

**THE EFFECTS OF ILLEGAL SMALL-SCALE GOLD MINING (“Galamsey”)
ACTIVITIES ON THE WATER QUALITY OF THE AKANTANSU AND SINTIM
RIVERS IN THE ASUTIFI NORTH DISTRICT OF THE BRONG AHAFO
REGION OF GHANA.**

KNUST

By

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PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE**

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DECLARATION

I hereby declare that this submission is my own work towards the Master of Science in Environmental Science and that, to 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.

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DEDICATION

I dedicate this work to my family, my mother (Aisha Adiyah) and my father (Nicholas Adiyah), and my sisters Hanatu and Rashida Adiyah and to my husband Reagan K. Daplah and my friend Kwasi Abroampah Mensah.

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ACKNOWLEDGEMENT

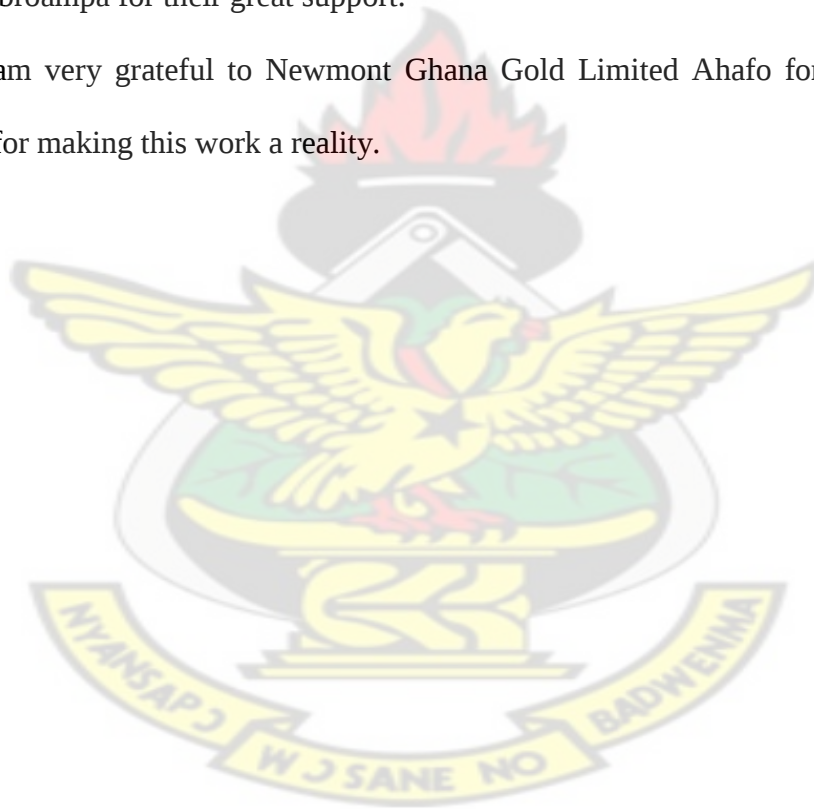
I thank the almighty God for his grace and mercy shown to me throughout the period.

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ABSTRACT

This study was carried out to investigate the effect of illegal small-scale gold mining ("Galamsey") operations on the water quality of the Akantansu and Sintim rivers in the Asutifi North District of the Brong-Ahafo Region of Ghana. Water samples were collected from the two rivers for physico-chemical and heavy metal analyses. Levels of physico-chemical parameters were determined by standard methods while heavy metals were by Atomic Absorption Spectrophotometry (AAS). Results show that, generally, higher values were recorded at downstream locations for most of the physico-chemical parameters studied. Mean values for temperature, pH, conductivity, TDS and TSS were within the WHO recommended guideline values for drinking water. However, samples from the rivers were found to be very turbid (> 5 NTU) and consequently coloured (> 20 TCU). Dissolved oxygen decreased at the downstream sampling locations and the mean values were generally slightly below the 5 mg/l recommended by the WHO. Mean levels of copper, arsenic, lead, cadmium and mercury were generally higher downstream of the rivers, but were lower than the WHO acceptable limits. However, levels of iron were above the WHO acceptable limits, with very high values being recorded downstream of the rivers. The general trend in the levels of the parameters studied suggests influence from the small-scale gold mining activities along the banks of the two rivers.

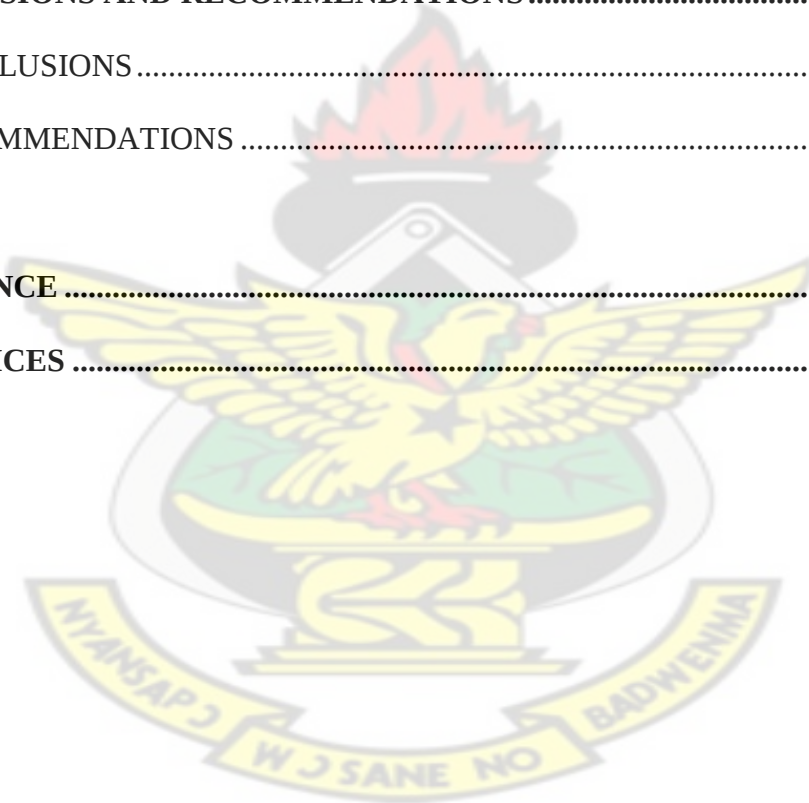
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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Water is one of the most essential constituents of the human environment. The water resources generate development in socio-economic issues crucial to the society in general and more specifically for industries, agricultural activities and for the public use.

The Hungarian Nobel prize winner Albert Szert-Gyargyi once said, “Water is life’s mater and matrix, mother and medium. There is no life without water.” if the water resources are contaminated, so is life. Providing clean drinking water for the growing population of the world is one of the most pressing issues we stand against in the 21st century. Both anthropogenic and natural processes can affect the water quality. Except from the metals man has created through nuclear reactions, the rest has been on Earth since the planet was formed. There are few examples of local metal pollutions through natural weathering but in most cases metals become an environmental health issue because of anthropogenic activity. Mainly, mining and smelting plant release metals from the bedrock (Walker and Sibly, 2001).

Integrated water resources management (IWRM) is an essential approach to water resources within the catchment. There are different activities (such as mining) that occur within a catchment that use and affect water resources. The impacts of mining activities for instance, can create problems for ecosystems functioning.

Comprising of about 70% of the surface of the Earth, water is the most valuable natural resource existing on our planet. Without this invaluable compound, life on the earth would

not exist. Although this fact is widely recognized, pollution of water resources is a common problem being faced today. Heavy metal pollution occurs directly by effluent outfalls from industries, refineries and waste treatment plants and indirectly by the contaminants that enter the water supply from soils/groundwater systems and from the atmosphere via rain water (Vijayaraghavan and Yun, 2008). Modern industry is, to a large degree, responsible for contamination of the environment. Lakes, rivers and oceans are being overwhelmed with many toxic contaminants. Among toxic substances reaching hazardous levels are heavy metals (Vieira and Volesky, 2000). Heavy metals are the group of contaminants of concern, which come under the inorganic division. Some metal ions such as mercury are very toxic even in concentrations as low as 0.001 mg/l. Under certain environmental conditions, metals may accumulate to toxic levels and cause ecological damage (Jefferies and Firestone, 1984). Of the important metals, mercury, lead, cadmium, arsenic and chromium (iv) are regarded as toxic, whereas, others such as copper, nickel, cobalt and zinc are not as toxic, but their extensive usage and increasing levels in the environment are of serious concern (Brown and Absanullah, 1971; Moore, 1990; Volesky; 1990). Various techniques have been employed for the treatment of metal bearing industrial effluents, which usually include precipitation, adsorption, ion exchange, membrane and electrochemical technologies but these techniques are expensive, not environment friendly and usually independent on the concentration of the waste which are ineffective in very diluted solution.

Physical parameters such as pH, temperature and conductivity influence the concentration of many pollutants by altering their availability and toxicity. The temperatures at which environmental samples are collected and of which physicochemical measurements are

made are important for data correlation and interpretation (Tay *et al.*, 2009). Also, at high temperatures the toxicity of many substances may be increased. In addition to microbial activities, within an aquatic medium, temperatures and pH are two important parameters that govern the methylation of elements such as Lead and mercury (Von Loon, 1982). The electrical conductivity (EC) is also useful indicator of mineralization in a water body which has a correlation with the Total Dissolved Solids (TDS) in the water body.

In several mining communities in Ghana, groundwater has become the drinking water source of choice due to extensive contamination of surface water by mining activities particularly small scale illegal mining (Armah *et al.*, 2011; Armah *et al.*, 2010).

With the discovery and the eventual extraction of gold in the area by Newmont Ghana Gold Limited, the activities of galamsey operators have increased in the area. It is their activities on the quality of surface water including the Akantansu and Sintim Rivers in the Asutifi district that serves as the basis of this research.

1.2 PROBLEM STATEMENT

The presence of Newmont Ahafo operations has resulted in the emergence of illegal small scale mining (galamsey) and their activities are normally done alongside water bodies within communities. Mercury, a poisonous chemical, is used to recover gold from the ore, and in the process some spillages occur resulting in drainage of mercury into the nearby streams especially the Akantansu and Sintim Rivers. It also seeps down into the soil causing plants to die. In addition, Galamsey operators also bath and wash their clothing, tools and equipment in these rivers where their operations are usually done. This poses serious health threat to the inhabitants of Kenyasi I, Kenyasi II and other communities

within the catchment area of the mine. The Akantansu and Sintim Rivers serve as sources of drinking water for the inhabitants of these towns. In recent times there have been serious concerns about physical changes in water bodies by community members. The illegal miners also leave behind uncovered holes and trenches which are dangerous for both animals and human beings. It is for these reasons that this project was carried out to highlight the impact of illegal mining activities on the Akantansu and Sintim Rivers.

1.3 JUSTIFICATION OF THE STUDY

Many of the residents in the Kenyasi I and II and other communities within the catchment area of the mine in the Asutifi District depend on groundwater and surface water for their drinking and other domestic water purposes. The lives of both humans and animals, especially aquatic life, are very much dependent on the quality of water that runs in our streams and rivers. People who consume contaminated aquatic organisms are prone to serious health hazards.

