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DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

PHYSICO-CHEMICAL AND MICROBIOLOGICAL QUALITY OF SURFACE WATERS WITHIN THE NEWMONT GHANA GOLD MINING CONCESSION AREAS

A THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY, COLLEGE OF SCIENCE KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN ENVIRONMENTAL SCIENCE.

BY

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DECLARATION

I hereby declare that this Thesis is the result of my own field work towards the MSc. and has been composed under supervision. It has not been submitted previously either wholly or partially for a degree in the Kwame Nkrumah University of Science and Technology or elsewhere, except where due acknowledgement has been made in the text.

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DEDICATION

I dedicate this work to the almighty God Jehovah and to my beloved wife Patience Asamoah Boateng and my three lovely daughters.

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I wish to express my heartfelt gratitude and profound appreciation to a number of people who have been extremely helpful to me in accomplishing this piece of research.

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ABSTRACT

The physico-chemical and Microbiological quality of the surface waters within the Newmont Gold Mines Concession area were assessed for the levels of Total coliforms, faecal coliforms, pH, electrical conductivity, Total Dissolved Solids, Total Suspended Solids, Cyanide, Arsenic, Iron among others. A total of 8 sampling sites were sited along rivers, streams and proposed pits over a period of six months (from March 2005 to August 2005).

The results of the study revealed a high microbial indicator counts in all the water bodies suggesting high bacterial pollution of the waters. This was found to have come partly and indirectly from the Mines since the sources of the bacterial contamination could be traced to accidental leakages from the sewage treatment plants (STPs I and II), settlements along these river courses (resettlement villages), population explosion in this mining area with its attendant high waste generation, poor or non-existence sewage system coupled with poor sanitary conditions all contributed immeasurably to the high incidence of bacterial pollution of the water bodies.

The research findings also made it abundantly clear that Arsenic, Lead and Iron were the most prevalent mining- related metallic pollutants found in all the water bodies investigated and that the contamination of these heavy metals could primarily be attributed to natural geological and climatological conditions but not from the mines as full scale production had not begun at the time this study was being conducted. However, the high Turbidity and Total Suspended Solids values recorded in all the water bodies could be blamed on the various activities of the Mines.

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CHAPTER ONE

1.0 INTRODUCTION

The provision of safe drinking water for the world's 1. 3 billion deprived population has become one of the topmost priorities of many governments in recent years. In the year 2000, more than a hundred and fifty governments the world over launched an ambitious plan to halve the number of people without access to safe drinking water by the year 2015 (World Resources Institute, 2000).

Water resources such as streams, rivers, lakes, dams, water falls, underground and rain water abound in Ghana (Allotey, 1991). However, the major headache has been how to make these sources safe for human consumption as these sources are affected by natural and anthropogenic influences as well as point and non-point impacts. Water pollution and wasteful use of fresh water threaten development projects, agriculture, industry and even human existence and make water treatment essential in order to produce safe drinking water.

Discharge of toxic chemicals, over pumping of aquifers, long-range atmospheric transport of pollutants and contamination of water bodies with substances that promote algal growth (leading to eutrophication) are some of today's major water quality degradation (World Development Report, 2000).

It has been unequivocally demonstrated that water of good quality is crucial to sustainable socio-economic development. Aquatic ecosystems are threatened on a

world wide scale by a variety of pollutants as well as destructive land use or water management practices. Some problems related to water quality deterioration have been present for a long time but have only recently reached a critical or alarming proportion, while others are newly emerging.

Direct contamination of surface waters with metals in discharges from mining, smelting and industrial manufacturing is a long standing phenomenon (Pearse, 1996). Contamination of water by synthetic micro pollutants results either from direct discharge into surface waters or after transport through the atmosphere. Today, there is trace contamination not only of surface waters but also of ground water bodies, which are susceptible to leaching from waste dumps, mine tailings and industrial production sites (Pearse, 1996).

1.1 THE IMPACT OF MINING ON WATER QUALITY

Generally, some of the pertinent environmental issues pertaining to mining include erosion and sediment control, water conservation and balance, fugitive dust control, hydrocarbon or chemical spill control, waste streams or hazardous substances control, air pollution and mine tailings containment.

Acid mine drainage (AMD) is the mining industry's greatest environmental and greatest liability, especially to our water ways (Pearse, 1996). An acid generating mine has the potential for long term devastation on rivers, streams and aquatic life becoming in effect a "perpetual pollution machine".

In the United States, AMD and other toxins from abandoned mines have polluted 180,000 acres of reservoirs and lakes and 12,000 miles of streams and rivers. It has been estimated that cleaning up these polluted waterways will cost US tax payer between $ 32 billion and $72 billion (Kleinman, 1989).

In Canada., there are an estimated 351 million Tonnes of waste rock, 510 million Tones of sulphide tailings and more than 44 million Tonnes of other mining sources which have the potential to cause Acid mine drainage (Government of Canada, 1991). By 1994, the British Columbia State of the Environment report noted that there were an estimated 240 million Tonnes of acid – generating mine tailings in the province. Each year, the stockpile of acidic and heavy metal –generating tailings and waste rock from mining in the province grows by 25 million Tonnes. Once it starts, AMD can effectively sterilize an entire water system for generations to come, turning it into a biological waste land and a huge economic burden.

Similarly, in Ghana, a research conducted by a group of students from the University of Ghana, Legon , reports that it is unwholesome to eat oranges that are grown in Obuasi and its environs due to the presence of high levels of arsenic and mercury since they are beyond the WHO recommended values.

1.2 Impact of Gold Mining on Livelihoods, Health and the Environment in Ghana

Several communities in the Wassa West District in the Western region of Ghana are facing serious threats from gold mining operations. The Wassa West District is said to be the single largest agglomeration of mines and mining companies in the entire Africa continent, containing over eight major and international mining companies operating surface mines (Drill Bits and Tailings, 2000).

Surface mining requires the acquisition of large tracts of land, the average of which is about 58 square miles (150 sq.km), with a 30 year lease period (Ghana Chamber of Mines, 2000) while the mining companies and, to a less extent, the central government reap the benefits of mining, very little benefits, if any go to the people in the mining communities. The people, who mostly practice traditional and subsistence agriculture, are displaced from their lands on which they farm, leading to loss of livelihoods and breakdown of social ties. Most of these subsistence farmers are women who cannot find jobs in these mining companies. Political and military intimidations are not uncommon in these communities. The process of good mining and processing involves activities which give rise to various environmentally caused diseases. Such activities include blasting which creates dust, increasing particulate matter in air and water, processing methods which produce toxic chemicals such as Arsenic, Cyanide, Sulphur dioxide, etc. Major diseases exacerbated by mining operations include: Vector borne diseases such as malaria, schistosomiasis and onchocerciasis; respiratory tract diseases, especially, pulmonary tuberculosis and silicosis; acute conjunctivitis caused by high dust content in the air by surface mining; skin diseases, e.g. skin rashes caused by air and water pollution

by toxic chemicals used in the mining process; mental disorders related to Arsenic dermatitis; sexually transmitted diseases, such as, Syphilis and HIV – increasing incidence caused by migration of people to mining areas seeking employment and large expatriate population working in the mining industry who patronize local prostitutes (Third World Network, Ghana, 2000).

It is against this background that this research seeks to assess the general drinking water quality of some surface waters within the Newmont Gold Mining concession areas at Ahafo Kenyase and its environs.

Water supply for the population of Ahafo Kenyasi area is derived from river Tano and other rivers and streams in the area supplemented by few bore holes. Even though Newmont Ghana Gold Limited (NGGL) had not started mining the mineralized ore at the time this study was being conducted, exploratory activities, staff village, resettlement villages, assess and haulage roads, sewage treatment plants (STPs), inert and hazardous waste dumps were under construction.

These activities have the potential of impacting either directly or indirectly, temporarily or permanently, positively or negatively or even synergistically on the water bodies in the catchment area. And since the Ahafo Kenyasi mine is located in an area of high rainfall, incessant or heavy rains can flush contaminants from tailing dumps, construction sites, waste sites and agricultural sites into the downstream environment and subsequently into surface waters, thereby affecting the quality of these waters.

1.3 JUSTIFICATION OF THE STUDY

According to Allotey and Gyamfi (1991), problems of water management in Ghana is mostly attributed to the paucity of accurate and reliable database on the water resource itself including some other related factors. With regards to water pollution, the Ghana Chamber of Mines has admitted that not much has been achieved in the last decade of pollution abatement measures (Ghana Minerals Commission, 2000).

Besides, the Tano river, Awonsu stream, Subika stream, Subri river, Ntotro and other streams within the study area are all vital sources of potable water for the people of Ahafo Kenyasi I and II, Hwidiem, Ntotroso, including the small towns, villages and hamlets within and around the mining concession area. And since no comprehensive research has ever been conducted with respect to pollution levels along the rivers and streams in this area, the quality of these surface waters becomes very imperative and the quality can therefore never be compromised. Admittedly, the Environmental Department of NGGL has been conducting a mandatory routine compliance monitoring of some of the water bodies within and around the gold belt but obviously, not all the potential parameters in relation to water quality monitoring were captured. For instance, the microbiological quality, nitrate and phosphate levels as well as some other important physico-chemical parameters in all the rivers and streams within and around the gold belt have not been included as has been stated clearly in the Environmental Impact Statement report compiled by SGS Environment (2005). There is therefore the need for a more comprehensive, reliable and accurate data for the assessment of water quality in this area, in order to raise awareness of the urgent need to address the consequences of the present

and future threats of mining contamination.

1.4 THE SIGNIFICANCE OF THE STUDY

Since gold mining in Ghana reached industrial scale during the last half of the 19th century, the main problems associated with these mining activities have been soil and land degradation, aerial and water pollution.

The fact that water is a universal solvent and easily dissolves substances that come its way, making it very liable to pollution. But then polluted water is sometimes very difficult to treat and may be very expensive. The awareness of effective control of pollution has been realized to avert the burden of costly treatment programs. The first stage in such control programs is research and detailed study to investigate the factors involved and their inter-relationship. This will serve as a basis for mitigation or control measures, and environmental management plans (EMPs) and best management practices (BMPs)

The research would:

i. Provide evidence of the types or kinds of prevalent water contaminant(s) if any, and whether or not it is associated with the mining activities in the Kenyasi area.

ii. Provide a baseline set of data for future monitoring changes in the quality of these waters.

iii. Reveal or identify potential point sources of water pollutants in the mining concession and their subsequent mitigation or control measures.

iv. Help in the implementation or revision of environmentally sustaining policies.

