

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

DEPARTMENT OF THEORETICAL AND APPLIED

BIOLOGY



IMPACT OF SMALL SCALE GOLD MINING ON SOME WATER QUALITY

PARAMETERS OF RIVER ASHIRE

THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED

**BIOLOGY IN PARTIAL FULFILMENT FOR THE AWARD OF MASTER OF SCIENCE
(ENVIRONMENTAL SCIENCE) DEGREE**

BY

EMMANUEL ARMAH (BSC. HONS)

March, 2013

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DECLARATION

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

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DEDICATION

This piece of work is dedicated to my late mum; Cecilia Armah and Dad; John Armah whose toil and sweat has brought me thus far.

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I wish to acknowledge with thanks the help I received from many people who in diverse ways made it possible for me to write this dissertation.

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ABSTRACT

The study investigated the impact of Small Scale Mining on some water quality parameters in River Ashire in the Wassa Amenfi East District of Western Region by measuring the concentration of heavy metals (Mercury, Arsenic, Cadmium, Copper and Lead) and some physicochemical parameters using the Atomic Absorption Spectrophotometer and other standard methods. Water samples from River Ashire were collected monthly at seven (7) different locations along the river over a six month period from October 2010 to March 2011. Mean pH at the sampling points along the river ranged from 6.30-7.01, Electrical Conductivity ranged from 50-103.58 $\mu\text{S}/\text{cm}$, 0.026-0.113 ppm for Salinity and a range of 30.50-49.83mg/L for Total Dissolved Solids were all below the EPA guideline values, but mean Total Suspended Solids 166.83-127.78mg/L and 172-513NTU Turbidity values were above the EPA guideline values. The range of value for Dissolved Oxygen for downstream was 4.09-6.91mg/l; for which the upper limit of 6.91mg/l higher than the Ghana EPA Standard of 5.00mg/l. Lead values ranged from 0.035-0.064, Arsenic value ranged from 0.019-0.0372 mg/L and Mercury range of 0.009-0.085 mg/l values exceeded the EPA Standards. However, levels of Copper 0.001-0.004 mg/l and Cadmium 0.002-0.085 mg/l were lower than the Ghana EPA permissible levels of effluent discharged into natural water bodies. Considering the higher levels of Turbidity, Total Suspended Solids, Lead and Mercury in the River which all exceeded the EPA and WHO levels, Small Scale Mining activities along River has an impact on the river water quality. From the results obtained the levels of heavy metals and Physico-Chemical parameters can be injurious to human health and the environment since according to the World Health Organization, (WHO) (1996), about five million people die every year from drinking polluted water.



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CHAPTER ONE

INTRODUCTION

The historical importance of mining in the economic development of Ghana is considerable and well documented, with the country's colonial name - Gold Coast - reflecting the importance of the mining sector in the development of the country. Gold dominates the mining sector and Ghana is Africa's second most important producer of gold after South Africa, the third largest producer of manganese and aluminium and a significant producer of bauxite and diamonds (Coakly, 1999).

In addition, inventories of iron, limestone, kaolin, salt and other industrial mineral resources exist but are not exploited on a large scale.

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The Wassa Amenfi East District is one of the major areas in Ghana where Small Scale Mining activities dominate considering the fact that an area in the district (Japa/Dadieso) has been designated for small scale mining activities (Mineral Commission, 2000). Most of these Small Scale Mining companies in the area have caused severe environmental damage to the water bodies as well as the ecosystem within their areas of operation. The companies either mine close to the water bodies or their effluents are drained into these water bodies.

The Ghanaian small-scale mining industry is well over 2,000 years old. Vestiges of alluvial gold extraction and winning activities have been found that date as far back as the sixth century, and there is a wealth of evidence indicating that precious metals recovered from regional artisanal activities were attracting Arab traders to certain areas of the country as early as the 7th and 8th centuries AD (PMMC, 2006). In fact, it was the rich gold deposits of the Western Sahara that were largely responsible for the wealth

and strength of large ancient Ghanaian empires and cultures, and by the 15th and 16th centuries, at the peak of European colonial exploration, Ghana was fittingly labelled the ‘Gold Coast’ (Hilson, 2001).

Small-scale mining in Ghana, as in most developing countries, was for decades treated as an informal industrial sector, employing thousands of people but featuring largely rudimentary, unmonitored and uncontrolled practices. Up until the 1980s, small-scale mining activities in Ghana remained largely unregulated and received little, if any, support from governmental bodies. This, however, changed with the implementation of the national Economic Recovery Plan (ERP), which, following years of careful planning, was finally launched in the mid-1980s. In a desperate move to revitalize a stagnating economy, the then Provisional National Defence Council (PNDC) government consulted authorities from both the World Bank and International Monetary Fund (IMF) to assist in the drafting of national economic plans and policies. The Ghanaian minerals sector was heavily targeted, which, between 1960 and 1980, had experienced massive declines in mineral output: gold production had declined from 900,000 oz in 1960 to 232,000 oz in 1982; manganese output had dropped from 600,000 t in 1960 to 160,000 t in 1982; bauxite production declined from 407,000 in 1974 to 64,700 t in 1982; and diamond output had declined from 2,340,000 carats in 1975 to 683,524 carats in 1982 (Hilson, 2001). Foreign investment was promoted, and a series of tax breaks and benefits were offered to foreign companies seeking to acquire mineral prospecting licenses in Ghana. The small-scale mining segment of the industry was also heavily targeted. For the first time in history, the Ghanaian government discussed plans to formalize the sector after identifying the potential earnings in the industry, revenue that under an informal organizational scheme is largely lost via smuggling and other avenues of illegal trading. By the end of the 1980s, the

government had fully regularized the small-scale mining sector through a series of policies and regulations (Hilson, 2001).

Small scale mining also called Artisanal mining involves alluvial mining operations from certain reserves where both indigenous peasant miners pan for gold especially along the bank of rivers and in the bed of streams. In some areas of Ghana especially the Central, Western and Northern regions, miners go quite deep down before discovering gold bearing rocks to be blasted for treatment and recovery of gold.

Artisanal miners, particularly alluvial panners are nomadic and the effects of their negative environmental impact are felt by local and distant users of environmental services; while government and/or non-governmental organizations pick up the cost. Alluvial mining everywhere is driven by the gold-rush mentality. Tools normally used are mainly a panning dish, pick axes, shovels and other local implements including wooden boxes with riffles and recovery mats to conduct sluicing operations. In small to medium operations mechanized Alluvial Mining is practiced using excavators, earth moving equipment and washing plants (PMMC, 2006).

In many parts of the world, artisanal or small-scale mining (ASM) activities are at least as important as large-scale mining activities, particularly in terms of the numbers of people employed. ASM can play a crucial role in poverty alleviation and rural development; most of those involved are poor and mining represents the most promising, if not the only, income opportunity available. However, the sector is perhaps better known for its high environmental costs and poor health and safety record. Many continue to view it as dirty, unprofitable and fundamentally unsustainable. Irrespective of one's perspective of whether or not the sector is a net contributor to sustainable development, the fact remains that small-scale and artisanal mining activities will

continue for at least as long as poverty continues to necessitate them. It is therefore essential that effort be made to maximize the benefits brought and enabled by small-scale mining, and to mitigate the costs. According to a recent survey carried out by ILO and MMSD, at present we can reckon with around 13 million people working directly in small mines throughout the world, mainly in developing countries. A large percentage of these miners are women, and regrettably, also children (Hilson, 2001).

The international development community is discussing the ASM sector now for about 30 years. Many changes and progress on issues and research have occurred since then. In the last 10 years the international donor agencies have recognized the close relation of ASM to poverty and the ASM sector is gaining more and more attention. ASM is now on the agenda of many national governments and of bilateral and multilateral donor organizations and different assistance programs have been or are carried out. Even one step further actually through the CASM (Collaborative Group on Artisanal & Small-Scale Mining) initiative of the World Bank exists as a valuable instrument for donor coordination, experience and information exchange and channelling. For the past two decades artisanal mining as an economic activity had been sweeping across the globe in Africa, Australia, Latin America, Asia etc. Artisanal mining is however associated with informal, unregulated, undercapitalized and under-equipped mining operations where technical and management skills are lacking.

The concentration of trace elements, particularly heavy metals, in stream sediments and in surface waters may reflect the abundance of these metals in a particular environment (Lacerda and Solomons, 1998). Anthropogenic activities can result in heavy metals fluxes equally or exceeding the amount released under natural weathering conditions. It has been suggested that the metals derived from anthropogenic activities are less

effectively bound to particulate matter compared with those derived from natural processes and will remobilize more readily following physico-chemical variability of water system (Lacerda and Solomons, 1998).

Streams and Rivers are major sources of fresh water in the Wassa Amenfi District in that most communities lack potable water. The Ashire River is a major supplier of fresh water to most communities in the district. However, small scale mining or Artisanal miners in the district use large quantities of this river resource to wash mineral ores in order to extract gold and in the process generate effluent which has the potential of polluting the water body.

1.1 STATEMENT OF PROBLEM

Small Scale Mining operations have the potential to cause several adverse changes in the environment especially in mining areas and communities. Such changes do not only affect the inhabitants in terms of life-threatening illnesses, but also other vital natural resources such as rivers or streams. Meanwhile, people hold the perception that surface waters have the capability of naturally purging itself of contaminants, and thus free from posing any eminent health risk. According to the World Health Organization, (WHO) (1996), about five million people die every year from drinking polluted water. There is therefore the need to assess surface water quality in any given area especially in small scale mining communities.

Secondly, water from these streams are used by the inhabitants downstream to cultivate vegetables and for various domestic activities. The presence of these chemicals can harm both aquatic and human lives. The assessment will enable preventive measures to be taken, while the knowledge of extent of pollution will inform on the level of

treatment, if any, required to make the water potable for communities who depend on them for survival.

1.2 JUSTIFICATION

The most predominant mining operation in Ghana is surface mining which forms about 75% of the mining activities in the country (Tsikata, 1997). Despite the boom in the gold sector, the local communities have not benefited but instead caused environmental problems. One of the most affected medium is water bodies which is probably most vulnerable to changes brought about by human activities from both point and nonpoint sources. The concentration of Small scale mining operations in the Wassa Amenfi East District has been a major source of surface water pollution. Chemicals such as Mercury, Arsenic, etc. are used during ore processing. Chemical pollution could also occur through the misuse, mishandling and poor storage of these chemicals. The presence of heavy metals above a certain threshold can be injurious to human health and the environment. The health implications of this scenario on the people and other living organisms depending on this stream are also obvious. Many communities along the stretch of the river depend on it for drinking, bathing and other domestic uses.

1.3 OBJECTIVE OF THE STUDY

The main objective of this work is to assess the impact of small scale mining on some water quality parameters in River Ashire in the Wassa Amenfi East District of Western Region.

1.4 SPECIFIC OBJECTIVES

- To determine the levels of heavy metals including mercury, Cadmium, lead, Copper and Arsenic in the water and sediment samples from Ashire River.
- To measure some Physico-Chemical parameters (pH, E. Conductivity, Salinity, Dissolved Oxygen, Total Dissolved Solids, Total Suspended Solids and Turbidity)

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CHAPTER TWO

2.0 LITERATURE REVIEW

Several researches have been conducted on small scale mining and its effects as well as contributions to economic development of countries endowed with mineral resources. Whereas some researches highlight the benefits of small scale mining to economic development, others focus on the negative impacts of small scale mining on the overall development of such economies. This chapter reviews what has been documented regarding Artisanal and Small scale mining as a concept and its impact on water bodies.

2.1 DEFINING MINING

Mining encompasses the extraction of metals and minerals from the ground (Weber-Fahr and Andrews, 2002). My definition of mining in this thesis does not include oil or gas extraction. It is the extraction of non-renewable resources from the ground (Pouling and Sinding, 1992). Mining operations include open-pit (surface mining) and underground mining, and large-scale operations as well as activities of small-scale and artisanal miners.

2.2 SMALL SCALE MINING DEFINED

There is currently no universal definition of Artisanal and small scale mining (ASM), due to the fact that, definition varies from country to country. A number of attempts have been made to define small – scale mining in an international context using criteria such as investment cost, mine output, labour productivity, size of concessions and amount of reserves, levels of technology or combination of these. Broad definition characterized the small – scale mining operation as both labour-intensive and low technology.

Small scale mining definition is sometimes placed under two areas that is high value mineral extraction like Gold, Silver and other precious stones and the other being quarry mining or the mining of industrial minerals and construction materials (Hilson, 2002).

Although there were many definitions most literature tended to provide definitions based on the study which was undertaken and applied. It was generally accepted that “Small Scale Mining or artisanal mining generally encompasses small, medium, informal, legal and illegal miners who use rudimentary methods and processes to mine and extract more than 30 different mineral substances worldwide. Usually such mines are individual enterprises, co-operative of few or small family owned companies which were affiliated to any multinational companies. It is therefore indicative that studying such small mines also needs a critical analysis of scale of mining (Hilson, 2002).

In 1999, the international Labour organization (ILO) estimated that there were thirteen (13) million small scale miners in about fifty – five (55) countries with the majority in the developing countries. The number suggested that about 80 to 100 million people indirectly or directly depend on this activity for their livelihood. In Latin America alone, there were an estimated 1.4 to 1.6 million miners.

2.3 NATURE OF SMALL SCALE MINING

Artisanal mining also called small scale mining involves alluvial mining operations from uncertain reserves where both indigenous peasant miners pan for gold especially along the banks of rivers and in the beds of streams. In some areas in Ghana especially the Central, Western and Northern regions, miners go quite deep down before discovering gold bearing rocks to be blasted for treatment and recovery of gold.

Artisanal miners’ particularly alluvial panners are nomadic and the effects of their negative environmental impacts are felt by local and distant users of environmental services; while governments and/or non-governmental organisations have to pick up the cost. Alluvial

mining everywhere is driven by gold-rush mentality. Tools used are mainly are panning dish, pick axes, shovels and other local implements including wooden boxes with riffles and recovery mats to conduct sluicing operations. In small to medium operations Mechanized Alluvial Mining is practised using excavator earth moving equipment and washing plants. For the past two decades artisanal mining as an economic activity had been sweeping across the globe in Africa, Asia, Australia

2.4 MINING LEGISLATION IN GHANA

2.4.1 The Mineral Commission law 1986 (PNDCL 154)

This law was promulgated to establish the mineral commission and the commission given the mandate to formulate policies on exploration and mining of mineral resources in Ghana.

The commission therefore has contractual obligation with proponents in the country. The government however appoints the chairman and Chief Executive Officer to run the administration of the commission.