The pits dug during mining by these illegal miners remain as stagnant water pools, which then serve as breeding grounds for mosquitoes and other water-inhabiting insects. People living in Kenyasi I, II and nearby communities have high possibility of getting water-borne diseases. The gravel, mud and rocks displaced during river dredging mining disrupt the natural flow of the river.

Mercury poisoning will result in the loss of skilled labour and long term damage to communities. This is an issue that is worth all the attention since the ability to find solutions will be to protect the environment.

1.4 OBJECTIVES

1.4.1 General Objective

The general objective of the study was to investigate the effects of illegal small scale mining (Galamsey) operations on the water quality of the Akantansu and Sintim rivers in the Asutifi District of the Brong Ahafo Region.

1.4.2 Specific Objectives

To achieve the general objective, the research aimed at addressing the following specific objectives:

1. To assess the practices of Galamsey operators that have the potential of affecting the water bodies.
2. To determine the physico;chemical parameters (pH, Electrical conductivity, Total Dissolved Solids, Total Suspended Solids, Turbidity, Dissolved Oxygen and Apparent and True colors) in the Akantansu and Sintim rivers.
3. To determine the levels of selected metals (Iron, Lead, Cadmuim, Mercury, Asenic and Cupper) in water samples in the Akantansu and Sintim rivers.

1.5 DELIMITATIONS/LIMITATIONS

The study focuses on only the illegal small scale mining operations along the Akantansu and Sintim Rivers in the Asutifi District. Willingness to take part in the study on the part of galamsey operators is an inclusion factor that was part and parcel of the study. There was much of a limitation in relation to access to the galamsey operators. Most of these are found remotely along the river sometimes far away from the villages and towns. Access to

the places was a problem coupled with access to the operators themselves. Most of them perceived some level of association between the presence of the research team and law enforcing agencies. This posed an initial restraint on the part of the operators in wanting to speak. The objective of the research was explained to them and they were assured of maximum confidentiality.

1.6 ORGANISATION OF CHAPTERS

The study is grouped under six (6) chapters. These are introduction, literature review, methodology, presentation of results, discussion, and conclusion and recommendations. The chapter one of the study introduces the topic. Chapter two reviews some relevant literature in relation to the research work. Chapter three discusses the methodology used in the research work and analysis of the data. Chapter four talks about presentation of results, while Chapter five presents discussion the results in relation to reviewed literature. Chapter six draws conclusion and suggests some recommendation.

CHAPTER TWO

LITERATURE REVIEW

2.1 SMALL SCALE MINING IN GHANA

Small-scale mining in Ghana is defined as “mining by any method not involving substantial expenditure by any individual or group of persons not exceeding nine in number or by a cooperative society made up of ten or more persons” (Government of Ghana, 1989). They are estimated to number over 150,000 in Ghana, of which many operate illegally on concessions belonging to large scale operators, or in restricted areas (Ghana Academy of Arts and Sciences, 2003). The illegal small-scale miners account for approximately 10% of the gold production in Ghana (Ntibery, 2004). These are locally referred to as *galamsey* (Hilson, 2002c).

The technique mostly used for small-scale mining is amalgamation (Akosa *et al.*, 2002). In this process, mercury is mixed with gold concentrate to form gold amalgam, which is heated to separate the gold (Ntibery *et al.*, 2003). Both legal and illegal small-scale mining is practiced in the country (Avotri *et al.*, 2002). In the Tarkwa area, small-scale mining is found all around, both in the forest and along rivers.

2.2 IMPACT OF MINING AND ENVIRONMENTAL DEGRADATION

Large- and small-scale mining cause somewhat different environmental concerns. The major concerns observed in this area are discussed in the following sections: (the following section is mostly collected from Akosa *et al.* (2002).

2.2. 1 Large-Scale Mining

Environmental problems caused by large-scale gold mining include the following:

- Land degradation, for example, removal of vegetative cover and destruction of flora and fauna.
- Impact due to processing technique includes contamination of water bodies and soil by release of cyanide, arsenic, sulphate, and heavy metals as Pb, Cu, Zn and Fe.
- Cyanide spillage. There have been a number of accidental cyanide spillages in Ghana. The major spillages occurred in 1989, 1991, 1994, 1996, 1999 and 2001.
- Roasting of ore containing pyrite gives rise to the production of SO₂ in the atmosphere which produces acid rain. The acid water then releases high levels of toxic ions from the rock matrix in the groundwater. This has been the main mode of extraction for the Prestea mine during the last decade. SO₂ could also be transported with north-eastern winds from the Ashanti Goldfields in the northeast (Kortatsi, 2004).
- Noise and vibrations.
- Dust from blasting operations.
- AMD (Acid Mine Drainage) from solid waste from sulphidic ore leaching heavy metals and acidity into water and soil.
- Siltation of surface waters.
- Grease and oils from various activities in the mine.

The management of waste from large scale mining is done in accordance with approved environmental plans. The spent heap and waste rock heaps are stabilized and re-vegetated.

Tailing slurries are channeled into tailing dams that also are re-vegetated. Reagent containers and packing materials are sold out to contractors who dispose of them. The monitoring of these contractors is poor. Spent oil and grease are sold to end-users.

2.2.2 Small-scale mining

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

- Land degradation;
- Pollution of rivers and streams by mercury;
- Atmospheric impacts from mercury fumes during gold recovery and dust;
- Mercury in groundwater from accidental spillage during gold processing;
- AMD from solid waste from sulphidic ore leaching heavy metal and acidity into water and soil;
- Siltation of surface waters;
- Deforestation due to wood used for stabilizing mining shafts;
- Damage to infrastructure due to undermining of roads and houses.

The management of waste on small-scale mines particularly illegal ones does not have a Waste management plan. Estimated 5 tonnes mercury is released from small-scale mining operations in Ghana each year (Hilson, 2001). High concentrations of mercury have been found in sediments and fish in the vicinity of small-scale mining activities using

amalgamation as their main technique. The concentration in most fish fillets in these areas exceeds the recommendations of the United States Food and Drug Agency (Babut *et al.*, 2003).

2.3 SURFACE WATER QUALITY

All natural water contains substances derived from the environment, both natural and man-made. The amount of these constituents in the water determines its quality. Thus, water quality can be defined in terms of the physical, chemical and biological characterization of water.

Surface water comprises inputs from rainfall, runoff and base flow. Each of these inputs to the surface-water system can contribute natural compounds of relevance to water quality. Rainfall in highly industrialized regions may consist of acidic precipitation which is introduced to the surface water; runoff may bring with it natural organics, sediment; and base flow may have elevated levels of hardness from the flow of the water through the subsurface. Human activities may increase the concentration of existing compound in surface water or may cause additional compounds to enter surface water. Discharge of wastewater (treated or otherwise) greatly adds to the organic load of the surface water. Clearing of land for construction or farming, river course dredging, sand production for construction material, etc., can result in increased erosion and sediment load in the surface water (Pollution Control Department, 1997).

2.3.1 Water Quality Parameter

Physico-chemical parameters used to assess water quality include color, temperature, conductivity, total dissolved solids, turbidity, dissolved oxygen, pH, conductivity and total suspended solids.

2.3.1.1 Water pH

Scientists measure the acidity of water by testing the pH level. The pH ranges from 0 to 14 with pH of 7 being neutral. The low end of the scale represents high acidity, while the high end represents alkalinity.

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

The pH is a measure of the acidity or basic (alkaline) nature of a solution. A pH range of 6.0 to 9.0 appears to provide protection for the life of freshwater, fish and bottom dwelling invertebrates. Many enzymes and other proteins are denatured by low pH which differs much from pH 7, which disrupts the functioning of the organism and may kill it. Low pHs also increase the release of metals, some toxic, from soils and sediments. Alkalinity is an important parameter because it measures the water's ability to resist acidification, for

instance, to acid rain. The significant environmental impact of pH involves synergistic effects. That is, the pH value of the water may influence levels at which certain chemical substances become toxic.

High levels of either acidity or alkalinity can destroy life. Acid rain is particularly harmful to trees and other plants. Acid rain adds aluminum to the soil and destroys important nutrients (www.ehow.com/about_6723807_effect). As a result, trees and plants are less able to absorb the groundwater they need for growth. Additionally, acid rain damages plant health, making them less resistant to insect damages and diseases. Acidic water similarly affects aquatic plant life, destroying important food sources. Acid water robs fish and other aquatic species of sodium in the blood and oxygen in the tissues. Additionally, it affects the functioning of fish gills, and also kills individual fish, reduces fish population numbers, and completely eliminates fish species from a water body (http://www.epa.gov/acid_rain/effects/surface-water.html).

2.3.1.2 Turbidity

The turbidity of a body of water is related to the cleanliness of the water. Waters with low concentration of total suspended solids (TSS) are clearer and less turbid than those with high TSS concentrations. Turbidity is the cloudiness or haziness of a fluid. This can be caused by high concentration of biota such as phytoplankton, or by loading of abiotic matter such as sediments. Human activities that disturb land, such as construction, can lead to high sediment levels entering water bodies during rain storms due to storm water runoff. Areas prone to high bank erosion rates as well as urbanized areas also contribute large

amount of turbidity to nearby water, through storm water pollution from paved surfaces such as roads, bridges and parking lots. Certain industries such as quarrying, mining and coal recovery can generate very high levels of turbidity from colloidal rock particles (www.slideshare.net/guest5907f90).

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

Solids particles suspended in water absorb or reflect light and cause the water to appear “cloudy”. These particles are suspended inorganic minerals or organic matter picked up over or under the ground. Since the earth acts as an excellent filter, the water from deep well is usually clear without significant amounts of turbidity. This problem is more common in the water from surface supplies. The major problem with turbidity is aesthetic, but in some cases suspended matter can carry pathogens with it. Large amounts of organic matter can also produce stains on sinks, fixtures, and laundry (WHO, 1985).

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

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

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

2.3.1.3 Total dissolved solids (TDS)

TDS are correlated fairly well to the total mineral content of the water (deposits left after evaporation of a water sample), primarily salts, carbonates and metals. Organic compounds

may also be dissolved solids. A high concentration of TDS is an indicator of possibly high volume contamination and further investigation may be recommended.

Water is a good solvent and picks up impurities easily. Dissolved solids refer to any minerals, salts, metals, cations or anions dissolved in water. Total dissolved solids in drinking water originate from natural sources, sewage, urban runoff, industrial wastewater, and chemicals used in the water treatment process, and the nature of piping or hardware used to convey the water. In general, total dissolved solids concentration is the sum of the cations and anions in water. Total dissolved solids test provides a quantitative measure of the amount of dissolved ions. It is used to determine the general quality of the water. The total dissolved solids concentration can be related to the conductivity of the water, but the relationship is not a constant.

The most important aspect of TDS with respect to drinking water quality is its effect on taste. The potability of drinking water with TDS level less than 600 mg/l is considered to be good. Drinking water supplies with TDS levels greater than 1200 mg/l are unpalatable to most consumers (Bruvold and Ongerth, 1969).