1.5 THE OBJECTIVE OF THE STUDY

The research will assess the water quality of surface waters within the Newmont Ghana Gold Limited (NGGL) concession areas and establish a primary and reliable database which could be used by NGGL and the regulatory agencies for detecting any signs of deterioration in water quality as the mining operation progresses. The specific objectives of this study are to:

1. identify the most prevalent contaminant(s) if any, in the surroundings of the study area
2. establish how the quality of water in each of the water bodies under study is affected by natural processes, anthropogenic activities, or both.
3. identify control measures that should be implemented or strengthened to improve or prevent further deterioration of water quality in the study area
4. conduct physico-chemical studies on the rivers and streams in the area of study to determine the current levels of any mining related heavy metals (e.g. Arsenic, Iron, Zinc, Lead and Copper).
5. investigate the microbiological quality of the surface waters within and around the concession area.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 SURFACE WATER

Precipitation that does not evaporate or infiltrate into the ground runs as surface water, which may accumulate to form streams, and streams join to form rivers. Lakes are inland depressions that hold standing freshwater. Ponds are generally considered to be small temporary or permanent bodies of water shallow enough for rooted plants to grow over and at the bottom. While lakes contain nearly one hundred times as much water as all rivers and streams combined, they are still a major component of total World water supply (Mallard, 1982).

2.2 WATER QUALITY

Water quality is a term used here to express the suitability of water to sustain various uses or processes. Water quality is affected by a wide range of natural and anthropological (human) influences. The most important of the natural influences are geological, hydrological and climatic, since these affect the quality and quantity of water available.

2.2.1 Water Quality Monitoring

The main elements of water quality monitoring are on-site measurements, the collection and analysis of water samples, the study and evaluation of the analytical results and the reporting of the findings. Some of the common water quality monitoring strategies are Ambient Monitoring, Baseline Monitoring and Compliance or regulatory monitoring.

2.3 NATURAL PROCESSES AFFECTING WATER QUALITY

Although degradation of water quality is almost invariably the result of human activities, certain natural phenomena can result in water quality falling below that required for particular purposes. Natural events such as torrential rainfall and hurricanes lead to excessive erosion and landsides in affected rivers and lakes (Balek, 1977).

Seasonal overturn of the water in some lakes can bring water with little or no dissolved oxygen to the surface. Such natural events may be frequent or occasional. Permanent natural conditions in some areas may make water unfit for drinking or for specific uses such as irrigation.

(Peavy et al., 1986)

The nature and concentration of chemical elements and compounds in a fresh water system are subject to change by various types of natural processes, that is, physical, chemical, hydrological and biological (Balek, 1977). Some chemical elements have a strong affinity for particulate matter and, as a result of precipitation/dissolution and adsorption /desorption reactions, they may be found in only trace amounts in solution. Other elements, however, are highly soluble and rarely, if ever, present in water in particulate form. The tendency for a chemical to be present in the soluble form rather than associated with particulate is expressed as the Soluble Transport Index.

In small watersheds, local geological conditions can lead to wide variations in the concentration of trace elements in particulates and that within any one water body quality

can differ with time and with place (May beck and Chapman, 1989). Point sources emanate from a pipe or other definable point of discharge or release representing a specific location. Non-point sources, however, are more diffuse and they have many origins and numerous routes by which contaminants enter ground and surface waters. It is very difficult to identify, let alone monitor and control urban wastewater, Agricultural runoff and urban runoff. Point sources include industrial discharges, hazardous waste facilities, mine drainage, spills and accidental releases. Point discharges associated with a facility are usually regulated.

The impact of waste water on a receiving stream depends on the stream's ability to assimilate pollutants. The assimilative capacity of a stream refers to its ability to self-purify naturally (Chapman, 1986). Wastewater discharges are a major source of nutrients, bacteria, viruses, parasites and chemical contamination. Discharged treated wastewater with elevated levels of ammonia and nitrogen may support algal growth.

2.4 THE IMPACT OF MINING ON WATER QUALITY

Mining operations are associated with a number of water quality problems that include acid drainage, leaching and run off of heavy metals and sedimentation. Mine drainage becomes acidic in the presence of sulphur bearing minerals, air exposure and water that together form Tetraoxosulphate (vi) acid (H_2S0_4).

Contaminated drainage from mine spoils and tailings can acidify streams and cause dissolution of metals from surrounding rock and soil and precipitate iron in streams that have a neutral pH (Hem, 1984). Mining operations disturb the surface topography and

remove vegetations, causing excessive erosion. Acid Mine Drainage (A M D) may alter source water chemistry and carry dissolved iron, manganese and other contaminants. Metals associated with mine drainage include zinc, lead, arsenic, copper and Aluminum (Balek, 1997).

2.5 **WATER AND HUMAN HEALTH**

Pollution of surface water occurs when the quantity of wastes entering a body of water overwhelms its capacity to assimilate the pollutants these wastes contain. Water, although an absolute necessity for life can be a carrier of many diseases. Paradoxically, the ready availability of water makes possible the personal hygiene measures that are essential to prevent the transmission of enteric diseases. Infections water–related diseases can be categorized as waterborne, water-hygiene, water-contact and water-habitat vector diseases (McJunkin, 1982).

Some water-related diseases, however, may fall into more than one category. Waterborne infections diseases are those in which the pathogen, or causative organism, is present in water and ingested when the water is consumed. All of the faecal-oral diseases can also be transmitted through media other than water, for example, faecally contaminated food, fingers or utensils. The principal faecal-oral diseases are cholera, typhoid, shigellosis, amoebic dysentery, hepatitis A and various types of diarrhoea. One disease that is exclusively waterborne is dracunculiasis, or guinea worm diseases, which is caused by *Dracunculus medinensis.* An individual can become infected with Dracunculus only by consuming water contaminated with the microscopic crustaceans (Cyclops) that contain the larvae of the pathogens. Dracunculiasis is not a faecal-oral diseases.

Water contact diseases are transmitted when an individual's skin is in contact with pathogen infested water. The most important example is Schistosomiasis (bilharziasis) in which the eggs of the pathogen (*Schistosoma spp.*) are present in the faeces and / or urine of an infected person.

Water – habitat vector diseases are transmitted by insect vectors that spend all or part of their lives in or near water. The best known examples are malaria and filariasis (mosquito vector) and onchocerciasis (aquatic fly vector).

Health effects from chemicals in water occur when an individual consumes water containing a harmful amount of a toxic substance. Infant methaemoglobinaemia, caused by the consumption of water with a high nitrate concentration by infants (usually those which are bottle fed), is an example. The occurrence of methaemoglobinaemia is usually related to nitrate (often in ground waters) which has been derived from extensive use of nitrate fertilizers. Fluorosis, damage to the teeth and bones, results from long-term consumption of water containing excess fluorides, usually from natural sources (WHO, 1993).

2.6 FORMS OF WATER POLLUTION

Water quality can be affected by different forms of pollution: chemical, biological and physical pollution. These polluting factors can influence natural and human environment whether directly or indirectly by creating conditions that limit water utilization for

specific purposes. Indicators of water quality degradation include physical, chemical and biological parameters. Examples of biological parameters include species diversity and abundance. Examples of physical and chemical parameters include dissolved solids, pH, suspended solids, turbidity and nutrient concentration.

2.7 CHEMICAL AND PHYSICAL POLLUTION

2.7.1 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.

2.7.2 Total Suspended Solids (TSS)

Suspended Solids originate from ploughed fields, construction and logging sites, urban areas, strip- mined land, and eroded stream banks when it rains. As these sediments enter rivers, lakes coastal waters, and wetlands, fish respiration is impaired; plant productivity and water depth are reduced. Aquatic organisms and their habitats are smothered and our aesthetic enjoyment of the water is reduced (WHO, 1993).

2.7.3 Nitrate

The Nitrate anion (NO_3^-) is not adsorbed by soil and moves with infiltrating water. Nitrates are present in water particularly in regions where agriculture fertilization is intense. Other important routes of entry of nitrogen into bodies of water are municipal

and industrial wastewater, septic tanks, feedlot discharges from car exhausts. The nitrate level in drinking water is extremely important with infants, because of their high intake of water with respect to body weight. Nitrates in the infant are converted by the body to nitrites that oxidize blood haemoglobin to methaemoglobin. The altered bloods cells can no longer carry oxygen, which can result in brain damage or suffocation. Water with nitrite levels exceeding 1.0 mg/l should not be used for feeding babies. Epidemiological studies show a correlation between high nitrate levels and gastric and stomach cancers in humans

(WHO, 1993)

2.7.4 Sulphates

Sulphates are associated with gypsum formations and are common in several areas. Sulphates of Calcium and Magnesium can cause hardness in water. Sulphate levels at 500 ppm or greater can have a laxative effect and cause an astringent after taste to the water. High sulphate levels can also have a corrosive effect on plumbing (WHO, 1985).

2.7.5 Turbidity

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).

2.7.6 Acidity

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 disrupt the functioning of the organism and may kill it. Low pH's 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.

2.7.7 Some Mining-related Metals

Some mining-related heavy metals (such as Lead, Arsenic, Copper, Zinc 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).

2.7.8 Iron (Fe)

The presence of Fe and manganese (Mn) in large quantities is very easy to notice because of the reddish brown stain these minerals cause. The stain shows on laundry, sinks and every other object touched by water.

Iron is the fourth most abundant element, by weight, in the earth's crust. Nature water contain variable amount of iron despite it universal distribution and abundance. Iron in groundwater is normally present in the ferrous or bivalent from (Fe^{2+}), forming a clear, colourless solution until it comes into contact with oxygen. Oxygen changes iron to the ferric state (Fe^{3+}) which react with alkalinity in the water or exposure to air and forms an insoluble brown ferric hydroxide precipitate. 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. Ferrous (Fe^{2+}) and Ferric (Fe^{3+}) ions are the primary forms of concern in the aquatic environment. 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. They form masses of gelatinous and filamentous organic matter that traps the iron they use for growth. A good indication of the presence of Fe in the system is a brown slimy growth in the toilet flush tank (WHO, 1993).

2.7.9 Arsenic

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 tones of arsenic to the oceans annually, accounting for < 0.01mg/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, 1989). 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).

2.8 Lead (Pb)

All credible evidence indicates that Pb is neither essential nor beneficial to living

organisms, and that all measured effects are adverse, including those on survival, growth, reproduction, development, behaviour, learning, and metabolism.

Various living resources are at increased risk from Lead: migratory waterfowl that frequent hunted areas and ingest shot; avian predators that eat game wounded by hunters ; domestic livestock held in enclosures coated with lead based paints: wildlife that forage extensively near heavily traveled roads; aquatic live in proximity to mining activities, areas where Lead arsenate pesticides are used, metal finishing industries, organolead industries and areas of Lead aerosol fallout; and crops and invertebrates growing or living in lead-contaminated soils (Pearse,1996).

Lead is toxic to both the central and peripheral nervous system, inducing neurological and behavioural effects.

Lead is a general toxicant that accumulates in the skeleton as well. Infants, children up to 6 years of age pregnant women are most susceptible to its adverse effects. Lead also interferes with calcium metabolism, both directly and by interfering with vitamin D metabolism. Lead is exceptional in that, most Pb in drinking water arises from plumbing and fittings containing Pb (WHO, 1985).

2.8.1 Copper (Cu)

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, if also imparts a colour 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 taped-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, 1996).

2.8.2 Cyanide

It is uncertain how much cyanide is derived from food; however, many of the foods we eat are cooked, and this process destroys most of the small amounts of inorganic cyanide present. In general, apart from special foodstuffs (e.g. almonds) the dietary input of cyanide appears to be small. Allowing for a safety factor, a guideline value of 0.1mg/l is considered to be a reasonable level for the protection of public health (WHO, 1993).

