

**KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY**

**DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY**

**INSTITUTE OF DISTANCE LEARNING**

**HEAVY METAL CONCENTRATION IN THE OWERE RIVER AT KONONGO**

**A THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND  
APPLIED BIOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENT  
FOR THE DEGREE OF MASTER OF SCIENCE**

**BY**

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## DECLARATION

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

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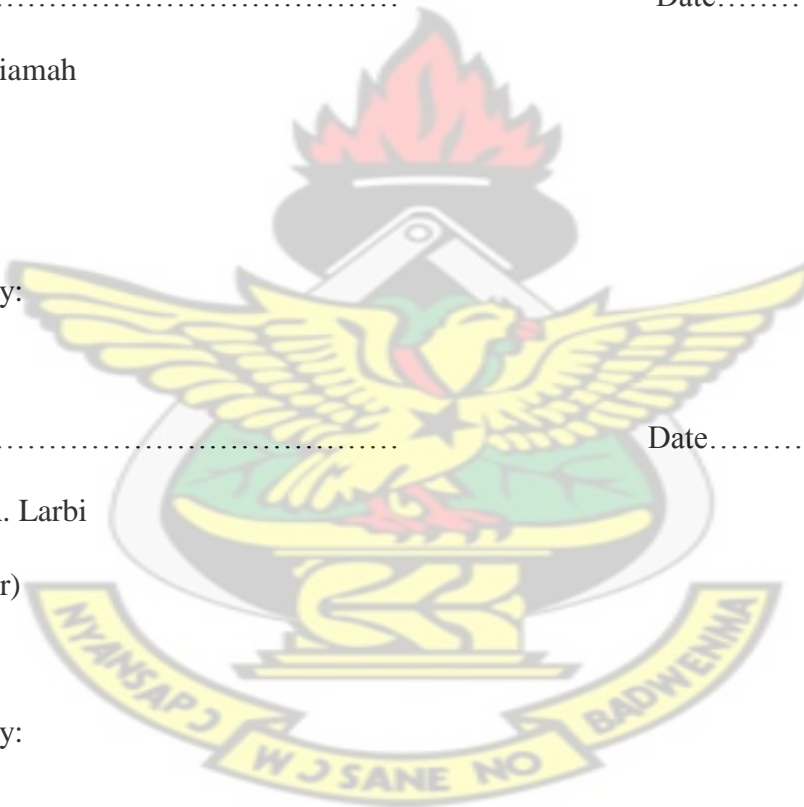
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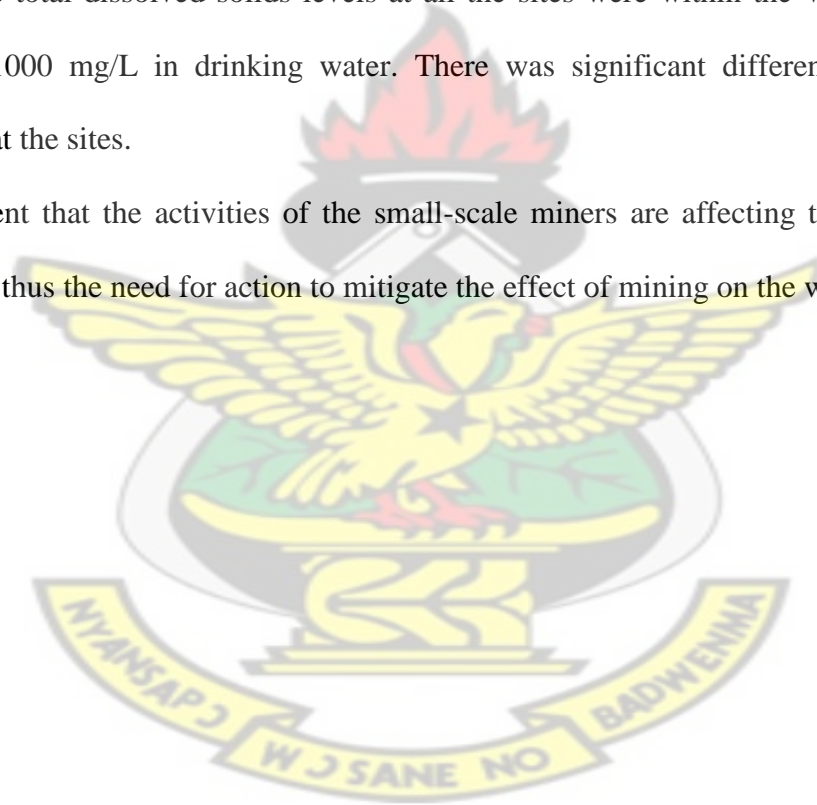
## ABSTRACT

The Owere River located in the Asante Akyem Central Municipality of Ghana is one of the major sources of water for household and farming purposes in the municipality. In recent times there has been indiscriminate small-scale gold mining activity in and around the river which has led to pollution of the river. The study was thus carried out to assess the levels of heavy metals and some physico-chemical parameters in the Owere River at Konongo in the Asante Akyem Central municipality of Ghana. Water samples from the Owere River were collected from upstream, midstream and downstream sites of the river and analyzed for some heavy metals: Arsenic, Cadmium, Iron, Lead and Mercury. pH, temperature, electrical conductivity (EC), alkalinity and turbidity were also determined

Results indicated that the mean levels of Arsenic from upstream, midstream and downstream were  $0.022 \pm 0.024$  (mg/L),  $0.007 \pm 0.002$  (mg/L) and  $0.012 \pm 0.008$  mg/L respectively. There was no significant difference in the Arsenic levels between and within the sites. The level in the upstream was above the WHO permissible limit of 0.01mg/L. The mean levels of Cadmium from the sites ranged between  $0.027 \pm 0.011$  mg/L to  $0.066 \pm 0.094$  mg/L and were above the WHO permissible limit of 0.003 mg/L. The levels of Lead in the midstream and downstream were above the WHO permissible limit of 0.01 mg/L. The mean levels of iron from upstream, midstream and downstream were  $4.907 \pm 1.063$  mg/L,  $1.785 \pm 0.350$  mg/L and  $2.015 \pm 0.438$  mg/L respectively. These levels were high compared to the WHO permissible limit of 1.0 mg/L for drinking water. There was a significant difference between the upstream and midstream water samples. There were no significant differences in the levels of mercury recorded at the three sites and were above WHO permissible limit of 0.001 mg/L except in the upstream where it was below

instrument detectable limit. pH was within the range of  $6.23 \pm 0.316$  to  $6.78 \pm 0.588$ . However the upstream water samples recorded the highest mean temperature of  $25.9 \pm 1.152^\circ\text{C}$ . This was within the WHO acceptable limit of 25 to  $28^\circ\text{C}$  for drinking water sample. Mean conductivity for the water samples ranged between  $262.5 \pm 80.328 \mu\text{S/cm}$  to  $298.0 \pm 14.508 \mu\text{S/cm}$ . Alkalinity levels were below WHO limit of 700mg/L. The levels recorded ranged between  $74.3 \pm 0.424$  to  $107.2 \pm 0.282 \text{ mg/L}$ . Turbidity levels at all sites were high and above the WHO limit of 5NTU ranging between  $55.5 \pm 8.602$  –  $62.5 \pm 6.390$  NTU. The total dissolved solids levels at all the sites were within the WHO permissible limit of 1000 mg/L in drinking water. There was significant difference in the levels recorded at the sites.

It is evident that the activities of the small-scale miners are affecting the quality of the water and thus the need for action to mitigate the effect of mining on the water body.



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## LIST OF ABBREVIATIONS

AACMA	Asante- Akyem Central Municipal Assembly
ASGM	Artisanal and Small- Scale Gold Mining
ATSDR	Agency for Toxic Substances and Disease Registry
ANOVA	Analysis of Variance
DHHS	Department of Health and Human Services
EHFS	Environmental Health Fact Sheet
EPA	Environmental Protection Agency
IGRLCL	Independent Geologist Report- Lion Gold Corporation Limited
IOSHIC	International Occupational Safety and Health Information Centre
ODNR	Ohio Department of Natural Resources
PCTU	Pennsylvania Council of Trout Unlimited
PNDCL	Provisional National Defence Council Law
Site A	Upstream
Site B	Midstream
Site C	Downstream
TGHC	Turbidity Guideline by Health Canada
TWGLI	Testing Water for Gardening and Lawn Irrigation
UNEP	United Nations Environmental Programme
UNIDO	United Nations Industrial Development Organization
WHO	World Health Organization

## **DEDICATION**

I dedicate this work to the Almighty God, my source of strength and wisdom.

# KNUST

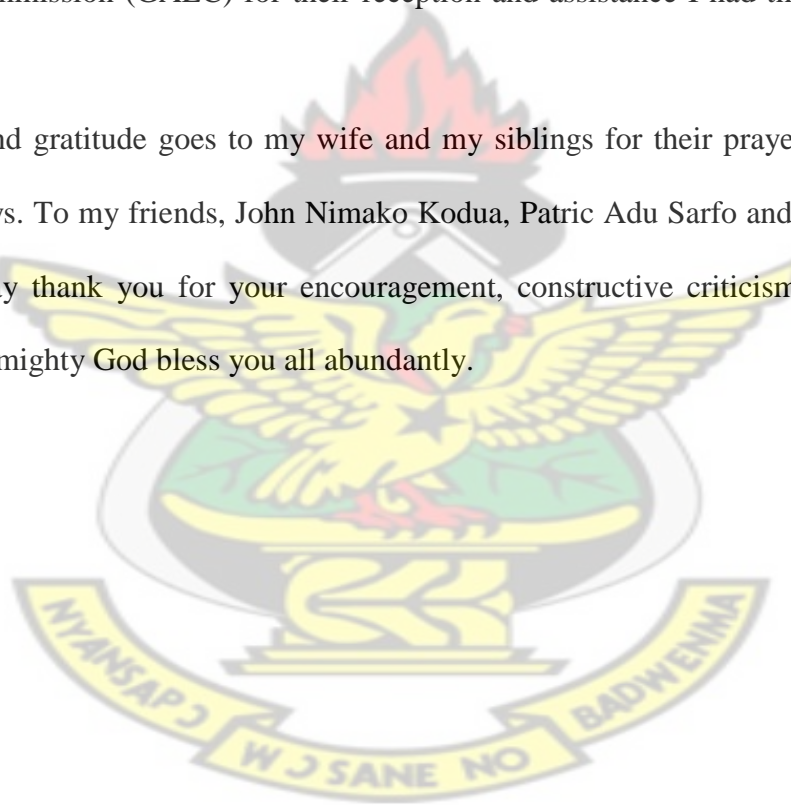


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## CHAPTER ONE

### INTRODUCTION

The Ghanaian economy depends on cocoa, gold and timber which together account for over 80 percent of the country's exports. The mining sector is the largest foreign exchange earner and is playing a significant role in the economic recovery program of the country. However, the negative socio-economic impacts of mining are enormous. While the country benefits from mining, the increasing negative impact through environmental degradation must not be left unresolved (Ntow et al., 1996).

Heavy metals are highly toxic or poisonous even at low concentration (Duruibe et al., 2007). In small quantities, certain heavy metals are nutritionally essential for healthy life. These are referred to as trace elements and these include copper, manganese and zinc. These elements, or some form of them, are commonly found naturally in foodstuffs, in fruits and vegetables, and in commercially available multivitamin products (IOSHIC, 1999). Heavy metals become toxic when they are not metabolized by the body and accumulate in the soft tissues. Heavy metals may enter the human body through food, water, air or absorption through the skin when they come in contact with humans (Lide, 1992). The mining industry remains the backbone of many economies in the developing world. Its resurgence in Ghana since 1989 was driven by the global paradigm which emphasizes private sector-led development as an engine of economic growth in developing countries (Akabzaa and Darimani, 2001). Mining contributes about 70% of Ghana's total tax earnings, 41% of total exports, 12% of revenue collected by the Internal Revenue Service and 5% of Gross Domestic Product (Ghana Chamber of Mines, 2008). Mining, it



has been realized, affects environmental and society no matter where it occurs. Mining related disruptions can impact the physical environment and or local communities (Miranda et al., 2005).

Most mining in Ghana is small scale mining. This type of mining is the most destructive to the environment due to the uneducated individuals and undeveloped methods of mining that are used. The government regularized the operations of small-scale miners since 1989, but they were not under the Environmental Protection Agency laws until recently. A large number of these miners have very little knowledge about environmental hazards and hence cause most of the environmental damage through their activities (Laing, 1994).

Heavy metals present in the environment do not necessarily indicate an environmental problem. However, it is a matter of concern when the amounts detected approach or exceed the concentrations that can harm organisms, including humans. Mercury, Zinc and other metals occur naturally in rocks and in ore minerals. Therefore, there is a normal background concentration of these metals in soils, waters, sediments and living organisms. However, concentrations more than the background concentrations give rise to pollution in the medium of concern (Hangi, 1996). It is therefore very important to determine and know the concentration that is released into the environment all the time. Heavy metals are mobile and easily taken up by plants in the environment. Several metals have a very long biological half-life and tend to accumulate in the body. For example, the half-life for cadmium in humans is estimated to be two decades or more. With continuing exposure, accumulation will thus go on during the whole lifetime (Hangi, 1996). The metal

contamination in superficial soils and vegetation is derived largely from anthropogenic activities such as mining operations, industrial process emissions and so on (Arambbarri et al., 1999). Neurological disorders, Central Nervous System destruction, and cancer of various body organs are some of the reported effects of heavy metal poisoning (ATSDR, 1994; ATSDR, 1999a; ATSDR, 2000).

## **JUSTIFICATION**

The Owere River flows through Konongo and its nearby communities. Some communities along the river use the water for domestic purposes and irrigation farming. However there are small- scale mining activities in and along the river. These anthropogenic activities may lead to pollution. There is therefore the need to ascertain the extent of pollution and how safe the water is for domestic purposes. Heavy metal toxicity can result in damage or reduced mental and central nervous functioning, lower energy levels and damage to blood composition, lungs, kidneys, liver and other vital organs (IOSHIC, 1999).

Aim and Objectives of research

### **Aim:**

To determine the levels of heavy metals (Mercury, Cadmium, Lead, Arsenic and Iron) in water from the Owere river and compare the results from upstream, midstream and downstream to the guideline values by World Health Organization (WHO) , Ghana Standards Authority (GSA).

## Objectives

To determine;

- i. The presence and levels of the heavy metals (Mercury, Cadmium, Arsenic, Lead and Iron) in the Owere River.
- ii. Physico-chemical parameters such as (pH, Temperature, Conductivity, Total Dissolved Solids, Alkalinity and Turbidity) of the water.



## **CHAPTER TWO**

### **LITERATURE REVIEW**

#### **2.1 GOLD MINING IN GHANA**

The Ghanaian small-scale mining industry is well over 2,000 years old. 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 artisan activities were attracting Arab traders to certain areas of the country as early as the 7<sup>th</sup> and 8<sup>th</sup> centuries AD. In fact, it was the rich gold deposit of Western Sahara that were largely responsible for wealth and strength of large ancient Ghanaian empires and cultures, and by the 15<sup>th</sup> and 16<sup>th</sup> centuries, at the peak of European colonial exploration, Ghana was fittingly labeled the 'Gold Coast' (Hilson, 2001).

The earliest European attempts to extract gold on a large scale were concentrated in Tarkwa and Prestea in the late 19<sup>th</sup> century and the first official European gold mining company was the African Gold Coast Company which was registered in February 18<sup>th</sup> 1878. A gold rush in the early 20<sup>th</sup> century was followed by a mass in gold. After this the gold production decreased. Due to unwillingness of Ghanaians to work for Europeans in the late 1920s the British passed the Mercury Ordinance, which made it illegal for Ghanaians to own mercury. The gold production fluctuated until the Second World War. After Ghana gained independence in 1957 the industry collapsed (Hilson, 2002a). In 1983 the government started the Economic Recovery Program (ERP) under guidance of International Monetary Fund (Hilson, 2002a). The objective of the program was to quickly attract investors to the mining sector and other key sectors, which had export potential, to

turn around the general economy of the country (Aryee, 2001). After the implementation of the Economic Reform Program the mining industry saw a phenomenal growth, which mainly can be attributed to the adoption of World Bank recommendations in a new national policy through the 1986 Mineral and Mining Law. This law provided that the government left the mine operation, management and ownership to private sector (Addy, 1998). Ghana has a long history of mineral endowment, which led in colonial times to the country being known as Gold Coast. Despite being Africa's second largest gold –producer, modern-day Ghana has experienced disappointing results in translating this mineral wealth into broad economic development (Ayee et al., 2011). The largest gold deposits are found in the Ashanti, Western, Central and Brong -Ahafo regions. The mining sector currently contributes approximately 41percent of total exports earnings, 14 percent of total tax revenue, and 5.5 percent of Ghana's Gross Domestic Product (Ayee et al., 2011).

### **2.1.1 Mining activities in the area**

The Konongo gold mining region has been mined in several phases since 1903 and during this time has produced 4.4 million tones of ore producing approximately 1.6 million ounces of gold at an average recovered grade of 11.8 g/t. Mining activities predates European settlement at Konongo. Colonial mining commenced with the discovery of gold at Obenemase in 1903, when the B1 shaft was sunk and four levels developed between 1903 and 1907, when production ceased (IGRLCL, 2012).

Mined development recommenced at Konongo in 1918 which formed the bulk of production and was ultimately developed to maximum depth of 844m through four shafts,



with ore bodies discovered on the Odumase- Boabedroo, Awere and Akyenase structures. Production ceased in 1986 with a total of 2.8 million tonnes mined for approximately 1.4 Moz of gold, at recovered grade of 15.7 g/t gold. In 1986 the State Gold Mining Corporation of Ghana (SGMC) was granted a 125 Km<sup>2</sup> ML over the Konongo Project area for a term of thirty years (IGRLCL, 2012).

The Konongo Goldfield is based on the exploitation of ore load ores, which occur fused in the earthy material and in which the gold is contained as the native metal. The process of recovery involves excavating the ore from the earth, followed by agglomeration with cement. The agglomerated ore is conveyed to heap leached pads. The pads are sprayed with dilute cyanide solution to leach the gold cement. The gold solution is subjected to treatment with zinc powder, and activated by lead nitrate to precipitate the gold (Ntow et al., 1996). River Owere is the most significant river in the Konongo district serving for drinking, fishing and other domestic purposes. It flows through the mining areas of Obenemase and Konongo, thereby serving as a repository of mine wastes. The river joins the Annuru, which has been dammed for irrigation in the Municipality (Ntow et al., 1996).

## **2.2 Artisanal and Small- scale Gold mining (ASGM) in Ghana**

### **2.2.1 Definition and Historical background**

Artisanal and small-scale gold mining is the extraction of minerals, most commonly gold, by miners working in small or medium sized operations, using rudimentary techniques. Mercury is often used to separate the metal from the ore and is generally handled by people with little or no awareness of its risk (UNEP, 2007). In Ghana small-scale gold mining is



defined as mining by any method not involving substantial expenditure by an individual or group of persons not exceeding nine in number or by a co-operative society made up of ten or more persons (Aryee et al., 2003). Also, according to Leilanie (2012), small scale mining is a single unit mining operation with an annual production of unprocessed material of 50,000 tons or less. It is usually characterized as informal, illegal and unregulated by government, undercapitalized, utilizing simple tools and lacking in technology, and hazardous under labor intensive conditions.