High TDS reduces consumer confidence. High levels of TDS can adversely affect industrial applications requiring the use of water, such as cooling tower operations, boiler feed water, food and beverage industries. High concentration of TDS may reduce water clarity, which contributes to a decrease in photosynthesis and lead to an increase in water temperature. Concentration of TDS that are too low or too high may limit growth and may lead to the death of many aquatic organisms.

2.3.1.4 Conductivity

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

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

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

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

2.3.1.5 Dissolved Oxygen Content in Rivers and Streams

Dissolved oxygen is essential to the respiratory metabolism of most aquatic organisms. The dynamics of oxygen distribution in inland waters are governed by a balance between inputs from the atmosphere and photosynthesis and losses from chemical and biotic oxidations. Oxygen distribution is important for the direct needs of many organisms and affects the solubility and availability of many nutrients and therefore the productivity of aquatic ecosystems.

Rapidly moving water, such as in a mountain stream or large river, tends to contain a lot of dissolved oxygen, while stagnant water contains little. The organic matter degradation

carried out by water micro-organism consumes oxygen. Thus, excess organic material in lakes and rivers, a situation known as eutrophication, can cause an oxygen-deficient situation to occur. Aquatic life can suffer in stagnant water that has a high content of rotting, organic material in it, especially in summer, when dissolved-oxygen levels are at a seasonal low.

Adequate dissolved oxygen is necessary for good water quality. Oxygen is necessary element to all forms of life. Natural stream purification processes require adequate oxygen levels in order to provide for aerobic life forms. As dissolved oxygen levels in water drop below 5.0 mg/l, aquatic life is put under stress. The lower the concentration, the greater the stress. Oxygen levels that remain below 1-2 mg/l for a few hours can result in large fish kills.

2.3.1.6 Temperature

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

Human activities should not change water temperatures beyond natural seasonal fluctuations. To do so could disrupt aquatic ecosystems. Human activities can introduce thermal pollution into streams in several ways. Industries and power plants may use water to cool machinery and then discharge the warm water into a stream. Storm water warmed

by urban surfaces such as roads, roofs and parking lots, can flow into nearby streams. Water temperature rises when trees and vegetation providing shade are cut down. Soil erosion caused by construction, removal of streamside vegetation, poor farming practices, overgrazing and recreation increases the amount of suspended solids in the water. The suspended particles absorb sun's rays and also increase temperature (Allan, 1995).

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

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

2.4 MAJOR METALLIC CONTAMINANTS RELATED TO MINING

Some mining-related heavy metals (such as Lead, Arsenic, Copper, Mercury, Cadmium and Iron) may originate in industrial dischargers, run off from city streets, mining activities, leachate from landfills and a variety of other sources (WHO, 1993). These toxic chemicals, which are generally persistent in the environment, can cause death or reproductive failure in fish, shellfish and wildlife. In addition, they can accumulate in animal and fish tissue, be adsorbed in sediments, or find their way into drinking water supplies, posing long term health risks to humans (Anon, 1993).

Several of the metals are essential to the human body. The metals are mainly utilized in enzymes to make them function properly.

Iron is a trace element required by both plants and animals. Iron is an essential element in human nutrition. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability and range from about 10 to 50 mg/day. In drinking-water supplies, iron (II) salts are unstable and are precipitated as insoluble iron (III) hydroxide, which settles out as a rust-coloured silt. Anaerobic groundwater may contain iron (II) at concentrations of up to several milligrams per litre without discolouration or turbidity in the water when directly pumped from a well.

Turbidity and discolouration may develop in piped systems at iron levels above 0.05-0.1 mg/l, whereas levels of 0.3-3 mg/l are usually found acceptable. As a precaution against storage of excessive iron in the body a provisional maximum tolerable daily intake was calculated to about 2 mg/l drinking water. That level does not present a hazard to health.

The taste and appearance of drinking water will usually be affected below this level, although iron concentrations of 1-3 mg/l can be acceptable for people drinking anaerobic well-water.

No health-based guideline value for iron is proposed (WHO, 1996). Previous studies show maximum levels in groundwater to be 18.3 mg/l and maximum levels in surface water to be 4.01 mg/l (Kuma, 2004).

Iron is a trace element required by both plants and animals. It is necessary for vital oxygen transport mechanism in the blood of all vertebrate and some invertebrate animals. Iron in water may be present in varying quantities depending upon the geological area and other chemical components of the waterway. In addition to staining problems, large amounts of Fe can influence the taste of water and cause the development of iron bacteria, which are not a health hazard but are very unpleasant. A good indication of the presence of Fe in the system is a brown slimy growth in the toilet flush tank (WHO, 1993).

Mercury naturally occurs in groundwater and surface water at levels of less than 0.5 $\mu\text{g/l}$. The WHO guideline value for total mercury is 0.001 mg/l. Previous studies show maximum levels in groundwater to be 0.037 mg/l (Kortatsi, 2004) and maximum levels in surface water to be 0.093 mg/l (Kuma, 2004).

Cadmium is chemically similar to zinc and occurs naturally with zinc and lead in sulphide ores. Cadmium concentrations in unpolluted natural waters are usually below 1 $\mu\text{g/l}$. Median concentrations of dissolved cadmium measured at 110 stations around the world were less than 1 $\mu\text{g/l}$. The maximum value recorded being 100 $\mu\text{g/l}$ in the Rio Rimao in

Peru. Food is the main source of cadmium intake. Crops grown in polluted soil or irrigated with polluted water may contain increased concentrations, as many meats from animals grazing on contaminated pastures. The estimated lethal oral dose for humans is 350-3500 mg of cadmium; a dose of 3 mg of cadmium has no effects on adults. A guideline value for cadmium is calculated to 0.003 mg/l drinking-water (WHO, 1996). Previous studies show maximum levels in groundwater to be 0.003 mg/l (Kortatsi, 2004) and maximum levels in surface water to be <0.05 mg/l (Kuma, 2004).

Lead is the most common of the heavy elements, accounting for 13 mg/kg of the earth's crust. More than 80% of the daily intake of lead is derived from the ingestion of food, dirt, and dust. That means that an average of 5 µg/l lead intake from water forms a relatively small proportion of the total daily intake for children and adults, but a significant one for bottle-fed infants. Lead is possible human carcinogen (evidence inadequate in humans, sufficient in animals) and it is also a cumulative poison so that any increase in the body burden of lead should be avoided. A provisional tolerable daily intake is set to 3.5 µg of lead per kg of body weight for infants lead to a calculated guideline value of 0.01 mg/l. As infants are considered to be the most sensitive subgroup of the population, this guideline value will also be protective for other age groups (WHO, 1996). Previous studies show maximum levels in groundwater to be 0.026 mg/l (Kortatsi, 2004) and maximum levels in surface water to be <0.05 mg/l (Kuma, 2004).

Copper is an essential element in human metabolism and is generally considered to be non-toxic for man at the levels encountered in drinking water. The presence of Cu in a water

supply, although not considered as a health hazard, may interfere with the intended domestic uses of the water. Copper in public water supplies increases the corrosion of galvanized iron and steel fittings. At levels above 5 mg/l, it also imparts a color and an undesirable bitter taste to water.

Staining of laundry and plumbing fixtures occurs at Cu concentration above 1.0 mg/l. Copper is extensively used in domestic plumbing systems, and levels in tap-water can therefore be considerably higher than the level present in water entering the distribution system. The guideline value of 1.0 mg/l is recommended for drinking water quality based on its laundry and other staining properties (WHO, 1993).

Copper in soils may come from a variety of anthropogenic sources: mining and smelting activities; other industrial emissions and effluents; fly-ash; traffic; dumped waste materials; contaminated dust and rainfall; sewage and sludge; pig slurry; composted refuse; and agriculture fertilizers, pesticides, and fungicides (Pearse, 2002).

The results of available studies indicate that arsenic may be an essential element for several animal species, but there is no evidence that it is essential for humans. The level of arsenic in natural waters generally varies between 1 and 2 $\mu\text{g/l}$. Concentrations may be elevated, however, in areas containing natural sources; values as high as 12 mg/l have been reported. Inorganic arsenic compounds are classified as carcinogenic to humans. Lethal doses in humans range from 1.5 mg/kg to 500 mg/kg of body weight depending on the compound.

In one form or another, arsenic is present in rocks, soils, water, and living organisms at concentrations of parts per billion to parts per million (Chapman, 1996). Soil arsenic levels are normally elevated near arseniferous deposits, and in mineralized zones containing gold, silver, and sulphides of lead and zinc. Natural weathering of rocks and soils adds about 40,000 tons of arsenic to the oceans annually, accounting for $< 0.01\text{mg/l}$ input to water on a global basis (WHO, 1992).

Arsenic is introduced into the aquatic environment through atmospheric deposition of combustion products and through runoff from fly-ash storage areas near power plants and nonferrous smelters (Chapman, 1996). Elevated arsenic concentrations in water are recorded near mining operations, and from mineral springs and other natural water-usually alkaline and with high sodium and bicarbonate contents (WHO, 1992).

Agricultural applications provide the largest anthropogenic source of arsenic in the environment (Chapman, 1989). Inorganic arsenicals (Arsenic trioxide; arsenic acid; Arsenates of calcium, copper, lead, and sodium, and Arsenites of sodium and potassium) have been used widely for centuries as insecticides, herbicides, algicides, and dessicants. An arsenic concentration of 0.05 mg/l is recommended as WHO guideline value (WHO, 1985).

CHAPTER THREE

MATERIALS AND METHODS

3.1 STUDY AREA

3.1.1 Location and size

Asutifi District is one of the Nineteen (19) districts in the Brong Ahafo Region. It is located between latitudes 6°40' and 7°15' North and Longitudes 2°15' and 2°45' West. It shares boundaries with Sunyani Municipal Assembly to the north, Tano South District to the north- east, Dormaa District to north-west, Asunafo North and South Districts to the south-west and Ahafo Ano South and North Districts (Ashanti Region) to the south-east ((Figure 1).

With a total land surface area of 1500 sq. km, the district is one of the smallest in the region. There are a total of 117 settlements in the district and four paramountcies, namely: Kenyasi No. I, Kenyasi No. II and Hwidiem. The district capital is Kenyasi, which is about 50 km from Sunyani, the regional capital of Brong Ahafo, through Atronie and Ntotroso.

