KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY KUMASI

DEPARTMENT OF ENVIRONMENTAL SCIENCE COLLEGE OF SCIENCE

The Effect of Small Scale Gold Mining activities on the Birim River in the East Akim Municipality of the Eastern Region

By

Osafo Emmanuel

(PG 3116409)

SEPTEMBER, 2011

THE EFFECT OF SMALL SCALE GOLD MINING ACTIVITIES ON THE BIRIM RIVER IN THE EAST AKIM MUNICIPALITY OF THE EASTERN REGION

by

Osafo, Emmanuel

A Thesis submitted to the Department of Environmental Science

Kwame Nkrumah University of Science and Technology

In partial fulfillment of the requirements for the

Master of Science degree

in

Environmental Science

SEPTEMBER, 2011

DECLARATION

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

OSAFO EMMANUEL …..…………..……………

…..…………………………….

(Student) Signature Date

Certified by:

……………………..…. …..……………………….

…..…………………………….

MR. A. K. APETORGBOR Signature Date

(Supervisor)

Certified by:

……………………..   …..…………………………

…..……………………………..

DR. P. K. BAIDOO   Signature   Date

(Head of Department)

ACKNOWLEDGEMENT

My greatest thanks go to the Almighty God for granting me wisdom, protection and strength during my two year study of this course and also bringing this piece of work to a successful end.

I am very thankful to my supervisor, Mr. A. K. Apetorgbor for his constant supervision, guidance and directions. I also acknowledge the assistance given to me by the management of AngloGold Ashanti Environmental Laboratory,especially Mr. Albert Osei-Bonsu, a senior research analyst.

Lastly, my appreciation goes to my colleagues and friends who have contributed to make this piece of work a successful one.

I ask for God blessings for all.

ABSTRACT

Ghana has been a producer of gold since the 16th century and boasts of one of the largest and richest gold reserves in the world with a long history of mining. Mining of gold in Ghana is categorized into small scale and large scale minings. The activities of small scale gold mining have been the target of strong opposition in recent years mainly because of its various environmental and social effects, the foremost of these is mercury pollution. The Birim River in the East Akim Municipality of the Eastern Region is heavily polluted due to the activities of small scale gold mining. The aim of this study was to determine the effect of small scale gold mining activities on the Birim River in the East Akim Municipality of the Eastern Region. Twenty-five water samples were collected from the Birim River at the following points: Apapam, Kibi, Pano, Bunso and the upstream of Apapam which served as a control. Sampling of the water started at the beginning of January, 2011 and ended in March, 2011. The water samples were treated and analyzed using Unicam 929 Atomic Absorption Spectrophotometer and Automatic Mercury Analyzer to determine heavy metal concentration in the water samples. The physico-chemical parameters of the water samples were also determined. The values obtained for turbidity, 353.2 NTU; conductivity, 156.2 µs/cm; total dissolved solids, 3254 mg/l; and heavy metal concentration: iron (Fe), 436 mg/l; copper (Cu), 0.908 mg/l; mercury (Hg), 0.301 mg/l; lead(Pb), 0.753 mg/l; zinc (Zn), 0.735 mg/l; and cadmium (Cd), 0.067 mg/l; were very high well above the control values. The high levels of the parameters could have been caused by the activities of the small scale gold mining. The high levels may have a detrimental effect on the health of the communities that use the river. It is suggested that the mining activities in the river should stop and alternative livelihood be found for those engaged in the small scale mining activities.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

CHAPTER ONE

INTRODUCTION

1.1 Background information

Ghana is Africa's second biggest producer of gold after the Republic of South Africa. Ghana mines produced 2.9 million ounces of gold in 2009 compared with 2.6 million ounces in 2008. Statistics show that gold represents Ghana's major export commodity, providing approximately 42% of the Gross Domestic Product (GDP) (Ghana Statistical Service Report, 2010). Gold has been the backbone of the Ghanaian economy. Ghana has been a producer of gold since the 16th century and boasts of one of the largest and richest gold reserves in the world with a long history of mining. Ghana's largest mine is Tarkwa, owned by Gold Fields Limited. During the2010 financial year, Tarkwa produced 720,700 ounces of gold. Other important gold mines in Ghana are the Obuasi Gold mine, Bogoso/Prestia Gold mine, Damang Gold mine and Chirano Gold mine (Ghana Chamber of Mines Report, 2010).

Mining of gold in Ghana is categorized into small scale mining and large scale mining. Large scale mining usually involves a Company with many employees and heavy duty equipment. The Company mines at one or two large sites and usually stays until the mineral is completely excavated. Small scale gold mining refers to all formal and informal, manual and mechanized mining that uses crude methods to extract gold from primary and secondary ore bodies. Small scale mining is currently seen globally as a source of subsistence for the poor, especially developing countries, and as a determinant of environmental degradation and resource depletion in areas where such precious minerals are mined (United Nations, 1996; Barry, 1996). Although it is a humble form of livelihood, it contributes significantly to gold production and rural employment in Ghana. The activity of small scale gold mining in Ghana is said to have preceded the advent of large scale industrial gold mining especially in the Ashanti and Western Regions where both surface and alluvial gold were exploited using varying crude techniques and methods (Acquah, 1992).

Ironically, with the emergence of large scale contemporary commercial gold mining industries mostly from European countries, the activities of small scale mining were banned and were made illegal with mining concessions exclusively given to metropolitan companies by the then colonial Governments. This was an action in an attempt to make cheap labour supply more accessible to the large expatriate mining companies and simultaneously to ensure that the monopoly position of these large metropolitan mining companies was firmly affixed regarding the prospecting, exploration, mining and marketing of gold and other precious minerals (Acquah, 1992; Hilson, 2001). Some of the people who were previously engaged in small scale mining became laborers for the established large scale miners. Others continued with the small scale mining despite the ban. The enactment of the mineral and mining law, PNDC law 153, in1986, failed to take into consideration the activities of small scale miners. Some small scale gold miner's later, formed companies and then acquired permit in order for them to operate as legal entities. Most people who could not acquire permit operated illegally. They acquired a local name known as "Galamsey operators", and are scattered across various gold mining communities in the country.

According to the 2008 Ghana Chamber of Mines (GCM) report, illegal mining activities (Galamsey) have increased with an estimated number between 300,000 and 500,000 artisan miners comprising one of the largest group of miners on the continent (Ghana Chamber of Mines Report, 2008). For instance, the inhabitants of Kibi and its environs in the East Akim

Municipality are seriously involved in the business of Galamsey for revenue and employment.

The East Akim Municipality in the Eastern Region of Ghana occupies a total of 725km square land area. The main river in the area is the Birim River. The life of the river is being threatened by the activities of Galamsey which is rampant in the area. The Birim River takes its source from the Atiwa Range, north of Apapam, and passes through Kibi, Pano, and Bunso. The Birim River, the pride of the Akyem Abuakwa State, is under threat and risk of being dried up due the activities of Galamsey. The Galamsey activities carried out along and inside the river have changed the colour of the river to the extent that it is impossible for people to drink or use the water for other domestic activities as it used to be (Plate 1).

Plate 1. Section of Birim River, destroyed by Galamsey operations.

1.2Problem statement

While economically significant, small-scale gold mining in Ghana has been the target of strong opposition in recent years mainly because of its various adverse environmental and social side effects, foremost of these being mercury pollution. Mining is destructive to the environment as trees and vegetation are cleared and burnt for mining. It is one of the causes of deforestation. When the environment is drastically affected, naturally the people will be affected. Chemicals used during mining process cause pollution to the environment. The chemicals such as cyanide and mercury used to amalgamate the gold are discharged into rivers and streams, thus contaminating the water bodies and killing the aquatic organisms such as fish living within the water bodies. People who consume such contaminated aquatic organisms are prone to serious health hazards. The contaminated water cannot be used for bathing, drinking, cooking or washing, thus creating water scarcity problems for people nearby.

The pits dug during mining remain as stagnant water pools, serving as breeding ground for mosquitoes and other water-inhabiting insects. People living near such water pool areas have high possibility of getting water-borne diseases. The gravel, mud and rocks displaced during river dredging mining disrupt the natural flow of the river. As a result, fish and other aquatic organisms often die and fishermen find it very difficult to navigate in the obstructed rivers.

Using mercury to extract gold can pollute the water bodies. Mercury entering the human body may cause kidney problems, headaches, tremors and comas. Mercury exposure can occur directly through physical contact or indirectly through contaminated water or fish.

Mercury poisoning will result in the loss of skilled labour and long term damage to communities.

For instance, the activities of small scale mining at Kibi and its environs are threatening the environment and life in the East Akim Municipality. According to the East Akim Municipal Chief Executive, reported by the Ghana News Agency, the illegal mining is threatening the environment and the very survival of human beings and animals in the Municipality. He added that the illegal diggers were poisoning water bodies that serve as sources of drinking water. The illegal diggers also left behind uncovered holes and trenches which were dangerous for both animals and human beings (Ghana News Agency,2009). It is for these reasons that this project was carried out to highlight the impact of illegal mining activities on the Birim River and to find ways of mitigating the effects of the practice.

1.3 Justification

Though small scale mining brings several benefits to developing countries, manifested mainly as employment and revenue, its activities pollute water bodies. Polluted water bodies are threatening economic growth, environment and health. Freshwater is finite and essential to sustain life, development and environment. The Birim River which has been the main source of drinking water for the inhabitants of Kibi and its environs cannot be used for any economic activities because it is heavily polluted due to the activities of small scale miners (Ghana Business News, 2010).

This study was carried out to make the inhabitants of East Akim Municipality and the world at large to become aware of the dangers of polluting their source of drinking water, and also be sensitized and educated on the dangers of using polluted water for their economic activities. Polluted water also creates problems for water companies when they use it as water source and supply it to the surrounding communities. For instance, the Ghana Water Company Limited (GWCL) found it difficult to supply pipe-borne water to the consuming public in Kibi and its environs due to the high level of pollution of the Birim River. The Eastern Regional Production Manager of the company confirmed this in an interview with Radio Ghana on 8th December, 2010. He said that due to the huge sums of money spent on the treatment of the polluted water, GWCL had reduced the quantity of water supply to the consumer by 75%. He disclosed that it operated only for six hours instead of twenty four hours daily for the production of 11,880 gallons which was far below its expectation of 47,520 gallons.

The GWCL could only resume full operation when the pollution of the water body was stopped. The pollution of the water could end if alternative livelihood is found for the miners.

1.4 Objectives

The main objective of this study was to determine the effect of small scale gold mining activities on the Birim River in the East Akim Municipality of the Eastern Region.

The specific objectives were to determine

a. the turbidity, total suspended solids, pH, conductivity and temperature of the Birim River at five designated locations in the East Akim Municipality.
b. the presence of heavy metals (mercury, lead, iron, cadmium, copper and zinc) in the Birim River at specified locations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Small scale gold mining in Ghana

2.1.1 Historical perspective

Small scale gold mining in Ghana was for decades treated as an informal industrial sector, employing thousands of people but featuring largely rudimentary, unmonitored and uncontrolled practices. Up until the 1980's, small scale mining activities in Ghana remained largely unregulated and receive no support from governmental bodies. This however, changed with the implementation of the National Economic Recovery Plan (ERP), which, following years of careful planning, was finally launched in the mid-1980s.

The small scale mining segment was heavily targeted. The Ghanaian government discussed plans to formalize the sector after identifying the potential earnings in the industry, revenue that under an informal organizational scheme is largely lost through smuggling and other avenues of illegal trading. By the end of the 1980s, the government had fully regularized the small scale-mining sector through a series of policies and regulations. In 1989, as part of the mineral sector restructuring, the sector was formalized through the enactment of PNDC law 218, the small-scale mining law. Under this law, the small-scale mining project, a department of the Mineral Commission is responsible for registering and supervising small-scale miners in the country. The government has also established the Precious Minerals Marketing Corporation. This was the sole governmental agency for the purchase of the produce of the small-scale miners. The government has since opened up the marketing to private licensed buyers.

Despite the legalization of their operations, some still operate illegally. The small-scale mining law requires them to register with the Mineral Commission who would assign them specific areas to operate. But because of the several frustrations they meet in the process, many of them operate illegally. This has given rise to two groups of small-scale miners; those registered and licensed and those operating illegally (Hilson, 2001).

2.1.2 Organization of small scale gold mining operations

Gold and diamond are the most important minerals mined on a small-scale in Ghana. In the case of gold, operators are awarded licenses by the government to mine in a designated area not exceeding 25 acres for three to five years. Typically, a licensed operator employs between five and twenty groups of tributers consisting of five to ten workers each who excavate ore and process gold (Agyapong, 1998).

The most common equipment used are basic hand tools such pick axes sluice boxes and shovels, although occasionally water pumps, explosives and washing machines are seen on sites. The ore is crushed into pebbles by hand or machines, and is contained in storage sacks in sheds. The pebbles undergo primary, secondary and tertiary grinding in preparation for washing. Carried to the riverside in cloth bags, the finely crushed sediment is laid along washing blankets or in hand washed along river banks to separate valuable gold particles. The sediment is then panned using mercury and the resulting amalgam is roasted over a charcoal fire in the open air (Appiah, 1998).

2.1.3 Socio-economic impact of small-scale gold mining in Ghana

Small-scale mining brings benefits to Ghana, mainly in employment and revenue. No precise small scale mining employment figures can be found in Ghana, although it is estimated some 300,000 to 500,000 are involved directly in the extraction of gold and diamond (Ghana Chamber of Mines Report, 2008). Although not capital intensive, small-scale miners require sufficient manpower; labour-intensive small-scale mining operations are economically feasible because investment cost per job is typically only 10% to 12% as those costs in large-scale mining operations (United Nations, 1992). Small-scale mining has a major impact on the employment situation in Ghana especially in rural areas where there are few alternatives. It is estimated that only fifteen percent of the small-scale miners work on registered plots. The rest are illegal Galamsey. Sixty percent of the known Ghanaian mining labour force is employed at small-scale mines (Ghana Chamber of Mines Report, 2008).

It is estimated that gold production from small-scale gold mining accounts for approximately one—sixth of the global gold output (United Nations, 1992). In Ghana, since complete legalization of its small-scale mining segment, significant revenues have generated in the sector. Prior to legalizing and regularizing operations, most of these revenues were lost through illegal smuggling channels.

2.2 Support schemes for small-scale mining in Ghana

The government took a series of initiatives to support the small-scale miners. The small-scale mining project (SSMP) was launched in 1989 and four institutions were given the responsibility to provide institutional support for the project; the Geological Survey, Mines Department, Minerals Commission and Precious Minerals and Mining Corporation (PMMC). The Minerals Commission was to recruit district officers for the project; the Mines Department was to recruit mines wardens; the Geological Survey was to give mineralization and identify areas suitable for small-scale mining; and the PMMC was to ensure that products would be captured by establishing purchasing centres and recruiting licensed buying agents (Hilson, 2001).

