that the reagent made contact with the whole of the solid material derived from the sample, and allowed to stand for 10 minutes. Then 10ml of de-ionized water was added, the mixture cooled, and gradually concentrated ammonia solution added until the solution is alkaline; again cooled, and diluted with de-ionized water to 25ml. At the same time, 'blank' solution containing the same quantities of the reagents, omitting the sample analyte, was prepared.

Standard solutions of $\text{NO}_3^-/\text{NO}_2^-$ were prepared. The absorbance using was measured at 410nm. A calibration curve was drawn. Now, each sample analyte was taken and the concentration was measured at a wave length of 410nm.

3.12.2 Preparation of Standard Curve

$\text{NO}_3^-/\text{NO}_2^-$ calibration standards in the range 0 to 7mg NO_3^- -N/ NO_2^- N/L was prepared by diluting to 50ml the following volumes of intermediate nitrate solution: 0, 1.00, 2.00, 4.00, and 7.0035.00ml. Thus, let x = volume of intermediate nitrate solution required in 50ml of solution.

Example, for a 1 ppm standard solution,

$$\frac{1}{50} = \frac{1000 \times x}{50}$$

$$x = 0.05\text{mg} = 50\mu\text{g} \equiv 5.00\text{ml}$$

3.13. Determination of Sulphate (SO_4^{2-}) – Using Turbidmetric Method

Principle of the Method

Sulphate ion (SO_4^{2-}) is precipitated in an acetic acid medium with barium chloride (BaCl_2) so as to form barium sulphate (BaSO_4) crystals of uniform size. Light absorbance of the BaSO_4 suspension is measured with AAS (Agilent 240FS at 420nm) and the SO_4^{2-} concentration is determined by comparison of the reading with standard curve.

Colour or suspended matter in large amounts will interfere. Some suspended matter may be removed by filtration. In potable waters, however, there are no ions other than SO_4^{2-} that will form in solution compounds with barium under strongly acidic conditions.

3.14 Determination of pH

This was determined by means of a portable pH meter, WTW pH 323-B/ Set 2, Wissenschaftlich-Technische Werkstätten GmbH, 82362 Weilheim.

3.15. Determination of Total Dissolved Solids (TDS)

This was done with a portable TDS meter, WTW LF 538, Wissenschaftlich-Technische Werkstätten GmbH, 82362 Weilheim.

3.16 Determination of Total Hardness

Principle

The hardness of water is due, mainly, to the presence of calcium and magnesium salts. The total hardness is determined by EDTA -

(ethylenediaminetetraacetic acid- $C_{10}H_{16}N_2O_8$) titration, and is expressed as calcium carbonate.

Procedure

100cm³ of water sample was transferred into a 250cm³ conical flask and 2cm³ of ammonia solution added. 2 drops of indicator solution was added and mixed thoroughly. A pink colour indicates the presence of calcium and / or magnesium salts. The resulting solution was titrated with standard EDTA (ethylenediaminetetraacetic acid) solution, with continuous swirling, until the last pink disappeared. The titration was continued, drop – wise, to a blue end – point.

Calculation

$$\text{Total hardness (mg CaCO}_3\text{/dm}^3\text{)} = \frac{a \times 1000}{V}$$

Where: a is the volume of EDTA used in the titration (cm³)

V is the volume of sample (cm³)

3.17 Determination of Total Alkalinity

Principle

Alkalinity is accepted universally as a measure of the concentration of hydroxide, carbonate and bicarbonate. The measurement of alkalinity by titration, with a standard acid, to pH values of 8.3 and 4.8 enable the calculation of the approximate concentration; alkalinity is reported as mg CaCO₃/dm³.

Procedure

Water sample, 100cm³, was transferred into a 250cm³ conical flask and 2 drops of methyl orange indicator added. The yellow solution was titrated against the standardized hydrochloric acid to a faint red colouration.

Calculation

Total alkalinity (as mg CaCO₃/dm³) = $\frac{d \times 1000}{e}$

Where: “d” is the volume of HCl used in the titration (cm³); “e” is the volume of sample (cm³)

3.18 Determination of Turbidity

Principle

Turbidity is measured by comparison of the intensity of light scattered by the sample, with that of light scattered by a standard reference suspension. The higher the intensity of lights scattered, the higher the turbidity of the sample. The intensity of the scattered light is influenced significantly by the particle size of the suspended solids and the wavelength of incident light. NEPHLA – EU turbidimeter (LPG 325, Great – Nr 1002684) was used. Results are expressed as nephelometric turbidity units (NTU).

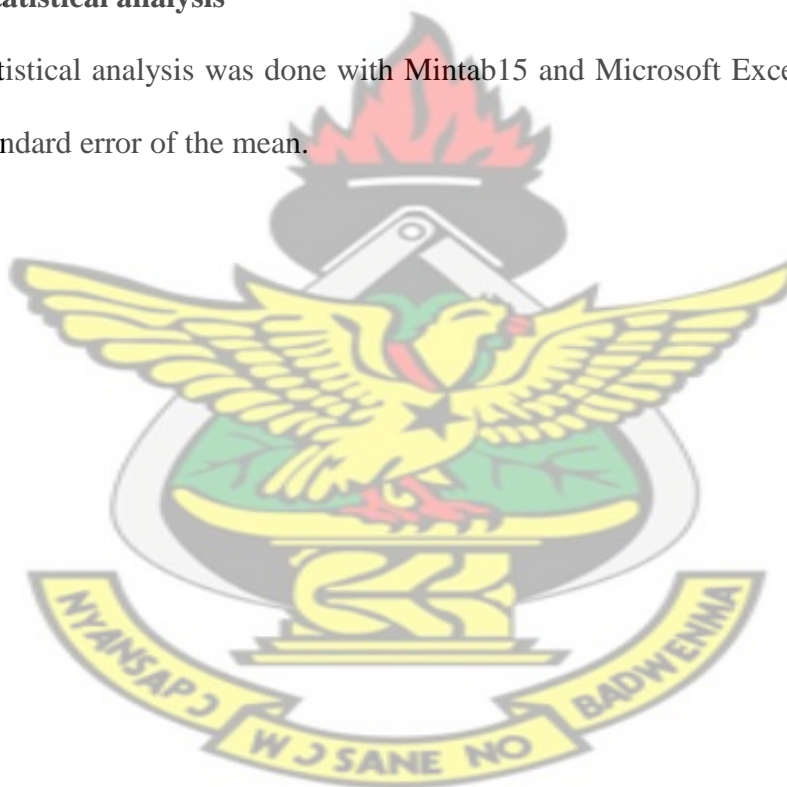
3.19 Quality Assurance

Samples were taken in three replicates and the average of each result was taken for the analysis. All instruments used in this study were calibrated with standard and known concentrations. Calibration curves were prepared separately for all the metals by running suitable concentrations of the standard solutions. Concentrations of the analyte samples were determined from a calibration curves. Suitable blanks were also prepared and analysed in the same manner.

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3.20 Statistical analysis

All statistical analysis was done with Mintab15 and Microsoft Excel 2007 for mean and standard error of the mean.

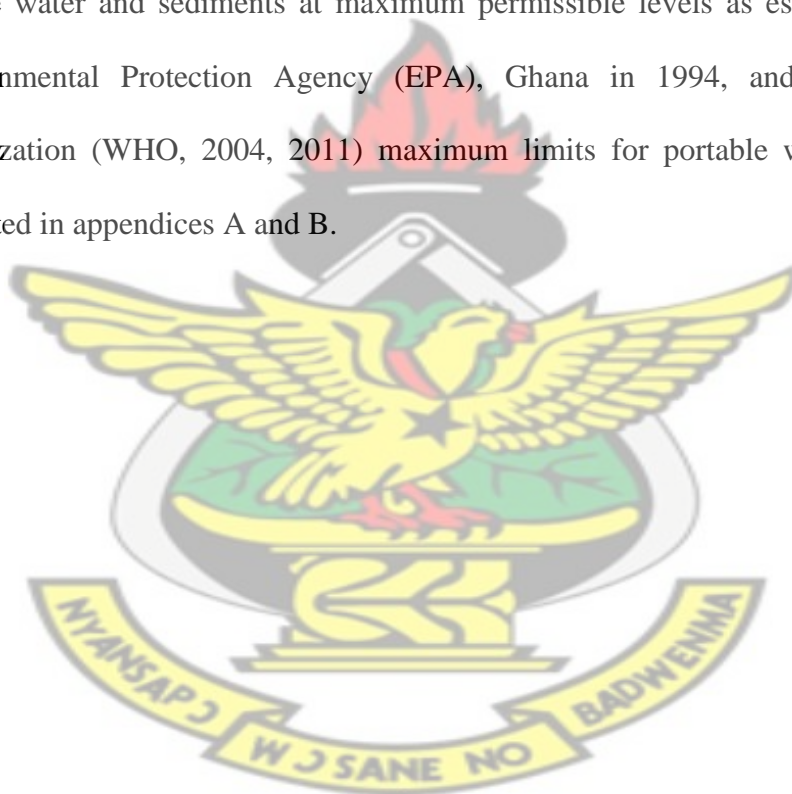


CHAPTER FOUR

4.0 RESULTS

To achieve the objectives of this research, surface water and sediment samples were collected from three sampling sites in river Birim within the catchment area. These samples were subjected to laboratory analyses to assess the level of some heavy metal as well some Physico-chemical parameters. The results obtained within the period of assessment at the sampling sites are shown in appendices A to F.

Water quality parameters which were above the WHO and/or EPA Ghana recommended values are illustrated in column graphs. Environmental guidelines for surface water and sediments at maximum permissible levels as established by the Environmental Protection Agency (EPA), Ghana in 1994, and World Health Organization (WHO, 2004, 2011) maximum limits for portable water values are presented in appendices A and B.



4.1 Turbidity

The turbidity values recorded at each site were all above the normal range as contained in the WHO standards for drinking water 5.00 ± 0.00 NTU. The downstream (Bunso) recorded the highest mean turbidity values of 171 ± 133 NTU with the upstream (Apapam) recording the least mean turbidity values of 8.67 ± 1.20 NTU. The mid stream (Kyebi) recorded a mean turbidity values of 85.7 ± 68.7 NTU. With EPA, Ghana standard of 75 ± 0.00 NTU, only the upstream was below, but the down and mid streams well all above.

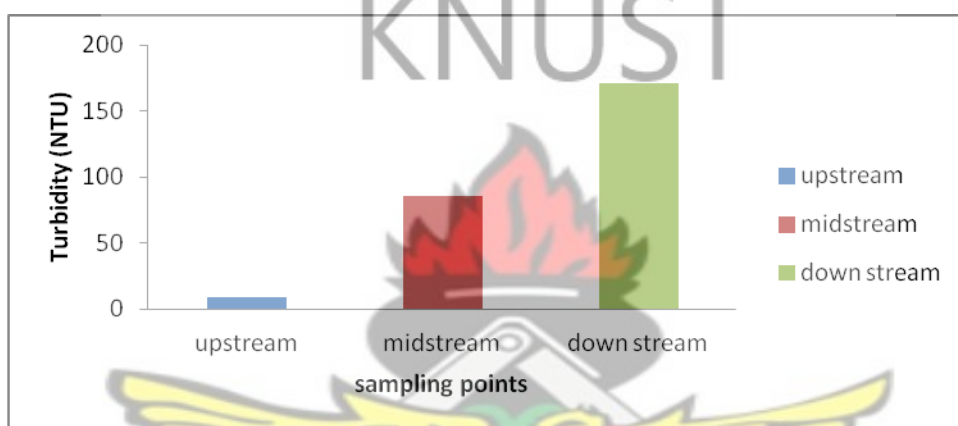


Fig. 4.1a comparison of turbidity levels at the sampling points.

4.2 Colour

Except the upstream, the rest had mean apparent colour values above the WHO of 15.00 ± 0.00 colour unit. The downstream had the highest of 85.00 ± 57.5 colour unit while the upstream had the lowest of 8.67 ± 1.86 colour unit. The mid stream had 57.5 ± 46.3 colour unit. With the EPA, Ghana values of 150.00 ± 0.00 colour unit, all of the mean values of colour of the samples were below.

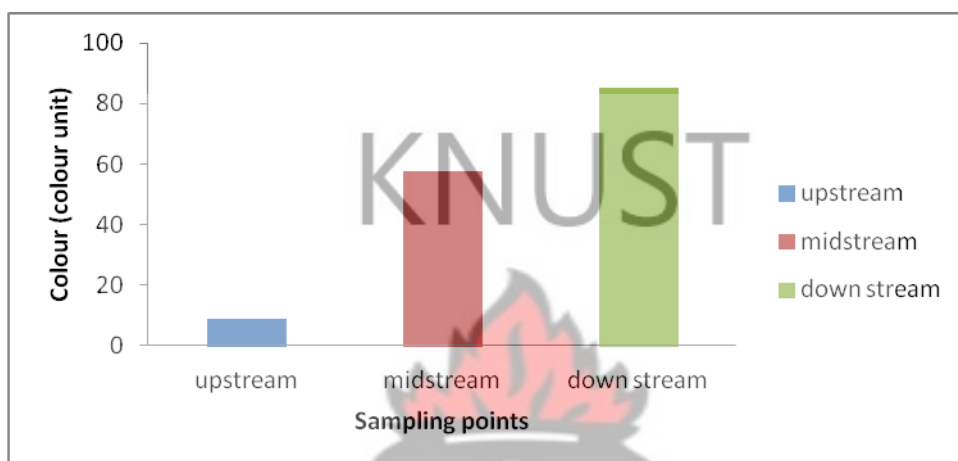


Fig. 4.2a comparison of colour levels at the sampling points.



4.3 pH

The WHO pH value of 7.50 ± 0.00 pH unit makes only the mid stream unpolluted with a mean pH value of 7.44 ± 0.22 pH unit. Mean pH of upstream value of 7.70 ± 0.20 pH unit with the downstream recording the highest mean pH value of 7.84 ± 0.13 pH unit. With the EPA, Ghana values of pH 7.50 ± 0.00 pH unit, except the downstream all the rest were within the mean values. Downstream mean pH value of 7.84 ± 0.13 pH unit.

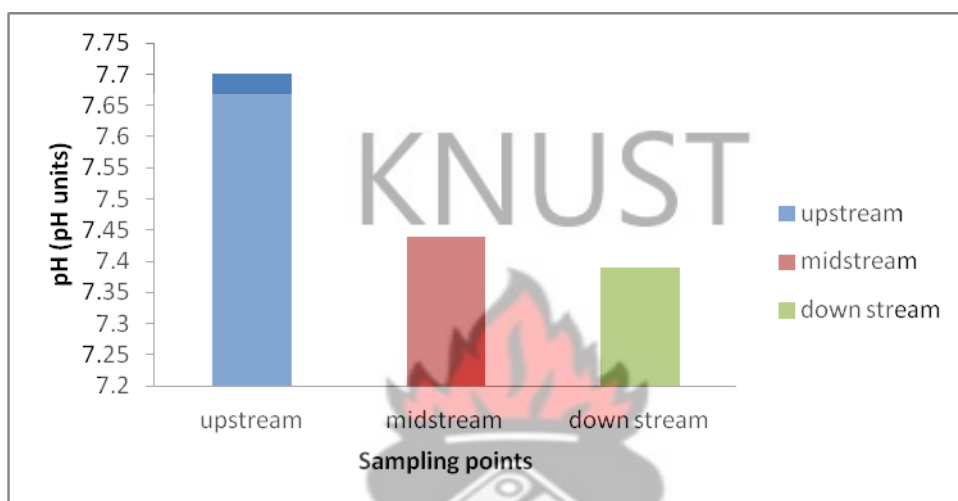


Fig. 4.3a comparism of pH levels at the sampling points.