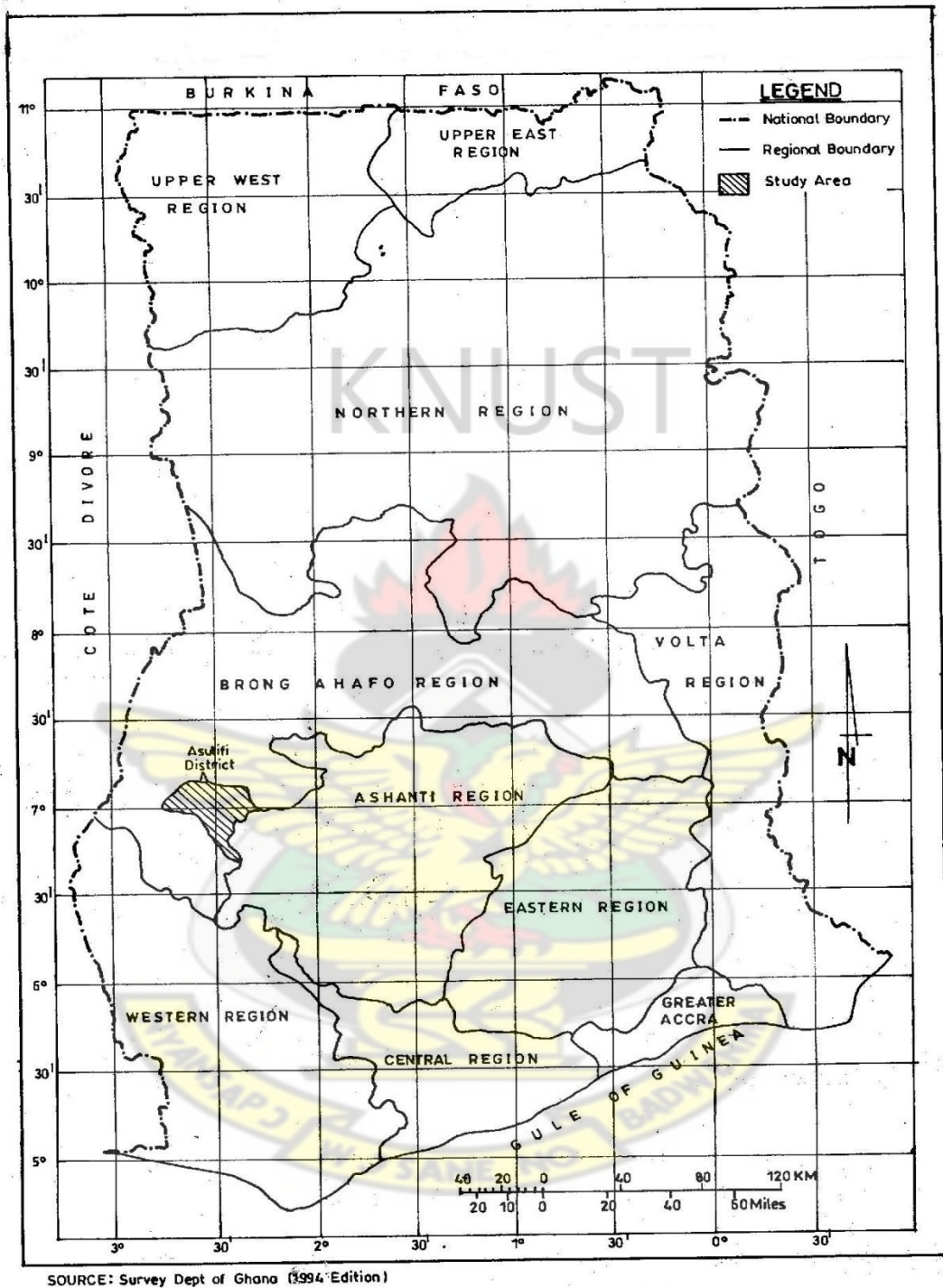


Figure 1 Map of Ghana showing the Asutifi District

3.1.2 Climate

The study area falls within the wet semi-equatorial climatic zone of Ghana. It is characterized by an annual double maxima rainfall pattern occurring in the months of May and July and from September to October with a mean annual rainfall between 125 mm and 200 mm. Typically, minimal rainfall is experienced from December month. Mean monthly temperature within the area ranges between 23.9 °C and 28.4 °C. In general, March is the hottest month of the year with mean temperature of 27.8 °C. August is the coolest month with a mean temperature of 24.6 °C. Relative humidity is generally high ranging between 75% to 80% during the two rainy seasons and 70% to 80% during the rest of the year.

3.1.3 Topography and Drainage

The district lies within the forest dissected plateau physiographic region with average height of about 700 feet above sea level. The lowest part is about 650ft above sea level found along the river basins whilst the highest point is found within a chain of mountains in the north east reaching a height of 1400 feet above sea level. These mountains form watershed for the many tributaries of the Tano river and other streams. There are outcrops of gigantic rocks found over Birimian rocks basement standing about 750-900 feet above the broad plateau surface.

The district is drained by Tano River and its many tributaries which include Nsubin, Goa, Akantansu, Sintim and Ntotro rivers exhibiting a dendritic pattern. These youthful fast flowing rivers have cut up the plateau surface giving rise to the dissected nature of the plateau. The study area is drained by a number of seasonal streams and perennial rivers which feed into the upper Basin of the Tano River.

3.1.4 Geology and Minerals

This physiographic region is underlain by precambrian rocks of Birimian and Dahomeyan formations. The Birimian formations are known to be the gold bearing rocks. The Birimian rocks also have a high potential for Manganese and Bauxite. Currently gold is being mined in the areas where these rocks are found by Newmont Ghana Gold Limited, one of the biggest mining companies in the world. These areas include Kenyasi No. I & II, Ntotroso, Gyedu-Wamahinso and other smaller communities. However, other exploration activities are on-going in other communities within the district.

Diamond is discovered at Wamahinso. There is also a widespread deposit of sand and clay in the district. The Sand deposits can be found at Kenyasi, Gambia No. II, Hwidiem and Acherensua whilst the clay deposits can be found at Nsunyameye and Dadiesoaba. There are rounded out crops of granite found over the Birimian rocks at Kwadwo AddaeKrom, Goa Asutifi, Georgekrom and Konkontreso which have high potential of iron and bauxite.

3.1.5 Vegetation

The study area lies within the semi-deciduous agro-ecological zone of Ghana. This is characterized by tall trees often exceeding 50 m in height. Man's activities notably farming, lumbering and occasional bush fires have however disturbed this vegetation. This has changed some areas into a derived wooded savanna. Such transitional zones could be observed along the roads to Goamu-Koforidua, Kensere and dadiesoaba.

3.2 SAMPLING

3.2.1 Sampling Sites

Sampling points were carefully chosen in order to assess the water quality of the Akantansu and Sintim rivers in Kenyasi I & II and its environs. Four (4) sampling points: two along each river (upstream and downstream) for water sampling. Table 1 below gives a description of the sampling points.

The under listed factors were considered in choosing the sampling points:

- Proximity: This has to do with the location of the sampling points in relation to the illegal mining activities (whether it is within or outside the galamsey concession).
- Purpose: What the water source is used for; drinking, domestic, agricultural or industrial purposes. The water bodies selected for the study are mainly used for drinking and/or domestic purposes.
- Population: The size of the population that depends on water from that sample point (size of the population served by the water source). Pipeline had the least population of about 70 people

Table 1 Sampling codes and locations

Sampling site code	Location
SDS	Sintim downstream located at the confluence of Sunti-Akantansu (Bridge K1)
SUS	Upstream of Sintim river on Sunti Headwater Crossing K2
ADS	Downstream of Akantansu river in Galamsey Swamp K2
AUS	Upstream of Akantansu river located at OLA (Akantansu headwater)

3.2.2 Method of Sampling

Sampling was done for a period of five months from February, 2013 to June, 2013. Duplicate water samples were collected at one month interval from four (4) sampling points. To obtain reliable results, sampling procedures which eliminate or minimize potential contaminants were adopted. This was achieved by soaking sample containers in nitric acid solution overnight and thoroughly flushing the container with distilled water and finally rinsing them with de-ionized water.

Water samples for physico-chemical analysis were collected into 500 ml plastic containers. Samples were stored in an ice chest containing ice and transported to the laboratory where some of the samples were filtered and preserved for dissolved metal analyses.

Samples for trace metal analysis were also collected into 500 ml containers but were acidified with concentrated nitric acid. This was done to preserve the samples for six months if the need arose (low pH keeps the metals in solution).

In sampling surface water, bottles showing the Type of Sample, Location, Site Name and Date were held near the base and its neck was plunged downward below the surface of the water body. Bottle was turned until the neck pointed slightly upwards, the mouth being directed towards the current of the water body. Bottles were filled directly from the water body. Temperature, pH, TDS and electrical conductivity, Turbidity, TSS and dissolved Oxygen were measured on site.

3.3 DETERMINATION OF PARAMETERS

3.3.1 Measurement of pH

The water pH was measured using a pH meter ORION 4 STAR (pH Conductivity portable) equipped with a temperature probe. The pH meter was initially calibrated by dipping the electrode into a buffer solution of known pH (pH 7.01) and the asymmetric potential control of the instrument altered until the meter reads the known pH value of the buffer solution. The standard electrode after rinsing with distilled/deionised water was then immersed in a second buffer solution (pH 4.01) and the instrument adjusted to read the pH value of this buffer solution. The standard electrode after rinsing with distilled / demonized water was then immersed in a third buffer solution (pH 10.01) and the instrument adjusted to read the pH value of this buffer solution. With the pH meter calibrated, it was immersed in the water sample, allowed to stabilize and the pH value read from the instrument. The beaker and the electrode were washed in between samples with deionised water in order to prevent contamination by other samples. Duplicate pH values were taken.

3.3.2 Measurement of Electrical Conductivity (EC)

Conductivity meter ORION 4 STAR (pH. Conductivity portable) was used to measure the conductivity of the water samples. The instrument was initially calibrated using standard solution of conductivities 1413 $\mu\text{S}/\text{cm}$ and 12.9 $\mu\text{S}/\text{cm}$ and duplicate values were taken.

3.3.3 Total Dissolved Solids (TDS)

TDS was measured using ORION 4 STAR (pH, Conductivity portable). One hundred millilitres of the sample was poured into a 250 ml beaker. The probe was then immersed in the sample and the value read on the digital screen.

3.3.4 Total Suspended Solids (TSS)

TSS was measured directly on the field by means of a TSS meter (PELICAN 1500, Model 3150). The water sample was stirred thoroughly and 25 ml of the sample was immediately poured into a sample cell. Twenty five milliliters pupil of distilled water (the blank) was filled into the sample cell. The blank was then placed in the cell holder and the light shield was closed. The zero button was pressed and the suspended solids value of the sample was displayed on the digital screen in mg/l.

3.3.5 Measurement of Turbidity

Turbidity of the water samples was measured in-situ with a microprocessor turbid meter HACH 2100Q. The instrument was first calibrated by dipping the probe into standard solution with turbidity values of 0.00 and 10.00 Nephelometric Turbidity Unit (NTU) and calibrated before using the turbidity values of the samples.

3.3.6 Measurement of Dissolved Oxygen

The Dissolved Oxygen of each water sample was determined using the HACH Model HQ30d basic unit USB DO meter using 200 ml of the water sample.

3.3.7 Measurement of Apparent and True Color

The Apparent and true color of each water sample was determined using the LaMotte (Color) model LTC3000e basic unit USB color meter using 200 ml of the water sample.

3.3.8 Determination of metals (Fe, Pb, Cd, As and Cu)

Fifteen millilitres (15 ml) of concentrated HNO_3 was added to 50 ml of sample collected. The mixture was heated slowly to evaporate to a lower volume of 15–20 ml after which 5 ml of concentrated HNO_3 was again added to the 15 ml of the mixture obtained. The mixture was then diluted to 50 ml with distilled water. This was then heated slowly to obtain a gentle refluxing action. Further heating continued until digestion was complete (a light coloured solution). The sample was then transferred to a 50 ml volumetric flask and diluted to the mark after allowing it to cool for about 30 minutes.