2.4.2 Mineral and Mining law 1986 (PNDCL 153)

The section I of the law states that “All minerals are the property of the Republic of Ghana and the government has power to acquire compulsorily any land which may be required to secure the development or utilization of any mineral resources”. Section 14 subsection 2 states that “the secretary (now minister) for lands and natural Resources shall on behalf of the Republic have power to negotiate , grant, revoke, suspend or renew any mineral right under this law”.

The secretary is also empowered to make legislative instructions to restrict prospecting near any water body, prevent pollution of water, ensure public safety and welfare of workers, prevent injury to persons and property by chemicals and set penalties for offences against the regulations.

Section 9 directs the holder of a mining right to have a responsible manager in charge of his mining operations at all times and also provides for appointment of a Chief Inspector of Mines who shall supervise the proper carrying out of provisions of the law.

The Chief Inspector of Mines has power to enter into a mining area to take samples of rocks, tailings and ore and inspect explosive, magazines to satisfy him that all documents and records are kept well. He also has powers to enquire into accidents on the mine that result in fatalities.

2.4.3 Small Scale Gold Mining law 1989 (PNDCL218)

This law states that “No person shall engage in or undertake any small scale mining operations unless there is existences in respect of such operation a license and granted by the secretary (now minster) for lands and Natural Resources or by an officer auditioned in that behalf”.

Section 2 of the law limits the granting of license to only Ghanaian citizens who have reached the age of 18 years. However the companies’ code may allow for the participation of non-Ghana provided that a Ghanaian is the majority shareholder.

A prospective applicant for small scale mining notifies the District officer in charge of small scale mining of his intention, who would intend inspect the site to determine its suitability before demarcating the area.

A site plan is then prepared by the prospective miner. A notice of intention to allocate the area for small scale Gold mining is published at the District Assembly, local information centre and magistrate court for twenty one (21) days.

If no objections are made the applicant completes the application form to fulfil other obligations of the mineral commission and recommendation is submitted to the secretary (now minister) for mines and energy.

- A successful applicant is given a code of practice which details other guidelines for:

- Protection for working place.
- Environmental Protection.
- Surface protection (i.e. land surface protection).

Section 13 prohibits the use of explosives by small scale miners (No small scale gold miner shall use any explosive in his operations) but due to lack of supervision and poor enforcement of this section of the law, small scale miners use explosives.

It is however indicated under section 14 that small scale gold miners are allowed to purchase mercury.

2.5 REGULATORY FRAMEWORK FOR SMALL-SCALE MINING IN GHANA

Initially, only diamonds could be legally mined on a small scale in Ghana. However, in 1989, a much-needed move was taken to legalize small-scale gold mining, which, from an economic perspective, is by far a more important sector of the economy. The following three laws [3] were passed:

- The Small-scale Gold Mining Law (PNDCL 218): provides for the registration of activity; the granting of gold-mining licences to individuals or groups; the licensing of buyers to purchase product; and the establishment of district-assistance centres.
- The Mercury Law (PNDCL 217): legalized the purchasing of mercury (for mineral processing Purposes) from authorized dealers.
- The Precious Minerals Marketing Corporation Law (PNDC Law 219): transformed the Diamond Marketing Corporation into the Precious Minerals Marketing Corporation (PMMC), which was authorized to buy and sell gold.

2.6 AN OVERVIEW OF THE GHANAIAN SMALL-SCALE GOLD-MINING INDUSTRY

A favourable geological setting enables widespread small-scale gold mining to occur in Ghana. Following stabilization of the West African Craton during the early Proterozoic Period some two billion years ago (Minerals Commission, 2000), a series of tectonic processes occurred - namely, folds, faults, metamorphosis, igneous activity, erosion and sedimentary processes - which gave rise to a series of gold belts that today, collectively cover approximately one-sixth of the surface area of the country (Lunt *et al.*, 1995). The first group of belts, which ranges between 15 and 40 km in width, contains Birimian gold: supracrustal West African rocks that extend from Ghana westward into Senegal and Mauritania, and northward into Burkina Faso. These belts are richly endowed with Proterozoic greenstone-type gold lode deposits, and are highly variable and structurally complex overall, featuring gold that occurs in both quartz filled shear zones and within altered rocks adjacent to shear zones. The second group contains Tarkwaian gold: auriferous quartz-pebble conglomerate deposits - quintessentially, a matrix of fine-grained quartz and black sands (mainly hematite, and to a lesser extent, ilmenite, magnetite and rutile) Vein-quartz pebbles account for 90% of its volume and the balance comprises quartzite and phyllite particles (Leube *et al.*, 1990; Dzigbodi-Adjimah and Bansah, 1995; Lunt *et al.*, 1995; Hammond and Tabata, 1997).

2.7 SOCIO-ECONOMIC IMPACTS

In general artisanal mining in Ghana is driven by get rich quick mentality of transient peasant miners hence there is the possibility negative social and environmental side effects exceeding any benefit and assistance to be derived thus compounding the rural poverty problem. In consequence socio-economic benefit will be realized if comprehensive reforms are initiated to improve the conditions of miners and to transform artisanal mining orderly, safe, technically sound/viable and environmentally sustainable small scale mining.

2.7.1 Employment

Artisanal Mining is labour intensive and thus provides employment and income to large numbers of people who are generally uneducated, poor and live in remote areas where no opportunities exist for formal employment.

The most recent ILO research undertaken on a global scale estimates that 13 million people are engaged directly in small-scale mining activities throughout the world, mainly in *Global Report on Artisanal & Small-Scale Mining* 11

In 1996, the UN calculated that the small scale mining sector provided employment and benefit to over 30 million people worldwide, equivalent of 20% of global mining employment. It is estimated that up to 10 million people benefit from artisanal mining activities in the Southern African region. In Ghana assuming an average of four additional family members per worker, the total number of people dependent on artisanal mining is running into several thousands. There is a lack of clarity over the actual number of people employed in the sector. Many factors make it difficult to ascertain the full extent of employment including: the informality of the sector, the lack of official statistics, the number of seasonal and occasional workers and definitional issues. The significance of this is demonstrated by the MMSD Country Study for China, which estimated that anything between 3 and 15 million people are involved in artisanal and small scale mining activities in this country.

In spite of these difficulties, there is no doubt that ASM is an important employment generating sector.

2.7.2 By Products

By products from artisanal mining such as sand, stones, concentrates and over burden may be utilized in road, building construction and blocks manufacture. Pools of water created may be developed into fish farms or mined out areas may be reclaimed for cottage industries, agricultural purposes and other infrastructure in the locality (PMMC, 2006).

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 response- 2 Mine Support Service companies are companies that have been accorded certain concessions in view of the services they provide exclusively to companies operating in the mining sector of Ghana (Aryee, 2003). In Ghana, environmental problems associated with the small-scale mining of precious minerals can be broadly grouped into three categories.

2.8.1 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. In the Choco region of Colombia, for example, gold production increases 7.2% each year, resulting in an estimated deforestation rate of 1000 ha (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 100 000 ha 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 firewood, 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 and Salomons, 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).

2.8.2 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 (Aryee, 2003).

2.8.3 Impact on Atmosphere

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 (Aryee, 2003). It is important to note that many small-scale miners have rejected the use of a protective apparatus.

2.9 HEAVY METALS

2.9.1 Mercury

Although small-scale gold-mining activity is responsible for triggering a number of often irreversible erosional and siltation processes, it is a known widely recognized fact that the most serious environmental problem in the industry is excessive mercury

pollution. Metallic mercury (Hg) has long been the preferred leach reagent for gold processing in developing countries.

However, gold prices have increased more than five-fold in the past three decades, which in turn has triggered several small-scale gold-mining rushes in a number of developing countries, and today, amalgamation is responsible for the production of >100 t gold annually (Lacerda and Marins, 1997).

It is now a well-known fact that mercury, in sufficient quantities, poses a serious threat to human health and is deleterious to a wide range of ecological entities. Once in the natural environment, mercury undergoes a change in speciation from an inorganic form to a stable methylated state (MeHg). Wolfe and Liston (1998) stated that, MeHg toxicity in mammals is primarily manifested as central nervous system damage. Since it is readily transferred across the placenta, and concentrates selectively in the foetal brain, acute exposure causes animals to initially become anorexic and lethargic, after which muscle ataxia, motor control deficits, and visual impairment develop, with convulsions preceeding death. Similarly, for birds, acute MeHg poisoning can lead to weight loss, progressive weakness in legs and wings (Lacerda and Salomons, 1998), and kidney disease. It is well known that MeHg has long proven to be a chemical threat to man, with a maximum permissible daily intake determined to be 0.2 mg [g.sup.-1] of blood; there are now well-documented examples from many countries, involving hundreds of people, of poisoning following exposure to MeHg. More recent study undertaken in the field (Fitzgerald *et al.*, 1998), however, confirm the reality of these impacts.

Poor mercury management practices are prevalent throughout the developing world, and recent research confirms that emissions from small-scale gold-mining regions have caused serious environmental problems. In the Brazilian Amazon, for example, where amalgamation has been widely practised since the late 1970s, small-scale gold-mining

operators (garimpeiros) release an estimated 77.9 t mercury into the atmosphere (accounting for over two-thirds of regional atmospheric emissions of mercury) each year (Lacerda and Marins, 1997). The studies undertaken to assess both the aquatic and health impacts of mercury emitted from resident operations have proven that vast portions of land surrounding many small-scale gold-mining regions now contain elevated levels of mercury contamination (Palheta and Taylor, 1995; Malm, 1998b;). Specifically, elevated levels of mercury -- i.e. concentrations exceeding the World Health Organization's limit of 50 mg have been observed in Brasilia Legal, Sao Luis, Tapajos and Madeira. In another example, Tanzania, small-scale gold-mining operations collectively released between 3 and 4 t Hg (van Straaten, 2000). A study by Ikingura and Akagi (1999), in which 25% of water samples obtained from the Lake Victoria goldfield had concentrations of mercury that exceeded the maximum permissible limits set by the World Health Organization, proves that uncontrolled mercury emissions were contaminating the local environment. Similar studies have been undertaken in Suriname, the Philippines and China (Hilson, 2002). Results from each analysis verify that mercury emissions from small-scale gold mines have persisted in the natural environment, and have had severe ecological and human health effects. The Environmental Protection Agency Ghana has set 0.005mg/l as the standard for Conventional Pollutants for the Mining Sector.

2.9.2 Arsenic

Environmental geochemistry research is concentrated on anthropogenic accumulations of potentially harmful elements (PHEs) such as As, Cd, Hg and Pb and other elements that may be classified as carcinogens, neurotoxins or irritants; some others may cause reproductive failure of birth defects. Occurrence of high As concentrations in drinking water is relatively rare, most case being associated with sources of natural sulphide minerals, such as pyrite and arsenopyrite. Hence, high As levels may be produced by

the disposal of associated mine wastes. The Arsenic concentrations in unpolluted fresh waters typically range from 1 to 10 $\mu\text{g l}^{-1}$ rising to 100-5000 $\mu\text{g l}^{-1}$ in areas of sulphide mineralization and mining. WHO (1996) recently reduced its recommended limit for As in drinking water from 50 to 10 $\mu\text{g l}^{-1}$ in response to evidence from toxicological studies.

Both mining processes and natural weathering of these materials release the elements of minerals into the liquid phase. There are two main processes that transform the elements from solid phase to aqueous species. Biological mediated oxidation of sulphide minerals produces acid and iron in solution. The abiotic actions may further dissolve the solids, due to low pH and oxidation-reduction reactions and under acidic conditions arsenic is co-dissolved with the major elements and transformed into an aqueous solution.

Nature of Arsenic

Arsenic appears in three allotropic forms: yellow, black and grey; the stable form is a silver-gray, brittle crystalline solid. It tarnishes rapidly in air, and at high temperatures burns forming a white cloud of arsenic trioxide. Arsenic is a member of group VA of the periodic table, which combines readily with many elements. The metallic form is brittle, tarnishes and when heated it rapidly oxidizes to arsenic trioxide, which has a garlic odour. The non-metallic form is less reactive but will dissolve when heated with strong oxidizing acids and alkalis. (Aryee, 2003)

Arsenic in the environment

Arsenic can be found naturally on earth in small concentrations. It occurs in soil and minerals and it may enter air, water and land through wind-blown dust and water runoff. Arsenic in the atmosphere comes from various sources: volcanoes release about

3000 tonnes per year and microorganisms release volatile methyl arsines to the extent of 20.000 tonnes per year. But human activity is responsible for much more: 80.000 tonnes of arsenic per year are released by the burning of fossil fuels. (Aryee, 2003).

Despite its notoriety as a deadly poison, arsenic is an essential trace element for some animals, and may be even for humans, although the necessary intake may be as low as 0.01 mg/day.

Arsenic is a component that is extremely hard to convert to water-soluble or volatile products. The fact that arsenic is naturally a fairly a mobile component, basically means that large concentrations are not likely to appear on one specific site. This is a good thing, but the negative side to it is that arsenic pollution becomes a wider issue because it easily spreads. Arsenic cannot be mobilized easily when it is immobile. Due to human activities, mainly through mining and smelting, naturally immobile arsenics have also mobilized and can now be found on many more places than where they existed naturally. (Ferguson, 1990).

Health effects of arsenic

Arsenic is one of the most toxic elements that can be found. Despite their toxic effect, inorganic arsenic bonds occur on earth naturally in small amounts. Humans may be exposed to arsenic through food, water and air. Exposure may also occur through skin contact with soil or water that contains arsenic. Levels of arsenic in food are fairly low, as it is not added due to its toxicity. But levels of arsenic in fish and seafood may be high, because fish absorb arsenic from the water they live in (Moore and Ramamoorthy, 2008).

Arsenic exposure may be higher for people that work with arsenic, for people that live in houses that contain conserved wood of any kind and for those who live on farmlands where arsenic-containing pesticides have been applied in the past.

Exposure to inorganic arsenic can cause various health effects, such as irritation of the stomach and intestines, decreased production of red and white blood cells, skin changes and lung irritation. It is suggested that the uptake of significant amounts of inorganic arsenic can intensify the chances of cancer development, especially the chances of development of skin cancer, lung cancer, liver cancer and lymphatic cancer (Aryee, 2003).

Health effects of arsenic in water.

Arsenic related illness is usually caused by consumption of contaminated drinking water. In the old days it was applied as a poison. Arsenic appears to be essential for some plant and animal species. A possible safe dose for humans was calculated. If arsenic is a dietary mineral, this dose would be 15-25 μg . This amount could be absorbed from food without any trouble. The total amount of arsenic in a human body is about 0.5-15 mg. Many arsenic compounds are absorbed 60-90%, but they are also easily excreted (Moore and Ramamoorthy, 2008). Humans can develop resistance to certain arsenic concentrations. Shortly after absorption arsenic can be found in liver, spleen, lungs and digestive tract. Most arsenic is excreted, and residues may be found in skin, hair, nails, legs and teeth. (Wang *et al.*, 2005). Under conditions of prolonged exposure, many organs may be damaged, skin pigmentation may occur, hair may fall out and nail growth may stop (Aryee, 2003).