4.4 Total Dissolved Solids

All the mean concentration of total dissolved solids of the samples was far below the WHO values of $1000.00 \pm 0.00 \text{ mg/L}$. With the EPA, Ghana standard of $50.00 \pm 0.00 \text{ mg/L}$, the mid stream had the highest mean concentration value of $72.13 \pm 7.59 \text{ mg/L}$. The least mean concentration was recorded up stream with a value of $64.90 \pm 7.99 \text{ mg/L}$.

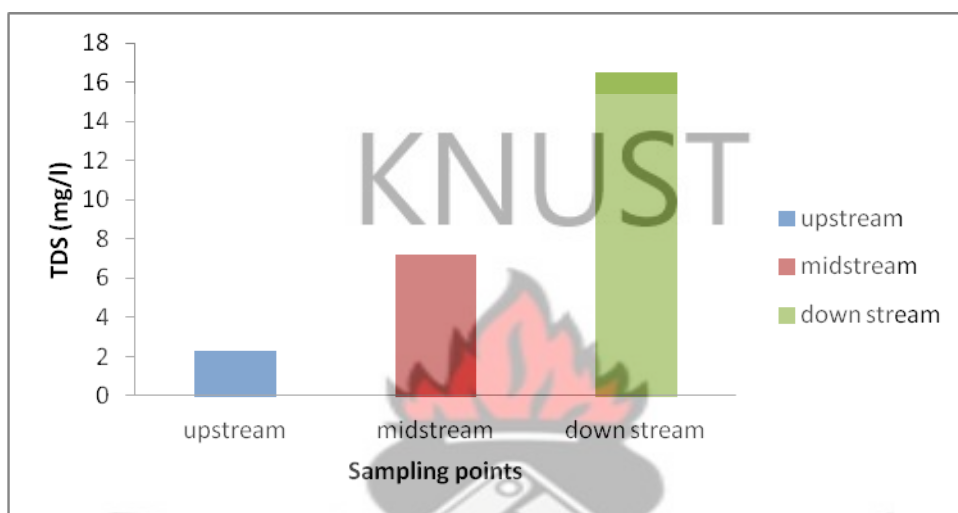


Fig. 4.4a comparison of Total Dissolved Solids levels at the sampling points.



4.5 Total Hardness

The WHO total hardness value of $500.00 \pm 0.00 \text{ mg/L}$ and EPA, Ghana value of total hardness $400.00 \pm 0.00 \text{ mg/L}$. All the mean total hardness concentration of the sites were far below; upstream mean concentration of total hardness $44.20 \pm 6.52 \text{ mg/L}$, mid stream mean concentration of total hardness $46.17 \pm 2.67 \text{ mg/L}$ and Downstream mean concentration of total hardness of $43.67 \pm 1.33 \text{ mg/L}$.

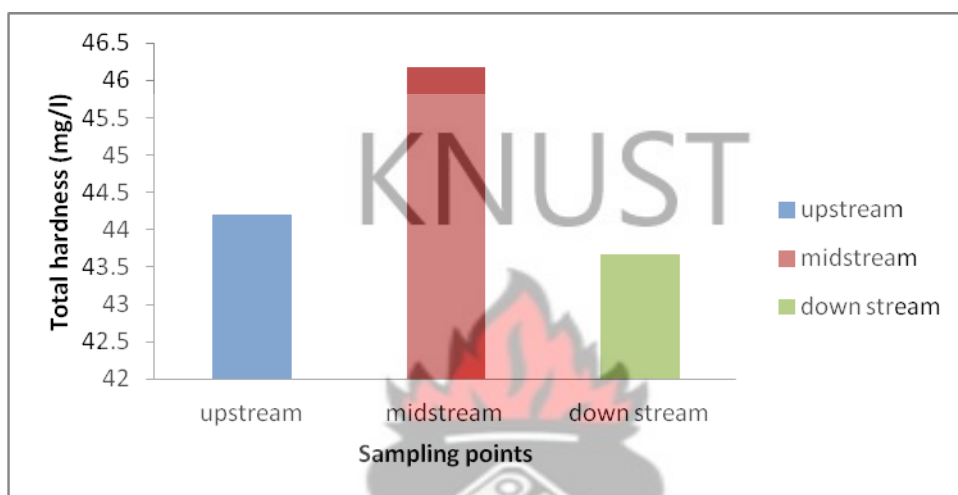


Fig. 4.5a comparison of Total Hardness levels at the sampling points.



4.6 Iron

All the mean concentration values of the sampling sites were above the WHO value of $0.30 \pm 0.00 \text{ mg/L}$. The least was the upstream with a mean iron concentration of $0.49 \pm 0.13 \text{ mg/L}$. The highest was the downstream with a mean iron concentration of $4.64 \pm 3.43 \text{ mg/L}$. Only the downstream with mean iron concentration of $4.64 \pm 3.43 \text{ mg/L}$ was above the EPA, Ghana value $3.00 \pm 0.00 \text{ mg/L}$.

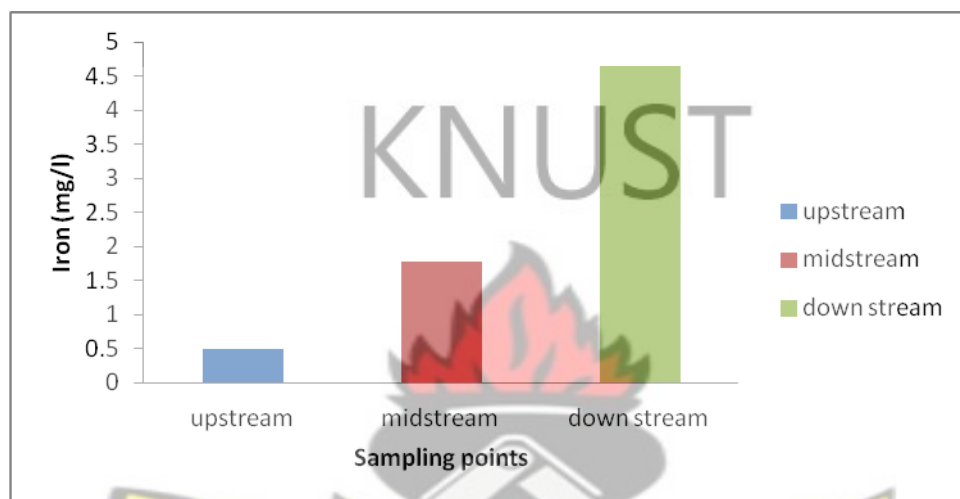


Fig. 4.6a comparison of Iron levels at the sampling points.

4.7 Manganese

No EPA, Ghana values available. All the mean concentration of manganese of the samples was far below the WHO value of $0.40 \pm 0.00 \text{ mg/L}$.

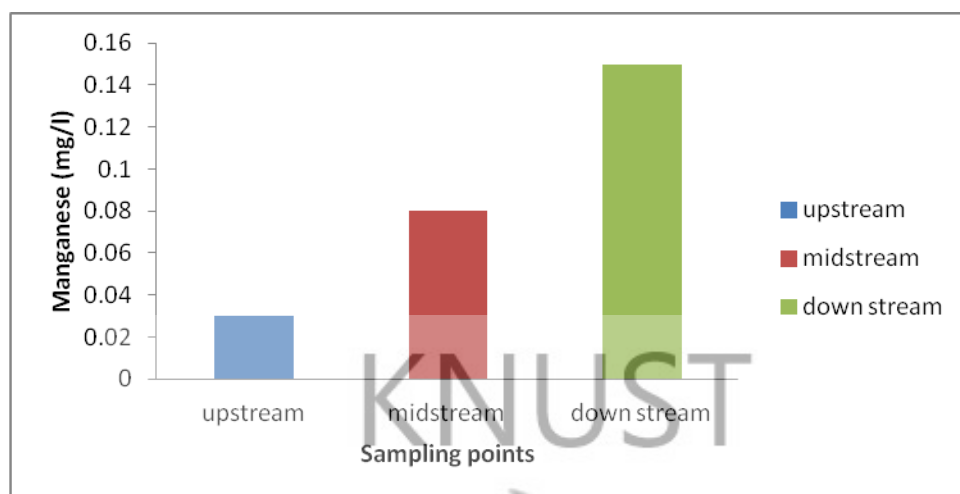


Fig. 4.7a comparison of Manganese levels at the sampling points.



4.8 Lead

Both the EPA, Ghana value and WHO value of concentration of lead are the same $0.10 \pm 0.00 \text{ mg/L}$, all the mean lead concentration of the samples were below but amongst them, the highest was the mid stream with mean lead concentration of $0.021 \pm 0.00 \text{ mg/L}$ and the least was the upstream $0.01 \pm 0.00 \text{ mg/L}$.

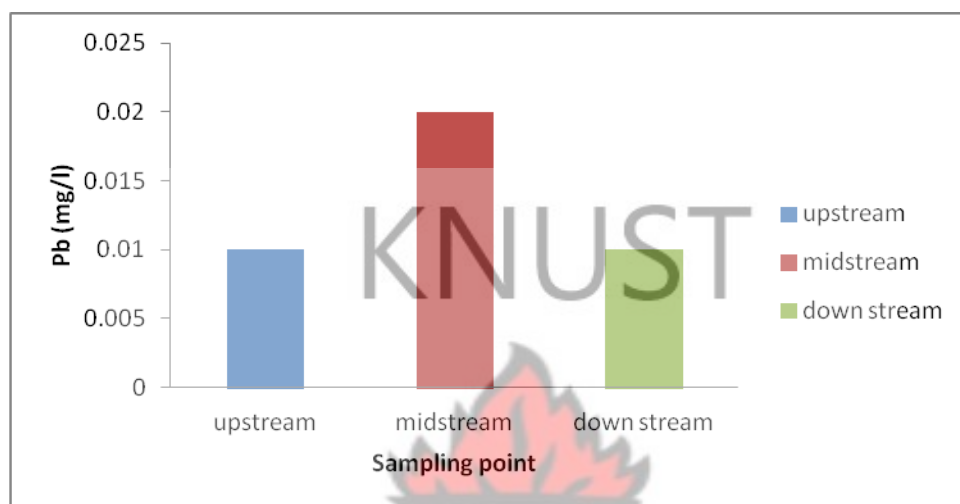


Fig. 4.8a comparison of Lead (Pb) levels at the sampling points.



4.9 Mercury

WHO mercury value for drinking water is $0.001 \pm 0.000 \text{ mg/L}$. The mean mercury concentration of the samples shows that all were below the WHO value with a mean Hg concentration value of $0.0001 \pm 0.000 \text{ mg/L}$.

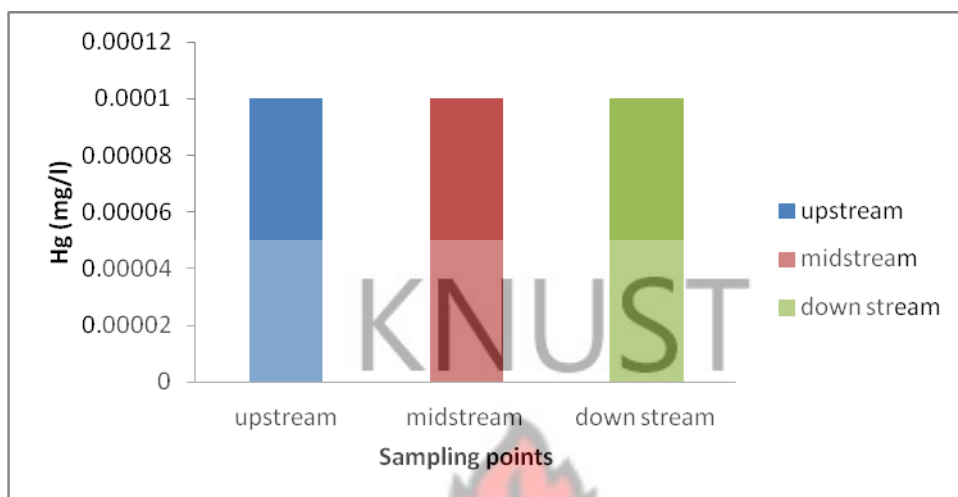
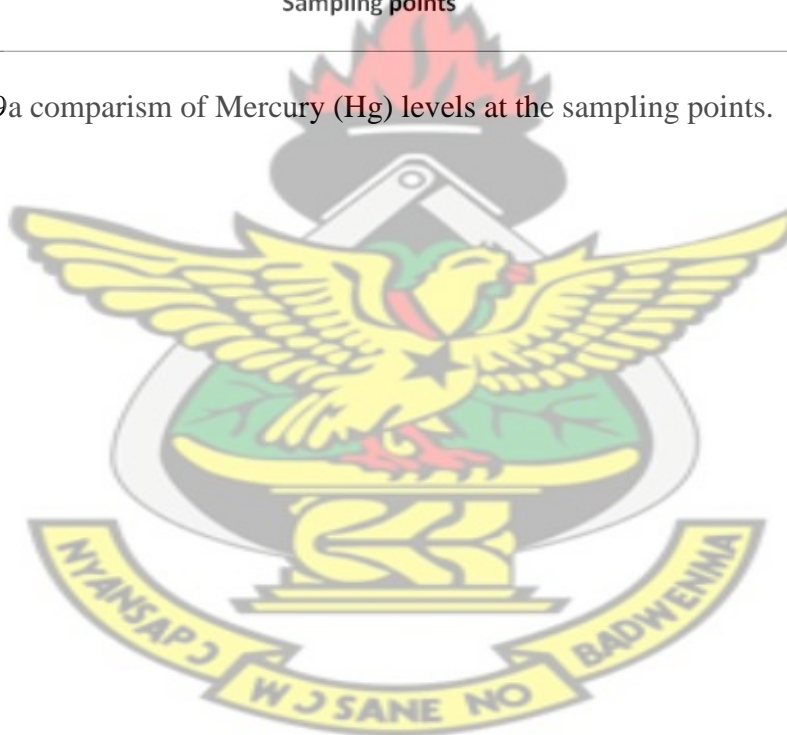


Fig. 4.9a comparison of Mercury (Hg) levels at the sampling points.



4.10 Temperature

All the mean temperature values of the samples were below the EPA, Ghana temperature value of $39.50 \pm 0.00^{\circ}\text{C}$.