The levels of the individual metals were then determined using an Atomic Absorption Spectrophotometer (AAS) (Parkin Elmer 5100 PC). The absorbance of the standards and samples as well as the blank solution were read at 193.7 nm. Sensitivity for 1% absorption was 2.5 $\mu\text{g/l}$. A calibration curve was constructed and the concentration equivalent to the absorbent of the sample was read from the curve and was recorded accordingly.

3.4 Statistical Analysis

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

CHAPTER FOUR

RESULTS

4.1 PHYSICO-CHEMICAL PARAMETERS OF THE WATER SAMPLES

4.1.1 Water samples from the Sintim River

Table 2 below presents results of the physico-chemical analysis of water samples collected from the Sintim River.

The table indicates that, mean pH of water samples from the river was 6.57 with a range of 6.01-6.85 at the upstream sampling point (SUS) whereas the mean was 6.89 and ranged from 6.63-7.15 at the downstream sampling point (SDS). All the pH values were within the range (6.5-8.5) recommended by the WHO for drinking water. The mean values did not vary significantly ($p>0.05$) from the upstream to the downstream (Appendix 2a).

Table 2: Physico-chemical parameters of water samples from the Sintim River

PARAMETERS	UP STREAM (SDS)		DOWN STREAM (SDS)		WHO
	MEAN	SD	MEAN	SD	
pH	6.57	0.37	6.89	0.25	6.5-8.5
Temp (°C)	27.92	0.46	27.98	0.41	< 30
TSS (mg/l)	14.40	4.98	43.60	8.47	50
EC (µS/cm)	179.76	6.59	283.52	10.28	1500
TDS (mg/l)	88.08	3.23	138.92	5.017	1000
Turbidity (NTU)	22.20	7.35	58.96	13.72	5
DO (mg/l)	5.14	1.45	4.84	0.602	5
App. Color (TCU)	21.4	3.27	37.04	12.16	-
True Color (TCU)	13.54	2.256	21.84	3.19	20

Mean temperature of samples from the Sintim river varied between 27.5°C and 28.6°C at sampling site SUS and between 27.4°C and 28.3°C at site SDS (Table 2). These temperature ranges were within the WHO recommended level (<30°C) for drinking water. The differences in temperature between the upstream and downstream were statistically insignificant ($P>0.05$) (Appendix 1a).

Total Suspended Solids (TSS) in samples from the Sintim river were within the WHO recommended guideline limit of 50 mg/l. Site SUS recorded a mean TSS value of 14.40 mg/l while SDS recorded a mean of 43.6 mg/l (Table 2). Variations in TSS did not differ significantly from the sampling points (Appendix 5a).

According to Table 2, Electrical Conductivity (EC) of samples from the upstream sampling point of the river ranged from 172.1 to 189.4 $\mu\text{S}/\text{cm}$ with a mean of 179.76 $\mu\text{S}/\text{cm}$. EC values at the downstream sampling point (SDS) ranged from 271.8 to 296.2 $\mu\text{S}/\text{cm}$ with a mean of 283.52 $\mu\text{S}/\text{cm}$. All the EC values were within the 1500 $\mu\text{S}/\text{cm}$ recommended by the WHO for drinking water purposes. These variations in conductivity among the different sampling sites were statistically significant ($p<0.05$) (Appendix 3a).

The upstream of the Sintim river recorded lower mean TDS (88.08 mg/l) than the downstream which recorded mean TDS of 138.92 mg/l (Table 2). The mean values were far below the WHO maximum allowable limit of 1000 mg/l for drinking water. These differences, however, were not statistically significant ($P > 0.05$) (Appendix 4a).

Like TDS, turbidity increased from the upstream to the downstream sampling points on the Sintim river. Mean values recorded for the upstream and downstream points were, respectively, 22.20 mg/l and 58.96 mg/l, which far exceeded the WHO guidelines for drinking water quality of 5 NTU (Table 2). Even though high mean turbidity values were recorded in all the samples, the variations within the sampling sites were not statistically significant ($P>0.05$) (Appendix 6a).

Unlike the other physico-chemical parameters determined in this study, Dissolved Oxygen (DO) levels in the Sintim river decreased from the upstream sampling point (SUS) to the downstream point (SDS). DO values of the samples were 5.14 mg/l and 4.84 mg/l, respectively, at SUS and SDS (Table 2). The recorded DO values were generally within the WHO guideline value (5 mg/l) for drinking water. Variations in mean DO values were not statistically significant ($P>0.05$) (Appendix 7a).

It can be seen from Table 2 that true and apparent colour increased from the upstream to the downstream of the Sintim river. While true colour increased from 13.54 at upstream to 21.84 TCU at downstream, apparent colour also increased from 21.4 to 37.04 TCU. The mean values recorded for true colour at SDS and ADS exceeded the Ghana EPA guidelines (20 TCU) for surface water quality.

4.1.2 Water samples from the Akantansu River

Results of the physico-chemical analysis of water samples from the Akantansu river are presented in Table 3 below. According to this table, higher values were recorded at the

downstream sampling point than the upstream sampling point for all the physico-chemical parameters studied. The only exception was dissolved oxygen which recorded a higher value at the upstream.

The pH of the samples were ranged 6.40-7.52 and 6.59-8.32, respectively, for the upstream (AUS) and downstream (ADS) points of the river. These values were generally within the range recommended by the WHO guideline value of 6.5-8.5. The mean values did not vary significantly ($p>0.05$) from the upstream to the downstream (Appendix 2b).

Table 3: Physico-chemical parameters of water samples from the Akantansu River

Parameters	UPSTREAM (AUS)		DOWN STREAM (ADS)		WHO
	Mean	SD	Mean	SD	
pH	7.07	0.54	7.40	0.773	6.5-8.5
Temp (°C)	28.24	1.07	28.80	0.997	22-29
TSS (mg/l)	13.00	3.54	28.40	8.73	50
EC (µS/cm)	137.84	50.54	172.34	51.82	1500
TDS (mg/l)	67.50	24.76	84.44	25.41	1000
Turbidity (NTU)	20.00	6.05	38.70	10.02	5
DO (mg/l)	4.70	1.59	4.40	1.41	5
Apparent Color (TCU)	28.32	5.589	46.94	16.41	15
True Color (TCU)	18.68	3.02	29.80	9.53	20

Mean temperatures ranged from 27.3°C to 30°C at upstream and 27.7°C to 30.4°C at downstream. Generally, the values were within the permissible limit ($<30^{\circ}\text{C}$) recommended by the WHO guidelines. Mean upstream temperatures did not vary significantly from downstream mean values ($P>0.05$) (Appendix 1b).

Total Suspended Solids (TSS) of all the Akantansu upstream samples ranged from 9–18 mg/l with the downstream (ADS) samples ranging from 18-39 mg/l (Table 3). The values were within the WHO guideline limit of 500 mg/l for drinking water. TSS did not vary significantly between the sampling points ($p>0.05$) Appendix 5b.

Like the other parameters, electrical conductivity recorded higher values at the downstream (93.1 to 231.4 $\mu\text{S}/\text{cm}$) than the upstream section of the river (71.5 to 195.8 $\mu\text{S}/\text{cm}$) (Table 3). Nevertheless, these were far below the 1500 $\mu\text{S}/\text{cm}$ guideline limit recommended by the WHO for drinking water. Statistically significant differences existed between the sampling points ($p<0.05$) (Appendix 3b).

TDS and turbidity followed the trends exhibited by most of the other parameters. Mean TDS recorded for the upstream and downstream of the river were 67.50 and 84.44 mg/l, respectively. The respective values for turbidity were 20 and 38.7 NTU. While TDS met the WHO recommended guideline (1000 mg/l) for drinking water, turbidity far exceeded the WHO guideline value (5 NTU) (Table 3). Also, values for both parameters did not vary significantly from the sampling sites ($p>0.05$) (Appendices 4b and 6b).

Levels of dissolved oxygen (DO) at the upstream section of the Akantansu river varied between 2.50 and 6.30 mg/l while the range was 2.30-6.20 mg/l at the downstream (Table 3). The mean values (4.7 and 4.4 mg/l, respectively at AUS and ADS) were slightly below the value (5 mg/l) recommended by the WHO. The variations within the sampling sites were not statistically significant ($P>0.05$) (Appendix 7b).

According to Table 3, both true and apparent colour of water samples exceeded the Ghana EPA recommended limit of 20 TCU for surface water quality. Again, it can be seen from the table that the upstream recorded lower values in both parameters than the downstream. While the upstream recorded 28.32 and 18.68 TCU for apparent and true colours, respectively, the downstream registered 46.94 and 29.8 TCU for these parameters.

4.2 METAL ANALYSIS

4.2.1 Levels of Heavy Metals in Water samples from the Sintim River

Table 4 below presents results of the metal analysis of the water samples from the Sintim river. The range for total iron (Fe) for upstream and downstream were 2.20-5.19 and 6.06-10.50 mg/l, respectively, with the respective mean concentrations being 3.89 and 7.34 mg/l (Table 4). Dissolved iron upstream of the river varied between <0.0005 and 3.91 mg/l while it was 0.002-1.60 mg/l downstream of the river (Table 4). Fe concentrations recorded at all the sampling points were clearly in excess of the WHO and EPA guideline limit of 0.3 mg/l.

Total arsenic values for Sintim upstream ranged from 0.0015 to 0.0036 mg/l while the range for downstream was 0.0028 to 0.004 mg/l (Table 4). Mean values for dissolved arsenic were <0.0001-0.0021 mg/l and <0.0001-0.0018 mg/l, respectively at upstream and downstream (Table 4). Both total and dissolved arsenic in the water samples were generally within the WHO guideline limit of 0.01 mg/l for drinking water.

Table 4: Trace metal levels in water samples from the Sintim River

Metal (mg/l)	UPSTREAM (SUS)		DOWN STREAM (SDS)	
	Mean	SD	Mean	SD
Total Fe	3.89	1.537	7.34	1.832
Dissolved Fe	2.06	1.758	0.75	0.665
Total As	0.0024	0.0009	0.0027	0.0007
Dissolved As	0.0014	0.0008	0.0011	0.0007
Total Hg	0.0009	0.0012	0.00052	0.0007
Dissolved Hg	0.0002	0.0002	0.0002	0.0002
Total Cd	0.00068	0.0013	0.00068	0.0013
Dissolved Cd	0.0001	0.0001	0.0001	0.0001
Total Cu	0.00074	0.0004	0.0026	0.0008
Dissolved Cu	0.0005	0.0005	0.0014	0.0010
Total Pb	0.00092	0.0010	0.00138	0.0004
Dissolved Pb	0.00014	0.0001	0.00072	0.0003

Total and dissolved mercury levels upstream of the Sintim river ranged from <0.0002 to 0.003 mg/l and <0.0002 mg/l, respectively, while the values for these parameters were <0.0002 to 0.0018 mg/l and <0.0002, respectively, downstream of the river (Table 4). The values were generally within the WHO guideline value (0.001 mg/l) for total mercury.