Toxicity differs between various arsenic compounds, for example, monomethyl arsenic acid and inorganic arsenide have a higher toxicity level than arsenic choline. Acute toxicity is generally higher for inorganic arsenic compounds than for organic arsenic compounds. Oral intake of more than 100 mg is lethal. The lethal dose of arsenic trioxide is 10-180 mg, and for arsenide this is 70-210 mg. The mechanism of toxicity is binding and blocking sulphur enzymes. Symptoms of acute arsenic poisoning are

nausea, vomiting, diarrhoea, cyanosis, cardiac arrhythmia, confusion and hallucinations. Symptoms of chronic arsenic poisoning are less specific. These include depression, numbness, sleeping disorders and headaches. Arsenic related health effects are usually not acute, but mostly encompass cancer, mainly skin cancer. Arsenic may cause low birth weight and spontaneous abortion. (Wang *et al.*, 2005).

Environmental effects of arsenic

The arsenic cycle has broadened as a consequence of human interference and due to this, large amounts of arsenic end up in the environment and in living organisms. Arsenic is mainly emitted by the copper producing industries, but also during lead and zinc production and in agriculture. It cannot be destroyed once it has entered the environment, so that the amounts that we add can spread and cause health effects to humans and animals on many locations on earth.

Plants absorb arsenic fairly easily, so that high-ranking concentrations may be present in food. The concentrations of the dangerous inorganic arsenics that are currently present in surface waters enhance the chances of alteration of genetic materials of fish. This is mainly caused by accumulation of arsenic in the bodies of plant-eating freshwater organisms. Birds eat the fish that already contain eminent amounts of arsenic and will die as a result of arsenic poisoning as the fish is decomposed in their bodies (Damoah, 2007)

2.9.3 CADMIUM

Cadmium is a lustrous, silver-white, ductile, very malleable metal. Its surface has a bluish tinge and the metal is soft enough to be cut with a knife, but it tarnishes in air. It is soluble in acids but not in alkalis. It is similar in many respects to zinc but it forms more complex compounds (Wang *et al.*, 2005).

Cadmium in the environment.

Cadmium can mainly be found in the earth's crust. It always occurs in combination with zinc. Cadmium also exists in the industries as an inevitable by-product of zinc, lead and copper extraction. After being applied it enters the environment mainly through the ground, because it is found in manures and pesticides.

Naturally a very large amount of cadmium is released into the environment, about 25,000 tons a year. About half of this cadmium is released into rivers through weathering of rocks and some cadmium is released into air through forest fires and volcanoes. The rest of the cadmium is released through human activities, such as manufacturing. (Wang *et al.*, 2005). No cadmium ore is mined for the metal, because more than enough is produced as a by-product of the smelting of zinc from its ore, sphalerite (ZnS), in which CdS is a significant impurity, making up as much as 3%. Consequently, the main mining areas are those associated with zinc. World production is around 14,000 tonnes per year; the main producing country is Canada, with the USA, Australia, Mexico, Japan and Peru also being the major suppliers.

Health effects of cadmium

Human uptake of cadmium takes place mainly through food. Foodstuffs that are rich in cadmium can greatly increase the cadmium concentration in human bodies. Examples are liver, mushrooms, shellfish, mussels, cocoa powder and dried seaweed. An exposure to significantly higher cadmium levels occurs when people smoke. Tobacco smoke transports cadmium into the lungs. Blood will transport it through the rest of the body where it can increase effects by potentiating cadmium that is already present from cadmium-rich food (Wang *et al.*, 2005).

Other high exposures can occur with people who live near hazardous waste sites or

factories that release cadmium into the air and people that work in the metal refinery industry. When people breathe in cadmium it can severely damage the lungs. This may even cause death (Moore and Ramamoorthy, 2008). Cadmium is first transported to the liver through the blood. There, it is bond to proteins to form complexes that are transported to the kidneys. Cadmium accumulates in kidneys, where it damages filtering mechanisms. This causes the excretion of essential proteins and sugars from the body and further kidney damage. It takes a very long time before cadmium that has accumulated in kidneys is excreted from a human body (Wang *et al.*, 2007).

Other health effects that can be caused by cadmium are:

- Diarrhoea, stomach pains and severe vomiting
- Bone fracture
- Reproductive failure and possibly even infertility
- Damage to the central nervous system
- Damage to the immune system
- Psychological disorders
- Possibly DNA damage or cancer development (Wang *et al.*, 2007).

Cadmium waste streams from the industries mainly end up in soils. The causes of these waste streams are for instance zinc production, phosphate ore implication and bio industrial manure. Cadmium waste streams may also enter the air through (household) waste combustion and burning of fossil fuels. Because of regulations only little cadmium now enters the water through disposal of wastewater from households or industries? (Moore and Ramamoorthy, 2008). Another important source of cadmium emission is the production of artificial phosphate fertilizers. Part of the cadmium ends up in the soil after the fertilizer is applied on farmland and the rest of the cadmium ends up in surface waters when waste from fertilizer productions is dumped by production companies.

Cadmium can be transported over great distances when it is absorbed by sludge. This cadmium-rich sludge can pollute surface waters as well as soils. (Moore and Ramamoorthy, 2008). Cadmium strongly adsorbs to organic matter in soils. When cadmium is present in soils it can be extremely dangerous, as the uptake through food will increase. Soils that are acidified enhance the cadmium uptake by plants. This is a potential danger to the animals that are dependent upon the plants for survival. Cadmium can accumulate in their bodies, especially when they eat multiple plants. Cows may have large amounts of cadmium in their kidneys due to this (Wang *et al.*, 2005).

Environmental effects of cadmium

Earthworms and other essential soil organisms are extremely susceptible to cadmium poisoning. They can die at very low concentrations and this has consequences for the soil structure. When cadmium concentrations in soils are high they can influence soil processes of microorganisms and threaten the whole soil ecosystem.

In aquatic ecosystems cadmium can bioaccumulate in mussels, oysters, shrimps, lobsters and fishes. The susceptibility to cadmium can vary greatly between aquatic organisms. Salt-water organisms are known to be more resistant to cadmium poisoning than freshwater organisms. Animals eating or drinking cadmium sometimes get high blood-pressures, liver disease and nerve or brain damage (Moore and Ramamoorthy, 2008).

2.9.4 COPPER

Copper is a reddish metal with a face-centered cubic crystalline structure. It reflects red and orange light and absorbs other frequencies in the visible spectrum, due to its band structure, so it has a nice reddish colour. It is malleable, ductile, and an extremely good conductor of both heat and electricity. It is softer than iron but harder than zinc

and can be polished to a bright finish. It is found in group Ib of the periodic table, together with silver and gold. Copper has low chemical reactivity. In moist air it slowly forms a greenish surface film called patina; this coating protects the metal from further attack. (Damoah, 2007)

Copper in the environment

Copper is a very common substance that occurs naturally in the environment and spreads through the environment through natural phenomena. Humans widely use copper. For instance it is applied in the industries and in agriculture. The production of copper has lifted over the last decades and due to this copper quantities in the environment have expanded (Wang *et al.*, 2005).

The world's copper production is still rising. This basically means that more and more copper ends up in the environment. Rivers are depositing sludge on their banks that is contaminated with copper, due to the disposal of copper-containing wastewater. Copper enters the air, mainly through release during the combustion of fossil fuels. Copper in air will remain there for an eminent period of time, before it settles when it starts to rain. It will then end up mainly in soils. As a result soils may also contain large quantities of copper after copper from the air has settled (Moore and Ramamoorthy, 2008). 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. (Damoah, 2007)

World production of copper amounts to 12 million tonnes a year and exploitable reserves are around 300 million tonnes, which are expected to last for only another 25 years. About 2 million tonnes a year are reclaimed by recycling. Today copper is mined as major deposits in Chile, Indonesia, USA, Australia and Canada, which together account for around 80% of the world's copper. The main ore is a yellow copper-iron sulphide called chalcopyrite (CuFeS_2).

Health effects of copper

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 (Moore and Ramamoorthy, 2008).

Intentionally high uptakes of copper may cause liver and kidney damage and even death. Whether copper is carcinogenic has not been determined yet. 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 (Damoah, 2007).

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, characterized by a hepatic cirrhosis, brain damage, demyelination, renal disease, and copper deposition in the cornea (Jonnalagadda and Mhere, 2001).

Environmental Effects of Copper

When copper ends up in soil it strongly attaches to organic matter and minerals. As a result it does not travel very far after release and it hardly ever enters groundwater. In surface water copper can travel great distances, either suspended on sludge particles or as free ions. Copper does not break down in the environment and because of that it can accumulate in plants and animals when it is found in soils. On copper-rich soils only a limited number of plants have a chance of survival. That is why there is not much plant diversity near copper-disposing factories. Due to the effects upon plants copper is a serious threat to the productions of farmlands. Copper can seriously influence the proceedings of certain farmlands, depending upon the acidity of the soil and the presence of organic matter (Jonnalagadda and Mhere, 2001).

Copper can interrupt the activity in soils, as it negatively influences the activity of microorganisms and earthworms. The decomposition of organic matter may seriously slow down because of this. When the soils of farmland are polluted with copper, animals will absorb concentrations that are damaging to their health. Mainly sheep suffer a great deal from copper poisoning, because the effects of copper are manifesting at fairly low concentrations ((Moore and Ramamoorthy, 2008).

2.9.5 LEAD

Lead is a soft, silvery grey metal, melting at 327.5 degree C. The usual valence state in inorganic lead compounds is +2. The level of lead in the earth's crust is about 20 mg/kg. Lead in the environment may derive from either natural or anthropogenic sources. Lead and its compounds may enter the environment at any point during mining, smelting, processing, use, recycling or disposal. Major uses are in batteries, cables, pigments, petrol (gasoline) additives, solder and steel products. The EPA

guideline for lead is 0.1mg/L. Also according to Momodu and Anyakora (2010), WHO permissible level is 0.1mg/l

Health Effects of Lead

In the general non-smoking adult population, the major exposure pathway is from food and water. Airborne lead may contribute significantly to exposure. For infants and children, lead in dust and soil often constitutes a major exposure pathway. Lead is absorbed in humans and animals following inhalation or ingestion; percutaneous absorption is minimal in humans. Depending upon chemical speciation, particle size, and solubility in body fluids, up to 50% of the inhaled lead compound may be absorbed. (Jonnalagadda and Mhere, 2001).

The effects of lead on the hemopoietic system result in decreased hemoglobin synthesis, and anemia has been observed in children at PbB concentrations above 1.92 umol/L (40 ug/dL). For neurological, metabolic and behavioral reasons, children are more vulnerable to the effects of lead than adults. Both prospective and cross-sectional epidemiological studies have been conducted to assess the extent to which environmental lead exposure affects CNS-based psychological functions. Lead has been shown to be associated with impaired neurobehavioral functioning in children. Impairment of psychological and neurobehavioral functions has been found after long-term lead exposure of workers. Electrophysiological parameters have been shown to be useful indicators of subclinical lead (Jonnalagadda and Mhere, 2001).

2.10 PHYSICOCHEMICAL PARAMETERS

All freshwater bodies are interconnected to the oceans, the atmosphere, and aquifers via a complex hydrological cycle. Wetlands, icecaps and biopheric 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. 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 (Bellingham, 2008).

2.10.1 pH

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 CO_2 that will dissolve and equilibrate with the water forming carbonic acid (H_2CO_3). Other organic acids such as humic and fluvic acid can also result from organic decomposition (Bellingham, 2008).

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 aluminium 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 $[\text{OH}^-]$. 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, livestock, drinking water sources, industrial discharges, intakes, and storm water runoff. (Schwarzenbach, *et al.*, 2003).

2.10.2 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 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 10 mg/l. (Bellingham, 2008)

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 2 mg/l will kill fish. Insitu 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.

2.10.3 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. (Bellingham, 2008). 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. At about 0.3 S/m is the point as which the health of some crops and fresh water aquatic organisms will to be affected by the salinity.

Field measurements of EC reflect the amount of total dissolved solids (TDS) in natural waters. The relationship between TDS and EC can be described by the equation;

$$\text{TDS (mg/L)} \approx \text{EC (mS/cm)} \times 640.$$

Salinity refers to the presence of dissolved inorganic ions such as Mg^{++} , Ca^{++} , K^+ , Na^+ , Cl^- , SO_4^{4-} , HCO_3^- and CO_3^{2-} 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 (Schwarzenbach, *et al.*, 2003).

2.10.4 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. (Bellingham, 2008).

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 45 μm 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 mater. 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.

2.10.5 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).

2.10.6 Salinity

Salinity is measured for maintenance of saltwater aquariums, to determine the suitability of water for drinking and for ecological monitoring of aquatic habitats. Salt concentration can be directly measured by evaporating a water sample and measuring the dried salts left behind (total dissolved solids, or TDS). More practical methods for estimating water salinity have been developed based on the relationships between the concentration of salt ions and electrical conductivity, density and refractive index. (Bellingham, 2008).

Water is defined as freshwater when its salt concentration is less than 1,000 parts per million (ppm). This is also the general limit for drinking water, although drinking water should be less than 600 ppm for palatability. Seawater's salt concentration is about 35,000 ppm. (WHO, 2008).

Salt water becomes more saline when water evaporates and leaves salts behind. Saline lakes and ponds, including solar salt evaporation ponds used for the commercial production of salt, can reach salinity levels up to the point of saturation (about 264,000 ppm, depending on temperature). (Schwarzenbach, *et al.*, 2003).

2.11 WATER QUALITY

2.11.1 Definitions Related to Water Quality

In view of the complexity of factors determining water quality, and the large choice of variables used to describe the status of water bodies in quantitative terms, it is difficult to provide a simple definition of water quality. Furthermore, our understanding of water quality has evolved over the past century with the expansion of water use requirements and the ability to measure and interpret water characteristics.

For the purposes of this work the following definitions have been adopted:

Table 1 Quality of the aquatic body, defined by GESAMP (2002)

TERM	DEFINITION
Quality of the aquatic environment	<p>Set of concentrations, speciation and physical partitions of inorganic or organic substances</p> <p>Composition and state of aquatic biota in the water body.</p> <p>Description of temporal and spatial variation due to factors internal and external to the water body.</p>
Pollution of the aquatic environment	<p>Introduction by man directly or indirectly of substances or energy which results in such deleterious effects as;</p> <p>Harm to living resources.</p> <p>Hazards to human health.</p> <p>Hindrance to aquatic activities including fishing.</p> <p>Impairment of water quality with respect to its use in agriculture, industrial and economic activities.</p>



CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The study was conducted on River Ashire which runs through the Wassa Amenfi East District in the western region of Ghana. The study focused on the following communities; Nsuopon, Abesewa Gyaman, Ashireso and Wassa Akropong which were all located along River Ashire where small scale mining activities are intense. The Wassa Amenfi East District was established in 2004 by LI, 1788 with Wassa Akropong as its District capital. The district has a land size of 1600sqkm with a population of 155,092, a growth rate of 2.9% and about 150 communities (Ghana Statistical Service, 2002). It is bounded on the North by upper Denkyira East, East by Prestea Huni- Valley, West by both Upper Denkyira West and Wassa Amenfi West and South by Prestea Huni Valley District.