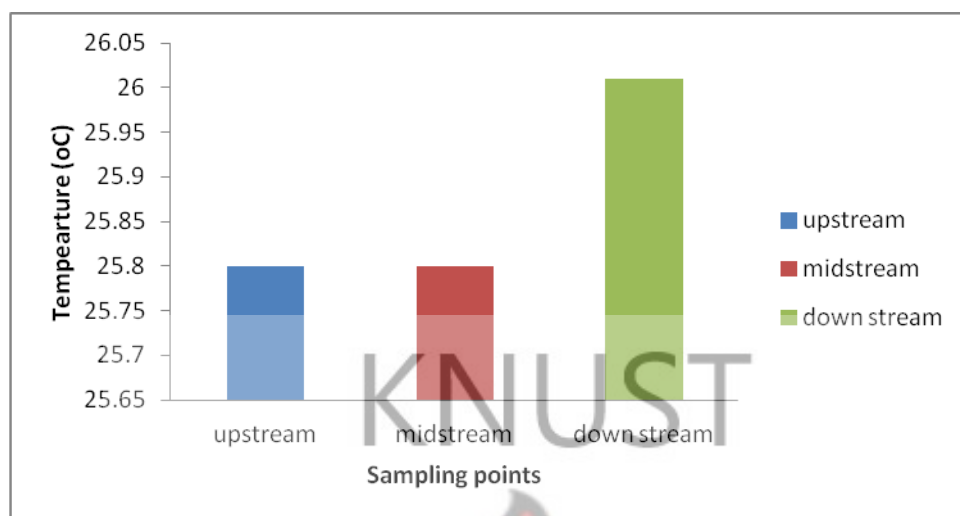
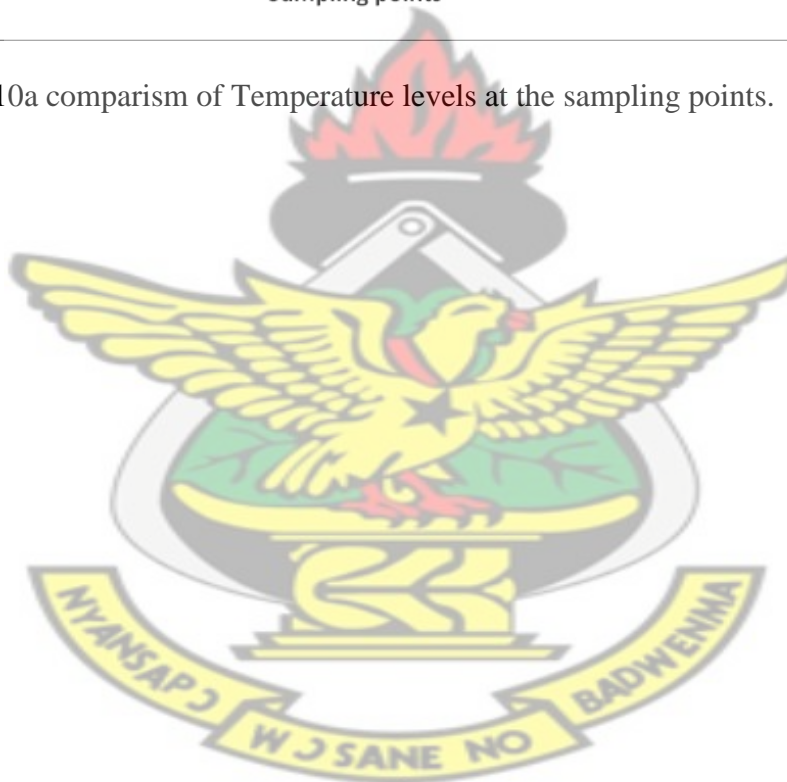


Fig. 4.10a comparison of Temperature levels at the sampling points.



4.11 Sodium

The mean concentration values of Sodium for the samples were far below the WHO value of $200.00 \pm 0.00 \text{ mg/L}$ as shown below;

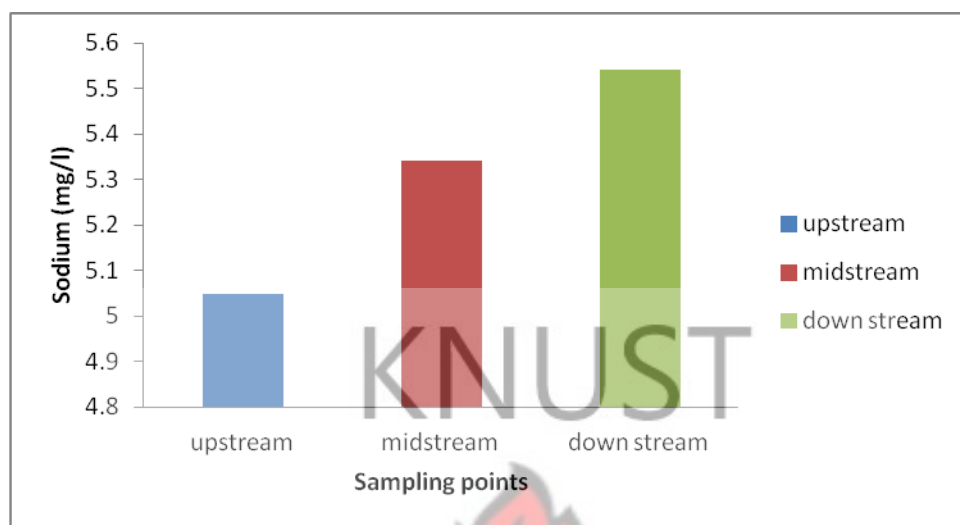
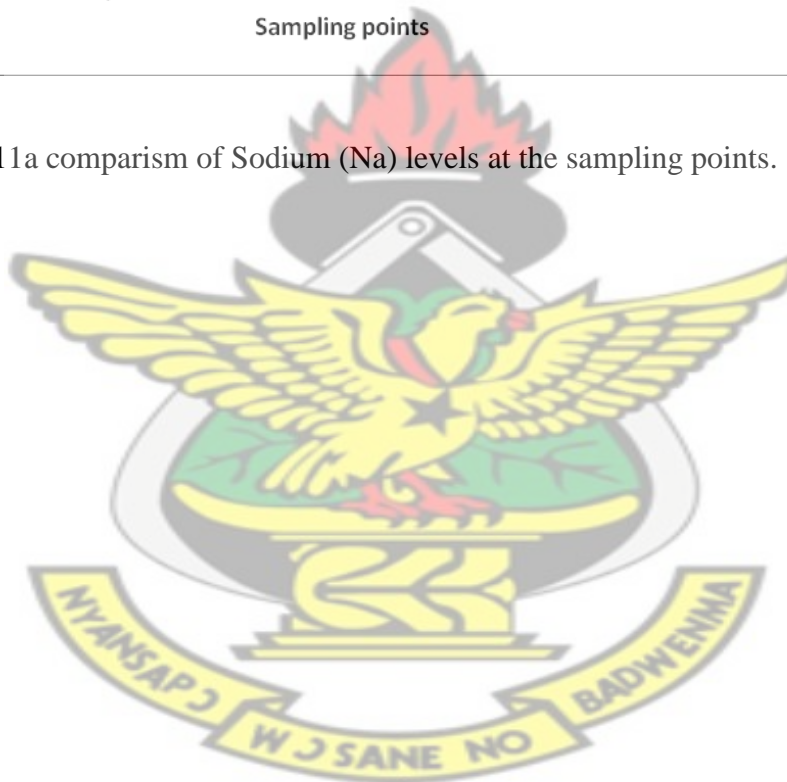


Fig. 4.11a comparison of Sodium (Na) levels at the sampling points.



4.12 Potassium

With the WHO value of $30.00 \pm 0.00 \text{ mg/L}$, the mean concentration values of sodium from all the samples were far below with the downstream having the highest value of $3.093 \pm 0.258 \text{ mg/L}$.

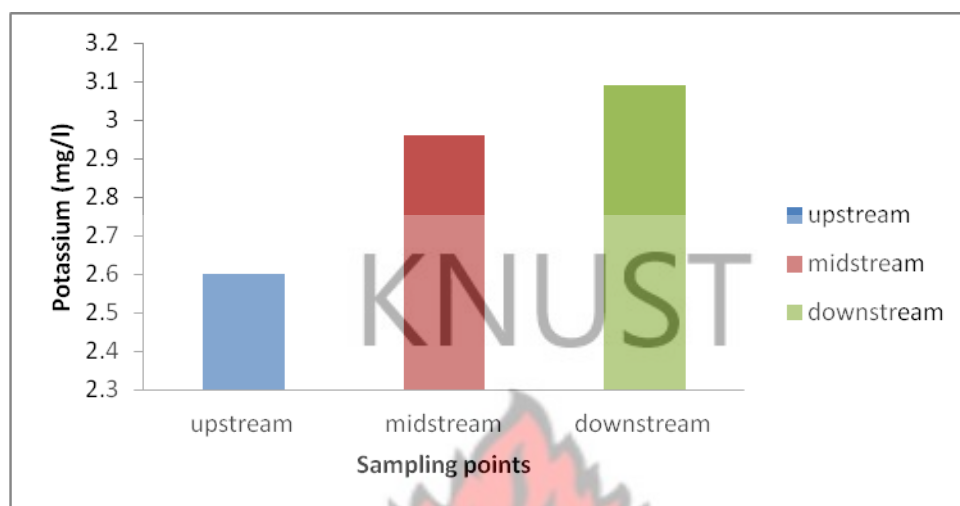


Fig. 4.12a comparison of Potassium (K) levels at the sampling points with WHO permissible values.



4.13 Calcium

The midstream with the highest mean calcium concentration of $10.90 \pm 1.31 \text{ mg/L}$ was below the WHO value of $200.00 \pm 0.00 \text{ mg/L}$. The comparison is as shown in Fig. 4.13a below;

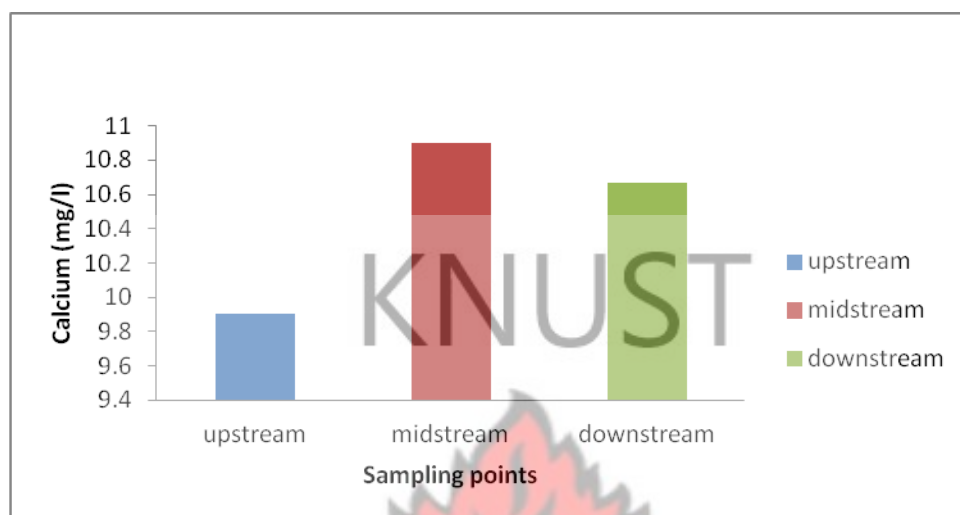


Fig. 4.13a comparison of Calcium levels at the sampling points.



4.14 Magnesium

The mean concentrations of all the samples were below the WHO value of $150.00 \pm 0.00 \text{ mg/L}$.

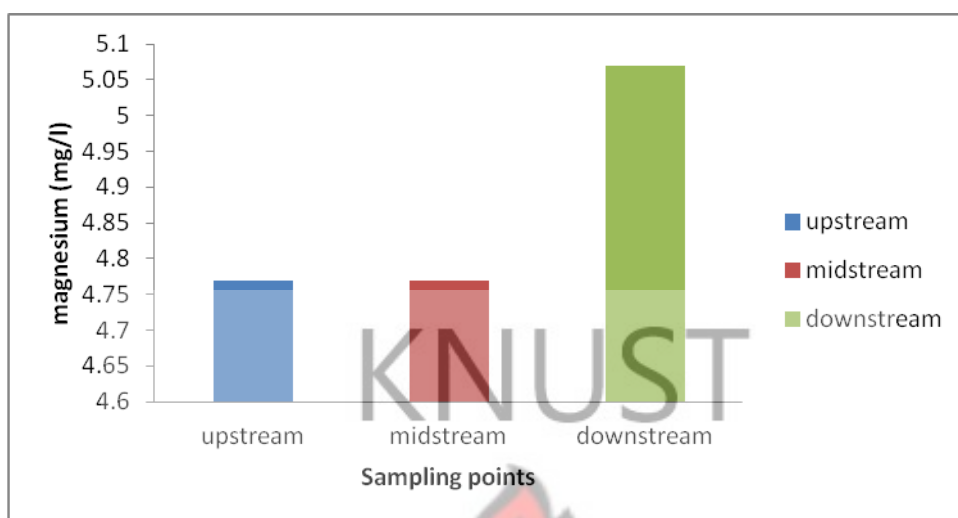
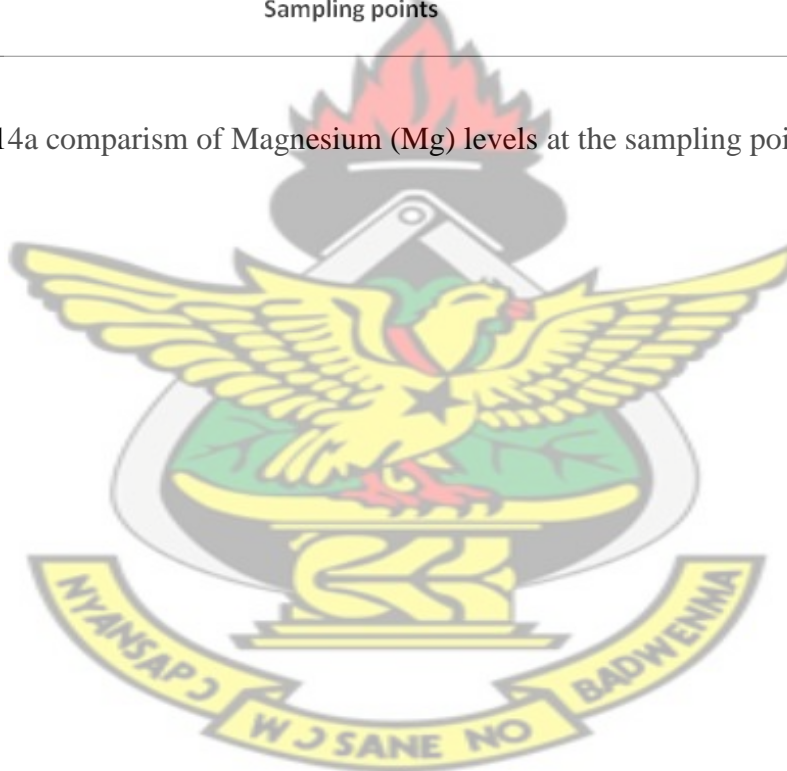


Fig. 4.14a comparison of Magnesium (Mg) levels at the sampling points.



4.15 Chloride

All the mean concentration values of the samples were above the WHO value $1.50 \pm 0.00 \text{ mg/L}$ with the midstream having the highest of $6.27 \pm 0.32 \text{ mg/L}$. The upstream had the least value of $5.87 \pm 0.09 \text{ mg/L}$.

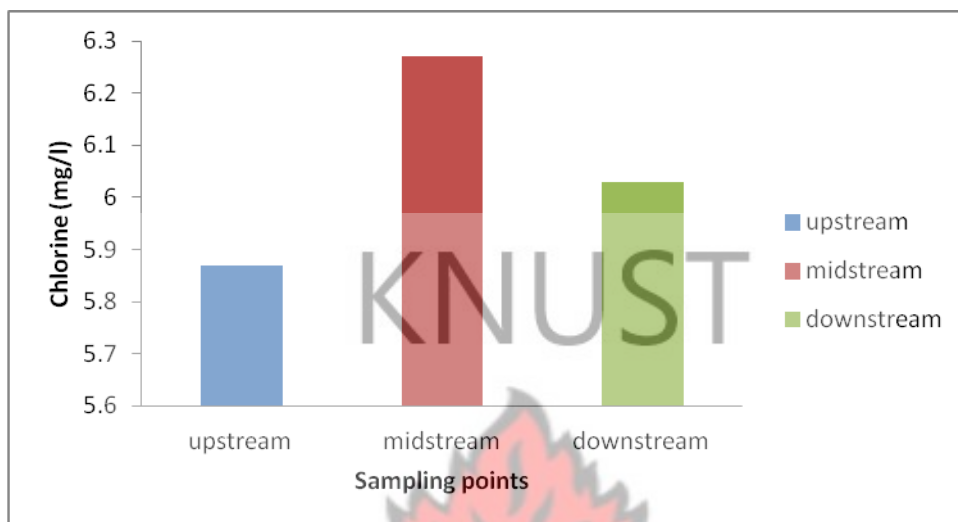


Fig. 4.15a comparison of Chloride levels at the sampling points.