Cyanides are very reactive and unstable. Because of this oxidizing agent such as chlorides and even sunlight destroys most of the cyanide ions (WHO, 1993).

2.8.3 Zinc (Zn)

Zinc is an essential element in human nutrition. The daily requirement is 4-10 mg depending on age and sex. Food provides the most important sources of zinc. Long term ingestion of Zn in considerable excess does not result in adverse effects. The guideline value of zinc in drinking water is, therefore, based on aesthetic considerations.

2.9 MICROBIOLOGICAL QUALITY OF SURFACE WATERS

Although it is now possible to detect the presence of many pathogens in water, the method of isolation and enumeration are often complex and time consuming. It is therefore impracticable to monitor drinking water for every possible microbial pathogen that might occur with contamination. A more logical approach therefore, is the detection of organisms usually present in the faeces of many and other warm blooded animals as indicators of excremental pollution, as wall as the efficacy of water treatment and disinfection. The presence of such organisms indicates the presence of faecal material and that intestinal pathogens could be present. Conversely, the absence of faecal commensally organisms indicates that pathogen are probably also absent. A search for such indicators of faecal pollution thus provides a means of quality control. Surveillance of the bacterial quality of raw water is also important (Cairncross, 1991)

Bacteriological examination offers the most sensitive test for the detection of recent and therefore potentially dangerous faecal pollution thereby providing a hygienic assessment of water quality with a sensitivity and specificity that is absent from routine chemical analysis. It is essential that water is examined regularly and frequently as contamination

may be intermittent and may not be detected by the examination of a single sample. For this reason, it is important that drinking water is examined frequently (Muller, 1980).

2.9.1 Indicator Organisms

Indicator bacteria are bacteria organisms which are always excreted in large numbers by warm- blooded animals, irrespective of whether they are healthy or sick. The presences of indicator organisms are the coliforms (Kool, 1988). The concentration of any given indicator suggests the level of risk from associated pathogens. Bacterial indicators are thus valuable in short term monitoring, for instance bacteriological water quality testing (Ellis, 1986).

The desirable characteristics of indicator organisms have been summed by WHO (1997) as follows:

They should be:

1. harmless to humans especially laboratory workers.
2 present in polluted waters when pathogens are or might be present.
3. present in polluted water in number higher than those of the pathogens.
4. easy and quick to identify through relatively simple laboratory tests.
5. easy to enumerate
6. able to survive unfavourable environmental conditions longer than those pathogens.
7. able to multiply only under conditions when pathogens multiply, and finally;
8. their number should be correlated with the probability that pathogens are also present.

2.9.2 How Colilert Works

Two nutrient indicators, ONPG and MUG are the major sources of carbon in colilert and must be metabolized by the coliform enzyme ß –galactosidase and the *Escherichia coli* enzyme ß –galacoronidase respectively.

As coliforms grow in colilert, they use ß-galactosidase as the media to metabolize MUG and create fluorescence. Since most non-coliforms do not have these enzymes, they are unable to grow and interfere. The few non-coliforms that do have these enzymes are selectively suppressed by colilert's specifically formulated matrix. This approach is different from the traditional media, which provide a nutrient–rich environment that supports the growth of both targets and non-target organisms. When non-target grow and mimic target organism, false positives occur. Growth of non–targets can also suppress target organisms and give false negatives in traditional media of ten include high levels of salts detergents or other selective agent which may inadvertently suppress target organisms and give further negatives.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 STUDY AREA

The Ahafo Kenyase Gold Project is being developed by Newmont Ghana Gold Limited (NGGL) and is one of the two Greenfield developments in Ghana being sponsored by Newmont Ghana. Ahafo Kenyase is located in the Brong Ahafo Region some 300 km north east of the capital city of Accra, 107 km North West of the second largest city, Kumasi and 40 km south east of the regional capital of Sunyani. The Ahafo project originally consisted of two projects: the Sefwi Gold Project and the Ntotroso Gold Project. These two projects were developed and permitted by Normandy Ghana Gold Limited in 1997. Newmont Ghana Gold Limited obtained the projects from Normandy when Newmont purchased Normandy in 2002. This study was thus conducted within these two gold projects, that is the Sefwi and Ntotroso gold projects, currently called the Ahafo Kenyasi Gold Project.

3.1.1 The Existing Environment

Environmental baseline studies of the project area were undertaken from 1997 through 2000 (Commissioned by Normandy Mining) and continued by NGGL from 2003 onwards. Baseline information gathered by the two mining and prepared by SGS Environment, 2005, are summarized below:

3.1.2 Aquatic Environment

The study area is drained by a number of seasonal streams and perennial rivers which feed into the upper basin of the Tano River. The seasonal streams and rivers divide the project area up into a number of smaller sub-basins. Sub-basins within the project area include the Suraw, Awonsu, Subika, Ntotroso and Amama. The Tano River is a vital source of potable water for the Brong Ahafo Region and people from Sunyani and several small towns located within and around the study area. Water from the river is pumped and treated through small to medium size treatment plants operated by the Ghana Water Company Limited (GWCL).

The various mining pits and proposed infrastructure are situated within different sub-basins of the study area. Two of the proposed pits namely, Area E and Kenyasi Central, fall within the Subri Sub-basins and partly within the Awonsu Sub-basin.

3.1.3 Atmospheric Environment

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. Typically, minimal rainfall is experienced from December month. Mean monthly temperature within the area ranges between 23.9 ^{o}C and 28.4 ^{o}C. In general, March is the hottest month of the year with mean temperature of 27.8 ^{o}C. August is the coolest month with a mean temperature of 24.6 ^{o}C.

3.1.4 Hydrogeology

In the type of geological formation found in the study area (Metasediments and Granitoids), there is no primary porosity and ground water occurrence linked only to fractured and weathered zones. The typical aquifer system is composed of low permeability weathered zones drained by

the fractures underneath.

3.1.5 Floral Environment

The study area lies within the semi-deciduous agro-ecological zone of Ghana and belongs to the Celtis-Triplochiton Association as classified by Taylor (1952). In a more recent Classification, Hall and Swine, (1981), included the area under the moist semi-deciduous zone North West sub-type. This is characterized by a three-story structure with emergent tall trees often exceeding 50 m in height.

3.1.6 Soil Environment

The soil associations identified (according to FAO Procedures and Guidelines) within the study area, are the Bekwai, Hwidiem, Kumasi and Birim-Chichiwere associations. Intensive farming activities for the production of both plantation and food crops and other human activities within this thickly populated area, have greatly influenced the nature of the soils resulting in nutrient depletion, soil erosion, pan formation and land degradation.

3.1.7 Socio-economic Environment

Agricultural production is the main economic activity in the Kenyasi District and is practiced mainly on subsistence level with a few farmers engaged in plantation

agriculture. Agriculture accounts for about 65% of the labour force. This reflects the agrarian nature of the local economy. Manufacturing and processing activities in the district, though practiced on a small scale, represent important economic activity.

3.2 SAMPLING SITES

A total of 12 sampling sites were selected along streams and rivers based on an environmental management plan drawn by the Environmental Department of NGGL and approved by the Brong Ahafo Regional Environmental Protection Agency (EPA) of Ghana for water quality monitoring programs. The sampling sites were later short-listed to 8 after two months of reconnaissance sampling survey where potential areas of pollution threats were identified and monitored further in line with the objectives of the research.

For consistency and reliability of the results, the sampling was done on monthly basis for a period of six consecutive months (March 2006 – August 2006).

The sampling sites are as shown in Table 3.1 and in Fig. 3.1

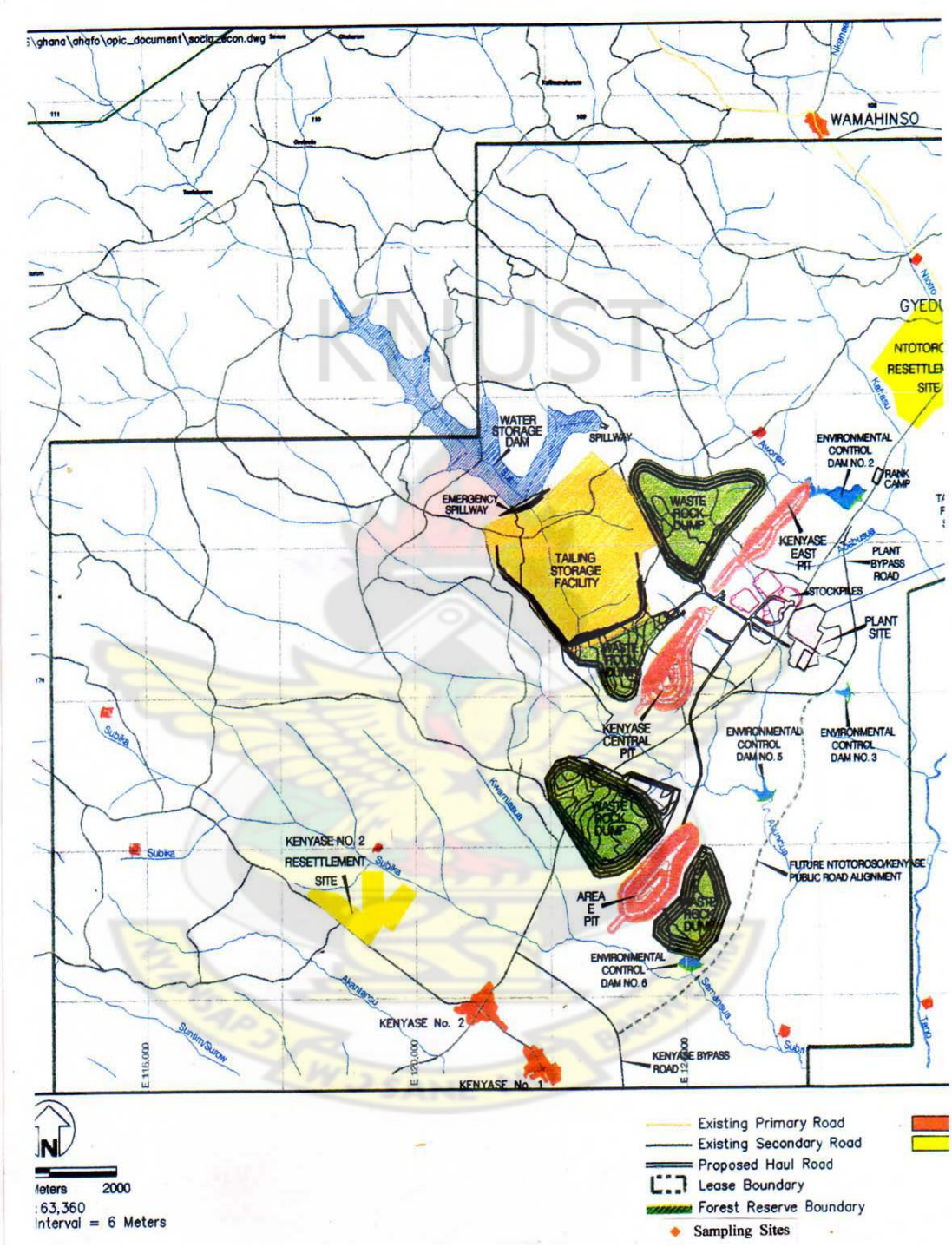

Figure 3.1 A map of NGGL concession areas at Ahafo Kenyasi Showing some of the sampling sites.