3.1.1 Climate

The Wassa Amenfi East District lies within the south western equatorial zone and has an average temperature ranging from 24°C in August to about 30°C in March. Relative humidity is between 70-80 per cent in the dry season and 75-80 per cent in the wet season. The district records a very high rainfall of between 140mm and 173mm during the rainy season of between May and July with the peak in June.

3.1.2 Economic Activities

Agriculture is the main economic activity in the district employing about 80% of the active labour force. Cash crops mostly grown are cocoa, oil palm and coffee with

cassava, plantain, cocoyam, maize, rice as major food crops and garden eggs, tomatoes and pepper are the major vegetables.

3.1.3 Geology

The topography of the area is generally undulating.

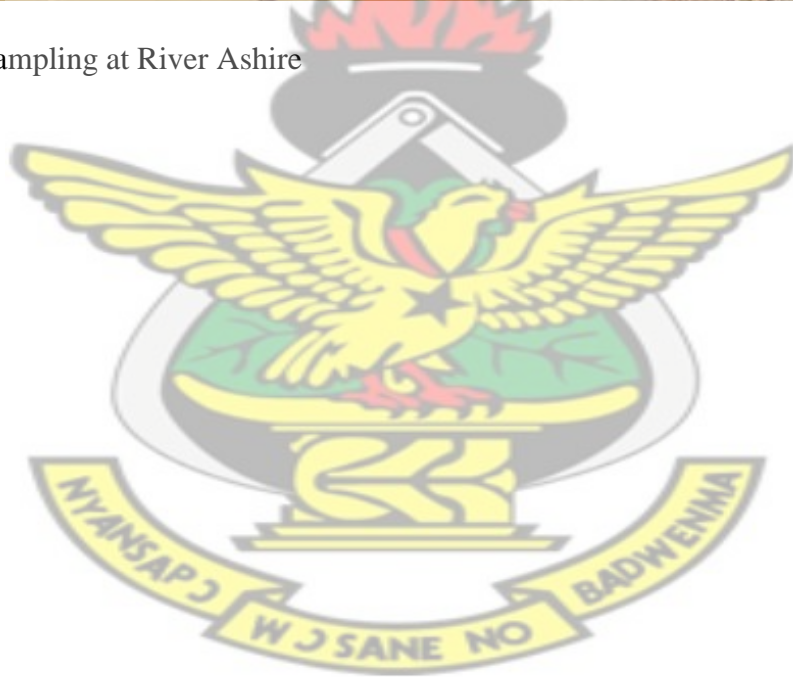
There are three main geological soil formations identified in the district. These are the Upper Birimian, Lower Birimian and Granites. The granite deposits in the district make most part of it rich in minerals like gold. This has given rise to a number of small scale mining activities in the district. Although they offer employment potential for the youth, their mode of operations pose environmental as well as health challenges to the people.

3.2 SAMPLE COLLECTION

Surface water samples were collected from seven sampling points located along the River Ashire (Fig1 & Plate 1). The seven sampling points were located three kilometres from each other except for the seventh point which was at a point closer to the source of the river. At each sample point, samples were collected using sterilised 1.5 L plastic bottles. Representative water samples were collected from mid-stream by orienting the sample bottle against the direction of flow of the river. The samples were kept in an ice chest under ice packs at a temperature of 4°C. All water samples collected from the river were sent to the Environmental Laboratory of Golden Star Resources (Bogoso/Prestea) and Ghana Atomic Energy Commission at Kwabenya.



Plate 1. Water Sampling at River Ashire



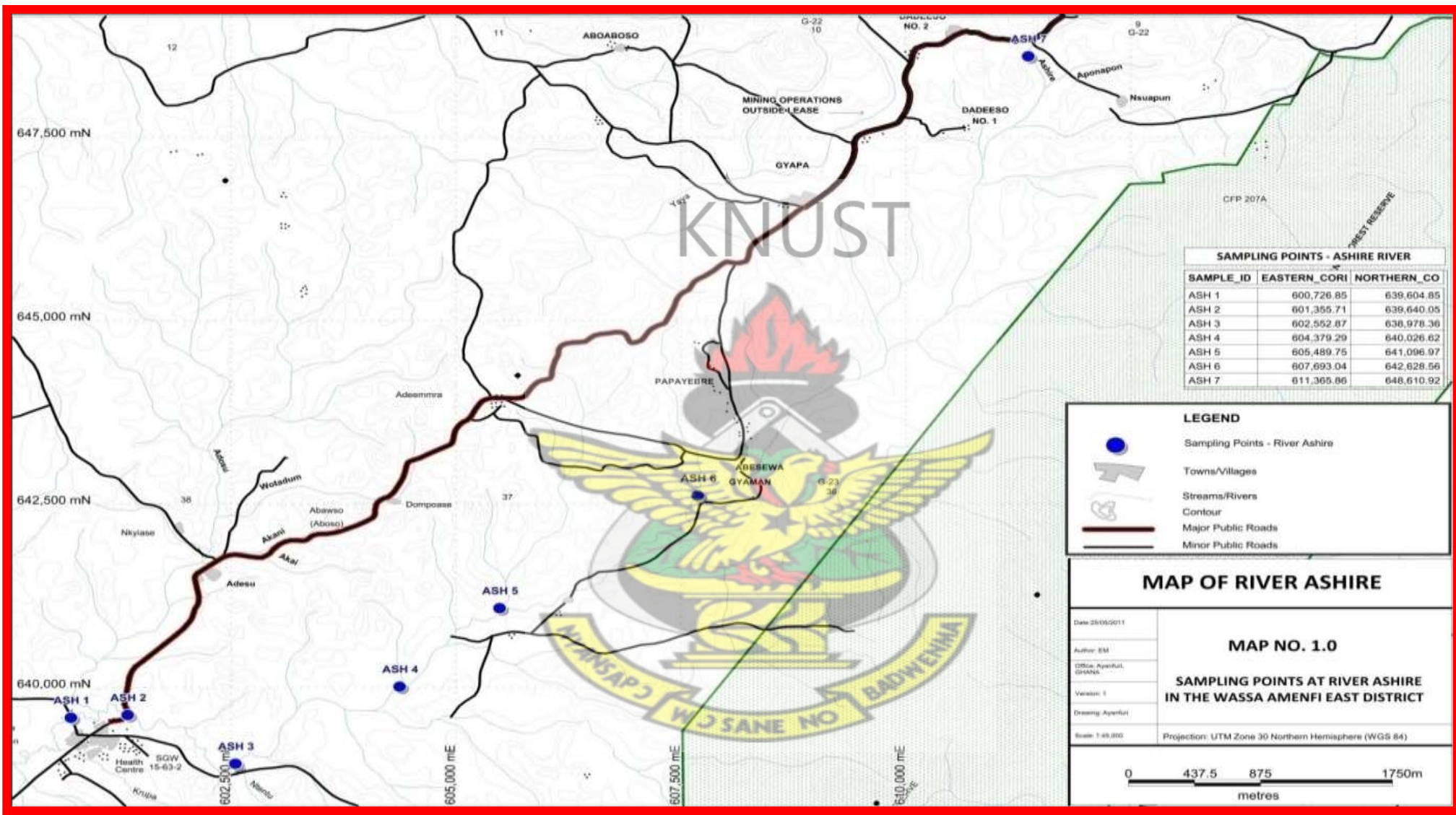


Figure 1 Map of River Ashire with sampling points shown in BLUE



Plate 2. Chanfan' Machine used in milling the Ore.

3.3 LABORATORY AND ON-SITE ANALYSIS

3.3.1 Physical Parameters

At each sample location, the physical parameters of the water sample was analysed using the Horiba pH Multi-parameter. The parameters determined were pH, Conductivity, Dissolved Oxygen, Turbidity, Total Dissolved Solids and Salinity. The equipment was calibrated before using it for analysis.

A representative water sample was fetched into a clean plastic bucket and the Horiba probe was gently placed into the sample in the bucket. Readings on the meter were allowed to stabilize and then recorded into a field note book.

TSS Analysis

Total suspended solid (TSS) was determined by gravimetric method. A known volume of each sample was filtered through a pre-weighed 0.45 μ Whatman filter paper using vacuum pump. After filtration, the filter paper was gently removed and dried in an oven at a temperature of 103°C for thirty minutes to expel the water. The filter was allowed to cool and then weighed and recorded (Grey *et al.*, 2000).

The TSS was calculated using the following formula;

$$\text{TSS is calculated as} = \frac{\text{Final Weight of filter} - \text{Initial Weight (mg)}}{\text{Volume of water filtered (L)}}$$

3.3.2 Heavy Metals

Heavy metals Copper, Lead, Arsenic, Cadmium and Mercury were determined using the Atomic Absorption Spectrometer. The analysis was conducted at the Environmental Laboratory of Golden Star Resources (Bogoso/Prestea) and Environmental Laboratory of the Ghana Atomic Energy Commission. The samples for AAS were digested with nitric acid before analysis.

Digestion Procedure

The water samples were digested by filtering 100ml through a 0.45 μ filter paper and transferred into a volumetric flask. One millilitre of concentrated nitric acid (HNO₃) was added to the filtered sample in the flask. The content was heated on a hot block at a temperature of 95°C for 2 hours and allowed to cool after 2 hours. The flask was top with double distilled water to the 100 ml mark for heavy metal analysis (Maiz *et al.*, 2000).

Atomic Absorption Spectrometry

The Atomic Absorption Spectroscopy (AAS) (Plate 3) works on the principle of absorbance versus concentration. Appropriate hollow cathode lamps were fitted into the AAS and optimised at the required wavelength for at least 15 minutes. A blank prepared from distilled water as well as the standard reference solutions for the individual metals were used to calibrate the instrument. Once the required calibration was achieved, the digested samples were sprayed into the spraying chamber through a capillary tube to determine the concentration of the sample (Figure 2 and Plate 3).

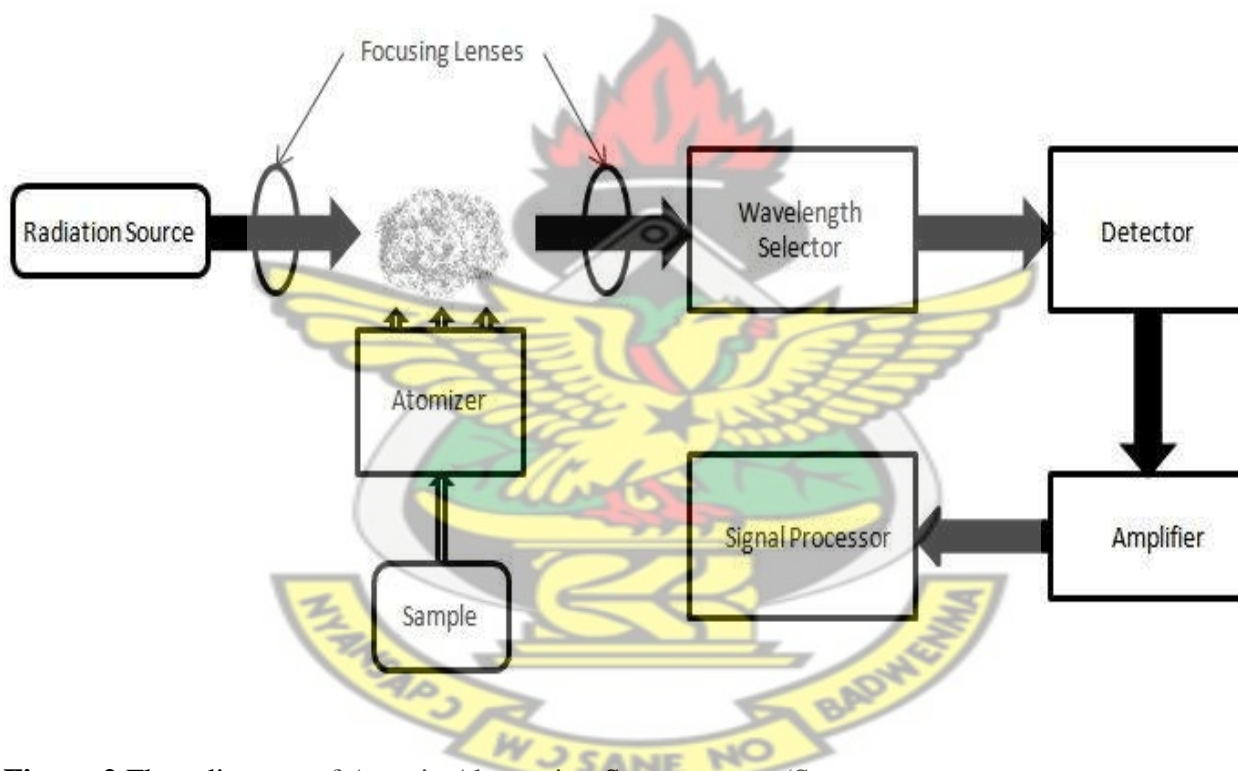


Figure 2 Flow diagram of Atomic Absorption Spectrometer (Source: wikimedia.org/wiki/File:aasblock.jpg)



Plate 3. A modern Atomic Absorption Spectrometer.



CHAPTER FOUR

4.0 RESULTS

4.1 Physical Observations

The following were observed at some of the sampling sites along the river during the three sampling periods;

- ❖ Even though water is colourless, the river was brownish in colour from ASH 006 downwards.
- ❖ The vegetation around the river was dense and Bamboo was the dominant plant

The vegetation around the ASH 006 and 007 sites were secondary forest.

- ❖ The flow of the river was slow during the dry and mid-seasons.
- ❖ The flow rate of the river was quite high during the rainy season.
- ❖ There were heaps of sand and gravels at most of the sampling sites which indicate the washing of gold ore.
- ❖ There were 'chanfan' machines on site. This is the machine that is used for illegal gold mining "Galamsey" activities (Plate 2).
- ❖ Sand and gravel winning activities was also a common practise

4.2 Informal Interviews

A total of thirty (30) inhabitants were informally interviewed on the many uses of the stream water within the various households although it is perceived to be contaminated. Respondents' answers were as follows; Drinking (13%), irrigation (13%), bathing and washing (47%) and cooking (27%).