4.16 Ammonium ion

None of the mean concentration of ammonium ion in the samples was near the WHO value of $250 \pm 0.00 \text{ mg/L}$.

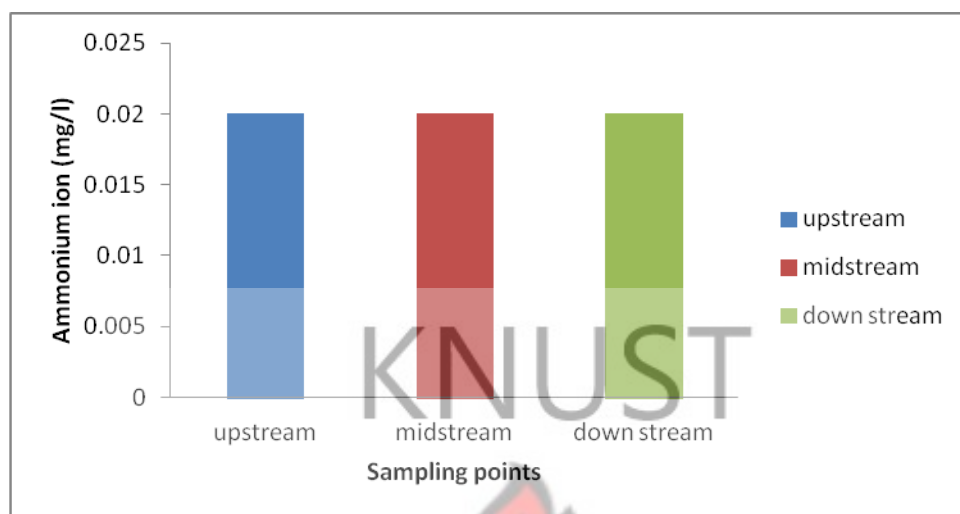
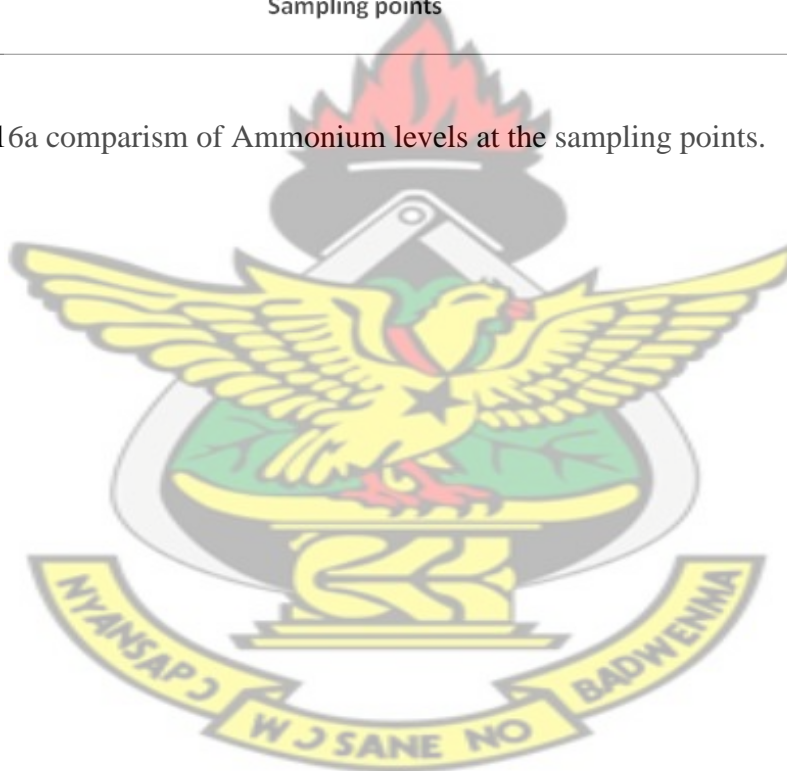


Fig. 4.16a comparison of Ammonium levels at the sampling points.



4.17 Nitrite

Though, the downstream had the highest mean Nitrite concentration of $0.05 \pm 0.03 \text{ mg/L}$, it was below the WHO value of $1.00 \pm 0.00 \text{ mg/L}$.

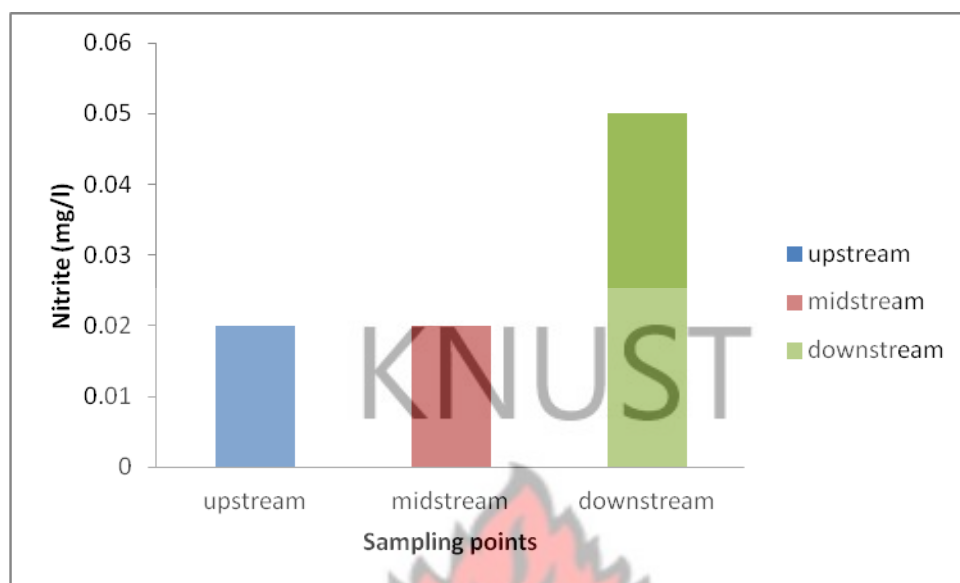


Fig. 4.17a comparison of Nitrite levels at the sampling points.



4.18 Nitrate

Though, the midstream had the highest mean Nitrate concentration of $0.14 \pm 0.01 \text{ mg/L}$, it was below the WHO value of $10.00 \pm 0.00 \text{ mg/L}$.

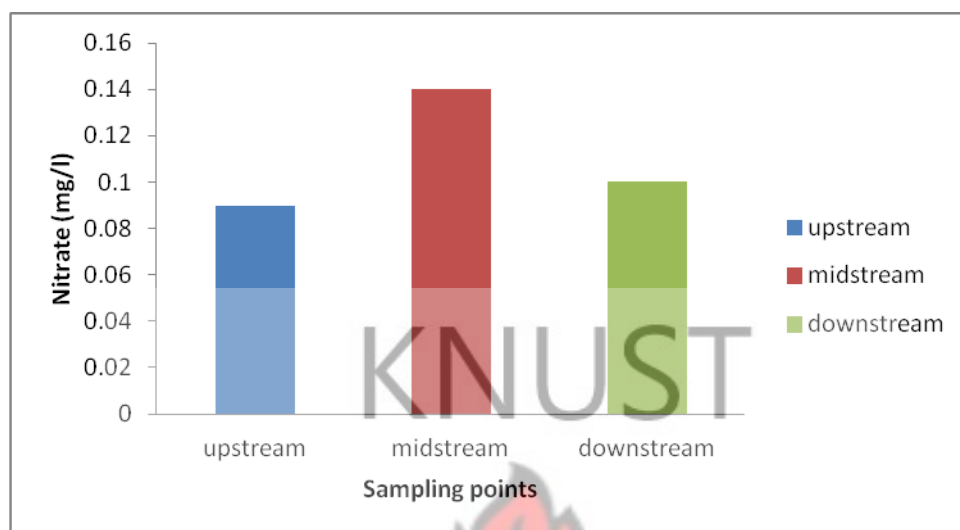
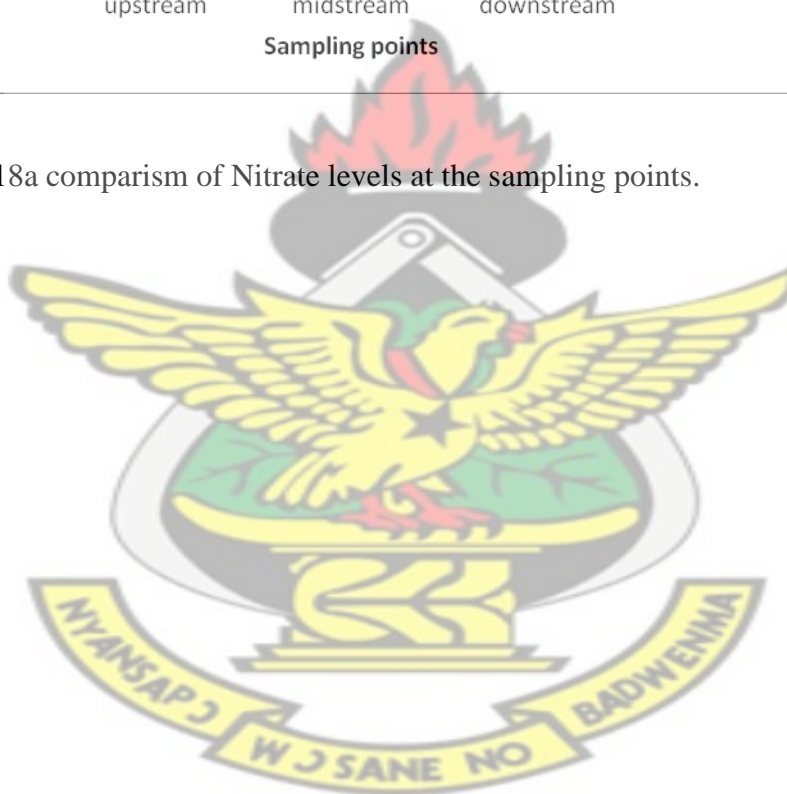


Fig. 4.18a comparison of Nitrate levels at the sampling points.



4.19 Nickel

Both the upstream and downstream $0.02 \pm 0.00 \text{ mg/L}$ had mean nickel concentration value less than the WHO value of $0.05 \pm 0.00 \text{ mg/L}$.

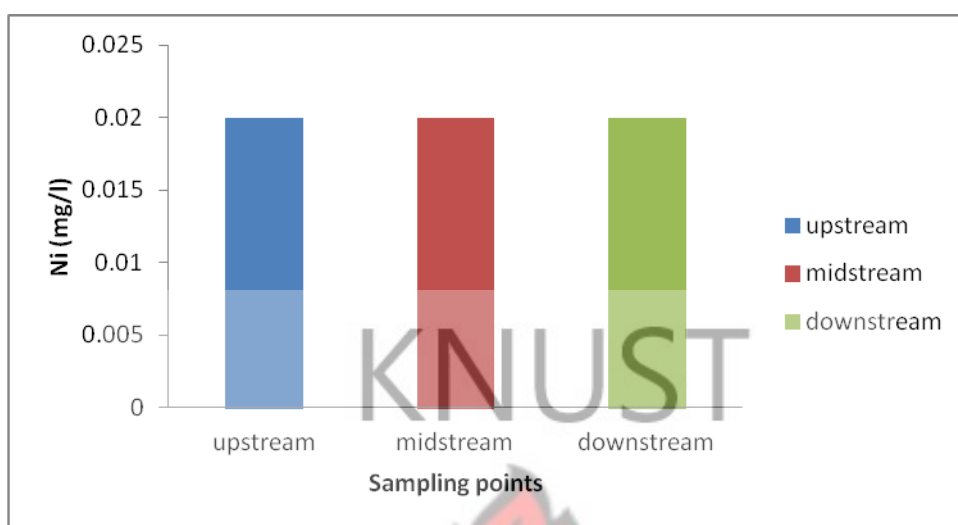
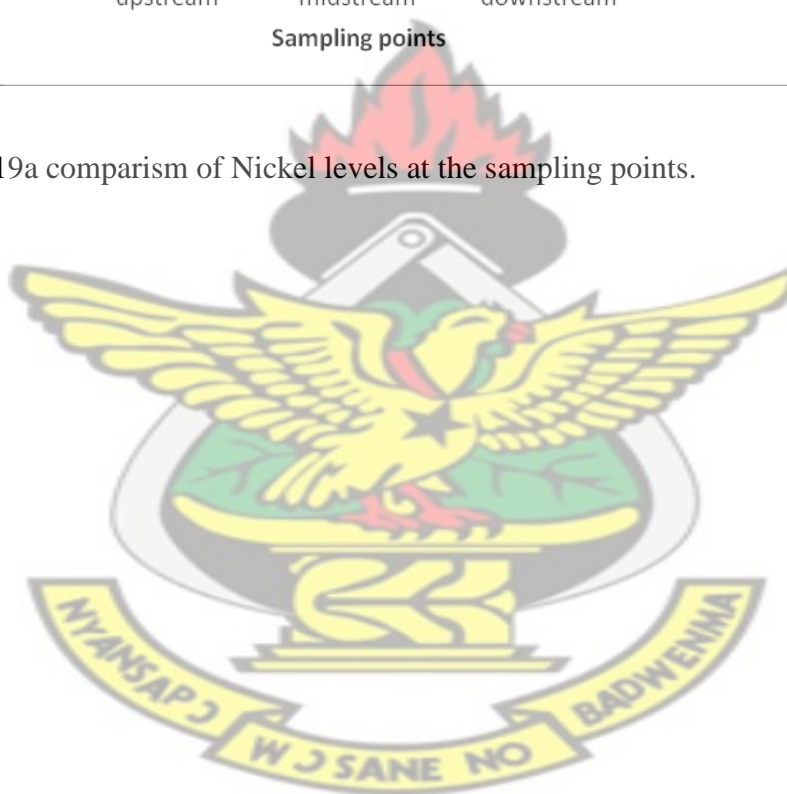


Fig. 4.19a comparison of Nickel levels at the sampling points.



4.20 Arsenic

With the WHO value of $0.01 \pm 0.00 \text{ mg/L}$ and EPA, Ghana value of $0.010 \pm 0.00 \text{ mg/L}$, only the upstream had a mean Arsenic concentration value of $0.01 \pm 0.00 \text{ mg/L}$ below with the downstream having the highest Arsenic mean concentration value of $0.02 \pm 0.00 \text{ mg/L}$.