Table 3.1: Sampled Surface Water Locations

Sample Identification	Location
TNR1	Tano River below the bridge on the Acherensua- Hwidiem Road
TNR2	Tano River below the bridge on the Ntrotroso Acherensua Road
TNR3	Tano River at NGGL water Abstraction point
SBR1	Subri River on Ntotroso – Amama Road
SBR2	Subri River near the proposed Bosomkese pit
SBR3	Subri River at Area E fetching point
AWS1	Awonsu stream at the fetching point of Tawiakrom
SBK1	Subika stream along Kenyase –Ntotroso road

3.2.1 Method of Sampling

Monthly water samples were collected from the Tano River, Subri River, Awonsu stream and Subika stream and their various sub-basins from March to August 2006. Plastic sample bottles were acid washed and well rinsed with distilled water before sampling. Sample bottles were submerged to a depth of 0.5 m, opened, filled, corked and removed using the 'grab' method. Duplicate samples were collected and the water samples were immediately placed in an 'ice chest' in ice packs and transported to the laboratory where analyses were performed within six hours.

To every one litre of sample for metal analysis, 5 ml of Conc. HNO_3 was added. This treatment was used to minimize adsorption of metals on the container walls. The acidified samples were then refrigerated at 4 ^{o}C. About 2 to 3 pellets of NaOH were also added to

the sample bottles containing the samples to be analysed for Cyanide in order to raise the pH of the sample thus stabilizing Cyanides in the samples.

3.2.2 Measurement of pH

pH was measured in situ using a pH meter JENWAY 3071, model pH 82 (degree of accuracy 0.01) equipped with a temperature probe. The pH meter was initially calibrated by dipping the electrode into a buffer solution of known pH (pH 4) 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 9) 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.

3.2.3 Measurement of Electrical Conductivity (EC)

A high powered microcomputer conductivity meter JENWAY 40710 model HI 9032 with a degree of accuracy of 0.01 as used to measure the conductivity of the water samples in situ. The instrument was initially calibrated using standard solution of conductivities 500 µs/cm and 1500 µs/cm as described in 3.2.2 above. Duplicate values were taken and units were in micro siemens per centimeter.

3.2.4 Total Dissolved Solids (TDS)

TDS was measured in situ using a JENWAY 40710, model HI 9032 (0.01 degree of accuracy) (MAKE/MODEL). One hundred milliliters of the sample was poured into a 250 ml beaker .The probe was then immersed into the sample and the value read on the digital screen.

3.2.5 Total Suspended Solids (TSS)

TSS was measured directly on the field by means of a TSS meter (PELICAN 1500, Model 3150) provided by NGGL. The water sample was stirred thoroughly and 25 ml of the sample was immediately poured into a sample cell. Twenty five milliliters pupils 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.

3.2.6 Measurement of Turbidity

Turbidity of the water samples was measured in situ with a microprocessor turbidimeter JENWAY 3071, model HI93703 (0.0001 degree of accuracy). 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 as described in 3.2.2 above before using the turbidity values of the samples.

3.2.7 Determination Of Total Hardness (TH)

Total hardness was determined by titration using EDTA (titrant), and Erichrome Black T indicator at pH 10. One hundred milliliters of the samples was put into a 250 ml conical flask and 10 ml ammonia buffer solution added to the contents of the flask to give a pH of 2. Three drops of Erichrome Black T (indicator) were then added. The content of the conical flask was then titrated against EDTA solution (0.02 M) until the contents of the flask changed from wine-red to blue at the end–point. The volume of the titre was then recalled and the total hardness concentration determined by calculation as follows:

$$\text{TH, as } CaCO_3 \text{ (mg/l)} = \text{titre value} \times 20$$

3.2.8 Determination of Alkalinity

Alkalinity in natural water is caused mostly by carbonates, bicarbonates and hydroxides. These substances are basic in nature. The neutralization of these substances with a standard acid using methyl orange as indicator (especially if pH of water samples are below pH 8) to determine the end-point could be used to estimate the alkalinity of the water.

32.9 Reagents

a) Hydrochloric acid (0.02 M)

1.66 ml of conc. HCl acid was diluted to 1000 ml wish redistilled water in a volumetric flask.

b) **Methyl Orange**

0.5 g of methyl orange indicator was dissolved in 100 ml redistilled water.

c) **Standardization of Hydrochloric acid (HCl)**

0.088 g anhydrous Sodium trioxocarbonate (IV) (Na_2CO_3) was weighed into a 250 ml conical flask and 50 ml redistilled water added. Methyl orange indicator (2 ml) was added and the resulting solution titrated with the HCl acid to immediate faint red colour.

3.3.0 Determination of Total Alkalinity

Hundred milliliters of the water sample was measured into 250 ml conical flask. Methyl orange indicator (2 drops) was added. The resulting yellow solution was titrated with standardized HCl acid solution to immediate orange colour. The total alkalinity of the water sample was then calculated as follows:

$$Total\ Alkalinity = \frac{Volume\ of\ HCL\ used\ x\ 1000}{Volume\ of\ water\ sample\ used}\ \ (\frac{Mg}{l})$$

3.3.1 Nitrate – Nitrogen

The Devarda's alloy method which involves oxidation, distillation and titration was used to determine the concentration of Nitrate-Nitrogen in all the samples. In this method, Nitrate is reduced to Ammonia by Nascent hydrogen, by the use of Devardas' alloy (59%

Al, 39%Cu, 2% Zn). The resulting ammonia is distilled and its concentration determined by titration.

Apparatus:

Distillation apparatus, consisting of a 1-litre, round bottomed, heat-resistant glass flask fitted with a splash head, together with a suitable vertical condenser of either the spiral tube or double surface type. The condenser must be arranged so that the outlet tip can be submerged in the liquid in the receiver.

Reagents:

a) Ammonia – free water. This was prepared fresh for each batch of samples.

i) Distillation: - To each litre of tap water, 2 ml of a solution of ferrous sulphate (100 g l^{-1} $FeSO_4.7H_2O$) and sufficient H_2SO_4 acid were added to give a slight acidic reaction to methyl orange. The distillation was carefully done in an all-glass distillation apparatus. The first 50 ml of the distillate was rejected and then proceeded until three-quarters of the volume of water had distilled over. The absence of ammonia in the distillate was tested with Nessler's reagent.

b) Light Magnesium oxide.

c) Indicating Boric acid solution. Twenty grams pure Boric acid, H_3BO_3 was dissolved in warm water and diluted to approximately 1 litre. Twenty milliliters (20 ml) methyl red solution and 0.4 ml Methylene blue solution were thoroughly mixed with-

d) Hydrochloric acid, 0.00714 mol l^{-1}

e) Devarda's alloy, powered

f) Sodium hydroxide, 10 mol l^{-1}.

Procedure

The distillation flask, splash head and condenser were thoroughly cleaned before assembling the apparatus. In order to free the apparatus from possible contamination by ammonia, about 350 ml water was added to the flask (ammonia-free) and distilled until the distillate showed to be free from ammonia by testing with Nesster's reagent.

Two hundred millilitres of the water sample was then measured and 10 ml of 10 mol l^{-1} Sodium hydroxide solution was added. This was evaporated in the distillation flask to 100 ml and the residue was allowed to cool. Sufficient ammonia-free water was added to the cooled residue to bring the volume in the distillation flask to about 350 ml. One gram Devarda's alloy was added and the flask was immediately connected to the condenser.

The distillation was then started, keeping the lower end of the delivery tube from the condenser below the surface of the liquid in the receiver throughout the distillation process. Fifty milliliters (50 ml) of the Boric acid solution was placed in the receiver and was distilled at a rate of about 10 ml per minute. When the absorbent solution changed colour, it was titrated with 0.00714 mol l^{-1} HCl acid until a permanent pink colour was produced in the solution. At the completion of the titration, the receiver was removed from the apparatus before the source of heat was withdrawn. Blank determination was also carried out.

The total Nitrate- nitrogen was then calculated using the formula below:

$$Nitrate - nitrogen(asN) = \frac{(a-b)x100}{v} - n(mg/l)$$

Where:

a = volume of 0.00714 mol l^{-1} Hydrochloric acid used for titration of the distillate of sample (ml).

b = volume of 0.00714 mol l^{-1} Boric acid solution used for titration of the blank (ml).

n = concentration of Nitrite – nitrogen (as N) mgl $^{-1}$ N, determined separately.

V = Volume of the undiluted sample (ml)

n = Concentration of nitrite nitrogen in mg/l N, determined separately.

(The result is reported as Nitrate-nitrogen {N) mg/l and is rounded off to two significant figures}

3.3.2 Determination of Total Cyanide

Five hundred millilitres (500 ml) of sample was measured into a boiling flask and 10 ml of NaOH solution was put into the gas absorber and diluted with 60 ml deionized water. About 60 mg powdered $PbCO_3$ was added to the NaOH solution to suppress Sulphide interference. The Cyanide distillation apparatus was then connected to an electrical outlet after connecting the suction flask to vacuum/pressure pump, and the flask to the gas dispersion tube via a needle valve. The suction was adjusted using the needle valve until one air bobble entered the boiling flask.

About 2.0 g sulphamic acid (NH_2SO_3H) was weighed into the thistle tube and washed down with deionized water in the boiling flask to suppress nitrites and nitrates. 50 ml of 18 M H_2SO_4 was then measured and poured through the thistle tube into the boiling flask, rinsed the tube with deionized water and the contents were allowed to mix with air for three minutes. About 20 ml $MgCl_2$ solution was measured and poured through the tube into the flask.

The heating at this time was discontinued and refluxed for one hour (at a reflux rate of 44 – 46 drops per minute) but the air suction was continued to ensure that all distilled Hydrogen Cyanide gas was swept into the scrubbler solution. The Cyanide concentration in the solution was then determined by the colorimetric method.

3.3.3 Determination of metals (Fe, Pb, Zn, As and Cu)

Fifteen milliliters (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 absorbances of the standards and samples as well as the blank solution were read at 193.7 mm. Sensitivity for 1% absorption was 2.5 µg/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.

Plate 3.1 Analysing levels of Fe, Pb, As, Cu, etc and Total and Faecal Coliforms at NGGL Environmental Lab.

3.4 MICROBIOLOGICAL ANALYSES

IDEXX Colilert reagents, often used by United States Environment Protection Agency (USEPA) for the detection of coliforms and *Escherichia coli* in water and as listed in standard methods for the examination of water and waste water (Anon, 1994). Colilert reagents were used as the media for the microbiological analyses in this study.

3.4.1 Enumeration of Total coliforms (TC)

The water sample was added to a colilert reagent and the contents poured into a quanti-tray. This was then put into a Quanti-tray Sealer where the entrance was sealed to prevent the contents from coming out.