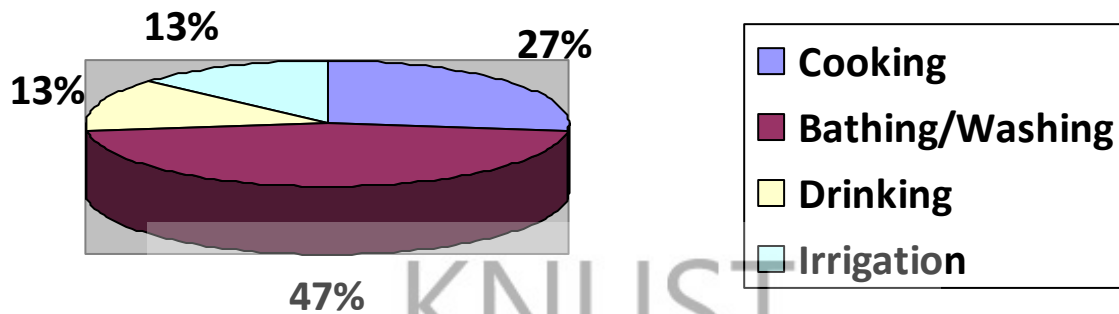
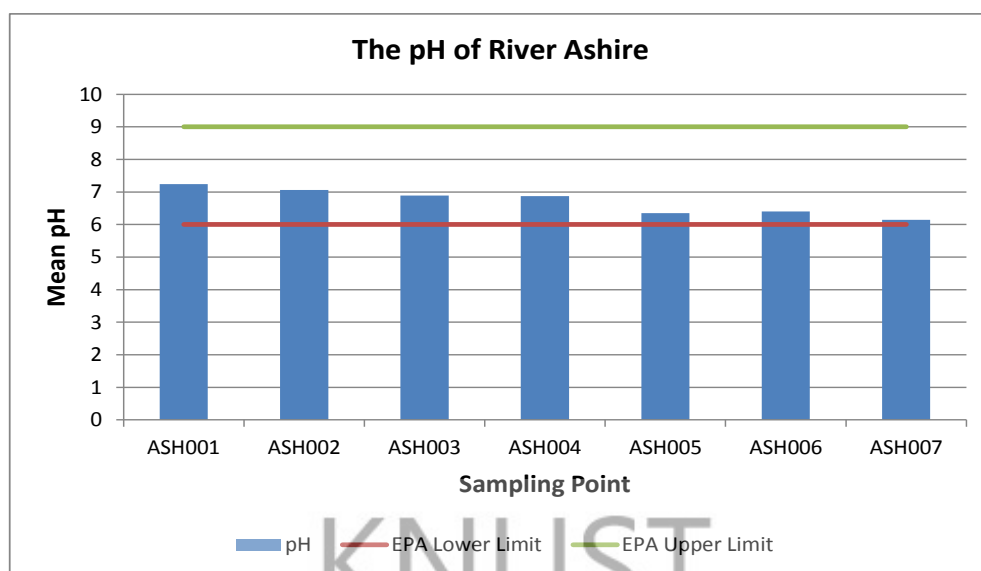


Figure 3 Various uses of River Ashire by Communities.

4.3 QUALITY OF RIVER ASHIRE

4.3.1 Physicochemical

Upstream pH values were slightly acidic and ranged between pH of 6.09-6.53 whereas the downstream was basic ranging between 6.69-7.91. pH at both upstream and downstream points was within the Ghana EPA Standard for drinking water.

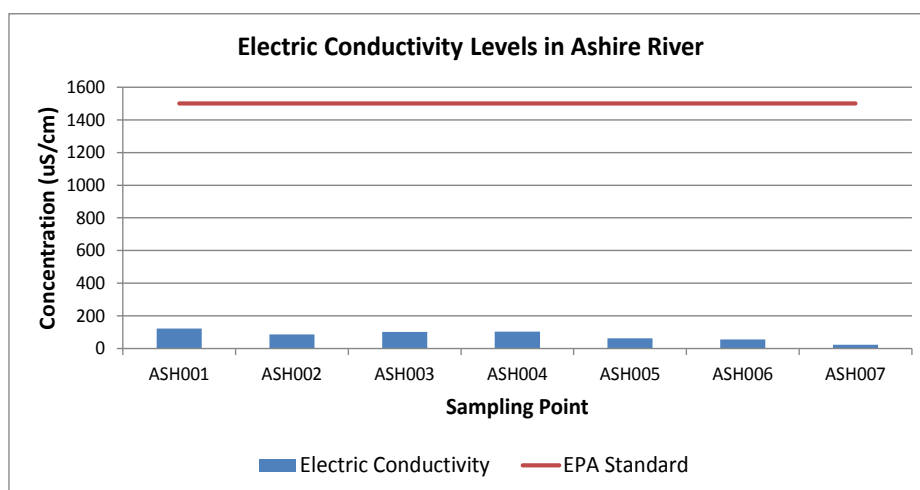


Upstream: Ash 005-007; Downstream: ASH 001-004

Figure 4 pH values at the various sampling sites in relation to EPA recommended standard.

Mean conductivity for upstream and downstream was 50.00 $\mu\text{S}/\text{cm}$ and 103.58 $\mu\text{S}/\text{cm}$, respectively and were all within the Ghana EPA Standard for drinking water.

Generally, very low conductivity levels were observed for all the samples when compared with the EPA and WHO guidelines limit of 1500 $\mu\text{S}/\text{cm}$ for drinking water.

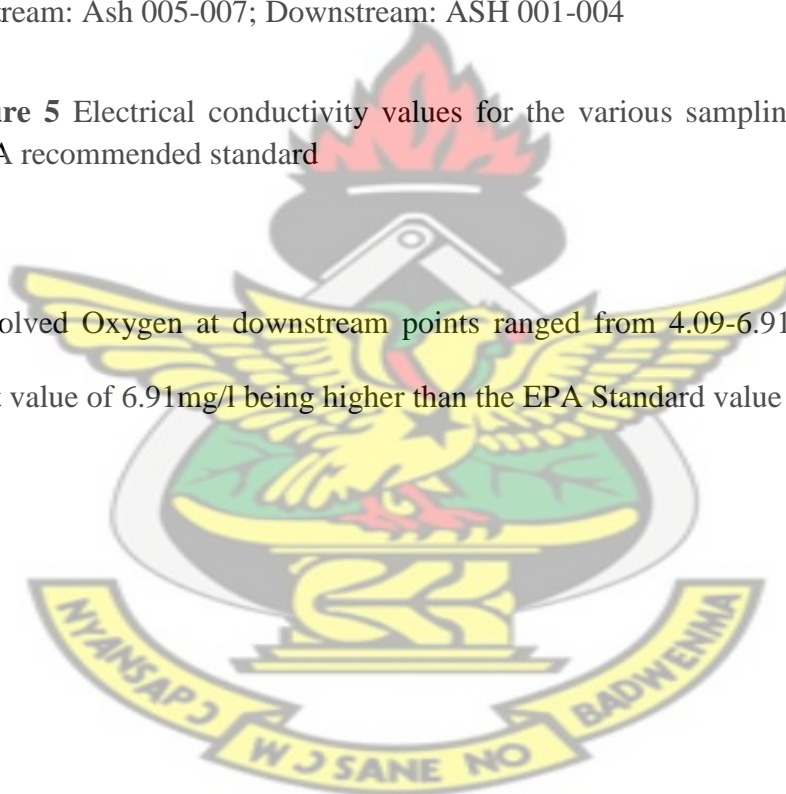


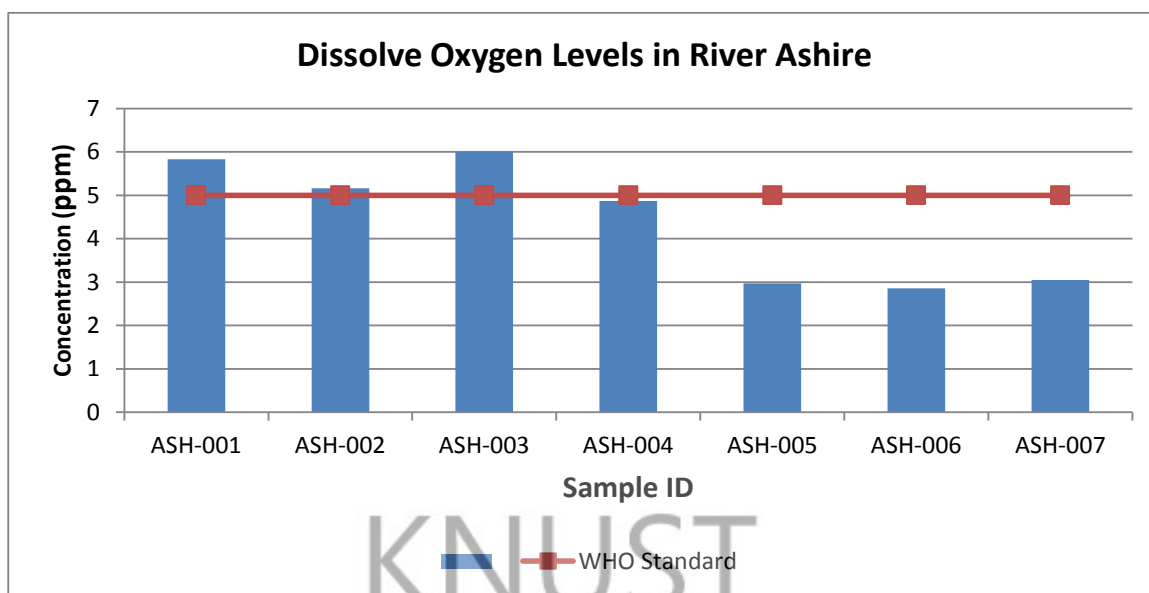
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Upstream: Ash 005-007; Downstream: ASH 001-004

Figure 5 Electrical conductivity values for the various sampling sites in relation to EPA recommended standard

Dissolved Oxygen at downstream points ranged from 4.09-6.91mg/l with the upper limit value of 6.91mg/l being higher than the EPA Standard value of 5.00mg/l.





Upstream: Ash 005-007; Downstream: ASH 001-004

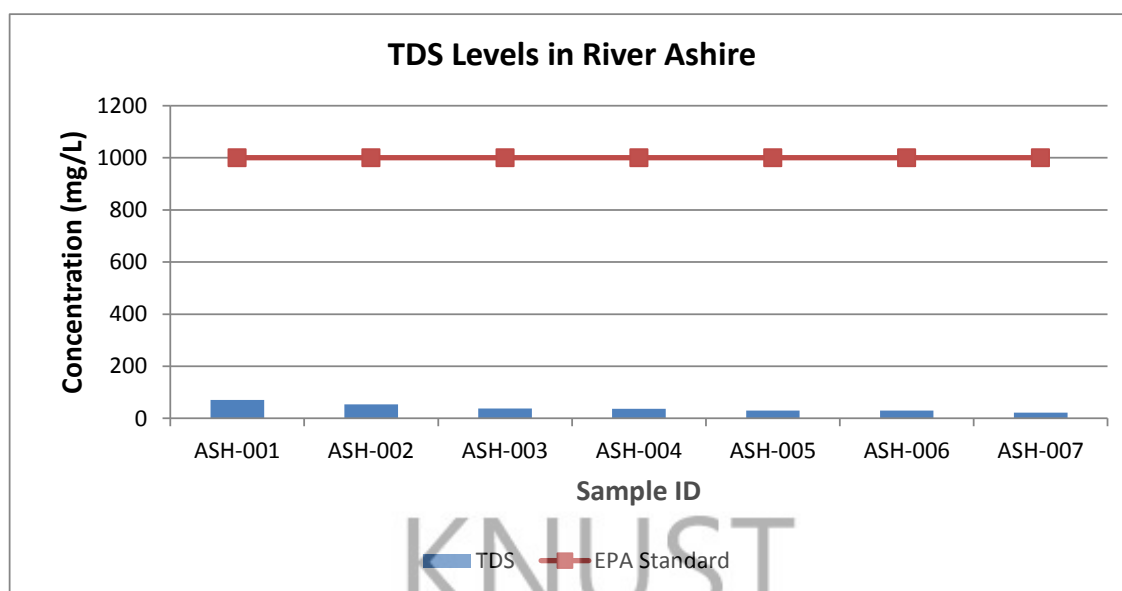
Figure 6 Dissolved Oxygen values for the various sampling sites in relation to EPA recommended standard

Mean salinity levels in River Ashire for both upstream and downstream ranged from 0.026 – 0.113 ppm (Table 2).

Table 2 Levels of salinity in the Ashire River for the various sampling sites in relation to World Health Organisation Guidelines for drinking water.

Sample ID	Upstream Mean Value	Range	Downstream Mean Value	Range	P Value	WHO Standard
Salinity (ppm)	0.026	0.02-1.00	0.113	0.02-0.23	0.173	600

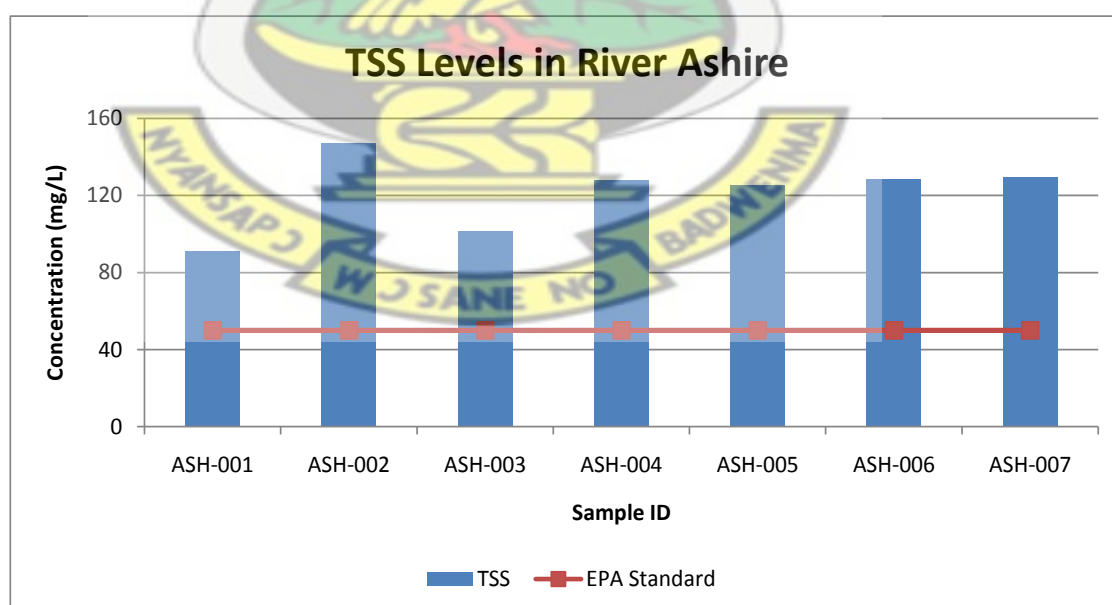
Total dissolved solids (TDS) were far below the EPA guideline value of 1000 mg/L. Mean TDS values for both upstream and downstream ranged from 30.50-49.83mg/l.