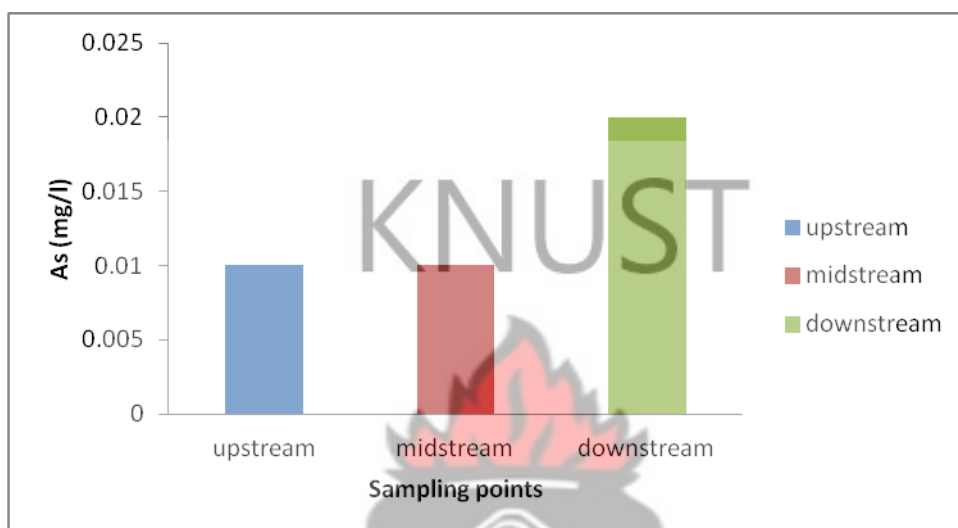
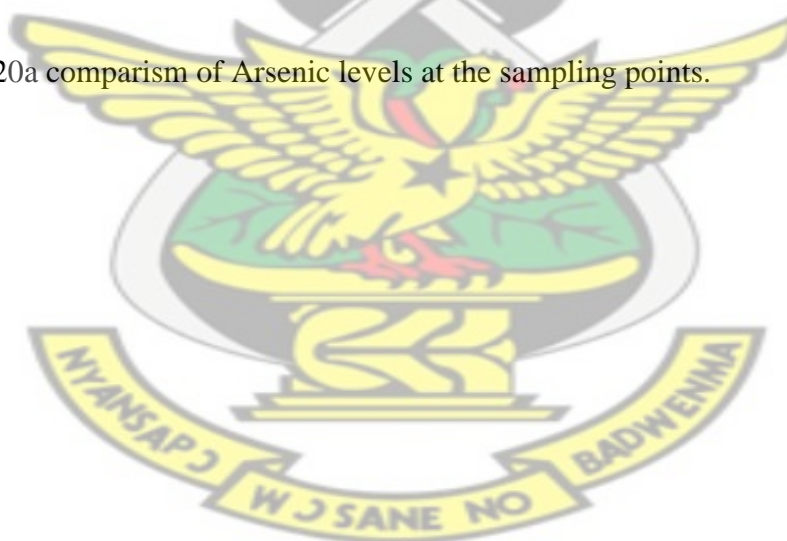


Fig. 4.20a comparison of Arsenic levels at the sampling points.



4.21 Cadmium

All the values from the sampling points were the same with a value of $0.001 \pm 0.00 \text{ mg/L}$ which was below the WHO value of $0.003 \pm 0.000 \text{ mg/L}$.

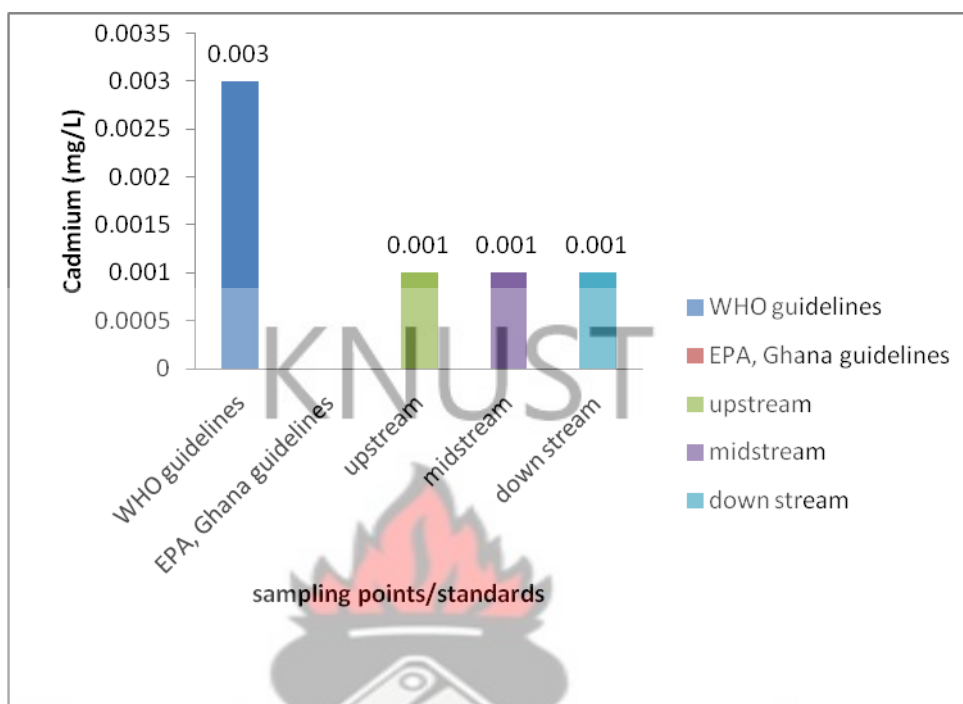


Fig. 4.21a comparism of Cadmium levels at the sampling points with WHO permissible values.

4.22 Copper

All the mean copper concentration values of the samples were below the WHO value of $2.00 \pm 0.00 \text{ mg/L}$ however, the midstream recorded was the largest value of $0.01 \pm 0.00 \text{ mg/L}$.

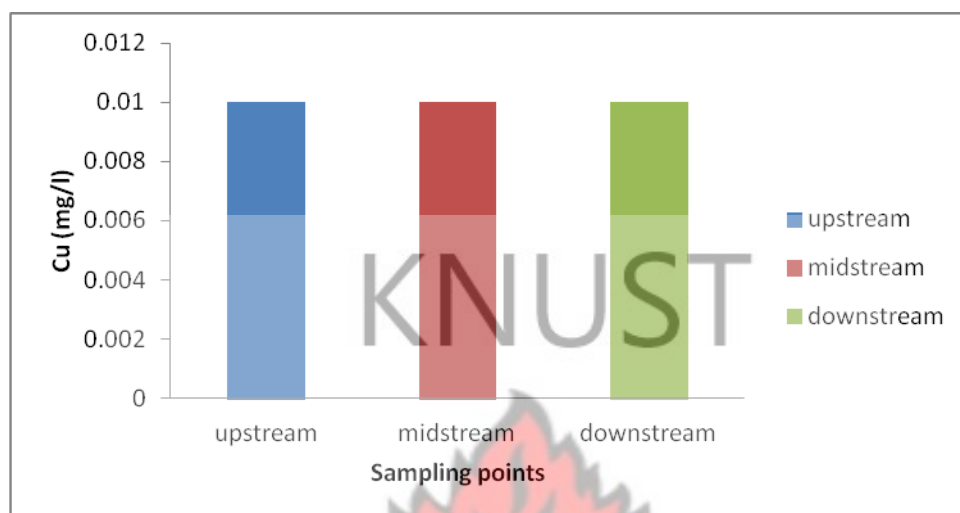


Fig. 4.22a comparison of Copper levels at the sampling points.



4.23 Nickel

All the mean values of the concentration of nickel of the sediment at the sampling sites were far below the (threshold effect level) TEL-Canada value of $18.00 \pm 0.00 \text{ mg/kg}$.

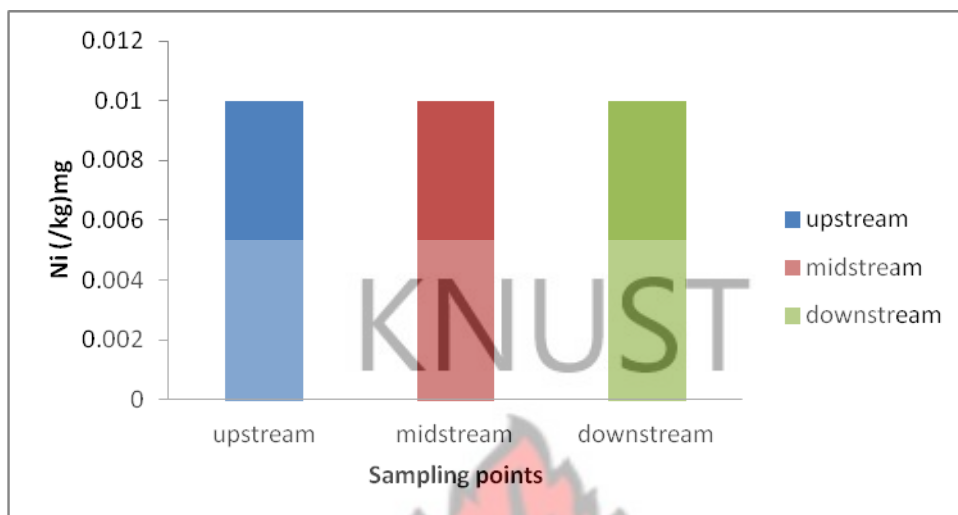


Fig. 4.23a comparison of Nickel levels in the sediment at the sampling.



4.24 Arsenic

Samples mean concentrations of Arsenic in sediment were below the TEL-Canada Arsenic for sediment concentration value of $5.90 \pm 0.00 \text{ mg/kg}$.

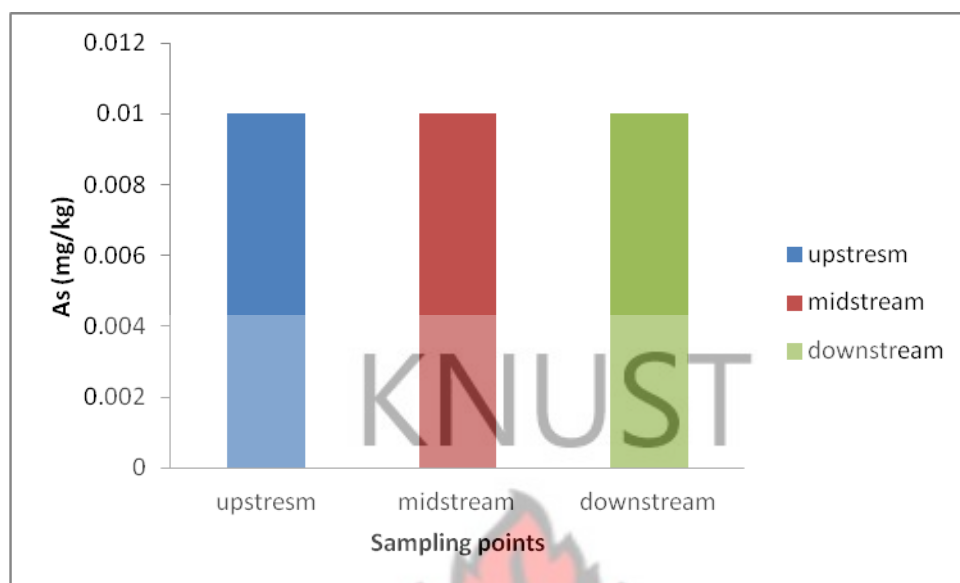


Fig. 4.24a comparison of Arsenic levels in the sediment at the sampling points.



4.25 Cadmium

For TEL-Canada value of $0.60 \pm 0.00 \text{ mg/kg}$, all the mean concentration of Cadmium in the sediment samples was far below it.

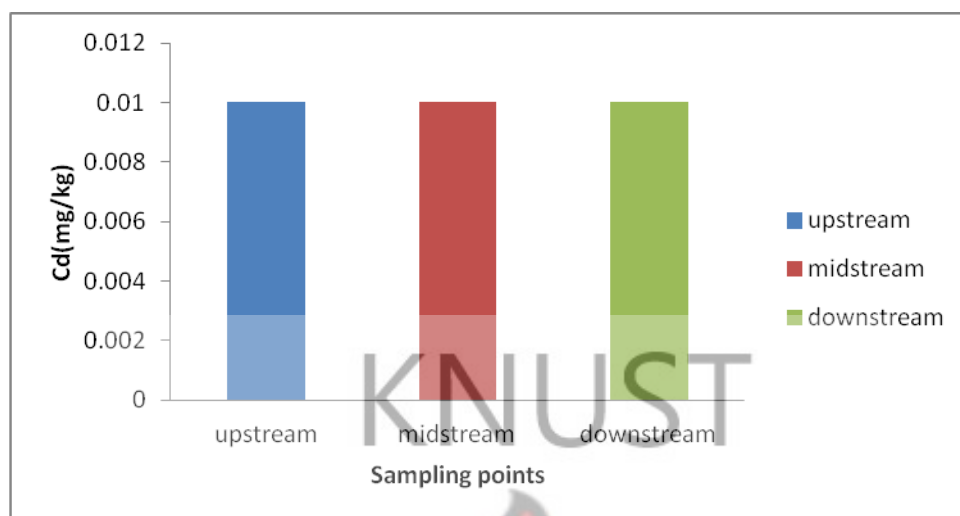
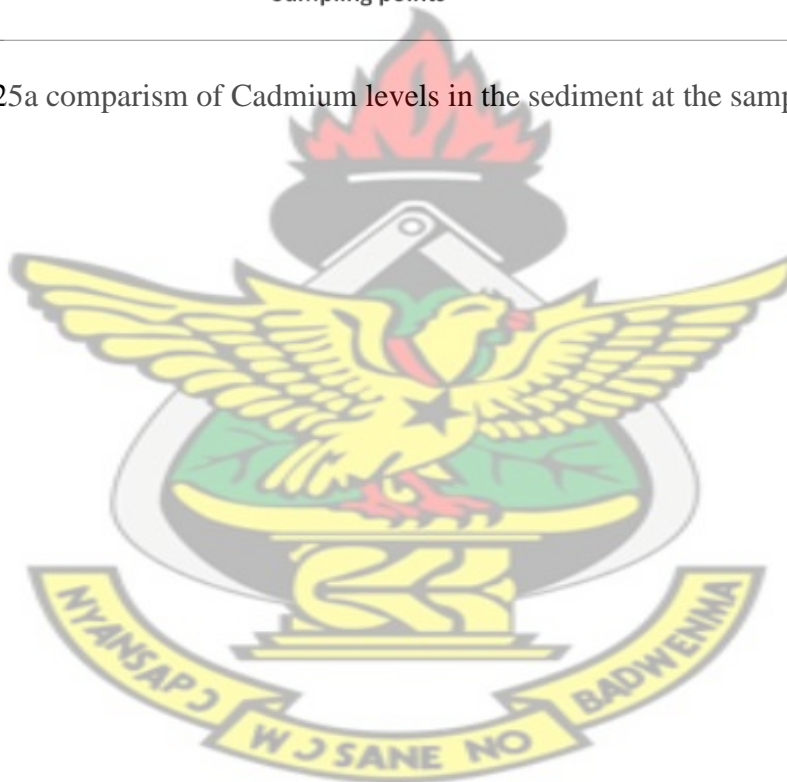


Fig. 4.25a comparison of Cadmium levels in the sediment at the sampling points.



4.26 Copper

The mean copper concentration value of the sediment samples were very low as compared with the TEL-Canada value of $37.50 \pm 0.00 \text{ mg/kg}$

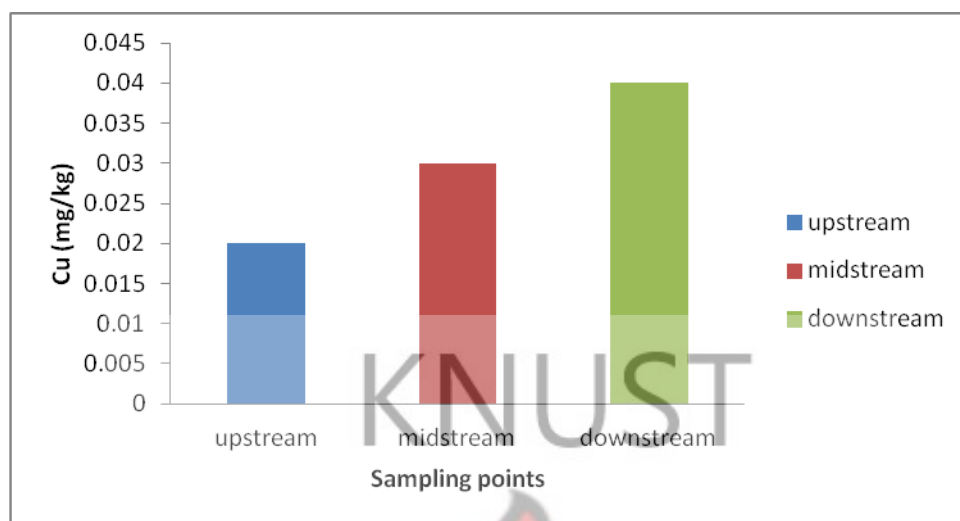


Fig. 4.26a comparison of Copper levels in the sediment at the sampling points.