However, once the initial tasks were performed, virtually all small-scale mining responsibilities were given to the Mineral Commission. Initially, the Mineral Commission worked to improve the technological aspect of the Ghana small-scale mining sector and introduced three-horse water pumps (for alluvial mining), sluice boxes and pick axes. The Minerals Commission stored equipment locally, and a district officer dispensed it on a hire-cost basis—more specifically, at prices beyond the budget of small-scale miners. As a result, the majority of the equipment was not purchased, or was sold off at a loss, and all revenues returned to the project (Hilson, 2001)

Minerals Commission also contacted the Central Regional Development Commission (CEDECOM) for consultation and support. Management asked CEDECOM to make recommendations for the provision of equipment but the suggestions provided, overall, were highly ineffective largely because CEDECOM, which had had no interactions with the small-scale miners in the past, used information drawn heavily from experienced small-scale fisheries to craft each. This made the Minerals Commission discontinue the scheme, sold newly purchased equipment at discounted prices, and again, returned remaining funds to the SSMP.

It is important to note that the Ghana government, in regularizing and formalizing small-scale mining operations, took a necessary first step towards improving the sustainable of the sector. More specifically legalization, intervention, and control are keys to eliminating unacceptable work practices and illicit marketing of minerals, and are a necessary prerequisite for removing operational constraints limiting productivity and competiveness (Noestaller, 1994).

However, these efforts have only led to the creation of a much needed regulatory framework for use by the government. However these regulations have not benefited the small-scale miners who had operated illegally using the same methods before the enactment of the legislation. In effect, they could not provide better support to the small-scale miners (Hilson, 2001).

Few support projects were undertaken to provide environmental improvements in resident small-scale mines. Baseline studies were carried out by the University of Ghana to quantify the environmental impacts of small-scale mining, including climate and air quality, water bodies, geology, soil, ecology and environmentally sensitive areas. The Minerals Commission throughout the 1990s did sponsor a series of independent but most of the recommendations made are still implemented. Lack of resources and manpower has prevented the Minerals Commission from putting a number of those recommendations into practice. They were to establish district support centres which were to provide regional registration, and purchasing services to precious metal miners. Eight small-scale mining district centres were initially constructed in the southern part of the country. Each was staffed with a district officer, a mining engineer and mining inspectors who were to register claims, provide technical advice, and encourage the safe and productive operation of mines

(Davidson, 1993). Attempts were also made to organize training sessions at district centres; the aim was to educate miners on important issues of health and safety, business management, environmental protection and use of technology (Hilson, 2001).

Loans were also provided to needy small-scale miners to purchase handheld and mechanized equipments. Government mandated PMMC to provide competitive rate for purchase of mined small-scale gold (World Bank, 1995). The World Bank has been involved in small-scale mining research in Ghana, through its Mining Sector Development and Environment Project. The aim of the project is to support the sustainable development of Ghana's mining sector on and environmentally sound basis through the application of improved technology and strengthened mining institutions. The project also sought to provide pilot testing of small-scale mining equipment for improving productivity and yield; making available valuable geological information to small-scale miners; improving the regulatory framework for small-scale miners; and reclaiming abandoned land.

However, many of these support services and strategies have since stopped functioning, particularly the environmental-related activities. The environmental component of the industry has not been prioritized whatsoever and is dire need of attention (Hilson, 2001).

2.3 Environmental impact of small-scale gold mining in Ghana

The principal environmental problems caused by small-scale mining activity are mercury pollution from gold processing and land degradation. The mercury amalgamation technique is relied upon heavily as it is a cheap, dependable, portable operation for concentrating and extracting gold from low-grade ores. The chemical, in sufficient quantities, poses a serious threat to human health and is deleterious to a wide range of ecological entities. Once in the natural environment, mercury undergoes a change in speciation from an inorganic to a methylated state (MeHg) by microbial action, and when ingested, eco-toxicological effects result. In Ghana, an estimated five tons of mercury are released into the environment each year from small-scale mining operations (World Bank, 1995).

Analysis of mercury in hair samples obtained from miners in Tarkwa shows a mean value of 7.4µg/g; it is recommended by the World Health Organization (WHO) that the average weekly intake of mercury should be not more than 5µg/kg of the body weight, of which not more than 3.3µg/kg should be MeHg (World Bank, 1995).

Two unpublished studies commissioned by UNIDO confirm further that there is mercury pollution problem within certain small-scale mining regions in Ghana. The first analysis involved hair, urine, blood and nail samples from 187 adults residing in an artisanal gold-mining community. Clinical examinations identified 13 men as having slight neurological disorders (as a result of mercury exposure), many gold washers having elevated concentrations of mercury in their bloodstreams, and that there is an exposure to mercury in the community through contaminated food and water (Rambaud *et al.*, 2001). The second study was carried out in Dumasi, Western Region. Sediments, fish, vegetables, surface water and ground water were sampled in April 2000 in order to determine levels of mercury contamination. Results indicate that although surface and ground water feature mercury concentration below WHO standards, sediments were seriously polluted and fish were contaminated to the point where they should not be consumed (Rambaud *et al.*, 2001).

2.4 Illegal mining activities and its effect on water bodies

Illegal gold mining activities known as Galamsey along Bunso and Kibi stretch of the Birim River is posing a great danger to the water treatment plant in the area. The Eastern Regional Quality Control Manager of Ghana Water Company, lamented that the high level of pollution as a result of miners washing mineral bearing rocks into the Birim River after excavation pose a great danger to residents who rely on the pipe water. He said the fluoride content in the water which was supposed to be 1.5 for human consumption has risen to 2.3 standards, describing the situation as unacceptable and dangerous to humans as far as dental health was concerned. He said another mineral found in the water which was equally dangerous was mercury. He said the company spent more than the estimated amount of money to treat the water. According to him, the miners have been trying to divert the course of the river to suit their operations which, he said would be at a great cost to the Ghana Water Company (GNA, 2009).

Illegal mining activities of water bodies have been identified as one of the major causes affecting production and supply of potable water in the Western Region. The Pra River, which serves as the major source of for the production of water in the region, has been taken over by Galamsey operators, whose inhuman activities pose great danger to the continuous availability of potable water. The Deputy Minister for Water Resources, Works and Housing on a working visit to assess the level of water crisis in the region, admitted that illegal mining activities pose a great challenge to the operations of Ghana Water Company. She said that both the Ntweaban and the Daboase treatment plants have the capacity to produce six million gallons of water a day to serve the twin-city but production is low and inadequate. These illegal mining activities pose problems for the treatment plants and makes cost of production very high. She admitted that the current situation in the region was bad and could affect industry and even household consumption (GNA, 2011).

Determination of heavy metals in water bodies in Tarkwa and Obuasi areas by the Wassa Association of Communities Affected by Mining Changes (WACAM), particularly on Nyam River in Obuasi showed that Arsenic concentration of 13.56mg/l as against 0.01mg/l required by the WHO and Environmental Protection Agency (EPA).This was due to pollution by small scale mining activities. Data from Asuakoo River revealed that it had 22.72mg/l as against 0.4mg/l of Manganese prescribed by the WHO permissible guideline. The Executive Director, WACAM, said pollution of water bodies in the mining communities posed serious health implication to the people who were found to be suffering from various illnesses. He said the result of the research showed that most water bodies in the study areas were polluted with high Arsenic level ranging from 0.005 to 35.4mg/l. Manganese, Lead and Mercury are neurotoxic metal which could affect the IQ of children exposed to high levels in drinking water. He continued that, in all 400 water samples, made up of 200 from Obuasi and 200 from Tarkwa areas were collected between May and September 2008 and each sample was analyzed separately for toxic chemicals including Arsenic, Manganese, Cadmium, Iron, Copper, Mercury, Zinc and Lead. He said physico-chemical parameters such as pH, conductivity, turbidity and total dissolved solids were measured using standard methods of analysis as prescribed by the American Water Works Association (AWWA, 1998). The turbidity of some of the water bodies and alternate sources of water provided had low pH and high turbidity values, which exceeded the WHO and GEPA permissible limits (GNA, 2009).

Studies conducted by the Ghana Atomic Energy Commission (GAEC) on water bodies and stream sediments as a result of small-scale mining activities at Tarkwa and its environs in the Western Region indicated excessive pollution of high mercury concentration, a toxic element that affects human health. The results suggested that the level of mercury detected from the water samples from the Western Region gold mining towns exceeded the WHO tolerable limit of 0.001mg/l for drinking water. According to the GAEC, areas that contained high concentration of mercury are sites that experienced extensive Galamsey gold mining activities, showing that mercury concentration varied between 6.80mg/l and 19.82mg/l for water, and 28.90mg/kg and 84.30mg/kg in sediment at sites with extensive small-scale mining activities (Ghanaian Chronicle, 2005).

At Prestea and its environs, total mercury concentrations in water were measured. The samples were analyzed by instrumental neutron activation analysis (INAA). Higher levels of total mercury concentration were found in samples at the sites with extensive small-scale ‘galamsey’ gold mining activities than at the sites with low small-scale mining activities. Concentrations varied between 7.5mg/l to 20.6mg/l with extensive small-scale mining activities. At low small-scale mining sites, mercury concentration varies between 0.50mg/l to 9.10mg/l (Serfor-Armah*et al*., 2006).

At Bibiani-Anwiaso-Bekwai District,(a typical mining community in the south western part of Ghana), surface water and sediment samples were collected from seven streams that drain this mining community and analyzed for mercury concentration. Total mercury content of the water ranged between 0.125µg/l to1.341µg/l while sediment values ranged between 0.169mg/kg to 1.739 mg/kg. Physico-chemical parameters were also determined for the water samples. The pH range varied from 8.4 to 7.1. Temperature also ranged from

22.7°C to 31.6°C. Conductivity also ranges from 2.77 µs/cm to 0.21 µs/cm. Total dissolved solids was from 185.9 mg/l to 111 mg/l (Nartey *et al*., 2011).

2.5 Health Risk of Heavy Metal; Cadmium, Iron, Lead, Copper, Zinc and Mercury

2.5.1 Cadmium (Cd)

Cadmium (Cd) is a rare metal and, for uncontaminated soils, total content of cadmium may be <1mg/kg. Its geochemistry closely parallels that of zinc. One of the major sources of cadmium in the wider environment is through zinc mining and smelting (http://en.wikipedia,org/wiki/cadmium). It is toxic to animals at quite low concentration and this toxicity is exacerbated by its accumulation in the kidneys of humans (Friberg et al, 1974).

2.5.1.1 Health effects of cadmium

Cadmium is found in the earth's crust. It occurs in combination with zinc, and is released into the environment during zinc extraction. Human uptake of cadmium is mainly through food. Foodstuffs that are rich in cadmium can greatly increase the cadmium concentration in human bodies. Examples are liver, mushrooms, shellfish, mussels and cocoa powder. The average daily intake for humans is estimated as 0.15µg from air and 1µg from water (Adamsson et al, 1979).An exposure to higher cadmium levels occurs when people smoke. Tobacco smoke transports cadmium into the lungs. The blood transports it through the rest of the body where it can increase its effect by potentiating cadmium that is already present from cadmium-rich food (ATSDR, 1989).

Cadmium contamination in humans occurs as follows: first it is transported to the liver through the blood. Within the blood, it is bonded to proteins to form complexes that are transported to the kidneys. It then accumulates in kidneys, where it damages filtering mechanisms. This causes the excretion of essential proteins and sugars from the body and further kidney damage. It takes a very long time for cadmium accumulated in kidneys to be excreted from the human body (Johnson and Sauberic, 1982). Other adverse health effects caused by cadmium are;

- Diarrheoa
- Stomach pains and severe vomiting
- Bone fracture
- Reproductive failure and possible infertility
- Damage to the central nervous system
- Damage to the immune system
- Cancer development and
- Psychological disorders (ATSDR, 1989).

2.5.2 Copper (Cu)

The average concentration of copper in the earth's crust is around 60mg/kg but values given for soils are generally much lower at around 30mg/kg (http://en.wikipedia.org/wiki/copper). Copper is an essential element for the health of plants and animals where it plays an important role in enzyme mediated systems (Wolf, 1982).

2.5.2.1 Health effects of copper.

Copper is a very common substance that occurs naturally in the environment and spread through the environment through natural phenomena. Copper can be found in many kinds of food, in drinking water and in air.

Because of this, we absorb quantities of copper each day by eating, drinking and breathing. The absorption of copper is necessary because copper is a trace element that is essential for human health. Although humans can handle proportionally large concentration of copper, too much copper can still cause health problems (Wolf, 1982). Soluble copper compounds form the largest threat to human health. Long term exposure to copper can cause the following;

- Irritation of the nose, mouth and eyes
- Headaches, stomachaches and dizziness
- Vomiting and diarrheoa.

High uptake of copper may cause liver and kidney damage, and even death (Goyer, 1991).

Chronic copper poisoning will result in the following;

- Wilson's disease, characterized by hepatic cirrhosis
- Brain damage
- Renal disease, and
- Copper deposition in the cornea (Collins, 2003).

2.5.3 Iron (Fe)

Iron is the most abundant metal on earth, and is believed to be the tenth most abundant element in the universe. Iron is the second abundant element by mass, making 34% of the mass of the earth. The concentration of iron in the various layers of the earth ranges from high at the inner core to about 5% in the outer crust. The large amount of iron in the Earth is thought to contribute to its magnetic field (http://en.wikipedia.org/wiki/iron).

2.5.3.1 Health effects of iron

Iron can be found in meat, potatoes and vegetables. The human body absorbs iron in animal products faster than iron in plant products. Iron is an essential part of haemoglobin; the red colouring agent of the blood that transport oxygen through our bodies. Iron may cause conjunctivitis, choroiditis and retinitis, if it contracts and remain in the tissues. Inhalation of excessive concentration of iron oxide may enhance the risk of lung cancer development in workers exposed to pulmonary carcinogens.

2.5.4 Lead (Pb)

The average concentration of lead in the earth's crust is around 13mg/kg, but there is considerable in natural levels because of inputs from mineralized deposits of lead. However, a major feature of the environmental chemistry of lead (Pb) is the general diffuse pollution in top soils from a series of sources, including mining and smelting, recycling of sewage sludge and from motor vehicle exhausts (http://en.wikipedia.org/wiki/lead).