During pre-colonial times mainly gold and diamonds were mined on small scale. Gold was traded with Moors and the Phoenicians on the trans-Saharan trade routes before the advent of the Portuguese and other Europeans incursions which began in 1471. Artisanal mining and processing methods were employed to work both hard rock and alluvial gold deposits. Alluvial gold was mined by collecting gravel from the beds of streams and washing sediments clean of sand and earth (Aryee et al., 2003). 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. Until the 1980s, small scale mining activities in Ghana remained largely unregulated and received little, if any, support from governmental bodies (Hilson, 2001). Gold was reported to be so abundant in the region that no serious thought was given to the method of exploiting it. It could literally be picked from the ground and river beds (Botchway, 1995). In Ghana, gold is mined in two fundamentally different ways. Small-scale gold miners mostly open pits by hand and sell gold through regional marketers. On the other hand large –scale surface and underground mining enterprises operate with

industrialized production chains and direct ties to international markets (Schueler et al., 2011). Initially only diamonds could be legally mined on 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 (Hilson, 2001). The decision to legalize small- scale gold mining led to the passing of the Mercury Law (PNDCL 217), Small –scale Gold Mining Law (PNDCL 218 ) , and Precious Mineral Marketing Law (PNDCL 219) in 1989 (Hilson and Potter , 2005). Although the Ghanaian government has collected well over US\$ 300 million in gold from artisanal and small-scale miners since instituting a regulatory and policy framework for the industry in 1989, an overwhelming majority continue to operate as illegal “galamsey”, without any legal entitlement to land (Hilson and Potter, 2005).

### **2.2.2 Environmental and health impacts of mining**

In most parts of mining areas, the environment is undergoing rapid degradation and its immense economic value is diminishing from year to year, due mainly to heavy concentration of mining activities in those areas. The principal elements of the environment land, water and air have been severely impacted by mining operations (Akabzaa and Darimani, 2001). From the general operational methods the possible environmental pollutants from the mining processes are cyanide, zinc, lead, boron and manganese (Ntow et al., 1996). The activities of illegal small-scale miners have resulted in land degradation through loss of vegetation and soil erosion. The Upper East region of Ghana is highly degraded with the resultant loss of vegetation cover, fertile top soil and wild fauna species as a result of small-scale gold mining (Tom- Dery et al., 2012). Various

chemicals such as cyanide and mercury are used during ore processing. These chemicals constitute the major pollutant of surface and ground water (Akabzaa and Darimani, 2001). Also, data obtained from District Medical Office, Tarkwa, suggest that mining impact related diseases such as malaria, diarrhea, upper respiratory diseases, skin diseases, acute conjunctivitis and accidents form the top ten diseases in the area (Akabzaa and Darimani, 2001). The technique mostly used by small-scale gold miners in their extraction is amalgamation with mercury (Ofosu- Mensah and Ababio, 2011).

## **2.3 Amalgamation**

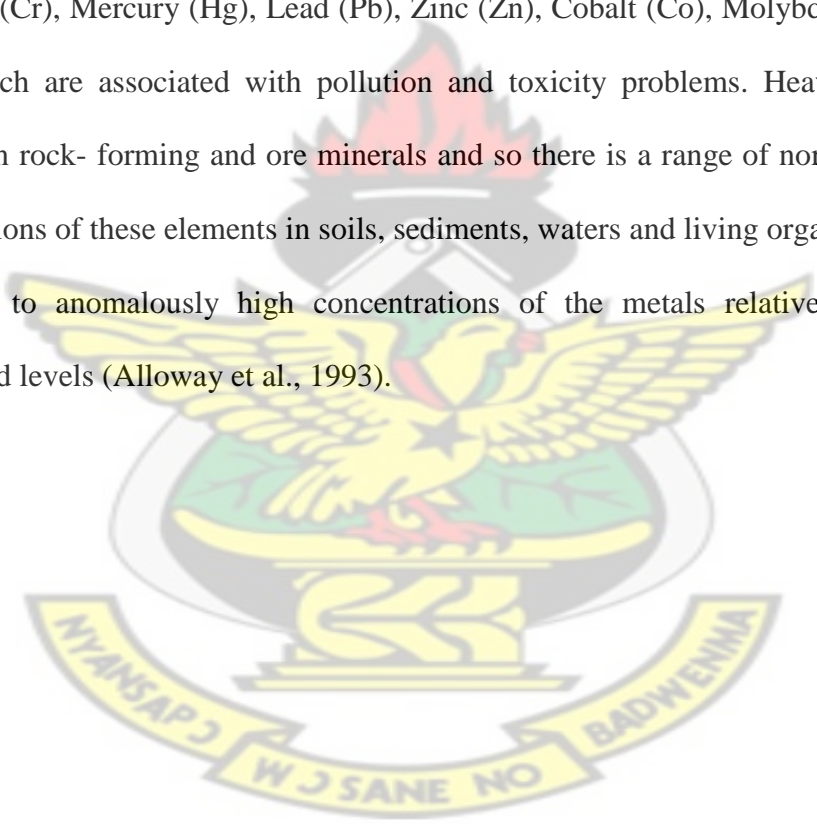
### **2.3.1 Theory of Amalgamation**

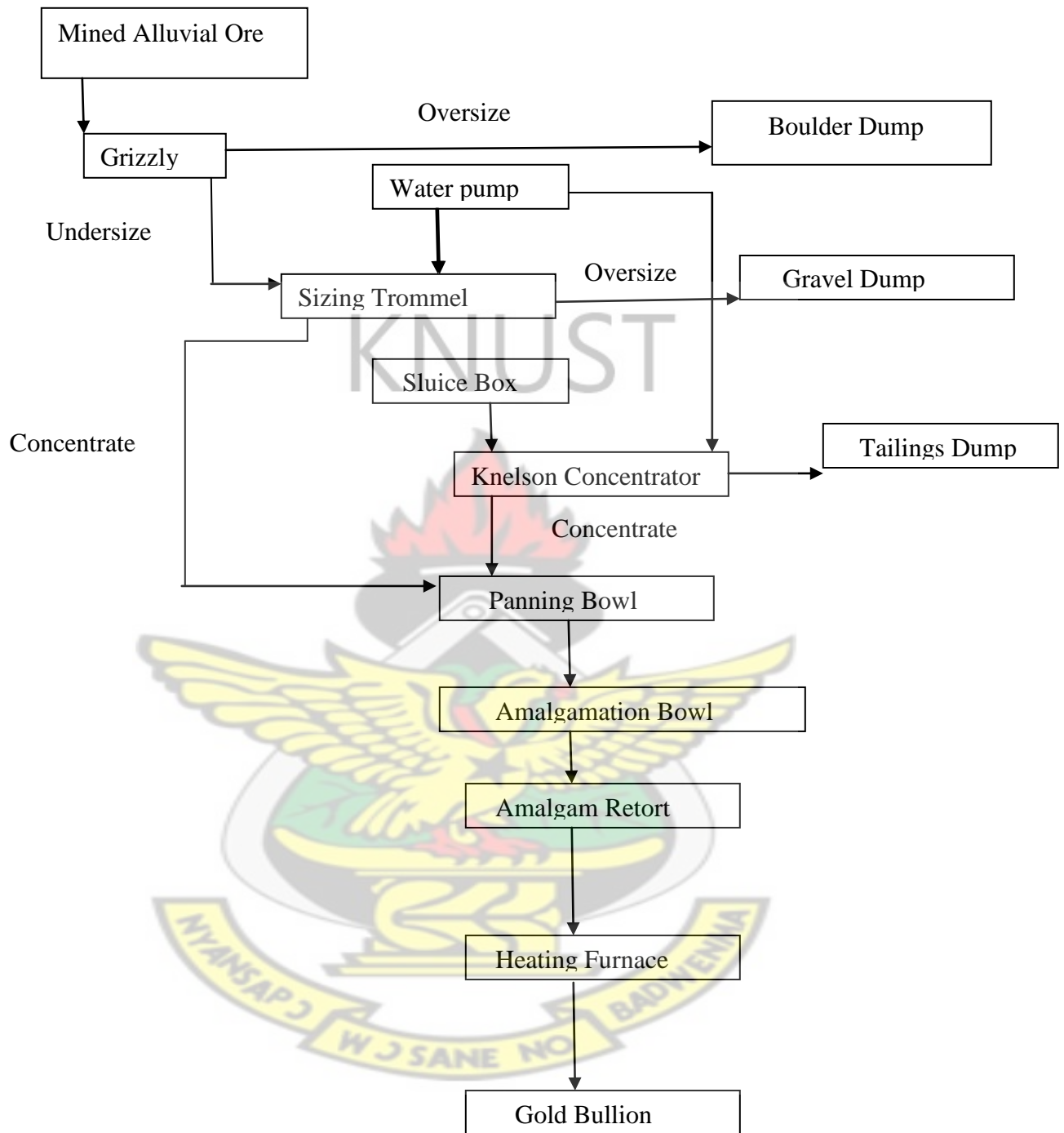
As in the case in most developing countries, the mercury amalgamation technique is relied upon heavily as it is a cheap, dependable, portable operation for concentrating and extracting gold from low-grade ores (Hilson, 2001). The gold bearing ores are dug from the ground or sometimes the tailings from the gold treatment plants are washed several times with water in a pan to remove the slime. Usually, an inclined table is then set up and covered with a blanket or jute sack that can hold heavy particles. The gold bearing material in the bucket or pan is then poured onto the covered table and further washed with enough water to remove the light material. This continues until the sack is saturated with the concentrate and the initial material is reduced to a very small lump but very rich in gold. At this stage, mercury is then mixed with the gold concentrate to form gold amalgam. The bonded gold-mercury amalgam is then heated with blow torches or over open fires to burn off the mercury leaving the gold behind (Aryee et al., 2003).

## 2.4 Heavy metals

### 2.4.1 General properties

Heavy metals constitute a very heterogeneous group of elements widely varied in their chemical properties and biological functions (Raikwar et al., 2008). Chemical elements with a specific gravity that is at least five times the specific gravity of water are called “Heavy metals” (Lide, 1992). Although it is only a loosely defined term it is widely recognized and usually applied to elements such as Arsenic (As), Cadmium(Cd), Chromium(Cr), Mercury (Hg), Lead (Pb), Zinc (Zn), Cobalt (Co), Molybdenum (Mo), and so on which are associated with pollution and toxicity problems. Heavy metals occur naturally in rock- forming and ore minerals and so there is a range of normal background concentrations of these elements in soils, sediments, waters and living organisms. Pollution gives rise to anomalously high concentrations of the metals relative to the normal background levels (Alloway et al., 1993).





Source: (Aryee *et al.*, 2003)

**Figure 1 Methods used by artisanal mining operators to extract gold**



### 2.4.2 Biochemical properties

Some heavy metals have bio- importance as trace elements but, the biotoxic effects of many of them in human biochemistry are of great concern. Some heavy metals like Iron, Zinc, Calcium, Copper and Selenium are reported to be of bio-importance to man (Duruibe et al., 2007).

Copper is incorporated into many enzymes and is necessary for their action. For example, the copper containing ceruloplasmin is involved in the transport of iron in the blood to places where haemoglobin synthesis occurs. Another enzyme is involved in maintaining connective tissue integrity, and in copper deficiency the defective bone matrix and osteoporosis may occur (Duruibe et al., 2007).

Iron is important in transportation of oxygen from the lungs by way of the bloodstream to the tissues. It is present in red blood cell protein, haemoglobin. A similar protein in muscle, myoglobin also contains iron and stores oxygen for use during muscle contraction. Iron is found in the portion of the cell involved in energy production and as a cofactor for several enzymes (Duruibe et al., 2007). Selenium is an essential nonmetallic element. Food containing selenium includes meat, poultry, grains and seafood. Selenium is important for the function of several proteins. One of these is glutathione peroxidase, an enzyme that prevents oxidative damage to cells from a variety of peroxides. Selenium also appears to bind to some minerals such as arsenic and mercury and decrease their toxicity (Duruibe et al., 2007). Zinc is important in growth, appetite, development of the testicles, skin integrity, mental activity, wound healing and proper functioning of the immune system.



Zinc is a cofactor for many enzymes. These enzymes participate in the metabolism of carbohydrates, lipids, proteins and nucleic acids such as DNA. Zinc is involved in the functioning of the immune system and in the expression of genetic information. Zinc is present in bones and is involved in the regulation of bone calcification (Deruibe et al., 2007).

At the biochemical level, the toxic effects caused by excess concentrations of these metals include competition for sites with essential metabolic, replacement of essential ions, reactions with –SH groups, damage to cell membranes, and reaction with the phosphate groups of ADP and ATP. Organisms have homeostatic mechanism which enables them to tolerate small fluctuations in the supply of most elements but prolonged excesses eventually exceed the capacity of the homeostatic system to cope and toxicity occurs (Alloway, 1990). Plant responses to heavy metals include: metal ion binding to the cell wall and root exudates; reduction of metal influx across the plasma membrane; membrane efflux pumping into the apoplast; metal chelation in the cytosol by ligands such as phytochelatins, metallothioneins, organic acids and amino acids; transport of metal-ligand complexes through the tonoplast and accumulation in the vacuole (Manara, 2012).

#### **2.4.3 Sources of heavy metals**

Heavy metals can be emitted into the environment by both natural and anthropogenic causes. The major causes of emission are the anthropogenic sources specifically mining operations. In some cases even long after mining activities have ceased, the emitted metals continue to persist in the environment (Duruibe et al., 2007).

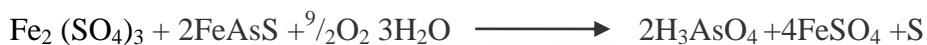
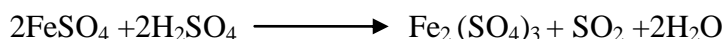
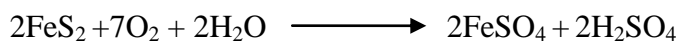
#### 2.4.4 Natural sources

Heavy metals occur naturally in soil environment from the pedogenetic processes of weathering of parent materials at levels that are regarded as trace ( $<1000\text{mgKg}^{-1}$ ) and rarely toxic. Due to the disturbance and acceleration of nature's slowly occurring geochemical cycle of metals by man, most soils of rural and urban environments may accumulate one or more of the heavy metals above defined background values high enough to cause risks to human health, plants, animals, ecosystems or other media (Wuana and Okieimen, 2011). In rocks, heavy metal exists as their ores in different chemical forms, from which they are recovered as minerals. Heavy metal ores include sulphides, such as iron, arsenic, lead, lead- zinc, cobalt, gold- silver and nickel sulphides. Ore minerals tend to occur in families where metals that exist naturally as sulphides would mostly occur together. Therefore sulphides of lead, cadmium, arsenic and mercury would naturally be found occurring together with sulphides of iron (Pyrite,  $\text{FeS}_2$ ) and copper (Duruibe et al., 2007).

#### 2.4.5 Anthropogenic sources

There are a multitude of anthropogenic emissions in the environment. The major source of these metals is from mining and smelting. Mining releases metals to the fluvial environment as tailings and to the atmosphere as metal - enriched dust whereas smelting releases metals to the atmosphere as a result of high- temperature refining process (Callender, 2005). Mining activities and other geochemical processes often result in the generation of acid mine drainage. It is generated when pyrite ( $\text{FeS}_2$ ) and other sulphide minerals in the aquifer and present and other former mining sites are exposed to air and

water in the presence of oxidizing bacteria such as Thiobacillus ferrooxidans, and oxidized to produce metal ions, sulphate and acidity (Duruibe et al., 2007). The reaction is as follows:



Metal-bearing solids at contaminated sites can also originate from a wide variety of anthropogenic sources in the form of disposal of high metal wastes and improperly protected landfills, leaded gasoline and lead-based paints, land application of fertilizer, animal manures, biosolids (sewage sludge), compost, pesticides, coal combustion residues, petrochemicals and atmospheric deposition (Wuana and Okieimen, 2011).

The two main pathways for heavy metals to become incorporated into air, soil, sediment and water are transport by air (atmospheric) and water (Callender, 2005). Airborne sources of metal include stack or duct emission of air, gas or vapor streams, and fugitive emission such as dust from storage areas or waste piles. Metals from airborne sources are generally released as particulates contained in the gas stream. Some metals such as Arsenic, Cadmium, and Lead can also volatilize during high temperature processing (Wuana and Okieimen, 2011). The pollution of surface waters is significant; however, the heavy runoff associated with perennial rainfall may mitigate the impact. Several small and heavy industries involved in activities such as battery and paint manufacturing, petroleum refining, cement and ceramic production, steel production are now being located haphazardly, mostly near metropolitan centres. No centralized sewage system exists, and

the industrial effluents from the factories are usually discharged untreated into streams, lagoons, open drains and water bodies (Olade, 1987).

#### **2.4.6 Human exposure to Heavy metals**

Heavy metal pollution of surface and underground water sources results in considerable soil pollution and pollution increases when mined ores are dumped on the ground surface. Surface dumping exposes the metals to air and rain thereby generating much acid mine drainage. When agricultural soils are polluted, these metals are taken up by plants and consequently accumulate in their tissues. Animals that graze on such contaminated plants and drink from polluted waters also accumulate such metals in their tissues. Humans are in turn exposed to heavy metals by consuming contaminated plants and animals (Duruibe et al., 2007). Industrial products that are used in homes, and which have been produced with heavy metals are sources of human exposure to such heavy metals. Mercury exposure is through disinfectants like mercurochrome, antifungal agents, toiletries, creams and organo-metallics; cadmium exposure is through nickel/cadmium batteries and artist paints; lead exposure is through wine bottle wraps, mirror coatings, batteries, old paints and tiles (Duruibe et al., 2007). Heavy metal exposure also occurs significantly by occupational exposure. Workers of mining and production of cadmium, chromium, lead, mercury, gold and silver have been reported to be thus exposed; also inhabitants around industrial sites of heavy metal mining and processing, are exposed through air by suspended particulate matters (Duruibe et al., 2007).

## 2.5 Selected Heavy Metals and their Toxicity

The elements Arsenic (As), Cadmium (Cd), Iron (Fe), Lead (Pb) and Mercury (Hg) which are noted for their toxic effects on human health, plants and environment were selected for quantitative estimation in the Owere River at the study area. These heavy metals are expected to get into the environment when such metals contained in excavated rocks come into contact with water. These metals are leached out and carried downstream as water washes over the rock surface. When sulphides in rocks are exposed to air and water, sulphuric acid is produced as Acid Mine drainage in the reaction:



### 2.5.1 Arsenic (As)

Arsenic can form both inorganic and organic compounds in the environment and human body. Inorganic arsenic includes arsenite ( $\text{AsO}_3^{3-}$ ) and arsenate ( $\text{AsO}_4^{3-}$ ). The inorganic arsenic can either be methylated (monomethylarsenic acid) or dimethylarsenic acid. The most common source of arsenic is drinking water. The concentration of ( $\text{AsO}_3^{3-}$ ) arsenite in drinking water is in the range 0.01 – 4mg/L. Besides carcinogenic effects of arsenic, arsenic compounds can be used as medicine to treat acute promyelotic leukaemia (Valko et al., 2005). Arsenic occurs naturally in soil and minerals and it therefore may enter the air, water, and land from wind-blown dust and may get into water from runoff and leaching. Volcanic eruptions are another source of arsenic. Arsenic is associated with ores containing metals, such as copper and lead. Arsenic may enter the environment during the mining and smelting of these ores. Small amounts of arsenic also may be released into the atmosphere from coal-fired power plants and incinerators because coal and waste products



often contain some arsenic. Arsenic cannot be destroyed in the environment. It can only change its form, or become attached to or separated from particles. It may change its form by reacting with oxygen or other molecules present in air, water, or soil, or by the action of bacteria that live in soil or sediment. Arsenic released from power plants and other combustion processes is usually attached to very small particles. Arsenic contained in wind-borne soil is generally found in larger particles. These particles settle to the ground or are washed out of the air by rain. Arsenic that is attached to very small particles may stay in the air for many days and travel long distances. Many common arsenic compounds can dissolve in water. Thus, arsenic can get into lakes, rivers, or underground water by dissolving in rain or snow or through the discharge of industrial wastes. Some of the arsenic will stick to particles in the water or sediment on the bottom of lakes or rivers, and some will be carried along by the water. Ultimately, most arsenic ends up in the soil or sediment. Inorganic arsenic has been recognized as a human poison since ancient times, and large oral doses (above 60,000 ppb in water which is 10,000 times higher than 80% of U.S. drinking water arsenic levels) can result in death. If you swallow lower levels of inorganic arsenic (ranging from about 300 to 30,000 ppb in water; 100–10,000 times higher than most U.S. drinking water levels), you may experience irritation of your stomach and intestines, with symptoms such as stomachache, nausea, vomiting, and diarrhea. Other effects that might be experienced from swallowing inorganic arsenic include decreased production of red and white blood cells, which may cause fatigue, abnormal heart rhythm, blood-vessel damage resulting in bruising, and impaired nerve function causing a "pins and needles" sensation in your hands and feet. Perhaps the single-most characteristic effect of long-term oral exposure to inorganic arsenic is a pattern of



skin changes. These include patches of darkened skin and the appearance of small "corns" or "warts" on the palms, soles, and torso, and are often associated with changes in the blood vessels of the skin. Skin cancer may also develop. Swallowing arsenic has also been reported to increase the risk of cancer in the liver, bladder, and lungs.