4.27 Zinc

The sediment was not polluted because all the mean concentration of zinc in the samples was below the TEL-Canada value of $123.00 \pm 0.00 \text{ mg/kg}$.

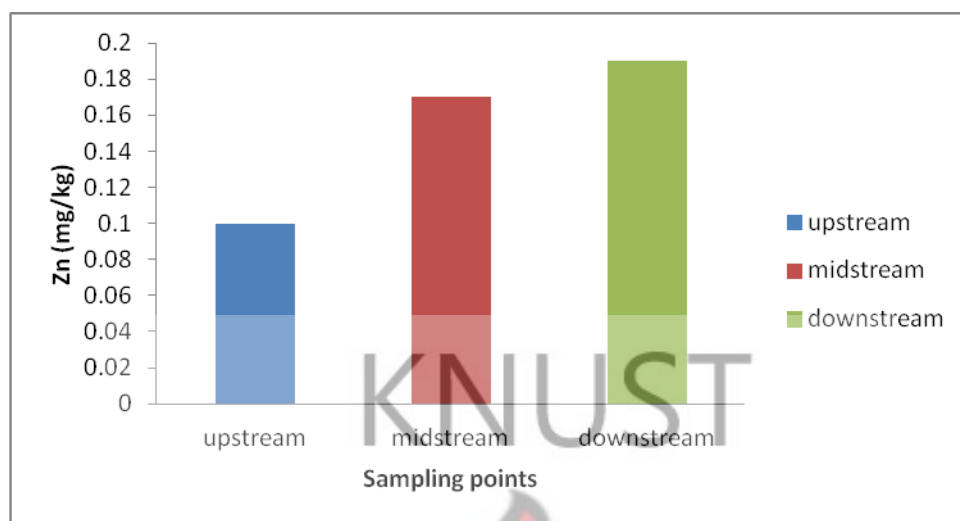
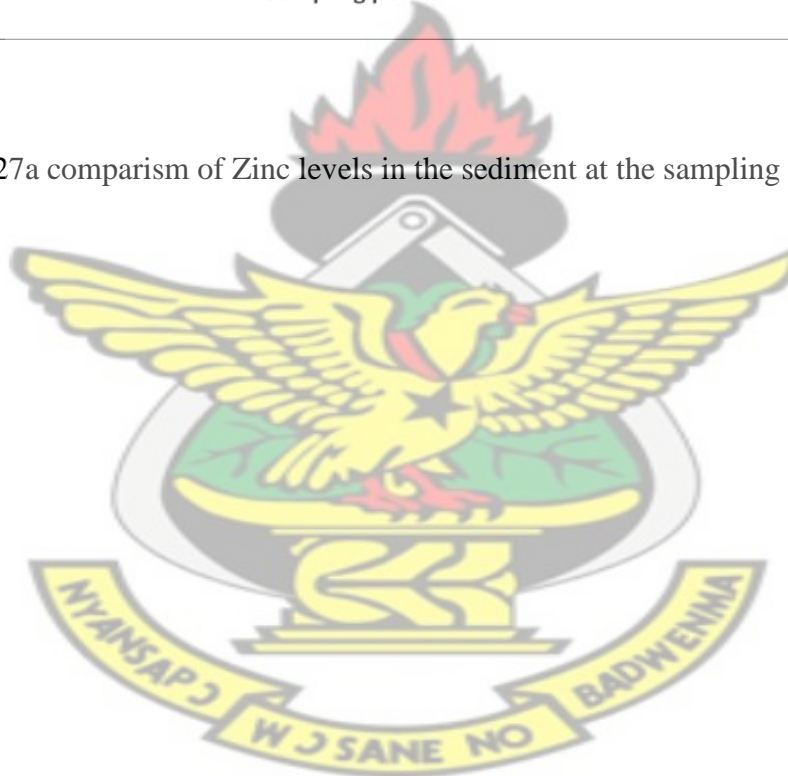


Fig. 4.27a comparison of Zinc levels in the sediment at the sampling points.



4.28 Lead

The mean lead concentration values of the sediment samples were lower as compared with the TEL-Canada value of $35.00 \pm 0.00 \text{ mg/kg}$.

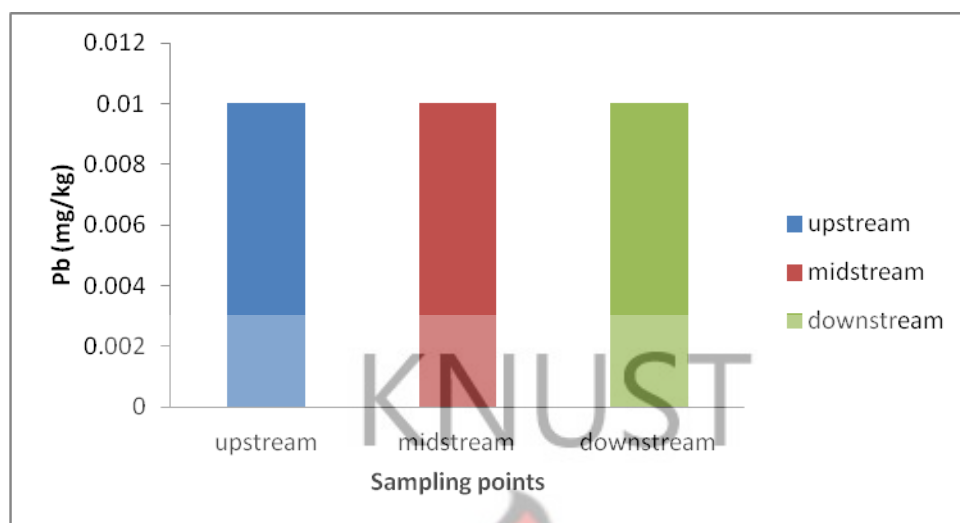
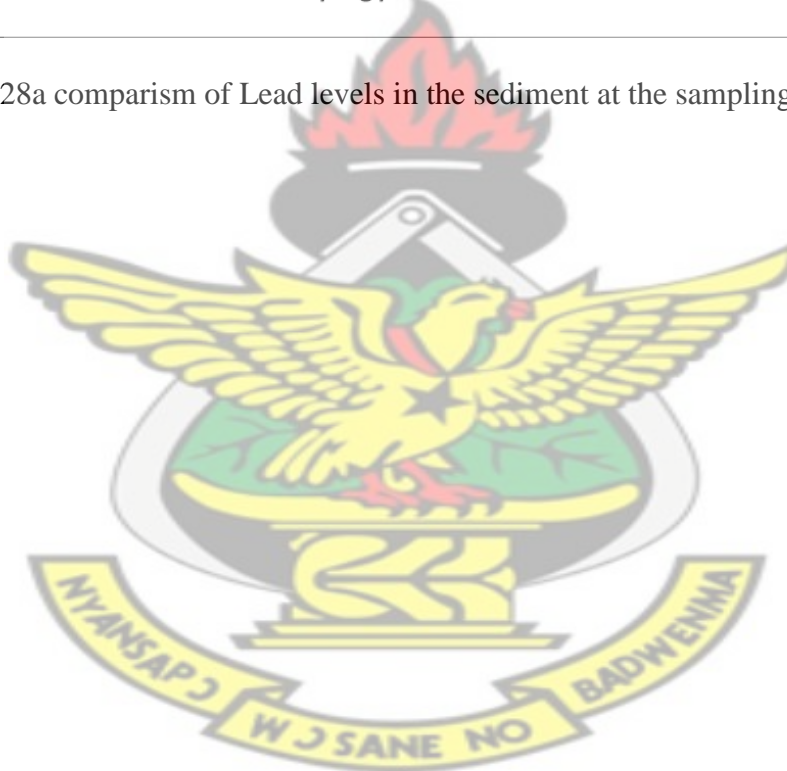


Fig. 4.28a comparison of Lead levels in the sediment at the sampling points.



4.29 Mercury

The mean mercury concentration values of all the sediment samples were astronomically higher as compared with TEL-Canada value of $0.17 \pm 0.00 \text{ mg/kg}$. The highest been the mean value of the downstream $0.09 \pm 0.00 \text{ mg/kg}$. The upstream has the least mean mercury value of $0.03 \pm 0.00 \text{ mg/kg}$ even this is far above the TEL-Canada value. The mid stream also had a value of $0.05 \pm 0.01 \text{ mg/kg}$.

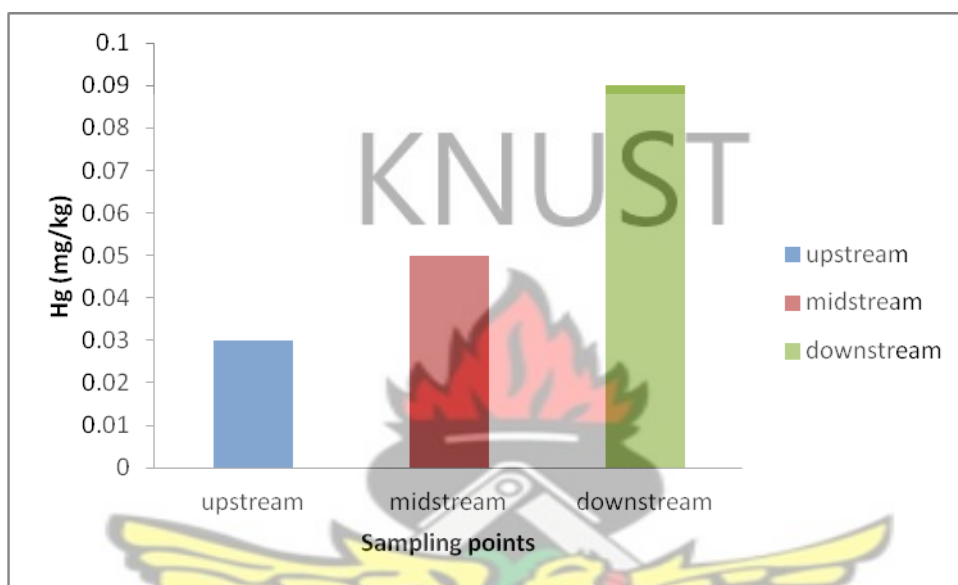


Fig. 4.29a comparison of Mercury levels in the sediment at the sampling points with TEL-Canada permissible values.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Physicochemical parameters

The mean pH of the samples collected from the selected sampling sites ranged from 7.39-7.70 indicating slightly alkaline nature. This indicates that all the samples fall within the WHO and EPA, Ghana recommended standards of 6.5-8.5. The recorded pH was higher than the natural background of 7.0 for surface water (Chapman, 1992). The increase in pH of the water samples above the normal background level was due to the presence of dissolved carbonates and bicarbonates present in the water, which is known to affect pH of almost surface water (Chapman, 1992). This shows that the pH of the water should not affect its use as domestic, recreational and the aquatic ecosystem.

The mean temperature of the samples ranged from 25.80°C at both upstream and midstream to a maximum of 26.03°C at downstream. There is no set standard temperature for WHO but EPA, Ghana had 38.00°C - 40.00°C. The water temperature is influenced by the atmospheric ambient temperature at the time of sampling. The high temperature recorded at downstream may be due to the high turbidity in the stream (DWAF, 1998).

The mean colour of the samples ranged from a minimum of 8.67colour unit at the upstream to a maximum of 85.0colour unit at the downstream. All mean colour levels were above the WHO acceptable limit for surface water of 15.00colour unit but were within the EPA, Ghana acceptable limit of 150colour unit. This colour could have been influenced by humic substance from the soil, dissolved organic materials and decaying plants and animals. Colour is also strongly influenced by iron

and other metals, either as impurities or as a corrosion product (Karikari and Ansa-Asare, 2006).

Mean turbidity values ranges from 8.67NTU at the upstream to 171NTU at the downstream. The WHO limit is 5.00NTU while that of EPA, Ghana is 75.00NTU. However, an average turbidity of 37.5NTU has been recorded in the Birim basin by Ansa-Asare and Asante (2000). The high turbidity values recorded may be due to excavation of the river beds by the illegal miners. Water turbidity affects water temperature, as suspended particles in a water column absorb and scatter sunlight and hence determine the extinction of solar radiation.

TDS is the most common indicator of polluted water (Tay, 2007). The mean TDS values ranged from 16.49mg/L downstream to 72.139g/L midstream. These values were not alarming as compared to the WHO limit of 1000mg/L. However, in Ghana, it is of much concern since the EPA - Ghana guideline for TDS is less than 50mg/L (EPA - Ghana, 1994). According to MacCutcheon et al. (1983), the palatability of water with TDS level less than 600mg/L is generally considered to be good whereas water with TDS greater than 1200mg/L becomes increasingly unpalatable, hence with EPA, Ghana guidelines, the water could be considered unpalatable.

The mean total suspended solids (TSS) values ranged from 2.27mg/L at upstream to 16.49mg/L downstream. Though these were not a problem as compared to EPA-Ghana guidelines of 50.00mg/L but when compared to WHO limit of 20.00mg/L,

high turbidity values could be due to land-use practices such as excavation etc, discharge of raw sewage and domestic waste which brings large quantities of silt and debris into the streams (Cloern, 1987).

The midstream recorded the highest mean total alkalinity value of 44.94mg/L where as the downstream recorded the minimum value of 40.20.93mg/L. These values could be due to the excavation of the stream and its banks by the illegal miners.

The mean nitrite concentrations were below the recommended limit of 1.00mg/L in all the sampling sites (WHO, 2004), (Meybeck and Helmer, 1989). The lowest mean concentration was recorded at midstream with a value of 0.02mg/L while that highest at downstream with a value of 0.050mg/L. These values could be as a result of human activities such as bathing around the area. Mean nitrate concentration were also below the WHO (2004) recommended limit of 10.00mg/L. the lowest mean concentration of 0.09mg/L was recorded at the upstream whereas the highest of 0.14mg/L was recorded at the midstream. This could be due to human activities such as washing activities around that area.

Ammonium mean concentration values were far below the WHO (2004) value of 250mg/L, with the upstream recording the least value of 0.014mg/L and maximum of 0.02mg/L at the downstream. Although these values were far below the WHO, human activities such as bathing along the area could have had an impact. The

problem of dour could arise when $\text{NH}_3\text{-N}$ level is greater than 2.0mg/L (WHO, 1993; Kempster et al., 1997).

EPA-Ghana has a permissible limit value of phosphate concentration as 2.0mg/L. All the mean concentration values of the samples were below, with the highest recorded at downstream with a value of 0.60mg/L and the upstream having the least value of 0.20mg/L but these values were higher as compared to WHO value of 0.3mg/L.

In most natural surface waters phosphorous ranges from 0.005 to 0.020mg/L (Chapman, 1992). Higher concentration of phosphate in water bodies is an indication of pollution and is largely responsible for eutrophication (MacCutcheon et al., 1983). This higher phosphate level at the downstream was due to numerous farming activities along the banks of the stream (Sharpley et al., 1987).