Lead is known to show significantly enhanced levels in surface soils. Like cadmium, lead has no beneficial effect on living organisms, but its detrimental impacts have been the subject of a specific report by the Royal Commission on Environmental Pollution, Ninth Report (Andrea, 1993). The symptoms of clinical blood poisoning are wide ranging and it is thought that a blood concentration of 100µg/l is lethal.

However, there is considerable debate over the impact of sub-clinical levels, particularly in relation to the behavior and development of intelligence in younger children (Markowitz, 2003).

2.5.4.1 Health effects of lead

Lead can enter the human body through uptake of food (65%), water (20%) and air (15%). Lead accumulates in the bodies of water organisms and soil organisms. These organisms experience health effects from lead poisoning. Food such as fruits, vegetables, meat, grains, seafood, soft drinks and wine may contain significant amount of lead. Cigarette smoke also contains small amount of lead. Lead fulfils no essential function in the human body; it only causes harm after uptake from food, air and water. Lead can cause several unwanted effects such as;

- Disruption of the biosynthesis of haemoglobin and anaemia
- A rise in blood pressure
- Kidney damage
- Miscarriages and subtle abortions
- Disruption of the nervous system
- Declined fertility of men through sperm damage
- Diminished learning abilities of children

- Behavioural disruption of children, such as aggression, impulsive behaviour and hyperactivity.

Lead canenter a foetus through the placenta of the mother. Because of this, it can cause serious damage to the nervous system and brain of unborn children(Markowitz, 2003).

2.5.5 Zinc (Zn)

The average concentration of zinc in the earth's crust is around 80mg/kg, although there is some variation of natural levels with rock type. There are a number of major entry routes into the soil environment, including atmospheric deposition of recycling of organic wastes and the use of agrochemicals. Zinc is an essential trace element for a range of plants and animals, including man. For humans, daily intake below the recommended value of 15mg/day is likely to result in skin lesions, severe growth depression and a suppression of the immuno–response system. Zinc deficiency can be seen in a wide range of plant species and is frequently observed as a chlorosis of the leaf tissue along with stunted growth (http://en.wikipedia.org/wiki/zinc).

2.5.5.1 Health effects of zinc

Zinc is a very common substance that occurs naturally. Many foodstuffs contain certain concentration of zinc. Drinking water also contains certain amount of zinc, which may be higher when it is stored in metal tanks. Industrial sources or toxic waste sites may cause the zinc amounts in drinking water to reach levels that can cause health problems.

Zinc is a trace element that is essential for human health. Lower level of ingestion of zinc can result in loss of appetite, decreased sense of taste and smell, slow wound healing and skin sores. Zinc shortages can even cause birth defects (Wolf, 1982).

Although humans can handle proportionally large concentration of zinc, too much zinc can still cause health problems such as stomach cramps, skin irritations, vomiting, nausea and anaemia.

Very high levels of zinc can damage the pancreas and disturb the protein metabolism, and cause arteriosclerosis. Extensive exposure to zinc chloride can cause respiratory disorders. In the work place environment, zinc contagion can lead to a flu-like condition known as metal fever. This condition will pass after two days and is caused by over sensitivity. Zinc can be a danger to unborn and newborn babies. When their mothers have absorbed large concentration of zinc, the children may be exposed to it through blood or milk of their mothers (Newman *et al*, 1999).

2.5.6 Mercury (Hg)

Mercury is an extremely rare element in the earth's crust, having an average crustal abundance by mass of only 0.08 parts per million. However, because it does not blend geochemically with those elements that comprise the majority of the crustal mass, mercury ores can be extraordinarily concentrated considering the element's abundance in ordinary rock. The richest mercury ores contain up to 2.5% mercury by mass and even the least concentrated deposits are at least 0.1% mercury (12,000 times average crustal abundance). This makes mercury ore the most easily depleted of all metal ores (http://en.wikipedia.org/wiki/mercury(element)).

2.5.6.1 Health effects of mercury

Mercury is an element that can be found naturally in the environment. It may exist in metal form, as mercury salts or as organic mercury compounds. Metallic mercury is used in a variety of household products such as barometers, thermometers and fluorescent light bulbs. The mercury in these devices is trapped and usually does not cause any health problems. However, when a thermometer breaks, a significantly high exposure to mercury through breathing will occur for a short period of time while it vaporizes. This can cause harmful effects such as nerve, brain and kidney damage, lung irritation, skin rashes, vomiting and diarrheoa (www.lenntech.com/mercury/Hg.htm).

Mercury is not naturally found in foodstuffs, but it may appear in food as it can be spread within food chains by smaller organisms that are consumed by humans, for instance through fish. Mercury concentration in fish usually greatly exceeds the concentration in the water they live in (bioaccumulation). Mercury is not commonly found in plant products, but it can enter human bodies through vegetables and other crops, when insecticides that contain mercury are applied in agriculture (FDA, 2004).

The effects of mercury in the human bodies include the following;

- Disruption of the nervous system
- Damage to brain functions
- DNA damage and chromosomal damage
- Allergic reactions, resulting in skin rashes, tiredness and headaches
- Negative reproductive effects; such as sperm damage, birth defects and miscarriages.

Damage brain functions can lead to the following;

- Degradation of learning abilities
- Personality changes
- Tremours, deafness and vision changes
- Muscle in coordination and memory loss.

Chromosomal damage is known to cause mongolism (Brown, 2003).

Mercury concentration in the environment is increasing; and this is ascribed to human activity. Most of the mercury released from human activities is released into the environment, through fossil fuel combustion, mining, smelting and waste combustion. All mercury that is released in the environment will eventually end up in soils or surface waters (El-Ray and Saad, 1986).

2.6 Physico-chemical parameters of Water; pH, Turbidity, Total Dissolved Solids, Conductivity and Temperature

2.6.1 Water pH

Scientists measure the acidity of water by testing the pH level. The pH ranges from zero (0) to fourteen (14) with pH of seven (7) being (perfectly) neutral. The low end of the scale represents high acidity, while the high end represents alkaline. The balance of positive hydrogen ions and negative hydroxide ions in water determines how acidic or basic the water is. In pure water, the concentration of positive hydrogen ions is in equilibrium with the concentration of negative hydroxide ions, and the pH measures exactly seven (7).

Harmful acidic water can come from both acid rain and acidic mine drainage. Water from mines, particularly abandoned coal mines, can leach into ground and surface water. Some of the minerals found in mines react with either air or water, or both, to create acidic liquids. Acid mine drainage directly affect surface water and can render streams and lakes nearly lifeless. Environmental groups can neutralize the effects by adding limestone and other alkaline substance to the water, but this is expensive and does not cure the problem of metals in water (US Environmental Protection Agency, 1997).

2.6.1.1 Effect of water pH on living organisms

High levels of either acidity or alkalinity can destroy life. Acid rain is particularly harmful to trees and other plants. Acid rain adds aluminium to the soil and destroys important nutrients (www.ehow.com/about_6723807_effect). As a result, trees and plants are less able to absorb the ground water they need for growth. Additionally, acid rain damages plant health, making them less resistant to insect damages and diseases. Acidic water similarly affects aquatic plant life, destroying important food sources. Acid water robs fish and other aquatic species of sodium in the blood and oxygen in the tissues. Additionally, it affects the functioning of fish gills, and also kills individual fish, reduces fish population numbers, and completely eliminates fish species from a water body (http://www.epa/gov/acid_rain_effects/surface-water.html).Some species of fish tolerate water with a pH as low as 5.0 while small mouth bass feel the effects at a pH of 6.0. Even if the acidity does not kill fish, the additional stress can stunt growth and make them less able to compete for food. Acidic water also poisons fish eggs, as they will not hatch if water pH is too low.

U.S. Environmental Protection Agency has found out that most eggs will not hatch in water with a pH level of 5.0 or less. In addition to the direct effects on fish, acid water also destroys ecosystems by killing organisms lower in the food chain. For example, the Pennsylvania Department of Environmental Protection found that mayflies are particularly vulnerable to acidic water; because it lowers sodium in the blood (U.S. Environmental Protection Agency, 2002).

2.6.2 Turbidity

The turbidity of a body of water is related to the cleanliness of the water. Waters with low concentration of total suspended solids (TSS) are clearer and less turbid than those with the high TSS concentrations. Turbidity is the cloudiness or haziness of a fluid. This can be caused by high concentration of biota such as phytoplankton, or by loading of abiotic matter such as sediments. Human activities that disturb land, such as construction, can lead to high sediment levels entering water bodies during rain storms due to storm water runoff. Areas prone to high bank erosion rates as well as urbanized areas also contribute large amount of turbidity to nearby water, through storm water pollution from paved surfaces such as roads, bridges and parking lots. Certain industries such as quarrying, mining and coal recovery can generate very high levels turbidity from colloidal rock particles (www.slideshare.net/guest5907f90/water)

Turbidity is not specific to the type of particles in the water and the particles can be suspended, as well as inorganic, organic or biological. At high concentration, turbidity is perceived as cloudiness, haze, or absence of clarity in the water (Sethi*et al*., 1997).

A turbidimeter is a general term for a meter that measures turbidity. Measuring low level turbidity requires precisely quantifying the scattering of light in water using a turbidimeter that is also a nephelometer. The unit of measurement for the EPA method is recorded as nephelometric turbidity units (NTU) (U.S. Environmental Protection Agency, 2002).

2.6.2.1 Effect of turbidity on living organisms

Turbidity is important in aquatic systems as it can alter light intensities through water column, thus potentially affecting rate of photosynthesis and the distribution of organism within the water column. Lowered rates of photosynthesis may in turn affect the levels of dissolved oxygen available in a given body of water, thus affecting larger populations such as fish. High turbidity can also cause infilling of lakes and ponds if the suspended sediments settle out of the water column and are deposited (American Public Health Association, 1998).

Turbid waters inhibit light from penetrating deeply into water column and therefore, negatively affect primary productivity and dissolved oxygen available to support other organisms. The more turbid a lake is, the less biota it will be able to support. In drinking water, the higher the turbidity level, the higher the risk that people may develop gastrointestinal diseases. This is especially problematic for immune-compromised people, because contaminant like viruses or bacteria can become attached to the suspended solids. The suspended solids interfere with water disinfection with chlorine because the particles act as a shield for the viruses or bacteria. Similarly, suspended solids can protect bacteria from ultraviolet (UV) sterilization of water (American Public Health Association, 1998).

It is very important to measure the turbidity of domestic water supplies, as these supplies often undergo some type of water treatment which can be affected by turbidity. For example, when mud and silt are washed into streams and rivers, high turbidity can quickly block filters and stop them from working effectively. High turbidity will also fill tanks and pipes with mud and silt and can cause damage to the valves and taps. When chlorination is practiced even quite low turbidity will prevent the chlorine from killing the germs in the water efficiently. Drinking water should have a turbidity of 5 NTU or less (US Environmental Protection Agency, 1997).

2.6.3 Total dissolved solids (TDS)

Water is a good solvent and picks up impurities easily. Dissolved solids refer to any minerals, salts, metals, cations or anions dissolved in water. Total dissolved solids (TDS) comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphates) and some small amounts of organic matter that are dissolved in water. Total dissolved solids in drinking water originate from natural sources, sewage, urban runoff, industrial waste water, and chemicals used in the water treatment process, and the nature of piping or hardware used to convey the water.

In general, total dissolved solids concentration is the sum of the cations (positively charged) and anions (negatively charged) in water. Total dissolved solids test provides a quantitative measure of the amount of dissolved ions. It is used to determine the general quality of the water

The total dissolved solids concentration can be related to the conductivity of the water, but the relationship is not a constant. For example, sodium chloride (NaCl) solution and potassium chloride (KCl) solution with a conductivity of 10,000 μs/cm will not have the same sample concentration of NaCl or KCl, and they will have different total dissolved solids concentration. Conductivity is measured trough the use of a meter and is usually about

100 times the total cations or anions expressed as equivalents and the total dissolved solids(TDS) in part per million (ppm) usually ranges from 0.5 to 1.0 times the electrical conductivity (American Public Health Association, 1998).

2.6.3.1 Effects of total dissolved solids (TDS)

The effects of total dissolved solids in water source include the following;

Some of the components of TDS can have effect on human health. High TDS concentration may add a laxative effect to the water or to cause the water to have unpleasant mineral taste. The most important aspect of TDS with respect to drinking water quality is its effect on taste. The portability of drinking water with TDS level less than 600mg/l is considered to be good. Drinking water supplies with TDS levels greater than 1200mg/l are unpalatable to most consumers (Bruvold & Ongerth, 1969).

High TDS reduces consumer confidence. High levels of TDS can adversely affect industrial applications requiring the use of water, such as cooling tower operations, boiler feed water, food and beverage industries. High concentration of TDS may reduce water clarity, which contributes to a decrease in photosynthesis and lead to an increase in water temperature. Many aquatic organisms cannot survive under high temperatures conditions. Concentration of TDS that are too low or too high may limit growth and may lead to the death of many aquatic organisms (WHO/UNEP, GEMS, 1989).

Concentrations of TDS above 500mg/l result in excessive scaling in water pipes, water heaters, boilers and household appliances. High TDS can accelerate corrosion of pipes to the point that water coming out of tap becomes reddish and turbid. High TDS greatly increase the cost of water treatment and produces brines that requires safe disposal.

If TDS increase in the water body, a shift to more salinity-tolerant species can be affected. High salinity may interfere with the growth of aquatic vegetation. Salt may decrease the osmotic pressure, causing water to flow out of the plant to achieve equilibrium; less water can be absorbed by the plant, causing stunted growth and reduced yield (Singh & Kalra, 1975).

It is possible for dissolved ions to affect the pH of the body of water, which in turn may influence the overall health of many aquatic species. If TDS levels are high, especially due to dissolved salts, many forms of aquatic life are affected. The salts act to dehydrate the skin of animals (American Public Health Association, 1998).

2.6.4 Water Conductivity

Conductivity of a substance is the ability or power to conduct or transmit heat, electricity, or sound. Its SI unit is Siemens per meter (S/m). An electrical current results from the motion of electrically charged particles in response to forces that act on them from an applied magnetic field. Within most solid materials, a current arise from the flow of electrons, which is called electronic conduction. Electrical conductivity is strongly dependent on the number of electrons available to participate in the conduction process. Most metals are extremely good conductors of electricity, because of the large number of free electrons that can be excited in an empty and available energy state.

In water, a net motion of charged ions can occur. Pure water has a fairly low conductivity. The electrical is transported by the ions in solution. The conductivity increases as the concentration of ions increases. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulphate, and phosphate ions (ions that carry negative charge) or sodium, magnesium, calcium, iron, and aluminium (ions that carry a positive charge). Organic compounds like oil, phenol, alcohol, and sugar do not conduct current very well and have low conductivity when in water (International Organization for standardization, 1985).