**Table1 Health effects of arsenic**

Organ affected	Effects
Skin	Hyper pigmentation , Hyperkeratosis, Skin tumours
Lungs	Lung cancer
Liver	Liver dysfunction
Cardiovascular system	Peripheral vascular disturbances leading to gangrene
Nervous system	Peripheral neuropathy, Hearing defects
Reproductive system	Increased frequency of spontaneous abortions

The Department of Health and Human Services (DHHS) has determined that inorganic arsenic is known to be a human carcinogen (a chemical that causes cancer). The International Agency for Research on Cancer (IARC) has determined that inorganic arsenic is carcinogenic to humans. EPA also has classified inorganic arsenic as a known human carcinogen (ATSDR, 2007). Long term exposure to inorganic arsenic can give rise to health effects in a large number of organs. Those effects reported to occur in populations environmentally exposed to arsenic are shown in the table 1 (Hutton, 1987). The arsenic level detected in the Suraw River in the Chirano Gold Mines Operations in the Babiani Ahwianso Bekwai District Assembly of Ghana was found to be 0.004 mg/L (Kyekyeku,

2011). The guideline limit for Arsenic in drinking water is 0.01mg/L (WHO, 1996). Arsenic is also associated with diseases such as diabetes, hypertension, and tumours of skin, bladder, liver and lung (Ercal et al., 2001). Furthermore arsenic blocks the Krebs cycle and interrupts oxidative phosphorylation, resulting in marked depletion of cellular ATP and eventually death of the metabolizing cell (Flora, 2009).

### 2.5.2 Cadmium (Cd)

Cadmium is toxic and metal non- biodegradable and its environmental levels are increasing due to industrial practices (Flora, 2009). In a natural aerobic, freshwater aquatic system,  $\text{Cd}^{2+}$  is the predominant species below pH 8 (Callender, 2005). While many inorganic Cd compounds are water soluble CdS and CdO are almost insoluble in water. In nature Cd occurs together with Zn and is a byproduct of zinc refining, as some zinc ores may contain as much as 5% Cd (Ziemacki et al., 1989). Cadmium compounds are used in metal electroplating, as stabilizers or pigments, in alkaline batteries and in alloys (Ziemacki et al., 1989). Refined foods, water foods, water pipes, coffee, tea, coal burning and cigarette are all the most important source of cadmium. Cadmium accumulates within the kidneys and the liver over long period of exposure (Raikwar et al., 2008). After ingestion, cadmium ions are absorbed by the body and become concentrated mainly in the liver and kidney. Cadmium is a potent human carcinogen and has been associated with cancers of the lung, prostate, pancreas and kidney (Flora, 2009). The guideline for Cadmium level in drinking water is 0.003mg/L (WHO,1996). In a study conducted on the impact of Chirano Gold Mines Operations on the Suraw River in the mining community, the level of Cd in the river was found to be < 0.002 mg/L (Kyekyeku, 2011).

### 2.5.3 Lead (Pb)

Lead is found as mineral combined with other elements such as sulphur ( $\text{PbS}$ ,  $\text{PbSO}_4$ ), or oxygen ( $\text{PbCO}_3$ ) in nature (Wuana and Okieimen, 2011). Lead occurs naturally in the environment. However, most of the high levels found in the environment come from human activities. Environmental levels of lead have increased more than 1,000-fold over the past three centuries as a result of human activity. The greatest increase occurred between the years 1950 and 2000, and reflected increasing worldwide use of leaded gasoline. Lead can enter the environment through releases from mining lead and other metals, and from factories that make or use lead, lead alloys, or lead compounds. Lead is released into the air during burning coal, oil, or waste. Before the use of leaded gasoline was banned, most of the lead released into the U.S. environment came from vehicle exhaust. Before the 1950s, lead was used in pesticides applied to fruit orchards. Once lead gets into the atmosphere, it may travel long distances if the lead particles are very small. Lead is removed from the air by rain and by particles falling to land or into surface water. Sources of lead in surface water or sediment include deposits of lead-containing dust from the atmosphere, waste water from industries that handle lead (primarily iron and steel industries and lead producers), urban runoff, and mining piles. The effects of lead are the same whether it enters the body through breathing or swallowing. The main target for lead toxicity is the nervous system, both in adults and children. Long-term exposure of adults to lead at work has resulted in decreased performance in some tests that measure functions of the nervous system. Lead exposure may also cause weakness in fingers, wrists, or ankles. Lead exposure also causes small increases in blood pressure, particularly in middle-aged and older people. Lead exposure may also cause anemia. At high levels of exposure, lead

can severely damage the brain and kidneys in adults or children and ultimately cause death. In pregnant women, high levels of exposure to lead may cause miscarriage. High-level exposure in men can damage the organs responsible for sperm production. The Department of Health and Human Services (DHHS) has determined that lead and lead compounds are reasonably anticipated to be human carcinogens based on limited evidence from studies in humans and sufficient evidence from animal studies, and the EPA has determined that lead is a probable human carcinogen. The International Agency for Research on Cancer (IARC) has determined that inorganic lead is probably carcinogenic to humans (ATSDR, 2007). Lead enters drinking water mainly from industrial effluents, and household sewage. Toxic level of lead in human body is 500 ppm beyond which it causes anemia, brain damage and vomiting (Patil and Ahmad, 2011). The maximum permissible concentration of lead in drinking water is 0.01mg/L (WHO, 1996). Other sources of lead pollution are mining and smelting of lead ores, refining and manufacturing of compounds and lead containing goods and refuse incineration (Ziemacki et al., 1989). Most of the lead particles deposited on soil are retained and eventually become mixed into the surface layer. Lead accumulated at the soil surface may be taken up directly by grazing animals and by soil micro-organisms and so enter terrestrial food chain, or, bypass food chains completely as in the case of children consuming dust and dirt during normal land-to-mouth activity (Denny et al., 1987). Lead binds to sulfhydryl and amide groups, frequent components of enzymes altering their configuration and diminishing their activities. It may also compete with essential metallic cations for binding sites, inhibiting enzyme activity, or altering the transport of essential cations such as calcium (Flora, 2009). Lead poisoning also causes inhibition of the synthesis of haemoglobin; dysfunctions in the kidneys, joints and reproductive system,

cardiovascular system and acute and chronic damage to the central nervous system (CNS) and Peripheral nervous system (PNS). Other effects include damage to the gastrointestinal tract and urinary tract resulting in bloody urine, neurological disorder and can cause severe and permanent brain damage. Lead affects children by leading to the poor development of the grey matter of the brain, thereby resulting in poor intelligent quotient (IQ). Its absorption in the body is enhanced by calcium and zinc deficiencies (Duruibe et al., 2007). The generally recognized effects of lead on the CNS is encephalopathy while, headache, poor attention irritability, memory loss, and dullness are early symptoms (Flora, 2009). Studies have shown that levels of lead detected in three different streams in Tarkwa mining region by Akabzaa and Darimani, (2001) were 0.04 mg/L, 0.2 mg/L and 0.13mg/L.

#### **2.5.4 Iron (Fe)**

Iron is the most abundant trace mineral in the body and is an essential element in most biological systems. It is likely that iron was essential for developing aerobic life on Earth. But iron is toxic to cells in excessive amounts. Iron absorption is a two-step process. First, iron ions are absorbed from the intestinal lumen into mucosal cells. Ferrous iron is better absorbed than ferric iron because ferric iron precipitates out of solution at around pH 7 or under normal physiologic conditions. However, both forms can be absorbed if they are ionized. Because iron must be ionized to be absorbed, metallic iron and iron oxide (rust) are not generally of concern when they are ingested. Most iron absorption occurs in the duodenum and upper jejunum, but in animals with iron toxicosis, the iron seems to be well-absorbed along all parts of the intestinal tract. A diet high in sugar and vitamin C increases iron absorption, while a high-phosphate diet reduces iron absorption. But in acute



overdoses, the iron seems to be absorbed in a passive, concentration-dependent fashion, similar to how most other metals are absorbed. Second, iron is transferred to ferritin or into circulation bound to transferrin proteins. Transferrin is an  $\alpha_1$ -globulin produced in the liver. Complexed with transferrin, iron is distributed to other iron storage locations in the body. A unique feature of iron metabolism is the almost complete absence of iron excretion. Any iron lost from hemoglobin degradation is rapidly bound to transferrin and transported to the bone marrow for the resynthesis of hemoglobin. Consequently, little iron is lost in the urine and feces. Iron exerts its most profound effects on the cardiovascular system. Excessive iron can cause fatty necrosis of the myocardium, postarteriolar dilatation, increased capillary permeability, and reduced cardiac output (Albretsen, 2006). Iron in drinking water is present as  $\text{Fe}^{2+}$  or  $\text{Fe}^{3+}$  in suspended form. It causes staining in clothes and imparts a bitter taste. It comes into water from natural geological sources, industrial wastes, domestic discharge and also from byproducts. Excess amounts of iron (more than 10mg/Kg) causes rapid increase in pulse rate and coagulation of blood in blood vessels, hypertension and drowsiness (Patil and Ahmad, 2011). The maximum allowed concentration of iron in drinking water is 1.0 mg/L (WHO, 1996). In fact, iron has been implicated as an agent in numerous cancers, probably most markedly in the etiology of colorectal cancer. One of the possible mechanism by which iron could be involved in the initiation or promotion is through the oxidation of DNA. It has been clearly established that oxidant induced damage to naked DNA and intracellular DNA is greatly enhanced by iron. In the presence of added iron, DNA scission occurs, preferentially in internucleosomal linker regions, producing “ladders” resembling those typical of apoptosis (Valko et al., 2005). Akabzaa and Darimani, (2001) in a study conducted to assess the



impact of mining sector investment in Ghana in the Tarkwa mining region found the levels of Iron in the Nkwanta Krom, Damang Nkrakra and Damang Tamang streams to be 0.4 mg/L, 1.8mg/L and 2.4 mg/L respectively.

### **2.5.5 Mercury (Hg)**

Mercury also exists as cation with an oxidation state of +1 ( $\text{Hg}^+$ ) and 2+ ( $\text{Hg}^{2+}$ ). Methylmercury (MeHg) is the most frequently encountered compound in the environment. It is formed mainly as a result of methylation of inorganic (mercuric) forms of mercury by micro-organisms in soil and water (Valko et al., 2005). Mercury is a naturally occurring element. It has been used by humans for at least 3500 years. Mercury can exist in a wide variety of physical and chemical states which all have their inherent toxic properties and different applications in industry and agriculture. Metallic mercury is a heavy silvery liquid at normal temperatures and pressures (WHO, 1991). Mercury is involved in a whole chain of environmental transformations where the physical and chemical properties of mercury is changed, which makes it exceedingly difficult to follow the pathways of mercury from emission source to ultimate sinks. Mercury is employed primarily by small-scale miners for the extraction of gold by the process of amalgamation. The mercury is burnt off without any good retorting facility (Hug, 1989).

The residual mercury affects the environment. Mercury has a high vapour pressure and therefore vapourizes easily into the atmosphere. It may condense and attach to particulate matter in the atmosphere. The condensed mercury may then fall back to the earth during precipitation to contaminate soils, vegetation, humans and livestock (Hug, 1989).

Once released in the environment, mercury may be redistributed between and within environmental compartments. It is more mobile than other heavy metals. Inorganic mercury may be methylated to more toxic organic forms. The alkyl mercury compounds are more toxic, particularly methyl mercury, than the aryl mercury compounds. Environmental methyl mercury arises largely, if not solely, from the methylation of inorganic mercury. Methylation can occur non-enzymatically or through microbial action. However, some studies have found no clear relation between methylation of mercury in soil or water and the microbial activity indicates that the process may be of chemical in nature. It is possible that formation of methyl mercury also occur in the atmosphere. Once methyl mercury is released, it enters the food chain by rapid diffusion and tight binding to proteins giving rise to bioaccumulation and biomagnifications (WHO, 1990; WHO, 1991). Mercury and its compounds are used for a number of applications. The uses in the chlor-alkali industry (cathode in the electrolysis of sodium chloride), batteries, electrical equipment, paints, and tooth filling are some of the main areas. However, there are a wide variety of other uses in industry, gold mining, agriculture, cosmetic (for light skin and mascara), military application, and medicine (WHO, 1991; OECD, 1994). The primary sources of chronic, low-level mercury (Hg) mercury exposure are dental amalgams and fish. Mercury enters water as natural process of off-grazing from the earth's crust and as a result of industrial pollution. Algae and bacteria methylate the mercury entering the waterways. Methylmercury (MeHg) makes its way through the food chain into fish and shellfish and ultimately into humans. The two major, highly absorbed subspecies of mercury are elemental mercury ( $\text{Hg}^0$ ) and MeHg. Silver dental amalgams contain over 50%  $\text{Hg}^0$ , which is the only metal with a melting point below room temperature. Elemental

mercury vapor is highly lipophilic and is efficiently absorbed through the lungs and oral mucosa. After entering the blood, it rapidly passes the cell membranes including the blood-brain barrier and placental barrier. Once inside a cell,  $\text{Hg}^0$  is oxidized by catalase and becomes highly reactive  $\text{Hg}^{2+}$  (Ercal et al, 2001).

When elemental mercury is inhaled, its vapour easily passes through pulmonary alveolar membranes and enters the blood, where it distributes primarily to the red blood cells, central nervous system, and kidneys. In contrast, less than 0.1% of elemental mercury is absorbed from the gastrointestinal tract after ingestion, so it has little toxicity when ingested. Only minimal absorption occurs with dermal exposure (Clarkson, 1997). Elemental mercury in contact with tissue oxidizes to mercuric ion, which does not cross the blood-brain barrier well. On the other hand when elemental mercury is converted to the mercuric form within the CNS, it is less able to diffuse out of the brain. Elemental mercury also crosses the placenta and concentrates in the foetus. In adults, the half-life of mercury is 60 days (ATSDR, 2007).

Mercury exerts its toxicity by the metal or its ions binding to sulfhydryl groups in the body. These groups may be part of some enzymes, and hence mercury and its compounds are potent inhibitors of some enzymes. Mercury also blocks the transport of potassium into cells and also blocks the transport of sugars. These effects are due to the binding of mercury to the S-H groups in or on the cell membrane (Timbrell, 1995). In eukaryotic organisms, mitochondria are the primary sites for the production of superoxide radical ( $\text{O}^{\cdot -}$ ) and hydrogen peroxide ( $\text{H}_2\text{O}_2$ ), converting 1-5% of cellular oxygen to superoxide radical

during normal metabolism. Inorganic mercury is suspected to increase hydrogen peroxide production by impairing the efficiency of oxidative phosphorylation and electron transport at the ubiquinone-cytochrome b5 step. This mechanism is highly plausible for the nephrotoxic effects of Hg, which is known to accumulate in kidney at high levels (Ercal et al., 2001). Acute ingestion of organic mercury compounds can cause: diarrhea, tenesmus and blisters in the upper gastrointestinal tract. There may also be symptoms of neurotoxicity (nerve damage), such as: parsthesia, impaired peripheral vision, muscle weakness, irritability, memory loss. There is also an increased risk of foetal toxicity, with effects including: mental retardation, retention of primitive reflexes, cerebellum symptoms, dysarthria, hypokinesia, hyper salivation and atrophy of the cerebral cortex (Fauci et al., 1998). Exposure of children to mercury in any of its forms may cause acrodynia, or Pink disease with symptoms including: flushing, itching, swelling, tachycardial, hypertension, excessive salivation or perspiration, weakness and rashes (Fauci et al., 1998). The permissible limits for mercury in drinking water are 0.001mg/L (WHO, 1996). In a study conducted to assess the extent of mercury pollution of some rivers that drain the Bibiani-Anwiaaso-Bekwai district which is a typical mining community in South Western part of Ghana, the highest concentration of total mercury in the water sample was found to be 1.341 mg/L (Nartey et al., 2011).

## **2.6 Physicochemical parameters of water samples**

Some physicochemical parameters that could impact on the water quality were selected for consideration. These include Total Dissolved Solids (TDS), Temperature, Turbidity, Electrical Conductivity (EC), Alkalinity and pH.

### 2.6.1 Total Dissolved Solids

Total Dissolved Solids (TDS) is defined as the concentration of all dissolved minerals in water. TDS are a direct measurement of the interaction between ground water and subsurface minerals. High TDS greater than 1000mg/L is commonly objectional or offensive to taste. A high TDS may cause corrosion of pipes and plumbing system (ODNR, 2006). TDS may also indicate elevated levels of ions such as aluminium, arsenic, copper, lead, nitrate, and others that do pose health concern. Water with extremely low concentrations of TDS may also be unacceptable to consumers because of its flat, insipid taste; it is also corrosive to water supply systems. Water containing TDS concentrations below 1000mg/L is usually acceptable to consumers, although acceptability may vary according to circumstances. The United States Environmental Protection Agency recommends treatment when TDS concentrations exceed 500mg/L or 500 parts per million (Qaiser et al., 2008). Changes in TDS levels in natural water often result from industrial effluent or salt-water intrusion (Anhwange et al., 2012). In a study carried out by Kyekyeku, (2011) on the impact of Chirano Gold Mines Operations on River Suraw, the Total Dissolved Solids in the river was between the ranges of 96.80-381.00 mg/L. The permissible limit by WHO ranges from 250- 500 (mg/L).