Electrical conductivity values varied between 112.3 $\mu\text{S/cm}$ for the upstream and 121.7 $\mu\text{S/cm}$ for the midstream as the highest. According to Koning and Roos, (1999), the average electrical conductivity value of a neutral unpolluted stream is exactly 350 $\mu\text{S/cm}$. All the values of the samples were below the WHO limit of 1500 $\mu\text{S/cm}$. Health effect of high level of electrical conductivity in humans may include disturbance of the salt and water balance with an adverse effect on certain heart patients and individuals with high blood pressure (Fatoki and Awofolu, 2003).

5.4 Total Hardness and Dissolved ion Characteristics

The mean range concentration of total hardness of all the samples could be said to be soft because their values fell below both EPA-Ghana and WHO value of 500mg/L. The hardness of the river reduced from downstream 43.67mg/L to midstream 46.17mg/L. Antwi and Ofori-Danso, (1993) has reported a range of 19-38mg/L in River Volta.

KNUST

5.5 Heavy Metal Characteristics

Mean concentration of iron varied from a minimum of 0.494mg/L at the upstream to a maximum of 4.64mg/L at the downstream. All the mean concentration of the samples exceeded the WHO, (2004) limit of 0.30mg/L. The increase could be due to surface erosion of iron contaminated soils into the stream. Other possible sources of pollution of iron could be the geology of the area and seepage from waste sites.

The mean concentration of zinc was below the WHO and EPA-Ghana limit of 3.00mg/L with the upstream having the least value of 0.08mg/L. The midstream had the highest value of 0.12mg/L. There is therefore, no detrimental effect in using this water for domestic and other purposes. In the sediments, the highest mean zinc concentration was recorded at the downstream 0.19mg/kg and the lowest recorded at the upstream 0.10mg/kg. The mean concentrations were very low as compared to the TEL-Canada value of 123.00mg/kg.

The stream was characterised by a mean lead concentration of 0.02mg/L at the midstream while the upstream had 0.01mg/L as the lowest. These mean

concentrations were below the WHO limit of 0.10mg/L. In the sediments, all the mean concentrations recorded were <0.01mg/kg as compared to the TEL-Canada value of 35.00mg/kg.

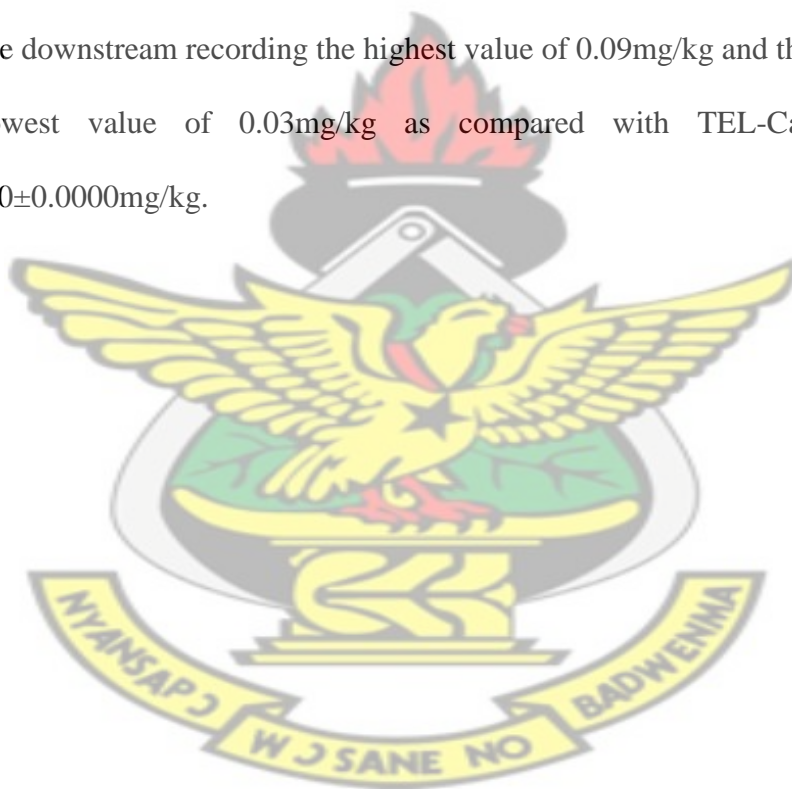
The mean concentration of copper in all the samples 0.01mg/L were below the WHO value of 2.0mg/L. The sediments, the downstream had the highest mean copper concentration 0.04mg/kg and the upstream had the lowest value 0.02mg/kg. Based on the TEL-Canada value of 35.70mg/kg, the water is not a threat to human health and aquatic life or use.

Mean concentration of Nickel in all the samples recorded the same value 0.02mg/L. WHO limit of 0.05mg/L. In the sediment, the mean concentration of Nickel in the samples were extremely low <0.01mg/kg as compared to TEL-Canada limit of 18.00mg/kg. This indicates that both the water and sediment were harmless to human health and aquatic life.

Arsenic, although all the mean concentration values were below the WHO of 0.010mg/L, as compared, the lowest value recorded was 0.01mg/L for the upstream and the downstream recorded the highest 0.02mg/L. Similarly, the mean concentration of arsenic in the sediment was also below the TEL-Canada value of 5.90mg/kg with all the sampling points recording <0.01mg/kg. Hence this will not cause any health problems and other aquatic ecosystem.

The mean concentration of cadmium at all the sampling point was below the WHO value of 0.003mg/L. The values for all the sampling points were the same 0.001mg/L, additionally, the values of mean cadmium concentration of all the samples in the sediment were also the same <0.01mg/kg and far below the TEL-Canada value of 0.60mg/kg.

Mercury, has WHO limit of 0.001mg/L but all the mean concentration values of the samples were <0.0001mg/L though, in the sediment there was significant changes at with the downstream recording the highest value of 0.09mg/kg and the upstream with the lowest value of 0.03mg/kg as compared with TEL-Canada limit of 0.17000 ± 0.0000 mg/kg.



CHAPTER SIX

6.0 CONCLUSION

In general, almost all the physicochemical parameters including heavy metals determined in both water and sediment samples from the Birim River were below the minimum permissible limit of E.P.A-Ghana, WHO and TEL-Canada. Much importance should be attached or placed on heavy metals in the choice of sources of drinking water as their potential toxicity to both man and animals could be fatal.

Currently only the upstream at Apapam can be considered clean and not polluted as only pH, total dissolved solids, chlorides and iron were slightly above the WHO and E.P.A-Ghana guidelines compared with.

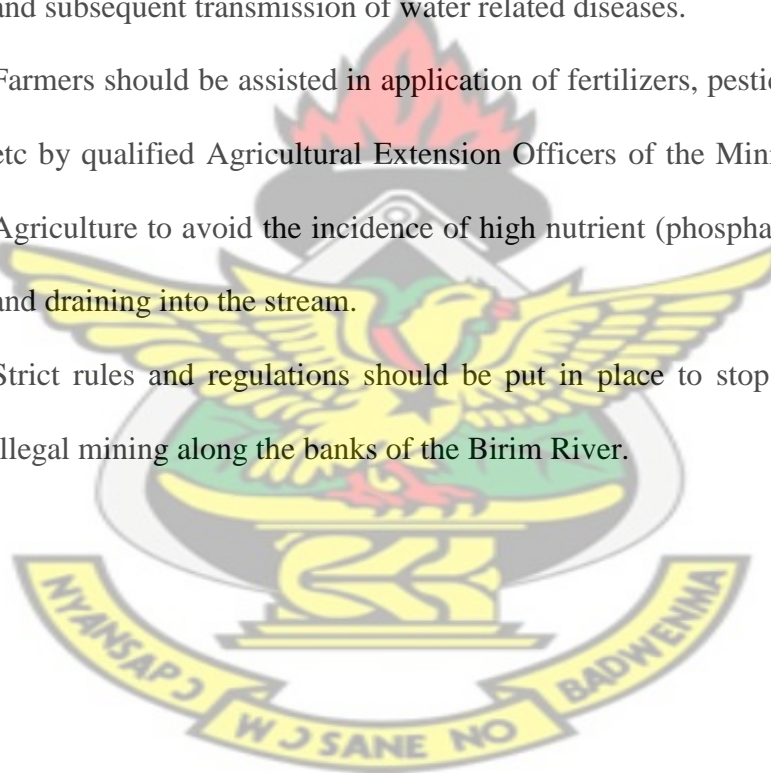
Aesthetically, both midstream sampling point at Kyebi and down stream sampling point at Bunso could be said to be polluted as their values compared with that of minimum permissible limit of E.P.A-Ghana and WHO were above for the following parameters; colour (apparent), total dissolved solids, chloride, turbidity, calcium hardness, magnesium hardness, and iron. The pollution was intense in areas of human activities such as illegal mining, washing bay (washing of vehicles), and farming activities. Hence such activities need to be checked to avoid long term pollution and destruction of the ecosystem.

The Birim River as is it now does not have the capacity to cleanse itself when it is polluted with external pollutants.

6.1 RECOMMENDATION

Since the Birim River is used for a variety of purposes such as drinking, fishing, and other domestic purposes without prior treatment for sustainable management of the water resources, the following must be observed.

- ✚ Regular monitoring of the catchments is required to ensure good water quality standards are achieved in the catchments for use.
- ✚ Kyebi Municipal Assembly should design sanitation programmes and propagate these through environmental education throughout the communities in the catchments to prevent further pollution of the Birim River and subsequent transmission of water related diseases.
- ✚ Farmers should be assisted in application of fertilizers, pesticides, herbicides, etc by qualified Agricultural Extension Officers of the Ministry of food and Agriculture to avoid the incidence of high nutrient (phosphate) loads seeping and draining into the stream.
- ✚ Strict rules and regulations should be put in place to stop the activities of illegal mining along the banks of the Birim River.



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APPENDIX A

Table 1: summary of results taken on 06/02/2012 for heavy metals and physicochemical parameters

PARAMETER	UNIT	UPSTREAM	MIDSTRE AM	DOWNS TREAM	WHO GUIDELINE
Turbidity	NTU	11.0	223	436	5
Colour (apparent)	Hz	5.00	150	200	15
pH	pH	8.16	7.87	7.65	
	Units				6.5-8.5
Conductivity	$\mu\text{S/cm}$	144	145	120	-
Tot. Susp. Solids	mg/l	6.00	15.0	32.0	-
Tot. Dis. Solids	mg/l	79.7	85.2	68.4	1000
Sodium	mg/l	5.50	6.00	5.90	200
Potassium	mg/l	2.50	3.30	3.00	30
Calcium	mg/l	13.1	13.5	13.2	200
Magnesium	mg/l	6.00	5.90	5.50	150
Chloride	mg/l	6.00	6.90	6.20	0.00-1.5
Ammonium	mg/l	0.012	0.012	0.014	250
Sulphate (SO_4)	mg/l	18.2	18.6	19.0	250
Phosphate (PO_4 -P)	mg/l	0.093	0.206	0.230	-
Nitrite (NO_2 -N)	mg/l	0.029	0.036	0.109	1
Nitrate (NO_3 -N)	mg/l	0.123	0.262	0.081	10
Total Hardness	mg/l	57.2	51.4	41.4	500
Total Alkalinity	mg/l	62.0	53.2	34.4	-
Cal. Hardness	mg/l	32.7	31.1	24.4	-
Mag Hardness	mg/l	34.5	20.3	17.0	-
Flouride	mg/l	0.200	0.201	0.206	1.5
Bicarbonate	mg/l	60.6	64.9	62	-
Carbonate	mg/l	0	0	0	-
Iron	mg/l	0.242	3.54	11.5	0.3

Manganese	mg/l	0.004	0.188	0.459	0.4
Ni	mg/l	0.021	0.022	0.018	0.05
As	mg/l	0.007	0.01	0.017	0.01
Pd	mg/l	0.01	0.02	0.01	0.1
Cd	mg/l	<0.002	<0.002	<0.002	0.003
Cu	mg/l	<0.010	<0.010	<0.010	2
Zn	mg/l	<0.010	0.119	0.123	3
Hg	mg/l	<0.001	<0.001	<0.001	0.001
Temperature	°C	25.4	25.2	25.2	

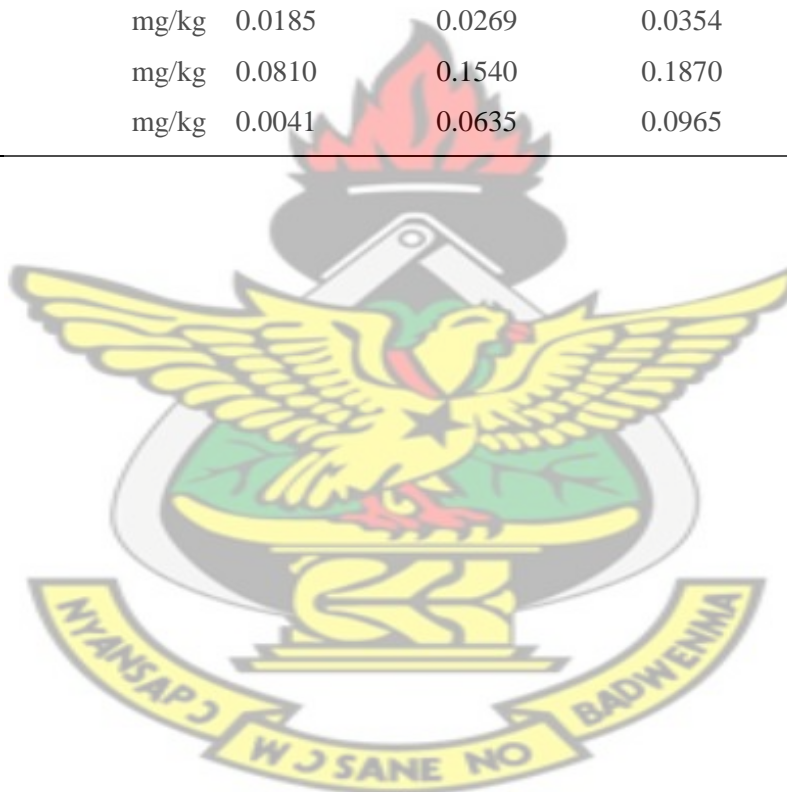
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APPENDIX B

Table 2: summary of the results of the sediment taken on 06/02/2012

PARAMETER	UNIT	UPSTREAM	MIDSTREA M	DOWNSTREA M	CANAD A (TEL)
Iron	mg/kg	9.57	36.26	36.99	
Manganesse	mg/kg	0.31	0.37	0.37	
Ni	mg/kg	0.0003	0.0006	0.0008	18
As	mg/kg	0.0003	0.0006	0.0009	5.9
Pd	mg/kg	<0.00060	<0.00060	0.0090	35
Cd	mg/kg	<0.00025	<0.00025	<0.00025	0.6
Cu	mg/kg	0.0185	0.0269	0.0354	35.7
Zn	mg/kg	0.0810	0.1540	0.1870	123
Hg	mg/kg	0.0041	0.0635	0.0965	0.17



APPENDIX C

Table 3: summary of results taken on 05/03/2012 for heavy metals and physicochemical parameters