Upstream: Ash 005-007; Downstream: ASH 001-004

Figure 7 Total Dissolved Solids values for the various sampling sites in relation to EPA recommended standard

Total Suspended Solids (TSS) levels in Ashire River ranged from 122.00 – 134.00 mg/L for upstream and 85.00-191.00mg/l for downstream.



Upstream: Ash 005-007; Downstream: ASH 001-004

Figure 8 Total Suspended Solids values for the various sampling sites in relation to EPA recommended standard.

Turbidity values range from 172.00-513.00NTU for both upstream and downstream. The relatively low turbidity levels were observed upstream compared with that of downstream and was far above the recommended EPA limit.

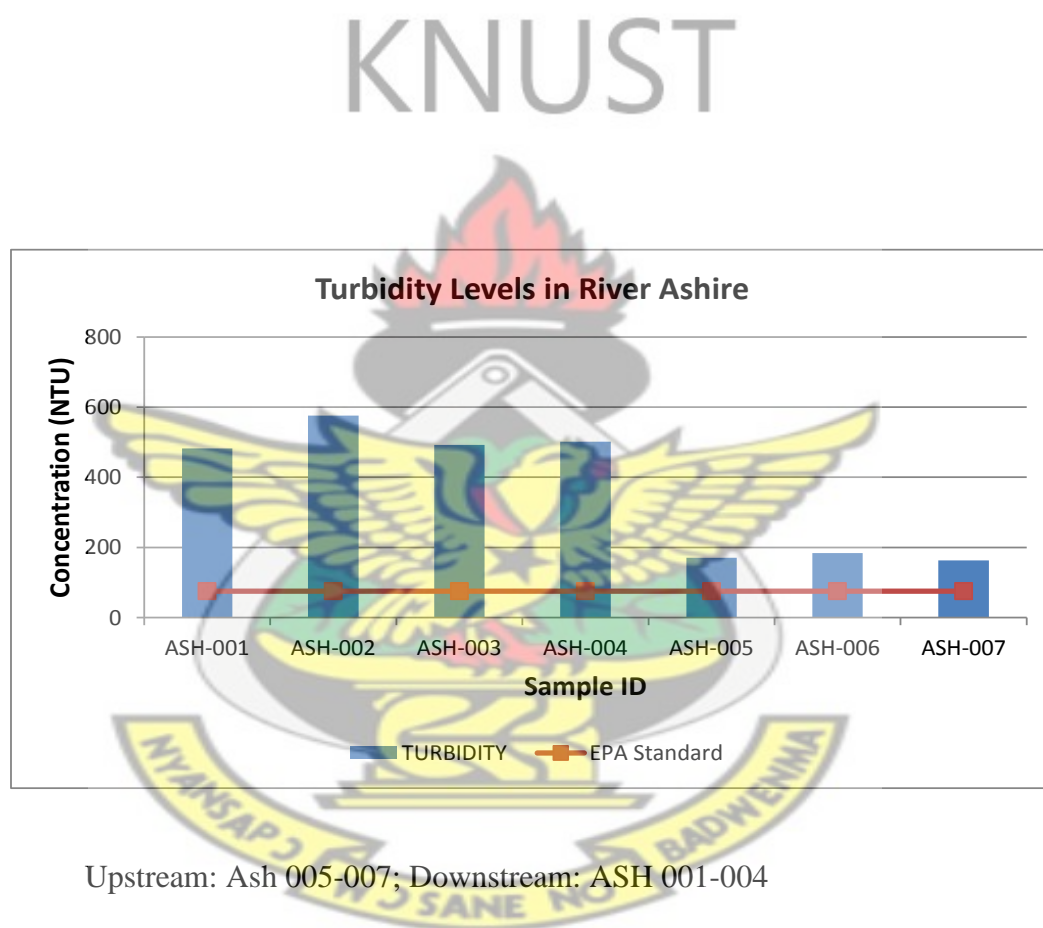


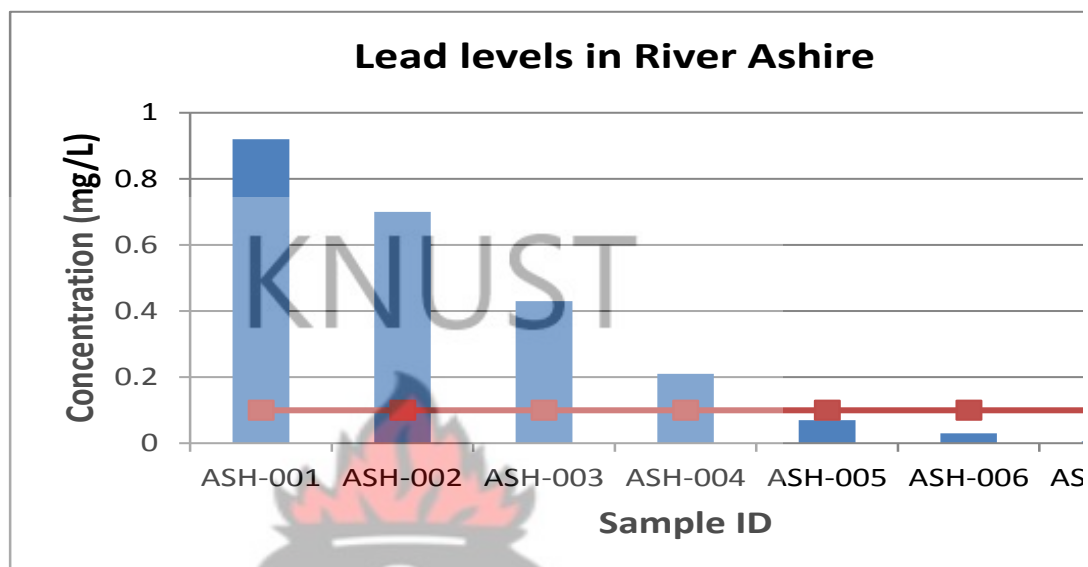
Figure 9 Turbidity values for the various sampling sites in relation to EPA recommended standard.

4.3.2 Heavy Metals

Mean lead values ranged from 0.035-0.564mg/l for upstream and downstream.

Lead values were higher (0.186-0.987mg/l) for downstream points compared to

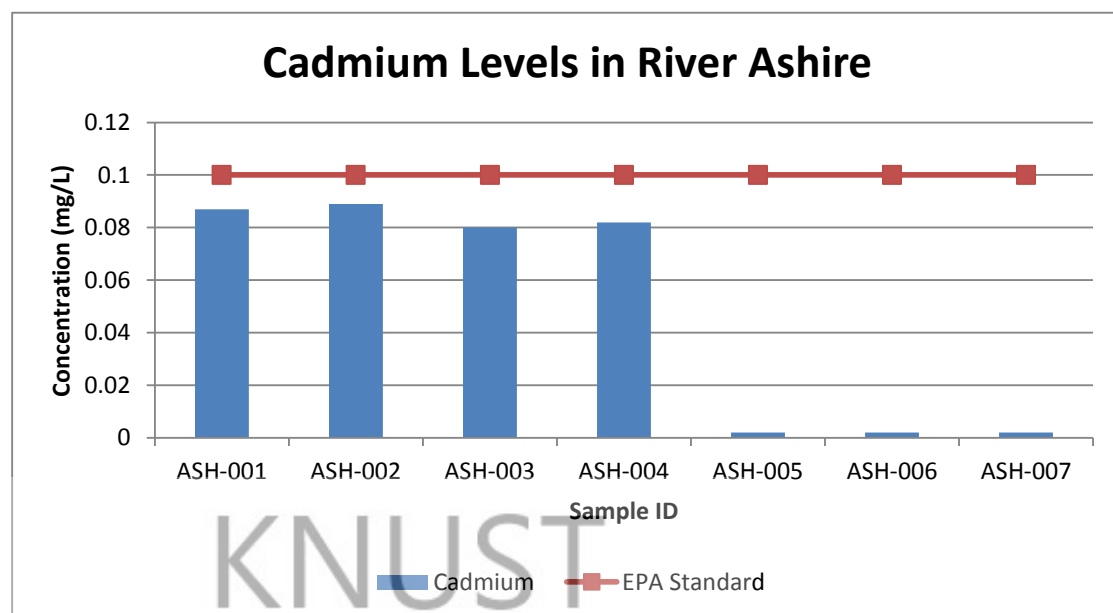
the upstream (0.001-0.165 mg/l) points. All concentrations of Lead recorded downstream were above the EPA guideline.



Upstream: Ash 005-007; Downstream: ASH 001-004

Figure 10 Lead values for the various sampling sites in relation to EPA recommended.

Cadmium concentrations were low and ranged from 0.002 mg/L – 0.085 mg/L. EPA guideline for dissolved cadmium is 0.1mg/L.



Upstream: Ash 005-007; Downstream: ASH 001-004

Figure 11 Cadmium values for the various sampling sites in relation to EPA recommended

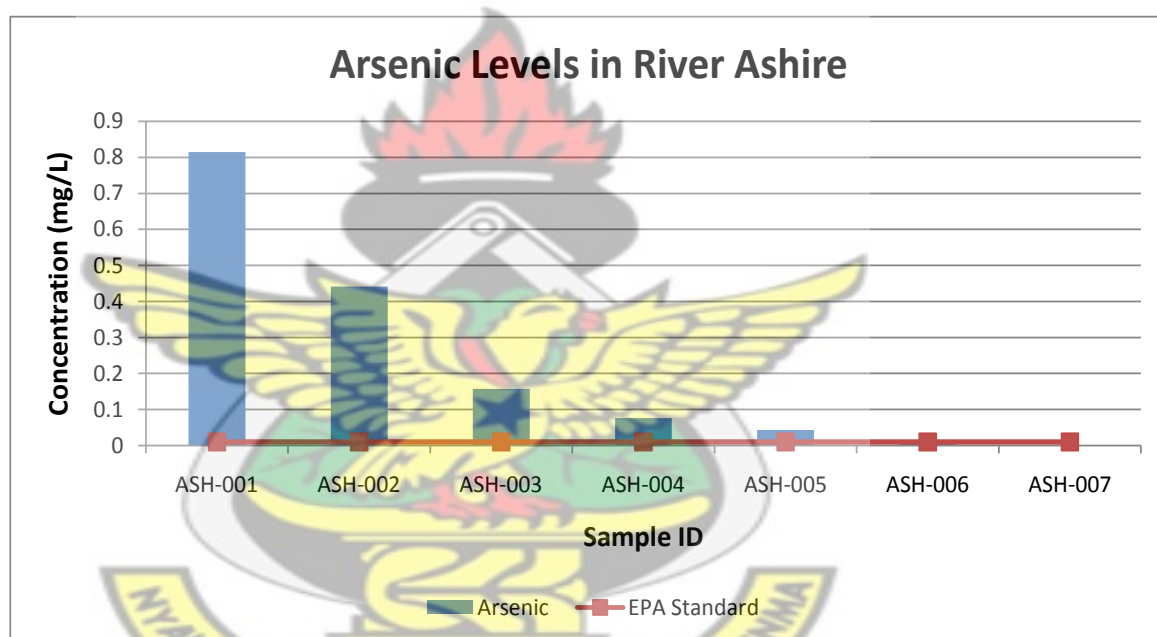
Mercury concentrations ranged from 0.001-0.030 mg/l and 0.100-0.986mg/l for upstream and downstream respectively.

Mean copper concentrations ranged from 0.001 mg/L – 0.004 mg/L for both upstream and downstream (Table 3) and were below the 5 mg/L water quality standard for copper set by EPA.

Table 3 Mercury and Copper values for the various sampling sites in relation to EPA recommended standard.

Sample ID	Upstream Mean Value	Range	Downstream Mean Value	Range	P Value	EPA Standard
Mercury (Mg/l)	0.0099	0.001-0.030	0.6922	0.100-0.986	0.000	0.005
Copper(Mg/l)	0.001	0.001-0.003	0.004	0.001-0.009	0.003	5.00

Dissolved arsenic concentrations ranged from 0.001 mg/L – 0.052 mg/L with the mean concentration of 0.019-0.372 mg/L. The concentrations were slightly high at some of the sampling points upstream while the concentration was high along all the sampling points downstream.



Upstream: Ash 005-007; Downstream: ASH 001-004

Figure 12 Arsenic values for the various sampling sites in relation to EPA recommended

CHAPTER FIVE

5.0 DISCUSSION

This study shows that the River Ashire, the only source of drinking water for the inhabitants is being adversely polluted by the activities of the illegal small scale miners “Galamsey” operators. As a result of this, River Ashire is slightly acidic. Downstream the river, mean conductivity is high 513 NTU which can be attributed to anthropogenic activities including illegal mining along the River Ashire resulting in high amount of ions or dissolved solids in the river. The mean salinity levels in River Ashire for both upstream and downstream ranged from 0.026 – 0.113 ppm. The low salinity level 0.026 ppm observed upstream is typical of surface waters due to the introduction of Ca^{2+} or Mg^{2+} from the rocks as the water flows pass them. However, the increased levels of 0.113 ppm recorded downstream may be attributed to the illegal mining and farming along the river course as this enhances weathering of rocks and increase Ca^{2+} and Mg^{2+} ions. Additionally, land use issues, the clearing of vegetation and the resultant rise in the water table, excessive irrigation, groundwater seepage and runoff containing salts, fertilizers, organic matter and dissolved solids from agriculture may contribute to the salinity of the river (McCaffrey, 2010).

Organic matter or oxidisable minerals present in some aquifers rapidly deplete the dissolved oxygen (Chapman, 1996). Mean DO levels ranged from 2.95-5.46 mg/l for upstream and downstream respectively. 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, 1999).

The study further showed that the upstream points recorded lower values of 2.46-3.60mg/l which indicated that the upstream is more polluted than downstream which was not the real situation on the ground. According to McCaffrey (2010), oxygen enters water as a result of diffusion of oxygen into the water which is accelerated when the water turbulence is increased (moving through rapids and waterfalls) and when there is a strong wind blowing. Additionally, oxygen will diffuse into cold water at a higher rate than it will into warm water. River Ashire experiences some turbulence upstream and also flows through secondary forest which could reduce the temperature of the river to increase the oxygen level of the river.

