KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

KUMASI, GHANA

THE IMPACT OF SMALL SCALE GOLD MINING ACTIVITIES ON THE WATER QUALITY OF RIVER BIRIM IN THE KIBI TRADITIONAL AREA

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(B.ED SCIENCE)

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A THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY (KNUST), KUMASI, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE.

JUNE, 2012

DECLARATION

Candidate's Declaration

I hereby declare that this work presented to the Department of Theoretical and Applied Biology in partial fulfillment for the award of MSc. Degree, is a true account of my own work except where particularly all sources of information have been acknowledged by means of reference.

Candidate's signature…………………………………. Date……………………

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ABSTRACT

The study of the impact of small scale gold mining activities on the water quality of river Birim in the Kibi Traditional Area was carried out at the four sampling sites along the river profile. Water and sediment samples of the River were analyzed for various parameters and compared with Ghana Environmental Protection Agency (GEPA) and World Health Organization (WHO) permissible guidelines for drinking water. The water quality parameters included pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Dissolved Oxygen (DO) and True Colour. Metals (such as Arsenic, Copper, Cadmium, Lead, Nickel, Iron and Mercury) in the water samples and the river sediments were determined using atomic absorption spectro-photometer (AAS) using AAS 220 model. The result of the study revealed that, the mean values for true colour and total suspended solids of the river water at the various sampling sites exceeded GEPA permissible level for drinking water. However, dissolved oxygen, pH, total dissolved solid and electrical conductivity were below acceptable levels. The concentrations of heavy metals, mainly Arsenic, Iron and mercury recorded in the River water and sediments were also above GEPA and WHO standards, rendering the water unsafe for domestic use.

The study revealed that Small Scale Mining activities in the area have impacted on the water quality of River Birim considering the higher levels of True colour, Total Suspended Solids, Iron, Arsenic and Mercury which exceeded the GEPA and WHO levels.

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May the Almighty God shower his blessings on all contributors.

DEDICATION

This work is lovingly dedicated to my dearest wife Mrs. Love Amponsah Asamoah, my sweet mother Rose Ama Nyanfoa, my dad Mr. Kwadwo Opoku Twum, my siblings and the entire Oye family for their encouragement, motivation and support throughout my education.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The environmental impact of small-scale gold mining in developing countries has been well documented (Hollaway 1993; Mireku-Gyimah and Suglo 1993; Lacerda and Salomons 1998; Meech *et al.*, 1998). Operations, which feature a number of highly rudimentary technologies and management practices, have caused significant damage around the world, manifested primarily as water and land contamination. In most instances, resource-strapped governments are the only bodies capable of directing regional activities along an efficient course, and are therefore burdened with the challenge of having to both regularize what has for decades been treated as an informal industry, and facilitate environmental improvements in resident operations. One country in which the environmental impacts of small-scale gold-mining activities are becoming increasingly unmanageable is Ghana (Karikari *et al.*, 2007).

In Ghana, most communities are established along rivers, forests and places where they could have access to water bodies because of the nature of income generating activities of these communities. Many communities in Ghana are named after rivers. Examples of such communities are Huniso, Densuso, Subriso, Praso, etc. Community people have good reasons to live along rivers/streams especially in a developing economy such as Ghana, where provision of potable water is an illusion even for many urban communities not to talk about the mining communities, which are rural and remote. For this reason, rivers and streams are revered in most Ghanaian communities, as they perceive the rivers/streams to protect them in times of calamities. Rivers and streams provide communities with water for cooking, drinking, farming, building, recreation and aesthetics.

Mining is an activity classified as most polluting as well as draining the dwindling water resources in the world. A study conducted by the Economic Commission for Africa (ECA) in 1999 on the water situation in African countries specifically cited Ghana as being one of the most water – stressed countries (Tenkorang, 2000).

In Ghana, the effects of the activities of mining companies on our water bodies through dewatering, ground water pollution, the virtually free use of water for mining operations, pollution of streams with cyanide and other waste spillages, are affecting the health status of residents of mining communities. A study by Commission for Human Right and Administrative Justice (CHRAJ) confirms the above assertion (Tenkorang, 2000).

The negative effects of mining are depriving mining communities of access to clean water and this has implications for the health status of mining communities since the ingestion of cyanide and heavy metals in rivers for long periods could lead to many serious health problems for people living in mining communities. It is recognized that, access to clean water is a human right and the pollution of rivers by mining operations constitutes a violation of the rights of the mining communities to clean water and environment free of contamination.

1.2 STATEMENT OF THE PROBLEM

Healthy rivers are a vital part of our heritage and in several places they are sources of community identity and pride. Healthy rivers provide drinking water, fish and wildlife habitats, recreational opportunities and economic benefits for local communities, protection against flooding, among other benefits. Unfortunately, over the years several aspects of water pollution have worked together, and continue to work together, to reduce the overall quality of our water bodies. For instance, careless people continue to pollute rivers by dumping solid and liquid waste into them, while increased indiscriminate illegal mining activities produce a large quantity of polluting chemicals. It would be recalled that River Birim which was the main source of water for the people of Kibi and its environs in recent times has been polluted by mining activities which has brought an intense scarcity of water in the community.

Water samples collected from Asikam, Kibi, Apapam, Bunso, Nsutam, Osino, Anyinam and other towns are brown in colour, a departure from the colour of River Birim known to the people over the ages. Reports from the area indicate that the bad state of the river has compelled inhabitants to rely on sachet water as their source of drinking water, denying thousands of people access to good drinking water.

It is against this background that a study of this nature is important to determine the extent of pollution by heavy metals in the river and compare them with World Health Organisation (WHO) and Ghana Environmental Protection Agency (GEPA) permissible guidelines in order to ascertain whether indeed the community's perception of pollution of their river is justifiable.

1.3 OBJECTIVES OF THE STUDY

The main objective of this study was to assess the impact of small-scale gold mining activities on the water quality of River Birim in the Kibi Traditional Area.

1.4 SPECIFIC OBJECTIVES

The specific objectives of the study sought to look into some physico-chemical parameters of the given water and levels of zinc, lead, iron etc in the river water and sediment in order to;

- Determine whether or not the present practice of gold mining at Kibi Traditional area is affecting the quality of its surface water and to what extent.
- Quantify the levels of zinc, lead, iron etc in the river water and sediment and to compare results of the various parameters obtained with those of WHO (World Health Organization) and GEPA (Ghana Environmental Protection Agency) maximum recommended levels.

1.5 SCOPE OF THE STUDY

The focus of the study was on the domestic consumption of water from River Birim. Only physico-chemical parameters and heavy metals such as lead, arsenic copper, cadmium etc were monitored.

1.6 SIGNIFICANCE OF THE STUDY

- The study would provide updated information to add to existing data on the quality of water in Kibi and its environs.
- The finding of the study would be a great source of information to environmental experts, stakeholders, policy makers and educational institutions.

1.7 JUSTIFICATION OF THE STUDY

- Ensuring water quality at all times must be a concern for us because pollutants in drinking water for instance are a threat to life since adults drink on the average 2.5 L of water/day and are therefore susceptible to these pollutants from this route than from the diet.
- Water is vital for life–not only for drinking and washing but also for many other purposes such as industrial water supply, effluent disposal, irrigation, power production, recreation such as sailing and swimming. For instance, the water reservoir in Akosombo (Akosombo dam) serves as the main source of hydroelectric power production for Ghana. It is also used for irrigation purposes and recreational activities such as sailing and swimming.
- Each different use of water has its own requirement for composition and purity and therefore the need for analysis on regular basis to ensure its suitability.
- The environment is never static and the levels of substances found in it may vary greatly with locations and seasons, hence the need for periodic analysis of water that serves as drinking source for people.

- Potential pollutants are released into the environment as a result of mining activities. The need for verification and constant monitoring of the levels of pollutants by an independent body necessitates studies such as the present one.
- The environmental consequences of small-scale mining in the Kibi Traditional Area came to the fore when recent news items in a section of the Ghanaian media reported that "there has been incessant and blatant depletion of more than 80% of forest reserves in this mining community, and the heavy pollution of the Birim River which has been the main source of drinking water for the inhabitants over the years" (Ghana Business News (GBN), March 13, 2010). There are few surveys and pertinent data to corroborate these speculations.

There was therefore the need for an independent scientific investigation to ascertain the levels of pollution or otherwise of the River. It was against this background that the present study was undertaken.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Gold mining by itinerant miners is acknowledged by the International Labour Organization (ILO) as the means of livelihood for more than 13 million people in the developing world (Ballard, 2001). Though there are many potential socio-economic benefits of small scale mining, there are also negative impacts from these small and inefficient operations due to wasteful extraction and processing techniques, often involving mercury amalgamation.

2.2 ARTISANAL AND SMALL-SCALE MINING -DEFINED

There is currently no universal definition of artisanal and small-scale mining (ASM), due to the fact that the definition often varies from country to country (Africa, 2002). A number of attempts have been made to define small-scale mining in an international context using criteria such as investment costs, mine output, labour productivity, size of concessions, amount of reserves, annual sales, levels of technology, or some combination of these.

A broad definition of small-scale mining characterizes the operations as both labor-intensive and low-tech. This definition is sometimes expanded, placing small-scale mining operations in one of two categories: high value mineral extraction including gold, silver and precious stones; and quarry mining or the mining of industrial minerals and construction materials (Hilson, 2002). Most literature tends to provide a specific definition based on the study which was undertaken and provides this definition to the reader (Africa, 2002; Hilson, 2002). Although there are many different definitions it is generally accepted that, “small-scale or artisanal mining generally encompasses small, medium, informal, legal and illegal miners who use rudimentary methods and processes to extract more than 30 different mineral substances worldwide” (GEF et al., 2003). Usually such mines are individual enterprises or small family-owned companies which are not affiliated to any multinational corporations. Thus, studying such small mines also provides a critical analysis of scale in mining.

2.3 BRIEF HISTORY OF SMALL SCALE MINING IN GHANA

Mining is the process of extracting minerals from the earth. The history of small scale gold mining in Ghana dates as far back as the 4th century, when indigenous craftsmen made use of gold in diverse ways. The search for gold took a higher dimension in 1471, when the Europeans arrived and the silent trade began. Commercial scale gold mining, however, is believed to have commenced in Ghana during the 19th century by the British (Tsikata, 1997).

Mining in Ghana currently includes the extraction of gold, bauxite, manganese and diamond in commercial quantities. Among these, gold mining is the most prominent and contributed to 93% of the exports made in 2004 (Minerals Commission, Ghana, 2004). Ghana is one of the major gold producing countries; ranking 10th in the world and second in Africa. The mining sector currently (2008) contributes about 7% of Ghana’s total corporate tax earnings. It forms 41% of total export, 12% of Government revenue collected by the Internal Revenue Service and 5% of the total GDP.

2.3.1 The geological setting

Ghana, a West African nation located on the Gulf of Guinea, is well endowed with many natural resources. The country covers an area of 238,555 square kilometers, about the size of Great Britain or the state of Oregon. Ghana’s population is approximately twenty million, and Cote D’Ivoire, Burkina Faso, and Togo border the country. It was formerly a British colony, at which time the territory was known as the Gold Coast for its abundance of gold reserves.

Ghana’s geographic setting is the primary reason for its wealth of mineral resources. The country falls within the Precambrian Shield of West Africa. The major Precambrian rock units in Ghana are the primary source of the country’s major mineral products: gold, bauxite, diamonds, and manganese (Grubaugh, 2002). They are associated with Proterozoic, Birimian, and Tarkwaian rocks, and the majority of gold produced in Ghana comes from Birimian rocks, which constitute approximately one-third of the country (Grubaugh, 2002).

2.4. SMALL-SCALE MINING ACTIVITIES IN GHANA

The favorable geological setting of Ghana allows small scale mining of gold and diamonds to thrive. Several small scale mining areas are dotted throughout the country, specifically within the Tarkwaian and Birimian rock systems of Ghana. The miners acquire concessions in areas where the deposits are rich, but too small to justify investment in the infrastructure and equipment necessary for large-scale operations. Small-scale miners have very low overheads due to the use of unsophisticated or inexpensive equipment.

The most common equipment used are basic hand tools such as picks, axes, sluice boxes and shovels, although occasionally Honda water pumps, explosives and washing plants are seen within regions. It was discovered during visits to certain small-scale gold-mining regions, however, that even the sites that feature the most advanced of machinery are, for the most part, rudimentary in design. The most organized of set-ups have separate 'stations' or locations for performing the necessary activities of the gold-production process. First, ore is crushed into pebbles by hand or machine, and is contained in storage sacks in sheds.

Next, 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 is hand washed along riverbanks 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.

The term "Gather them and sell" explains what these workers do. "Galamsey operators'' dig only to a limited depth, supported by wooden logs. Hand dug tunnels and shafts created by these artisans are shallower and smaller than those of commercial mining companies, and have no logistical support. This makes them prone to various problems and dangers such as pit collapse and landslides. On Wednesday, November 11, 2009 an estimated 30 illegal miners (Galamseyers) lost their lives as a result of a landslide at Dopaose in the Wassa Amenfi East District of the Western Region-14 out of the 18 retrieved corpses were women. A Deputy Minister of Lands and Natural Resources (MLNR), Mr. Henry Ford Kamel, in a press conference four days after the happening announced that all efforts to retrieve the remaining bodies were abandoned due to the likelihood of another landslide in the area. The incident is one of many such disasters that have been associated with illegal gold mining (Galamsey) over the years. Apart from the fatalities and various malicious health-related issues associated to these activities, there are also immense environmental damages done to the natural habitat within their immediate and surrounding milieu. Results vary from contaminating water into the environment.

2.5 SOCIO-ECONOMIC SIGNIFICANCE OF SMALL-SCALE MINING

Though illegal, hazardous, and inimical to the country's development, Galamsey serves as a source of income and livelihood for these mining communities and their over ten thousand inhabitants.

The small-scale mining of these precious minerals has made significant socioeconomic impact on many individuals and communities since it provides both part and fulltime jobs for the people and in some cases it is the only source of income available to the people. In the rural communities where mining takes place, the activity has reduced rural exodus, promoted local economic development and contributed towards poverty reduction. In addition, the mining operations are useful in basic skill development and contribute to the transformation of unskilled labor into semi-skilled and skilled workers. More importantly, due to the low barriers to entry in terms of capital needs and formal educational requirements, small-scale mining operations offer excellent opportunities for the evolution of indigenous entrepreneurs. In rural areas where other jobs are low paying or non-existent, small-scale mining appears as a valuable source of employment. The sector also provides raw materials for local industries.

2.6 POLICY FRAMEWORK OF SMALL-SCALE MINING

Regularization of the activities of small-scale miners was the first policy made towards the sustenance of the industry since it has allowed for intervention and control in their activities (Noetstaller, 1987). The policy in place has worked very well and over the years it has proved to be very useful. These advances notwithstanding, more inputs are needed. For better control and supervision in the sector, the drive to regularize the activities of galamsey miners should be intensified since they have poor records on health, safety, environmental issues and child labor. Given the scattered units and remote areas where the operations take place, legislation and enforcement is unlikely to cause positive changes. Preferably, promotion of educational programs, safer alternatives, and incentives such as tax holidays and access to credit for those who register may encourage galamsey miners to regularize their activities.

The Ghana Chamber of Mines has encouraged small-scale miners to form a federation that could have representation at the Chamber level. Fortunately, the National Association of Small-scale Miners' Association of Ghana has taken up the challenge and has made presentation to the Chamber of Mines. The Chamber has also called for improvement in the laws governing community-related activities so that the members could contribute more meaningfully towards sustainable development (Addo, 1999; Anaman, 2002). The step taken by the National Small-scale Miners' Association could be boosted further if the mining companies, as part of the social responsibilities and compensation packages for mining communities could make available some mineralized areas that are not suitable for large-scale mining to small-scale miners for them to operate legally. This would make large tracts of mineral rich land available to the miners and it will go a long way in sustaining the small-scale mining sector.

2.7. LEGAL FRAMEWORK OF SMALL-SCALE MINING

The legal framework for registration of small-scale gold and diamond mines, mineral production and sales in the sector was established in Ghana in 1989. The Small-scale mining law, PNDCL 218 (Anon, 1989a) led to the establishment of the Small-scale Mining Project within the Ghana Minerals Commission. The Small-scale Mining Project (now Small-scale Mining Department) has the responsibility of providing technical assistance to prospective and registered small-scale miners in Ghana and promoting their activities.

The Mercury Law, PNDCL 217 (Anon, 1989b) legalized the purchasing of mercury for gold recovery purposes from authorized dealers and the Precious Minerals Marketing Corporation (PMMC) Law, PNDCL 219 (Anon, 1989c), created an authority to buy and sell gold and diamonds. The PMMC operates gold and diamond purchasing offices in Accra, Tarkwa and Bolgatanga and has licensed buying agents and sub-agents throughout mining areas in the country who buy gold and diamonds for resale to the corporation. In order to introduce some form of competition into the gold purchasing set up, the Government of Ghana granted buying licenses to private owned companies namely, Miramex and Precious Metal Refinery Limited to purchase gold from small-scale miners. Since the regularization exercise, two types of small scale miners have emerged-legal and illegal. Legal small-scale miners comprise those who have acquired mining licenses from the Minerals Commission of Ghana to cover their concessions. Illegal small-scale miners include those mining and/or processing ores without the requisite mining license and they usually operate on concessions held by other companies. Illegal small-scale gold or diamond mining is popularly known in local parlance as galamsey, a corruption of the phrase 'gather them (the gold) and sell'.

By the end of 2001, 420 small-scale mining concessions had been licensed in the country. Of these, nine were diamond licenses and 411 were gold. Together these mines generated employment for over 100,000 miners (Minerals Commission, Ghana, 2002). Some small-scale diamond miners recover gold as a by-product or vice-versa.