### 2.6.2 Turbidity

Turbidity refers to the solid or organic material that does not settle out of water. This means that the material is not dissolved but is in suspension. Such materials include dust particles and colloidal inorganic matter. Suspended solids are rarely harmful, yet elimination of turbidity is important. Clear water is more appealing to drink (ODNR,



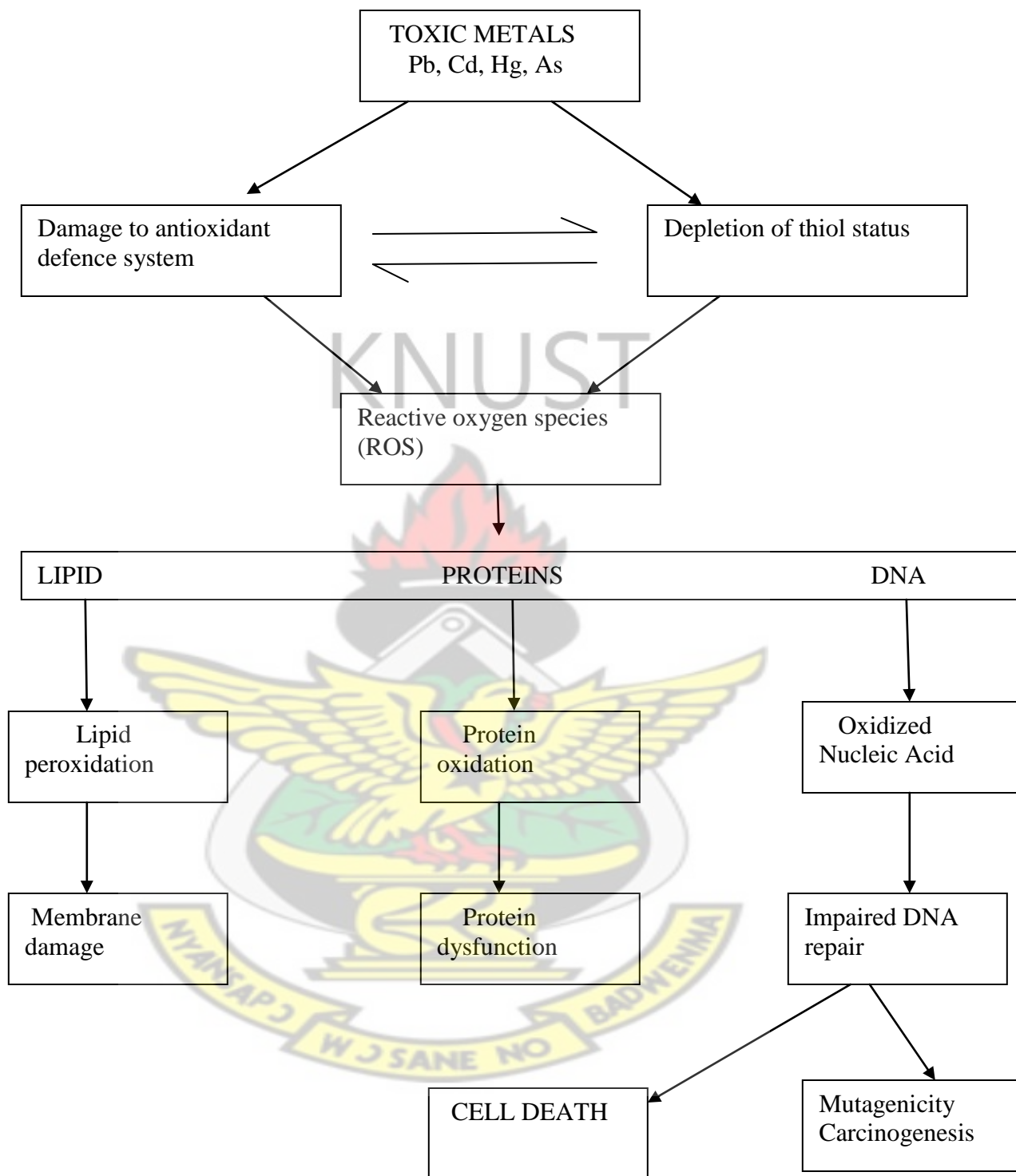
2006). High turbidity can increase the water temperature since heat is absorbed by the particles (Hernandez, 2011). Deterioration in drinking water quality in distribution network is probably due to an increase in microbial numbers, an elevated concentration of iron or increased turbidity, all of which affect taste, odour and colour, in the drinking water. Turbidity can provide shelter for opportunistic microorganisms and pathogens. Hence, waters with high turbidity, from organic sources, also give rise to a substantial chlorine demand for disinfection purposes. This could result in reductions in the free chlorine residual in distribution systems as protection against possible recontamination. Therefore, increased pre-chlorination dosage requirements are strongly correlated with increases in turbidity. Increase in turbidity will result in increase in coliform count (Qaiser et al., 2008). Higher turbidity increases water temperatures because suspended particles absorb more heat. This in turn reduces the concentration of dissolved oxygen (DO) because warm water holds less DO than cold. Higher turbidity also reduces the amount of light penetrating the water, which reduces photosynthesis and the production of dissolved oxygen. Suspended materials can clog fish gills, reducing resistance to disease, lowering growth rates and affecting egg and larval development. Sources of turbidity include tailings from small scale mining, soil erosion, waste discharge, urban runoff, eroding stream banks, large numbers of bottom feeders and excessive algal growth (PCTU, 2010). The maximum acceptable concentration for turbidity in water entering a distribution system is 1 nephelometric turbidity unit (NTU), established on the basis of health considerations (TGHC, 1995). In a study conducted by Asamoah- Boateng, (2009) on the physico-chemical and microbiological quality of surface waters within the Newmont Ghana Gold mining



concession areas the turbidity range was found to be 56.40 to 112.96 NTU. The turbidity guideline for drinking water is 5NTU (WHO, 1997).

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Source: (Ercal *et al.*, 2001)

**Figure 2 Possible mechanisms for metal-induced oxidative stress**

### 2.6.3 Electrical conductivity (EC)

Conductivity is the ability of water to conduct an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids, such as chloride, nitrate, sulphate and phosphate anions, or sodium, magnesium, calcium, iron and aluminium cations. Pure water has very low conductivity; the higher the levels of dissolved solids, the higher the conductivity. Conductivity is also affected by temperature; the warmer the water, the higher the conductivity. Conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows. Streams that run through areas with granite bedrock tend to have lower conductivity because granite is composed of more inert materials that do not ionize when washed into the water. On the other hand streams that run through areas with clay soils tend to have higher conductivity because of materials that ionize rapidly when washed into the water. Mining, industrial and other discharges can dramatically increase the conductivity of streams through the addition of dissolved solids. Conductivity is measured in micromhos per centimeter ( $\mu\text{mhos/cm}$ ) or microsiemens per centimeter ( $\mu\text{S/cm}$ ). Distilled water has a conductivity in the range of 0.5 to 3  $\mu\text{S/cm}$  (PCTU, 2010). High conductivity reflects the pollution load as well as the trophic levels of aquatic organisms. Conductivity levels in drinking water are 700  $\mu\text{S/cm}$  (WHO, 1987). Conductivity measures indicate whether the water contains excessive salts that could be unhealthy for plants, producing root death and leaf drop. The conductivity level in the Suraw river as a result of Chirano Gold Mines Operations in Ghana was found to be in the range of 181 – 605  $\mu\text{S/cm}$  (Kyekyeku, 2011).

#### 2.6.4 Temperature

Water temperature is an important parameter because it is a critical factor in determining the growth of the microorganisms. Bacterial growth rates, decay of disinfection residual, corrosion rates and even distribution hydraulics are all affected by water temperature. Temperature also affects the dissolved oxygen (DO) level in a water body. DO is critical for the survival of aquatic organisms for aerobic respiration (Qaiser et al., 2008). Optimal temperatures for fish depend on the species: some survive best in cold water, whereas others prefer warmer water. Benthic microinvertebrates are also sensitive to temperature and will move in the stream to find their optimal temperature. If temperatures are outside their optimal range for a prolonged period of time, organisms are stressed and can die. Temperature also affects the conductivity of the water; the warmer the water, the higher the conductivity (PCTU, 2010). The temperature of water samples from River Suraw in the Chirano Gold Mines Operation was found to be in the range of 25.9 °C to 28.0 °C (Kyekyeku, 2011). According to WHO, (2003) the maximum permitted standard of drinking water is 25 to 28 °C.

#### 2.6.5 pH

pH is a term used to indicate the alkalinity or acidity of a substance as ranked on a scale from zero to 14.0, with 7.0 being neutral (neither acidic nor alkaline). pH decreases as acidity increases. pH affects many chemical and biological processes. For example different organisms flourish within different ranges of pH. The largest variety of aquatic animals prefers a range of 6.5 to 8.0. A pH outside this range reduces biological diversity in a stream because it stresses the physiological systems of most organisms and can reduce

reproduction. Low pH can also allow toxic elements and compounds (such as aluminium in acid mine drainage) to become mobile and available for uptake by aquatic plants and animals. This can produce conditions toxic to aquatic life. Changes in acidity can be caused by atmospheric deposition (acid rain), erosion and solution of surrounding rock, and certain water discharges, including acid mine drainage (PCTU,2010). The desirable pH range for drinking water is 6.5 to 8.5 (WHO, 1996). Exposure to extreme pH values results in irritation to the eye, skin, and mucous membranes. Eye irritation and exacerbation of skin disorders have been associated with pH values greater than 11. In sensitive individuals gastrointestinal irritation may also occur. Exposure to low pH values can also result in similar effects (WHO, 1996). In a study conducted on the impact of Chirano Gold Mines Operations on the Suraw river, the pH level of the water samples collected from the river was found to be in the range of 6.50 – 7.60 ( Kyekyeku, 2011).

#### **2.6.6 Alkalinity**

Alkalinity of water is the quantitative capacity to react with a strong acid to a designated pH. High alkaline waters are usually unpalatable. Excess alkalinity in water is harmful for irrigation which leads to soil damage and reduce crop yield. Alkalinity measures the ability of water bodies to neutralize acids and bases thereby maintaining a fairly stable pH. Water that is a good buffer contains compounds, such as bicarbonates, carbonates, and hydroxide which combine with  $H^+$  ions from the water there raising the pH (more basic) of the water. Without the buffering capacity, any acid added to a lake would immediately change its pH. Aquatic organisms benefit from a stable pH value in their optimal range. To maintain a fairly constant pH in water body, a higher alkalinity is preferable. High alkalinity means

that the water body has the ability to neutralize acid pollution from rainfall or basic inputs from waste water. Alkalinity is measured as the amount of acid needed to bring the water sample to a pH of 4.2 (Addy et al., 2004). In a study conducted by Asamoah- Boateng, (2009) on the physico-chemical and microbiological quality of surface waters within the Newmont Ghana Gold mining concession areas the alkalinity range was found to be 95.54 to 244.24mg/L. The guideline for alkalinity in a drinking water sample is 600mg/L (WHO, 2003).





## **CHAPTER THREE**

### **METHODOLOGY**

#### **3.1 DESCRIPTION OF THE STUDY AREA**

##### **3.1.1 Location**

The Asante Akim North Municipal Assembly is one of the 27 Districts in the Ashanti region. It has Konongo-Odumase as its twin capital town. The municipality is located in the Eastern part of the Ashanti Region and lies between latitude 6° 30' North and 7° 30' North and longitude 0° 15' West and 1° 20' West. It covers a land area of 1,160Km<sup>2</sup> with an estimated population of 142,434 in 2006 (Source: National population and housing census 2000). The Municipality shares boundaries with Sekyere east on the North, Kwahu South on the east, Asante Akim South on the south and Ejisu Juabeng Municipality on the west.

##### **3.1.2 Climate**

The Municipality lies within semi-equatorial belt characterized by double rainfall maxima. The first rainy season starts from May to July and the second from September to November. The dry harmattan season occurs between December and April and is associated with drought condition (Boadi et al., 2013). The annual rainfall of the Municipality averages between 150 – 170 mm. The daily temperature ranges from 22°C – 30°C with minimum monthly temperature of 26°C and maximum temperature of 30°C recorded in March and April. The average humidity in the area is 75 – 80% (Boadi et al., 2013).

### **3.1.3 Topography and drainage**

The topography of Konongo is that of undulating land. To the north of the Municipality is the prominent Kwahu escarpment, where elevations are about 550 – 600 meters above sea level near Agogo. The escarpment stands well above the low rolling hills in much of the Municipal, where elevations are mainly in the range of 180 – 260 meters above sea level. In the South- east corner of the Municipal is the very large batholiths of the Bansa intermediate granitoid with a peak elevation of about 580 meters above sea level in the central area of the batholiths (Boadi et al., 2013).

### **3.1.4 Vegetation**

The municipality lies within the moist semi-deciduous forest belt. The major vegetation types are the open forest covering 576km<sup>2</sup> over the highland areas, the closed forest covering 230km<sup>2</sup> on the range and the Wooded Savannah covering 246sq.km. These varieties consist of different species of tropical woods such as Wawa, Ofram, Sapele, Sanfina, Okyere, Onyina, Kyenkyen, Otie, Yaya, wich have high economic value. Most of the original forest in the municipality has degenerated into secondary forest and grassland due to indiscriminate felling of trees, bush fire and poor farming practices such as shifting cultivation, bush fallowing, slash and burn and bush burning for fresh forage for cattle feeding. In some parts of the districts, which fall within the Afram Plains, the semi-deciduous forest is gradually degenerating into interior wooded savannah due to intensive farming activities (AACMA, 2007).

### **3.1.5 Geology**

The geology of the area is dominated by Birimian meta-sediment/volcanic and the Tarkwaian clastic formation. To the east, the Tarkwaian formation widens out very substantially and to the west of the Municipal there are mainly Birimian meta-sedimentary units of Kumasi Basin. Within the basin domain are large masses of basin –type granitoids belonging to Kumasi complex. Early workers in the area believed this granitoid to be post-Birimian and pre Tarkwaian because of the lack of contact metamorphic effects in the Tarkwaian formation close to the batholiths. However, recent work has revealed that the Babso batholiths is a fairly late stage intrusion that apparently post dates the Tarkwaian formation (Boadi et al., 2013).

### **3.2 Data collection**

Data collection involved collection of water samples of the Owere river at different locations namely upstream, midstream and downstream. The sampling was done in a period of four months from 10<sup>th</sup> February to 10<sup>th</sup> May, 2012. The code P1, K1 and O1 were used to represent Upstream (Patrensa), Midstream (Konongo) and Downstream (Odumase) water samples respectively. Figures were used to represent the number of samples taken.

### **3.3 Sampling site**

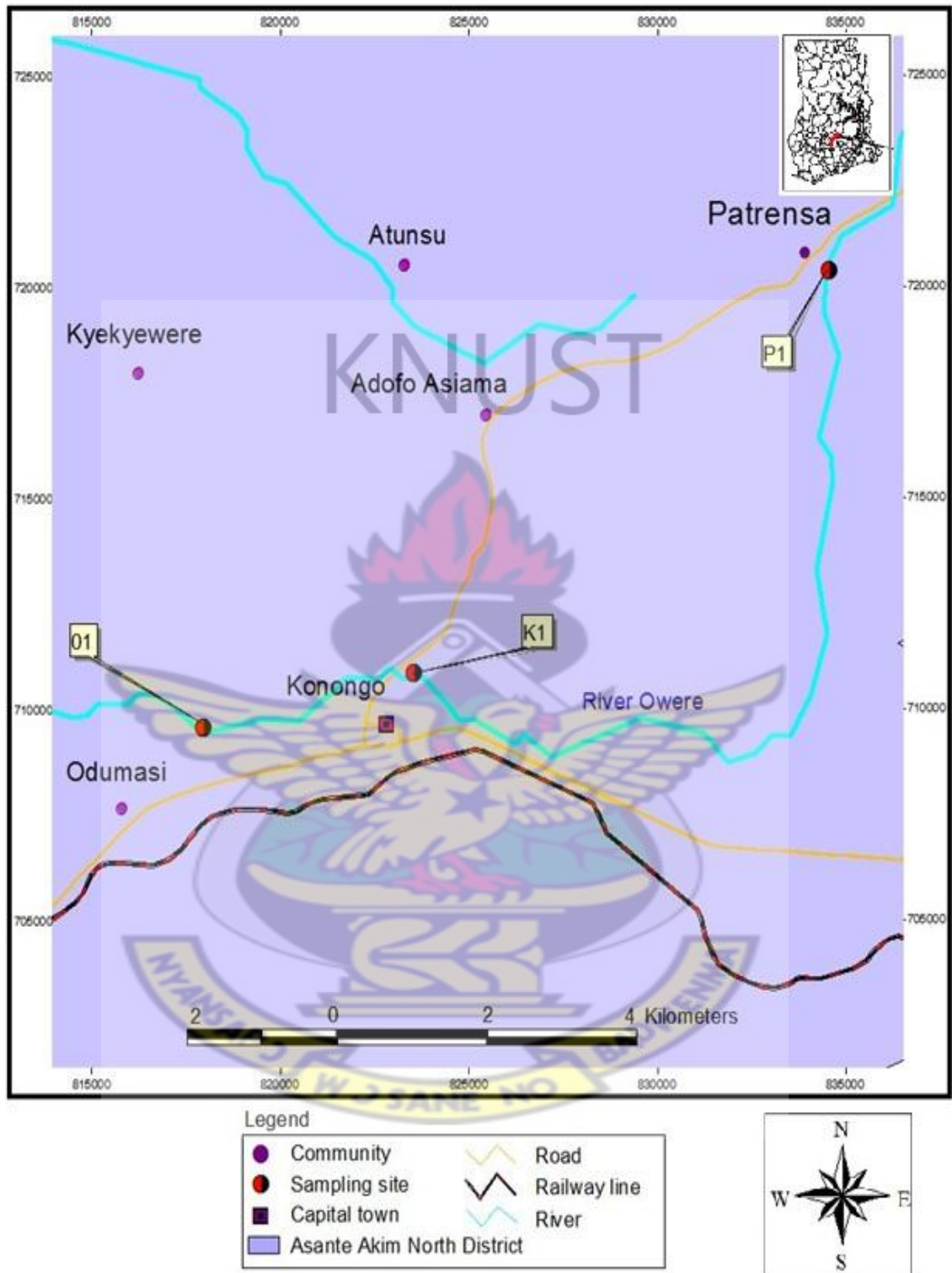
The sampling sites were the upstream, midstream and downstream of the Owere river. The codes P1, K1 and O1 were used to indicate Upstream, Midstream and Downstream sampling points respectively as shown in figure 3. The upstream sample site was selected

because it is closer to the source of the river. The midstream sample site was selected because it is the area where the small-scale mining activities are very prominent while the downstream sample site was also chosen because it is closer to the place where the Owere joins the Annuru River.

### **3.4 SAMPLING**

#### **3.4.1 Water sampling**

River water samples were collected from three sampling sites (upstream, midstream and downstream). In all a total of twenty four water samples were collected from the three sampling sites. On each sampling occasion two samples were taken from each sampling point. This was done bimonthly for a period of four months. Prior to sampling, the 500ml plastic bottles were washed with detergent and rinsed with deionised water. Some of the river water was used to rinse the bottles before sampling to prevent mixing of rinse water with final sample. The water samples were collected by tilting the bottles against the direction of flow stream. After sampling, the water samples were acidified and the bottles were tightly covered with caps and packed on ice in an ice chest and transported to the laboratory where they were stored in a refrigerator at 4°C. Acidification of samples was done to keep metal ions from precipitating and to minimize adsorption of dissolved species onto the sample containers. The temperatures, pH, total dissolved solids and electrical conductivity of the water were determined at the sampling sites with the Hach Sensations 5 Conductometer instrument. All instruments were calibrated before use.



**Figure 3: A map showing surface water sampling points of the River Owere**

Source: Global-map Consult, 20



### 3.5 SAMPLE ANALYSIS

#### 3.5.1 Calibration of equipments

The pH meter was calibrated with a pH buffer 4, 7 and 9. The electrode was rinsed with distilled water but the membrane was not wiped. The electrode was submerged into the pH 7 buffer and waited until the icon stops flashing. The calibration button was then pressed again. The procedure was repeated for the pH buffer 4 and 9.

The probe of the conductivity meter was calibrated by immersing it into 0.14 M KCl solution at 18.0 ms/cm and 0.14 M KCl solution at 1413 ms/cm.

The AAS standardization was done by calibration solutions at three point concentrations for each element. The  $R^2$  for each calibration curve should be 0.99 or better up to 1.0. Prior to this the gains for the signals and lamps are optimized. To ensure quality control of the AAS, blank sample was used first. The samples to be analysed were also duplicated.

#### 3.5.2 Analysis of physico-chemical parameters

The turbidity was determined at the laboratory with DR/890 Colorimeter. The alkalinity was also determined using the titration method.

During the titration method, the burette was filled with  $0.02 \text{ Mol dm}^{-3}$  (HCl) to a certain volume. 50ml of the water sample was placed in a beaker and the pH meter probe was placed in the water sample in the beaker. The HCl was titrated against the water sample while stirring with the pH meter probe continuously. Titration and stirring continued until



the pH meter reading reached 4.5. The final burette reading was taken and the titre value was calculated. The value multiplied with a factor of 20 gave the alkalinity of the water samples.