Conductivity is also affected by temperature; the warmer the water, the higher the conductivity. Conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows. Streams that run through areas with granite bedrock tend to have lower conductivity because granite is composed of more inert materials that do not ionize when washed into water. On the other hand, streams that run through areas of clay soils tend to have higher conductivity because of the presence of materials that ionize when washed into the water. Discharges to streams can change the conductivity; a failing sewage system would raise the conductivity because of the presence of chloride, phosphate, and nitrate; an oil spill would lower the conductivity (American Public Health Association, 1992).

Distilled water has conductivity in the range of 0.5 S/cm to 3.0 S/cm. Studies of inland fresh water indicate that the streams supporting fisheries have a range between 150 S/cm and 500 S/cm. Conductivity outside this range could indicate that the water is not suitable for certain species of fish or macroinvertibrates (Montpelier, 1997) .

The relationship between conductivity and turbidity is that, conductivity is the amount of dissolved ions in the water column, whereas turbidity is the amount of suspended particles in the water column. The values for conductivity and turbidity in an aquatic habitat influence water clarity, which in turn stimulate phytoplankton growth. An increase in turbidity due to an increase in suspended particles and a decrease in conductivity result in a decrease in light penetration and phytoplankton growth.

Conductivity measurement is directly affected by the number of dissolved ions in the solution and will increase as the quantity and mobility of ions increases. The higher the conductivity reading, the better ability the solution has to conduct electricity. Conversely, the lower the conductivity reading, the poorer ability the solution has to conduct electricity. Differences in conductivity among different watersheds are likely due to interactions with soils as well as human activity (American Public Health Association, 1998).

2.6.5 Temperature

Temperature of stream water is influenced by both natural processes and human activities. Climatic zone, altitude, air temperature and season of the year produce variation in water temperature. Other natural factors include shade provided by streamside vegetation depth, snow melt, and mixing with ground water.

Human activities can introduce thermal pollution into streams in several ways. Industries and power plants may use water to cool machinery and then discharge the warm water into a stream. Storm water warmed by urban surfaces such as roads, roots and parking lots, can flow into nearby streams. Water temperature rises when trees and vegetation providing shade are cut down. Soil erosion caused by construction, removal streamside vegetation, poor farming practices, overgrazing and recreation increases the amount of suspended solids in the water. The suspended particles absorb sun's rays and also increase temperature (Allan, 1995).

2.6.5.1 Effects of temperature

Chemical processes involved in the metabolism, growth, reproduction and behavior of aquatic organisms are sensitive to water temperature. Thermal stress and even shock can occur when the temperature changes more than 1°C or 2°C in less than 24hours. In addition, the sensitivity of an aquatic organism to toxic wastes, parasites and diseases often increases with rising temperatures. Water temperature affects the amount of dissolved oxygen and other gases that water can hold at specific atmospheric pressure. A rise in temperature decreases the ability of water to hold oxygen molecules (Dodds, 2002).

Water temperature has direct and indirect effect on nearly all aspects of stream ecology. For example, the amount of oxygen that can be dissolved in water is partly governed by temperature. As cold water can hold more oxygen than warm water, certain species of aquatic invertebrates and fish with high oxygen demands (including popular sport fish such as trout and salmon) are found only in these waters (Allan, 1995).

Temperature also influences the rate of photosynthesis by algae and aquatic plants. As water temperature rises, the rate of photosynthesis increases provided there are adequate amounts of nutrients.

Metabolic rates of most stream organisms are controlled by temperature. As most aquatic animals are cold-blooded, their metabolic rate is faster in warm water. The increase in metabolic rate occurs only up to a point before the upper temperature tolerance is exceeded and the organisms die. Approximate upper limits range from 38°C for fish and 50°C for aquatic insects to 73°C for blue-green algae (Bolton, 1993). However, elevated temperatures lower than these maximum limits still are stressful, especially to organisms at sensitive juvenile stages (Boulton and Brock, 1999).

2.7 Purpose of the investigation

The aim of this writing is to provide an overview of water pollution normally caused by small scale mining activities and to outline some strategies that could mitigate the problem. Despite providing thousands of indigenous people with employment, problems with mercury pollution and land degradation have intensified within the small scale mining activities over the years. The purpose of the investigation is to prescribe a series of recommendations for improving environmental performance in the small scale mining sector. It is expected that this investigation would help to bring outcome recommendations that could mitigate some of the problems caused by the activities of small scale mining.

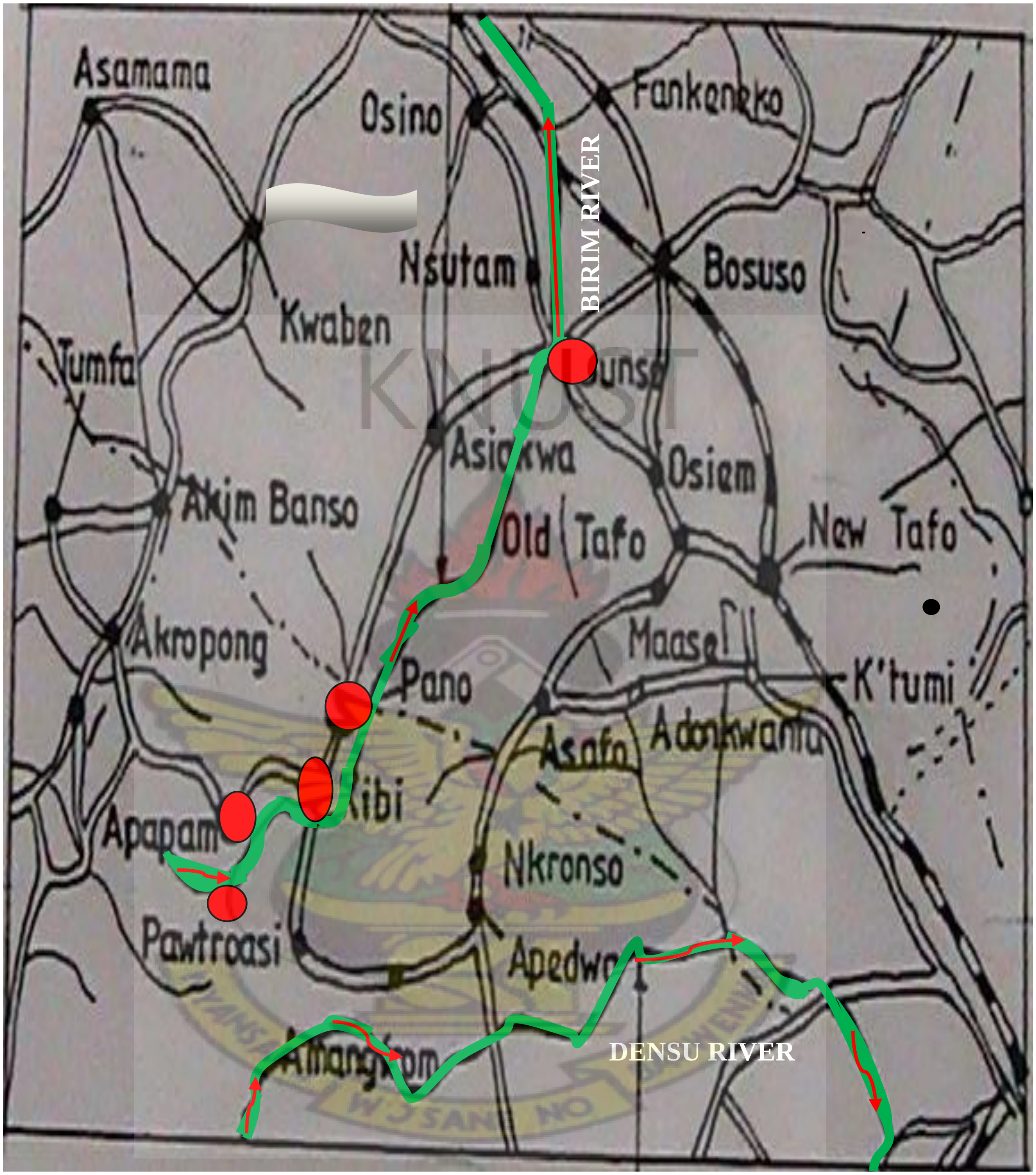
CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The study was carried out in the East Akim Municipality of the Eastern Region. The East Akim Municipality is located in the central portion of the Eastern Region with a total land area of approximately 725 square kilometers. The municipality is bounded by six administrative districts, namely the Atiwa District to the north, West Akim Municipal to the north-west, Fanteakwa District to the east, New Juaben Municipal to the south, Yilo Krobo District to the south-east and Suhum Kraboa Coaltar District to the west (Fig 1). The capital of the municipality is Kibi.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. The underlying rocks are the Birimmian formation. Also found are masses of granite which occur in parallel belts. These rock groups contain several mineral deposits including gold, diamond, bauxite and kaolin (http://eastakim.ghanadistricts.gov.gh).

The municipality is drained by rivers such as the Birim, Densu and Bompong but the main river used by many people is the Birim. The Birim River takes its source from north of Apapam, and passes through Kibi, Pano and Bunso. The main occupation of the inhabitants of the Municipality is farming; many people are also engaged in small-scale mining activities known as Galamsey, mostly along the banks and inside of the Birim River. The activities of the Galamsey have affected the river to such an extent that the water is no longer useful (http://eastakim.ghanadistricts.gov.gh).



Scale: 1: 150 000.

Plate 2. Map of East Akim Municipality showing Birim River and sampling sites

Legend

Road River Railway Sampling sites Towns Direction of flow of river

3.2 Sampling

Twenty-five water samples were collected from the Birim River at the following points: Apapam, Kibi, Pano, Bunso and upstream of Apapam which served as a control (Fig.1).Sampling of the water was done by dipping Voltic 1.5-litre bottles below the water surface at each of the designated sampling points. Sampling of the water started at the beginning of January, 2011 and ended in March, 2011. The sampling was done in two weeks interval.

3.3 Cleaning of sample bottles and glassware

All glassware and amber bottles for cadmium, copper, iron, lead and zinc analysis were soaked in detergent solution overnight after which they were washed and then rinsed with distilled water and soaked in 10% HNO_3 solution overnight. They were then rinsed again with several changes of distilled water and dried.

In the mercury analysis, the glassware, after being soaked in 10% HNO_3 solution overnight, were then rinsed with 0.5% $KMNO_4$ solution. They were finally rinsed first with tap water and then with distilled water, and then dried.

3.4 Treatment of samples for analysis

Exactly 5ml of concentrated HNO_3 was added to 1000ml each of the water samples for preservation. Digestion of samples was done by further addition of 20ml of concentrated HNO_3 and then reduced to 25ml by heating. The water was then allowed to cool at room temperature and then diluted to 50ml with distilled water. A blank solution was prepared without the sample.

3.5 Calibration of standards

3.5.1 Preparation of calibration standards for the metals (Cd, Cu, Fe, Pb Zn).

Calibration standards were prepared by single or multiple dilutions of the stock metal solutions. Reagent blanks and three calibration standards in graduated amounts in the appropriated range of the linear part of the curve were prepared, all containing the same acid concentration as in the samples.

3.5.2 Preparation of standard mercury solutions.

Mercury standard solution was prepared by dissolving 0.0677g of $HgCl_2$ in the acid mixture $HNnO_3$-H2SO_4-$HClO_3$ (2+10+2) in a 50ml digestion flask. The mixture was then heated on a hot plate at 250ºC ± 5ºC for 30 minutes until the solution became clearer. It was cooled and made up to 50mlwith deionised water. The standard was then diluted one thousand times to obtain the working solution (www.uspbpep.com/uep29/v29240/usp29n).

3.6 Measurement of pH

The pH of each water sample was determined using the PHYME cobros 3 basic unit USB pH meter using 200ml of the water sample.

3.7 Measurement of conductivity

Conductivity of each water sample was determined by Jenwey 4010 conductivity meter using 200ml of water sample.

3.8Measurement of turbidity

Turbidity of the water samples was determined using the Hanna instrument LP 2000 turbidity meter.

3.9Measurement of temperature

Temperature of the water was taken on site using mercury in glass thermometer.

3.10 Measurement of total dissolved solids

The total dissolved solids of each sample were determined using the Jenwey 4010 conductivity meter.

3.11 Analysis of samples for the presence of heavy metals

The concentration of heavy metals (. Cd, Cu, Fe, Pb, Zn) was determined with the Unicam 929 Atomic Absorption Spectrophotometer.

The concentration of Hg was determined with the Automatic Mercury Analyzer (model HG 5000).

3.12 Statistical Analysis

Analysis of variance (ANOVA) was carried out with all the data obtained from the five sampling sites to determine the mean values and least significant difference of means. The software used to carry out the analysis was GenStat 12.1 version.

CHAPTER FOUR

RESULTS

4.1 Physico-chemical parameters

The pH values of water from the various sampling sites of Birim River are presented in Fig. 2.

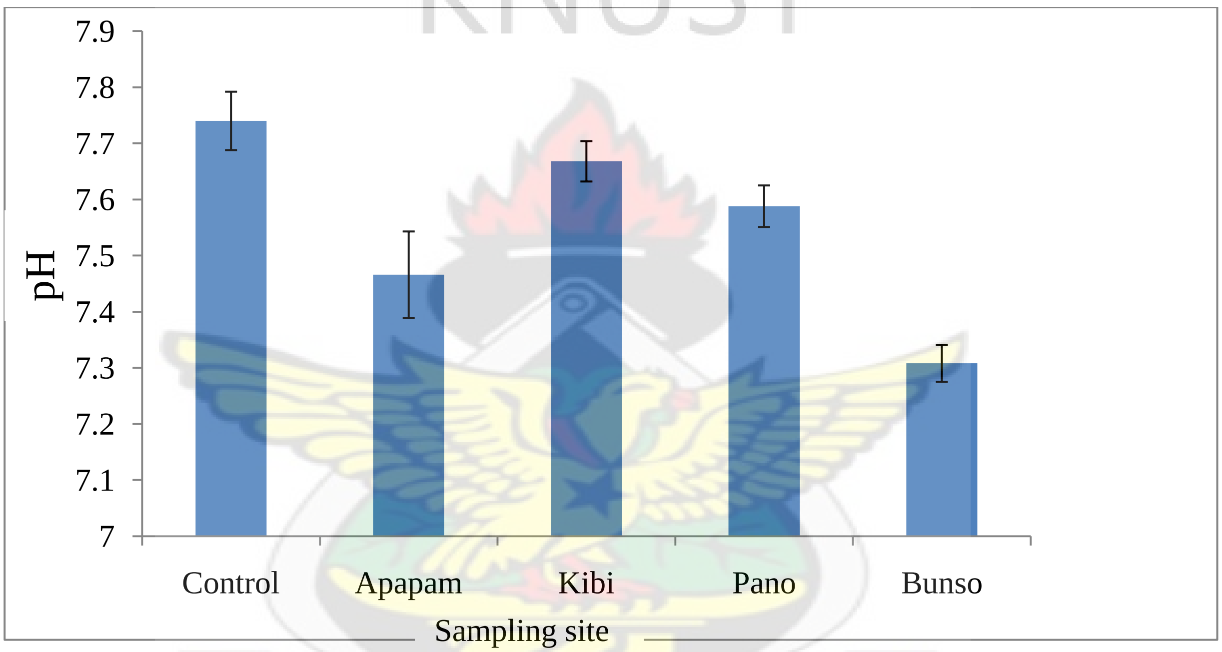


Fig.2. Mean pH values of water from selected sampling sites of Birim River

The average pH of the water ranged from 7.30 to 7.74. The value obtained for the Control was higher than those for the other sampling sites. Kibi obtained the second highest pH value, followed by that of Pano, Apapam and then Bunso with the least pH value (Fig. 2). The pH value recorded at Kibi (7.668) was significantly higher than that recorded at Apapam (7.466) and Bunso (7.308) (LSD 0.05) (Appendix 1).