According to Table 4, both total and dissolved cadmium concentrations in all the samples from the Sintim River were less than the WHO recommended guideline limit (0.003 mg/l) in drinking water.

Table 4 indicates that total copper concentrations ranged from <0.0005 to 0.0014 mg/l and <0.0012 to 0.0028 mg/l, respectively, upstream and downstream of the Sintim river. While a concentration of <0.0005 mg/l was recorded for dissolved copper upstream of the river, values in the range of 0.0007-0.003 mg/l were recorded downstream of this river.

Generally, all the sampling points recorded mean values that were far below the WHO recommended value of 1.0 mg/l.

Total lead concentrations in samples from this river ranged from 0.0002 to 0.0021 mg/l at the upstream sampling point and 0.0011 to 0.002 mg/l at the downstream of the river (Table 4). The dissolved concentrations were much lower, with upstream recording values that were generally <0.0002 mg/l and the downstream registering values <0.001 mg/l (Table 4).

4.2.2 Water samples from the Akantansu River

Concentrations of Fe, As, Cd, Hg, Cu and Pb in water samples from the Akantansu river are presented in Table 5. The table indicates that total iron varied from 4.64 to 5.28 mg/l at upstream (AUS) while the variation was from 2.70 to 55.20 mg/l at downstream (ADS). Dissolved iron obtained for Akantansu upstream varied between <0.0005 and 2.36 mg/l (Table 5). Dissolved iron value for Akantansu downstream ranged from 0.0009 to 0.55 mg/l. Fe concentrations recorded at all the sampling points were clearly in excess of the WHO and EPA guideline limit of 0.3 mg/l.

Table 5: Trace metal levels in water samples from the Akantansu River

UPSTREAM (AUS)			DOWN STREAM (ADS)	
Metal (mg/l)	Mean	SD	Mean	SD
Total Fe	4.96	0.293	25.70	26.915
Dissolved Fe	1.87	1.048	0.23	0.272
Total As	0.0025	0.0002	0.0055	0.0041
Dissolved As	0.0018	0.0012	0.0008	0.00049
Total Hg	0.00076	0.0007	0.0015	0.0012
Dissolved Hg	<0.0002	0.0002	0.0002	0.0002
Total Cd	0.0012	0.0012	0.0015	0.0013
Dissolved Cd	0.0001	0.0001	0.0001	0.0001
Total Cu	0.00074	0.0003	0.0094	0.0155
Dissolved Cu	0.00054	0.00009	0.0038	0.0058
Total Pb	0.0015	0.0018	0.0064	0.00702
Dissolved Pb	0.00014	0.0001	0.00072	0.0003

A range of mean concentrations varying from 0.0022 mg/l to 0.0027 mg/l was recorded for total arsenic upstream (AUS) of the Akantansu river (Table 5). At the downstream sampling location (ADS), total Arsenic concentrations ranged from 0.0022 to 0.01 mg/l. Values for dissolved As were respectively, 0.0001-0.003 mg/l and 0.0022-0.01 mg/l, for AUS and ADS.

Total mercury (Hg) ranged from 0.0003 to 0.0019 mg/l at site AUS and 0.0003 to 0.0026 mg/l at ADS (Table 5). Dissolved mercury obtained for both AUS and ADS was <0.0002 mg/l (Table 5).

Table 5 indicates that both total and dissolved cadmium concentrations in all the samples from the Akantansu river were generally within the WHO recommended guideline limit (0.003 mg/l) in drinking water.

Total copper (Cu) values for Akantansu upstream ranged from <0.0005 to 0.0012 mg/l while the range for downstream was 0.0012 to 0.037 mg/l (Table 5). The range for dissolved copper obtained for the samples were <0.0005 to 0.0007 mg/l and 0.001 to 0.0141 mg/l, respectively for sites AUS and ADS.

Both total and dissolved Pb were below the WHO. Total lead values for Akantansu upstream ranged from <0.0002 to 0.004 mg/l while they ranged from 0.0004 to 0.0141 mg/l downstream of the river (Table 5). Concentrations of dissolved lead in the samples ranged from <0.0002 to 0.003 mg/l at site AUS and <0.0002 to 0.0005 mg/l at site ADS (Table 5). The values were within the WHO guideline value of 0.01 mg/l for lead in drinking water.

CHAPTER FIVE

DISCUSSION

5.1 PHYSICO-CHEMICAL QUALITY OF THE SINTIM AND AKANTANSU RIVERS

Generally, the mean pH of the water samples from the Sintim river were slightly higher at the downstream sampling point (6.89 ± 0.25) than the upstream sampling point (6.57 ± 0.37). Similar trend was shown by samples from the Akantansu river with the upstream and downstream recording mean values of 7.07 ± 0.54 and 7.40 ± 0.77 , respectively. Nevertheless, the mean values fell within the 6.5-8.5 range recommended by the WHO guidelines for drinking water. The slightly higher values at the downstream sampling locations for both rivers indicate anthropogenic influence such as small-scale gold mining.

Small-scale gold mining (also called "galamsey") involves activities that loosen the soil or disturb the soil structure, and, hence could facilitate the leaching of certain ions into water bodies to influence the pH. Agyapong *et al.* (2012), have reported similar pH values in surface waters in the Bogoso mining area in Ghana's Western Region. The range of pH recorded in the present study is also consistent with a study by Nartey *et al.* (2011), who reported a pH range of 7.1-8.5 in water samples from Bibiani-Anwiaso-Bekwai District, a typical mining community in Ghana.

Mean temperatures generally were high (27.92 - 27.98°C in the Sintim river and 28.24 - 28.80°C in the Akantansu river) but were less than 30°C generally preferred for drinking water. The temperatures were also fairly constant in both rivers. The high temperatures

could be attributed to the fact the study was conducted in the months (December-April) where temperatures were generally high in the study area. The temperature of a water body is influenced by the prevailing weather conditions (Fritz, 2001). The observed temperatures are consistent with the study by Agyapong *et al.* (2012). However, the temperature range recorded in the present study was narrower compared with the study by these authors, and also the work by Nartey *et al.*, (2011).

Total dissolved solids (TDS) recorded values that ranged from mean of 67.50 ± 24.76 to 138.92 ± 5.02 mg/l. The values were lower than the WHO permissible limit of 1000 mg/l. According to WHO, the palatability of water with a TDS level less than 600 mg/l is generally considered to be good. Hence, all the water samples appeared to be suitable for drinking in terms of TDS. The slight increase in TDS downstream of both rivers could be attributed to the increase in activities of the small-scale gold mining which increases the probability of runoff water carrying loosened soil particles containing minerals and ions into the rivers.

Conductivity followed a similar trend to TDS. Highest conductivities were recorded at the downstream of both rivers. Sintim downstream recorded the highest conductivity with a mean value of 283.52 ± 10.28 $\mu\text{S}/\text{cm}$ while Akantansu upstream recorded the least value of 137.84 ± 50.54 $\mu\text{S}/\text{cm}$. All the conductivity values were low compared with the WHO recommended guideline value (1500 $\mu\text{S}/\text{cm}$) for drinking water. The low values indicate that contaminations due to dissolved ions were low. However, the increase in conductivity values downstream of the streams could be due in part to human activities (mainly, small-scale mining) along the banks of the two rivers. These mining activities may have

disturbed mineralized rocks and released adsorbed ions into the water to increase the ion content, and consequently the conductivity of the water.

Such low conductivity values in a mining area have been reported in previous studies (Agyapong *et al.*, 2012; Ansa-Asare and Gordon, 2012).

The average turbidity levels in the two rivers were higher at the downstream than at the upstream, and exceeded the WHO recommended guideline limit (5 NTU) for drinking water at all sampling locations. The high turbidity levels may imply lower primary productivity in the two streams due to lower light penetration for photosynthesis. They may also negatively affect available dissolved oxygen to support other organisms.

The turbid nature of the rivers at the various sampling points could be attributed to decay of leaf litter and vegetation, erosion and runoff from the intense small-scale mining along the banks of the rivers. These could have also made light penetration more difficult. Hence, the high turbidity of the water samples could be attributed to runoff resulting from small-scale gold mining activities in and along the banks of the rivers.

In drinking water, the higher the turbidity level, the higher the risk that people may develop gastrointestinal diseases. This is especially problematic for immune-compromised people, because contaminants like viruses or bacteria can become attached to the suspended solids.

Dissolved oxygen (DO) decreased from the upstream to the downstream of both rivers. Mean DO varied from 5.14 mg/l at upstream to 4.84 mg/l at downstream of the Sintim river. The respective values for samples from the Akantansu river were 4.7 to 4.4 mg/l. The mean values were generally slightly lower than the 5.0 mg/l level below which aquatic

life is put under stress. The lower the concentration, the greater the stress. Oxygen levels that remain below 1-2 mg/l for a few hours can result in large fish kills.

The observed lower concentrations downstream of the rivers is attributable to the small-scale mining activities which increased the turbidity of the water. Turbidity lowers the rate of photosynthesis which in turn affects the levels of dissolved oxygen available in a given body of water.

The mean values for colour recorded at both sampling locations over the period were above the permissible levels of 15 CU set by the WHO. The very high turbid nature of the water resulting from the intense small-scale mining activities along the banks of the river could have possibly impacted on the colour.

5.2 METAL CONCENTRATIONS

The results of the heavy metal analysis of water samples from the Sintim and Akantansu streams show that, iron, arsenic, mercury, cadmium, copper and lead were present in both total and dissolved forms in measurable quantities. Generally, copper, arsenic, lead, cadmium and mercury concentrations measured in the water samples were lower than the respective WHO acceptable limits of drinking. A comparison of the results shows that samples from downstream of the rivers generally recorded higher values of total metal concentrations than those from the upstream (Table 4 and 5).

Iron recorded values that exceeded the WHO recommended limit (0.3 mg/l) in all the samples. This includes both total and dissolved iron. Mean concentration of total iron

ranged from 3.89 mg/l to 25.70 mg/l. Dissolved iron recorded much lower values (0.23-2.06 mg/l). Also, dissolved iron values recorded upstream of the rivers were much lower than those at the downstream, contrary to the trend observed for total iron.

The very high values recorded for iron in the samples may be attributed to the natural existence of iron in the Earth's crust, and concentrations in the range of 0.5 to 50 mg/l in surface water and groundwater sources are not unusual. Also, the study area which is rich in arsenopyrite and pyrite rocks might be the sources of high iron concentrations in the water. Processing of the ores could have released these high concentrations of iron to the surface waters in the study area (Langmuir, 1997).

The generally high levels of iron in the water samples may cause staining problems, and also influence the taste of water and cause the development of iron bacteria, which are not a health hazard but are very unpleasant (Kuma, 2004).