### **3.5.3 Sample Digestion and analysis**

Water samples were filtered with the filtration set up pump before digestion. For water sample digestion, 5 ml of each sample was pipette into a teflon beaker. 6ml of concentrated  $\text{HNO}_3$  (67%) was added to each water sample. 3 ml of concentrated  $\text{HCl}$  (37%) and 0.25ml (30%) of  $\text{H}_2\text{O}_2$  was added to each sample. The beakers were covered and swirled gently for the content to mix. The Teflon beakers were placed vertically in the rhoto and tightened. The samples were sent to the (ETHOS 900) microwave milestone digester at GAEC and digested for 21minutes and vented for 5minutes. After digestion, the beakers were cooled in water bath for 30 minutes to reduce the temperature and the pressure within the teflon beakers. The mixture was transferred to a volumetric flask and diluted with deionised water to the 20 ml mark and transferred to labeled test tubes for analysis. Blank samples were also prepared in a similar way and digested together with the samples. Analysis of heavy metals in the water samples were done using Atomic Absorption Spectrophotometer ( VARIAN AA 240FS) instrument.

### **3.6 DATA ANALYSIS**

Statistical analysis for data in the study were performed using statistical software SPSSS (Statistical Package for the Social Sciences, Version 16.0). One-way Analysis of Variance (ANOVA) was performed to test the differences in heavy metals levels among the three

sampling sites: Upstream, Midstream and Downstream. The significant level considered was  $< 0.05$ . The Multiple Comparisons table which contains the results of Tukey post-hoc test was used to find where statistically significant differences exist among the three sites

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## CHAPTER FOUR

### RESULTS

#### 4.1 Mean concentrations of Heavy metals

The mean concentrations of heavy metals in water samples recorded for the entire study period is shown in the Table 2.

There was no significant difference within and between arsenic levels recorded at the various sites ( $p=0.357$ ). However the level recorded at the upstream was higher as compared to the midstream and downstream samples. The levels of cadmium recorded at the three sites showed no significant difference ( $P=0.547$ ). Comparatively the highest level of cadmium was recorded in the upstream, followed by midstream and downstream samples. Furthermore the difference in iron levels recorded showed significant difference ( $P<0.001$ ) at the sites. There was a significant difference between upstream and midstream samples ( $P<0.001$ ) and upstream and downstream samples of iron ( $P=0.001$ ). However, the difference between midstream and downstream samples was not statistically significant ( $P=0.887$ ). Meanwhile there was a significant difference ( $P=0.035$ ) in the lead levels recorded at the three sites. There was no significant difference in lead levels between the upstream and midstream samples ( $P=0.240$ ). However there was a significant difference in lead levels between the upstream and downstream samples ( $P=0.028$ ), but the difference between the midstream and downstream water samples was not statistical significant ( $P=0.378$ ). In addition the levels of mercury recorded at the sites showed no significant difference ( $P=1.47$ ).

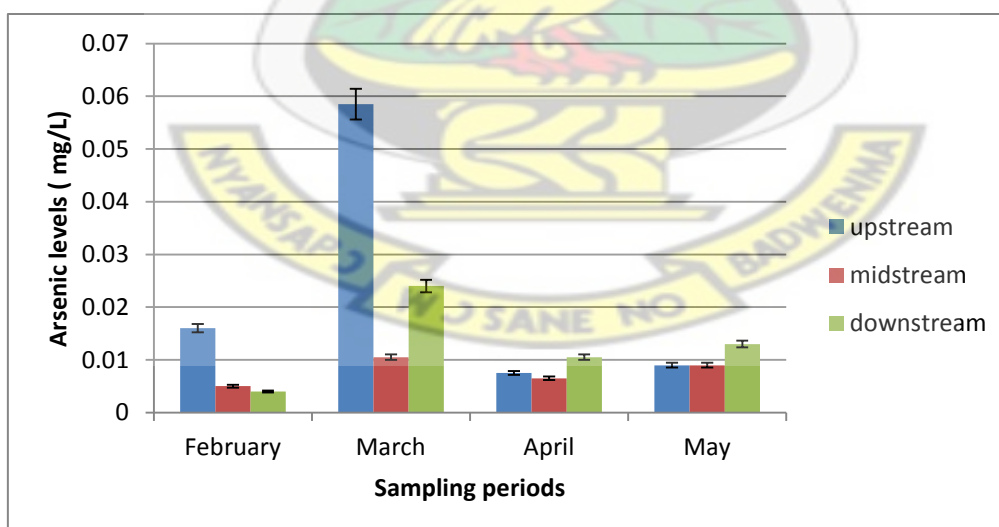
**Table 4.1 Mean concentration of Heavy metals (mg/L)**

Heavy metal	Mean and Standard deviation		
	Upstream (A)	Midstream (B)	Downstream (C)
Arsenic (mg/L)	0.022 ± 0.024	0.007 ± 0.002	0.012 ± 0.008
Cadmium (mg/L)	0.066 ± 0.094	0.029 ± 0.009	0.027 ± 0.011
Iron (mg/L)	4.907 ± 1.063	1.785 ± 0.350	2.015 ± 0.438
Lead (mg/L)	0.010 ± 0.0041	0.131 ± 0.128	0.228 ± 0.109
Mercury (mg/L)	0.001 ± 0.0005	0.002 ± 0.0007	0.001 ± 0.0005

## 4.2 Monthly concentrations of Heavy metals (mg/L) during study period

### 4.2.1 ARSENIC

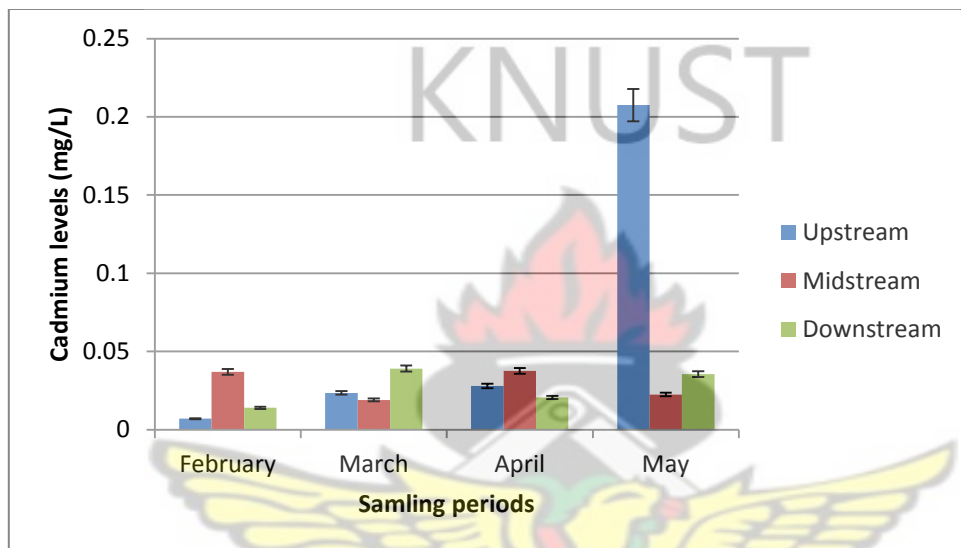
The level of Arsenic was high in the upstream, followed by downstream and midstream (Table 4.1). The highest level was recorded during the month of March (Figure 4). Levels recorded in the upstream and downstream in February and March were above WHO guideline for drinking water of 0.01 mg/L.



**Figure 4 monthly mean of arsenic concentration in water samples (mg/L) during study period.**

#### 4.2.2 CADMIUM

The monthly mean levels for Cadmium recorded during the study period is shown in figure 5. The level recorded in the upstream in May was 0.21 mg/L and was the highest among the three sites. However, the levels recorded from all the sites were above WHO 0.003 mg/L guideline for drinking water.

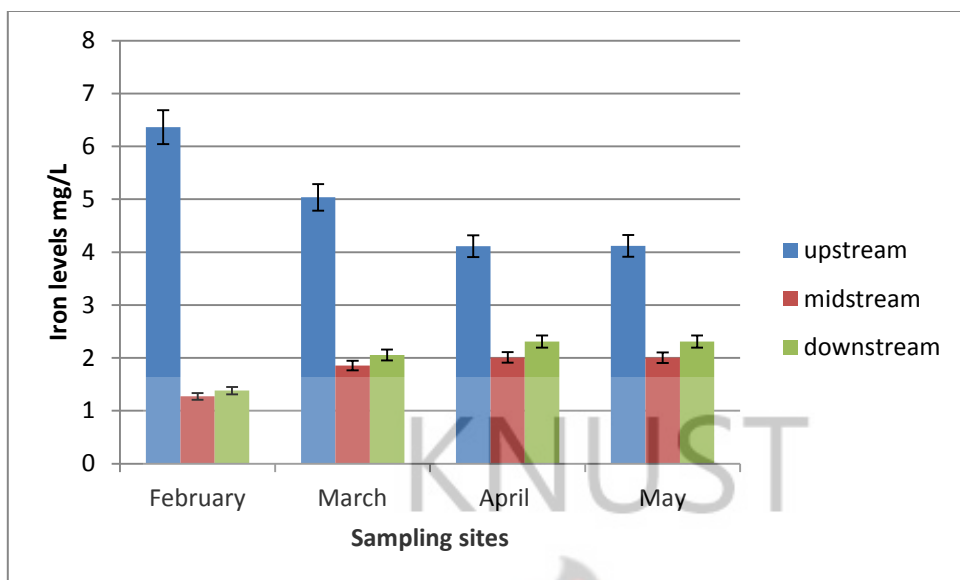


**Figure 5 Monthly mean of Cadmium concentration in water samples (mg/L) during study period.**

#### 4.2.3 IRON

The mean levels of iron the upstream samples recorded in February, March, April and May were 6.36, 5.03, 4.11 and 4.12 mg/L respectively (Figure 6). Comparatively, levels recorded in the midstream and downstream samples were low. However, the levels recorded at all the sites were above WHO permissible limit of 1.0 mg/L for drinking water.

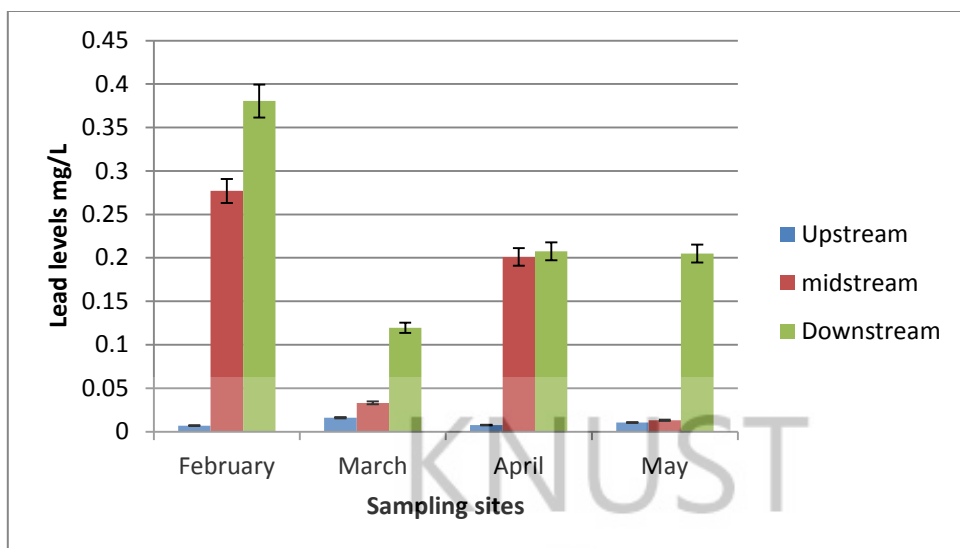




**Figure 6 Monthly mean of Iron concentrations (mg/L) in water samples during study period.**

#### 4.2.4 LEAD

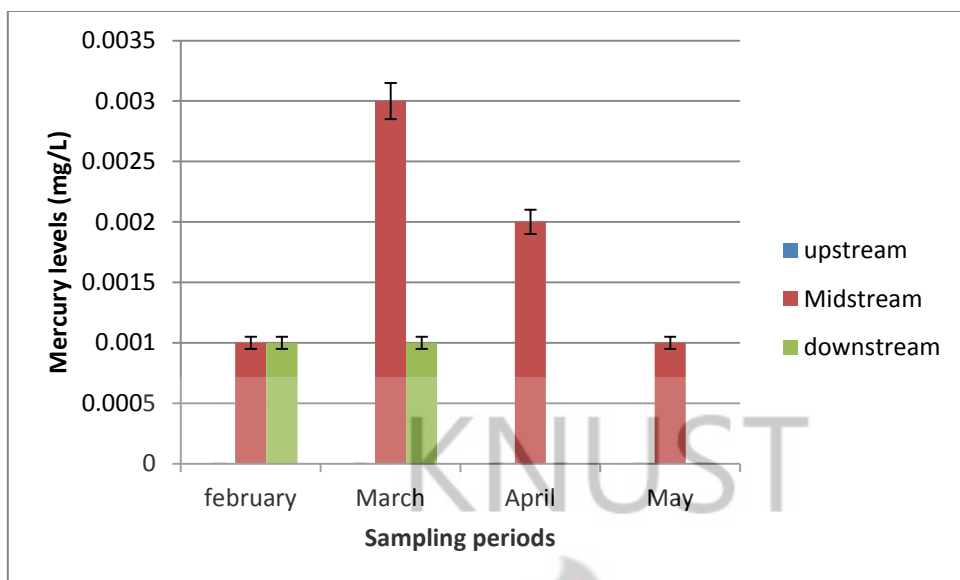
The highest level of lead was recorded in the downstream water samples and the lowest in the upstream samples followed by midstream as shown in figure 7. In the downstream the highest level was recorded in February. This level decreased in March and increased again in April. The upstream samples recorded the least level of lead in the water samples. Levels recorded in midstream and downstream from all the sites were above WHO guideline for drinking water limit of 0.01 mg/L.



**Figure 7 Monthly mean of Lead concentrations (mg/L) during study period**

#### 4.2.5 MERCURY

The mean concentrations of mercury recorded in water samples during the study period are shown in figure 8. The levels in the upstream water samples were below instrument detectable limit of 0.001 mg/L. The levels recorded in the midstream and downstream water samples in March and April were above WHO guideline of 0.001 mg/L for drinking water. Levels recorded in the downstream were within the permissible limit.



**Figure 8 Monthly mean of Mercury concentrations (mg/L) during study period**

#### 4.3 Physico- Chemical Parameters

The mean values of the selected physico-chemical parameters are shown in Table 4.2.

The highest pH was recorded in the downstream water samples and the lowest in the upstream samples. There was no significant difference between the sites ( $P=0.319$ ). The mean electrical conductivity recorded in the midstream samples was high compared to the conductivity levels recorded in the downstream and upstream samples. Statistically, there was no significant difference ( $P=0.548$ ) in the conductivity levels between the sites. The highest total dissolved solids level was recorded in the downstream samples while the lowest was obtained in the upstream samples. However, there was a significant difference in the levels of total dissolved solids between the sites ( $P=0.009$ ). Turbidity levels from the water samples were high in the upstream samples and low in the midstream samples. However, there was no significant difference in the turbidity levels recorded at the various sites ( $P=0.428$ ). The mean temperatures recorded from the sampling sites were within the ranges of 24.9 to 25.1 ( $^{\circ}\text{C}$ ). The temperature difference among the sites was not significant

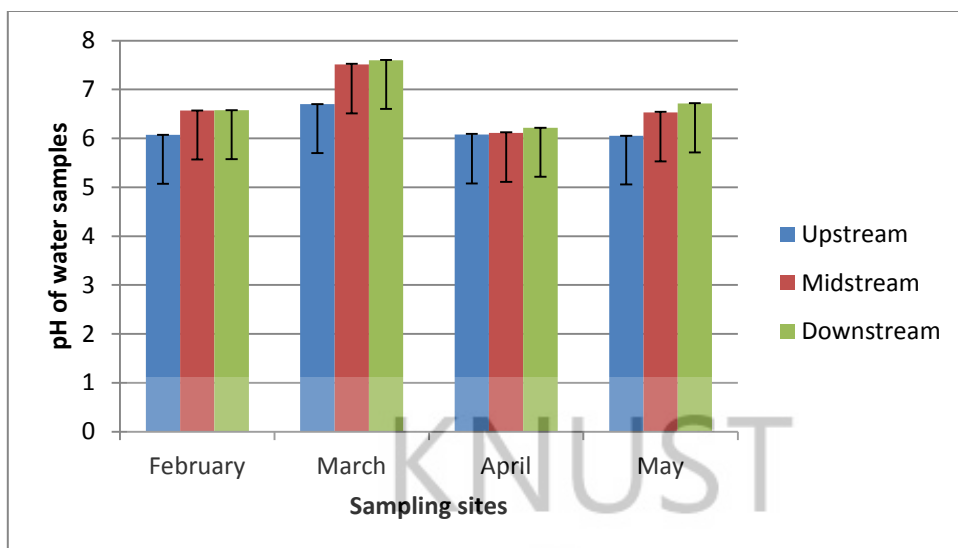
(P=0.209). The downstream samples recorded the highest alkalinity level and the least in the upstream samples. However the difference in alkalinity levels between the sites was not statistical significant (P=0.142).

**Table 4.2 Mean concentrations of physico- chemical parameters of water samples during study period.**

Physico – chemical parameters	Mean Concentrations		
	Upstream (A)	Midstream (B)	Downstream (C)
pH	6.23 ± 0.316	6.68 ± 0.591	6.78 ± 0.588
Electrical conductivity (µS/cm)	268.63 ± 6.811	298.0 ± 14.508	262.5 ± 80.328
Total dissolved solids (mg/L)	121.05 ± 10.509	144.23 ± 7.231	148.7 ± 12.499
Turbidity (NTU)	62.5 ± 6.390	55.5 ± 8.602	58.25 ± 6.701
Temperature (°C)	25.9 ± 1.152	24.9 ± 0.600	25.1 ± 0.342
Alkalinity (mg/L)	84.12 ± 9.467	91.87 ± 6.702	97.1 ± 8.651

#### 4.3.1pH

The pH levels recorded at the various sites were within the permissible limit of 6.5 to 8.5 standards for drinking water set by WHO. The least pH of 6.0 was recorded in the upstream samples in the months of February, April and May. Downstream samples recorded the highest pH of 7.6 in March as shown in figure 9.

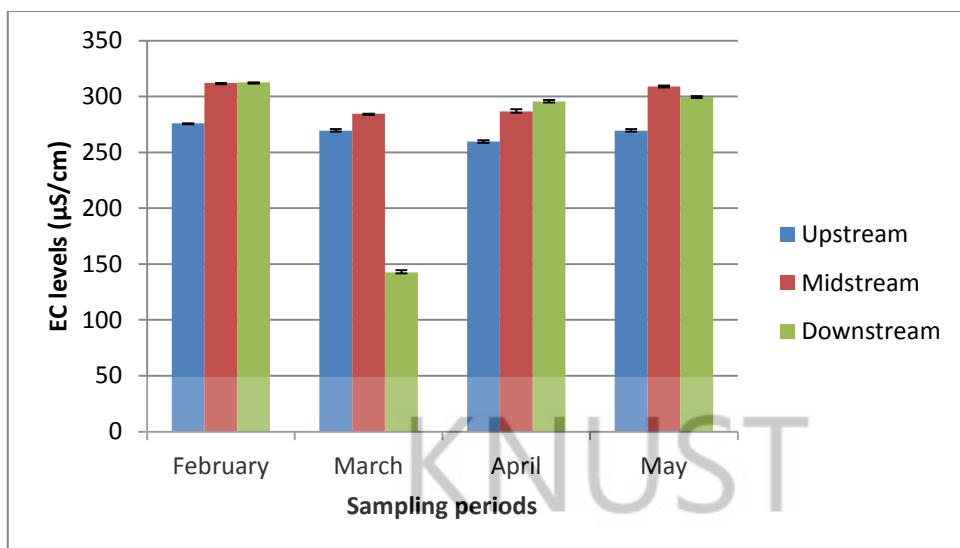


**Figure 9 Monthly mean concentrations of pH in water samples during study period**

#### **4.3.2 ELECTRICAL CONDUCTIVITY**

The mean levels of conductivity for the water samples were within the ranges of 142 to 312 ( $\mu\text{S}/\text{cm}$ ) in the Upstream, Midstream and Downstream water samples. The lowest conductivity level of 142.5 ( $\mu\text{S}/\text{cm}$ ) was recorded in the downstream samples in the month of March. This trend is shown in figure 10. Comparatively the upstream samples recorded low conductivity levels. Conductivity levels from all the sampling sites were below the guideline for drinking water limit of 700 ( $\mu\text{S}/\text{cm}$ ) set by WHO.