The conductivity values of water from various sampling sites of Birim River are presented in Fig. 3

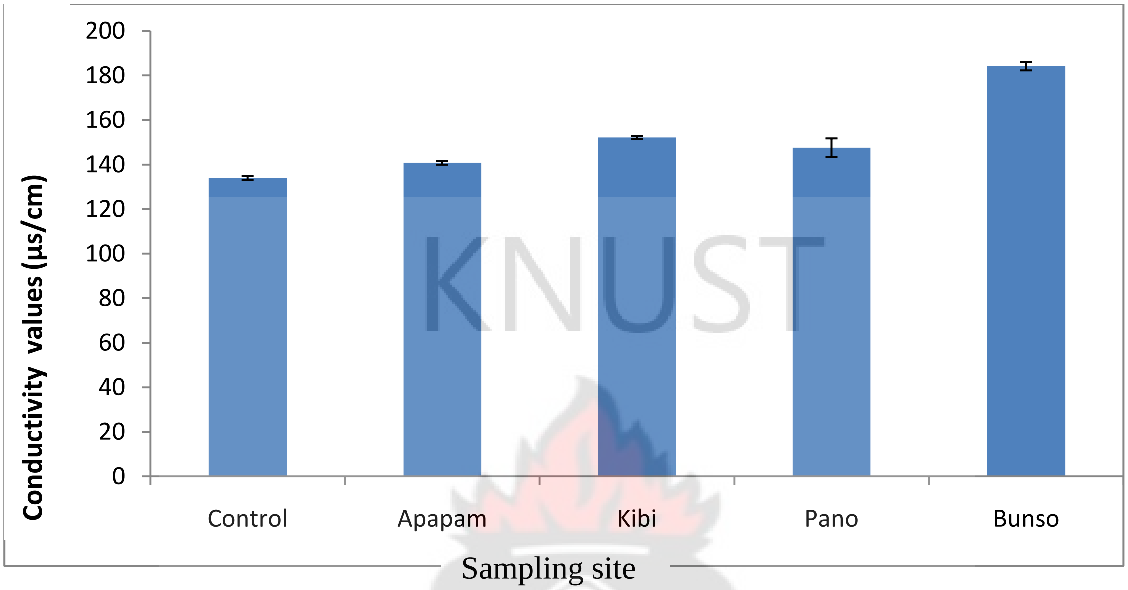


Fig. 3 Conductivity values of water from selected sampling sites of Birim River

Bunso recorded the highest conductivity of a mean value of 184.0 µs/cm while the Control recorded the least with the value of 134.0 µs/cm. The conductivity increased from the upstream of the river at the Control to the downstream of the river at Bunso. The conductivity values obtained from the various sampling sites were higher than the value obtained for the Control (Fig. 3). The conductivity value recorded at Bunso (184.0 µs/cm) was significantly higher than those recorded at Pano (147.0 µs/cm), Kibi (152.0 µs/cm) and Apapam (140.0 µs/cm) (LSD 0.05) (Appendix 1).

The turbidity values of water from various sampling sites of Birim River are presented in Fig. 4

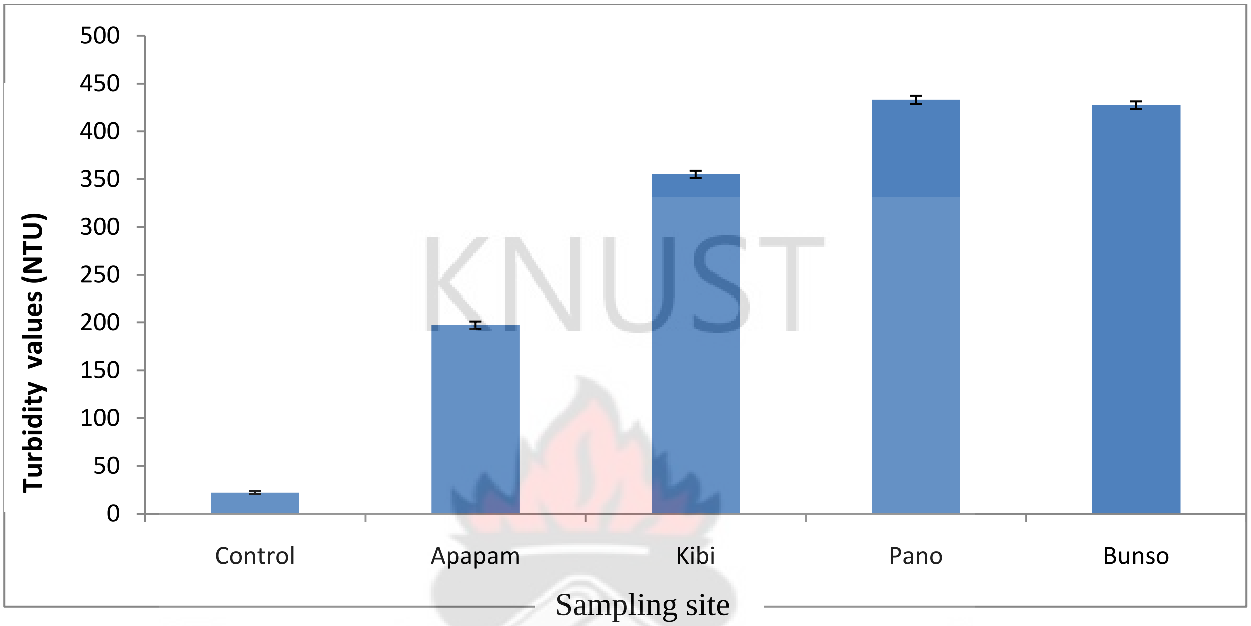


Fig**. 4. Turbidity values of water from selected sampling sites of Birim River**

Pano recorded the highest mean turbidity value of 433.0 NTU while Apapam recorded the least value of 197.5 NTU. All the turbidity values obtained from the various sampling sites were higher than the value obtained for the Control. The turbidity increased from the Control sampling site, which is the upstream to Bunso downstream of the river (Fig. 4).

The temperature values of water from various sampling sites of Birim River are presented in Fig.5

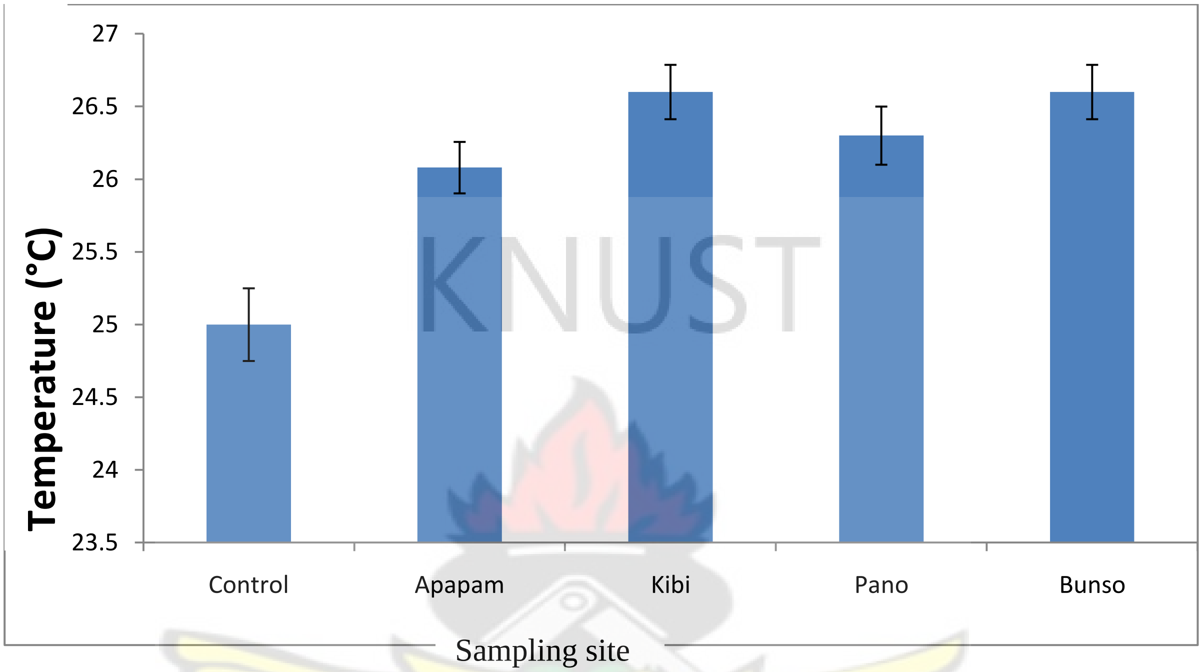


Fig. 5. Temperature values of water from selected sampling sites of Birim River

Temperature values obtained from the sampling sites were a little higher than the value obtained for the Control. Temperature values increased from the Control, which is the upstream of the river to Bunso downstream of the river (Fig. 5). Kibi and Bunso recorded the highest temperature followed by Pano and then Apapam.

The levels of total dissolved solids in water from various sampling sites of Birim River are presented in Fig. 6

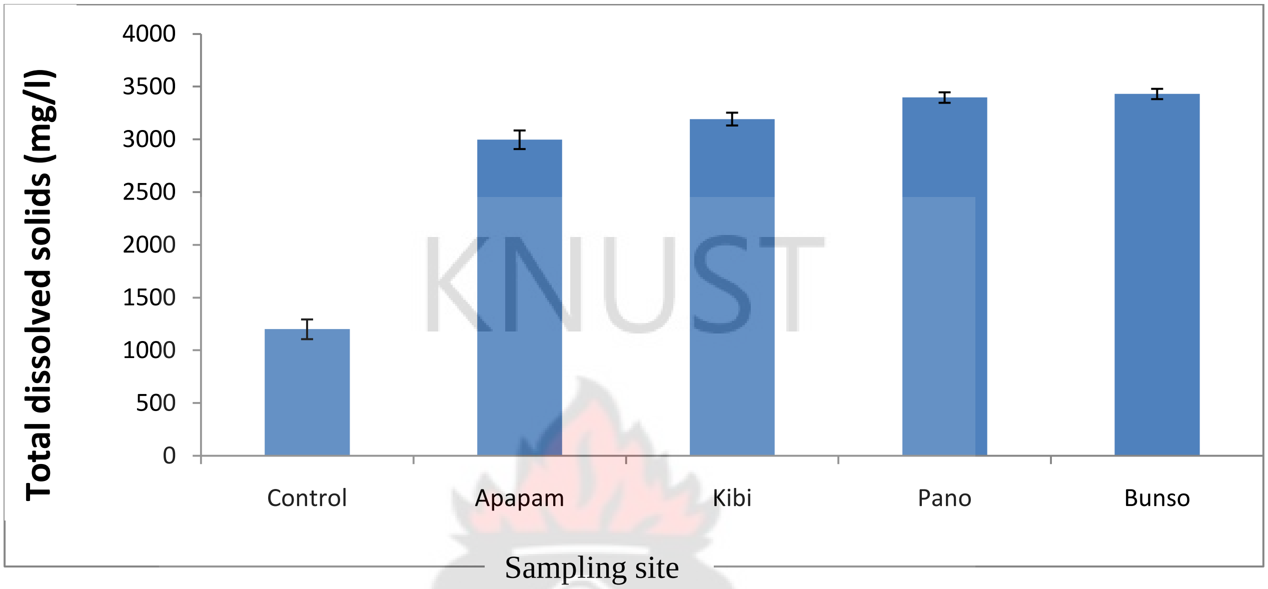


Fig.6. Levels of total dissolved solids in water from selected sampling sites of Birim River

The levels of total dissolved solids in water obtained from the selected sampling sites were higher than the value obtained for the Control. The levels of total dissolved solids increased from the Control, which is the upstream to Bunso, an area downstream. Bunso had the highest levels of total dissolved solids with a value of 3431 mg/l,and Apapam had 2997 mg/l (Fig.6).