The Quanti-tray uses Semi-automated quantification methods based on the MPN standard methods model. The quanti-tray Sealer automatically distributes the sample and reagents mixture into separate wells (48 larger wells and 48 smaller wells). Quanti-tray provides counts from one to 200 / 100 ml. The sealed quanti-tray was then placed in an incubator for 24 hours at 37 ^{o}C in the case of the total coliforms. The resulting yellow colour change in some of the wells after incubation represents total coliforms. The number of positive wells was counted and expressed as MPN 100 ml using MPN table

3.4.2 Faecal coliforms Enumeration

Faecal coliforms were estimated following the same procedure for Total coliforms as in 3.4.1 above. However, the Sealed Quanti-tray for estimation of Faecal coliforms was incubated at 44 ^{o}C for the same 24 hours. Wells showing changes of fluorescent

coloration (positive wells) were counted and expressed as MPN/100 ml using MPN tables.

3.4.3 Statistical Analyses

The Statistical Package for Social Scientists (SPPS) version 13.0 for windows was used for analyzing data in the various statistical relationships between experimental variables (SPSS Data Assess Pack, 2004).

In order to establish variations between and within the water bodies under investigation, a one way and multi-way randomized analyses of variance (ANOVA) was used to analyze the data. The data was further subjected to Duncan's Multiple Range Test for statistical comparison of all the parameters. This test provided information on variation within each sample location and orderly ranking of their mean values.

CHAPTER FOUR

4.0 RESULTS

4.1 PHYSICO –CHEMICAL PARAMETERS

4.1.1 pH

Mean pH levels of all the water bodies within the Newmont Ghana Gold Limited (NGGL) concession area varied between 5.80 and 11.60 (Appendix 1a), with Tano downstream (TNR3) recording the highest mean pH value of 7.61 and the lowest at Subika stream (SBK1) (Table 4.1a) . These differences in pH for all the water bodies were not statistically ($P>0.05$) significant (Table 4.1a).

Generally, the mean pH values of all the water samples were within the WHO guideline value of 6.50 - 8.50.

Table 4.1a: pH levels of water bodies within the Newmont Concession area and Mean ranked order for pH using the Duncan's Multiple Range Test.

Sampling site	Mean	Range	Rank
SBK1	6.93	6.30 – 7.20	D
SBR3	6.95	6.40 – 7.50	D
TNR2	6.98	6.40 – 7.50	D
AWS1	7.17	6.60 – 7.70	C
SBR2	7.45	5.80 – 11.50	B
TNR1	7.49	6.40 – 11.40	B
SBR1	7.51	6.10 – 11.40	B
TNR3	7.61	6.10 – 11.60	B
Significance	0.297		

WHO Guideline Value: 6.50 – 8.50.

Ranking Order and Interpretation for the Duncan's Multiple Range Test

Rank	Interpretation
A	Very High
B	High
C	Average
D-G	Low

4.1.2 Total Suspended Solids (TSS)

Mean Total Suspended Solids (TSS) of all the water bodies ranged from 3.10 - 538.0 mg/l with samples from the Subri midstream (SBR2) recording the highest mean value whilst Awonsu stream (AWS1) recorded the lowest (Table 4.1b), but these variations were not statistically significant (Table 4.1b). Generally, the TSS levels of the water bodies were much higher than the WHO guideline value for drinking water quality of 20 mg/l.

Table 4.1b: Total Suspended Solids levels in water bodies within the Newmont Concession area.

Mean ranked order for TSS using the Duncan's Multiple Range Test

Sampling sites	Mean (mg/l)	Range (mg/l)	Rank
AWSI	15.79	3.10 – 31.00	D
TNR3	16.58	5.00 – 26.00	D
SBR3	19.78	12.00 – 35.00	C
TNR1	29.50	20.00 – 60.00	B
SBR1	29.97	6.60 – 91.00	B
TNR2	34.83	16.00 52.00	A
SBK1	92.38	18.00 – 263.50	A
SBR2	166.58	25.00 – 538.00	A
Significance	0.052		

WHO Guideline Value: 20 mg/l

4.1.3 Conductivity Levels

Electrical Conductivity Levels for all the water bodies ranged from 12.70 to 771.00 µs/cm (Appendix 1c). The highest mean conductivity values were recorded at Awonsu stream (AWSI) and the lowest at Tano upstream (TNRI) (Table 4.1c). These variations in conductivity within the different water bodies were statistically not significant (Table 4. 1c). However, the mean conductivity values recorded in all the water bodies were comparatively lower and negligible as far as the WHO guideline value for drinking water quality of 1500 µs/cm is concerned.

Table 4. 1c: Mean Conductivity Levels in water bodies within the Newmont Concession area

Mean ranked order for TSS using the Duncan's Multiple Range Test

Sampling sites	Mean (µs/cm)	Range
TNR1	118.15	14.90 – 207.20
SBR2	158.98	24.80 – 385.00
SBR3	160.93	42.30 – 305.00
TNR3	161.73	15.10 – 389.00
TNR2	163.98	12.70 – 311.00
SBR1	194.91	56.30 – 550.00
SBK1	275.17	29.00 – 629.00
AWS1	341.08	73.00 – 771.00
Significance	0.298	

Who Guideline value: 1500 µs/cm.

4.1.4 Total Dissolved Solids (TDS)

The Mean Total Dissolved Solids (TDS) of the water bodies ranged between 19.00 mg/l and 530.00 mg/l (Appendix 1d) with Awonsu stream (AWSI) recording the highest mean value whiles the lowest mean was recorded at Tano upstream (TNR1, Table 4.1d). These differences, however, were not statistically significant ($P > 0.05$). The TDS values of all the water samples showed relatively negligible levels of below 300 mg/l which was far below the WHO maximum allowable limit of 1000 mg/l.

Table 4.ld: Mean Total Dissolved Solid Levels in water bodies within the Newmont Concession area.

Mean ranked order for TDS using the Duncan's Multiple Range Test

Sampling sites	Mean (mg/l)	Range (mg/l)	Rank
TNR1	70.60	20.00 – 105.00	E
TNR2	101.48	19.00 – 180.00	E
SBR2	121.64	33.00 – 203.00	E
SBR3	132.08	19.00 – 324.00	E
SBK1	158.39	43.00 – 313.00	E
TNR3	185.28	19.00 – 530.00	E
SBR1	222.89	26.00 – 463.00	E
AWS1	262.53	38.00 – 499.00	E
Significance	0.098		

WHO Guideline value: 1000 mg/l

4.1.5 Turbidity

Monitored turbidity levels of the water samples in the NGGL concession area varied between 10.00 and 335.00 NTU with samples from Subri midstream (SBR2) recording the highest mean value whilst the lowest was recorded at Tano upstream (TNR1) (Table 4.1e).

Even though high mean turbidity values were recorded in all the water bodies, the variations within the sampling sites were not statistically significant (P>0.05) (Table 4.1e). All mean values recorded in the study far exceeded the WHO guidelines for drinking water quality of. 5 NTU.

Table 4.1e: Turbidity Levels in water bodies within the Newmont Concession area

Mean ranked order for Turbidity using the Duncan's Multiple Range Test

Sampling sites	Mean (NTU)	Range (NTU)	Rank
TNR1	56.40	24.30 – 125.00	A
SBR1	57.35	23.00 – 141.00	A
AWS1	61.83	25.30 – 123.00	A
SBR3	72.67	10.00 – 183.00	A
TNR2	90.34	17.00 – 335.00	A
SBK1	104.38	12.70 – 270.00	A
TNR3	111.59	15.00 – 216.00	A
SBR2	112.96	18.00 – 217.00	A
Significance	0.114		

WHO Guideline Value: 5 NTU.

4.2 Total Hardness Concentration

Total Hardness Concentration of all the water bodies within the NGGL concession varied between 21.00 and 242.00 mg/l $CaCO_3$ (Appendix 2a). The minimum mean Total Hardness Concentration occurred at Subri midstream (SBR2) and the maximum at Subika stream (SBKI).

These not withstanding, all the sampling sites fell within the WHO guidelines for drinking water quality even though they fell far below the recommended value of 500 mg/g $CaCO_3$ (Table 4.2a). Similarly, the variations in the mean concentrations were not statistically significant (Table 4.2a).

Table 4.2a: Total Hardness Concentrations in water bodies within the Newmont Concession area.

Mean ranked order for Total Hardness using the Duncan's Multiple Range Test

Sampling sites	Mean (mg/l $CaC0_3$)	Range (mg/l $CaC0_3$)	Rank
SBR2	41.67	26.00 – 102.00	E
TNR1	49.50	27.00 – 66.00	E
TNR2	62.92	42.00 – 98.00	E
TNR3	71.92	21.00 – 166.00	E
SBR1	76.50	41.00 – 220.00	E
SBR3	81.33	50.00 – 114.00	E
AWSI	105.25	36.00 – 141.00	D
SBK1	123.75	41.00 – 242.00	D
Significance	0.072		

WHO Guideline Value: 500 mg/l $CaCO_3$

4.2.1 Alkalinity Concentrations

The highest mean alkalinity concentration occurred at Subri midstream (SBR2) whilst the lowest mean was recorded at Tano upstream (TNR1), with a range between 0.50 and 682.00 mg/l $CaCO_3$ (Table 4.2b).

The variation in alkalinity concentrations within the NGGL concession area was not significant statistically (Table 4.2b). Similarly, all the mean values recorded were within the WHO recommended permissible limit of 500 mg/l $CaCO_3$ (Table 4.2b).

Table 4.2b: Alkalinity Concentrations of water bodies within the Newmont Concession area

Mean ranked order for Alkalinity using the Duncan's Multiple Range Test

Sampling sites	**Mean (mg/l $CaCO_3$)**	**Range (mg/l $CaCO_3$)**	**Rank**
TNR1	95.54	0.50 – 226.00	D
TNR2	102.30	18.00 – 215.00	D
TNR3	112.41	37.00 – 268.00	D
SBR3	140.78	19.00 – 323.00	D
SBK1	183.51	10.00 – 461.00	C
SBR1	191.09	19.00 – 413.00	C
AWSI	222.22	5.80 – 490.00	C
SBR2	244.24	68.00 – 682.00	C
Significance	0.076		

WHO Guideline Value: 500 mg/l $CaC0_3$.

4.2.2 Nitrate-nitrogen Concentration

It was generally observed from the mean Nitrate-nitrogen concentrations of all the water samples that nitrate pollution in all the 8 water bodies was absent and the only water body which surprisingly recorded the highest mean concentration was the Subika stream (SBKI) whilst the lowest was recorded at Tano midstream (TNR2). All the values recorded compared favourably with the WHO guideline value of 5.0 mg/l except Subika (SBK1) and Awonsu stream (AWS1) which had their mean values falling a little above the WHO maximum permissible limit (Table 4.2d). However, the statistical variation within and between the sampling sites was not significant ($P \geq 0.05$) (Table 4.2d).