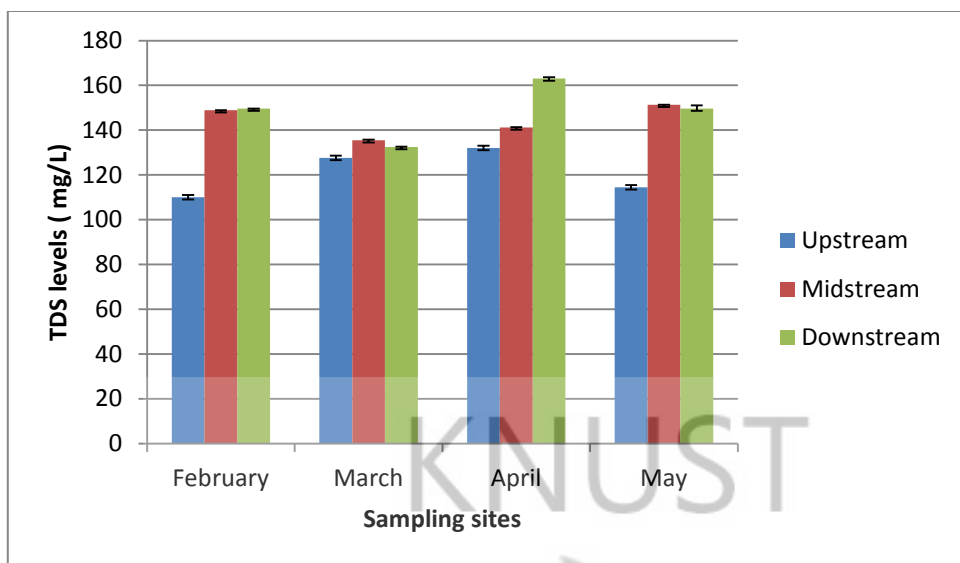




**Figure 10 Monthly mean of Electrical conductivity ( $\mu\text{S}/\text{cm}$ ) during study period.**

#### 4.3.3 TOTAL DISSOLVED SOLIDS

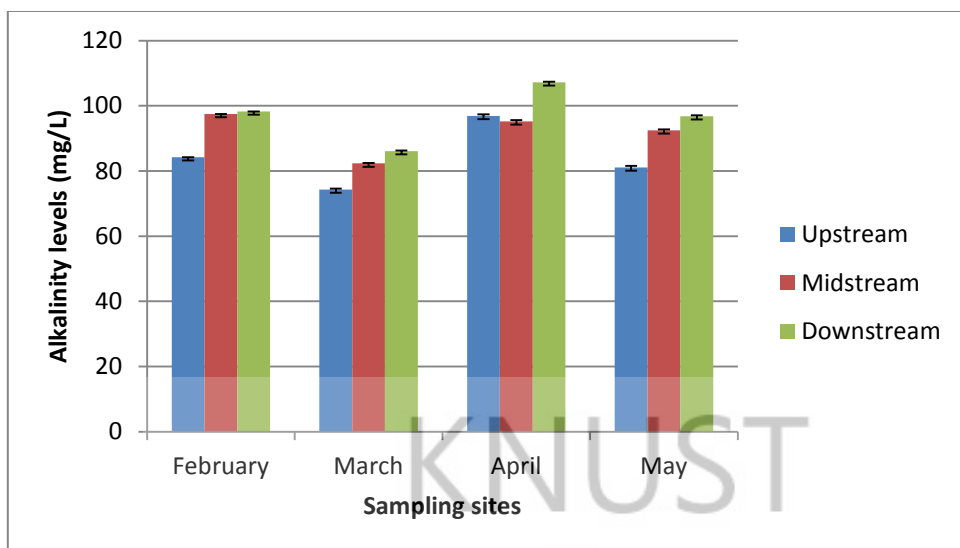
The mean levels of total dissolved solids (TDS) recorded during the study period is shown in figure 11. The minimum levels were recorded in the upstream samples during the month of February and May. A highest level of 163 mg/L was obtained in the downstream samples in April. This level decreased to 149.6 mg/L in May. The levels recorded in the upstream samples increased from 110 mg/L to 132.1 mg/L in April. However, the levels recorded from all the sites fell within the WHO drinking water guideline limit of 1000 mg/L.



**Figure 11 Monthly mean concentrations of Total dissolved solids (mg/L) in water samples during study period**

#### **4.3.4 ALKALINITY**

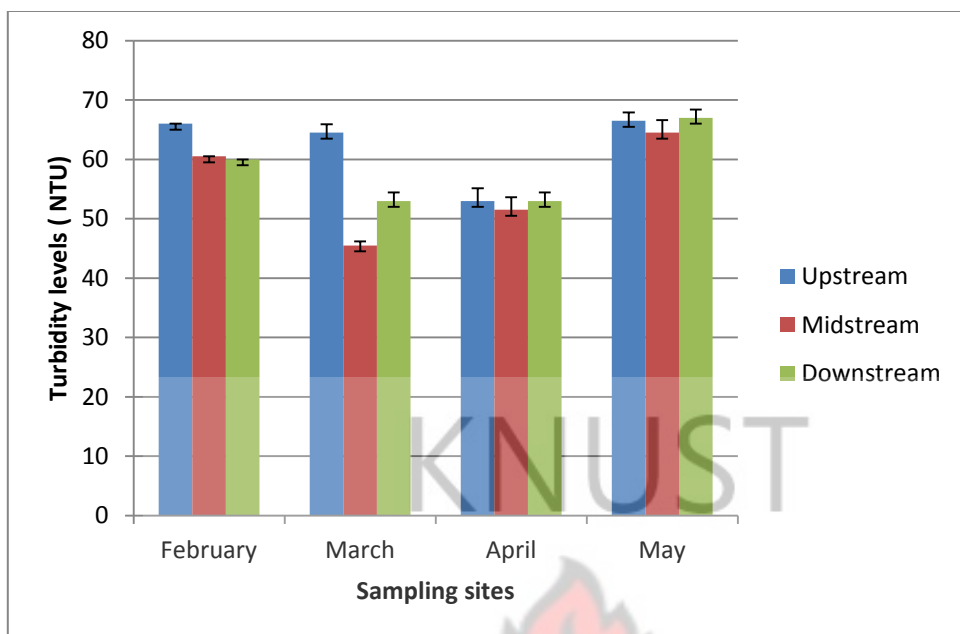
The means of alkalinity range from 74.3 to 107.2mg/L (figure 12). In the Downstream the highest mean of 107 (mg/L) was recorded during the month of April. Alkalinity levels in the midstream were 97.5, 82.3, 95.2 and 92.5 (mg/L). The guideline limit for drinking water by WHO is 600 (mg/L). The levels obtained from all the sampling sites were below the guideline limit. The trend in alkalinity is shown in Figure 14. To maintain a fairly constant pH in water body, a higher alkalinity is preferable. High alkalinity means that the water body has the ability to neutralize acid pollution from rain or basic inputs from waste water (Addy et al.,2004).



**Figure 12 Monthly mean levels of Alkalinity (mg/L) in water samples during study period.**

#### 4.3.5 TURBIDITY

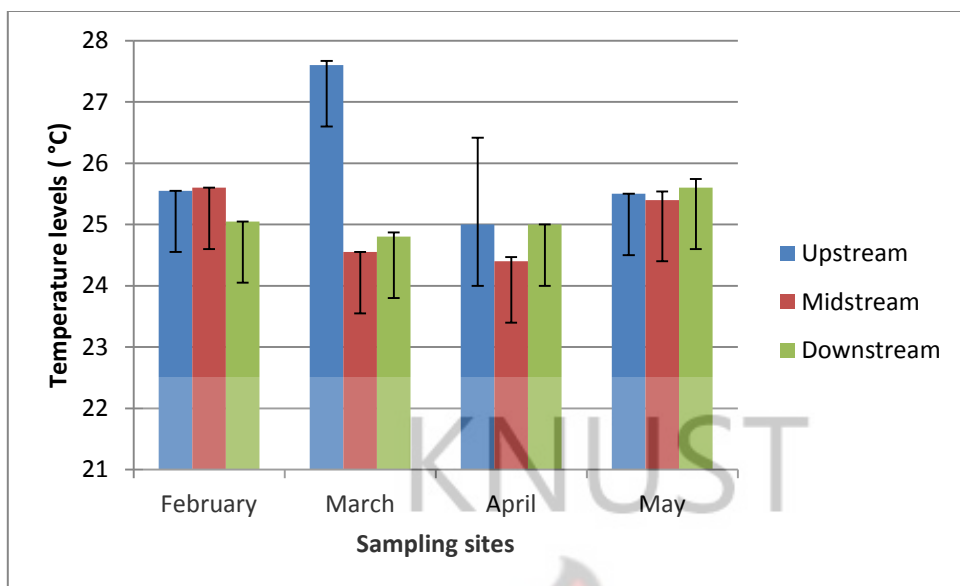
The least turbidity level of 45.5 (NTU) was recorded in the Midstream during the month of March (figure 13). However, the level at this site increased again for the subsequent months. Comparing the levels recorded in the various months, the highest turbidity level of 67 (NTU) was recorded in the downstream samples in May. The WHO guideline limit for turbidity in drinking water is 5 (NTU). However, levels recorded at all the sampling sites were above this limit.



**Figure 13 Monthly mean levels of Turbidity (NTU) of water samples during study period.**

#### **4.3.6 TEMPERATURE**

From Figure 14 the monthly mean temperatures recorded at the various sites fell within the 25 to 28 °C WHO guideline for drinking water. Among the months the highest temperature of 27.6 °C was recorded in March in the upstream samples and the least (24.4 °C) in April among the midstream samples. Temperatures obtained from all the sampling sites in February and May were above 25 °C.



**Figure 14 Monthly mean of Temperature (°C) of water samples during study period.**

#### **4.4 Analysis to Questionnaire**

##### **4.4.1 Demographic characteristics of respondents**

These miners engage in different kinds of other occupation but majority of them who represented 32% as shown in table 5 engage in mining as their main occupation (Table 4).



**Table 4 Demographic characteristics of respondents**

Sex		
Gender	Frequency	Percent
Male	45	90
Female	5	10
Total	50	100
Level of education		
Education	Frequency	Percent
Primary	9	18
JHS	15	30
SHS	6	12
Tertiary	5	10
Non –formal education	8	16
Never been to school	7	14
Total	50	100
Main Occupation		
Occupation	Frequency	Percent
Mining	16	32
Farming	10	20
Dress making	7	14
Driving	7	14
Other	10	20
Total	50	100

#### 4.4.2 Number of years in mining

From table 6, seventeen (17) persons constituting 34% of the total respondents have remained in mining for the past five years. Also nine (9) respondents representing 18% have been mining for the past four years while eight (8) respondents who represented 16% have been mining for more than five years. In addition, six of the respondents constituting 12% have also been mining for the past two years. It can be concluded that majority (34%) of the total respondents have been mining for the past five years.

**Table 5 Number of years in mining**

Years	Frequency	Percent
1 year	2	4
2 years	6	12
3 years	8	16
4 years	9	18
5 years	17	34
>5 years	8	16
Total	50	100

#### 4.4.3 Use of protective wear

The responses obtained from the miners on whether they use protective wear indicates that twenty nine (29) respondents constituting 58% do not use any protective wear while 42% of the respondents use protective wear.

**Table 6 Protective wear used by miners**

Do you use any protective wear during mining?

Responses	Frequency	Percent
Yes	21	42
No	29	58
Total	50	100

Out of the twenty (21) respondents who use protective wear, eleven (11) representing 52% use Wellington boots during mining. Five (5) other respondents who represented 24% use nose mask as protective wear. In addition three (3) respondents constituting 14% use overall suit while the same number of respondents representing 14% use both nose mask and

goggles for protection. Two (2) other respondents who represented only 4% use goggles for protection as shown in Table 7.

**Table 7: How miners protect themselves**

How do you protect yourself?		
Protective wear	Frequency	Percent
Nose mask	2	4
Goggles	2	4
Nose mask and goggles	3	6
Overall suit	3	6
Wellington boots	11	22
No protection	29	58
Total	50	100

#### 4.4.4 Chemicals used for extraction of gold

Forty eight (48) respondents constituting 96% use mercury for extraction of gold while only two respondents representing 4% use HCl and Borax for the extraction process. It can be concluded that majority (96%) use mercury for gold extraction.

**Table 8: Chemicals used for extraction of gold**

Chemicals	Frequency	Percent
HCl, Borax	2	4
Mercury	48	96
Total	50	100

#### 4.4.5 Effects of chemicals on fish

The responses obtained from the miners indicate that thirty four (34) of them who represented 68% have no idea that their chemicals can have adverse effect on fish. Only sixteen (16) of the respondents representing 32% responded that their chemicals can have effect on fish. It can be concluded that majority (68%) of the respondents have no idea that the chemical used for the extraction of gold can have effect on fish.

**Table 9 Can those chemicals use for mining have effect on fish?**

Responses	Frequency	Percent
Yes	16	32
No	34	68
Total	50	100

#### 4.4.6 Effects of chemicals on the health of miners

The responses obtained from the respondents to ascertain whether those chemicals used for extraction of gold can have any effect on their health indicate that majority (27) of them representing 54% are aware of the effects of the chemicals on their health. Twenty three (23) of the respondents who represented 46% are not aware of the effects of the chemicals on their health as shown in Table10.

**Table 10 Can those chemicals used in the extraction of gold have any effect on your health?**

Responses	Frequency	Percent
Yes	27	54
No	23	46
Total	50	100

#### **4.4.7 Role in mining and effects suffered by miners as a result of mining**

The responses obtained from various roles played by respondents indicate that twenty eight (28) persons who represented the majority are engaged in washing of excavated soil during mining activities. Out of this two (2) persons who represented 4% suffer from coughing. Twelve (12) other persons who constitute 24% do suffer from skin rashes while two (2) others representing 4% also suffer from irritating eyes. In addition three (3) other persons who represented 6% do suffer from stomach complications as a result of the washing activities.

Furthermore, sixteen (16) other respondents are also involved in excavation. Out of this thirteen (13) of them constituting 26% suffer from coughing while the remaining three (3) persons who constitute 6% also suffer from irritating eyes. Out of the three (3) respondents who are engaged in water fetching, one (1) of them representing 2% do suffer from skin rashes. In addition three (3) other respondents are engaged in other roles. Out of this one (1) person who represented 2% suffer from coughing while two (2) others also representing 4% do suffer from irritating eyes. It can be concluded that majority (26%) do suffer from coughing.



**Table 11: Role in mining and effects suffered by miners as a result of mining activities**

Role	Coughing		Skin rashes		Irritating eyes		Stomach complications	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Excavation (16)	13	26	Nil		3	6		
Washing (28)	2		12		2		3	6
Fetching water(3)		4	1	24		4		
Other (3)	1	2		2	2	4		

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## CHAPTER FIVE

### Discussion

The Owere River is a common source of water for domestic activities in the Asante Akyem Central Municipality of Ghana. Indiscriminate small- scale mining activities in and along the river might be one of the anthropogenic sources of heavy metal pollution of the river. From Table 2 total arsenic levels in water samples collected during the study period showed no significant difference ( $P= 0.357$ ) between the sites and within the sites. The mean concentration was high in the upstream ( $0.022\pm0.024$  mg/L) than in the midstream and downstream. Ingestion of Arsenic is known to have caused skin tumours, lung cancer, liver dysfunction, peripheral neuropathy, hearing defects, and increased frequency of spontaneous abortions (Ercal et al., 2001). The levels recorded in all the three sites were below WHO permissible limit of 0.1mg/L (Abbas et al., 2010). However the level recorded in the upstream was higher than what Kyekyeku (2011) found in his study on the impact of Chirano Gold Mines Operations on the levels of some heavy metals in the Suraw river. The presence of arsenic could be from soil and small- scale mining activities.

Cadmium levels in water samples collected during the study period showed no significant difference ( $P= 0.547$ ) between the sites and within the sites. The mean level recorded in the Upstream water sample in May was above what Kyekyeku, (2011) found in the sites in his study on the impact of Chirano Gold Mines Operations on the Suraw river. Though the mean concentration recorded at other sites were below WHO permissible limit of 0.1mg/L (Abbas et al., 2010), what was recorded in Upstream water samples in May was above the permissible limit. Cadmium is toxic to virtually every system in the animal body (Raikwar

et al., 2008). After ingestion, cadmium ions are absorbed by both tissues of the body and become concentrated mainly in the liver and kidney. It is associated with cancers of the lung, prostate, pancreas and kidney (Flora, 2009). Cadmium levels recorded at these sites could be attributed to the activities of small-scale miners around these sites.

The level of iron in the water samples collected showed a significant difference between the sites and within the sites ( $P < 0.001$ ). The iron level was high in the upstream ( $6.363 \pm 0$  mg/L) than the midstream and downstream. The levels recorded in the Upstream water samples were all above the range of 0.4 mg/L to 2.4 mg/L level found by Akabzaa and Darimani (2001) in three different streams polluted by mining activities in Tarkwa. These levels are above WHO permissible limit of 1.0 mg/L in drinking water. High levels of iron cause staining in clothes and impart a bitter taste. Excess amounts of iron (more than 10 mg/L) causes rapid increase in pulse rate and coagulation of blood in blood vessels, hypertension and drowsiness (Patil and Ahmad, 2011).

Lead levels recorded for the study period showed significant difference among the sites ( $P < 0.05$ ). Within the sites there is a significant difference between upstream and downstream water samples ( $P = 0.028$ ) but between upstream and midstream the difference is not statistically significant ( $P = 0.240$ ). The high levels of 0.2 mg/L recorded in the Midstream and Downstream water samples is equivalent to what Akabzaa and Darimani recorded in the Damang Nkrakra stream in the Tarkwa mining region. The mean recorded in all the sites were within the WHO permissible limit of 0.2 mg/L (Abbas et al., 2010). Lead accumulated at soil surface may be taken up directly by grazing animals and by soil

micro-organisms and so enter terrestrial food chain (Denny et al., 1987). Lead poisoning also causes inhibition of the synthesis of haemoglobin, dysfunctions in the kidneys, joints and reproductive system, cardiovascular system and acute chronic damage to the central nervous system (Duruibe et al., 2007). The levels of lead observed may be due to small-scale mining activities in and along the Owere river.