Total dissolved solids recorded for all the samples were far below EPA guideline value of 500 mg/L. Like electrical conductivity, the highest mean TDS value of 49.83 mg/L was recorded downstream whereas the lowest TDS value of 30.50 mg/L was observed upstream indicating the effect of anthropogenic activities on Ashire. This confirms the direct relationship between electrical conductivity and TDS. High levels of TDS in drinking-water may be objectionable to consumers and may be unsuitable for irrigation of many plants (Schwarzenbach *et al.*, 2003). The small scale mining activities on River Ashire did not have any significant impact on the TDS levels in the river.

Generally, high levels of TSS were recorded in Ashire River ranging from 122.00 – 134.00 mg/L for upstream and 85.00-191.00 mg/l for downstream. The higher the TSS level, the more turbid the water and less pleasant it is to serve as drinking water. Barnett *et al.* (2004) showed that high amounts of suspended solids block light penetration into water columns and increase heat absorption. It may also increase in surface waters due to increases in flow rate, as higher velocities increase water's capacity to suspend solids. Runoff from heavy rains can simultaneously introduce large amounts of solids

into surface waters and provide the capacity for their suspension. Factors that may have affected the TSS in Ashire include clearing of vegetation along the banks, excavation of top soil to pave way for erosion as a result of illegal mining activities. It is also possible that Artisanal mining activities discharge waste water from their gold processing activities which could be responsible for the high TSS. The total suspended solids concentrations recorded were all above the EPA guideline limit and therefore poses a health risk to users of River Ashire.

The EPA guideline limit for turbidity of mining and mineral processing is 75 NTU. Mean Turbidity values ranged from 172.00-513.00 NTU for both upstream and downstream. Though relatively low turbidity levels were observed upstream compared with that of downstream, the values were far above the recommended EPA limit. Similar results had earlier been reported by Appau-Attafuah (2000), in a study on River Ayensu in the Okyeman Traditional area. He showed that small scale mining has an influence on water quality as the turbidity and total suspended solids increase (Dowdell *et al.*, 2012). The numerous artisanal (galamsey) activities observed around the area are the major contributory factor to these high NTU values.

The study has shown that heavy metals concentration in the river varied; copper was below the 5 mg/L water quality standard for copper set by EPA implying that there is no significant impact from Small Scale Mining activities in the area on River Ashire so far as far as Cu is concerned. The low levels could be attributed to no agricultural activity (farming) in the area which could make use of Phosphate fertilizers to increase the copper levels in the river from run-offs. Water-soluble copper compounds occur in the environment after release through application in agriculture. Copper could also come from forest fires and sea spray mining, metal production, wood production and phosphate fertilizer production (Moore and Ramamoorthy, 2008).

Lead is very toxic and dangerous to human as well as aquatic life. Kortatsi (2004), measured levels in groundwater to be 0.026 mg/l and <0.05 mg/l in surface waters (Kuma and Younger, 2004). EPA guideline for Lead is 0.1 mg/L. The mean lead concentrations in this study ranged from 0.035 mg/L – 0.056 mg/L. The low levels of lead in River Ashire could be due to the fact that River bodies have the capacity of self-purification since in the rainy season the river overflows its banks. The use of ‘Chanfan’ Machines which is made of steel and spillage of fuel used in their machines in the area could also contribute to the lead levels in the river. Ramadan, (2003) showed that lead is a highly toxic metal to man since it causes brain damage, particularly to the young and induces aggressive behaviour.

Cadmium always occurs in combination with zinc; naturally a very large amount of cadmium is released into the environment, about 25,000 tons a year (Wang *et al.*, 2005). About half of this cadmium is released into rivers through weathering of rocks and some cadmium is released into air through forest fires and volcanoes. The rest of the cadmium is released through human activities, such as manufacturing and mining (Damoah, 2007). Mean Cadmium concentrations ranged from 0.002 mg/L – 0.085 mg/L. Compared with the EPA guideline value of 0.1 mg/L, the levels were low. The presence of some appreciable level of cadmium downstream could be attributed to the fact that Cadmium metal is used mainly as an anticorrosive, electroplated onto steel. Cadmium sulfide and selenide are commonly used as pigments in plastics. Cadmium compounds are used in electric batteries, electronic components and nuclear reactors, the mining activities were carried out mainly at downstream of the river thus corrosion of ‘chanfan’ machine used in milling the ore and abandoned used batteries could contribute to the presence of cadmium in the river. Also important source of cadmium

emission is the production of artificial phosphate fertilizers (Moore and Ramamoorthy, 2008).

Mercury levels in River Ashire were high. In Ghana, artisanal gold mining (AGM) uses an enormous amount of metallic mercury. The mercury used by the miners is usually discharged in an abusive manner into the ecosystem, this increases the concentrations of mercury in the river since it is used to amalgamate the fine gold (Donkor *et al.*, 2003). The mining sector has also been identified as an important anthropogenic source of mercury emissions (Donkor *et al.*, 2009; Villas Boas *et al.*, 2001). It has been reported that South America, Russia and Asia emit about 450 tonnes of mercury into the environment annually (Larceda, 2003). Given the toxic nature of mercury, its presence in water even in minute quantities poses serious health risk to users of the Ashire River. This confirms that poor mercury management practices are prevalent throughout the developing world, and recent research elsewhere confirms that emission from small scale gold mining have caused serious environmental problems.

Moreover, the higher presence of mercury could probably be attributed to broken fluorescent lamps at most of the Small Scale Mining sites which are used during the night. Fluorescent lamps contain mercury and are released when bulbs are broken.

Arsenic is introduced into water through the dissolution of rocks, minerals and ores, from industrial effluents, including mining wastes, and via atmospheric deposition (Besseah *et al.*, 2011). EPA guideline limit for dissolved arsenic concentration is 0.01 mg/L. Dissolved arsenic concentrations from the survey ranged from 0.001 mg/L – 0.052 mg/L with the mean concentration of 0.019-0.372 mg/L. The concentrations were slightly high at some of the sampling points upstream while the concentration was high

along all the sampling points downstream indicating that the levels were above the recommended EPA limit. According to Aryee, (2003), Arsenic can be found naturally on earth in small concentrations. It occurs in soil and minerals and it may enter air, water and land through wind-blown dust and water run-off and also due to human activities, mainly through mining and Smelting; naturally immobile arsenics have also mobilized and can now be found on many more places than where they existed naturally; therefore it confirms that at certain points along the River Arsenic level is quite significant which means that the Arsenic level in the river could be perhaps attributed to the activities of small scale mining in that Arsenic naturally found in the soil are released into water bodies during mining of the gold ore. In view of the fact that Ghana EPA and WHO guideline limits have been exceeded it has the potential of posing as a health hazard to the users of the river for domestic and agricultural purposes since the following illnesses have been associated with high levels of Arsenic in water; dermal lesions, peripheral neuropathy, skin cancer, and peripheral vascular disease. (WHO, 1996). Previous studies showed the maximum levels in groundwater to be 0.046 mg/l (Kortatsi, 2004) and maximum levels in surface water to be 0.137 mg/l (Kuma, 2004) indicating that arsenic contamination in river Ashire is very high comparing with previous studies on other rivers in Ghana.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS.

6.1 Conclusions.

Generally, River Ashire was slightly acidic to neutral in nature. The acidity was high (pH of 6.09-6.53) for the upstream samples compared with the downstream which were slightly basic ((pH of 6.69-7.91). The level of Dissolve Oxygen was higher in downstream (4.09-6.91 mg/l) compared to upstream values (2.42-3.60 mg/l). Turbidity and Total Suspended Solids in River Ashire were very high. Heavy Metals in River Ashire were high for Arsenic, mercury and Lead which is a health threat as it is the only source of drinking water for the communities.

Small Scale Mining activities along the River Ashire have a negative impact on the water quality parameters of River Ashire as levels of Turbidity, Dissolved Oxygen, Total Suspended Solids, Lead, Arsenic and Mercury all exceed the Ghana EPA standard for drinking water and WHO guideline for drinking water.

6.2 Recommendations

The following recommendations are made.

Further studies should be conducted to find out the following;

1. The Health impact on people who depend on the river for domestic and agricultural purposes.
2. The impact on aquatic organisms in the river.
3. Analysis on sediments in the river.

Recommendation to the Wassa Amenfi East District Assembly

In view of the above stated problems, it is recommended that the Wassa Amenfi East District Assembly should provide boreholes for communities who depend on the river for their livelihood.

6.2.1 Management Options for Minimizing Environmental Impacts of Small-Scale Mines

The challenge in managing environmental degradation caused by small-scale mining is to develop appropriate implementation strategies and environmental management systems. These strategies must be relevant, understandable, and affordable to the small-scale miners and should aim at maintaining a balance between encouraging economic developments and preserving high environmental standards. Various strategies for managing the water-related impacts caused by small-scale mining have been developed in South Africa. These government initiatives have focused on two levels, namely the small-scale miners themselves as well the regulators.

In order to reduce the water-related impacts of small-scale mines, the following tools and processes are recommended:

- The small-scale miners should be trained to mine in an environmental responsible manner, especially those that are applying to mine for the first time.
- The legislative requirements should be made more accessible and understandable to prospective small-scale miners.

- The water quality impacts of small-scale miners are to be monitored on a regional (large-scale) rather than on an individual mine basis.

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APPENDIX A Water Quality Results For Mid-Season Sampling

Sample ID	pH	E. Cond. μS/cm	Salinity ppm	DO mg/L	TDS mg/L	TSS mg/L	TURBIDITY mg/L	Copper mg/L	Lead mg/L	Cadmium mg/L	Mercury mg/L	Arsenic mg/L
ASH-001	6.89	77	0.04	2.82	40	85	317	<0.005	0.075	<0.005	0.020	0.005
ASH-002	7.02	75	0.03	3.25	38	118	308	<0.005	7.000	<0.005	0.030	0.010
ASH-003	6.78	106	0.05	3.11	54	94	415	<0.005	0.319	<0.005	0.080	0.005
ASH-004	6.69	59	0.03	4.62	30	121	311	<0.005	0.236	<0.005	0.010	0.003
ASH-005	6.52	50	0.02	3.54	27	127	388	<0.005	0.367	<0.005	0.009	0.002
ASH-006	6.32	53	0.02	3.02	28	132	391	<0.005	0.052	<0.005	0.100	0.002
ASH-007	6.87	77	0.04	3.60	39	128	327	<0.005	1.538	<0.005	0.005	0.003
Laboratory Blank	-	-	-	-	-	-	-	<0.005	<0.010	<0.005		<0.001
Detection Limit for Parameters	-	-	-	-	-	-	-	0.005	0.010	0.005		0.001
Standard/pH Buffer Reading	6.96	1415	-	-	-	-	-	0.972	0.988	0.200		0.010
Expected Value for Standards/Buffer	7.01	1413	-	-	-	-	-	1.000	1.000	0.200		0.010

APPENDIX B: Water Quality Results for Dry Season Sampling

Sample ID	pH	E. Cond. μS/cm	Salinity ppm	DO mg/L	TDS mg/L	TSS mg/L	TURBIDITY mg/L	Copper mg/L	Lead mg/L	Cadmium mg/L	Mercury mg/L	Arsenic mg/L
ASH-001	6.91	118	0.06	4.48	62	91	328	<0.005	0.010	<0.005	0.020	0.008
ASH-002	6.92	94	0.04	4.15	48	191	314	<0.005	0.008	<0.005	0.030	0.007
ASH-003	6.84	61	0.03	5.37	32	102	299	<0.005	0.006	<0.005	0.009	0.002
ASH-004	7.01	55	0.02	4.59	28	131	329	<0.005	0.753	<0.005	0.010	0.008
ASH-005	6.84	58	0.03	5.48	29	122	384	<0.005	0.022	<0.005	0.010	<0.001
ASH-006	6.71	54	0.03	6.58	29	131	378	<0.005	0.027	<0.005	0.100	<0.001
ASH-007	6.53	136	0.06	2.49	69	126	342	<0.005	1.608	<0.005	0.004	0.017
Laboratory Blank	-	-	-	-	-	-	-	<0.005	<0.010	<0.005		<0.001
Detection Limit for Parameters	-	-	-	-	-	-	-	0.005	0.010	0.005		0.001
Standard/pH Buffer Reading	6.96	1415	-	-	-	-	-	0.998	1.009	0.197		0.010
Expected Value for Standards/Buffer	7.01	1413	-	-	-	-	-	1.000	1.000	0.200		0.010

APPENDIX C: Water Quality Results for Rainy Season Sampling

Sample ID	pH	E. Cond. μS/cm	Salinity ppm	DO mg/L	TDS mg/L	TSS mg/L	TURBIDITY NTU	Copper mg/L	Lead mg/L	Cadmium mg/L	Mercury mg/L	Arsenic mg/L
ASH-001	6.31	125	0.06	4.09	64	97	309	0.009	0.013	<0.005	0.030	0.004
ASH-002	6.52	80	0.04	4.16	39	132	495	<0.005	0.013	<0.005	0.040	0.004
ASH-003	6.71	51	0.02	4.95	27	108	389	0.017	0.059	<0.005	0.006	0.003
ASH-004	6.50	48	0.02	4.1	24	132	386	0.008	0.454	<0.005	0.009	0.005
ASH-005	6.76	66	0.03	6.94	33	128	377	0.010	0.015	<0.005	0.030	0.002

ASH-006	6.86	62	0.03	6.5	33	122	397	<0.005	0.026	<0.005	0.090	<0.001
ASH-007	-	-	-	-	-	134	393	0.009	0.064	<0.005	0.003	0.003
Laboratory Blank	-	-	-	-	-	-	-	<0.005	<0.010	<0.005		<0.001
Detection Limit for Parameters	-	-	-	-	-	-	-	0.005	0.010	0.005		0.001
Standard/pH Buffer Reading	6.96	1415	-	-	-	-	-	1.001	0.998	0.201		0.010
Expected Value for Standards/Buffer	7.01	1413	-	-	-	-	-	1.000	1.000	0.200		0.010

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APPENDIX D: Summary of results obtained for physicochemical and heavy metal

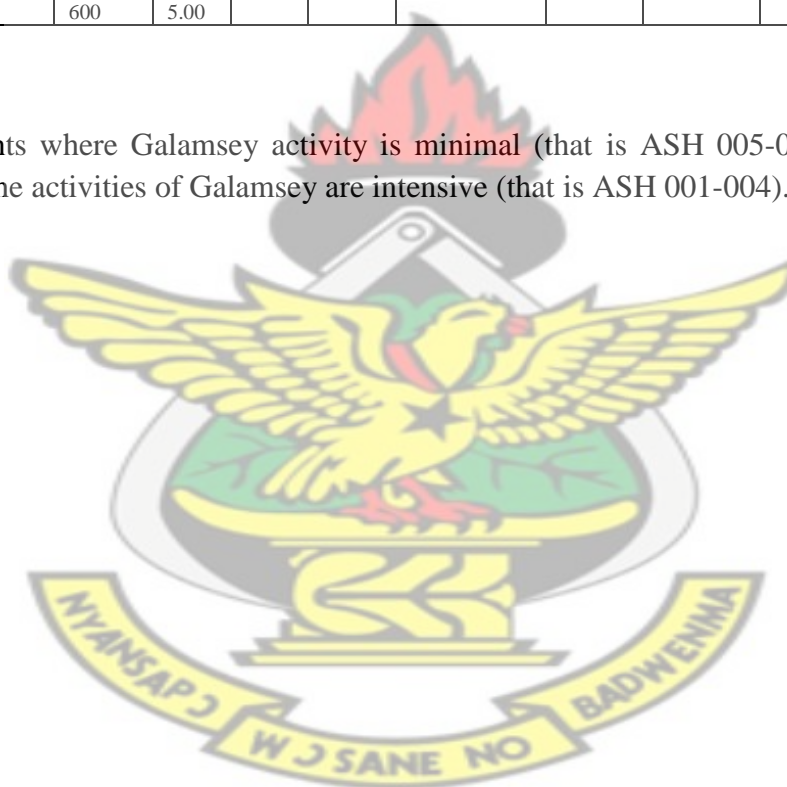
The results obtained for physicochemical and heavy metal analysis in the Ashire River for the three sampling regime at each sampling point are summarised and presented whereas the detail results are presented in Appendix A, B and C. The table indicates the mean, range and P-values for each sampling point as well as applicable EPA (Ghana) and WHO Guidelines for drinking water.