Table 4.2c Nitrate-Nitrogen Concentrations in water bodies within the Newmont Concession area

Mean ranked order for Nitrate-Nitrogen using the Duncan's Multiple Range Test

Sampling sites	Mean (mg/l)	Range (mg/l	Rank
TNR2	0.54	0.05 – 0.90	D
TNR1	0.57	0.20 - 0.90	D
TNR3	0.75	0.40 – 1.40	D
SBR2	0.98	0.30 – 2.70	D
SBR1	1.45	0.20 – 5.60	D
SBR3	3.59	0.60 – 18.00	C
AWS1	5.65	0.20 – 32.00	C
SBK1	6.50	0.56 – 31. 50	C
Significance	0.053		

WHO Guideline Value: 5.0 mg/l

4.2.3 Total Cyanide Concentration in water samples

The concentration of Cyanide recorded in all the water samples was relatively negligible with a range of 0.01 to 0.3 mg/l. The highest mean value of 0.05 mg/l occurred at Subri downstream (SBR3), and then reduced to 0.02 mg/l at both Tano midstream (TNR2) and Awonsu stream (AWSI). The rest of the sampling sites all recorded a minimum value of 0.01 mg/l each (Table 4.2e). However, the variations within the sites were not statistically ($P > 0.05$) significant (Table 4.2e). Similarly, all the values recorded in all the 8 sampling sites were far below the WHO recommended value of 0.1 mg/l.

Table 4.2d: Cyanide Concentrations in water bodies within the Newmont concession area

Mean ranked order for Cyanide Concentrations using the Duncan's Multiple Range Test

Sampling sites	Mean (mg/l)	Range (mg/l)	Rank
TNR1	0.01	0.01 – 0.02	D
SBR2	0.01	0.01– 0.02	D
SBR1	0.01	0.01– 0.03	D
SBK1	0.01	0.01– 0.05	D
TNR3	0.01	0.01– 0.03	D
TNR2	0.02	0.01– 0.03	C
AWS1	0.02	0.01– 0.10	C
SBR3	0.05	0.01– 0.05	C
Significance	0.646		

WHO Guideline Value: 0.1 mg/l.

4.3 SOME MINING-RELATED METALS

Heavy metal loads such as Lead (Pb), Iron (Fe) and Arsenic (As) investigated in the study were generally high. However, Copper (Cu) and Zinc (Zn) recorded very low values. These variations in metal concentrations were not significant statistically (P>0.05) (Table 4.3).

4.3.1 Arsenic (As) and Lead (Pb) Concentrations

Arsenic concentration ranged from 0.01-0.09 mg/l with the highest mean concentration occurring at Awonsu stream (AWSI) and the lowest at Subri midstream (SBR2) (Table 4.3a).

Lead concentrations, on the other hand, were very high in all the sites thus becoming the

most prevalent metal or contaminant in the water samples ranging between 0.00 and 2.71 mg/l. Four of the water bodies (sampling sites) recorded a high mean value of 0.03 mg/l each whereas the other remaining sites recorded a low mean value of 0.02 mg/l each (Table 4.3b).

However, the variations were statistically insignificant (P>0.05). Both As and Pb mean concentrations exceeded the WHO guideline values of 0.01 mg/l for As and 0.0l mg/l for Pb

(Tables 4.3a and 4.3b).

Table 4.3a: Arsenic concentrations in water bodies within the Newmont concession area. Mean ranked order for Arsenic Concentrations using the Duncan's Multiple Range Test.

Sampling sites	**Mean(mg/l)**	**Range(mg/l)**	**Rank**
SBR3	0.02	0.01-0.05	C
TNR3	0.03	0.01-0.06	C
SBR2	0.04	0.01-0.07	C
TNR2	0.05	0.01-0.08	C
SBR1	0.06	0.01-0.10	B
SBK1	0.06	0.02-0.10	B
TNR1	0.06	0.02-0.011	B
AWS1	0.54	0.07-1.14	B
Significance	0.813		

WHO Guideline value: 0.01 mg/l

Table 4.3b: Lead concentrations in water bodies within the Newmont Concession area. Mean ranked order for Lead Concentrations using the Duncan's Multiple Range Test

Sampling Sites	Mean(mg/l)	Range(mg/l)	Rank
SBR1	0.02	0.00-0.19	C
SBR2	0.02	0.00-0.10	C
SBK1	0.02	0.00-0.20	C
TNR2	0.02	0.00-0.20	C
TNR1	0.03	0.00-0.19	C
TNR3	0.03	0.00-0.15	C
SBR2	0.03	0.00-0.08	C
AWS1	0.03	0.00-2.71	C
Significance	0.184		

WHO Guideline value for Pb: 0.01 mg/l

4.3.2 Iron (Fe) concentration

Iron concentration in all the water bodies was very high ranging from 0.01 to 2.55 mg/l. The highest mean concentration occurred at Tano upstream (TNR1) and the lowest at the Awonsu stream (AWS1) (Table 4.3c). However, the variation within the sites was not significant statistically

(Table 4.3c). Generally, the mean concentrations far exceeded the WHO guideline value of

0.3 mg/l.

Table 4.3c: Iron concentrations in water bodies within the Newmont concession area

Mean ranked order for Iron Concentrations using the Duncan's Multiple Range Test

Sampling Sites	Mean(mg/l)	Range(mg/l)	Rank
AWS1	0.17	0.01-0.50	DC
SBK1	0.34	0.01-2.55	C
TNR2	0.50	0.01-1.90	C
SBR3	0.54	0.03-1.90	C
SBR1	0.63	0.02-2.30	C
TNR3	0.68	0.07-1.70	B
SBR2	0.90	0.10-2.55	B
TNR1	0.99	0.10-1.70	B
Significance	0.094		

WHO Guideline value: 0.3 mg/l

4.3.3 Zinc Concentrations

Zinc (Zn) concentration ranged from 0.00-0.19 mg/l with the highest mean concentrations occurring at Tano downstream (TNR3) and Subri midstream (SBR2) whilst the lowest mean were recorded at Awonsu stream (AWS1); Subri upstream (SBR1) and Tano midstream (TNR2). Generally, the mean values recorded at all the sites were far below the WHO recommended guideline value of 0.3 mg/l (Table 4.3d). However, the variation were statistically insignificant ($P>0.05$).

Table 4.3d: Zinc concentration in water bodies within the Newmont concession area.

Mean ranked order for Zinc Concentration using the Duncan's Multiple Range Test

Sampling Sites	Mean(mg/l)	Range(mg/l)	Rank
AWS1	0.01	0.00-0.03	D
SBR1	0.01	0.01-0.03	D
TNR2	0.01	0.01-0.04	D
SBR3	0.02	0.01-0.03	C
TNR1	0.02	0.01-0.04	C
SBK1	0.03	0.01-0.10	C
SBR1	0.04	0.01-0.15	C
TNR3	0.04	0.01-0.19	C
Significance	0.100		

WHO Guideline Value: 0.3 mg/l

4.3.4 Copper (Cu) Concentration.

Cu concentration ranged between 0.01 and 0.10 mg/l, making it the least prevalent metal detected in the study. The highest mean value occurred in 4 water bodies (sampling sites) each recording

0.02 mg/l whereas the remaining sites recorded a low mean value of 0.01 mg/l each (Table 4.3e). Generally, all the 8 sampling points recorded mean values that were far below the WHO recommended value of 1.0 mg/l. However, the differences in the mean values were statistically insignificant (Table 4.3e).

Table 4.3e: Copper concentrations in water bodies within the Newmont concession area. Mean ranked order for Copper Concentrations using the Duncan's Multiple Range Test.

Sampling Sites	Mean(mg/l)	Range(mg/l)	Rank
TNR2	0.01	0.01-0.01	G
TNR1	0.01	0.01-0.01	G
SBR2	0.01	0.01-0.02	G
AWS1	0.01	0.01-0.02	G
SBR3	0.02	0.01-0.10	F
SBR1	0.02	0.01-0.05	F
SBK1	0.02	0.01-0.07	F
TNR3	0.02	0.01-0.06	F
Significance	0.078		

WHO Guideline Value: 1.0 mg/l

4.3.5 Bacteriological Quality of Kenyasi Water Samples

Although the WHO guidelines recommend the complete absence of microbial indicators in any

100 ml of drinking water, this study recorded very high numbers of both Total and Faecal coliforms indicating very high bacterial contamination levels in all the water bodies sampled hence making them unsuitable for drinking without prior treatment.

Both Total and Faecal coliforms results of this study were estimated from IDEXX Quanti-Tray/2000 MPN Table (Appendix 2a), by direct count of both the larger and smaller wells. Total coliform (Tc) numbers ranged from 28.18-467.74 (100/ml) with the highest mean Total coliform count occurring at the Subika stream (SBK1) whilst the lowest mean count was recorded in Tano upstream (TNR1) (Table 4.4a).

This notwithstanding, the variations in total coliform numbers within the sampling sites did not show any statistical significance (P>0.05) (Table 4.4a).

Similarly, Faecal coliform (Fc) numbers (100/ml) in the water samples were comparatively lower, about half the number of Tc on the whole (Table 4.4b). Fc ranged between 5.01 and 223.87 (100/ml). The highest and lowest mean Fc numbers occurred at Tano downstream (TNR3) and Tano midstream (TNR2) respectively (Table 4.4b). Similarly, the variation in microbial numbers for Fc within the sites was also not significant statistically (P>0.05) (Table 4.4b).

Table 4.4a: Total coliform counts in water bodies within the Newmont concession area. Mean ranked order for Coliform Counts using the Duncan's Multiple Range Test

Sampling Sites	**Mean(100/ml)**	**Range(100/ml)**	**Rank**
TNR1	165.33	28.18-389.05	A
SBR2	175.83	43.65-398.11	A
TNR3	210.58	60.26-416.87	A
TNR2	214.00	48.98-416.87	A
SBR1	248.08	131.83-407.38	A
AWS1	258.08	43.65-446.68	A
SBR3	269.33	120.23-426.58	A
SBK1	270.42	50.12-467.74	A
Significance	0.096		

Table 4:4b: Faecal coliform counts in water bodies within the Newmont concession area.

Mean ranked order for Faecal Coliform using the Duncan's Multiple Range Test

Sampling Sites	Mean(100/ml)	Range(100/ml)	Rank
TNR2	36.42	6.03-89.13	A
SBR2	42.75	5.01-181.97	A
TNR1	49.08	7.08-218.78	A
AWS1	63.42	7.08-234.42	A
SBR3	67.63	18.20-144.54	A
SBR1	72.83	12.88-223.87	A
SBK1	76.58	12.02-194.98	A
TNR3	81.17	6.03-89.13	A
Significance	0.210		

CHAPTER FIVE

5.0 DISCUSSION

5.1 PHYSICO - CHEMICAL PARAMETERS OF AHAFO KENYASE SURFACE WATER BODIES

Levels of Total Suspended Solids (TSS) and Turbidity were generally very high in all the water bodies throughout the sampling period. TSS ranged from 3.10 to 538.0 mg/l with the highest mean occurring at the subri midstream (SBR2) recording the highest mean value of 166.58 mg/l which was considerably in excess of the WHO recommended guideline value of 20 mg/l (WHO, 1993).