4.2 Heavy metal concentration.

The levels of cadmium in water from various sampling sites of Birim River are presented in Fig. 7

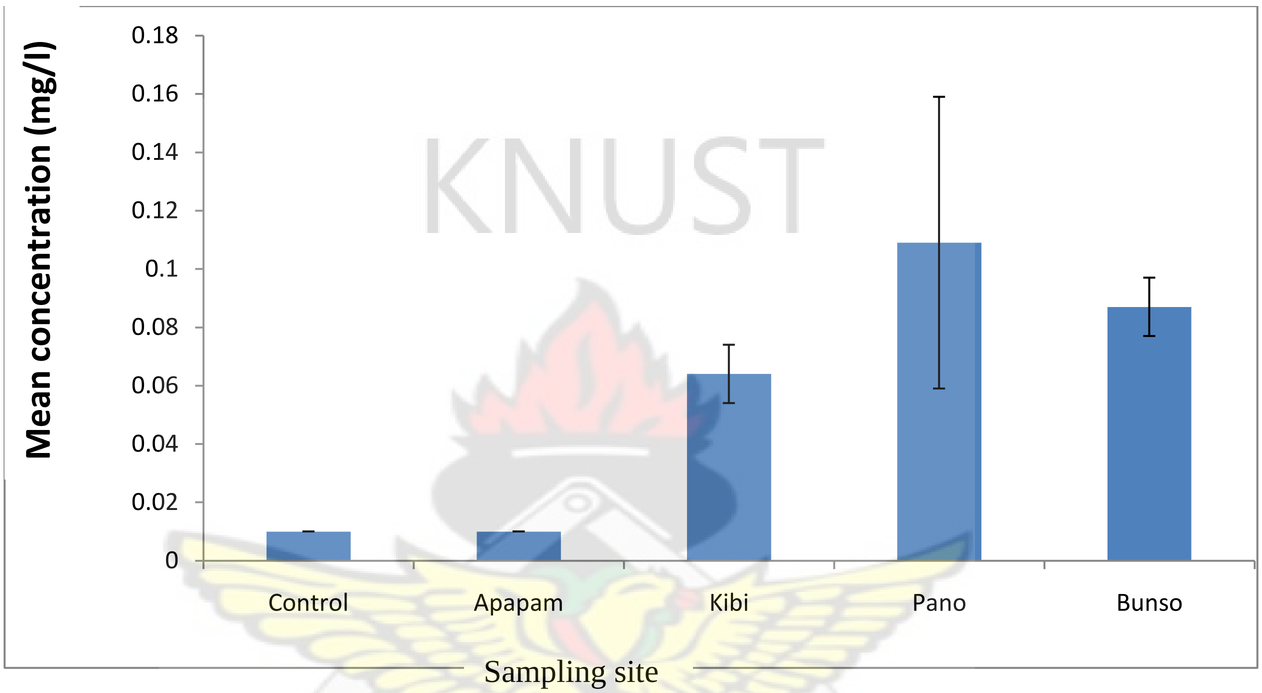


Fig. 7. Levels of cadmium in water from selected sample sites of Birim River

The levels of cadmium in water from the various sampling sites of Birim River were higher than the level in the Control. The concentration of cadmium showed a general increase from Apapam, which is the upstream to Bunso downstream of the river. Pano recorded the highest level of cadmium with a value of 0.1098 mg/l while Apapam recorded the least with a value of 0.01mg/l (Fig. 7).

The concentration of iron in water from the various sampling sites of Birim River are presented in Fig.8.

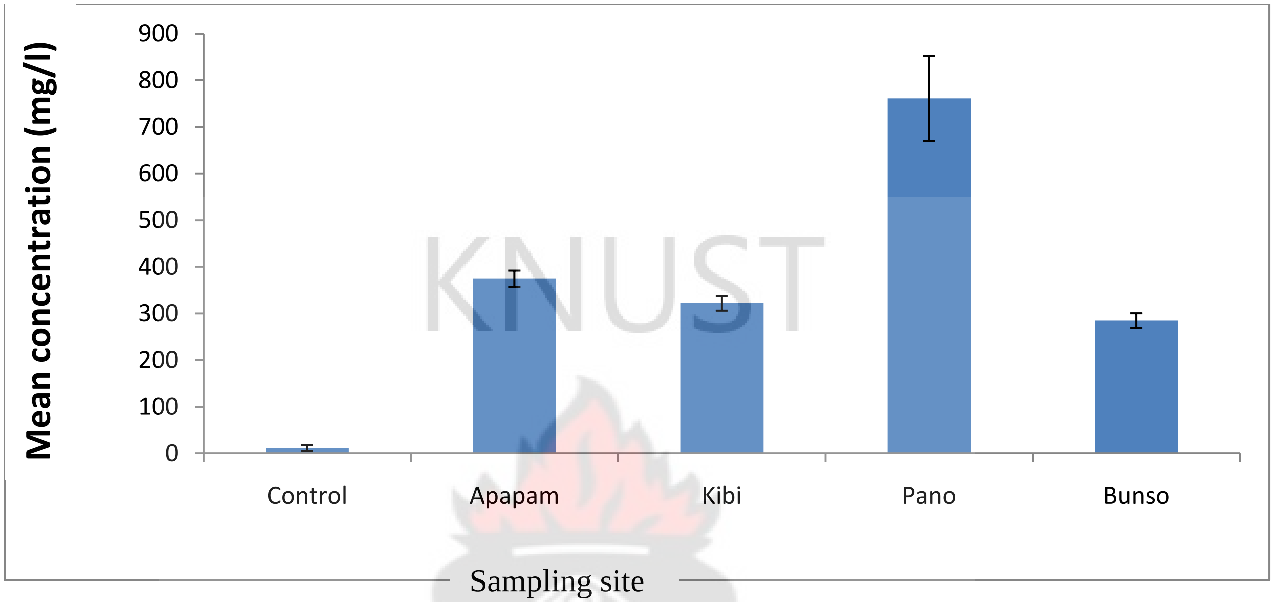


Fig. 8 Levels of iron in water from selected sampling sites of Birim River

The levels of iron in the water from the various sampling sites of Birim River were higher than the value recorded by the Control. Pano recorded the highest level of iron with a value of 761.3 mg/l while Bunso recorded the least with a value of 284.9 mg/l (Fig. 8). The mean value of iron recorded at Pano (761.3 mg/l) was significantly higher than those recorded atApapam (374.5 mg/l), Kibi (322.0 mg/l) and Bunso (284.9 mg/l) (LSD0.05) (Appendix 2).

The concentration of lead in water from various sampling sites of Birim River are presented in Fig. 9

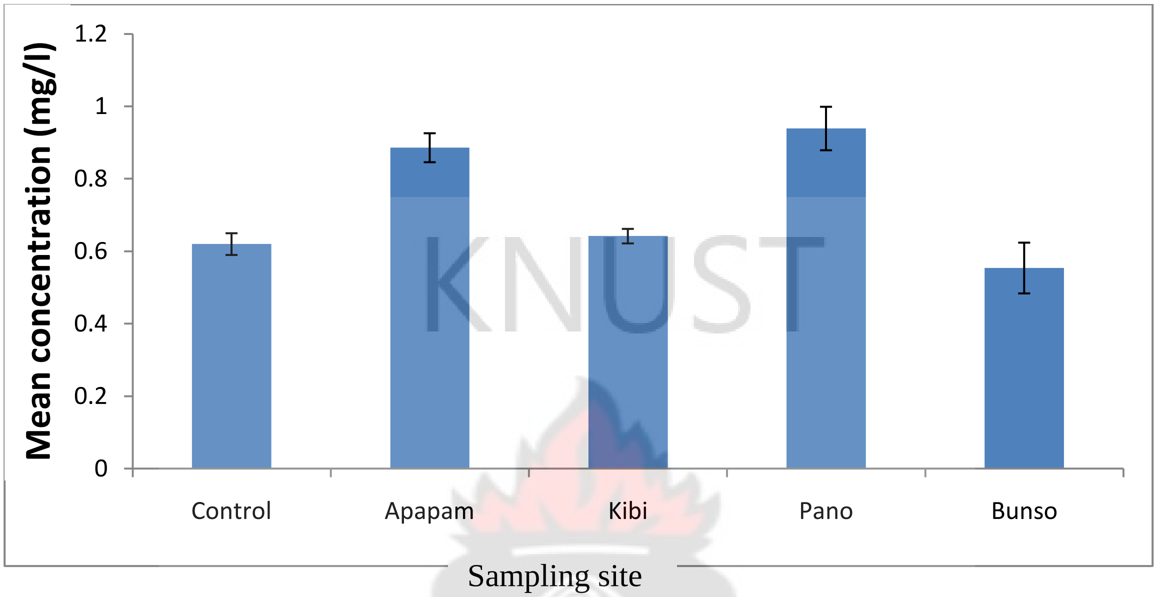


Fig. 9 Levels of lead in water from selected sampling sites of Birim River

The levels of lead in water obtained from Apapam, Kibi and Pano sampling sites were higher than the one obtained from the Control sampling site,but the level obtained from Bunso sampling site was lower than from the Control site. Pano recorded the highest level with a mean value of 0.9388 mg/l followed by that of Apapam with a mean value of 0.8856 mg/l (Fig. 9). The mean values of lead recorded at Pano and Apapam were significantly higher than those recorded at Kibi and Bunso (Fig.9).

The levels of copper in water from various sampling sites of Birim River are presented in Fig. 10

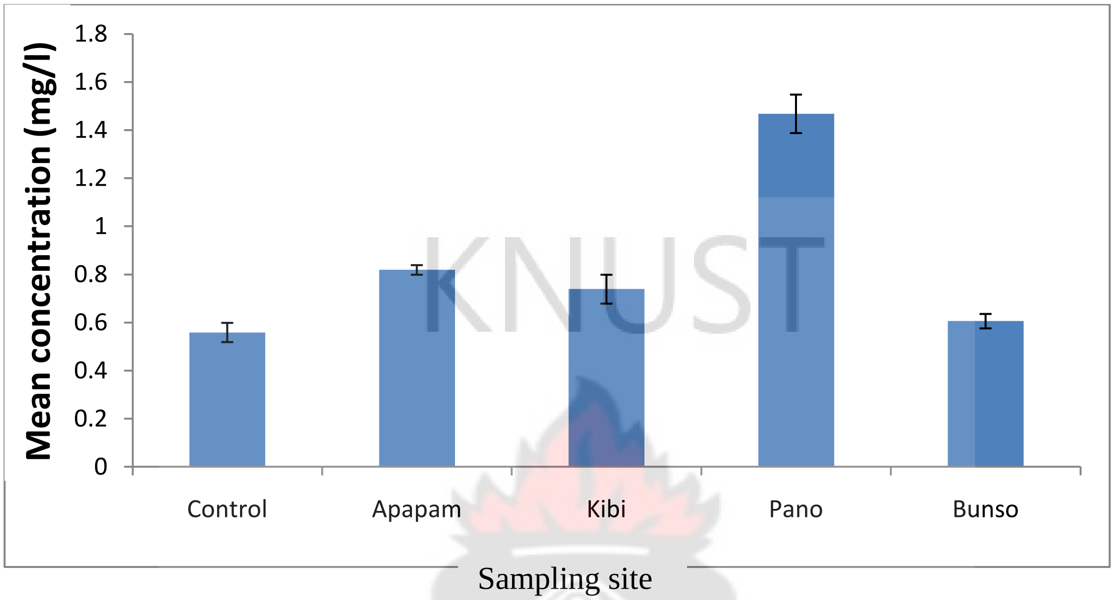


Fig. 10 Levels of copper in water from selected sampling sites of Birim River

The levels of copper in the water obtained from the various sampling sites were higher than the one obtained from the Control with a mean value of 0.559 mg/l. Pano recorded the highest with a mean value of 1.4682 mg/l followed by Apapam with a mean value of 0.8194 mg/l (Fig 10). The mean value of copper obtained from Pano was significantly higher than those recorded at Apapam, Kibi and Bunso (LSD 0.05) (Appendix 2).

The concentration of zinc in water from various sampling sites of Birim River are presented in Fig. 11

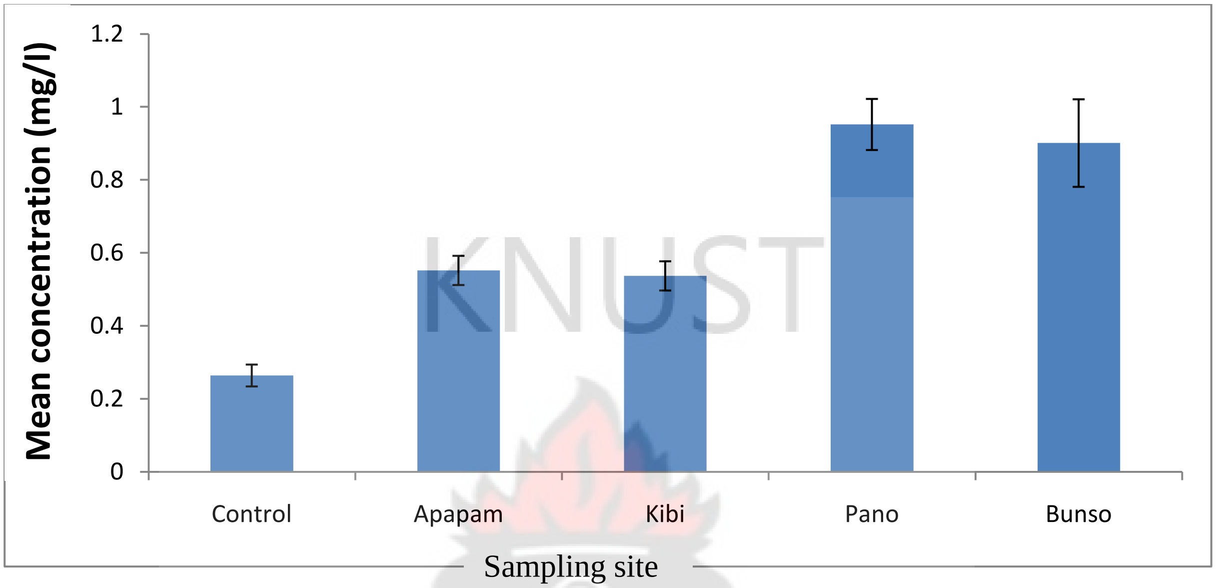


Fig. 11 Levels of zinc in water from selected sampling sites of Birim River

The levels of zinc in water obtained from the various sampling sites were higher than the one obtained from the Control. Pano recorded the highest concentration of zinc in the water with a mean value of 0.952 mg/l, followed by that from Bunso with a mean value of 0.9008 mg/l. Apapam and Kibi recorded the least concentrations of zinc with mean values of 0.5516 mg/l and 0.5374 mg/l respectively (Fig. 11).

The levels of mercury in water from various sampling sites of Birim River are presented in Fig. 12

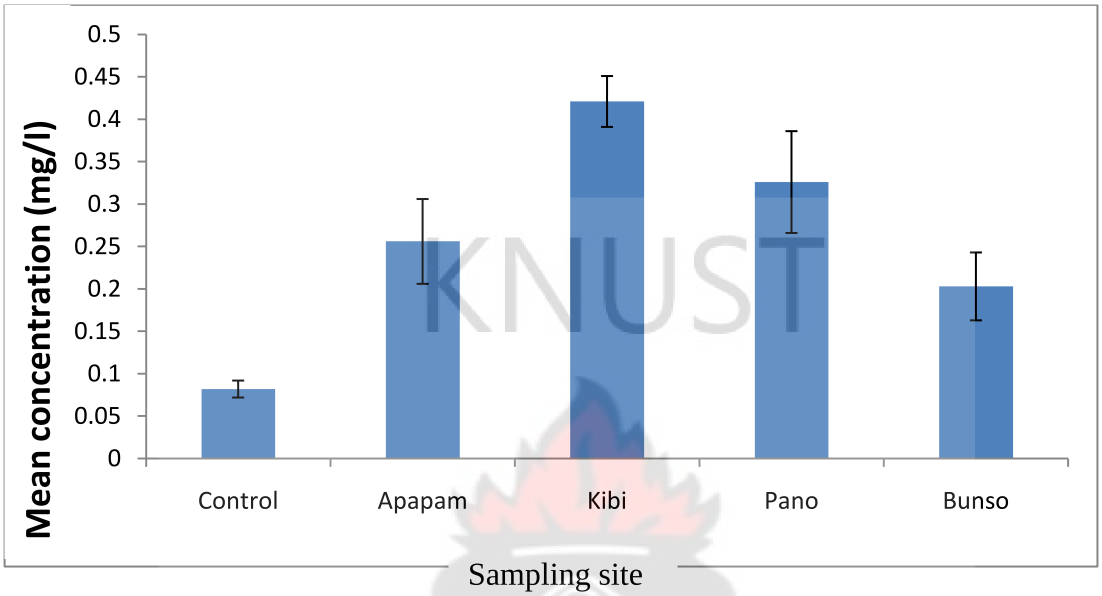


Fig. 12. Level of mercury in water from selected sampling sites of Birim River

The levels of mercury in the water obtained from the various sampling sites recorded mean values higher than the one obtained for the Control. Kibi recorded the highest concentration of mercury with a mean value of 0.4204 mg/l followed by Pano with a mean value of 0.3262 mg/l (Fig.12).