2.8 ENVIRONMENTAL IMPACTS

Mining, irrespective of the scale of operation, has some degree of impact on the environment. The extent of damage depends largely on the mining and processing methods being used. Although legalized small-scale mining activities have some negative impacts on the environment, in most cases, they can be minimized through environmental permitting and regular monitoring by field officers. Illegal miners, on the other hand, whose operations by their very furtive and clandestine nature are not amenable to being monitored, are detrimental to the environment.

2.9 IMPACT ON LITHOSPHERE

The first category includes all impacts on the lithosphere. The primary impact, land degradation, is a common phenomenon at many uncontrolled, unmonitored small-scale mining sites. Small-scale gold-mining activity also causes significant damage to landscapes. More specifically, as a migratory industry, small-scale gold mining has been responsible for the removal of vast quantities of surface vegetation and mass deforestation. Furthermore, miners typically abandon pits and trenches without properly reclaiming spoils. It is therefore quite common to find, following periods of intensive prospecting, landscapes scarred with potholes and virtually devoid of vegetative cover. Compounding the problem is the fact that the locations selected as exploration sites are largely based upon regional views. An absence of scientific and geological instruments for efficient prospecting makes community opinion and public knowledge the most reliable guidance sources available, which often results in large tracts of land being unnecessarily left with potholes and exposed to agents of erosion.

Several landscapes worldwide have been heavily damaged as a result of transient small-scale gold-mining activity. In the Choco region of Colombia for example, gold production increases 7.2% each year, resulting in an estimated deforestation rate of 1000ha (Lacerda and Solomons, 1998), largely because of intensified levels of exploration activity. Heavy gold prospecting is also contributing to mass deforestation in Zimbabwe, where an estimated 100,000ha of land are cleared annually in small-scale mining regions (Maponga and Anderson, 1995). Further, during mining operations, because sites are highly congested, sanitation is typically poor, additional deforestation occurs as a result of escalated demands for fuel wood, and productive soils are generally left contaminated. For example, as Traore (1994) explains, in the Liptako-Gourma region of West Africa - which includes Burkina Faso, Mali and Niger - small-scale gold mining has intensified since 1984, and by the early 1990s, as many as 10,000 people were to be found on a single site. In fact, regional gold rushes have occurred in an anarchic manner, resulting in excessive vegetation clearing and mass trenching. Widespread precious metal extraction activity throughout the Brazilian Amazonian and southwest Colombia, for example, has left several 'moon-surface' terrains devoid of vegetation (Lacerda et al., 1998). In the process, large pits have been left uncovered, which has rendered land unsuitable for any other purpose, and many have filled with water and now serve as breeding grounds for malaria-infected mosquitoes (Agyapong, 1998; Iddirisu and Tsikata, 1998; Ntibrey, 2001). Other noteworthy environmental impacts from small-scale gold mining include, inter alia, acid mine drainage (on a micro scale), cyanide contamination (in certain districts), siltation, river dredging and alteration, and erosion.

2.10 IMPACT ON HYDROSPHERE

The second category includes all impacts on the hydrosphere. The drainage system in many small-scale mining areas is adversely affected by such operations. Rivers and streams are polluted by solid suspensions and mercury, which are commonly discharged into resident water bodies during the sluicing process and amalgamation, respectively. This in turn leads to siltation and coloration of such waters. Improperly disposed tailings also find their way into streams and rivers during heavy rains, creating sedimentation problems and rendering streams unusable for both domestic and industrial purposes. Removal of vegetation also causes soil erosion, which in turn increases the turbidity of runoff surface waters. Drainage of lubricants and other oils into streams also causes problems such as de-oxygenation of water, which threatens aquatic life.

2.11 IMPACT ON ATMOSPHERE

The final category includes all atmospheric impacts. The effect of small-scale precious minerals mining on the atmosphere has generally been considered to be insignificant since operations are carried out in ambient air. Nevertheless, emissions of gaseous pollutants do occur. Small-scale mining operations that involve size reduction of ore generate some dust that could be hazardous to human health since the particles generated from such sources fall within the respirable dust range and are capable of causing dust-related diseases. Furthermore, a common practice of small-scale gold miners in Ghana is the burning of gold amalgam in the open air. This practice produces mercury fumes, which are released into the atmosphere. In some instances, the burning of amalgam is conducted in poorly ventilated rooms, exposing miners to the dangers of mercury. It is important to note that many small-scale miners have rejected the use of a protective apparatus- the amalgam retort-that effectively separates gold from mercury without emitting fumes into the atmosphere.

2.12 MINING AND WATER POLLUTION

Water is essential to life on our planet. A prerequisite of sustainable development must be to ensure uncontaminated streams, rivers, lakes and oceans. There is growing public concern about the condition of fresh water in Ghana. Mining affects fresh water through heavy use of water in processing ore, and through water pollution from discharged mine effluent and seepage from tailings and waste rock impoundments. Increasingly, human activities such as mining threaten the water sources on which we all depend. Water has been called "mining's most common casualty" (James Lyon, interview, Mineral Policy Center, Washington DC). There is growing awareness of the environmental legacy of mining activities that have been undertaken with little concern for the environment. The price we have paid for our everyday use of minerals has sometimes been very high. Mining by its nature consumes, diverts and can seriously pollute water resources.

2.12.1 Availability of water in Africa

Throughout the world, water is recognized as the most fundamental and indispensable of all natural resources and it is clear that neither social and economic development, nor environmental diversity, can be sustained without water. Today, virtually every country faces severe and growing challenges in their efforts to meet the rapidly escalating demand for water that is driven by burgeoning populations (Biswas et al., 1993; Gleick, 1998; Ashton and Haasbroek, 2001). Water supplies continue to dwindle because of resource depletion and pollution, whilst demand is rising fast because population growth is coupled with rapid industrialization, mechanization and urbanization (Falkenmark, 1999; Rosegrant, 1997; Gleick, 1998). This situation is particularly acute in the more arid regions of the world where water scarcity, and associated increases in water pollution, limit social and economic development and are linked closely to the prevalence of poverty, hunger and disease (Falkenmark, 1999; Gleick, 1998; Ashton and Haasbroek, 2001).

In comparison to the rest of the world, the distribution of water resources in Africa is extremely variable and water supplies are unequally distributed in both geographical extent and time. Large areas of the African continent have been subjected to series of prolonged and extreme droughts; very often these droughts have been "broken" or "relieved" by equally extreme flood events. There is also compelling, though as yet unproven, evidence that projected trends in global climate change will worsen this situation. In addition to climatic variability, a significant proportion of the continent's water resources are comprised of large river basins or underground aquifers that are shared between several countries. The countries sharing these water resources often have markedly different levels of social, economic and political development, accompanied by very different levels of need for water. The wide disparities between socio-economic development and needs for water further complicate the search for equitable and sustainable solutions to water supply problems (Ashton and Haasbrock, 2001).

In virtually every African country, population numbers have grown dramatically during the past century; these trends are expected to continue. Despite obvious inequalities within a variety of social, economic and political dispensations, this population growth has been accompanied by an equally dramatic increase in the demand for water. Several African countries have already reached or passed the point considered by Falkenmark (1999) to indicate severe water stress or water deficit, where the scarcity of water supplies effectively limits further development. Based on present population trends and patterns of change in water use, many more African countries will reach, and exceed, the limits of their economically usable, land-based water resources before the year 2025 (Ashton and Haasbrock 2001). These sobering statistics emphasize the urgent need to find sustainable solutions to the problem of ensuring secure and adequate water supplies for all African countries.

Equitable access to water is recognized as a fundamental right of all peoples (Gleick, 1998). However, in parallel with this right of equitable access, it is vitally important that we develop a shared appreciation of the true value of water, and understand the critically important need to change or redirect our approaches to water management and utilization on regional and continental scales (Ashton and Haasbroek, 2001). Whilst water allocation and distribution priorities in each country need to be closely aligned with national and regional development objectives, greater emphasis now needs to be placed on concerted efforts to ensure that the continent's scarce water resources are used to derive the maximum long-term benefits for the peoples of Africa as a whole. However, this goal can only be achieved if water resource management is both judicious and cautious. A key consideration is the pressing need to ensure that all sectors of society have equitable access to and use of the available water resources. This aspect is particularly important in the case of Africa's shared river basins. Ideally, each country's water resource management strategies need to be closely aligned with those of its neighbours if peace and prosperity are to be maintained and conflict is to be avoided (Pallett, 1997; Turton, 1999; Ashton and Haasbroek, 2001).

2.12.2 An overview of water situation in Ghana

Ghana is well endowed with water resources, but the amount of water available changes markedly from season to season as well as from year to year. Also the distribution within the country is far from uniform with the south-western part better watered than the coastal and northern regions.

Water availability is one of the important issues with health implications that confront Africa in particular and the world in general. The fourth assessment report of the Inter-governmental Panel on Climate Change (IPCC) states that twelve countries would be limited to 1,000 to 1,700 m3 of water /person/year, and the population at risk could be up to 460 million mainly in West Africa. The estimate was based only on population growth rates and did not take into account the variation in water resources due to climate change and other human activities including mining.

Ghana is one of the twelve countries that would face water scarcity. The Ghanaian Chronicle issue of July 25, 2003 gave a vivid picture of Ghana's imminent water crisis when it reported a statement attributed to the Ashanti Regional Programmes Officer of Environmental Protection Agency (EPA) that, Ghana is listed among countries in Africa that would experience water stress of 1700 cubic metres or less per person annually by 2025. This is due to the pollution of water bodies.

The Ghana Living Standard Statiscal Survey (GLSS, 2008) states that more than 40% of Ghanaians in rural, urban and peri-urban centres especially children die each year from diseases associated with unsafe water, inadequate sanitation and poor hygiene. According to the GLSS (2008) report, on the average, women and children walk a distance of six kilometres each day carrying 20 litres of water.

Surface mining including artisanal mining affects water availability to people through the use of large volumes of fresh water for processing as well as water pollution from discharged mine effluent and seepage from tailings and waste rock impoundments. Increasingly, human activities such as mining threaten the water sources on which human beings depend. James Lyon describes Water as “mining’s most common casualty” (James Lyon, interview, Mineral Policy Centre, Washington DC).

2.13 TYPES OF WATER POLLUTION FROM MINING

There are four main types of mining impacts on water quality. They are acid mine drainage/ acid rock drainage, erosion and sedimentation, pollution by processing chemicals and heavy metal contamination.

2.13.1 Acid Mine Drainage (AMD)/Acid Rock Drainage (ARD)

Acid Rock Drainage (ARD) is a natural process whereby sulphuric acid is produced when sulphides in rocks are exposed to air and water. Acid Mine Drainage (AMD) is essentially the same process, greatly magnified. When large quantities of rock containing sulphide minerals are excavated from an open pit or opened up in an underground mine, it reacts with water and oxygen to create sulphuric acid. When the water reaches a certain level of acidity, a naturally occurring type of bacteria called Thiobacillus ferroxidans may kick in, accelerating the oxidation and acidification processes, leaching even more trace metals from the wastes. The acid will leach from the rock as long as its source rock is exposed to air and water and until the sulphides are leached out to a process that can last hundreds, even thousands of years. Acid is carried off the mine site by rainwater or surface drainage and deposited into nearby streams, rivers, lakes and groundwater. AMD severely degrades water quality, and can kill aquatic life and make water virtually unusable.

The acidification of the water has immediate deleterious effects on aquatic ecosystems. A direct effect is the conversion of all carbonate and bicarbonate into carbonic acid, below pH 4.2 which dissociates into carbon dioxide and water. This destroys the bicarbonate buffer system in the water, which acts as a control on acidity. Secondly, since many photosynthetic organisms use bicarbonate as their inorganic carbon source, their ability to photosynthesize is limited or destroyed altogether as bicarbonate decomposes and becomes less available (Kelly, 1998). Thirdly, decomposition (and hence nutrient cycling) will be reduced and eventually cease, in water bodies severely affected by acid inflow (Dallas and Day, 1993). Fourthly, acid waters kill some organisms, by destroying ionic balances, or damaging cell components or carbonate exoskeletons (Kelly, 1998).

2.13.2. Erosion and Sedimentation

Mineral development disturbs soil and rock in the course of constructing and maintaining roads, open pits and waste impoundments. In the absence of adequate prevention and control strategies, erosion of the exposed earth may carry substantial amounts of sediment into streams, rivers and lakes.

Minimizing the disturbed organic material that ends up in nearby streams or other aquatic ecosystems represents a key challenge at many mines. Erosion from waste rock piles or runoff after heavy rainfall often increases the sediment load of nearby water bodies. In addition, mining may modify stream morphology by disrupting a channel, diverting stream flows, and changing the slope or bank stability of a stream channel. These disturbances can significantly change the characteristics of stream sediments, reducing water quality (Johnson, 1997).

Higher sediment concentrations increase the turbidity of natural waters, reducing the light available to aquatic plants for photosynthesis (Ripley, 1996). In addition, increased sediment loads can smother benthic organisms in streams and oceans, eliminating important food sources for predators and decreasing available habitat for fish to migrate and spawn (Johnson, 1997). Higher sediment loads can also decrease the depth of streams, resulting in greater risk of flooding during times of high stream flow (Mason, 1997).

Siltation is the process whereby fine solid particles build up on the bed of a river or lake and is the result of an excessive load of suspended solids in a river or rivers. Mining operations produce large quantities of dust and finely powdered rock, with much rock having been ground to particle sizes below 0.2mm. Though the materials that are dumped after removal of the commodity being mined have fine particle size and reasonable physical characteristics that could permit plant growth and retain adequate amounts of water, these materials have been formed from hard unweathered material and so may not contain much of the finest clay material and lack organic or microbial activity. The result is that mine dumps may be very unstable, easily blown by wind when they are dry and eroded by heavy rain when wet. The action of rain and wind thus removes fine particles into nearby water systems, leading to a build up of suspended solids and ultimately siltation.

2.13.3 Pollution by Processing Chemicals

This kind of pollution occurs when chemical agents (such as mercury) used by small scale mining operators to separate the target mineral from the ore spill, leak, or leach from the mine site into nearby water bodies. These chemicals can be highly toxic to humans and wildlife.

2.13.3.1 Mercury

Mercury exists in both inorganic and organic compounds. Methylation of inorganic mercury into organic mercury occurs in micro-organisms under anaerobic conditions, for example, in underwater sediments. Organic mercury is highly poisonous and is easily absorbed by the gastric and intestinal organs, and it is carried by blood into the brain, liver, kidney and even foetus. For centuries, mercury has been used in the amalgamation of gold (Au). It is estimated that about 1.32 kg of Hg is lost for every 1 kg of Au produced (Harada et al., 1997). About 40% of this loss occurs during the initial concentration and amalgamation stage of Au. The lost Hg is released directly into the soil, streams and rivers, initially as inorganic Hg, which later converts into organic Hg. This is then taken up into the food chain, mainly by fish and other aquatic life. The remaining 60% Hg is released directly into the air when the Hg–Au amalgam is heated during the purification process and is often inhaled. Mercury is a very volatile element, thus dangerous levels are readily obtained in air. Safety standards require that Hg vapour should not exceed 0.1mg/m^3 in air.

2.13.3.1.1 Mercury use

Mercury is one of the pollutants that are causing growing concern due to its long term impacts on ecosystem and human health. Though the use of mercury is illegal in most countries, artisanal and small-scale mining remains a dangerous source of mercury pollution affecting all developing countries where gold is produced (Veiga, 1997). Mercury is used to separate gold from ore and is leaked to the environment in many ways during the amalgamation process: unintentional spillage, discharge with other wastes into inadequate tailings ponds, direct discharge into rivers and waterways, or vaporization into the atmosphere.

Gold in the ore sludge is mixed with mercury into an amalgam, which is then separated by heating into mercury vapour and gold. It has been found that an estimated two grams of mercury are released into the environment for each gram of gold recovered (UNIDO 2001; Limbong et al., 2003). The negative impacts of gold mining due to the use of mercury amalgamation have been well documented all over the developing world. The Global Mercury Project, a joint effort of the Global Environment Facility (GEF), United Nations Development Programme (UNDP) and United Nations Industrial Development Organization (UNIDO), began in 2002 to address the environmental and health impacts from the use of mercury in small-scale gold mining. The Project focuses on six countries: Brazil, Sudan, Tanzania, Zimbabwe, Laos and Indonesia and was initiated to help demonstrate ways to overcome the barriers to the introduction of cleaner artisanal gold mining and extraction technologies. Preliminary investigations in these six countries were undertaken to establish the intensity of artisanal mining activities and their impacts on international water bodies (GEF et al., 2003).

The extent of mercury lost depends on which of a variety of mining and amalgamation methods are used, along with the fate of contaminated tailings and Au-Hg separation methods. When mercury is placed on sluice boxes or spread on the ground to amalgamate the whole ore, losses can be 3 times the amount of gold recovered. When just the gravity concentrates are amalgamated, the mineral portion is separated from the amalgam by panning, forming an amalgamation tailing which is then usually dumped directly into a water stream creating a “hot spot” of mercury contamination (Veiga, 1997).

2.13.3.1.2 Mercury in water

Once it is in the water, mercury attaches to sediment and is transported downstream. Larger sediment sinks to the bottom but later re-enters the aquatic system when channel or floodplain materials are reworked by erosion (Miller and Lechler, 2003).Mercury is also able to persist in surface waters for decades, which means that mercury use today will still impact these communities for years to come.

It is widely recognized that cleaner production methods for artisanal and small-scale gold mining are needed to reduce the negative impacts on environment and health and to achieve legitimacy of the sector as a means of poverty alleviation and sustainable development. The technologies that are developed must satisfy certain criteria in order to be viable for the sector: economically beneficial, simple and expedient (Hinton and Veiga, 2003).