Mean total arsenic concentrations increased from 0.0024 mg/l (at upstream) to 0.0027 mg/l (at downstream) in the Sintim river while the Akantansu river saw mean arsenic concentrations increase from 0.0025 mg/l to 0.0055 mg/l. However, dissolved arsenic levels decreased marginally from the upstream to the downstream of both rivers. These concentrations were less than the 0.01 mg/l recommended by the WHO for drinking water. According to WHO (1992), elevated arsenic concentrations in water are recorded near mining operations. Agricultural applications provide the largest anthropogenic source of arsenic in the environment (Chapman, 1989).

Total concentrations of Hg, Cd, Cu and Pb recorded in the Akantansu river followed a trend similar to those exhibited by Fe and As, i.e, mean values were higher at the downstream than at the upstream sections of the rivers. These trends could be attributed to the many human activities which go on along the banks of this river, which could contribute significantly to metal levels in the water. Mining activities occurring inside and along the banks of the river may have probably released some of these metals from loosened rocks into the river. The relatively high levels of these metals could have also come from other anthropogenic inputs, both point and non-point sources, such as the use of metal-based fertilizers or pesticides in farming. Lead, for example is known to be used in pesticides, and since the community members are also farmers, it appears that the use of pesticides is likely to be the greatest source of lead in the water bodies.

In general, very low concentrations (<0.001 mg/l recommended by the WHO) were recorded for mercury in both rivers. The relatively high levels of mercury in downstream samples from the Akantansu river could have resulted from the process of amalgamation, a popular method used to recover gold from ore minerals. Nevertheless, values recorded for mercury in the samples were low (0.0005-0.0015 mg/l), compared with studies in other mining areas in Ghana. For example, mean mercury range of 0.001-0.017 mg/l is reported by Agyapong *et al.* (2012). Serfoh-Armah *et al.* (2006), even report of higher mercury concentrations (6.80-19.82 mg/l) in an extensive mining area.

Naturally, about 25,000 tons of cadmium is released into the environment per year (Wang *et al.*, 2005). About half of this cadmium is released into rivers through weathering of

rocks. The rest is released through human activities, such as manufacturing and mining (Damoah, 2007). Mean levels of cadmium determined in the samples (0.0008-0.0013 mg/l) were within the permissible limit of 0.003 mg/l by the WHO. Cadmium metal is used both as an anticorrosive material for steel, and also cadmium compounds form a major component of batteries. Hence, the presence of some appreciable levels of cadmium in the water samples could indicate anthropogenic contribution from milling of ores to recover gold, and release from abandoned batteries.

Levels of copper in all the samples were below the 1.0 mg/l permissible limit recommended by the WHO. The low levels imply that contributions from small-scale mining and farming were low. The use of phosphate fertilizers is known to increase copper levels in rivers from runoffs. Significant copper levels may also be added to soils by application of fertilizers, pesticides and fungicides (Pearse, 2002).

However, not much differences in the total concentrations of these metals upstream and downstream of the Sintim river were observed in the study. These results were unexpected looking at the enormity of the small-scale mining activities in the vicinity of this river.

The observed trends could, however, be explained from the fact that the Sintim river is a very fast flowing river which could have washed away or diluted some of these metals to nullify the effects of any anthropogenic inputs into this river. Another reason for this observation is the fact that, the gold is recovered / washed in dams created some distance

from the banks of the river. The above reasons could also explain the trends observed in the dissolved concentrations of the metals in the Sintim River.

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CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The results of this study have generally shown low levels of some of the examined heavy metals and the physico-chemical parameters of the rivers during the period of sampling.

Generally, higher values were recorded at downstream locations for nearly all the physico-chemical parameters studied. Mean values for temperature, pH, conductivity, TDS and TSS recorded values that were within the WHO recommended guideline values for drinking water. However, the waters were found to be very turbid, and this possibly resulted in the high values recorded for the colour of the water samples. Dissolved oxygen decreased at the downstream sampling locations and the mean values were generally slightly below the 5 mg/l recommended by the WHO.

The mean levels of copper, arsenic, lead, cadmium and mercury were generally slightly higher downstream of the rivers, but were lower than the WHO acceptable limits. However, levels of iron in the water samples were above the WHO acceptable limits, and very high values were recorded downstream of the rivers.

The general trend in the levels of the parameters studied suggests influence from the small-scale gold mining activities along the banks of the two rivers. Thus, it can be concluded that, small-scale gold mining activities have impacted negatively on the water quality of

the Sintim and Akantansu rivers, and that the use of water from the two rivers for domestic purposes could pose a potential health risk to consumers.

6.2 RECOMMENDATIONS

To prevent or minimize any further pollution of surface waters within the Asutifi District by the illegal small-scale mining operations, the following mitigation measures are seriously recommended to:

1. There is the need to embark on an intensive educational campaign by the regulatory agencies to bring the findings of this research to the notice of the people of the study area to discourage them from using these untreated raw water bodies as a source of drinking water to prevent any future bacterial epidemics.
2. There could be public campaigns to educate the illegal small scale miners and communities involved on the short and long term dangers of illegal mining activities. Alternative livelihood should be instituted for those engaged in the illegal small scale mining activities.
3. Activities of miners should be monitored to ensure that gold extraction and other mining activities do not occur close to drinking water sources.
4. Illegal small scale miners and the entire community should be educated on the health risk associated with human exposure to trace metals to prevent them from polluting water bodies.

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APPENDICES

APPENDIX 1a: Two-sample t test with equal variances for SIntim Temperature

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
-----+-----						
TEMPSUS	5	27.92	.2059127	.4604348	27.34829	28.49171
TEMPSDS	5	27.98	.1827566	.4086561	27.47259	28.48741
-----+-----						
combined	10	27.95	.1301708	.4116363	27.65553	28.24447
-----+-----						
diff		-.0599998	.275318		-.6948843	.5748846
-----+-----						
diff = mean(TEMPCUS) - mean(TEMPCDS)					t = -0.2179	
Ho: diff = 0		degrees of freedom =			8	
Ha: diff < 0		Ha: diff != 0		Ha: diff > 0		
Pr(T < t) = 0.4165		Pr(T > t) = 0.8329		Pr(T > t) = 0.5835		

APPENDIX 1b: Two-sample t test with equal variances for Akantansu Temperature

-----+-----						
Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
-----+-----						
TEMPAUS	5	28.24	.4770745	1.066771	26.91543	29.56457

TEMPADS	5	28.8	.446094	.9974965	27.56144	30.03856
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-----+-----

combined	10	28.52	.3217314	1.017404	27.79219	29.24781
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-----+-----

diff		-.5600002	.6531462		-2.066158	.9461575
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-----+-----

diff = mean(TEMPAUS) - mean(TEMPADS) t = -0.8574

Ho: diff = 0 degrees of freedom = 8

Ha: diff < 0 Ha: diff != 0 Ha: diff > 0

Pr(T < t) = 0.2081 Pr(|T| > |t|) = 0.4162 Pr(T > t) = 0.7919

APPENDIX 2a: Two-sample t test with equal variances for Sintim pH

-----+-----

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]
----------	-----	------	-----------	-----------	----------------------

-----+-----

pHSUS	5	6.57	.1641646	.3670831	6.114206 7.025794
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pHSDS	5	6.89	.1132696	.2532784	6.575513 7.204487
-------	---	------	----------	----------	-------------------

-----+-----

combined	10	6.73	.1080946	.3418252	6.485473 6.974527
----------	----	------	----------	----------	-------------------

-----+-----

diff		-.3200001	.1994492		-.7799308 .1399307
------	--	-----------	----------	--	--------------------

-----+-----

diff = mean(pHCUS) - mean(pHCDS) t = -1.6044

Ho: diff = 0 degrees of freedom = 8

Ha: diff < 0

Ha: diff != 0

Ha: diff > 0

Pr(T < t) = 0.0736

Pr(|T| > |t|) = 0.1473

Pr(T > t) = 0.9264

APPENDIX 2b: Two-sample t test with equal variances for Akantansu pH

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
-----+-----						
pHAUS	5	7.072	.241545	.5401111	6.401364	7.742637
pHADS	5	7.4	.3455575	.77269	6.440579	8.359421
-----+-----						
combined	10	7.236	.2061294	.6518384	6.769703	7.702297
-----+-----						
diff		-.328	.4216088		-1.300232	.6442316

diff = mean(pHAUS) - mean(pHADS) t = -0.7780

Ho: diff = 0 degrees of freedom = 8

Ha: diff < 0

Ha: diff != 0

Ha: diff > 0

Pr(T < t) = 0.2295

Pr(|T| > |t|) = 0.4590

Pr(T > t) = 0.7705

APPENDIX 3a: Two-sample t test with equal variances for Sintim conductivity

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
-----+-----						
CONDSUS	5	179.76	2.945266	6.585815	171.5826	187.9374
CONSDSDS	5	283.52	4.599284	10.28431	270.7503	296.2897
-----+-----						
combined	10	231.64	17.48393	55.28904	192.0886	271.1914
-----+-----						
diff		-103.76	5.461502		-116.3542	-91.16575
-----+-----						
diff = mean(CONDCUS) - mean(CONDCDS)					t = -18.9984	
Ho: diff = 0		degrees of freedom =			8	
Ha: diff < 0		Ha: diff != 0		Ha: diff > 0		
Pr(T < t) = 0.0000		Pr(T > t) = 0.0000		Pr(T > t) = 1.0000		

APPENDIX 3b:

Two-sample t test with equal variances for Akantansu conductivity

-----+-----						
Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
-----+-----						
CONDAUS	5	137.84	22.6011	50.53759	75.08929	200.5907

CONDADS	5	172.34	23.17599	51.82309	107.9931	236.6869
---------	---	--------	----------	----------	----------	----------

-----+-----

combined	10	155.09	16.30758	51.5691	118.1997	191.9803
----------	----	--------	----------	---------	----------	----------

-----+-----

diff	-34.5	32.37184	-109.1496	40.1496
------	-------	----------	-----------	---------

-----+-----

diff = mean(CONDAUS) - mean(CONDADS) t = -1.0657

Ho: diff = 0 degrees of freedom = 8

Ha: diff < 0

Ha: diff != 0

Ha: diff > 0

Pr(T < t) = 0.1588

Pr(|T| > |t|) = 0.3176

Pr(T > t) = 0.8412

APPENDIX 4a: Two-sample t test with equal variances for Sintim TDS

-----+-----

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]
----------	-----	------	-----------	-----------	----------------------

-----+-----

TDSSUS	5	88.084	1.446394	3.234236	84.06817	92.09984
--------	---	--------	----------	----------	----------	----------

TDSSAS	5	138.92	2.243524	5.016673	132.691	145.149
--------	---	--------	----------	----------	---------	---------

-----+-----

combined	10	113.502	8.565601	27.08681	94.12527	132.8787
----------	----	---------	----------	----------	----------	----------

-----+-----

diff	-50.836	2.669355	-56.99154	-44.68046
------	---------	----------	-----------	-----------