Mercury levels recorded at all site during the study period showed no significant difference ( $P = 0.147$ ). The level recorded in the midstream ( $0.002 \pm 0.0007$  mg/L) was higher than the other sites. This may be due to the intensive small-scale mining activities along the midstream. However the levels recorded at all site were below 1.341mg/L level recorded by Nartey et al., (2011) in some rivers draining the Bibiani - Anwiaso – Bekwai mining community in Ghana. The level was below instrument detectable limit during the months of April and May at the upstream and downstream. The levels recorded at the three sites were below the permissible limit of 0.001mg/L in drinking water (WHO, 1996). The decline in downstream may be attributed to the mixing and dilution of contaminated water with uncontaminated water as the river flows. Acute ingestion of organic mercury compounds can cause diarrhoea, tenesmus and blisters in the upper gastrointestinal tract. There may also be symptoms of neurotoxicity such as impaired peripheral vision, muscle weakness and memory loss (Fauci et al., 1998).

The levels of pH recorded for the study period showed no significant difference among the sites and between the sites ( $P = 0.319$ ). The highest level was recorded in the Downstream water sample ( $7.60 \pm 0$ ). This level is similar to what Kyekyeku (2011) recorded in a study

conducted on the Impact of Chirano Gold Mines Operations on the Suraw river. Largest variety of aquatic animals prefers a pH range of 6.5 – 8.5. A pH outside this range reduces biological diversity in stream (PCTU, 2010). The pH recorded at all the sites were within the desirable pH range of 6.5 to 8.5 as recommended by WHO (WHO, 1996) for drinking water. Exposure to extreme pH value is known to have resulted in irritation to the eye, skin and mucous membrane (WHO, 1996).

Electrical conductivity recorded during the study period showed no significance difference among the sites ( $P= 0.548$ ). The highest level was recorded in the midstream samples,  $298.0 \pm 14.508$  ( $\mu\text{S}/\text{cm}$ ). However this level was below what Kyekyeku (2011) found in his study. The high level recorded in the midstream water sample may be attributed to the small - scale mining activities which is prominent along the midstream. Conductivity values obtained from all sites were below the permissible limit of 700 ( $\mu\text{S}/\text{cm}$ ) set by WHO. The mean values recorded at all the sites were below 700 ( $\mu\text{S}/\text{cm}$ ). Conductivity is also affected by temperature: the warmer the water, the higher the conductivity (PCTU, 2010).

The TDS levels recorded for the study period showed significance difference among the sites ( $P<0.05$ ). Comparing the sites there is significance difference between the levels observed in the upstream and midstream water samples ( $P= 0.027$ ); and upstream and downstream samples ( $P= 0.011$ ). The difference between the levels in the midstream and downstream samples is not statistical significant ( $P = 0.817$ ). The highest TDS level ( $163.0 \pm 1.41$  mg/L) in the water samples was recorded in the downstream water sample in the



month of April. However, this level was below what Kyekyeku (2011) found in his study. TDS may indicate elevated levels of ions that do pose health concern. Water containing TDS level below 1000mg/L is usually acceptable to consumers. The United States Environmental Protection Agency recommends treatment when TDS concentration exceeds 500mg/L (Qaiser et al., 2008). A range from 250- 500(mg/L) is the permissible limit for drinking water sample (WHO, 2003). Changes in TDS levels in natural water often result from industrial effluent or salt water intrusion (Anhwange et al., 2012). The levels recorded for the study period may be attributed to small-scale mining activities along the river.

The levels of alkalinity observed during the study period showed no significant difference at the sites ( $P= 0.142$ ). Water samples from the downstream recorded the highest alkalinity level of  $107.2 \pm 0.282$  (mg/L). This level is below the results obtained from the physico-chemical and microbiological quality of surface waters within the Newmont Ghana Gold mining concession areas. The alkalinity guideline for drinking water is 600mg/L (WHO, 1997). Aquatic organisms benefit from a stable pH value in their optimal range. To maintain a fairly constant pH in water body, a higher alkalinity is preferable. High alkalinity means that the water body has the ability to neutralize acid pollution from rainfall or basic inputs from waste water. Alkalinity is measured as the amount of acid needed to bring the water sample to a pH of 4.2 (Addy et al., 2004).

The results obtained from the levels of turbidity showed no significant difference in the levels of turbidity among the sites ( $P= 0.428$ ). During the study period turbidity was high



in the downstream water samples as compared to the upstream and midstream samples. The highest level recorded in the downstream water samples was  $67.0 \pm 0$  (NTU). This level may be due to run off rain water and effluent from small scale mining operations. The level is below what was recorded by Asamoah-Boateng (2009) in a study conducted in the Newmont Ghana Gold mining concession areas in surface waters. The turbidity guideline for drinking water is 5NTU (WHO, 1997). High turbidity can increase the water temperature since heat is absorbed by the particles (Hernandez, 2011). Increase in turbidity affects taste, odour and colour in drinking water. Turbidity can provide shelter for opportunistic microorganisms and pathogens (Qaiser et al., 2008). When temperature increases due to an increase in turbidity, the concentration of dissolved oxygen (DO) reduces because warmer water holds less DO than cold. Higher turbidity also reduces the amount of light penetrating the water, which reduces photosynthesis and production of dissolved oxygen (PCTU, 2010). The mean temperature recorded at the sites showed no significant difference among the sites ( $P=2.09$ ). The temperature at all sites was almost within the same range. The highest temperature ( $27.6^{\circ}\text{C}$ ) was recorded in the upstream water sample. The mean temperature of water sample recorded in the River Suraw in the Chirano Gold Mines was within the range of  $25.9$  to  $28.0^{\circ}\text{C}$ . Comparatively this level is higher than what was found in the Owere River. According to WHO, (2003) the guideline for temperature of drinking water is  $25$  to  $28^{\circ}\text{C}$ . The level recorded during the study is a little above the WHO limit as shown in table 13. Temperature affects dissolved oxygen level in water body (Qaiser et al., 2008). When temperatures in water bodies are outside the optimal range for a prolong period of time, organisms are stressed and can die. The warmer the water, the higher the conductivity (PCTU, 2010).

On the perception of galamsey operators/ workers of the environmental and health effects of their activities, thirty two (32%) of the sample size were of the view that chemicals used for extraction of gold have effects on fish. Twenty seven (27) people who represented 54% of the sample size were of the view that chemicals used for the extraction of gold have effects on their health. Results obtained from role played by miners and the effects they suffer indicate that the small scale miners do suffer from diseases like cough, skin rashes, irritating eyes and stomach complications.



## CHAPTER SIX

### CONCLUSION AND RECOMMENDATIONS

#### 6.1 Conclusion

Activities of small -scale miners and chemicals containing heavy metals are mostly used by “galamsey” operators in the extraction of gold and this may lead to heavy metal pollution of the Owere River. The following conclusions are drawn from the research:

The results revealed that heavy metals were present at all the sampling sites. The water samples analysed were found to contain arsenic, cadmium, mercury, Iron and Lead.

Arsenic levels at the sampling sites were below WHO guideline limit for drinking water, except in the month of March where the level recorded in the downstream was above the guideline limit.

Cadmium levels at all sites were above the guideline limit of 0.003 mg/L for drinking water sample set by WHO. The levels recorded may be due to continuous excavation of the river bed by the small- scale miners.

Iron levels from the sampling sites were above WHO permissible limit of 1.0 mg/L for drinking water. The upstream samples recorded the highest levels, and this may due to runoff from agricultural lands along the river and intensive mining activities within and along the river.

Lead levels recorded in the midstream and downstream samples were above the permissible limit of 0.01 mg/L by WHO. Continuous excavation in the river and runoff water from nearby streets into the river may have accounted for the high levels of lead recorded in the midstream and downstream samples.

Mercury levels in the upstream samples were below instrument detectable limit of 0.001 mg/L. Levels recorded in March and April in the midstream samples were above the WHO limit of 0.001 for drinking water.

The temperature, pH, alkalinity, electrical conductivity and total dissolved solids were within the permissible limit for drinking water. Turbidity levels from all the sampling sites were above the WHO guideline limit. The high turbidity may be due to the indiscriminate mining activities in and along the river and runoff from irrigation farming.

## **6.2 Recommendations**

The following recommendations are made to broaden the knowledge of the effects of heavy metals on the health of people, water bodies and the environment.

- Continuous survey and heavy metals monitoring in the Owere River should be put in place by agencies like Environmental Protection Agency, Minerals Commission in order to protect the river from further contamination and its adverse health effects.
- Creation of 100 metre buffer zone to protect the Owere River from pollution by anthropogenic activities.
- Government agencies like Minerals Commission and EPA should monitor the activities of Small Scale gold miners along the Owere River to minimize pollution.
- Health education programmes should be organized by the Municipal assembly, EPA, Ghana Health Services and other government agencies for galamsey

operators on the effects of their activities on their health, health of other people, the Owere River and the environment.

- Farmers who use water from the Owere River for irrigation should be educated by EPA and other agencies to find alternative source of water for their farming.

# KNUST



## REFERENCES

Abbas, M., Parveen, Z., Iqbal. S., Ahmed, M., and Bhutto, R. (2010). Monitoring of Toxic Metals (Cadmium, Lead, Arsenic, Mercury) in Vegetables of Sindh, Pakistan, Journal 6: 60-65.

Addy, K., Green, L., and Herron, E. (2004). pH and Alkalinity- University of Rhode Island, pp 1-4. <http://www.uri.edu/ce/eq/.../pH&alkalinity> (Accessed on January 4<sup>th</sup>, 2013).

Addy, S.N. (1998). Ghana: revival of the mineral sector, Resource Policy 24(4):229-239.

Akabzaa, T. and Darimani, A. (2001). Impacts of Mining Sector Investment in Ghana: A Study of Tarkwa Mining, Report to SAPRI, Accra, Ghana.

Albertsen, J. (2006). Toxicology Brief: The toxicity of iron, an essential element, Journal, pp 1-5.

Alloway, B.J. (1990). Heavy Metals in Soils in Alloway, B.J. (ed) Blackie and Son Glasgow.

Alloway, B.J., and Ayres, D.C. (1993). Chemical Principles of Environmental Pollution, Alden Press, Oxford, Pp 1-164.



Anhwange, B.A., Agbaji, E.B., and Gimba, E.C. (2012). Impact Assessment of Human Activities and Seasonal Variation on River Benue, within Makuedi Metropolis, Journal, 2 (5): 248-254.

Arambarri, R., Garcia, R., and Million, E.(1999). Relationship between metal content in soil and grass contaminated by different anthropogenic sources. Toxicol Environ. Chem., 72:221-231.

Aryee, B.N.A. (2001). Ghana's Mining Sector: Its contribution to national economy, Resource Policy, 27:61-75.

Aryee, B.N.A., Ntibery, B.K., and Atorkui, E. (2003). Trends in Small Scale mining of precious minerals in Ghana: a perspective on its environmental impact, Journal, 11: 131-140.

Asante – Akyem Central Municipal Assembly. (2007). Municipal profile.

ATSDR. (2007). Toxicological Profile for Arsenic. Atlanta, US Department of Health and Human Services, Public Health Service.

ATSDR.(2007). Toxicological profile for Lead. Atlanta, US Department of Health and Human Services, Public Health Service.

Ayee, J., Soreide, T., Shukla, G.P. and Minhle, T. (2011). Political Economy of the Mining Sector in Ghana, *Journal*, 5730:6-12.

Boadi, B., Wemegah, D.D., and Preko, K. (2013). Geological and Structural Interpretation of the Konongo area of the Ashanti gold belt of Ghana from aeromagnetic and radiometric data, *3 (3)*:124-135.

Boon, K. and Ababio, F. (2009). Corporate Social Responsibility in Ghana: Lessons from the Mining Sector. 29<sup>th</sup> Annual Conference of International Association for Impact Assessment. Pp2-6.

Botchway, F.N.N. (1995). Pre-Colonial Methods of Gold Mining and Environmental Protection in Ghana, *Journal*, 13:239-358.

Callender, E. (2005). Heavy Metals in the Environment- Historical Trends, *Journal*, 9:67-105.

Clarkson, T.W. (1997). The toxicology of mercury, *Critical Review, Clinical Laboratory Science*, 34:369-403.

Denny, P., Hart, B.T., Lasheen, M.R., Subramanian, V., and Wong, M.H. (1987). Group Report: Lead Monitoring and Assessment Research Centre, The Octagon Building, King's College, London, pp3-16.

Duruibe, J.O., Ogwuegbu, M.O.C., and Egwurugwu, J.N. (2007). Heavy Metal Pollution and human biotoxic effects, Journal, 2(5):112-118.

Ercal, N., Gurer-Orhan, H., and Aykin-Burns. (2001). Toxic Metals and Oxidative Stress Part I: Mechanism Involved in Metal induced Oxidative Damage, Journal, 1:529-539.

Fauci, A.S., Braunwald, E., Isselbacher, K.J., Wilson, J.D., Martin, J.B., Kasper, D.L., Hauser, S.L., Longo, D.L. (1998). Harrison's Principles of Internal Medicine. 14<sup>th</sup> ed. New York. Pp 2564-2569.

Flora, S.J.S. (2009). Metal poisoning: Threat and Management, Journal, 2(2):4-26.

Galamsey-Wikipedia. (2009). Free encyclopedia.

<http://www.wikipedia.org/wiki/Galamsey> (Accessed of March 20<sup>th</sup>, 2012).

Ghana Chamber of Mines, (2008). The performance of mining industry in 2007. Accra, Ghana. <http://www.ghana-chamber-of-mines.org> (Accessed on August 14<sup>th</sup>, 2012).

Hangi, A.Y. (1996). Environmental Impacts of Small Scale Mining: A Case Study of Merelani, Kahama, Nzega, Geita and Musoma, the Centre for Energy, Environment, Science and Technology (CEEST), 1: 46-52.

Hernandez, L.D.R. (2011). Exploratory analysis of Butler County Stream Team Water Quality. Miami University, Ohio.

Hilson, G.(2001). A Contextual Review of the Ghanaian Small-Scale Mining Industry, Journal, 76: 3-17.

Hilson, G.(2002a).Harvesting mineral riches: 100 years of gold mining in Ghana. Resource Policy, 28:13-26.

Hilson, G., and Potter. C. (2005). Structural Adjustment and Subsistence Industry: Artisanal Gold Mining in Ghana, Journal, 36(1):103-131.

Hug, M.M. (1989). The Economy of Ghana: The first 25 years since independence, Macmillan Press Ltd, London. Pp153-155.

Hutton, M. (1987). Human Health Concerns, Mercury, Cadmium and Arsenic, Monitoring and Assessment Research Centre, The Octagon Building, Kings College, London, pp53-68.

Independent Geologist Report- Liongold Corporation. (2012)  
<http://www.liongoldcorp.com/.../konongo-cp> ( Accessed on January 3<sup>rd</sup>, 2013).

International Occupational Safety and Health Information Centre, (1999). Heavy Metal Detox – Humet. Accessed on February 17<sup>th</sup>, 2012 on the World Wide Web: <http://www.humet.com/.../heavymetals.html>.

Khalid, A., Malik, A.H., Waseem, A., Zahra,S., and Murtaza,G. (2011). Qualitative and Quantitative Analysis of Drinking Water Samples of different Localities in Abbottahad District, Pakistan, Journal, 6(33):7480-7489.

Kyekyeku, O. (2011). Impact of Chirano Gold Mines Operations on levels of As, Pb, Hg and Cd in the Suraw River and the Possible Health Implications on Downstream Communities, M. sc Thesis. Department of Theoretical and Applied Biology. Kwame Nkrumah University of Science and Technology, Ghana.

Laing,E. (1994). Ghana Environmental Action Plan, Vol.2. Environmental Protection Council, Accra.

Leilanie Lu,J.(2012). Occupational Health and Safety in Small –Scale Mining: Focus on Women Workers in Philippines, Journal, 13:103-113.

Lide.(1992). Heavy Metal Toxicity. Available from  
URL<http://www.lef.org/protocols/prtcl-156.shtml>. (Accessed:August 18<sup>th</sup>, 2012).

Marana, A.(2012). Plant Responses to Heavy Metal Toxicity.  
<http://www.springer.com/.../9789400744400-C> (Accessed on November 16, 2012).

Miranda, M., Chambers, D., and Coumans, C. (2005). Framework for Responsible Mining: A Guide to Evolving Standards. Source URL : <http://www.google.com> (Accessed: August 18<sup>th</sup>, 2012).

Nartey, V. K., Doamekpor, L. K., Sarpong-Kumankuma, S., Akabzaa, T., Nyame, F.K., Kutor, J.K., and Adotey, D. (2011). Mercury Pollution Studies of Some Rivers Draining the Bibiani- Anwiaso- Bekwai Mining Community of South Western Ghana, Journal, 3 (4):375-384.

Ntow, W.J., Amonoo- Neazer, E.H., and Nyamah, D. (1996). Environmental Pollutants in the mining Environs of Konongo in Ashanti Region of Ghana, Journal, 31-36:73-80.

Ofosu-Mensah., and Ababio, E. (2011). Historical Overview of tradition and modern mining in Ghana, Journal, 1(1) :6-22.

Ohio Department of Natural Resources, (2006). Division of Water. Water Resource Program, Columbus, Ohio. <http://www.dnr.state.oh.us/water> (Accessed of May 22nd 2012)

Olade, M.A. (1987). Heavy Metal Pollution and the Need for Monitoring: Illustrated for Developing Countries in West Africa. Geology Department, University of Ibadan, Nigeria, pp 335-341.

Patil, G., and Ahmad, I. (2011). Heavy Metals Contamination Assessment of Kanhargaoon Dam Water near Chhindwara City, Journal, 1 (1): 7-9.



Pennsylvania Council of Trout Unlimited, (2010). Goldwater Conservation Corps. Field Manual.

Qaiser, S., Asma, S., Khan, M.T.A., and Hashmi, I. (2008). Drinking Water Quality Monitoring within a Distribution Network: F-8 and E-7 Sectors of Islamabad, Journal, 702:601-616.

Raikwar, M.K., Kumar.P., Singh, M., and Singh, A. (2008). Toxic Effects of heavy metals in livestock health, Journal, 1(1):28-30.

Schueler,V., Kuemmerle, T. and Hilmar,S. (2011). Impact of Surface Gold Mining on land use Systems in Western Ghana, Journal, 40(5):528-539.

Soghoian, S and Sinert, R. (2006). Toxicity of Heavy Metals.  
<http://www.medicine.com/emergency/opic237.htm> (Accessed on 4<sup>th</sup> February, 2012).

Testing Water for Gardening and Lawn Irrigation. Wellcare Information Sheet, (2007).  
<http://www.watersystemscouncil.org/VAiWebDO> (Accessed on December 14th, 2012).

Timbrell, J.A. (1995). Introduction to toxicology. London; Taylor and Francis, pp76-121.

Tom-Dery, D., Dagben, Z.J., and Cobbina, S.J. (2012). Effects of Illegal Small-Scale Mining Operations on Vegetation Cover of Arid Northern Ghana. Research Journal of Environmental and Earth Sciences, 4(6):674-679.

Turbidity Guideline By Health Canada, (1995). [http://www.greenclub.bc.ca/Green Club Activity/Water/ Turbidity](http://www.greenclub.bc.ca/Green_Club_Activity/Water/Turbidity) (Accessed on January 12, 2013).

UNEP. (2007). Module 3 Mercury Use in Artisanal and Small Scale Gold Mining. <http://www.chem.unep.ch/mercury/partnership/new.partnership.htm> (Accessed June 12, 2012).

Valko, M., Morris. H., and Cronin, M.T.D. (2005). Metal, Toxicity and Oxidative Stress, Journal, 12:1161-1208.

WHO, (1987). Global Environmental Monitoring Systems (Water operational guide), World Health Organization, Geneva.

WHO, (1991). Inorganic Mercury. Environmental Health criteria 118. IPCS, International Programme on Chemical Safety. Geneva, pp18-34.

WHO, (1996). Guideline for Drinking Water Quality, 2<sup>nd</sup> ed. Vol. 2. World Health Organization, Geneva.