2.13.3.1.3 Health effect of mercury

While most mercury released into the environment is in the form of elemental or inorganic mercury, it is organic mercury in particular, methylmercury that poses the greatest threat to humans and wildlife. A potent neurotoxin, exposure to methylmercury impairs the brain, kidneys, and liver, and causes developmental problems, reproductive disorders, disturbances in sensations, impairment of speech and vision, hearing and walking difficulties, mental disturbances, and death. Methylmercury concentrates in fish tissue, becoming increasingly potent in predatory fish and fish-eating mammals. A person with methylmercury poisoning has five typical symptoms: visual constriction, numbness of the extremities, and impairment of hearing, speech and gait (Veiga, 1997).

In a number of studies undertaken in artisanal and small-scale mining communities, neurological problems have been found in miners and surrounding communities due to inhalation of vapours when the amalgam is heated, as well as in fish eating populations who ingest methylmercury which has bioaccumulated in the fish. Thus, mercury affects not only the miners themselves, but surrounding communities and communities downstream from the mining locations as well. Previous studies on Hg pollution in Ghana dealt with research data on some of the rivers draining south-western Ghana. Adimado and Baah (2002) studied Hg concentrations in human blood, urine, and fish from Ankobra and Tano rivers. Bannerman et al. (2003) reported Hg and As contaminations in sediments and water in gold mining regions in the Ankobra river basin. Similarly, Bonzongo et al. (2003) investigated water, soil and sediments from artisanal gold mining areas, and reported high Hg and toxic element concentrations. Brief studies have also been carried out on toxic minerals in sediments and soils of the Offin River with similar results (Kwarteng, 2004).

The potential health risk from fish consumption was evident in people living 150 km downstream of the gold mining activities, affecting people who are not directly involved in gold extraction (Maurice-Bourgin and Quiroga 1999). Consequently, the use of mercury and resultant contamination of water and food supply can create tension and conflict with non-miners and communities whose water source has been affected.

2.13.4 Heavy metal contamination

Heavy metal pollution is caused when such metals as arsenic, cobalt, copper, cadmium, lead, silver and zinc contained in excavated rock or exposed in an underground mine come in contact with water. Metals are leached out and carried downstream as water washes over the rock surface. Although metals can become mobile in neutral pH conditions, leaching is particularly accelerated in the low pH conditions such as are created by Acid Mine Drainage.

2.13.4.1. Source of arsenic and its health effects

Arsenic is a naturally occurring element in the earth's crust. Arsenic is found in the deep bedrock materials as well as the shallow glacial materials in the study areas. They are also found alongside the gold ores such as arsenopyrites (FeAsS) (Coakley, 1996). Arsenic is usually present in the environment in inorganic form. The inorganic arsenic easily dissolves and enters underground and surface waters. The presence of arsenic in the environment may be attributed to one of the following sources: residual arsenic from former pesticidal use, smelter emission from ores of gold such as arsenopyrites from the sulphur treatment plant.

Arsenic in the study areas, especially Obuasi, is very high in the soil/sediment and river water (Obiri, 2005). Franblau and Lillis (1989), reported two cases of sub – chronic arsenic intoxication resulting from ingestion of contaminated well water (9-10.9mg/L), sporadically (once or twice a week) for about two months. Acute gastrointestinal symptoms, central and peripheral neuropathy, bone marrow suppression, hepatic toxicity and mild mucous membrane and cutaneous changes were observed. The calculated dose was between 0.03-0.08mg/Kg/day based on a body weight of 65kg and ingestion of arsenic from 238 to 475ml water/day. The effects observed for the short –term arsenic exposure (appearance of edema, gastrointestinal or upper respiratory symptoms), differ from those for long – term arsenic exposure (skin disorders and damages to the nervous system). Symptoms such as peripheral neuropathy appeared in some of the subjects or individuals even after cessation of the arsenic intake (USEPA, 1988). According to Tseng, et al. (1968), chronic dermal exposure to arsenic causes skin cancer. The prevalence of skin cancer is very high in areas where chronic exposure to inorganic arsenic is very high. According to (IARC, 1980), inorganic form of arsenic is classified as a class A Carcinogen (i.e. Human Carcinogen) (Rodricks, 1992). This classification is based on sufficient evidence from human data. That is, increased lung cancer mortality was observed in multiple populations exposed to arsenic primarily through drinking of arsenic contaminated water. Again, an increased mortality from multiple internal cancers (liver, kidney, lung and bladder) and an increased incidence of skin cancer had been observed in populations consuming drinking water with high inorganic arsenic concentration (Rodricks, 1992).

2.13.4.2. Sources of cadmium and its health effects

Cadmium is a soft, ductile metal which is obtained as a by-product from the smelting of lead and zinc ores. It is also found in chalophile as a mineral called greenockite, CdS. Volcanic eruption is also another source of cadmium in the environment. Naturally, cadmium levels in the atmosphere are thought to be about 2ng/m^3 though high values are found near zinc smelters. Cadmium in the study area may come from the mining and processing of zinc and other chalophilic metals.

The anthropogenic sources of cadmium in the environment pose serious threat because of their surface input to soil systems making the metal more accessible for plant and animal uptake. Cadmium is obtained mainly as a by-product during the processing of zinc-bearing ores and from the refining of lead and copper from sulphide ores. Cadmium is used primarily for the production of nickel-cadmium batteries, in metal plating, and for the production of pigments, plastics, synthetics and metallic alloys.

Cadmium has been shown to be toxic to human populations from occupational inhalation exposure and accidental ingestion of cadmium contaminated food. Inhalation of cadmium dust in certain occupational settings may be associated with an increased incidence of lung cancer. Other symptoms include; irritation of upper respiratory tract, metallic taste in the mouth, cough and chest pains (Foulkes, 1986). Ingestion of elevated levels of cadmium has resulted in toxicity to the kidney and skeletal system and may be associated with an elevated incidence of hypertension and cardiovascular disease.

2.13.4.3 Sources of lead and copper and their health effects

The presence of lead and copper in the study area is due to weathering and leaching of these two metals from waste rock dumps (AGC, 2001). Other sources of lead and copper are the weathering of the Birimain and Tarkwanian rocks, which contains high levels of lead and copper. Similarly, improper disposal of lead-acid batteries and copper wire also accounts for high levels of lead and copper in the study area. Copper can be released into the environment by both natural sources and human activities. Examples of natural sources are wind-blown dust, decaying vegetation, forest fires and sea spray.

A few examples of human activities that contribute to copper release have already been named.

Other examples are mining, metal production, wood production and phosphate fertilizer production. Because copper is released both naturally and through human activity, it is very widespread in the environment. Copper is often found near mines, industrial settings, landfills and waste disposals. Most copper compounds will settle and be bound to either water sediment or soil particles. Soluble copper compounds form the largest threat to human health. Usually water-soluble copper compounds occur in the environment after release through application in agriculture. Lead is a neurotoxin metal. It affects the central nervous system. Children exposed to high levels of lead contaminated water have low IQs (Rodricks, 1992). Other symptoms associated with exposure to lead are behavioural disorders, tremors, etc. Copper can be found in many kinds of food, in drinking water and in air. Because of that, we absorb eminent 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 concentrations of copper, too much copper can still cause eminent health problems. Copper concentrations in air are usually quite low, so that exposure to copper through breathing is negligible. However, people that live near smelters that process copper ore into metal do experience this kind of exposure. People that live in houses that still have copper plumbing are exposed to higher levels of copper than most people, because copper is released into their drinking water through corrosion of pipes. Occupational exposure to copper often occurs. In the work place environment, copper 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.

Long-term exposure to copper can cause irritation of the nose, mouth and eyes and it causes headaches, stomach aches, dizziness, vomiting and diarrhoea. Intentionally high uptakes of copper may cause liver and kidney damage and even death. There are scientific articles that indicate a link between long-term exposure to high concentrations of copper and a decline in intelligence with young adolescents (Rodricks, 1992). Whether this should be of concern is a topic for further investigation. Industrial exposure to copper fumes, dusts or mists may result in metal fume fever with atrophic changes in nasal mucous membranes. Chronic copper poisoning results in Wilson's disease, characterised by a hepatic cirrhosis, brain damage, demyelination, renal disease and copper deposition in the cornea.

2.13.4.4 Sources of iron and its health effects

Iron in the study area is associated with the Birimian and Tarkwanian rock systems. The Birimian and the Tarkwanian rock systems contain high amounts of iron and other toxic chemicals such as manganese. The high concentration of iron in the study area is from the weathering of the Birimian and Tarkwanian rock systems. Other sources of iron in the study area include the occasional discharge of mining waste, acid mine drainage which may increase iron levels in the surface water. Iron is one of the major constituent in the lithosphere (i.e. soil or rock) soil as oxides or hydroxides. Manganese is also used in the alloying of iron to produce stainless steel and other products of iron (AGC, 2001).

The toxicity of iron is governed by absorption. That is, the more one takes in the more one is at risk. The iron is absorbed in the ferrous state by cells of the intestinal mucous membrane. There are many health problems associated with ingestion of high amounts of iron in drinking water, these include: anorexia, oligura, diarrhoea, hypothermia, metabolic acidosis and, some extent, death.

2.14 PHYSICO-CHEMICAL PARAMETERS

All freshwater bodies are interconnected to the oceans, the atmosphere, and aquifers via a complex hydrological cycle. Wetlands, icecaps and biospheric water also participate in the continuous conveyance of water on planet Earth. The Earth's hydrological cycle is driven by evaporation and gravity on which ecosystems and human societies depend. Growing populations may put stresses on natural waters by impairing both the quality of the water and the hydrological budget (Keith, 2004).

The fate and transport of many anthropogenic pollutants are determined by not only hydrological cycles, but also physicochemical processes. In order to mitigate the impact human societies have on natural waters, it is becoming increasingly important to implement comprehensive monitoring regimes. Monitoring water resources will quantify water quality, identify impairments, and help policy makers make land use decisions that will not only preserve natural areas, but improve the quality of life. In situ environmental parameters that can be measured remotely by deployable sensors are discussed (Keith, 2004). Parameters covered in this work are pH, Dissolved Oxygen, Electrical Conductivity, Total Dissolved Solids, Total suspended solids and True colour.

2.14.1 pH

The pH of natural water can provide important information about many chemical and biological processes and indirect correlations to a number of different impairments. The pH is the measurement of the acid/base activity in solution, specifically it is the negative common logarithm of the activity/concentration of hydrogen ions. $pH = -\log[H^+]$

In natural waters, the pH scale runs from 0 to 14. A pH value of 7 is neutral; a pH less than 7 is acidic and greater than 7 represents base saturation or alkalinity. Pure water free of dissolved gases will naturally become ionized as; $H_2O \rightleftharpoons H^+ + OH^-$

The actual number of water molecules that will ionize is relatively very small with the amount of hydrogen ions $[H^+]$ being equal to the amount hydroxide ion $[OH^-]$. At room temperature the concentration of $[H^+]$ in pure water will be 1×10^{-7} moles per liter. A pH of 7 is neutral because the $-\log(1 \times 10^{-7})$ is 7 by definition.

In unpolluted or pure waters, the pH is governed by the exchange of carbon dioxide with the atmosphere. Carbon dioxide is soluble in water and the amount of $CO2$ that will dissolve in the water will be a function of temperature and the concentration of $CO2$ in the air. As the gaseous $CO2$ becomes aqueous, the $CO2$ will be converted into $H2CO3$ which will acidify the water to a pH of about 6. If any alkaline earth metals such as sodium are present, the carbonates and bicarbonate formed from the solublization of $CO2$ will interact with sodium increasing the alkalinity, shifting the pH up over 7.

Lower values in pH are indicative of high acidity, which can be caused by the deposition of acid forming substances in precipitation. A high organic content will tend to decrease the pH because of the carbonate chemistry. As microorganisms break down organic material, the by product will be $CO2$ that will dissolve and equilibrate with the water forming carbonic acid ($H2CO3$). Other organic acids such as humic and fluvic acids can also result from organic decomposition.

In addition to organic acids and the carbonate chemistry, the acidity of natural waters could also be controlled by mineral acids produced by the hydrolyses of salts of metals such as aluminum and iron. Most metals will become more soluble in water as the pH decreases. For example, sulphur in the atmosphere from the burning of coal will create acid rain. The acid rain will dissolve metals such as copper, lead, zinc and cadmium as the rain runs off of manmade structures and into bodies of water. The excesses of dissolved metals in solution will negatively affect the health of the aquatic organisms. The alkalinity of natural waters is controlled by the concentration of hydroxide and represented by a pH greater than 7. This is usually an indication of the amount of carbonates and bicarbonates that shift the equilibrium producing [OH-]. Other contributors to an alkaline pH include boron, phosphorous, nitrogen containing compounds and potassium.

Changes in pH can be indicative of an industrial pollutant, photosynthesis or the respiration of algae that is feeding on a contaminant. Most ecosystems are sensitive to changes in pH and the monitoring of pH has been incorporated into the environmental laws of most industrialized countries. pH is typically monitored for assessments of aquatic ecosystem health, recreational waters, irrigation sources and discharges, live stock drinking water sources, industrial discharges, intakes, and storm water run off (Schwarzenbach et al., 2003).

2.14.2 Dissolved oxygen

Dissolved oxygen (DO) is essential to all forms of aquatic life including the organisms that break down man-made pollutants. Oxygen is soluble in water and the oxygen that is dissolved in water will equilibrate with the oxygen in the atmosphere. Oxygen tends to be less soluble as temperature increases. The DO of fresh water at sea level will range from 15 mg/l at 0°C to 8mg/l at 25°C. Concentrations of unpolluted fresh water will be close to 10mg/l (Schwarzenbach et al., 2003).

In general, the concentration of dissolved oxygen will be the result of biological activity. Photosynthesis of some aquatic plants will increase the DO during day light hours and the DO levels will fall during the night time hours. In natural waters, man-made contamination, or natural organic material will be consumed by microorganisms.

As this microbial activity increases, oxygen will be consumed out of the water by the organisms to facilitate their digestion process. The water that is near the sediment will be depleted of oxygen for this reason. In waters contaminated with fertilizers, suspended material, or petroleum waste, microorganisms such as bacteria will break down the contaminants. The oxygen will be consumed and the water will become anaerobic. Typically DO levels less than 2mg/l will kill fish.

Figure 2.4 Fish kill due to industrial pollution and reduced dissolved oxygen

(Photo provided by the US Fish and Wildlife Service)

In situ DO sensors are usually membrane electrodes while laboratory methods are titrations. Other indirect laboratory tests for assessing the DO is the biological oxygen demand (BOD) and the chemical oxygen demand (COD). The BOD is the amount of oxygen required to biologically break down a contaminant and the COD is the amount of oxygen that will be consumed directly by an oxidizing chemical contaminant (Schwarzenbach et al., 2003).

2.14.3 Electrical conductivity

Electrical conductivity (EC) in natural waters is the normalized measure of the water's ability to conduct electric current. This is mostly influenced by dissolved salts such as sodium chloride and potassium chloride. The common unit for electrical conductivity is Siemens per meter (S/m). Most freshwater sources will range between 0.001 to 0.1 S/m.

The source of EC may be an abundance of dissolved salts due to poor irrigation management, minerals from rain water runoff, or other discharges. EC is also the measure of the water quality parameter "Total Dissolved Solids" (TDS) or salinity. EC of about 0.3 S/m is the point as which the health of some crops and fresh water aquatic organisms will be affected by the salinity. Field measurements of EC reflect the amount of total dissolved solids (TDS) in natural waters.

Salinity refers to the presence of dissolved inorganic ions such as Mg++, Ca++, K+, Na+, Cl-, SO24-, HCO3- and CO32- in the aqueous solution or soil matrix. The salinity is quantified as the total concentration of soluble salts and is expressed in terms of electrical conductivity. There exists no in-situ salinity probe (based on EC alone) that can distinguish between the different ions that may be present. When salts such as sodium chloride are in their solid form, they exist as crystals. Within the salt crystal, the sodium and the chlorine atoms are joined together in what is called an ionic chemical bond. An ionic chemical bond holds the atoms tightly together because the sodium atom will give up an electron to the chlorine thus ionizing the atoms. If an atom like sodium gives up an electron, it is said to be a positively charged ion (also called a cation). If an atom such as chlorine receives an electron, it is said to be a negatively charged ion (also called an anion and is given the suffix "ide", like chloride). The sodium and the chloride ions comfortably arrange themselves into a stacked- like configuration called a crystal lattice. The sodium chloride crystal lattice has a zero net charge.

Water will dissolve the sodium chloride crystal lattice and physically separate the two ions. Once in solution, the sodium ion and the chloride ion will float around in the solution separately and randomly. This is generally true for all inorganic salts. Once in a solution, the ions will float apart and become two separate species dissolved in the water. Typical, charged ions exist separately in a solution. If the water dries up, the cations and the anions will find each other and fuse back into a crystal lattice with a zero net charge.

2.14.4 Turbidity and TSS

Turbidity or Total Suspended Solids (TSS) is the material in water that affects the transparency or light scattering of the water. The measurement unit used to describe turbidity is Nephelometric Turbidity Unit (NTU). The range for natural water is 1 to 2000 NTU. There are a number of manual field methods for measuring TSS, such as Secchi discs where a metal disc is lowered in the water with a calibration line. The depth at which the disc disappears is directly correlated to TSS. In situ electronic turbidity sensors measure the backscatter of infrared light to determine the NTU of the water.