CHAPTER FIVE

DISCUSSION

The samples analyzed were taken from different sites along the Birim River such that they could represent the portion of the river in the East Akim Municipality.

The mean pH of the water ranged from 7.3 to 7.66 and it fell within the WHO permissible limit of drinking water, in a range of 6.5 to 8.5 (WHO, 2006). The values obtained for pH was little lower than the pH of the Control with a value of 7.74. The pH values obtained show that the water is slightly alkaline and decreases in the order Kibi>Pano>Apapam>Bunso. Nartey *et al*., (2011) obtained a pH range of 8.5 to 7.1 from water samples in Bibiani-Anwiaso-Bekwai District which is a typical mining community; pH values of the later gives wider range than pH of the water samples from East Akim Municipality. The pH of the water may be attributed to the nature of rocks that are embedded in the river, pollution from point and non-point sources, level of turbidity and total dissolved solids.

The average temperature of the water ranged from 26.08°Cto 26.60°C. The temperature recorded at all the sampling sites shows a sequence: Kibi>Bunso>Pano>Apapam. The temperature values recorded at Bibiani-Anwiaso-Bekwai District shows rather wider range from 22.7°C to 31.6°C (Nartey *et al.*, 2011), as compared to the one recorded at the East Akim Municipality. The differences in the temperature range may be attributed to the prevailing weather conditions found in the respective places.

Total dissolved solids recorded values that ranged from average of 2997mg/l to 3431mg/l. The values obtained from the sampling sites were higher than WHO permissible limit of 1000 mg/l (WHO, 2006). Bunso recorded the highest while Apapam recorded the lowest. The sequence was in the order: Bunso>Pano>Kibi>Apapam.

Bunso is downstream and could contain more dissolved solids than Apapam which is upstream because of the increase in activities of the small scale mining and runoff from the land into the river which add on more mineral particles as the water moves downwards. Total dissolved solids recorded at the sampling sites were higher than the Control samples with the mean value of 1200mg/l.

Conductivity values of water collected from sampling sites show a sequence of Bunso>Kibi>Pano>Apapam. Bunso recorded the highest conductivity with a mean value of 184.2 µs/cm while Apapam recorded the least value of 140.8 µs/cm. The Bunso sampling site could contain more ions of elements than the rest of the sampling sites because Bunso is found downstream of the river and so more particles from runoff and mining activities will add on to the river as it flows downwards.

Turbidity values of water collected from the sampling sites were high and were in the sequence: Pano>Bunso>Kibi>Apapam. Pano recorded the highest mean value of 433.0NTU while Apapam recorded the least value of 197.3 NTU. Turbidity recorded at various sites was higher than the Control value of 22.1 NTU (Appendix 1). The values obtained from the sampling sites were very high as compared to WHO permissible limit of drinking water, a value of 5.0 NTU (WHO, 2006). The high turbidity of the water samples could be caused by runoff and small-scale gold mining activities which is done inside the river.

Metal concentration from the four sampling sites showed a general sequence of Fe>Cu>Pb>Zn>Hg>Cd. The mean values obtained for the heavy metals wereFe (436mg/l), Cu (0.908mg/l), Pb(0.753mg/l), Zn(0.735mg/l), Hg (0.301mg/l)and Cd (0.067mg/l). Copper and zinc concentrations detected in the water had values lower than the WHO acceptable limits of drinking water with values Cu (2.0mg/l) and Zn (3.0mg/l).The rest of the heavy metals obtained from the sampling sites had values higher than the WHO acceptable limits of drinking water; Fe (0.03mg/l), Pb (0.01mg/l), Cd (0.003mg/l) and Hg (0.01µg/l) (WHO, 2006).A general comparison of the results shows that samples from Pano and Bunso recorded the higher values of metal concentration than those from Kibi and Apapam. This could be attributed to the following reasons:

The mining activities done inside the river and along the banks of the river may have probably released extremely high levels of the metals into the river.

The relatively high levels of these elements could also be due to anthropogenic inputs, both point and non-point sources of pollution.

The type of farming practice: It was observed that the people farm close to the river banks and it could be that they use metal based fertilizer or pesticides and these could have been washed into the river to contribute to the concentration of metals in the mining water.

Run-off from the road side, the community or affluent from domestic waste which are channeled into the river could also contribute to the metal concentration.

The high levels of these elements in the water could also be due to the inherent mineralogy of the ores of the study area.

The careless use of fuels like petrol can also be a factor contributing to the high levels of lead in the earth affecting water bodies.

Another reason could be that these metal loads were carried from upstream of the river. Pano and Bunso sampling sites recorded high metal concentration and high physico-chemical parameters than those Recorded at Kibi and Apapam sampling sites. The reason could be that the particles in the upstream portion of the river flows and add on to the downstream of the river. Also mining activities in the downstream portion of the river could be higher than the upstream of the river.

Iron recorded the highest metal concentration with a mean value of 761.3 mg/l with the least mean value of 284.9 mg/l at Bunso. These values are above the Control value of 11.375 mg/l. Pano's value of 761.3 mg/l of iron is significantly different from those of the other sampling sites such as Kibi, Apapam and Bunso. This might be attributed to natural existence of iron in the earth. Most of the heavy metals were introduced into the river through mining activities.

Copper and Zinc concentration detected in the water had mean values that were higher than the Control values of 0.559 mg/l for copper and 0.264 mg/l for zinc. Pano riverine water contained 1.4682 mg/l of copper which was significantly different from 0.8194 mg/l, 0.7396 mg/l and 0.6064mg/lApapam, Kibi and Buns respectively (Appendix 2)

Water samples from Pano and Bunso contained 0.952 mg/l and 0.9008 mg/l of zinc respectively which were significantly different from those from Kibi and Apapam.

Concentration of Lead (Pb) on the other hand was 0.753mg/l which exceeded the Control value of 0.62mg/l. This shows the presence of relatively high distribution of lead in the Birim River as a result of the mining activities and also in the district. It is known that lead is used in paints, pesticides etc. and therefore it is human activities that introduce lead into the environment. Since the community members are also farmers, it appears that the use of pesticides is likely to be the greatest cause of the high level of lead in the water. The use of fuels like petrol can also be a factor contributing to the high levels of lead in the earth affecting water bodies. Pano and Apapam riverine water contained 0.9388mg/l and 0.8856 mg/l of Pb respectively which were significantly different from the values obtained at Kibi and Bunso.

Cadmium (Cd) also recorded a mean value 0.067 mg/l that exceeded the Control value of 0.01 mg/l. (Appendix 2). This shows a little higher distribution of cadmium in the river as a result of human activities. Water collected from Pano and Bunso had the highest values of cadmium which were significantly different from those obtained from Apapam.

Mercury recorded a mean value of 0.301 mg/l which exceeded the Control value of 0.082 mg/l. This shows that there is higher distribution of mercury as a result of mining activities. Kibi recorded the highest value of mercury which was significantly different from the values from Apapam and Bunso. At Prestea and its environs, concentration of mercury from the sampling sites with extensive mining activities recorded values varying from 6.80mg/l to19.82 mg/l (Serfoh-Armah et al, 2006). The values obtained from Prestea were very high as compared to the values obtained from the East Akim Municipality. The reason for obtaining low concentration of mercury in Birim River of East Akim Municipality could be that, most of the miners normally extracted the gold at a place far away from the river and so the mercury could only get into the river by the runoff. Most of the small scale mining activities in the area were illegal and so the people doing them were afraid of being arrested by the security agencies. For others, mercury was expensive and so they tried to recoup it after use.

The metal concentrations detected from the Birim River are referred to as heavy metals. These can be distinguished from other metal known as light metals. Light metals are metallic element of the alkali and alkaline earth groups, as sodium, lithium, calcium magnesium, aluminium and nickel. These are metals of low molecular weight. Light metals are generally less toxic than heavy metals. Beryllium is toxic, but it is rarely found in large concentration. Metals heavier than nickel are usually called heavy metals.

Heavy metal refers to any metallic chemical element that has a relatively high density and is toxic at low concentrations. Examples of heavy metals include mercury, cadmium, arsenic, lead, iron and copper. Heavy metals are natural components of the earth's crust. They cannot be degraded or destroyed. They enter the human body through food, drinking water and air. Some heavy metals such as copper and zinc are referred to trace element. These are essential to maintain the metabolism of the human body. However, at higher concentrations, they can lead to poisoning.

Heavy metals are dangerous because they tend to bioaccumulate. The compounds accumulate in living things any time they are taken up and stored faster than they are metabolized or excreted. Some health risks of heavy metals include reduced growth and development, cancer, organs damage, nervous system damage and in extreme cases, death. Exposure to some metals such as metals, such as mercury and lead, may also cause development of autoimmunity, in which a person immune system attacks its own cells. This can lead to joint diseases such as rheumatoid arthritis, and diseases of the kidney, circulatory system, and nervous system.

Childhood exposure to some heavy metals can result in learning difficulties, memory impairment, damage to the nervous system, and behavioural problems such as aggressiveness and hyperactivity. At higher doses, heavy metals can cause irreversible brain damage. The heavy metals linked most often to human poisoning are lead, mercury, cadmium, copper and zinc (Brown, 2003; FDA, 2004).

According to hospital records obtained from Kibi Government Hospital, diseases viewed to be directly associated with small scale mining activities are infectious respiratory diseases caused through constant inhaling of dust particles; outbreaks of malaria, typhoid and cholera resulting from the polluted water. Skin diseases were also observed to be common in the study area especially in the mining communities were the result of the crude use of mercury in the washing and processing of gold. The mining communities need to be educated by stakeholders of various hospitals, for the communities to be aware of the hazards associated with small scale mining activities, and out line recommendations that could mitigate these problems.

Since the small scale mining activities is still in operation in the study area, future studies is required to augment present data.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The results of this study have generally shown high levels of all the examined element and physico-chemical parameters of the river during the period of sampling.

The values obtained for turbidity and total dissolved solids from the four sampling sites were very high above the WHO acceptable limits for drinking water, and also above the control values. The pH values from the four sampling sites were however slightly lower than the control value but within the range of WHO acceptable limits.

The level of the metal concentration from the four sampling sites, show a general sequence of Fe>Cu>Pb>Zn>Hg>Cd. The levels of iron, lead, cadmium, copper, zinc and mercury in the water samples were above the control values obtained from the upstream of the river. The levels of iron, lead, cadmium and mercury in the water samples were also above the WHO acceptable limits but the levels of copper and zinc were lower than the WHO acceptable limits. The high levels of the parameters have been caused by the activities of the small scale mining. This is because the values obtained from water samples with mining activities were higher than the upstream portion of the water samples without any mining activities. High levels of the physico-chemical parameters and concentration of most of the heavy metals observed in the river may have a detrimental effect on the health of the inhabitants of the communities that use the river directly without treatment for domestic purposes.

6.2. Recommendations

It is suggested that the illegal mining activities in the river should stop. There could be public campaigns to educate the illegal small scale miners and communities involved on the short and long term dangers of illegal mining activities. Alternative livelihood should be instituted for those engaged in the illegal small scale mining activities.

REFERENCES

Acquah, P. C. (1992). Mining and the Environment: The Ghanaian experience. Proc. of symposium on gold mining in Ghana, Mineral Commission, Accra, Ghana.

Adansson, E., Piscator, M. and Nogawa K. (1979. Pulmonary and Gastrointestinal exposure to cadmium oxide dust in a battery factory. Environmental Health Perspectives. 28, 219-222.

Agyapong, E. (1998). Streamlining Artisanal Gold Mining Activities and the Promotion of cleaner Production in the Mining Sector in Sub-Saharan Africa, Ghana as a case study. Unpublished MPhil Thesis, Lund University, Lund. Sweden.

Allan, J. D. (1995). Stream Ecology: Structure and Function of Running Waters. Chapman and Hall, London. Journal of the Marine Biological Association of the UK, 30, 233-263.

American Public Health Association (1992). Standard Methods for the Examination of Water and Wastewater. 18th edition. Australian Journal of Ecology, Washington D.C., pp. 89-102.

American Public Health Association (1998). Standard Methods for the Examination of Water and Wastewater, 20th edition. Australian Journal of Ecology, Washington D.C., pp 122-129.

Andrea, W. (1993). The UK's Royal Commission on Environmental Pollution after 25 Years, Ninth Report. Environmental Management and Health, 7(2) : 35-39.

Appiah, H. (1998). Organization of Small Scale Mining Activities in Ghana. The Journal of the South African Institute of Mining and Metallurgy 98(7): 307-310.

ATSDR (Agency for Toxic Substances and Diseases Registry) (1989) Toxicological Profile for Cadmium, ATSDR/US, Public Health Services, ATSDR/TP-88/08.

AWWA (American Water Works Association) (1998). Standard Methods of Analysis of Physico-chemical Parameters of Water. www.awwa.org. Accessed 15th February, 2011.

Barry, M. (1996). Regularizing Informal Mining. A summary of the Proc. of the Intl Roundtable on artisanal mining. World Bank Industry and Energy Dept., Washington D.C., USA.

Boulton, A.J. and Brock, M.A. (1999). Australian Freshwater Ecology. Processes and Management. Gleneagles Publishing, Glen Osmond, South Australia.

Brown, R. H. (2003). Mercury's fall from Medicine to Toxin, Georgia Public Policy Foundation. www.gppf.org/article.asp Retrieved March 3, 2011.