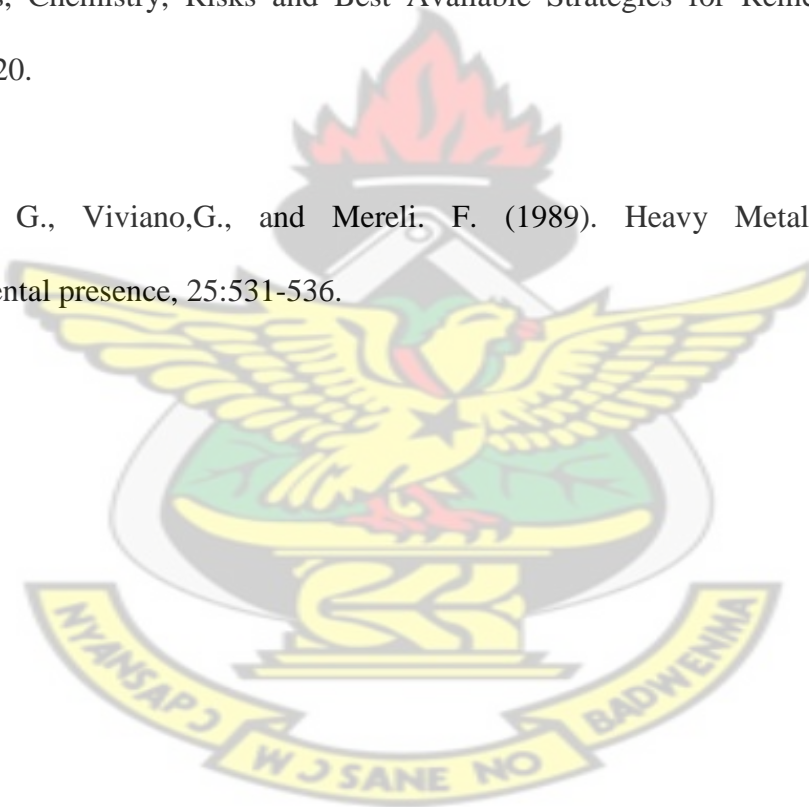
WHO, (1997), Guidelines for Drinking Water Quality, 2<sup>nd</sup> ed. Vol. 3. World Health Organization, Geneva.

WHO, (2003). Acceptable aspects. In Guidelines for Drinking Water Quality, World Health Organization, Geneva.

WHO, (2003), International Standards for Drinking Water, Vol. 12. World Health Organization, Geneva.

Wuana, R.A., and Okieimen. F.E. (2011). Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation, Journal, 402647:1-20.

Ziemacki, G., Viviano, G., and Mereli. F. (1989). Heavy Metals: Sources and Environmental presence, 25:531-536.



## APPENDICES

### APPENDIX I

#### Activities of small- scale miners along the Owere River



Figure 15: Some of the small- scale miners working in the Owere River.





**Figure 16 Small- scale miners working along the Owere River**



**Figure 17 Excavators used by small - scale gold miners**

## APPENDIX II

### Detailed descriptive report of heavy metal analysis from all sites

#### IRON

#### Descriptive

mass in mg per litre

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
A	4	4.907250E0	1.0636223	.5318112	3.214790	6.599710	4.1125	6.3630
B	4	1.785000E0	.3500802	.1750401	1.227944	2.342056	1.2710	2.0085
C	4	2.015125E0	.4386100	.2193050	1.317199	2.713051	1.3820	2.3110
Total	12	2.902458E0	1.6113161	.4651469	1.878677	3.926240	1.2710	6.3630

#### ONEWAY ANOVA

mass in mg per litre

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	24.221	2	12.111	25.122	.000
Within Groups	4.339	9	.482		
Total	28.560	11			



This is the table that shows the output of the ANOVA analysis and whether we have a statistically significant difference between our group (site) means. We can see that in this example the significance level is 0.000 ( $p = .000$ ), which is below 0.05. Therefore, there is a statistically significant difference in the mean amount of iron in the various sites. This is great to know, but we do not know which of the specific groups differed. We can find this out in the Multiple Comparisons table which contains the results of post-hoc tests.

### Post-hoc test for Iron

#### Multiple Comparisons

Dependent Variable: mass in mg per litre

	(I) Site	(J) Site	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	A	B	3.1222500	.4909561	.000	1.751498	4.493002
		C	2.8921250	.4909561	.001	1.521373	4.262877
	B	A	-3.1222500	.4909561	.000	-4.493002	-1.751498
		C	-.2301250	.4909561	.887	-1.600877	1.140627
	C	A	-2.8921250	.4909561	.001	-4.262877	-1.521373
		B	.2301250	.4909561	.887	-1.140627	1.600877
Dunnett C	A	B	3.1222500	.5598769		.782682	5.461818
		C	2.8921250	.5752545		.488299	5.295951
	B	A	-3.1222500*	.5598769		-5.461818	-.782682
		C	-.2301250	.2805953		-1.402654	.942404
	C	A	-2.8921250*	.5752545		-5.295951	-.488299
		B	.2301250	.2805953		-.942404	1.402654

### Multiple Comparisons

Dependent Variable: mass in mg per litre

			Mean			95% Confidence Interval	
	(I)	(J)	Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
	Site	Site					
Tukey HSD	A	B	3.1222500	.4909561	.000	1.751498	4.493002
		C	2.8921250	.4909561	.001	1.521373	4.262877
	B	A	-3.1222500	.4909561	.000	-4.493002	-1.751498
		C	-.2301250	.4909561	.887	-1.600877	1.140627
	C	A	-2.8921250	.4909561	.001	-4.262877	-1.521373
		B	.2301250	.4909561	.887	-1.140627	1.600877
Dunnett C	A	B	3.1222500	.5598769		.782682	5.461818
		C	2.8921250	.5752545		.488299	5.295951
	B	A	-3.1222500*	.5598769		-5.461818	-.782682
		C	-.2301250	.2805953		-1.402654	.942404
	C	A	-2.8921250*	.5752545		-5.295951	-.488299
		B	.2301250	.2805953		-.942404	1.402654

\*. The mean difference is significant at the 0.05 level.

## LEAD LEVEL

### Descriptive

mass in mg per litre

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
A	4	.010250	.0041332	.0020666	.003673	.016827	.0070	.0160
B	4	.131000	.1287685	.0643843	-.073899	.335899	.0130	.2770
C	4	.228125	.1095106	.0547553	.053869	.402381	.1195	.3805
Total	12	.123125	.1283051	.0370385	.041604	.204646	.0070	.3805

### ANOVA Lead

mass in mg per litre

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.095	2	.048	5.000	.035
Within Groups	.086	9	.010		
Total	.181	11			

Post-hoc test

### Multiple Comparisons

Dependent Variable: mass in mg per litre

	(I)	(J)	Mean Difference (I- J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	A	B	-.1207500	.0690302	.240	-.313483	.071983
		C	-.2178750*	.0690302	.028	-.410608	-.025142
	B	A	.1207500	.0690302	.240	-.071983	.313483
		C	-.0971250	.0690302	.378	-.289858	.095608
	C	A	.2178750*	.0690302	.028	.025142	.410608
		B	.0971250	.0690302	.378	-.095608	.289858
Dunnett C	A	B	-.1207500	.0644174		-.389932	.148432
		C	-.2178750	.0547943		-.446845	.011095
	B	A	.1207500	.0644174		-.148432	.389932
		C	-.0971250	.0845191		-.450306	.256056
	C	A	.2178750	.0547943		-.011095	.446845
		B	.0971250	.0845191		-.256056	.450306

\*. The mean difference is significant at the 0.05 level.

## CADMIUM LEVEL

### Descriptive

mass in mg per litre

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
A	4	.066500	.0944325	.0472163	-.083763	.216763	.0070	.2075
B	4	.029000	.0096350	.0048175	.013669	.044331	.0190	.0375
C	4	.027250	.0119338	.0059669	.008261	.046239	.0140	.0390
Total	12	.040917	.0534206	.0154212	.006975	.074859	.0070	.2075

### ANOVA for Cadmium

mass in mg per litre

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.004	2	.002	.645	.547
Within Groups	.027	9	.003		
Total	.031	11			

There is no significant difference between the cadmium level of the various site ( $p=0.547$ ) as compare to the significant level of  $p=0.05$ .



## ARSENIC LEVEL

### Descriptive

mass in mg per litre

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
A	4	.022750	.0241195	.0120597	-.015629	.061129	.0075	.0585
B	4	.007000	.0024152	.0012076	.003157	.010843	.0050	.0105
C	4	.012875	.0083304	.0041652	-.000381	.026131	.0040	.0240
Total	12	.014208	.0150083	.0043325	.004673	.023744	.0040	.0585

### ANOVA

mass in mg per litre

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.001	2	.000	1.157	.357
Within Groups	.002	9	.000		
Total	.002	11			

There is no significant difference in the arsenic level of the various sites

## MERCURY

### Descriptive

mass in mg per litre

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
A	4	.000950	.0000577	.0000289	.000858	.001042	.0009	.0010
B	4	.001500	.0007071	.0003536	.000375	.002625	.0010	.0025
C	4	.000950	.0000577	.0000289	.000858	.001042	.0009	.0010
Total	12	.001133	.0004599	.0001328	.000841	.001426	.0009	.0025

### ANOVA

mass in mg per litre

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.000	2	.000	2.388	.147
Within Groups	.000	9	.000		
Total	.000	11			

There is no significant difference

**pH**

**Descriptive**

mass in mg per litre

					95% Confidence Interval for Mean			
					Lower Bound	Upper Bound		
A	4	6.226250E0	.3160004	.1580002	5.723423	6.729077	6.0550	6.7000
B	4	6.680000E0	.5911571	.2955785	5.739337	7.620663	6.1100	7.5100
C	4	6.776250E0	.5881663	.2940831	5.840346	7.712154	6.2150	7.6000
Total	12	6.560833E0	.5288058	.1526531	6.224846	6.896821	6.0550	7.6000

**ANOVA**

mass in mg per litre

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.690	2	.345	1.302	.319
Within Groups	2.386	9	.265		
Total	3.076	11			

## CONDUCTIVITY

### Descriptive

mass in mg per litre

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
A	4	2.686250E2	6.8114487	3.4057243E0	257.786465	279.463535	259.5000	276.0000
B	4	2.980000E2	14.5086181	7.2543091E0	274.913551	321.086449	284.5000	312.0000
C	4	2.625000E2	80.3284922	4.0164246E1	134.679443	390.320557	142.5000	312.5000
Total	12	2.763750E2	45.7359641	1.3202836E1	247.315755	305.434245	142.5000	312.5000

### ANOVA

mass in mg per litre

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2880.875	2	1440.438	.644	.548
Within Groups	20128.688	9	2236.521		
Total	23009.562	11			

## TOTAL DISSOLVED SOLIDS

### Descriptive

mass in mg per litre

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
A	4	1.210500E2	10.5091230	5.2545615E0	104.327640	137.772360	110.0000	132.1000
B	4	1.442375E2	7.2315714	3.6157857E0	132.730456	155.744544	135.5000	151.3000
C	4	1.487000E2	12.4998667	6.2499333E0	128.809923	168.590077	132.5000	163.0000
Total	12	1.379958E2	15.7241774	4.5391790E0	128.005168	147.986499	110.0000	163.0000

### ANOVA

mass in mg per litre

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1762.795	2	881.398	8.289	.009
Within Groups	956.952	9	106.328		
Total	2719.747	11			

## ALKALINITY

### Descriptive

mass in mg per litre

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
A	4	4.206250E0	.4733634	.2366817	3.453023	4.959477	3.7150	4.8450
B	4	4.593750E0	.3351212	.1675606	4.060497	5.127003	4.1150	4.8750
C	4	4.852500E0	.4286899	.2143449	4.170359	5.534641	4.3050	5.3500
Total	12	4.550833E0	.4677598	.1350306	4.253633	4.848034	3.7150	5.3500

### ANOVA

mass in mg per litre

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.846	2	.423	2.441	.142
Within Groups	1.560	9	.173		
Total	2.407	11			

Difference not significant



## **TURBIDITY**

### **Descriptive**

mass in mg per litre

			Std.		95% Confidence Interval for			
	N	Mean	Deviation	Std. Error	Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
A	4	6.250000E1	6.3900965	3.1950483E0	52.331930	72.668070	53.0000	66.5000
B	4	5.550000E1	8.6023253	4.3011626E0	41.811781	69.188219	45.5000	64.5000
C	4	5.825000E1	6.7019898	3.3509949E0	47.585639	68.914361	53.0000	67.0000
Total	12	5.875000E1	7.2535258	2.0939125E0	54.141330	63.358670	45.5000	67.0000

### **ANOVA**

mass in mg per litre

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	99.500	2	49.750	.934	.428
Within Groups	479.250	9	53.250		
Total	578.750	11			

Difference not significant

## TEMPERATURE

### Descriptive

mass in mg per litre

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
A	4	2.591250E1	1.1520814	.5760407	24.079281	27.745719	25.0000	27.6000
B	4	2.493750E1	.5375484	.2687742	24.082140	25.792860	24.4000	25.4000
C	4	2.511250E1	.3424787	.1712394	24.567540	25.657460	24.8000	25.6000
Total	12	2.532083E1	.8181071	.2361672	24.801033	25.840634	24.4000	27.6000

### ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.162	2	1.081	1.870	.209
Within Groups	5.201	9	.578		
Total	7.362	11			

Difference not significant

### APPENDIX III

#### Questionnaire administered to small-scale mining operators

#### KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

#### DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

#### QUESTIONNAIRE

Please, provide your correct responses to the questions below. Your response is meant for educational purposes and the confidentiality of your responses is assured.

CODE: CD#

#### PERSONAL DATA

(Tick [ ☐ ] or write your correct responses)

1. Age.....
2. Sex: Male [ ☐ ]      Female [ ☐ ]
3. Level of education:  
Primary [ ☐ ]    JHS [ ☐ ]    Tertiary [ ☐ ]    Technical/ Commercial/Vocational [ ☐ ]  
Never been to school [ ☐ ]
4. What is your main occupation?  
Mining [ ☐ ]    Farming [ ☐ ]    Dress making [ ☐ ]    Driving [ ☐ ]    Carpentry [ ☐ ]  
Other.....
5. How long have you been mining?  
1 year [ ☐ ]    2 years [ ☐ ]    3 years [ ☐ ]    4 years [ ☐ ]    5 years [ ☐ ]  
10 years and above [ ☐ ]
6. Who in your opinion influenced you to enter into small- scale mining?  
Friends [ ☐ ]      parents [ ☐ ]

7. What is your role in the mining operation?

Excavation [    ]

Washing [    ]

Fetching of water [    ]

Other.....

8. When was the first time you heard of “galamsey” operation in the area?

3 years ago [    ]

5 years ago [    ]

10 years ago [    ]

15 years ago [    ]

20 years ago [    ]

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### MINING ACTIVITIES

9. Do you use any protective wear during mining? Yes [    ]

No [    ]

10. Where is your mining site located?

20 metres from the Owere river [    ]

50 metres from the Owere river [    ]

100 metres from the Owere river [    ]

200 metres from the Owere river [    ]

11. Where do you obtain water for the extraction of gold?

From the Owere river [    ]

From near by streams [    ]

From wells [    ]

12. By what means do you send the water to the mining site?

Using water pumping machines [    ]

Using vehicles [    ]

Using labourers [    ]

13. Where do you deposit your tailings?

Near the mining site [ ]

Into the Owere river

Into near by streams

14. What chemicals do you use in the extraction of gold?

### ENVIRONMENTAL EFFECTS

15. Can those chemicals used in the extraction process have any effect on the environment?

Yes [ ] No [ ]

16. Can those chemicals have effects on fish and other aquatic organisms?

Yes [ ] No [ ]

17. Do you cover your pit after mining?

Yes [ ] No [ ]

18. How was the environment before you started mining?

It was covered with vegetation [ ]

It was bare [ ]

19. Has your mining activities degraded the environment than before?

Yes [ ] No [ ]

20. Has the water quality of the Owere been negatively affected than before?

Yes [ ] No [ ]

21. Presently do people suffer any health effects from drinking or using water from the

Owere River for domestic purposes?

Yes [ ] No [ ]

## HEALTH EFFECTS

22. Can those chemicals used in the extraction of gold have any effect on your health?

Yes [ ☐ ]      No [ ☐ ]

23. How do you protect yourself?

With nose mask [ ☐ ]      With goggles [ ☐ ]      With overall suit [ ☐ ]

With Wellington boots [ ☐ ]      No protection [ ☐ ]

24. What effects do you suffer as a result of mining activities?

Coughing [ ☐ ]      Skin rashes [ ☐ ]      Irritating eyes [ ☐ ]

Stomach complications [ ☐ ]

25. How often do you experience such illness?

Weekly [ ☐ ]

Monthly [ ☐ ]

Every three months [ ☐ ]

Every four months [ ☐ ]

26. How do you treat yourself?

Self medication [ ☐ ]

I visit the hospital [ ☐ ]

I use herbal medicine [ ☐ ]



## APPENDIX IV

**Detailed results of responses of questionnaire administered to the “galamsey” operators**

### influence in small scale farming

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Friends	14	28.0	28.0	28.0
	Parents	36	72.0	72.0	100.0
	Total	50	100.0	100.0	

### first time you heard of galamsey

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	5 years ago	8	16.0	16.0	16.0
	10 years ago	21	42.0	42.0	58.0
	15 years ago	17	34.0	34.0	92.0
	20 years ago	4	8.0	8.0	100.0
	Total	50	100.0	100.0	

**location of mining site**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	20 metres from the Owere river	3	6.0	6.0	6.0
	50 metres from the Owere river	19	38.0	38.0	44.0
	100 metres from the Owere river	22	44.0	44.0	88.0
	200 metres from the Owere river	6	12.0	12.0	100.0
	Total	50	100.0	100.0	

**source of water**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	From the Owere river	31	62.0	62.0	62.0
	From nearby streams	2	4.0	4.0	66.0
	From wells	17	34.0	34.0	100.0
	Total	50	100.0	100.0	

**means of sending water to the site**

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid using water pumping machine	18	36.0	36.0	36.0
using vehicles	2	4.0	4.0	40.0
using labourers	30	60.0	60.0	100.0
Total	50	100.0	100.0	

**deposit site for tailings**

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid near the mining site	47	94.0	94.0	94.0
into the Owere river	2	4.0	4.0	98.0
into nearby stream	1	2.0	2.0	100.0
Total	50	100.0	100.0	

**chemicals has effect on environment**

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid yes	11	22.0	22.0	22.0
no	39	78.0	78.0	100.0
Total	50	100.0	100.0	

**covering of pit after mining**

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid    yes	22	44.0	44.0	44.0
no	28	56.0	56.0	100.0
Total	50	100.0	100.0	

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**environment before mining**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	It was covered with vegetation	35	70.0	70.0	70.0
	It was bare	15	30.0	30.0	100.0
	Total	50	100.0	100.0	

**degradation of environment due to mining activities**

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid    yes	11	22.0	22.0	22.0
no	39	78.0	78.0	100.0
Total	50	100.0	100.0	

**negative effect on the quality of Owere river**

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid yes	25	50.0	50.0	50.0
no	25	50.0	50.0	100.0
Total	50	100.0	100.0	

**health of the people for drinking or using water from Owere river**

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid yes	14	28.0	28.0	28.0
no	36	72.0	72.0	100.0
Total	50	100.0	100.0	

**how often you experience such illness**

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid weekly	6	12.0	15.4	15.4
monthly	12	24.0	30.8	46.2
every 3 months	13	26.0	33.3	79.5
every 4 months	8	16.0	20.5	100.0
Total	39	78.0	100.0	
Missing System	11	22.0		
Total	50	100.0		

# how treatment is done

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	self medication	18	36.0	46.2	46.2
	I visit hospital	13	26.0	33.3	79.5
	I use herbal medicine	8	16.0	20.5	100.0
	Total	39	78.0	100.0	
Missing	System	11	22.0		
Total		50	100.0		