TSS is typically composed of fine clay or silt particles, plankton, organic compounds, inorganic compounds or other microorganisms. These suspended particles range in size from 10 nm to 0.1 mm although in standardized laboratory tests, TSS is defined as the material that cannot pass through a 45μm diameter filter. TSS as well as TDS can be influenced by changes in pH. Changes in the pH will cause some of the solutes to precipitate or will affect the solubility of the suspended matter. The manmade sources of TSS include erosion, storm water runoff, industrial discharges, microorganisms, and eutrophication. Many fish species are sensitive to prolonged exposure to TSS and monitoring of TSS is an important criterion for assessing the quality of water.

2.14.5 Total dissolved solids (TDS)

TDS comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and small amounts of organic matter that are dissolved in water. TDS in drinking-water originate from natural sources, sewage, urban runoff and industrial wastewater. Salts used for road de-icing in some countries may also contribute to the TDS content of drinking-water. Concentrations of TDS in water vary considerably in different geological regions owing to differences in the solubilities of minerals. Reliable data on possible health effects associated with the ingestion of TDS in drinking-water are not available, and no health-based guideline value is proposed. However, the presence of high levels of TDS in drinking-water may be objectionable to consumers. (Schwarzenbach et al, 2003).

CHAPTER THREE

MATERIALS AND METHODS

3.1 STUDY AREA

The East Akim Municipality is located in the central portion of the Eastern Region of Ghana with a total land area of approximately 725km2. It used to be the second largest of the 15 districts in the Eastern Region until 2004 when the Atiwa district was carved out of it. The district capital, Kibi, is 55km from Koforidua, 105km from Accra and 179km from Kumasi. (Asomaning, 1992)

3.2 CLIMATE

The municipality lies in the west semi-equatorial zone characterized by double rainfall maxima occurring in June and October; the first rainy season from May to June and the second from September to October. The mean annual rainfall is between 125mm and 175mm. The dry seasons are really distinct with the main season commencing in November and ending in late February. Temperature is found to be fairly uniform ranging between 26oC in August and 30oC in March. Relative humidity is generally high throughout the year, ranging between 70% - 80% in the dry season and 75% - 80% in the wet season (Ansa-Asare and Asante, 2005).

3.3 ECONOMIC ACTIVITIES

The municipality has about 50 per cent of its 103,000 people living in the rural areas. It has an agro-based economy with most communal rural communities practising rain-fed agriculture. The occupational structure of the municipality has not changed since 1996.

Agriculture still constitutes the leading employer of the municipality's workforce accounting for 58% and followed by the service sector with 21.5%, commerce 11% and industry 9.5%.

To support their livelihoods the rural population exploits natural resources in the vicinity of their settlements. These activities include small scale mining, irrigated market gardening, wildlife hunting, and wood harvesting. Illegal miners have trooped into the municipality of late. Gold prospecting as well as small scale gold mining covers a total land area of about 500 acres. It must be emphasized that the activities of these illegal miners is posing serious threat to the environment in the municipality (Ansa-Asare and Asante, 2005).

3.4 RELIEF AND DRAINAGE

The land is generally undulating and rises about 240 metres to 300 metres above sea level with the highest point being the Atiwa ranges rising over 350 metres above sea level. The underlying rocks are of the Birimian formation covering over three-fourths of the closed forest zone. This rock group contains several mineral deposits including gold, diamond, bauxite and kaolin (Ansa-Asare and Asante, 2005).

The municipality is drained by rivers such as the Birim, Densu, and Bompong most of which have their catchment areas within the Atiwa and Apedwa Forest Ranges. Several other seasonal streams are found in the municipality. The pattern is largely dendritic flowing in the north-south direction.

3.5 THE BIRIM RIVER

The Birim River is one of the main tributaries of the Pra River in Ghana and in the country's most important diamond-producing area, flowing through most of the breadth of the Eastern region. It gives its name to the Birimian rock formation, which yields most of the gold in the region.

The river rises in the Kibi or Akim municipality of the Eastern Region of Ghana, in the Atiwa Range, which rises to 780m. The surrounding lowlands are about 180-200m above sea level. The Birim river gravels hold gold which has long been extracted through panning or Placer mining used in making ornaments and for trans-Saharan trade long before the Europeans discovered the Gold Coast (WRC, 2000). The communities around the river use the water extensively for drinking and other domestic purposes without prior treatment.

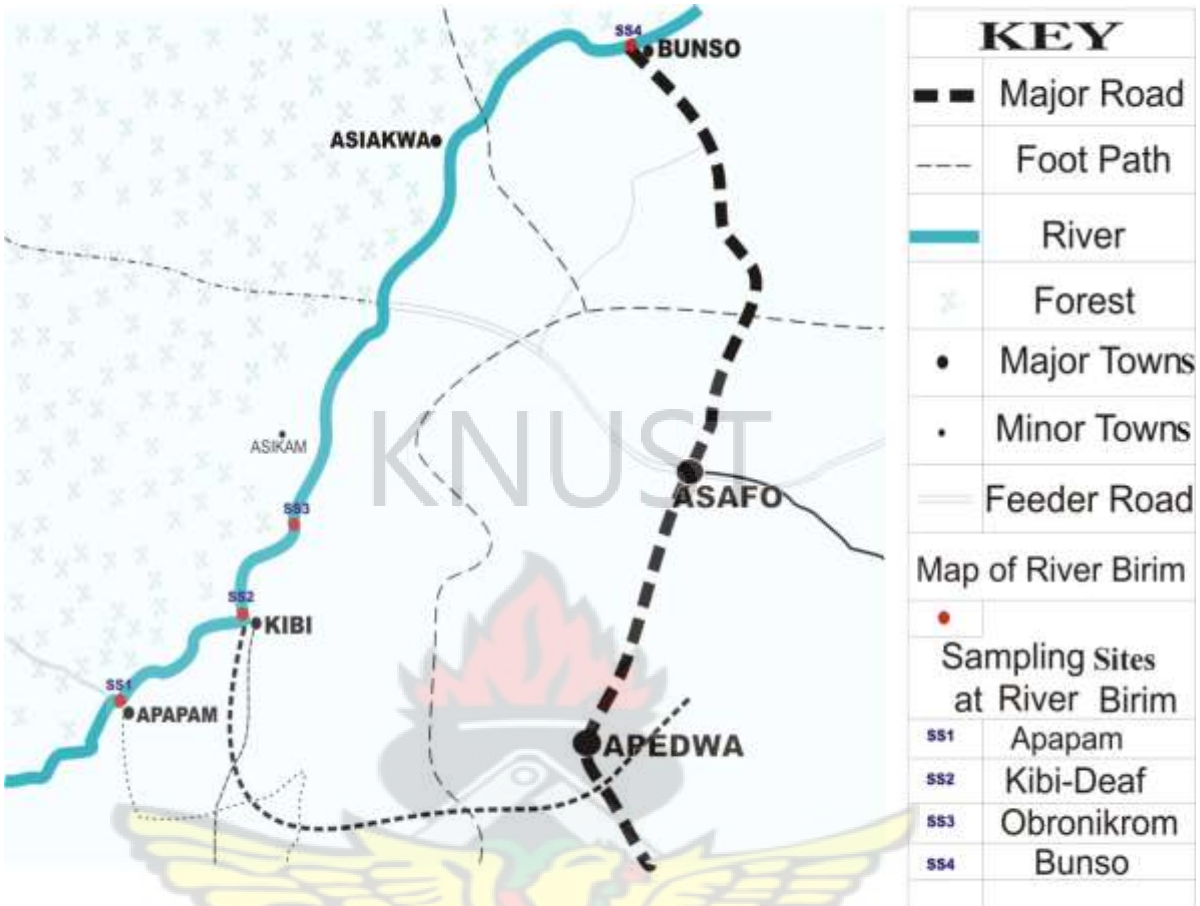

Figure 3.2 Map of river Birim showing the sampling sites with reference to Apapam as the source of the river.

3.6 DATA COLLECTION

The work, which was undertaken in the Kibi Traditional Area, incorporated visual observation, sample collection, preparation and analysis.

Data was collected from May, 2010 (representing the wet season) to November, 2010 (representing the dry season). The surface water samples and river sediments were collected simultaneously at four different sampling sites along the river profile. The water samples were collected from the river into plastic bottles that have been pre –

washed with detergent and tap water, and later rinsed with 1:1 conc. nitric acid and distilled water. The sampling bottles were rinsed three times with the water samples from the river after which 1.5L of the water samples were collected from the various sampling sites. Two samples were collected from each sampling site. One was acidified with 10% nitric acid for the analysis of heavy metals whilst the other was used for the physicochemical analysis. For the sediment samples, two sediment samples, weighing 2.0 kg were also collected at each sampling site and the samples were emptied into polyethylene bags. The samples were picked at about four Kilometers interval except for the one in Apapam which was picked at source of the river. All samples were labelled and described in the field, packed and transported to Bogoso for laboratory analysis.

3.7 SAMPLE PREPARATION AND ANALYSIS

The collected samples were submitted to the Environmental Laboratory of Golden Star Resources (Bogoso/Prestea).

The samples were analyzed for pH, Electrical Conductivity, Dissolved Oxygen, True Colour, Total Dissolved Solids and Total Suspended Solids. Dissolved Oxygen (DO) was determined using Winkler's Modification Method (Standard Method, 1998) whilst the electrical conductivities, total suspended solids and total dissolved solids of the samples were determined with Jennway Conductivity meter model 4520. The colour was measured by colour comparator and pH was measured in situ, using a portable pH meter, Horiba pH Multi-parameter.

Metals (such as Arsenic, Copper, Cadmium, Lead, Nickel, Iron and Mercury) in the water samples were determined using atomic absorption spectro-photometer (AAS), AAS 220 model. The samples for AAS were digested with nitric acid before analysis. In the laboratory, the acidified samples were filtered using Whatman's filter paper. The 0.45μm membrane filter paper was used because the analyte of interest in this work is the total dissolved metals. The filtered samples and the unfiltered samples were stored in the refrigerator at 4◦C for further analysis (APHA – AWWA, 1998). Statistical analysis of the results was done using Microsoft Excel. Comparisons were made with the World Health Organisation (WHO) drinking water standards (WHO, 2004) and Ghana Environmental Protection Agency (GEPA) standards (GEPA, 1999)

3.8. pH DETERMINATION FOR WATER SAMPLES

The pH for the water samples was determined using a pH meter. At each sampling site, samples were fetched with a 5.0L rubber bucket and the Horiba pH Multi-parameter was immediately immersed in it. The pH meter was switched on to allow the fetched samples for about five minutes for the readings to stabilize. Readings on the meter were then recorded into a field note book.

3.9 ACIDIFICATION OF WATER SAMPLES

Acidification of the water samples was done just after the pH determination. A 3.0 ml concentrated HNO3 was added to 300 ml of the samples. This was done to preserve the water samples and to bring the particulate metals into solution form (APHO, 1992). The samples were then covered tightly and transported to the laboratory for further treatment.

3.10 DIGESTION OF SEDIMENT SAMPLES

A 2.0 g of finely grounded sediment was weighed and placed into 300 ml volumetric flask and 20 ml of di-acid mixture of HNO3 and HClO4 with ratio 9: 4 was added and the contents well mixed by swirling thoroughly (Motsara and Roy, 2008; Okalebo and Gathua, 1993). The flask with contents was then placed on a hotplate in the fume chamber and heated, starting at 850 C and then the temperature was raised to 1500 C. Heating continued until the production of red NO2 fumes ceased. The contents were further heated until volume was reduced to 3-4 ml and became colorless or yellowish, but not dried. This was done to reduce interference by organic matter and to convert metal associated particulates to a form (the free metal) that could be determined by the Atomic Absorption Spectrophotometer (AAS). Contents were cooled and volume made up with distilled water and filtered through filter paper. The resulting solution was preserved at 40C, ready for AAS determination.

3.11 DIGESTION OF WATER SAMPLES

Each sample was thoroughly mixed by shaking and 100 ml transferred into a conical flask. A 5.0 ml concentrated HNO3 and a few boiling chips were added (APHO, 1992). The mixture was then heated until the volume was reduced to about 15 ml and complete digestion was indicated by either a light coloured or clear solution. Contents were washed down with double distilled water and then filtered. The filtrate was transferred into 100 ml volumetric plastic container which was prior washed with detergent and later, rinsed with distilled water and the volume finally adjusted to 100 ml with double distilled water and stored at 40C, ready for AAS analysis (APHO, 1992).

3.12 ATOMIC ABSORPTION SPECTROPHOTOMETER (AAS) ANALYSIS

AAS 220 model was used in determining the total dissolved arsenic, iron, copper, lead, cadmium, mercury and nickel concentrations in the previously digested samples. A blank prepared from distilled water as well as the standard reference solution for the individual parameters were used to calibrate the instrument after the required lamp has been fixed into the instrument. The instrument was adjusted until the acceptable calibration was achieved. Once the required calibration was achieved, the samples were run to determine the metal concentration of interest in the sample.

CHAPTER FOUR

RESULTS

4.1 PHYSICOCHEMICAL PROPERTIES

The pH, True Colour, Electrical conductivity, Dissolved oxygen, Total dissolved solid and Total suspended solids of river Birim along the various sampling sites have been presented in Fig.1- 6.

4.1.1 Total Suspended Solids (TSS)

The mean values of the total suspended solids recorded at the four sampling sites were far above GEPA background value of 50 mg/l with the exception of Apapam which recorded a value below the GEPA permissible level. Comparing the results obtained in this study among the sampling sites revealed that, Obronikrom recorded the highest value of 583 mg/l, followed by Kibi-Deaf with mean value of 546 mg/l and then Bunso with mean value of 119 mg/l.

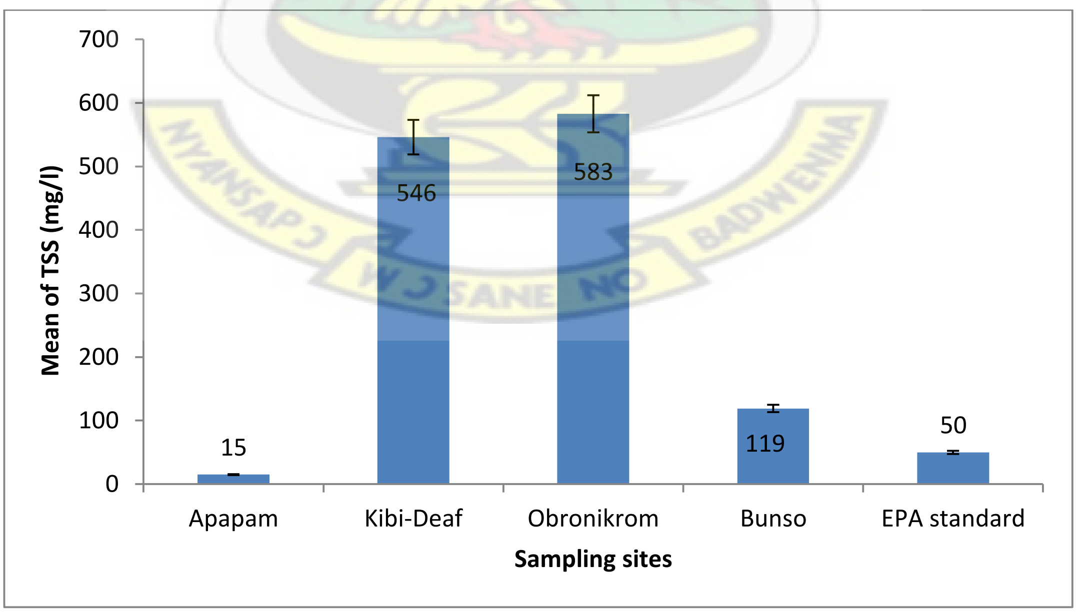

Figure 4.1 Total Suspended solids at the sampling sites on the River Birim

4.1.2 True Colour of River Birim

From Fig. 2, it is clear that the mean values of true colour in Bunso, Kibi-Deaf and Obronikrom are far above Ghana Environmental Protection Agency (GEPA) background value of 150 mg/l pt-Co. The mean value of true colour at Apapam was 90. Bunso recorded a mean value of 1190 with Kibi-Deaf and Obronikrom recording mean values of 4220 and 4900 mg/l pt-Co respectively.

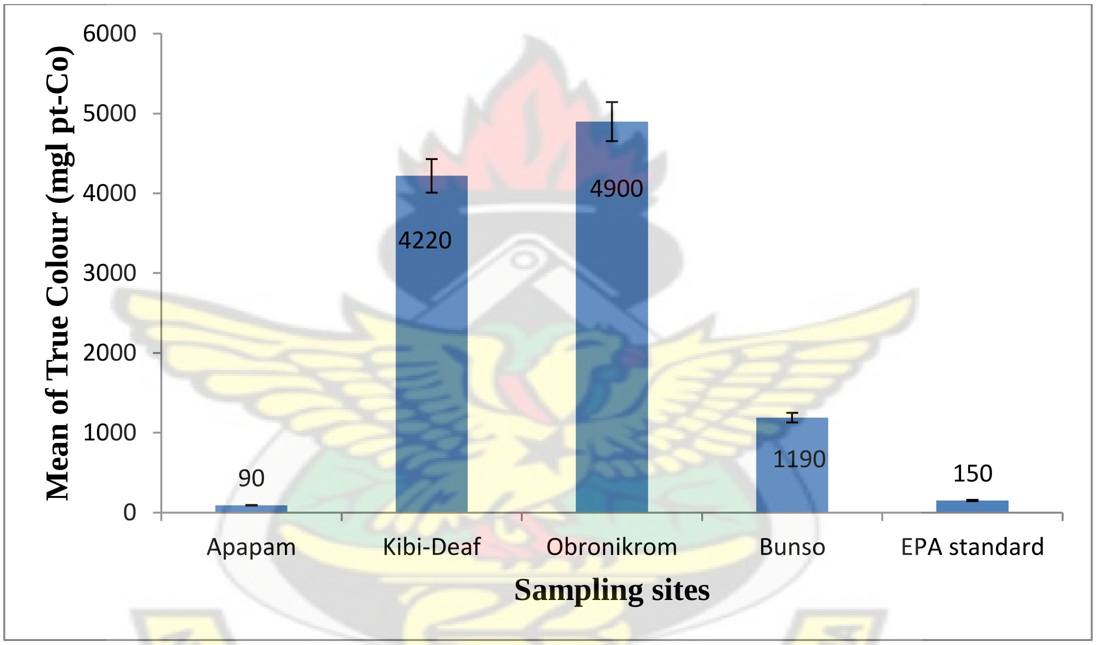

Figure 4.2 True Colour at the sampling sites on the River Birim

4.1.3 Electrical Conductivity (EC)

The mean values recorded at the four sampling sites along the river profile were generally low compared with GEPA standard of 1500 µS/cm. However, comparing the mean values among the sampling sites, Obronikrom recorded the highest value of

119µS/cm with Kibi-Deaf, Bunso and Apapam recording values of 111µS/cm, 115µS/cm and 101µS/cm respectively.