Inorganic solids such as clay silt and other soil constituents as well as some organic materials such as plant debris and leaf fall are common in surface waters and these materials are often natural contaminants resulting from the erosive action of water flowing over surfaces (Peavy *et al.*, 1985). Turbidity ranged from 10.00 to 335.00 NTU with Subri midstream (SNR2) recording an abnormal high value of 112.96 NTU (Table 4.1e) which far exceeded the WHO recommended guideline value of 5 NTU. High levels of turbidity can protect micro-organisms from the effects of disinfection and can stimulate the growth of bacteria. Generally, the high turbidity values recorded in all the sampling sites may be attributed to the construction of haulage roads, routes leading to mining sites, construction of staff villages by the mining company as well as bare farmlands around the water bodies by the settler farmers. Inorganic solids such as clay, silt and soil constituents are common in surface waters and these materials are often

natural contaminants resulting from the erosive action of water flowing over natural vegetations that has been disturbed (Peavy *et al.*, 1985).

In general, the Total Hardness, Alkalinity and Sulphate concentrations recorded in all the sampling sites were negligible and were far below the WHO recommended values for drinking water quality (Tables 4.2a, 4.2b and 4.2c). They were also not beyond the self-cleansing abilities of the water bodies under study (WHO, 1993).

Electrical conductivity ranged from 12.70 to 771.00 µs/cm (Appendix 1c). The moderate conductivities recorded in all the water bodies could be ascribed to natural occurrences which introduced inorganic substances into the water but most of these mineral and metallic ions, bicarbonate and chloride ions might have precipitated out causing some of the ions to settle out of water due to adsorption resulting in the low conductivities. The self-cleansing ability of the water bodies again came into play (USEPA, 1993).

It was generally observed from the mean Nitrate-nitrogen concentrations of all the water samples that nitrate pollution in most of the water bodies was absent. The only sampling sites which surprisingly recorded very high mean concentrations were the Subika stream (SBKI) and the Awonsu stream (AWSI) which recorded 6.50 mg/l and 5.65 mg/l respectively and failed to meet the WHO recommended guideline value of 5.0 mg/l for drinking water quality (Table 4.2d). Since the local economy of the study area is agrarian in nature, the high concentrations of nitrate – nitrogen at Awonsu and Subika streams could be attributed to agricultural activities where nitrogen fertilizers are extensively used

in these areas especially for maize and vegetable farming. Again, most of the communities around these streams raise their livestock (Sheep, Goats, Cattle, Pigs and Poultry) by the free range system. The animals roam the community in search of food and water and in the process indiscriminately contaminate these surface waters with their urine and faeces which are high sources of nitrogen.

5.2 MINING-RELATED METALS

The most prevalent metallic Pollutant in the water bodies of Ahafo Kenyase area was Arsenic and was recorded in the in the Awonsu stream (AWSI) which it exceeded the recommended guideline value of 0.0l mg/l. Generally, the concentrations in all the water bodies were very high and above WHO standards. High levels of Arsenic in fresh waters vary greatly, high concentrations being associated with areas of natural thermal activity, drainage from soils or rocks of high As content, or run-off from arsenic contaminated water sheds. This confirms the work done by Steevens, (1972).

Iron (Fe) concentrations in the study area were found to be another prevalent pollutant in all the water bodies with the highest mean concentration being recorded at Tano Upstream (TNR1, 0.99 mg/l) (Table 4.3c). The source of these high iron contents in the waters except AWSI was observed to be the lateritic bare farmlands lying along and around the Tano river and the other surrounding streams and rivers in the study area, neglected probably due to soil fertility exhaustion after erosion of the fertile top soil. Again, the soils of the project area are deep to moderately deep red to reddish brown in colour and are full of iron stone and quartz gravels and stones.

5.3 THE BACTERIOLOGICAL QUALITY OF AHAFO KENYASE WATER SAMPLE

Although the WHO guidelines recommend the complete absence of microbial indicators in any

100 ml of drinking water, this study recorded high numbers of both Total and Faecal Coliforms ranging from 28.18 to 467.74 / 100 ml and 5.01 to 316.23, respectively (Tables 4.4a and 4.4b). The concentrations of these microbial indicator counts in the water samples are an indication of serious bacterial contamination. These coliform bacterial may have several origins some of which could be attributed to poor or non-existent sewage systems or improper sanitary conditions in most of the villages (Zoeteman, 1980). Additionally, livestock are allowed to graze and drink freely around and from these water bodies, and in the process indiscriminately contaminate these surface waters with their faeces thus contributing to the high incidence of Total and faecal coliform build up (Morgan, 1990).

Since the people of Kenyase as well as the settler farmers within and around the Newmont Gold Mining Concession depend solely on these water bodies as their only source of drinking water, the quality of these surface waters can therefore, never be compromised.

CHAPTER SIX

6.0 CONCLUSION

The research has shown that most of the settler farmers within the communities rely solely on the Tano river, Awonsu, Subika, Subri, Ntotro and Asuadae as the main sources of drinking water for the people of Ahafo Kenyasi district.

The research findings made it abundantly clear that Arsenic (As), lead (Pb) and Iron (Fe) were the most prevalent mining-related metallic pollutants found in all the water bodies investigated within the Newmont concession area and that the contamination of these water bodies with these heavy metals was primarily due to natural geological and climatological conditions but not from the mines. It was again established that the high concentrations of especially As and Pb significantly pose a threat to human health and is also lethal to aquatic life since their lowest means even far exceeded the WHO recommended permissible limits for drinking water quality (WHO,1993).

The research findings also brought to light that the high TSS levels recorded in the study could primarily be attributed to the anthropological activities of NGGL. From appendix 1, high rainfalls in the study area resulted in high TSS, TDS, conductivity and turbidity values in most of the water bodies. The mining activities of NGGL have also contributed immensely to erosion and run-offs in the study area even though the mining company has put up few sediment control and erosion control structures. Traditional farming methods such as bush burning which leaves the land bare and at the mercy of the weather predisposes the land to erosion and run-off into these water bodies.

The moderately high Nitrate- nitrogen concentrations in the Subika (SBKI) and Awonsu (AWSI) streams is a true reflection of the kind of agricultural activities that are practised along the banks of these streams in these communities and that high nitrate – nitrogen concentrations could not be blamed on the mining company. Generally, other sources of contamination of these water bodies included domestic waste water, road run-offs and landfill impoundments that are washed into these streams and rivers.

Similarly, the high total and faecal coliform counts in all the water bodies were organic contamination from external sources and that the mines was not responsible for the cause. These heavily bacterial-contaminated water bodies rendered the use of these waters unwholesome and unsuitable for human consumption without prior treatment according to WHO recommended standard for drinking water quality which should contain zero total and Faecal coliform in any

100 ml of drinking water (WHO, 1993). Again other possible sources of this bacterial contamination could be the settlement along these river courses, population explosion in this mining area with its attendant high waste generation, poor or non- existent sewage system coupled with poor sanitary conditions, all contributed immeasurably to the high incidence of bacterial build-up and consequently contamination which were obviously beyond the self-cleansing abilities of these water bodies.

6.1 RECOMMENDATIONS

Water quality impact from hard rock mines are often very difficult to predict during the Environmental Impact Assessment (EIA) stage. Despite modern technology, government

and mining companies' impact predictions are often very wrong and the long term environmental and fiscal implications are often severe. By virtue of this ugly experience and to avert any possible future calamity, the following mitigation measures are seriously recommended to prevent or minimize any further deterioration of water quality within the Newmont concession area:

1. A detailed monthly water monitoring programme for both surface and groundwater should continue throughout the life cycle (i.e. Construction, operation and closure/ decommissioning phases) of the Ahafo Kenyase Mines.
2. The waste water released from the two sewage treatment plants at both the production site (camp A) and staff village (camp B) should be properly investigated by future researchers, Newmont Environmental Department Staff and the regulatory agencies (EPA and District Assembly) to check the nitrates, phosphates and bacterial levels to make it conform to EPA and WHO wastewater discharge policy before its release into the environment.
3. Progressive rehabilitation as opposed to post-mining rehabilitation as is currently being pursued by NGGL should be the key element in preventing generation of sediment erosion sources during mining.
4. As a proactive mitigation measure, new alternative sources of water supplies in the form of hand-dug wells or boreholes should be provided for communities whose traditional sources of drinking water could be potentially affected by the mining project when full scale production begins.
5. There is also the urgent 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 prevent them from using these untreated raw water bodies as a source of drinking water to prevent any future bacterial epidemics.

6. Open defaecation popularly known as the ‘free range’ in the communities which is gaining roots should be discouraged, and access to water bodies by domestic and grazing animals should be restricted.

7. The farmers should revise their traditional methods of farming by way of bush burning, vegetable farming along river banks with its attendant application of nitrogen fertilizers should be stopped to reduce nitrate levels as well as sediment deposits into these streams.

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APPENDIX A :

ANOVA FOR PHYSICO-CHEMICAL PARAMETERS

A1: TOTAL SUSPENDED SOLIDS

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
TNR1	12	29.50	14.745	4.256	20.13	38.87	20	61
TNR2	12	34.83	11.183	3.228	27.73	41.94	16	52
TNR3	12	16.58	6.934	2.002	12.18	20.99	5	26
SBR1	12	29.97	28.861	8.331	11.63	48.30	7	91
SBR2	12	166.58	207.735	59.968	34.59	298.56	25	538
SBR3	12	19.78	7.380	2.130	15.09	24.46	12	35
AWS1	12	15.79	8.932	2.579	10.12	21.47	3	31
SBK1	12	92.38	102.135	29.484	27.48	157.27	18	264
Total	96	50.68	94.031	9.597	31.62	69.73	3	538

Test of Homogeneity of Variances

TSS

Levene Statistic	df1	df2	Sig.
36.382	7	88	0.000

ANOVA

TSS

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	235,605.273	7	33,657.896	4.901	0.000
Within Groups	604,376.167	88	6,867.911		
Total	839,981.440	95			

A2: ANOVA FOR pH

	Sum of Squares	df	Mean Square	F	Sig.