Sample ID	pH	E. Cond. µS/cm	Salinity ppm	DO mg/L	TDS mg/L	TSS mg/L	TURBIDITY NTU	Copper mg/L	Lead mg/L	Cadmium mg/L	Mercury mg/L	Arsenic mg/L
ASH-001	7.24	122.67	0.17	5.83	70.33	91.00	482.00	0.008	0.92	0.087	0.885	0.815
Range	6.90-7.91	118-125	0.06-0.23	4.09-6.91	285-391	85-97	409-528	0.007-0.009	0.786-0.987	0.076-0.100	0.815-0.986	0.756-0.876
ASH-002	7.06	86.33	0.09	5.16	54.00	147.00	575.33	0.003	0.70	0.089	0.777	0.441
Range	6.80-7.45	80-94	0.04-0.16	4.16-6.15	298-432	118-191	436-695	0.001-0.005	0.654-0.754	0.084-0.098	0.734-0.812	0.3244-0.543
ASH-003	6.89	102.33	0.09	6.00	37.67	101.33	492.33	0.003	0.43	0.080	0.501	0.157
Range	6.71-7.10	91-110	0.03-0.14	4.95-6.59	230-432	94-108	399-589	0.001-0.005	0.321-0.534	0.065-0.092	0.415-0.654	0.113-0.234
ASH-004	6.87	103.00	0.11	4.87	37.33	128.00	501.33	0.003	0.21	0.082	0.308	0.076
Range	6.69-7.01	86-125	0.02-0.22	4.10-5.89	232-325	121-132	432-586	0.002-0.004	0.186-0.241	0.064-0.096	0.282-0.345	0.065-0.092
ASH-005	6.35	62.00	0.03	2.97	29.67	125.67	170.33	0.002	0.07	0.002	0.026	0.043
Range	6.20-6.45	58-66	0.03-0.03	2.48-3.43	86-127	122-128	107-220	0.001-0.003	0.015-0.165	0.001-0.003	0.021-0.032	0.032-0.052
ASH-006	6.40	56.33	0.03	2.86	30.00	128.33	183.67	0.001	0.03	0.002	0.006	0.013
Range	6.32-6.53	53-62	0.02-0.03	2.42-3.15	65-89	122-132	175-198	0.001-0.002	0.026-0.045	0.001-0.005	0.002-0.010	0.006-0.025
ASH-007	6.14	32.50	0.02	3.05	22.50	129.33	162.67	0.001	0.006	0.002	0.002	0.001
Range	6.09-6.21	21-24	0.04-1.00	2.49-3.60	26-32	126-134	142-193	0.001-0.001	0.001-0.015	0.001-0.003	0.001-0.003	0.001-0.002
P value	0.002	0.000	0.220	0.003	0.00	0.010	0.000	0.000	0.000	0.000	0.000	0.000
EPA Standard	6-9	1500			1000	50	75	5	0.1	0.1	0.005	0.01
WHO Standard			600	5								

APPENDIX E: Results of Physico-Chemical characteristics and Heavy metals concentration at upstream and downstream points on River Ashire

	pH	E. Cond.	Salinity	DO	TDS	TSS	TURBIDITY	Copper	Lead	Cadmium	Mercury	Arsenic
Sample ID		μS/cm	Ppm	mg/L	mg/L	mg/L	NTU	mg/L	mg/L	mg/L	mg/L	mg/L
Upstream	6.30	50.00	0.026	2.95	30.50	127.78	172	0.001	0.035	0.002	0.0099	0.019
Range	6.09-6.53	21-66	0.02-1.00	2.42-3.60	26-39	122-134	107-220	0.001-0.003	0.001-0.165	0.001-0.005	0.001-0.030	0.001-0.052
Downstream	7.01	103.58	0.113	5.46	49.83	116.83	513	0.004	0.564	0.085	0.6922	0.372
Range	6.69-7.91	80-125	0.02-0.23	4.09-6.91	24-85	85-191	399-695	0.001-0.009	0.186-0.987	0.064-0.100	0.100-0.986	0.065-0.876
P value	0.000	0.000	0.713	0.000	0.016	0.274	0.000	0.003	0.000	0.000	0.000	0.003
EPA Standard	6-9	1500			1000	50	75	5.00	0.1	0.1	0.005	0.01
WHO Standard			600	5.00								

Upstream represents where Galamsey activity is minimal (that is ASH 005-007 and Downstream represents where the activities of Galamsey are intensive (that is ASH 001-004).



APPENDIX F: GPS Data

SAMPLE ID	EASTERN CORDINATES	NORTHERN CORDINATES
ASH001	600,726.00	639,604.00
ASH002	601,355.71	639,640.05
ASH003	602,552.87	638,978.36
ASH004	604,379.29	640,026.62
ASH005	605,489.75	641,096.97
ASH006	607,693.04	642,628.56
ASH007	611,365.86	648,610.92



APPENDIX G: Statistical Analysis

pH								
					95% Confidence Interval for Mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
Mid-Season	7	6.7271	0.23998	0.09070	6.5052	6.9491	6.32	7.02
Dry Season	7	6.8229	0.15872	0.05999	6.6761	6.9696	6.53	7.01
Rainy Season	6	6.6100	0.20258	0.08270	6.3974	6.8226	6.31	6.86
Total	20	6.7255	0.21130	0.04725	6.6266	6.8244	6.31	7.02

Test of Homogeneity of Variances

pH

Levene Statistic	df1	df2	Sig.
0.782	2	17	0.473

ANOVA

pH

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.146	2	0.073	1.773	0.200
Within Groups	0.702	17	0.041		
Total	0.848	19			

Descriptives

Electric Conductivity

					95% Confidence Interval for Mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
Mid-Season	7	71.0000	19.24405	7.27357	53.2022	88.7978	50.00	106.00
Dry Season	7	82.2857	33.87582	12.80386	50.9558	113.6156	54.00	136.00
Rainy Season	6	72.0000	28.37605	11.58447	42.2212	101.7788	48.00	125.00
Total	20	75.2500	26.82276	5.99775	62.6966	87.8034	48.00	136.00

Test of Homogeneity of Variances

Electric Conductivity

Levene Statistic	df1	df2	Sig.
1.860	2	17	0.186

ANOVA

Electric Conductive

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	536.321	2	268.161	0.347	0.712
Within Groups	13133.429	17	772.555		
Total	13669.750	19			

Descriptives

Salinity								
					95% Confidence Interval for Mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
Mid-Season	7	0.0329	0.01113	0.00421	0.0226	0.0431	0.02	0.05
Dry Season	7	0.0386	0.01574	0.00595	0.0240	0.0531	0.02	0.06
Rainy Season	6	0.0333	0.01506	0.00615	0.0175	0.0491	0.02	0.06
Total	20	0.0350	0.01357	0.00303	0.0286	0.0414	0.02	0.06

Test of Homogeneity of Variances

Salinity

Levene Statistic	df1	df2	Sig.
0.432	2	17	0.656

ANOVA

Salinity					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.000	2	0.000	0.349	0.710
Within Groups	0.003	17	0.000		
Total	0.004	19			

Descriptives

Dissolve Oxygen

					95% Confidence Interval for Mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
Mid-Season	7	3.4229	0.59606	0.22529	2.8716	3.9741	2.82	4.62
Dry Season	7	4.7343	1.28001	0.48380	3.5505	5.9181	2.49	6.58
Rainy Season	6	5.1233	1.28597	0.52499	3.7738	6.4729	4.09	6.94
Total	20	4.3920	1.27392	0.28486	3.7958	4.9882	2.49	6.94

Test of Homogeneity of Variances

Dissolve Oxygen

Levene Statistic	df1	df2	Sig.
2.054	2	17	0.159

ANOVA

Dissolve Oxygen

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	10.604	2	5.302	4.455	0.028
Within Groups	20.231	17	1.190		
Total	30.835	19			

Descriptives

Total Dissolve Solid

					95% Confidence Interval for Mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
Mid-Season	7	36.5714	9.41377	3.55807	27.8651	45.2777	27.00	54.00
Dry Season	7	42.4286	17.30951	6.54238	26.4199	58.4372	28.00	69.00
Rainy Season	6	36.6667	14.37591	5.86894	21.5801	51.7533	24.00	64.00
Total	20	38.6500	13.60447	3.04205	32.2829	45.0171	24.00	69.00

Test of Homogeneity of Variances

Total Dissolve Solid

Levene Statistic	df1	df2	Sig.
2.012	2	17	0.164

ANOVA

Total Dissolve Solid

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	153.788	2	76.894	0.389	0.684
Within Groups	3362.762	17	197.810		
Total	3516.550	19			

Descriptives

Total Suspended Solid

					95% Confidence Interval for Mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
Mid-Season	7	115.0000	18.20256	6.87992	98.1654	131.8346	85.00	132.00
Dry Season	7	127.7143	31.81045	12.02322	98.2945	157.1340	91.00	191.00
Rainy Season	7	121.8571	14.14719	5.34713	108.7732	134.9411	97.00	134.00
Total	21	121.5238	22.16668	4.83717	111.4337	131.6140	85.00	191.00

Test of Homogeneity of Variances

Total Suspended Solid

Levene Statistic	df1	df2	Sig.
0.613	2	18	0.553

ANOVA

Total Suspended Solid

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	566.952	2	283.476	0.551	0.586
Within Groups	9260.286	18	514.460		
Total	9827.238	20			

Descriptives

Turbidity								
					95% Confidence Interval for Mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
Mid-Season	7	351.0000	45.17743	17.07546	309.2178	392.7822	308.00	415.00
Dry Season	7	339.1429	31.62504	11.95314	309.8946	368.3911	299.00	384.00
Rainy Season	7	392.2857	54.45706	20.58283	341.9213	442.6501	309.00	495.00
Total	21	360.8095	48.44339	10.57121	338.7584	382.8607	299.00	495.00

Test of Homogeneity of Variances

Turbidity

Levene Statistic	df1	df2	Sig.
0.563	2	18	0.579

ANOVA

Turbidity

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	10894.952	2	5447.476	2.721	0.093
Within Groups	36040.286	18	2002.238		
Total	46935.238	20			

Descriptives

Copper								
					95% Confidence Interval for Mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
Mid-Season	7	0.00500	0.000000	0.000000	0.00500	0.00500	0.005	0.005
Dry Season	7	0.00500	0.000000	0.000000	0.00500	0.00500	0.005	0.005
Rainy Season	7	0.00900	0.004041	0.001528	0.00526	0.01274	0.005	0.017
Total	21	0.00633	0.002938	0.000641	0.00500	0.00767	0.005	0.017

Test of Homogeneity of Variances

Copper

Levene Statistic	df1	df2	Sig.
5.370	2	18	0.015

ANOVA

Copper

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.000	2	0.000	6.857	0.006
Within Groups	0.000	18	0.000		
Total	0.000	20			

Robust Tests of Equality of Means

Copper

	Statistic	df1	df2	Sig.
Welch	3.227	2	10.667	0.080
Brown-Forsythe	6.857	2	6.000	0.028

a. Asymptotically F distributed.

Descriptives

Cadium								
					95% Confidence Interval for Mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
Mid-Season	7	0.00500	0.000000	0.000000	0.00500	0.00500	0.005	0.005
Dry Season	7	0.00500	0.000000	0.000000	0.00500	0.00500	0.005	0.005
Rainy Season	7	0.00500	0.000000	0.000000	0.00500	0.00500	0.005	0.005
Total	21	0.00500	0.000000	0.000000	0.00500	0.00500	0.005	0.005

Test of Homogeneity of Variances

Cadium

Levene Statistic	df1	df2	Sig.
	2		

ANOVA

Cadium					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.000	2	0.000	0.000	1.000
Within Groups	0.000	18	0.000		
Total	0.000	20			

Descriptives

Mercury								
					95% Confidence Interval for Mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
Mid-Season	7	0.03629	0.038056	0.014384	0.00109	0.07148	0.005	0.100
Dry Season	7	0.02614	0.033697	0.012736	-0.00502	0.05731	0.004	0.100
Rainy Season	7	0.02971	0.030126	0.011387	0.00185	0.05758	0.003	0.090
Total	21	0.03071	0.032648	0.007124	0.01585	0.04558	0.003	0.100

Test of Homogeneity of Variances

Mercury

Levene Statistic	df1	df2	Sig.
0.480	2	18	0.626

ANOVA

Mercury

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.000	2	0.000	0.159	0.854
Within Groups	0.021	18	0.001		
Total	0.021	20			

Descriptives

Arsenic

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Mid-Season	7	0.00429	0.002812	0.001063	0.00169	0.00689	0.002	0.010
Dry Season	7	0.00629	0.005707	0.002157	0.00101	0.01156	0.001	0.017
Rainy Season	7	0.00286	0.001574	0.000595	0.00140	0.00431	0.001	0.005
Total	21	0.00448	0.003868	0.000844	0.00272	0.00624	0.001	0.017

Test of Homogeneity of Variances

Arsenic

Levene Statistic	df1	df2	Sig.
3.257	2	18	0.062

ANOVA

Arsenic

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.000	2	0.000	1.450	0.261
Within Groups	0.000	18	0.000		
Total	0.000	20			

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