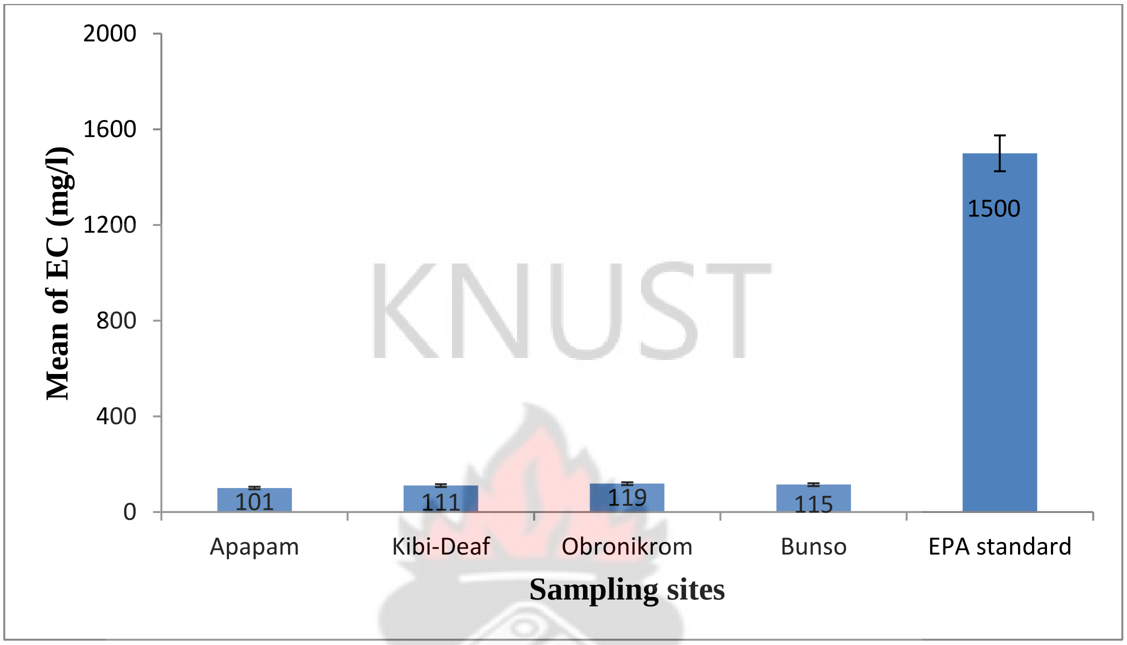

Figure 4.3 Electrical Conductivity at the sampling sites on the River Birim

4.1.4 Dissolved Oxygen

The Dissolved Oxygen (DO) values recorded at the sampling sites were lower than the World Health Organization (WHO) set limit of 6.01 mg/l with the exception of Obronikrom which recorded a value exactly equal to the WHO standard. The dissolved oxygen of the water samples of river Birim at Apapam indicated a mean value of 5.7 mg/l, Bunso recorded a mean of 5.8 mg/l, Kibi-Deaf recorded a mean value of 5.84 mg/l and Obronikrom with a mean value of 6.01 mg/l.

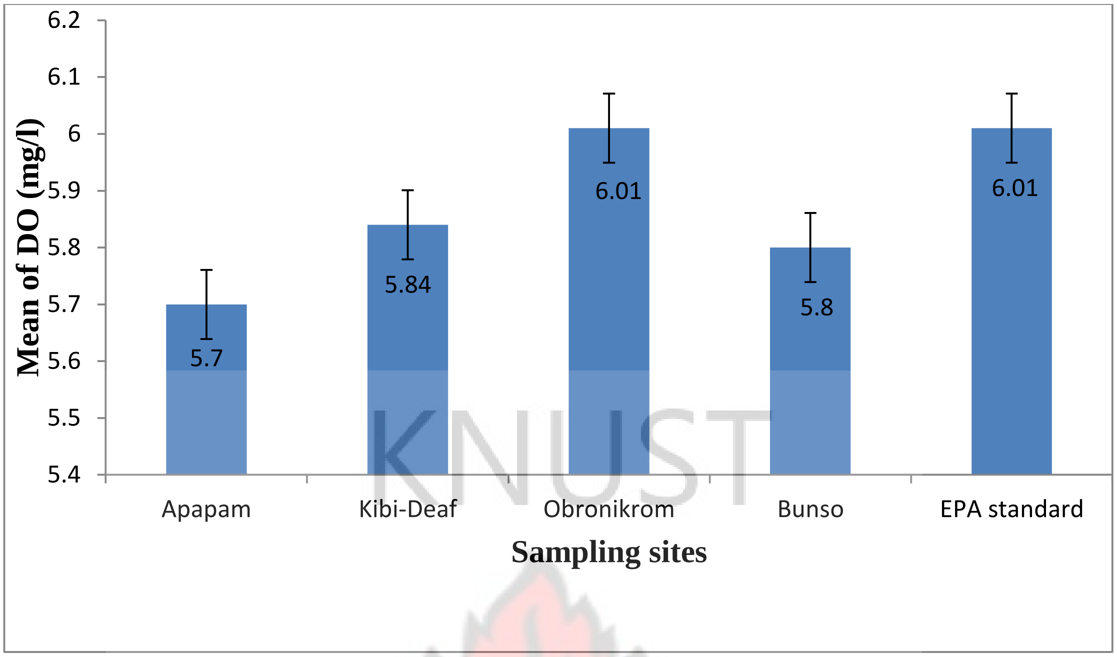

Figure 4.4 Dissolved Oxygen at the sampling sites on the River Birim

4.1.5 Total Dissolved Solids (TDS)

The levels of Total Dissolved Solids (TDS) recorded at the four sampling sites were far below EPA guideline value of 500 mg/l. It can be seen from the Figure 5 that, Obronikrom recorded the highest mean total dissolved solid of 80mg/L with Apapam, Bunso and Kibi-Deaf recording mean values of 25mg/L, 39mg/L and 41mg/L respectively.

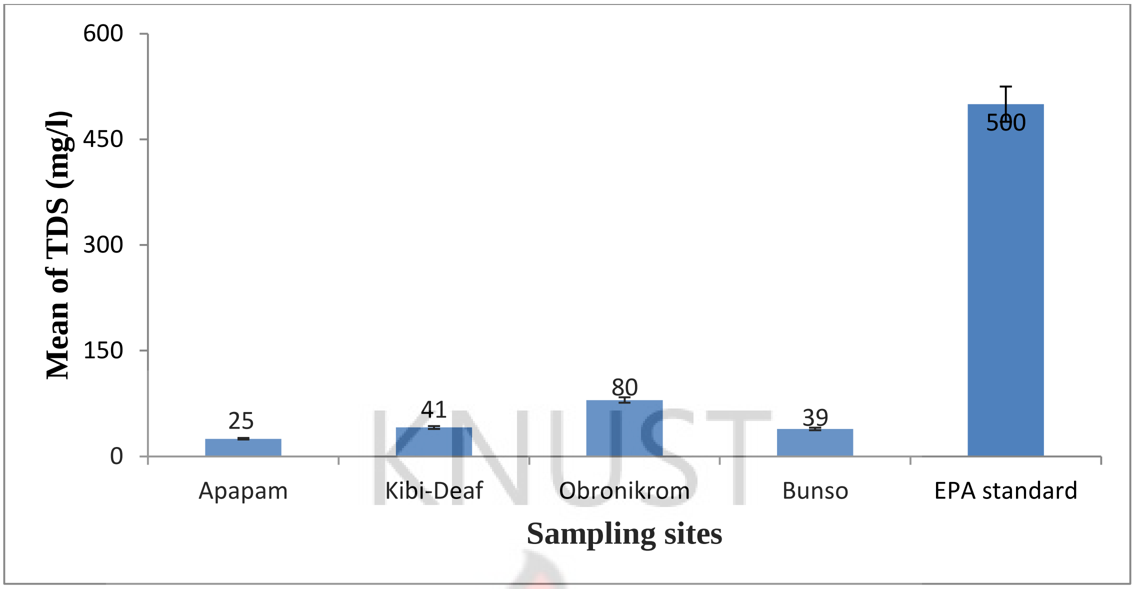

Figure 4.5 Total Dissolved Solids at the sampling sites on the River Birim

4.1.6 pH

The mean values of the pH recorded at the various sampling sites were below GEPA standard value of 9. The highest mean pH of 7 was recorded at Apapam signifying that the water is neutral. However, pH of 6.85, 6.55 and 6.51 recorded at Bunso, Kibi-Deaf and Obronikrom respectively mean that the River water at these sites is slightly acidic.

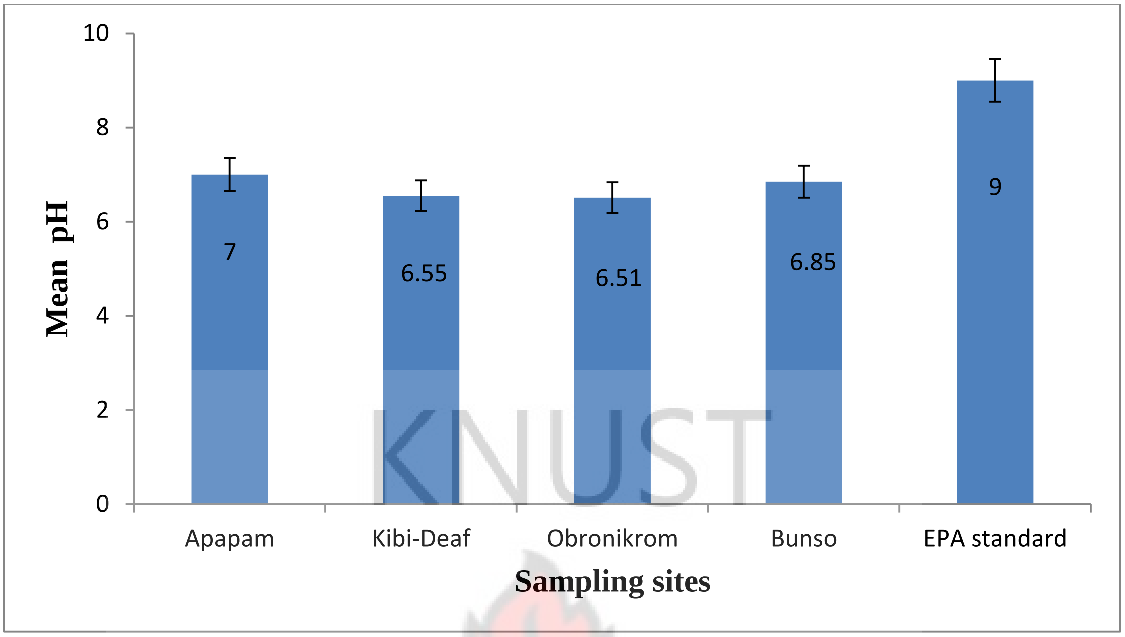

Figure 4.6 pH at the sampling sites on the River Birim

4.2 HEAVY METALS

The results of mean levels of Cadmium, Nickel, Iron, Copper, Lead, Arsenic and Mercury in the river water have been presented in Figure 7-13.

4.2.1 Cadmium (Dissolved)

The mean values of dissolved cadmium in the river water at sampling sites were below the EPA guideline value of 0.1 mg/l. The mean values of dissolved cadmium in the river water at Apapam, Bunso, Kibi-Deaf and Obronikrom were 0.006, 0.008, 0.008 and 0.010mg/l respectively.

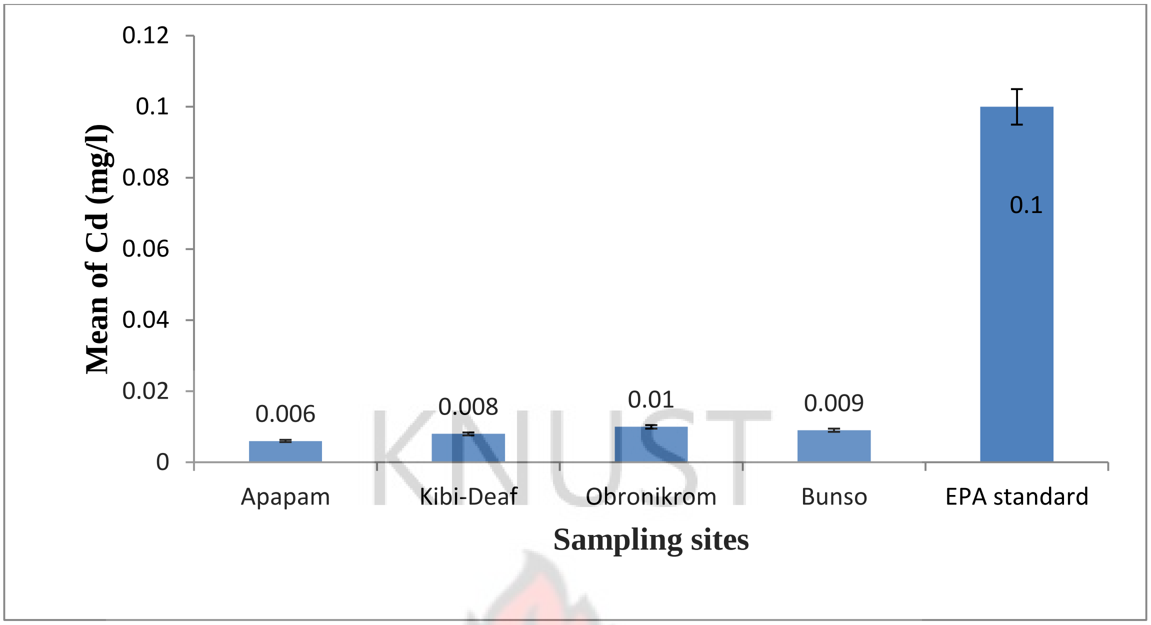

Figure 4.7 Cadmium level at the sampling sites on the River Birim

4.2.2 Nickel (Dissolved)

From Fig. 8, analysis of water samples from the four sampling sites on river Birim indicated mean values of nickel were within WHO guidelines. . A comparison of levels of nickel among the sampling sites saw Kibi-Deaf recording the highest mean value of 0.018mg/L, Obronikrom had 0.012mg/L, Bunso had 0.008mg/L with Apapam recording the lowest mean value of 0.006mg/L.

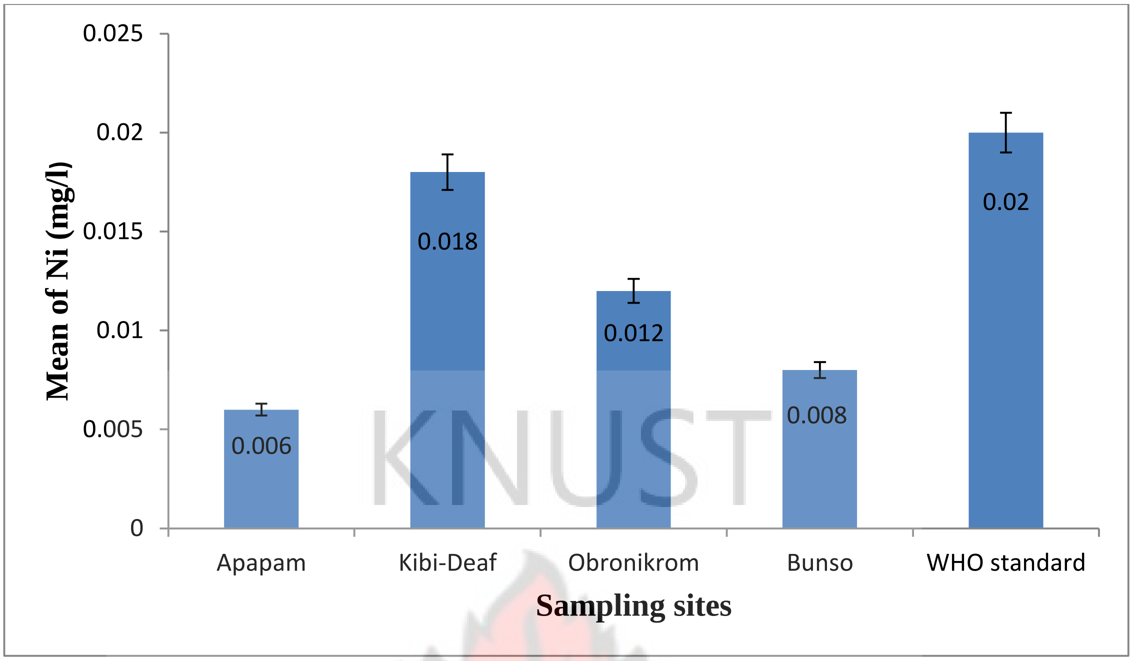

Figure 4.8 Nickel content at the sampling sites on the River Birim

4.2.3 Iron (Dissolved)

The mean values of dissolved iron in the river water at sampling sites were above the WHO standard value of 0.3 mg/l. Comparing the mean values of iron among the sampling sites, it was evident that Obronikrom recorded the highest value of 4.414mg/L, Kibi-Deaf had 3.366mg/L, Bunso had 0.934mg/L and Apapam recorded a mean value of 0.350mg/L.