Bruvold, W.H. and Ongerth, H.J. (1969). Taste quality of mineralized water. Journal of the American Water Works Association, 61: 170.

Collins, S. (2003). Heavy Metal Intoxication" In Nelson Textbook of Pediatrics, 17th ed. Edited by Richard E. Behrman, Saunders, Philadelphia; pp. 2355-2357

Davidson, J. (1993). The Transformation and Successful Development of Small Scale Mining Enterprises in Developing Countries, Natural Resources Forum 17 (4): 315-326.

Dodds, W. K. (2002). Freshwater Ecology: Concepts and Environmental Applications, Academic Press, San Diego, CA.

El-Rayis, O. and Saad, M.A. (1986). Heavy Metals in Suspended Matters and Sediment From a confined Lagoon on the North African Coast. Egypt, Rapp. P-V. Rẽum, CIESM, 30 (2): 50

FDA (2004). What you need to know about Mercury in Fish and Shellfish. FDA Washington DC, March, 2004. www.water.epa.gov/scitech/swguidance/fishshelfish Retrieved 21st February, 2011.

Friberg, L. M., Piscator, G. F. and Kjellstone, T.(1974).Cadmium in Environment, 2nd ed CRC Press, Boca Raton, FL.

Ghana Business News (13th March, 2010). Birim River is losing its importance. www.ghanabusinessnews.com. Accessed 15th February, 2011.

Ghana Chamber of Mines Report (2008).www.ghanachamberofmines.org. Accessed 20th January, 2011.

Ghana Chamber of Mines Report(2010).www.ghanachamberofmines.org. Accessed 20th January, 2011.

Ghanaian Chronicle (5th March, 2005). Galamsey 'breeds' mercury poisoning. GAEC Research. www.ghanaianchronicle.com. Accessed 15th February, 2011.

Ghana News Agency (22nd May, 2009). Illegal mining activities is depriving the people of Kibi of potable water. www.ghananewsagency.org. Accessed 15th February, 2011.

Ghana News Agency (19th August, 2009). Water bodies in Obuasi and Tarkwa poisoned. www.ghananewsagency.org. Accessed 15th February, 2011.

Ghana News Agency (9th October, 2009). Galamsey activities pose danger to water treatment www.ghananewsagency.org. Accessed 15th February, 2011.

Ghana News Agency (22nd February, 2011). Ghana Water Company face imminent closure at Ntweaban and Daboase due to illegal mining. www.ghananewsagency.org. Accessed 5thMarch, 2011.

Ghana Statistical Service Report (2010) . www.statsghana.gov.gh. Accessed 20th January, 2011.

Goyer, R. (1991). Toxic Effects of Metals. In: Amdur, M. O., Doull, J.D.and Klaaseen, Klaaseen, C.D. Eds. Casarett and Doull's Toxicology. 4th ed. Pergamon Press, New York. pp 623-680.

Hilson, G. (2001). The Environmental Impact of Small-scale Gold Mining in Ghana: Problems and Solutions. The Geographical Journal 168: 57-72.

http://eastakim.ghanadistricts.gov.gh. East Akim Municipality of Eastern Region of Ghana. Accessed 21st March, 2011

http://en.wikipedia.org/wiki/cadmium. Cadmium Element. Accessed 5th March, 2011.

http://en.wikipedia.org/wiki/copper. Copper Element. Accessed 5th March, 2011.

http://en.wikipedia.org/wiki/iron. Iron Element. Accessed 5th March, 2011.

http://en.wikipedia.org/wiki/lead. Lead Element accessed 7th March, 2011.

http://en.wikipedia.org/wiki/mercury(element) Mercury Element. Accessed 7th March, 2011.

http://en.wikipedia.org/wiki/zinc. Zinc Element. Accessed 7th March, 2011.

http://www.epa/gov/acidraineffects/surface-water.html Effect of Water pH on Living Organisms. Accessed 7th March, 2011.

International Organisation for Standardization (1985). Water quality-determination of electrical conductivity, Geneva, (ISO 7888: 1985).

Johnson, H.L. and Sauberlic, H.E. (1982). Trace Element Analysis in biological samples, Clinical, Biological and Nutritional Aspect of Trace Element. (Ed A.S. Prasad), Alan Lis Inc, New York USA. pp 405-426.

Markowitz, M. (2003). Lead Poisoning: In: Nelson Textbook of Pediatrics. 17th ed. Edited by Richard E. Behrman. Saunders, Philadelphia. pp 2358-2361.

Nartey, V.K., Doamekpor, L.K. and Sarpong-Kumankuma, S.(2011) Mercury Pollution Studies of some Rivers Draining the Bibiani-Anwiaso-Bekwai Mining Community of South Western Ghana. Research Journal of Environmental and Earth Sciences, 3 (4): 375-385.

Newman, M. C.,McIntosh, A.W.and Newman, N. C.(1999). Metal Ecotoxicology.. University Park Press, Baltimore, Maryland USA. pp. 302

Noestaller, R. (1994). Small-scale Mining; Practices, Policies and Perspective. In A.K. Ghose (ed) Small Scale Mining, A Global Overview, Intermediate Technology Publications, Rotterdam.

Rambaud, A., Casellas, C., Sackey, O., Ankrah, N., Potin-Gautier, M., Bannerman, W., Claon, S. and Beinhoff, C. (2001). Mercury Exposure in an Artisanal Mining Community in Ghana. United Nations International Development Organization. Unpublished study.

Serfor-Armah, Y., Nyarko, B. J. B., Adotey, D.K. and Akaho, E.H. K.(2006). The Impact of Small scale Mining Activities on the levels of Mercury in the environment. The case study of Prestea and its environs. Journal of Radioanalytical and Nuclear Chemistry. 262 (3): 625-690.

Sethi, V., Patnaik, P., Biswas, P., Clark, R.M. and Rice, E.W. (1997). Evaluation of Optical Detection Methods for Water Borne Suspensions, J. AWWA. 89(2): 98-112.

Singh, T. and Kalra, Y.P. (1975). Specific conductance method for in situ estimation of Total dissolved solids. Journal of the American Water Works Association, 67 (2): 99.

United Nations (1992). Mining and Environment: The Berlin Guidelines, Study Based on a an International Round Table in June, 1991. Mining Journal Books, Department of Technical Cooperation, United Nations, New York. .

United Nations (1996). Recent developments in Small-scale Mining: A report of the Secretary General of the United Nations, Natural Resource Forum 20 (3): 215-25.

United States Environmental Protection Agency (1997). National Primary Drinking Water Regulations: Interim Enhanced Surface Treatment Rule and Notice of Data Availability Proposed Rule 62 ER 59486, November 3.

United States Environmental Protection Agency (2002). National Primary Drinking Water Regulations: Long Term 1, part9, 141 and 142. Enhanced Surface Water Treatment Rule. Final Rule, (67 FR 1181).

WHO (2006). World Health Organization Guidelines for drinking water quality. Third edition. Geneva. ISBN 92 4 154696 4.

WHO/UNEP, GEMS (1989). Global freshwater quality, Alden Press, Oxford, UK.

Wolf, W. R.(1982). Trace Element Analysis in Food. In: Clinical, Biological and Nutritional Aspect of Trace Element (Ed A.S. Prasad) Alan Liss Inc. New York, USA. pp 427-446.

World Bank (1995). Staff Appraisal Report, Republic of Ghana. Mining Sector Development and Environmental Project. World Bank Report No. 13881-GH, Industry and Energy Operations, West and Central Africa Department.

www.ehow.com/about6723807effect . Effects of acid rain. Accessed 27th February, 2011.

www.lenntech.com/mercury/Hg.htm. Health effects of mercury. Accessed 27th

27th February, 2011.

www.slideshare.net/guest5907f90/water **.** Water turbidity. Accessed 27th February, 2011.

www.uspbpep.com/uep29/v29240/usp29n. Preparation of standard mercury solutions.

Accessed 5th April, 2011.

APENDICES

Appendix 1

Physico-chemical parameters of Birim River

Sampling site with dates for sampling	pH	Conductivity (µs/cm)	Turbidity (NTU)	Temperature (°C)	Total dissolved solids (mg/l)
Apapam 15/01/2011	7.24	138.6	180.0	26.5	3012
29/01/2011	7.33	150.3	203.0	26.0	2700
12/02/2011	7.54	131.9	185.7	25.5	3130
26/02/2011	7.59	143.4	217.0	26.0	3241
12/03/2011	7.63	139.7	201.0	25.4	2900
Mean	**7.466 ±0.077**	**140.8 ±0.808**	**197.3 ±3.763**	**26.08 ±0.177**	**2997 ±88.08**
Kibi 15/01/2011	7.72	151.8	341.0	26.5	3255
29/01/2011	7.69	140.7	350.0	27.0	3350
12/02/2011	7.75	163.2	366.0	26.5	3100
26/02/2011	7.55	150.7	358.0	26.0	3011
12/03/2011	7.63	155.8	363.0	27.0	3251
Mean	**7.668 ±0.036**	**152.2 ±0.708**	**355.2 ±3.720**	**26.6 ±0.187**	**3193 ±60.68**

Physico-chemical parameters of Birim River cont'd

Sampling site with dates for sampling	pH	Conductivity (µs/cm)	Turbidity (NTU)	Temperature (°C)	Total dissolved solids (mg/l)
Pano 15/01/2011	7.54	130.3	430.0	26.0	3321
29/01/2011	7.59	145.4	454.0	26,0	3400
12/02/2011	7.28	155.0	423.0	26.5	3500
26/02/2011	7.84	150.5	448.0	27.0	3511
12/03/2011	7.69	157.0	410.0	26.0	3255
Mean	**7.588 ±0.037**	**147.6 ±4.211**	**433.0 ±4.382**	**26.30 ±0.200**	**3397 ±49.78**
Bunso 15/01/2011	7.27	170.5	420.0	26.5	3105
29/01/2011	7.43	197.8	422.0	26.5	3551
12/02/2011	7.10	180.6	412.0	27.0	3425
26/02/2011	7.31	175.4	398.0	27.0	3265
12/03/2011	7.44	196.5	465.0	26.0	3411
Mean	**7.308 ±0.033**	**184.2 ±1.859**	**427.4 ±4.020**	**26.60 ±0.187**	**3431 ±48.63**

Physico-chemical parameters of Birim River cont'd

Sampling site with dates for sampling	pH	Conductivity (µs/cm)	Turbidity (NTU)	Temperature (°C)	Total dissolved solids (mg/l)
Control 12/01/2011	7.52	123.7	28.3	25.0	1100
29/01/2011	7.80	136.3	18.9	25.5	1255
12/02/2011	7.90	142.0	19.1	24.5	1245
26/02/2011	7.60	130.0	24.2	26.0	958
12/03/2011	7.88	138.0	20.0	24.0	1442
Mean	**7.74 ±0.052**	**134.0 ±0.907**	**22.1 ±1.670**	**25.0 ±0.250**	**1200 ±93.56**
LSD (0.05)	0.1468	7.09	191.2	0.5637	11.93

Appendix 2

Presence of Heavy Metals in Birim River

Sampling site	Cadmium (mg/l)	Iron (mg/l)	Lead (mg/l)	Copper (mg/l)	Zinc (mg/l)	Mercury (mg/l)
Apapam 15/01/2011	0.010	421.170	0.846	0.883	0.536	0.213
29/01/2011	<0.010	316.000	1.041	0.782	0.417	0.311
12/02/2011	0.010	399.500	0.806	0.777	0.599	0.342
26/02/2011	0.010	360.210	0.924	0.812	0.576	0.082
12/03/2011	<0.010	375.550	0.911	0.843	0.630	0.330
Mean	**0.01 ±0.00**	**374.5 ±17.8**	**0.886 ±0.04**	**0.819 ±0.02**	**0.552 ±0.04**	**0.256 ±0.05**
Kibi 15/01/2011	0.063	307.000	0.640	0.931	0.543	0.435
29/01/2011	0.068	268.000	0.621	0.573	0.402	0.353
12/02/2011	0.059	347.000	0.608	0.732	0.608	0.371
26/02/2011	0.055	300.300	0.655	0.661	0.599	0.523
12/03/2011	0.072	367.500	0.687	0.803	0.576	0.422
Mean	**0.064 ±0.01**	**322.0 ±15.8**	**0.642 ±0.02**	**0.739 ±0.06**	**0.537 ±0.04**	**0.421 ±0.03**

Presence of Heavy Metals in Birim River cont'd

Sampling site	Cadmium (mg/l)	Iron (mg/l)	Lead (mg/l)	Copper (mg/l)	Zinc (mg/l)	Mercury (mg/l)
Pano 15/01/2011	0.208	907.850	1.027	1.165	1.107	0.381
29/01/2011	0.010	406.000	0.832	1.147	0.752	0.091
12/02/2011	0.010	810.500	1.044	1.679	1.052	0.328
26/02/2011	0.103	798.120	0.870	1.334	0.980	0.405
12/03/2011	0.218	883.950	0.921	1.256	0.869	0.426
Mean	**0.109 ±0.05**	**761.3 ±91.3**	**0.939 ±0.06**	**1.468 ±0.08**	**0.952 ±0.07**	**0.326 ±0.06**
Bunso 15/01/2011	0.100	338.000	0.981	0.594	0.927	0.260
29/01/2011	0.083	295.000	0.310	0.533	0.470	0.285
12/02/2011	0.053	263.000	0.454	0.692	1.339	0.157
26/02/2011	0.122	205,500	0.568	0.655	0.912	0.083
12/03/2011	0.075	323.000	0.498	0.588	0.856	0.231
Mean	**0.087 ±0.01**	**284.9 ±15.7**	**0.554 ±0.07**	**0.606 ±0.03**	**0.901 ±0.12**	**0.203 ±0.04**

Presence of Heavy Metals in Birim River cont'd

Sampling site	Cadmium (mg/l)	Iron (mg/l)	Lead (mg/l)	Copper (mg/l)	Zinc (mg/l)	Mercury (mg/l)
Control 15/01/2011	0.010	10.800	0.526	0.457	0.347	0.076
29/01/2011	0.010	9.830	0.603	0.631	0.211	0.093
12/02/2011	0.010	9.140	0.731	0.589	0.234	0.077
26/02/2011	0.010	13.605	0.573	0.695	0.320	0.085
12/03/2011	0.010	13.500	0.667	0.423	0.208	0.079
Mean	**0.01 ±0.00**	**11.375 ±6.5**	**0.620 ±0.03**	**0.559 ±0.04**	**0.264 ±0.03**	**0.082 ±0.01**
LSD(0.05)	0.0705	143.3	0.1898	0.1576	0.2438	0.1372

LSD: Least Significant Difference of Means.