	Between Groups	6.852	7	0.979	0.544	0.799
	Within Groups	158.359	88	1.800		
	Total	165.212	95			
	Between Groups	458,072.786	7	65,438.969	2.722	0.013
	Within Groups	2,115,905.631	88	24,044.382		
	Total	2,573,978.417	95			

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
pH	96	7.26	1.319	0.135

One-Sample Test

	Test Value = 7.5					
					95% Confidence Interval of the Difference	
					Lower	Upper
pH	-1.788	95	0.077	-0.241	-0.51	0.03

A3: ANOVA FOR CONDUCTIVITY

					95% Confidence Interval for Mean		
					Lower Bound	Upper Bound	
TNR1	12	118.15	72.046	20.798	72.37	163.93	15
TNR2	12	163.98	115.769	33.420	90.43	237.54	13
TNR3	12	161.73	131.875	38.069	77.94	245.52	15
SBR1	12	194.91	180.552	52.121	80.19	309.63	56
SBR2	12	158.98	120.619	34.820	82.34	235.61	25
SBR3	12	160.93	95.561	27.586	100.21	221.64	42
AWS1	12	341.08	244.383	70.547	185.81	496.36	73
SBK1	12	275.17	200.918	58.000	147.51	402.82	29
Total	96	196.87	164.604	16.800	163.51	230.22	13

Test of Homogeneity of Variances

Levene Statistic	df1	df2	Sig.
2.135	7	88	0.048

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	458,072.786	7	65,438.969	2.722	0.013
Within Groups	2,115,905.631	88	24,044.382		
Total	2,573,978.417	95			

A4: ANOVA FOR TOTAL DISSOLVED SOLIDS(TDS)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
TNR1	12	70.60	27.774	8.018	52.95	88.25	20	105
TNR2	12	101.48	51.753	14.940	68.59	134.36	19	180
TNR3	12	185.28	170.288	49.158	77.09	293.48	19	530
SBR1	12	222.89	159.251	45.972	121.71	324.07	26	463
SBR2	12	121.64	70.540	20.363	76.82	166.46	33	203
SBR3	12	132.08	98.033	28.300	69.79	194.36	19	324
AWS1	12	262.53	157.901	45.582	162.20	362.85	38	499
SBK1	12	158.39	88.123	25.439	102.40	214.38	43	313
Total	96	156.86	125.673	12.826	131.40	182.32	19	530

Test of Homogeneity of Variances

TDS

Levene Statistic	df1	df2	Sig.
5.182	7	88	0.000

ANOVA

TDS

		Sum of Squares	df	Mean Square	F	Sig.
Between Groups		344,381.018	7	49,197.288	3.745	0.001
Within Groups		1,156,028.032	88	13,136.682		
Total		1,500,409.050	95			

A5: ANOVA FOR TURBIDITY

					95% Confidence Interval for Mean		
					Lower Bound	Upper Bound	
TNR1	12	56.40	40.170	11.596	30.88	81.92	24
TNR2	12	90.34	116.113	33.519	16.57	164.12	17
TNR3	12	111.59	87.265	25.191	56.15	167.04	15
SBR1	12	57.35	39.487	11.399	32.26	82.44	23
SBR2	12	112.96	81.200	23.440	61.37	164.55	18
SBR3	12	72.67	57.906	16.716	35.87	109.46	10
AWS1	12	61.83	36.691	10.592	38.51	85.14	25
SBK1	12	104.38	90.179	26.032	47.08	161.67	13
Total	96	83.44	74.720	7.626	68.30	98.58	10

Test of Homogeneity of Variances

Turbidity

Levene Statistic	df1	df2	Sig.
3.628	7	88	0.002

ANOVA

Turbidity

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	49,738.538	7	7,105.505	1.301	0.259
Within Groups	480,649.309	88	5,461.924		
Total	530,387.8473958330	95			

A6: ANOVA FOR ARSENIC (AS)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
TNR1	12	0.06	0.069	0.020	0.02	0.11
TNR2	12	0.05	0.060	0.017	0.01	0.08
TNR3	12	0.03	0.053	0.015	0.00	0.07
SBR1	12	0.06	0.063	0.018	0.01	0.10
SBR2	12	0.04	0.032	0.009	0.01	0.06
SBR3	12	0.02	0.034	0.010	0.00	0.05
AWS1	12	0.54	0.951	0.274	-0.07	1.14
SBK1	12	0.06	0.060	0.017	0.02	0.10
Total	96	0.11	0.366	0.037	0.03	0.18

Test of Homogeneity of Variances

As

Levene Statistic	df1	df2	Sig.
11.523	7	88	0.000

ANOVA

As

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.537	7	0.362	3.134	0.005
Within Groups	10.175	88	0.116		
Total	12.711	95			

A7: ANOVA FOR IRON (Fe)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum
					Lower Bound	Upper Bound	
TNR1	12	0.99	0.475	0.137	0.69	1.29	0
TNR2	12	0.50	0.683	0.197	0.06	0.93	0
TNR3	12	0.68	0.533	0.154	0.34	1.02	0
SBR1	12	0.63	0.810	0.234	0.12	1.14	0
SBR2	12	0.90	1.054	0.304	0.23	1.56	0
SBR3	12	0.54	0.623	0.180	0.15	0.94	0
AWS1	12	0.17	0.175	0.051	0.06	0.28	0
SBK1	12	0.34	0.433	0.125	0.06	0.61	0
Total	96	0.59	0.673	0.069	0.45	0.73	0

Test of Homogeneity of Variances

Fe

Levene Statistic	df1	df2	Sig.
5.293	7	88	0.000

ANOVA

Fe

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6.181	7	0.883	2.110	0.051
Within Groups	36.817	88	0.418		
Total	42.997	95			

A8: ANOVA FOR COPPER (Cu)

					95% Confidence Interval for Mean		
					Lower Bound	Upper Bound	
TNR1	12	0.01	0.000	0.000	0.01	0.01	0
TNR2	12	0.01	0.000	0.000	0.01	0.01	0
TNR3	12	0.02	0.021	0.006	0.01	0.04	0
SBR1	12	0.02	0.017	0.005	0.01	0.03	0
SBR2	12	0.01	0.003	0.001	0.01	0.01	0
SBR3	12	0.02	0.026	0.007	0.00	0.03	0
AWS1	12	0.01	0.003	0.001	0.01	0.01	0
SBK1	12	0.02	0.023	0.007	0.01	0.04	0
Total	96	0.02	0.016	0.002	0.01	0.02	0

Test of Homogeneity of Variances

Cu

Levene Statistic	df1	df2	Sig.
7.196	7	88	0.000

ANOVA

Cu

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	0.003	7	0.000	1.662	0.129
Within Groups	0.021	88	0.000		
Total	0.024	95			

A9: ANOVA FOR LEAD (Pb)

					95% Confidence Interval for Mean		
					Lower Bound	Upper Bound	
TNR1	12	0.03	0.024	0.007	0.01	0.04	0
TNR2	12	0.02	0.017	0.005	0.01	0.03	0
TNR3	12	0.03	0.027	0.008	0.01	0.04	0
SBR1	12	0.02	0.011	0.003	0.01	0.02	0
SBR2	12	0.03	0.028	0.008	0.01	0.05	0
SBR3	12	0.02	0.020	0.006	0.01	0.03	0
AWS1	12	0.03	0.032	0.009	0.01	0.05	0
SBK1	12	0.02	0.015	0.004	0.01	0.03	0
Total	96	0.02	0.023	0.002	0.02	0.03	0

Test of Homogeneity of Variances

Pb

Levene Statistic	df1	df2	Sig.
4.617	7	88	0.000

ANOVA

Pb

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	0.002	7	0.000	0.670	0.697
Within Groups	0.046	88	0.001		
Total	0.048	95			

A10: ANOVA FOR ZINC (Zn)

					95% Confidence Interval for Mean		
					Lower Bound	Upper Bound	
TNR1	12	0.02	0.010	0.003	0.01	0.02	0
TNR2	12	0.01	0.009	0.002	0.01	0.02	0
TNR3	12	0.04	0.067	0.019	0.00	0.08	0
SBR1	12	0.01	0.007	0.002	0.01	0.02	0
SBR2	12	0.04	0.050	0.014	0.00	0.07	0
SBR3	12	0.02	0.008	0.002	0.01	0.02	0
AWS1	12	0.01	0.008	0.002	0.01	0.02	0
SBK1	12	0.03	0.033	0.009	0.01	0.05	0
Total	96	0.02	0.033	0.003	0.02	0.03	0

Test of Homogeneity of Variances

Zn

Levene Statistic	df1	df2	Sig.
7.045	7	88	0.000

ANOVA

Zn

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.009	7	0.001	1.209	0.306
Within Groups	0.092	88	0.001		
Total	0.101	95			

A11: ANOVA FOR CYANIDE

					95% Confidence Interval for Mean			
					Lower Bound	Upper Bound		
TNR1	12	0.01	0.003	0.001	0.01	0.01	0	0
TNR2	12	0.02	0.009	0.003	0.01	0.02	0	0
TNR3	12	0.01	0.007	0.002	0.01	0.02	0	0
SBR1	12	0.01	0.006	0.002	0.01	0.02	0	0
SBR2	12	0.01	0.003	0.001	0.01	0.01	0	0
SBR3	12	0.05	0.098	0.028	-0.01	0.11	0	0
AWS1	12	0.02	0.025	0.007	0.00	0.03	0	0
SBK1	12	0.01	0.012	0.003	0.01	0.02	0	0
Total	96	0.02	0.037	0.004	0.01	0.03	0	0

Test of Homogeneity of Variances

CN

Levene Statistic	df1	df2	Sig.
9.359	7	88	0.000

ANOVA

CN

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	0.015	7	0.002	1.641	0.134
Within Groups	0.116	88	0.001		
Total	0.131	95			

APPENDIX B

ANOVA FOR BACTERIOLOGICAL PARAMETERS.

B1: TOTAL COLIFORMS (TC)

					95% Confidence Interval for Mean		
					Lower Bound	Upper Bound	
TNR1	12	165.33	137.560	39.710	77.93	252.73	28
TNR2	12	214.00	127.070	36.682	133.26	294.74	49
TNR3	12	210.58	123.199	35.565	132.31	288.86	60
SBR1	12	248.08	88.336	25.500	191.96	304.21	132
SBR2	12	175.83	134.028	38.690	90.68	260.99	44
SBR3	12	269.33	105.807	30.544	202.11	336.56	120
AWS1	12	258.08	173.300	50.027	147.97	368.19	44
SBK1	12	270.42	137.248	39.620	183.21	357.62	50
Total	96	226.46	131.398	13.411	199.83	253.08	28

Test of Homogeneity of Variances

TC

Levene Statistic	df1	df2	Sig.
2.406	7	88	0.027

ANOVA

TC

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	143,337.167	7	20,476.738	1.204	0.309
Within Groups	1,496,872.667	88	17,009.917		
Total	1,640,209.833	95			

B2: FAECAL COLIFORMS (FC)

					95% Confidence Interval for Mean		
					Lower Bound	Upper Bound	
TNR1	12	49.08	79.261	22.881	-1.28	99.44	7
TNR2	12	36.42	27.897	8.053	18.69	54.14	6
TNR3	12	81.17	109.378	31.575	11.67	150.66	6
SBR1	12	72.83	75.825	21.889	24.66	121.01	13
SBR2	12	42.75	66.298	19.139	0.63	84.87	5
SBR3	12	67.63	50.646	14.620	35.45	99.80	18
AWS1	12	63.42	82.202	23.730	11.19	115.65	7
SBK1	12	76.58	66.462	19.186	34.36	118.81	12
Total	96	61.23	72.185	7.367	46.61	75.86	5

Test of Homogeneity of Variances

FC

Levene Statistic	df1	df2	Sig.
1.383	7	88	0.222

ANOVA

FC

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	23,019.164	7	3,288.452	0.613	0.744
Within Groups	471,992.813	88	5,363.555		
Total	495,011.977	95			