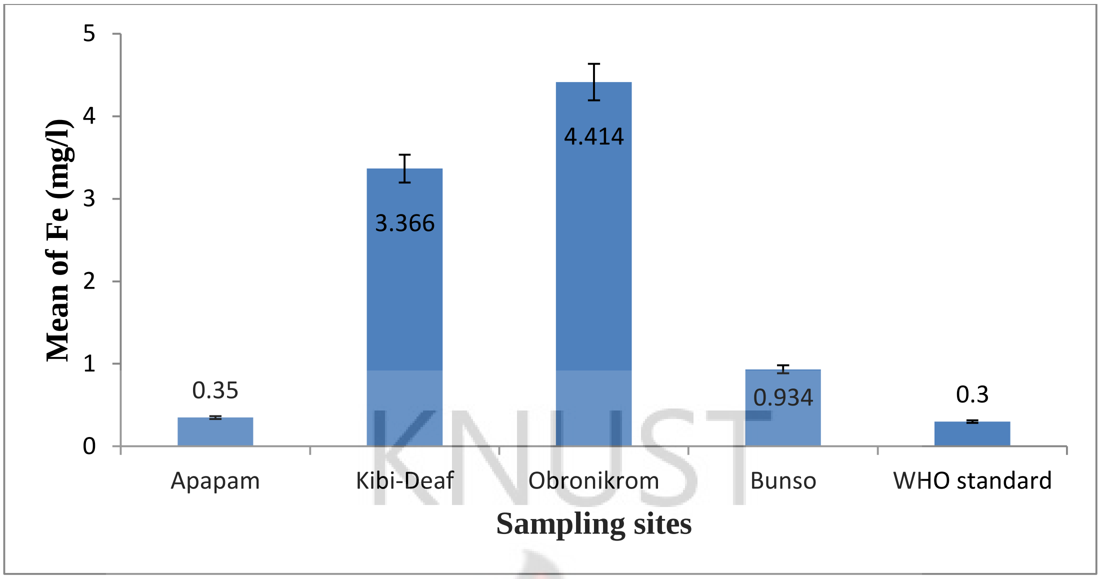

Figure 4.9 Iron content at the sampling sites on the River Birim

4.2.4 Copper (Dissolved)

Generally, very low levels of copper were observed for all the water samples at the sampling sites when compared with the EPA guideline limit of 5 mg/l for drinking water. The mean values of copper in the river water recorded at Apapam, Bunso, Kibi-Deaf and Obronikrom were also low, being respectively, 0.01mg/l, 0.01mg/l, 0.01mg/l and 0.11mg/l.

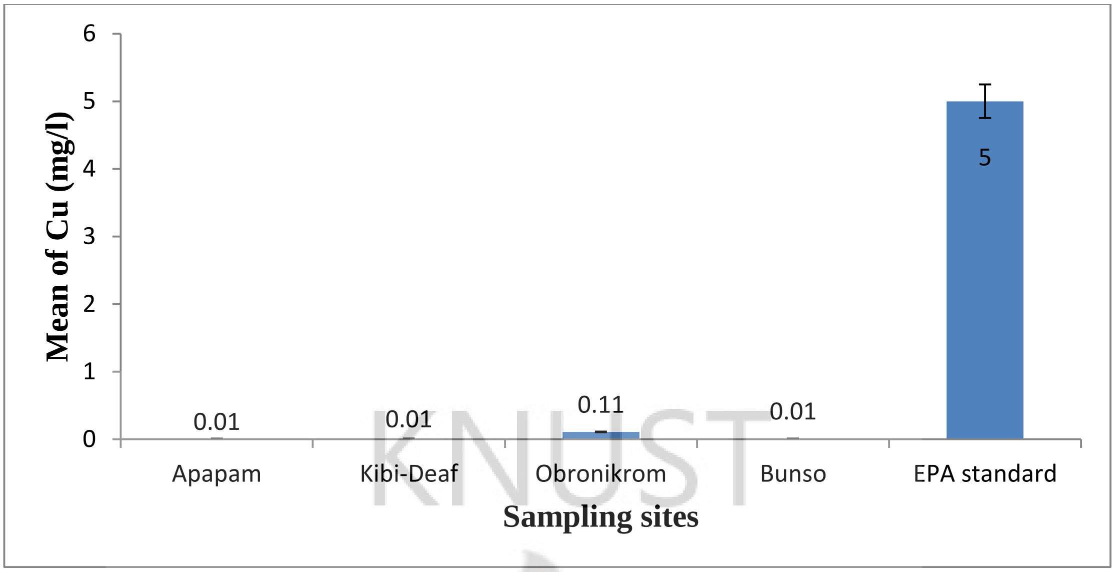

Figure 4.10 Copper level at the sampling sites on the River Birim

4.2.5 Lead (Dissolved)

From Fig. 11, the mean concentrations of lead in the water samples were below GEPA background value of 0.1mg/l for drinking water. Comparing the mean values of lead in the water samples among the sampling sites, Obronikrom had the highest value of 0.025mg/l, followed by Kibi-Deaf with mean value of 0.018mg/l, Bunso and Apapam recorded the lowest mean value of 0.006mg/l each.

Figure 4.11 Lead content at the sampling sites on the River Birim

4.2.6 Arsenic (Dissolved)

The mean dissolved Arsenic values recorded at the sampling sites were far above GEPA standard except Apapam which recorded a value less than GEPA standard value of 0.01 mg/l. Comparing the mean values of arsenic in the water samples among the sampling sites, Obronikrom recorded the highest value of 0.18mg/L, Kibi-Deaf and Bunso had 0.046mg/L each.

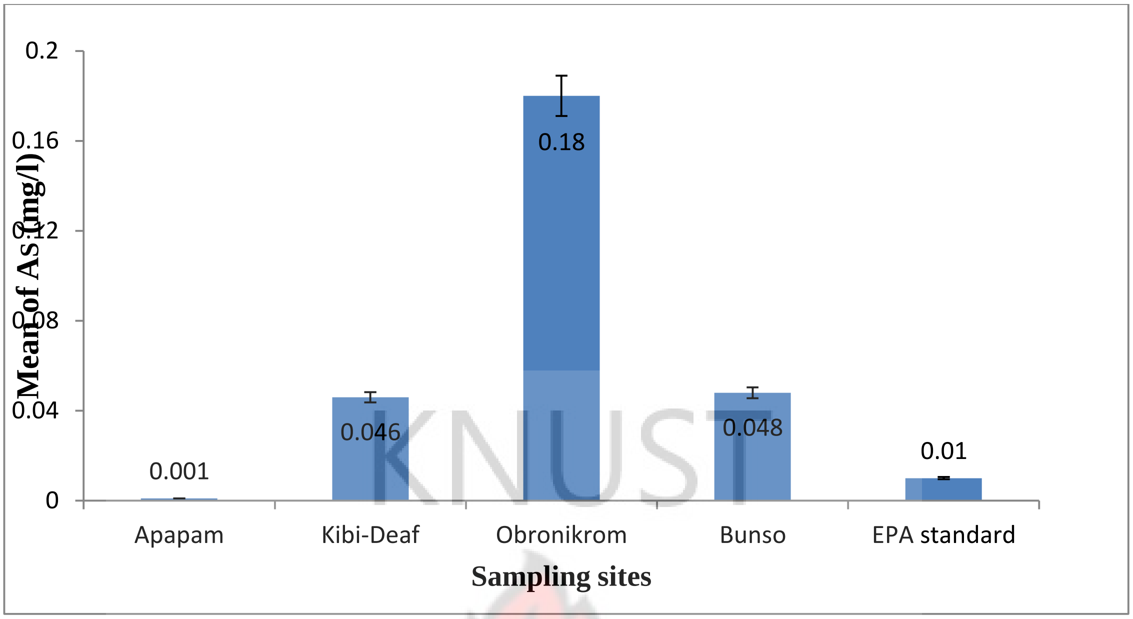

Figure 4.12 Arsenic content at the sampling sites on the River Birim

4.2.7 Mercury (Dissolved)

Analysis of mercury content of the water samples at the various sampling sites along river Birim revealed that, Kibi-Deaf and Obronikrom recorded mean values that were above GEPA permissible background value of 0.005mg/l whilst Apapam and Bunso recorded mean values that were below GEPA standard. A comparison of the mean dissolved mercury concentration at the sampling sites showed Obronikrom at the top with the mean value of 0.010mg/l, followed by Kibi-Deaf with a mean value of 0.008mg/l, Bunso and Apapam having mean values of 0.003mg/l and 0.002mg/l respectively.

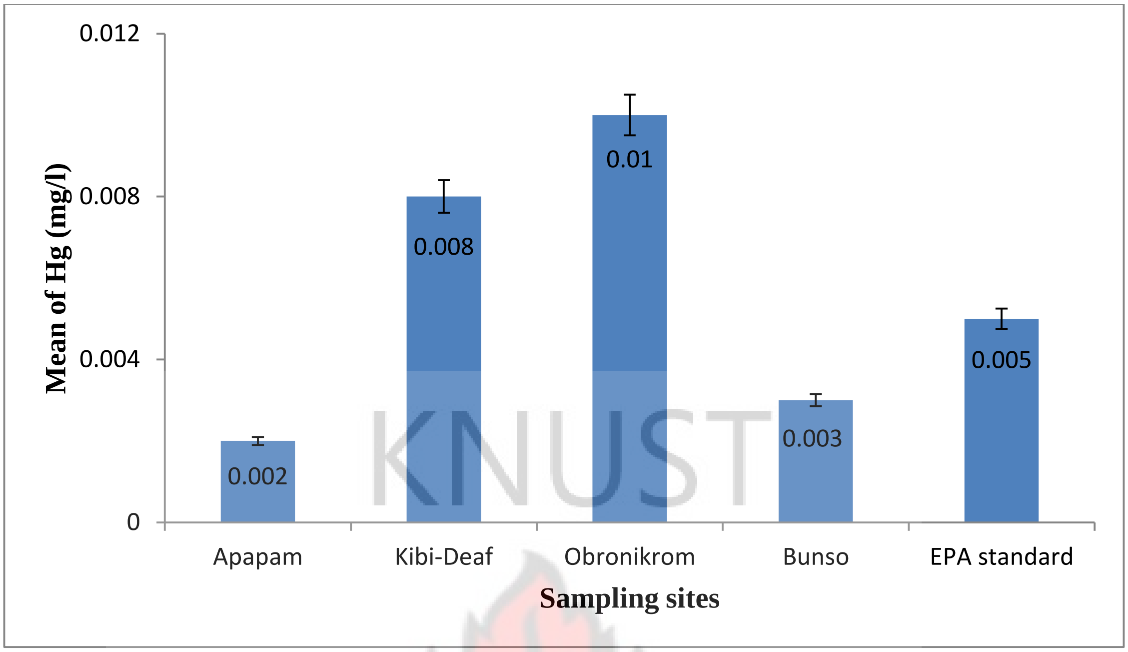

Figure 4.13 Mercury content at the sampling sites on the River Birim

4.3 HEAVY METALS IN RIVER SEDIMENTS

Comparisons of Cadmium, Copper and Lead in river sediments from sampling sites have been presented in Fig. 14 below. The mean sediment values of cadmium at Apapam, Bunso, Kibi-Deaf and Obronikrom are 0.0021mg/g, 0.0042mg/g, 0.0030mg/g and 0.0017mg/g respectively. The mean values of copper in the river sediment recorded at Apapam, Bunso, Kibi-Deaf and Obronikrom were also low, being respectively, 0.0076mg/g, 0.0156mg/g, 0.0122mg/g, and 0.0161mg/g. The concentration of lead in the river sediments at the sampling sites saw Bunso and Kibi-Deaf recording the highest mean values of 0.0240mg/g each with Obronikrom having mean value of 0.0159mg/g. The lowest mean concentration of lead of 0.0085mg/g was recorded in Apapam.

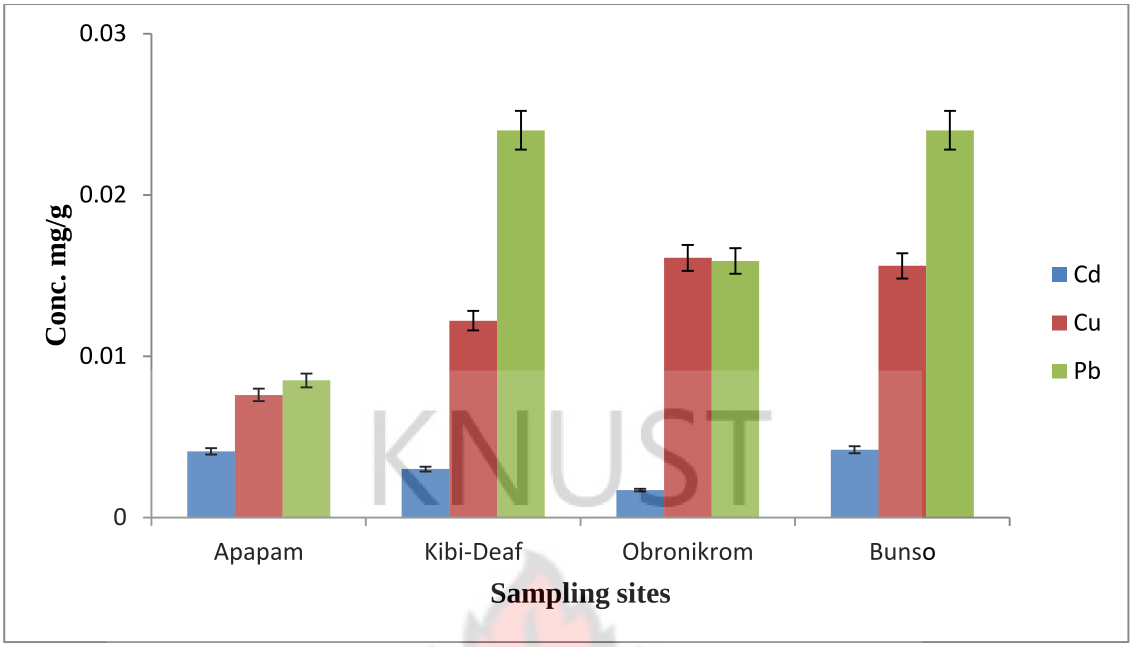

Figure 4.14 Comparison of Cd, Cu and Pb in the river sediment from the sampling sites on the River Birim

Comparisons of Nickel, Arsenic and Mercury in river sediments from sampling sites have been presented in Fig. 15 below. The mean sediment values of nickel at Apapam, Bunso, Kibi-Deaf and Obronikrom are <0.01mg/g, 0.0190mg/g, 0.0160mg/g and 0.0113mg/g respectively. A Comparison of the mean arsenic values in the river sediments among the sampling sites showed that Bunso had the highest value of 0.288mg/g, followed by Kibi-Deaf, Obronikrom and Apapam recording mean values of 0.217mg/g, 0.204mg/g and 0.152mg/g respectively. High concentrations of mercury were recorded in the river sediments at the sampling sites. Apapam, Bunso, Kibi-Deaf and Obronikrom recorded mean values of 0.06mg/g, 0.12mg/g, 0.40mg/g and 0.50mg/g respectively.

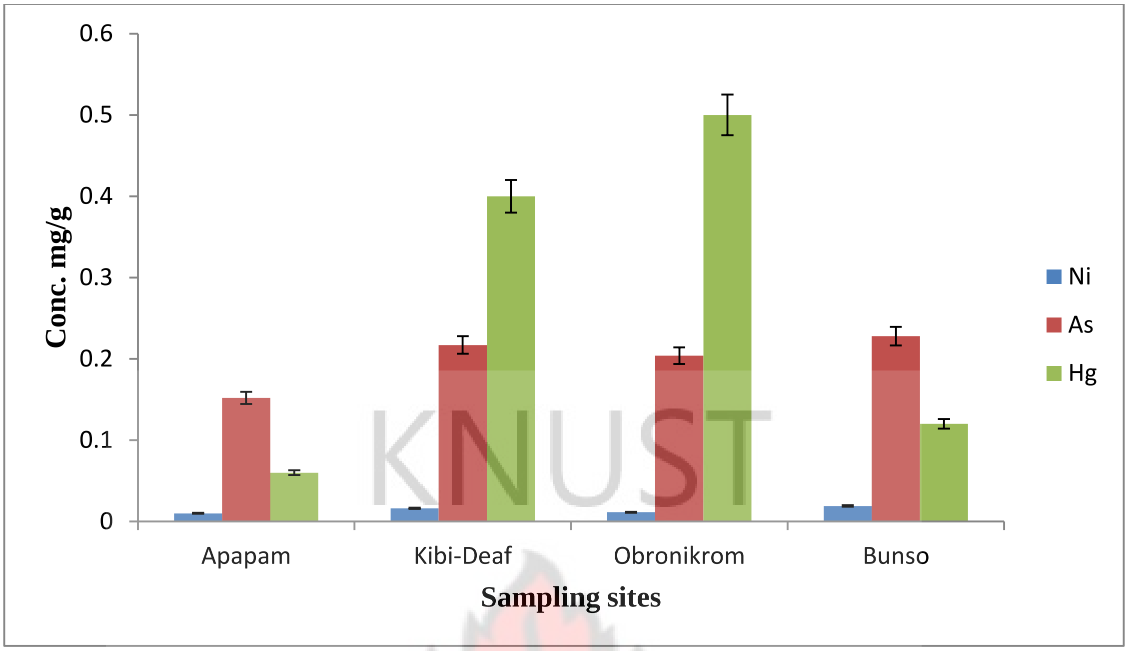

Figure 4.15 Comparison of Ni, As and Hg in the river sediment from the sampling sites on the River Birim

A comparison of Iron in river sediments from sampling sites have been presented in Fig. 16 below. The mean values of iron in the river sediments also showed high values with Apapam, Bunso, Kibi-Deaf and Obronikrom having mean values of 7.2665mg/g, 15.6805mg/g, 24.4245mg/g and 23.7565mg/g respectively.