PARAMETER	UNIT	UPSTREA M	MIDSTR EAM	DOWNSTR EAM	WHO GUIDELINE
Turbidity	NTU	7.00	16.0	36.0	5
Colour (apparent)	Hz	10.0	10.0	25.0	15
pH	pH unit	7.41	7.18	7.27	6.5-8.5
Conductivity	$\mu\text{S}/\text{cm}$	95.0	107	109	-
Tot. Susp. Solids	mg/l	1.80	3.00	8.00	-
Tot. Dis. Solids	mg/l	52.3	58.9	60.0	1000
Sodium	mg/l	5.16	5.42	5.62	200
Potassium	mg/l	3.00	3.19	3.58	30
Calcium	mg/l	8.00	9.80	9.60	200
Magnesium	mg/l	4.10	4.40	4.80	150
Chloride	mg/l	6.00	6.00	6.00	0.00-1.5
Ammonium	mg/l	0.016	0.019	0.02	250
Sulphate (SO_4)	mg/l	3.78	4.72	4.37	250
Phosphate ($\text{PO}_4\text{-P}$)	mg/l	0.246	0.35	0.829	-
Nitrite ($\text{NO}_2\text{-N}$)	mg/l	0.023	0.017	0.021	1
Nitrate ($\text{NO}_3\text{-N}$)	mg/l	0.071	0.087	0.124	10
Total Hardness	mg/l	36.8	42.6	43.6	500
Total Alkalinity	mg/l	34.8	41.2	42.4	-
Cal. Hardness	mg/l	20.0	24.4	24.0	-
Mag Hardness	mg/l	16.8	18.2	19.6	-
Flouride	mg/l	0.157	0.244	0.375	1.5
Bicarbonate	mg/l	42.5	50.3	51.7	-
Carbonate	mg/l	0	0	0	-
Iron	mg/l	0.557	0.895	1.25	0.3
Manganesse	mg/l	0.043	0.133	0.170	0.4
Ni	mg/l	0.019	0.022	0.023	0.05
As	mg/l	0.009	0.014	0.020	0.01

Pd	mg/l	0.011	0.021	0.013	0.1
Cd	mg/l	<0.002	<0.002	<0.002	0.003
Cu	mg/l	<0.010	0.015	<0.010	2
Zn	mg/l	0.121	0.120	<0.01	3
Hg	mg/l	<0.001	<0.001	<0.001	0.001
Temperature	°C	25.8	26.1	26.2	

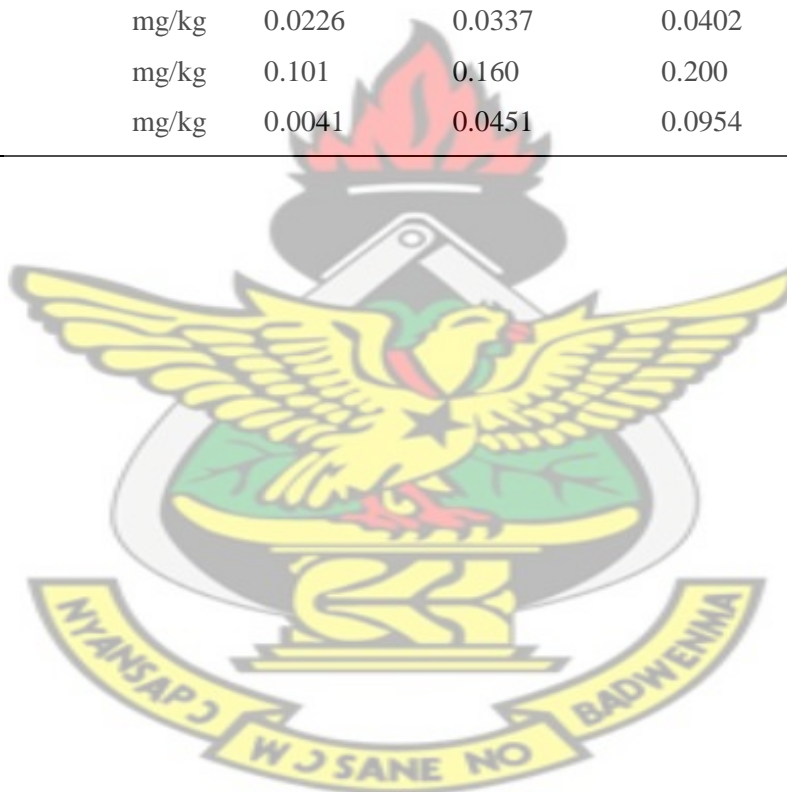
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APPENDIX D

Table 4: summary of the results of the sediment taken on 05/03/2012

PARAMETER	UNIT				CANADA (TEL)
		UPSTREAM	MIDSTREAM	DOWNSTREAM	
Iron	mg/kg	10.120	33.258	35.222	
Manganese	mg/kg	0.290	0.301	0.380	460
Ni	mg/kg	0.00031	0.000528	0.001	18
As	mg/kg	0.00020	0.001	0.001	5.9
Pd	mg/kg	0.0020	0.0030	0.0012	35
Cd	mg/kg	<0.00025	<0.00025	<0.00025	0.6
Cu	mg/kg	0.0226	0.0337	0.0402	35.7
Zn	mg/kg	0.101	0.160	0.200	123
Hg	mg/kg	0.0041	0.0451	0.0954	0.17



APPENDIX E

Table 5: summary of results taken on 04/04/2012 for heavy metals and physicochemical parameters

PARAMETER	UNIT	UPSTREA M	MIDSTR EAM	DOWNST REAM	WHO GUIDELINE
Turbidity	NTU	8.00	18.0	41.0	5
Colour	Hz	11.0	12.5	30.0	15
pH	pH	7.53	7.26	7.24	6.5-8.5
Conductivity	µS/cm	98.0	113	120	-
Tot. Susp. Solids	mg/l	2.00	3.60	9.46	-
Tot. Dis. Solids	mg/l	62.7	72.3	74.5	1000
Sodium	mg/l	4.50	4.60	5.10	200
Potassium	mg/l	2.30	2.40	2.70	30
Calcium	mg/l	8.60	9.40	9.20	200
Magnesium	mg/l	4.20	4.60	4.90	150
Chloride	mg/l	6.00	6.00	6.00	0.00-1.5
Ammonium	mg/l	0.014	0.014	0.020	250
Sulphate (SO ₄)	mg/l	4.00	4.96	4.68	250
Phosphate (PO ₄ -P)	mg/l	0.268	0.364	0.740	-
Nitrite (NO ₂ -N)	mg/l	0.020	0.014	0.020	1.0
Nitrate (NO ₃ -N)	mg/l	0.083	0.080	0.118	10
Total Hardness	mg/l	38.6	44.5	46.0	500
Total Alkalinity	mg/l	33.1	40.5	43.8	-
Cal. Hardness	mg/l	21.6	27.2	26.2	-
Mag Hardness	mg/l	17.0	17.3	19.8	-
Flouride	mg/l	0.150	0.214	0.226	1.5
Bicarbonate	mg/l	44.6	52.4	55.0	-
Carbonate	mg/l	0	0	0	-
Iron	mg/l	0.682	0.881	1.18	0.3
Manganesse	mg/l	0.050	0.108	0.162	0.4
Ni	mg/l	0.020	0.020	0.014	0.05
As	mg/l	0.010	0.012	0.020	0.01

Pd	mg/l	0.013	0.021	0.016	0.1
Cd	mg/l	<0.002	<0.002	<0.020	0.003
Cu	mg/l	<0.010	0.011	<0.010	2
Zn	mg/l	<0.10	0.122	0.130	3
Hg	mg/l	<0.001	<0.001	<0.001	0.001
Temperature	%C	26	25.6	25.9	

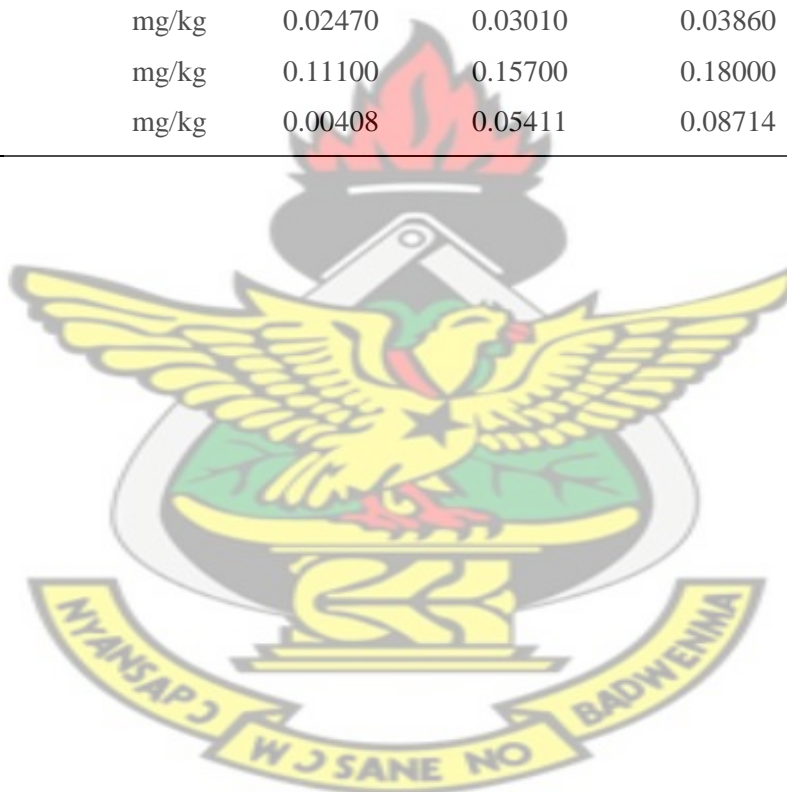
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APPENDIX F

Table 6: summary of the results of the sediment taken on 04/04/2012

PARAMETER	UNIT	UPSTREAM	MIDSTREAM	DOWNSTREAM	CANADA (TEL)
Iron	mg/kg	11.22000	33.00800	35.70000	
Manganese	mg/kg	0.26800	0.34000	0.37200	460
Ni	mg/kg	0.00034	0.00050	0.00061	18
As	mg/kg	0.00024	0.00054	0.00061	5.9
Pd	mg/kg	0.00300	0.00500	0.00900	35
Cd	mg/kg	<0.00025	<0.00025	<0.00025	0.6
Cu	mg/kg	0.02470	0.03010	0.03860	35.7
Zn	mg/kg	0.11100	0.15700	0.18000	123
Hg	mg/kg	0.00408	0.05411	0.08714	0.17



APPENDIX G

Table 7: Summary of the mean values of the water samples as compared to WHO and EPA, Ghana values

PARAMETER	UNIT	UPSTREAM	MIDSTREAM	DOWNSTREAM	WHO	EPA-GHANA
Turbidity	NTU	8.67±1.20*	85±68.7	171±133	5.00±0.00	75.00±0.00
Colour (apparent)	Colour unit	8.67±1.20*	58.5±45.8**	85.0±57.5	15.00±0.00	150.00±0.00
pH	pH units	7.70±0.23***	7.44±0.22	7.39±0.13**	7.50±0.00	7.50±0.00
Conductivity	µS/cm	112.3±15.9**	121.7±11.8**	116.33±3.67**	1500±0.00USEPA	
Tot.susp. solids	mg/l	2.27±0.37*	7.20±3.90	16.49±7.77	1000±0.00	50.00±0.00
Tot.Disolved solids	mg/l	64.90±7.99**	72.13±7.59**	16.49±7.77**	20.00±0.00	
Sodium	mg/l	5.05±0.29**	5.34±0.41**	5.54±0.23**	200.00±0.00	
Potassium	mg/l	2.60±0.21**	2.96±0.28**	3.09±0.26**	30.00±0.00	
Calcium	mg/l	9.90±1.61**	10.90±1.31**	10.67±1.27**	200.00±0.00	
Magnesium	mg/l	4.77±0.62**	4.77±0.58**	5.07±0.22**	150.00±0.00	
Chloride	mg/l	5.87±0.09**	6.27±0.32**	6.03±0.09**	1.50±0.00	
Ammonium	mg/l	0.02±0.00	0.02±0.00	0.02±0.00	250.00±0.00	
Sulphate (SO ₄)	mg/l	8.66±4.77**	9.43±4.59**	9.35±4.83**	250.00±0.00	
Phosphate (PO ₄ -P)	mg/l	0.20±0.00	0.31±0.05	0.60±0.19		2.00±0.00

Nitrite (NO ₂ -N)	mg/l	0.02±0.00	0.02±0.00	0.05±0.03**	1.00±0.00	
Nitrate (NO ₃ -N)	mg/l	0.09±0.16**	0.14±0.06**	0.10±0.01**	10.00±0.00	
Total hardness	mg/l	44.20±6.52**	46.17±2.67**	43.67±1.33**	500.00±0.00	
Total alkalinity	mg/l	43.30±9.36	44.94±4.12	40.20±2.93	500.00±0.00	
Calcium hardness	mg/l	27.57±1.94	27.57±1.94	27.57±1.94	2.00±0.00	
Magnesium hardness	mg/l	22.70±5.87	18.60±0.89	18.80±0.90	2.00±0.00	
Fluoride	mg/l	0.17±0.02**	0.22±0.01**	0.27±0.05**	1.50±0.00	
Iron	mg/l	0.49±0.13	1.77±0.88	4.64±3.43	0.30±0.00	
Magnesium	mg/l	0.03±0.01**	0.14±0.02**	0.26±0.10**	0.40±0.00	
Nickel (Ni)	mg/l	0.02±0.00	0.02±0.00	0.02±0.00	0.05±0.00	
Arsenic (As)	mg/l	0.01±0.00	0.01±0.00	0.02±0.00	0.01±0.00	1.00±0.00
Lead (Pb)	mg/l	0.01±0.00	0.02±0.00	0.01±0.00	0.10±0.000	
Cadmium (Cd)	mg/l	0.001±0.000	0.001±0.000	0.001±0.000	0.003±0.000	
Copper (Cu)	mg/l	0.01±0.00	0.01±0.00	0.01±0.00	2.00±0.00	
Zinc (Zn)	mg/l	0.08±0.03**	0.12±0.00	0.09±0.04**	3.00±0.00	
Mercury (Hg)	mg/l	0.0001±0.000	0.0001.000	0.0001±0.000	0.001±0.00	
Temperature	°C	25.80±0.12**	25.80±0.12**	26.00±0.12**		39.50±0.00

*significant change with Environmental Protection Authority (EPA) Ghana values

**significant change with World Health Organisation (WHO) values

***significant change with both EPA-Ghana and WHO values

Values represent \pm S.E.M (n=3); *p<0.05 when compared with WHO Guidelines; **p<0.05 when compared with EPA-Ghana Guidelines



APPENDIX H

Table 8: summary of the mean results of the sediments samples as compared to the Threshold Effect Level (TEL), Canada

PARAMETER	UNIT	UPSTREAM	MIDSTREAM	DOWNSTREAM	TEL-CANADA
Manganese (Mn)	mg/kg	0.29±0.01 ^{^*}	0.34±0.02 ^{^*}	0.37±0.00 ^{^*}	460.00±0.00
Nickel (Ni)	mg/kg	<0.01±0.00	<0.01±0.00	<0.01±0.00	18.00±0.00
Arsenic (As)	mg/kg	<0.01±0.00	<0.01±0.00	<0.01±0.00	5.90±0.00
Lead (Pb)	mg/kg	<0.01±0.00	<0.01±0.00	0.01±0.00	35.0±0.00
Cadmium (Cd)	mg/kg	<0.01±0.00	<0.01±0.00	<0.010±0.00	0.60±0.00
Copper (Cu)	mg/kg	0.02±0.00	0.03±0.00	0.04±0.00	35.70±0.00
Zinc (Zn)	mg/kg	0.10±0.01 ^{^*}	0.17±0.01 ^{^*}	0.19±0.01 ^{^*}	123.00±0.00
Mercury (Hg)	mg/kg	0.03±0.00	0.05±0.01 ^{^*}	0.09±0.00	0.17±0.00

^{^*}significant change with TEL-Canada values

Values represent mean ± S.E.M (n=3)

^{^*}p<0.05 when compared with TEL-Canada Guidelines

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