-----+-----

diff = mean(TDSCUS) - mean(TDSCAS) t = -19.0443

Ho: diff = 0 degrees of freedom = 8

Ha: diff < 0

Ha: diff != 0

Ha: diff > 0

Pr(T < t) = 0.0000

Pr(|T| > |t|) = 0.0000

Pr(T > t) = 1.0000

APPENDIX 4b: Two-sample t test with equal variances for Akantansu TDS

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
-----+-----						
TDSAUS	5	67.5	11.07384	24.76187	36.75408	98.24592
TDSADS	5	84.44	11.36317	25.40882	52.89079	115.9892
-----+-----						
combined	10	75.97	7.994749	25.28162	57.88462	94.05538
-----+-----						
diff		-16.94	15.86668		-53.52864	19.64863
-----+-----						

diff = mean(TDSAUS) - mean(TDSADS) t = -1.0676

Ho: diff = 0 degrees of freedom = 8

Ha: diff < 0

Ha: diff != 0

Ha: diff > 0

Pr(T < t) = 0.1584

Pr(|T| > |t|) = 0.3168

Pr(T > t) = 0.8416

APPENDIX 5a: Two-sample t test with equal variances for Sintim TSS

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
-----+-----						
TSSSUS	5	14.4	2.227106	4.97996	8.216563	20.58344
TSSSAS	5	43.6	3.789459	8.473488	33.07877	54.12123
-----+-----						
combined	10	29	5.289402	16.72656	17.03454	40.96546
-----+-----						
diff	-29.2	4.395452		-39.33593	-19.06407	
-----+-----						
diff = mean(TSSCUS) - mean(TSSCAS)					t = -6.6432	
Ho: diff = 0			degrees of freedom = 8			
Ha: diff < 0		Ha: diff != 0		Ha: diff > 0		
Pr(T < t) = 0.0001		Pr(T > t) = 0.0002		Pr(T > t) = 0.9999		

APPENDIX 5b: Two-sample t test with equal variances for Akantansu TSS

-----+-----						
Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
-----+-----						
TSSAUS	5	13	1.581139	3.535534	8.610055	17.38995
TSSADS	5	28.4	3.906405	8.734987	17.55408	39.24592

```
-----+-----
combined |    10    20.7  3.245681  10.26374  13.35776  28.04224
```

```
-----+-----
diff |      -15.4  4.214262      -25.1181  -5.681896
```

```
-----
diff = mean(TSSAUS) - mean(TSSADS)          t = -3.6543
Ho: diff = 0                                degrees of freedom =    8
```

```
Ha: diff < 0          Ha: diff != 0          Ha: diff > 0
Pr(T < t) = 0.0032    Pr(|T| > |t|) = 0.0065    Pr(T > t) = 0.9968
```

APPENDIX 6a: Two-sample t test with equal variances for Sintim Turbidity

```
-----+-----
Variable |  Obs   Mean  Std. Err.  Std. Dev.  [95% Conf. Interval]
-----+-----
TURBSUS |    5   22.202  3.289377   7.355271   13.06922   31.33478
TURBSDS |    5   58.962  6.137487  13.72384   41.9216   76.0024
```

```
-----+-----
combined |   10   40.582  6.950635  21.97984   24.85857   56.30543
```

```
-----+-----
diff |     -36.76  6.963386     -52.8176  -20.7024
```

```
-----
diff = mean(TURBCUS) - mean(TURBCDS)          t = -5.2790
```

degrees of freedom = 8

Ha: $\text{diff} \neq 0$

Ha: diff $\neq$ 0 Ha: diff $>$ 0

$$\Pr(|T| > |t|) = 0.0007$$
$$\Pr(|T| > |t|) = 0.0007 \qquad \Pr(T > t) = 0.9996$$

APPENDIX 6b: Two-sample t test with equal variances for Akantansu Turbidity

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
-----+-----						
TURBAUS	5	20	2.704811	6.04814	12.49024	27.50976
TURBADS	5	38.7	4.48029	10.01823	26.26072	51.13928
-----+-----						
combined	10	29.35	3.974928	12.56983	20.35809	38.34191
-----+-----						
diff		-18.7	5.23345		-30.76836	-6.631642
-----+-----						
diff = mean(TURBAUS) - mean(TURBADS)					t = -3.5732	
Ho: diff = 0			degrees of freedom = 8			

Ha: $\text{diff} \neq 0$

Ha: diff $\neq$ 0 Ha: diff $>$ 0

$$\Pr(|T| > |t|) = 0.0073$$
$$\Pr(|T| > |t|) = 0.0073 \qquad \Pr(T > t) = 0.9964$$

APPENDIX 7a: Two-sample t test with equal variances for Sintim DO

-----+-----						
Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
-----+-----						
DOSUS	5	5.14	.6477654	1.448447	3.341515	6.938485
DOSDS	5	4.84	.2694439	.6024948	4.091904	5.588096
-----+-----						
combined	10	4.99	.3344814	1.057723	4.233351	5.746649
-----+-----						
diff	.3000001	.7015697		-1.317822	1.917823	
-----+-----						
diff = mean(DOCUS) - mean(DOCDs)				t = 0.4276		
Ho: diff = 0		degrees of freedom =			8	
Ha: diff < 0		Ha: diff != 0		Ha: diff > 0		
Pr(T < t) = 0.6599		Pr(T > t) = 0.6802		Pr(T > t) = 0.3401		

APPENDIX 7b: Two-sample t test with equal variances Akantansu DO

-----+-----						
Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
-----+-----						
DOAUS	5	4.7	.709225	1.585875	2.730876	6.669124
DOADS	5	4.4	.6292853	1.407125	2.652824	6.147176

```

-----+-----
combined |    10    4.55  .449753  1.422244  3.532588  5.567412
-----+-----

diff |      .3000001  .9481561      -1.886452  2.486452
-----+-----

diff = mean(DO AUS) - mean(DO ADS)          t = 0.3164
Ho: diff = 0                                degrees of freedom = 8

Ha: diff < 0          Ha: diff != 0          Ha: diff > 0
Pr(T < t) = 0.6201    Pr(|T| > |t|) = 0.7598    Pr(T > t) = 0.3799

```

APPENDIX 8a: Two-sample t test with equal variances for Sintim True colour

```

-----+-----
Variable |  Obs   Mean  Std. Err.  Std. Dev.  [95% Conf. Interval]
-----+-----
TCSUS |    5   13.54  1.009752  2.257875   10.73648   16.34352
TCSDS |    5   21.84  1.427796  3.192648   17.8758   25.8042
-----+-----
combined |   10   17.69  1.610345  5.092358   14.04715   21.33285
-----+-----

diff |      -8.3  1.748771      -12.33267  -4.267327
-----+-----

diff = mean(TCCUS) - mean(TCCDS)          t = -4.7462

```

Ho: diff = 0 degrees of freedom = 8

Ha: diff < 0 Ha: diff != 0 Ha: diff > 0

Pr(T < t) = 0.0007 Pr(|T| > |t|) = 0.0015 Pr(T > t) = 0.9993

APPENDIX 8b: Two-sample t test with equal variances for Akantansu True colour

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
-----+-----						
TCAUS	5	18.68	1.352183	3.023574	14.92574	22.43426
TCADS	5	29.8	4.261103	9.528117	17.96928	41.63072
-----+-----						
combined	10	24.24	2.806429	8.874708	17.89142	30.58858
-----+-----						
diff	-11.12	4.470504		-21.429	-.8109999	
-----+-----						
diff = mean(TCAUS) - mean(TCADS)					t = -2.4874	
Ho: diff = 0		degrees of freedom =				8

Ha: diff < 0 Ha: diff != 0 Ha: diff > 0

Pr(T < t) = 0.0188 Pr(|T| > |t|) = 0.0377 Pr(T > t) = 0.9812

APPENDIX 9a: Two-sample t test with equal variances for Sintim Apparent colour

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
-----+-----						
ACSUS	5	21.4	1.463899	3.273377	17.33556	25.46443
ACSDS	5	37.04	5.441011	12.16647	21.93333	52.14667
-----+-----						
combined	10	29.22	3.721523	11.76849	20.80133	37.63867
-----+-----						
diff		-15.64	5.634501		-28.63318	-2.646818
-----+-----						
diff = mean(ACCUS) - mean(ACCDs)					t = -2.7758	
Ho: diff = 0		degrees of freedom =			8	
Ha: diff < 0		Ha: diff != 0		Ha: diff > 0		
Pr(T < t) = 0.0120		Pr(T > t) = 0.0241		Pr(T > t) = 0.9880		

APPENDIX 9b: Two-sample t test with equal variances for Akantansu Apparent colour

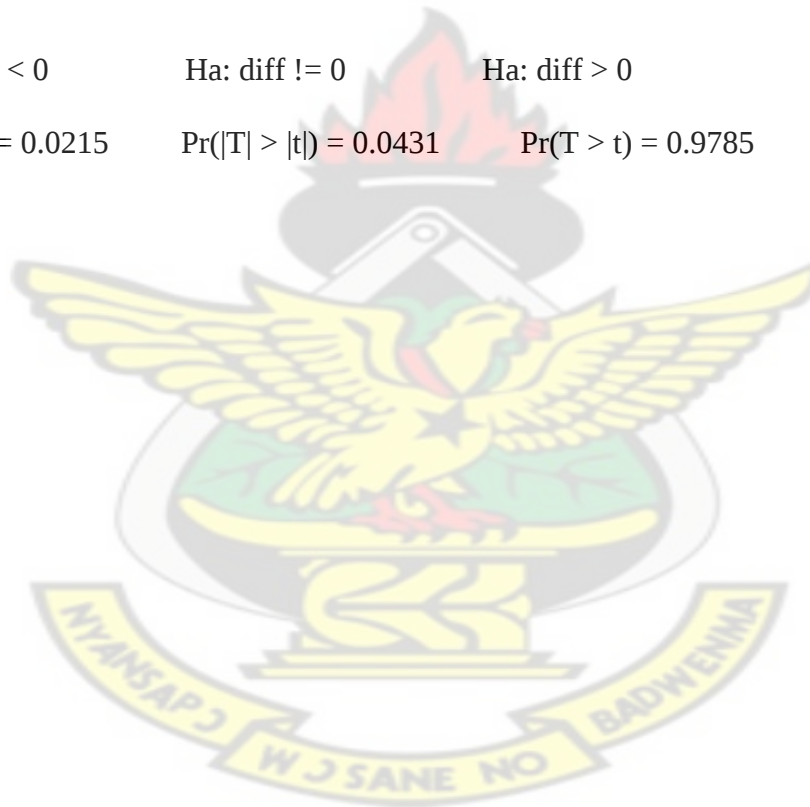
-----+-----						
Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
-----+-----						
ACAUS	5	28.322	2.496855	5.583137	21.38962	35.25438
ACADS	5	46.94	7.340001	16.41274	26.56089	67.31911

-----+-----
combined | 10 37.631 4.79441 15.16125 26.78529 48.47671

-----+-----
diff | -18.618 7.753057 -36.49658 -.7394198

diff = mean(ACAUS) - mean(ACADS) t = -2.4014
Ho: diff = 0 degrees of freedom = 8

Ha: diff < 0 Ha: diff != 0 Ha: diff > 0
Pr(T < t) = 0.0215 Pr(|T| > |t|) = 0.0431 Pr(T > t) = 0.9785





A ("Galamsey") Pit.





Gold Washing and Amalgamation.