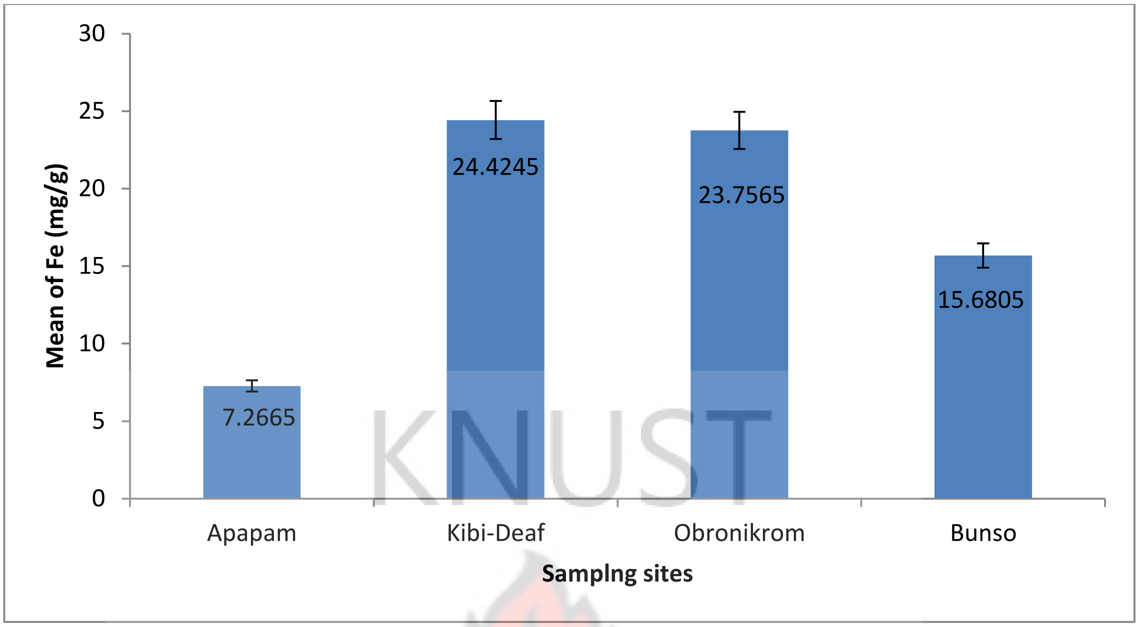

Figure 4.16 Comparison of Fe in the river sediment from the sampling sites on the River Birim

CHAPTER FIVE

DISCUSSION

5.1 PHYSICOCHEMICAL PARAMETERS

5.1.1 Total Suspended Solids (TSS)

The mean values of the total suspended solids recorded at the four sampling sites were far above GEPA background value of 50 mg/l with the exception of Apapam which recorded a value below the GEPA permissible level. The only human activity in River Birim which could contribute to such elevated levels is gold panning. The high values of 583, 546 and 119mg/l in Obronikrom, Kibi-Deaf and Bunso respectively from the upstream to downstream of the River may be attributed to the excavations made by panners; such activities increase the rate of weathering and susceptibility to erosion. In view of this it could be said that River Birim contains higher levels of clay or silt particles, plankton, organic compounds, inorganic compounds or other microorganisms. It is possible that small-scale mining activities discharge waste water from their gold processing activities as well as run-off of clay or silt particles, which could be responsible for the high TSS (Ghrefat and Yusuf, 2006).

5.1.2 True Colour of River Birim

To many people the colour of a river is an enough evidence to indicate how safe or unsafe that water is for drinking. Mean values of true colour obtained at the sampling sites were very high except that of Apapam. From figure 2, it is clear that the mean values of Bunso, Kibi-Deaf and Obronikrom are far above Ghana Environmental Protection Agency (GEPA) background value of 150 mg/l pt-Co. The high values of true colour could be attributed to the frequent panning which is carried out along the river profiles. Acid drainage is a legacy of past mining practices and current mining operations, particularly where sulphide minerals are present. for example, when the sulphide minerals are exposed to oxygen and water, they oxidize to sulphuric acid and ferrous hydroxide. It is the sulphuric acid that gives the strong acidic property, whereas ferrous hydroxide is responsible for the jelly-like yellowish orange colouration to the River water. Hence, the high values of true colour recorded at the sampling sites could be attributed to acid mine drainage which has been accelerated as a result of excavations made by the small scale gold mining operators along the River.

5.1.3 Electrical Conductivity (EC)

The mean EC values recorded at the four sampling sites along the river profile were generally low compared with GEPA standard of 1500µS/cm. The difference in mean values of EC at the various sampling sites along the Birim River may be attributed to the fact that a lot of particles may be introduced into the river water and dissolved into solution as a result of frequent panning at these sites. And that the intensity of mining activities at these sites was not the same. Electrical Conductivity is related to the concentration of Total Dissolved Solids (TDS). According to Chapman (1992), TDS may be obtained by multiplying the conductivity by a factor between the ranges of 0.55 to 0.75. Given these low conductivity values, it is not surprising that the TDS, which is an index of the amount of dissolved solids in water, which also determine the degree of salinity, would be low.

5.1.4 Dissolved Oxygen

Most of the Dissolved Oxygen (DO) values recorded were lower than the World Health Organization (WHO) set limit of 6.01 mg/L. However, the value at Obronikrom was exactly equal to the WHO limit. When DO is below 2 mg/L, many aquatic organisms perish and it is as a result of biological respiration including those related to decomposition processes which reduces the concentration of DO in water bodies (Cunningham and Saigo, 1995). The low level of DO recorded can be attributed to less flow of the River or the sewage discharges from the catchment area are gradually affecting the aquatic life of the River.

Measurement of DO is critical to the scientific understanding of the potential for chemical and biochemical processes in Rivers. Organic matter or oxidisable minerals present in some aquifers rapidly deplete the dissolved oxygen. The values recorded in the study area indicate that the organisms in the river will not be killed.

5.1.5 Total Dissolved Solids

The levels of Total Dissolved Solids (TDS) recorded at the four sampling sites were far below EPA guideline value of 500mg/l. The levels of Total Dissolved Solids for good fish culture were within 500 mg/l (Boyd and Lichtkoppler, 1979). The results of the present study fell within this range. The range of 25- 80 mg/l for Total Dissolved Solids was what was recorded for the study. However from Literature reliable data on possible health effects associated with the ingestion of TDS in drinking-water are not available and no health-based guideline value is proposed. Nevertheless, the presence of high levels of TDS in drinking-water may be objectionable to consumers.

5.1.6 pH

The mean values of the pH recorded at the various sampling sites were below GEPA standard value of 9. pH values of 6.51, 6.55 and 6.85 recorded at Obronikrom, Kibi-Deaf and Bunso respectively mean that the river water at these sites is slightly acidic. However, at Apapam the water samples exhibited neutrality with a mean pH value of 7. The slightly acidic nature of the River may be attributed to the initial stages of Acid Mine Drainage (AMD) which occurs when large quantities of rock containing sulphide minerals are excavated from an open pit or opened up in an underground mine reacts with water and oxygen to create sulphuric acid. The stronger the acid solution, the more the metals become soluble in water and this lowers the pH.The mean values obtained in the water samples were good for the River, since pH range of 6.50-9.00 is an indicator of a good fish population (Alabaster and Lloyd, 1980; Abulude and Lawal, 2002).

5.2 HEAVY METALS

Artisanal and small scale gold mining is a dangerous activity as the heavy metals, mainly Hg, Pb, As, Cu, Ni, Cd and Fe are released to the environment. They were selected because of their known toxicity in similar mining environments. Some of these metals especially As and Pb are major metals in gold-sulphide deposits, where they occur as minerals mainly in arsenopyrite (FeAsS) and galena (PbS), respectively. Under natural conditions, they are relatively stable. However, once mining has taken place, the minerals are broken down due to exposure to oxygen and water.

5.2.1 Cadmium (Dissolved)

Cadmium used to be an important factor in aquatic monitoring studies, because it has been found to be toxic to fish and other aquatic organisms (Woodworth and Pascoe, 1982). Also Cd has been implicated in endocrine disrupting activities which could pose serious health problems (Awofulu et al., 2005).

The mean values of dissolved cadmium recorded at the four sampling sites along the River profile were below the EPA guideline value of 0.1mg/l. The values obtained in the river sediments at the sampling sites were relatively low compared with the GEPA guideline/standard for dissolved cadmium. Apart from natural sources like runoff from agricultural fields where phosphate fertilizer might be in use, mining and processing of zinc and other chalophilic metals, other sources may include leachate from Ni-Cd based batteries (Hutton et al., 1987).Thus Cadmium in the study area may be attributed to excavations made by panners as these result in the metal being leached out and carried downstream as water washes over the rock surface.

5.2.2 Nickel (Dissolved)

From Fig. 8, analysis of water samples from the four sampling sites on river Birim indicated mean values of nickel were within WHO guidelines. The WHO guideline for dissolved nickel is 0.02mg/L. However, the values obtained in the river sediment at the sampling sites were relatively higher compared with the dissolved values. The high level of Ni in the sediment relative to levels in the water is expected since sediments have been described as a sink or reservoir for pollutants in water (Samir et al., 2006).According to Mckenzie and Symthe (1998) more attention has been focused on the toxicity of Ni in low concentration, such as the fact that Ni can cause allergic reaction and that certain Ni compounds may be carcinogenic. The typical concentration of Ni in unpolluted waters is given as 0.015 to 0.020 mg/L (Salnikow and Denkhaus, 2002). Possible contamination of the metal in some traditional fishes cannot be ruled out, since Pane et al. (2003) has reported Ni toxicity in rainbow trout. Although Ni is considered an essential element to plants and some animals (Ni is present in the enzyme urease), its essentiality to man is yet to be demonstrated (Teo and Chen, 2001). However, Ni related health effects such as renal, cardiovascular, reproductive and immunological effects have been reported in man.

5.2.3 Iron (Dissolved)

A comparison of iron concentration in water samples from the study area with the WHO permissible guideline values revealed that Kibi-Deaf and Obronikrom recorded mean values of dissolved iron that were above the recommended value of 0.3mg/L. Iron in the study area is associated with the Birimian rock system. The Birimian rock system contains high amounts of iron and other toxic chemicals such as manganese. The high concentration of iron in the study area is from the weathering of the Birimian rock system. Other sources of iron in the study area include the occasional discharge of mining waste, acid mine drainage which may increase iron levels in the surface water.

Iron is one of the major constituent in the lithosphere (i.e. soil or rock) soil as oxides or hydroxides. Manganese is also used in the alloying of iron to produce stainless steel and other products of iron (AGC, 2001).

High levels of iron recorded in water samples in the study area, pose significant health hazard to inhabitants. Exposure to high levels of iron in drinking water can result in iron storage disease where the liver becomes cirrhotic (Foulkes, 1986). Hepatoma, the primary cancer of the liver has become the most common death among patients with hemochromatosis (Foulkes, 1986).

5.2.4 Copper (Dissolved)

Generally, very low levels of copper were observed for all the water samples at the sampling sites when compared with the EPA and WHO guidelines limit of 5mg/l for drinking water. The mean values of copper in the river sediment recorded at Apapam, Bunso, Kibi-Deaf and Obronikrom were also low. The presence of copper in the study area is due to the excavations made by panners in the course of prospecting for gold in the Kibi traditional area. Such activities lead to the weathering and leaching of this metal from waste rock dumps (AGC, 2001). Other sources of copper are the weathering of the Birimain rock, which contains high levels of copper. Similarly, improper disposal of copper wire also accounts for presence of copper in the study area.

Long-term exposure to copper can cause irritation of the nose, mouth and eyes and it causes headaches, stomach aches, dizziness, vomiting and diarrhoea. Intentionally high uptakes of copper may cause liver and kidney damage and even death. There are scientific articles that indicate a link between long-term exposure to high concentrations of copper and a decline in intelligence with young adolescents (Rodricks, 1992).

5.2.5 Lead (Dissolved)

Lead is a highly toxic metal to man since it causes brain damage, particularly to the young and induces aggressive behaviour (Ramadan, 2003).

From Fig. 11, the mean concentrations of lead in the water samples were below GEPA background value of 0.1mg/l for drinking water. The presence of lead in the study area may be due to excavations made by panners as these results in the weathering and leaching of this metal from waste rock dumps. Other sources of lead are the weathering of the Birimain rock, which contains high levels of lead. Similarly, improper disposal of lead-acid batteries also accounts for the presence of lead in the study area. The major ways of toxicity by lead to man are caused through air respiration (inhalation), water contamination from lead piping and from polluted fish stuff. Lead toxicity is due to it mimics many aspects of metabolic behaviour of Ca and inhibit many enzyme systems (Mengel and Kirkby, 1982).

5.2.6 Arsenic (Dissolved)

EPA guideline for dissolved arsenic concentration is 0.01mg/l. From Fig. 12, it was evident that, the mean arsenic value in the sample water at Apapam was below the detection limit of the laboratory. However, Bunso, Kibi-Deaf and Obronikrom recorded mean values that were above GEPA permissible guideline value. Arsenic is found in the deep bedrock materials as well as the shallow glacial materials in the study area. They are also found alongside the gold ores such as arsenopyrites (FeAsS) (Coakley, 1996). Arsenic is usually present in the environment in inorganic form. The inorganic arsenic easily dissolves and enters underground and surface waters. The presence of arsenic in the environment may be attributed to one of the following sources: residual arsenic from former pesticidal use, smelter emission from ores of gold such as arsenopyrites from the sulphur treatment plant. Thus, during ore crushing and panning by the small scale gold miners, arsenopyrite like Arsenic is released into the environment and it finally finds its way into sediments and underground and surface water. Franblau and Lillis (1989) reported cases of sub-chronic arsenic intoxication resulting from ingestion of contaminated well water. Acute gastrointestinal symptoms, central and peripheral neuropathy, bone marrow depression, hepatic toxicity, skin pigmentation occurred when the mean level of arsenic from the contaminated well from which the inhabitants depend were between 0.03 mg/l and 0.08mg/l. Comparing the mean arsenic values in the Franblau and Lillis (1989) study to the calculated arsenic concentration obtained in this study, which residents in Kibi Traditional area ingest daily from drinking River Birim, it was found out that the mean arsenic concentration in River Birim is higher than the estimated arsenic value used in Franblau and Lillis (1989) study. Hence, symptoms associated with arsenic intoxication would be higher for residents in the study area.

5.2.7 Mercury (Dissolved)

Analysis of mercury content of the water samples at the various sampling sites along river Birim revealed that, some sampling sites had mean values above GEPA permissible background value of 0.005mg/l whilst others recorded mean values that were below GEPA standard. Similar trend of mercury concentration was seen in the river sediments. Mercury does not have a natural source in the municipality. It is introduced into the environment during gold processing. Mercury is used to recover gold from ore minerals by the process of amalgamation hence the high values are attributed to the processing of gold which is a widespread activity along the river. According to literature, mercury is more stable in sediments than in air (Kpekata, 1974). Therefore the values in water samples are taken as an indicator which shows that there is probably more mercury in the catchment in other forms. The occurrence of mercury in this river accentuated findings and reports that mercury is a major pollutant associated with gold panning in Ghana and elsewhere.

Given that mercury is a very poisonous metal, its presence in Birim river even in minute quantities poses serious health risk to users of the river.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The results of the study showed that the River is polluted. The mean values for true colour and total suspended solid of the river water at the various sampling sites exceeded GEPA permissible level for drinking water. This raises serious concern about the quality of drinking water being used by residents in the study area. It is important for residents in the study area to be provided with potable water.

The study has established that the concentrations of heavy metals, mainly Arsenic, Iron and mercury recorded in the River water and sediments were above GEPA and WHO standards, rendering the water unsafe for domestic use.

The survey revealed that the pollution of River Birim is associated mainly with panning along the river and excavations made by panners. Such activities increase the rate of susceptibility to erosion and weathering and leaching of the heavy metals as water washes over the rock surface. Evidence of pollution of the River includes siltation and water colouration due to chemical reactions, resulting in the formation of sulphuric acid and ferrous hydroxide. The River shows orange colouration and the water is slightly acidic, depicting chemical pollution.

It could be concluded that Small Scale Mining activities in the area have impacted on the water quality of River Birim considering the higher levels of True colour, Total

Suspended Solids, Iron, Arsenic and Mercury which exceeded the EPA and WHO levels.

6.2 RECOMMENDATIONS

From the results of this study, it is recommended that;

- There should be regular follow-up studies to measure the levels of heavy metals and other toxic chemicals in River Birim. This is necessary to further substantiate this study, document improvements and degradation, etc.

- The involvement of the local community including the individual active in panning in the mining area could improve environmental protection. In such instances capacity building should not only focus on authorities and agencies of environmental protection but rather on the local community. Such a wide spread of capacity can initiate the principle of subsidiarity which is crucial in environmental protection. Management and monitoring structures should be established at village level. Other advantages of local participation include lower policing costs and a strong sense of ownership and belonging by the local communities.

- Formalizations of small scale mining and other types of resource exploitation would also go a long way to reduce environmental impacts; clean technologies will significantly reduce impacts on water resources. One of the major pollutants being produced in this system is mercury. Cleaner production techniques have been reported world-wide, which can be used in the purification of gold to reduce its impacts on the workers and the environment.

- It is important for all stakeholders to supply polluted free drinking water to residents in the study area, since the main source of drinking water has been impacted upon negatively.

- Mining companies, Government, Minerals Commission, Water Resources Commission, Ghana Water Company Limited and the District Assemblies should adopt method or technology that removes high levels of toxic chemicals from the water bodies in the study area.

REFRENCES

Addo, B. O. (1999). Performance of the Mining Industry, Report of the President at the 72nd Annual General meeting of the Ghana Chamber of Mines, May 25, Accra, www.ghanachamines.com.

Abulude, F.O. and Lawal, L.(2002). Analysis of selected nutrients of wine obtained from felled palm tree. Pak. J. Sci. Int. Res., 45: 386-387.

Adimado, A. A. and Baah, D. A. (2002). Mercury in Human Blood, Urine, Hair and Fish from the Ankobra and Tano river basins in South-western Ghana. *Bull. envir. Contam. Toxicol.* **68**: 339-346.

Africa, E. C. (2002). Compendium on Best Practices in Small-Scale Mining in Africa. Addis Abba, Ethiopia, Economic Commission for Africa: 101.

AGC (2001). *Ashanti Goldfields Company: Environmental Impact Statement for the Sansu Project*, Ashanti Goldfields Company (AGC) Ltd., Obuasi, Ghana.

Anaman, J. K. (2002). Environment and sustainable development, Ghana Chamber of Mines, Conference on Mining, Environment and Sustainable Development, Feb. 21-22, Tarkwa, 2002 www.ghanachamines.com.

Anon, (1970). Mining and Explosives Regulations, L. I. 665 and L. I. 666. Ghana Publishing Corporation, Ghana, pp. 90-94.

Anon, (1989a). Small-scale Gold Mining Law, PNDCL 218. Ghana Publishing Corporation, Ghana, pp. 1-5.

Anon, (1989b). Mercury Law, PNDCL 217. Ghana Publishing Corporation, Ghana, pp. 1-2.

Anon, (1989c). Precious Minerals Marketing Corporation Law, PNDCL 219. Ghana Publishing Corporation, Ghana, pp. 1-3.

Anon, (1992). Mining and the Environment: The Berlin Guidelines. A Study Based on an International Round Table in June 1991. UNEP www. mineralsresourcesforum.org.

Anon, (1993). Review of the marketing function under the small scale mining project, Kwame Asanti and Associates (Chartered Accountants and Management Consultants), Accra, (Self published).

Anon, (1999). Assistance in Assessing and Reducing Mercury Pollution Emanating from Artisanal Gold Mining in Ghana-Phase www.Natural resources.org/minerals/CD/docs/unido/sub2igoatt6part2.pdf.

Anon, (2002). Breaking New Ground: Mining, Minerals, and Sustainable Development (MMSD). International Institute for Environment and Development and World Business Council for Sustainable Development www.iied.org/mmsd/finalreport.

Ansa-Asare O. D. and **Asante K. A.** (2000). The Water Quality of Birim River in South-East of Ghana.*West Afr. J. appl. Ecol.* **1**: 23-34.

APHA, (1992). Standard Methods For The Examination of Water and Waste Water. American Public Health Association, 18th ed., Academic Press. Washington D.C. pp. 214-218,

Asomaning, G. (1992). Groundwater Resources of the Birim Basin in Ghana. Parasitology International 49 (2): 155-163

Awofulu, O.R., Mbolekwa, Z., Mtshemia, V. and Fatoki, O. S. (2005). Levels of trace metals and sediment from Tyume River and its effects on an irrigated farmland. Water SA., 31(1): 87-94.

Biswas, J., Solano B and Acosta, I. (1993). Total mercury in muscle of fish from two marshes in goldfields, Colombia. Bull. Environ. Contam.Toxicol. 61:182–7.

Bonzongo, J. C., Donkor, A. K. and Nartey,V. K. (2003). Environmental impacts of mercury related to artisanal gold mining in Ghana. *J. Phys. IV France* **107**: 217-220.

Boyd, C.E. and Lichtkoppler, F. (1979). Water quality management in pond fish culture. Research and Development Series No. 22, Auburn University, Auburn

Chapman, D. (1992). Water Quality Assessment: A Guideof the use of Biota, Sediments and Water in Environmental Monitoring. University Press, Cambridge, pp: 585.

Coakley, G. J. (1996). *The Mineral Industry of Ghana*, U.S. Geological Survey.

Cunningham, W.P. and Saigo, B.W. (1995). Environmental Science, A Global Concern. 3rd Edn., WNC Brown Publishers

Dickson, K. B. and Benneh, G. (1980). *A new geography of Ghana*, Longmans Group Limited, London. pp. 17-19.

Foulkes, E. C. (1986). Absorption of Cadmium. In: Handbook of Experimental Pharmacology, E. C., Foulkes, (Ed.) Springer Verlag, Berlin. Vol. 80. pp.1-3.

Franblau, A. and Lillis, R. (1989). Acute Arsenic Intoxication from Environmental Arsenic Exposure. Archives of Environmental Health. 44: 385-390.

GEF, UNDP and ATSDR. (2003). "Removal of Barriers to Introduction of Cleaner Artisanal Gold Mining and Extraction Technologies." GMP News(1). pp. 11-13.

Ghrefat, H. and Yusuf, N. (2006). Assesssing Mn, Fe, Cu, Zn and Cu, Pollution in Bottom Sediment of Wadi Al-Arab Dam. J. Chemspeheric, 6: 043.

Gleick, E. (1998). Mercury contamination and floodplain sedimentation from former gold mines in North Georgia. Water Res. Bull. 30(4):739–48.

Grubaugh, K. (2002). "Profile of Ghana's Mining Industry," Arch Environ Health **54:**186-193.

Harada, M., Nakachi, S., Cheu, T., Hamada, H., Ono, Y., Tsuda, T. and Yanagida, T. (1997). *Mercury Pollution in Tanzania: Relation Between Scalp Hair, Mercury Level and Health*, Institute of Molecular Embryology and Genetics, Kumamoto, Japan, 1111.

Hilson, G. (2002). "Small-scale mining and its socio-economic impact in developing countries." Natural Resources Forum 26: 3-13.

Hinton, J. J. and Veiga, M. M. (2003). "Clean artisanal gold mining: a utopian approach?" *Journal of Cleaner Production 11*: 99-115.

Hutton, M., Chaney, R.L., Krishna, M., Murti, A. and Olade A.L. (1987). Group Report. In: Hutchson, T.C. and K.M. Meena, (Eds.), Lead, Mercury, Cadmium and Arsenic in the Environment. John Wiley, New York, pp: 35-41.

Kesse, G. O. (1985). Mineral and Rock Resources of Ghana. Balkema, Holland: Knight and Scott, Winston, Inc.

Keith, B. (2004). *Environmental Science, A Study Of Interrelationships.* Wm. C. Brown Publishers. USA.

Kpekata, A.E. (1974). Trace Inorganic And Organic Substances In Rivers Avon And Frome. PhD Thesis, University Of Bristol, UK.

Lacerda, W.M., Hansen ,L.G., Wood, S.G. and Salomons, M.(1998). Assessment of chemical contaminants in water and sediments samples from Degh Nala in the Province of Punjab, Pakistan. Arch. Environ. Contam. Toxicol. 26:79–89.

Limbong, D. A. (2006). Metal distribution in road dust samples collected in an Urban area close to a petrochemical plant at gela, sicily. Atmos. Environ., 40: 5929-5941.

Maponga, S.N. and Anderson G.W. (1995). A statistical assessment of the form of trace metals in oxidized estuarine sediments employing chemical extractants. Sci. Total Environ., 17: 165-196.

Mason, C. E. (1997). Water quality management in pond fish culture. Research and Development Series No. 22, Auburn University, Auburn.

Maurice-Bourgin and Quiroga, L. I. (1999). "Mercury Pollution in the Upper Beni River, Amazonian Basin: Bolivia." *Ambio 28*: 302-306.

Mckenzie, H.A. and Symthe, L.E. (1998). Quantitative Trace Analysis of Biological Material. Elsevier, Amsterdam.

Meech, E. A., John, A. and Raphael, H. (1995). "Educational measures to address mercury pollution from gold-mining activities in the Amazon." Ambio **24**(4): 216-220.

Mengel, K. and Kirkby, E.A. (1982). Principles of Plant Nutrition. 3rd Edn., Int. Pot. Inst. P.O. Box CH-3048, Worblaufen-Bern., Switzerland, pp: 655.

Miller, J. R. and Lechler, P. J. (2003). "Importance of Temporal and Spatial Scale in the Analysis of Mercury Transport and Fate: An Example from the Carson River System, Nevada." *Environmental Geology 43*: 315-325.

Minerals Commission, (2004). *Environmental Effects of Small and Large Scale Mining in Ghana.* Minerals Commission, Accra, pp. 1-3.

Mireku-Gyimah, D., Opare-Baidoo, S., Cobblah, A. (1996). Small-scale gold mining and its impact on the economy of Ghana, in: Glen, H.W. (Ed.), Surface Mining. South African Institute of Mining and Metallurgy, Johannesburg, pp. 13–16.

Noetstaller, R. (1987). Small-scale mining: a review of the issues, World Bank, Technical Report, Nº 75. World Bank, Washinton D. C.

Obiri, S. (2005). Risk assessment of toxic chemicals in mining operations in Ghana. An M. Phil thesis, Department of Chemistry, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Pane, E.F., Richard, J. G. and Wood, C.M. (2003). Acute water borne nickel toxicity in the rainbow trout (*Oncorhychus mykiss*) occurs by respiratory rather than ionoregulatory mechanism. Aquatic Toxicol., 63(1): 65-82.

Ramadan, A.A. (2003). Heavy metal pollution and biomonitoring plants in Lake Manzala, Egypt. Pak. J. Biol. Sci., 6(13): 1108-1117.

Ripley, R.J. (1996). Transport phases of transition metals in the Amazon River. Geol. Soc. Am. Bull., 88: 829-843.

Rodricks, J. V. (1992). *Calculated Risks.* Cambridge University Press. Cambridge, U. K.

Salnikow, K. and Denkhaus, E. (2002). Nickel essentiality, Toxicity and carcinogenicity. Crit. Rev. Oncol. Haematol., 42(1): 35-56.

Samir, M.N., Mohamed, A.O. and Shaif, M.K. (2006). Environmental assessment of heavy metal pollution in bottom sediments of Aden Port, Yemen. Int. J. Ocean Oceanogr., 1(1): 99-109.

Schwarzenbach, R. P., Gschwend, P. M and Imboden, D. M. (2003). Environmental Organic Chemistry, (2nd ed.). Van Nostrand Reinhold Publishers. New York, USA.

Standard Method, (1998). Standard Method for Water and Wastewater. 20th Edn., American Public Health Association. Washington D.C.

Suglo, R.S., Al-Hassan, S., Amankwah, R.K. (1998). Mining or the environment - a difficult choice, Proceedings of the Seventh International Symposium on Mine Planning and Equipment Selection, Calgary 1998, pp. 683–688.

Tenkorang, C. O. (2000). Mining and the Environment. Daily Graphic. pp. 2. Graphic Communications Group Ltd. Accra, Ghana.

Teo, K.C. and Chen, J. (2001). Determination of cobalt and nickel in water using atomic absorption spectrometry after cloud point extraction. Anal. Chim Acta., 434(3): 325-330.

Tsikata, F. S. (1897). The vicissitude of mineral policy in Ghana. *Resour. Pol.* **23** (1-2): 9-14. Maney Publishers.

Traore, L. (1994). An Ecological risk index for aquatic pollution control: A sedimentological approach. Water Res., 14: 975-1001.

UNIDO, (2001). Artisanal Gold Mining Without Mercury Pollution. Washington DC: Armed Forces Institute of Pathology, April 2000; **46** (2-4).

USEPA, (1988). Method 2008, Revision 5.5:Determination of Trace Elements In Waters And Wastes By Inductively Coupled Plasma-Mass Spectrometry, Office of Water, USEPA (4303), Washington, D. C., EPA-821-R-99-017.

Veiga, M. M. (1997). Introducing New Technologies for Abatement of Global Mercury Pollution in Latin America. UNIDO, UBC, CETEM, Rio de Janeiro.

Water Resources Commission (WRC) (2000). *Water Resources Management Problems, Identification, Analysis and Prioritization Study*. CSIR-Water Research Institute, Accra, Ghana. 130 pp.

Woodworth, J.C. and Pascoe,V. (1982). Cadmium toxicity of rainbow trout, salmon gairdneri richardson. A study of eggs and alevine. J. Fish Biol., 21: 47-57.

World Health Organization (WHO, 1996). Guidelines for drinking water quality, 2nd ed. criteria and other supporting information, vol. 2. http://www.who.int/water-sanitation— health/GDWQ/Summary—tables/Tab2a.htm. Geneva.

World Health Organization (WHO, 2004). Methylmercury. Environmental Health Criteria, No. 101, Geneva.

APPENDIX A

Summary of Physico-Chemical Parameters determined in Birim river water and EPA/WHO standards

Mean and Range values of pH, Electric Conductivity, True Colour, Dissolved Oxygen, Total Dissolved Solid and Total Suspended Solid at Four Sampling Sites of River Birim.

Sampling sites	**pH**	**E. C** μS/cm	**True colour** mg/l pt-Co	**DO** mg/L	**TDS** mg/L	**TSS** mg/L
Apapam	**7.00**	**101.00**	**90**	5.70	**25.00**	**15.00**
	6.32 - 7.02	98 - 110	85-98	5.5- 5.8	23 – 29	10 – 20
Bunso	**6.85**	**115.00**	**1190**	**5.80**	**39.00**	**119.00**
	6.32 - 7.01	113 -120	1160 – 1193	5.7 – 6.8	35 – 44	111 – 124
Kibi-Deaf	**6.55**	**111.00**	**4220**	**5.84**	**41.00**	**546.00**
	6.31 – 6.86	109 – 113	3800- 4227	5.80– 6.09	37 – 43	538 – 550
Kibi-Obronikrom	**6.51**	**119.00**	**4900**	**4.39**	**80.00**	**583.00**
	6.31- 7.02	108 – 123	4750 – 4930	4.20 – 6.01	77- 85	571 – 589
EPA standards	**6 – 9**	**1500**	**15(WHO)**	**6.01 (WHO)**	**500**	**50**

APPENDIX B

Summary of Heavy Metal Concentration in Birim river water

Mean and Range values of Copper, Lead, Cadmium, Mercury, Arsenic, Iron and Nickel in river water at Four Sampling Site of River Birim.

Sampling sites	**Copper** mg/L	**Lead** mg/L	**Cadmium** mg/L	**Mercury** mg/L	**Arsenic** mg/L	**Iron** mg/L	**Nickel** mg/L
Apapam	**<0.01**	**0.006**	**0.006**	**0.002**	**<0.01**	**0.350**	**0.006**
	<0.01	0.003-0.009	0.004-0.008	0.001-0.004	<0.01	0.289-0.41	0.002-0.008
Bunso	**<0.01**	**0.006**	**0.009**	**0.003**	**0.048**	**0.934**	**0.008**
	<0.01	0.003-0.009	0.004-0.012	0.001-0.006	0.022-0.066	0.900-1.23	0.005-0.020
Kibi-Deaf	**<0.01**	**0.018**	**0.008**	**0.008**	**0.046**	**3.366**	**0.018**
	<0.01	0.011-0.023	0.003-0.015	0.005-0.016	0.022-0.082	2.731-5.01	0.011-0.120
Obronikrom	**0.11**	**0.025**	**0.010**	**0.010**	**0.180**	**4.414**	**0.012**
	<0.01-0.15	0.02-0.040	0.007-0.022	0.006-0.122	0.09-0.228	4.001-5.36	0.009-0.023
Total	**0.04**	**0.014**	**0.031**	**0.006**	**0.071**	**2.266**	**0.011**
	<0.01-0.15	0.009-0.020	0.005-0.014	0.003-0.037	0.045-0.371	1.98-3.003	0.007-0.043
EPA standards	**5**	**0.1**	**0.1**	**0.005**	**0.01**	**0.3(WHO)**	**0.02(WHO)**
Standard error	±0.001	±0.002	±0.003	±0.003	±0.003	±0.006	±0.004

APPENDIX C

Summary of Heavy Metal concentration in Birim river sediment

Mean values of Copper, Lead, Cadmium, Mercury, Arsenic, Iron and Nickel in river sediment at Four Sampling Site of River Birim.

Sampling sites	**Copper** mg/g	**Lead** mg/g	**Cadmium** mg/g	**Mercury** mg/g	**Arsenic** mg/g	**Iron** mg/g	**Nickel** mg/g
Apapam	**0.0076**	**0.0085**	**0.0041**	**0.06**	**0.152**	**7.2665**	**0.0100**
Bunso	**0.0156**	**0.0240**	**0.0042**	**0.12**	**0.228**	**15.6805**	**0.0190**
Kibi-Deaf	**0.0122**	**0.0240**	**0.0030**	**0.40**	**0.217**	**24.4245**	**0.0160**
Obronikrom	**0.0161**	**0.0159**	**0.0017**	**0.50**	**0.204**	**23.7565**	**0.0113**
Total	**0.0129**	**0.0181**	**0.0033**	**0.07**	**0.200**	**17.7820**	**0.01408**
Standard error	**±0.02**	**±0.006**	**±0.007**	**±0.88**	**±0.08**	**±0.33**	**±0.38**