KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF THEORITICAL AND APPLIED SCIENCE

DEPARMENT OF ENVIRONMENTAL SCIENCE

EFFECTS OF SMALL SCALE MINING ACTIVITIES ON THE ANKOBRA RIVER: A CASE STUDY IN THE AMENFI EAST DISTRICT OF THE WESTERN REGION

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES IN PARTIAL FULFILMENT FOR THE AWARD OF MASTER DEGREE IN ENVIRONMENTAL SCIENCE

BY

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DECLARATION

I hereby declare that this submission is my own work towards the MSc. Environmental Science degree, and that to the best of my knowledge, this work contains no material previously published by another person, nor materials which have been submitted for the award of any other degree of the university or any other university anywhere, except where due acknowledgement has been made in the text.

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DEDICATION

This work is dedicated to my wife Gloria “Virtuous” Damoah.

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ABSTRACT

Small scale mining activities are undertaken in many parts of the world where mineral deposits are found. The process is carried out in or close to water bodies as water is needed in the washing of waste and the subsequent extraction of the mineral. In developing nations such as Ghana, the activity is done both legally and illegally, often with very little or no supervision. Hence much damage is done to these water bodies where the activities are carried out. In the present study, the impact of small scale mining activities on the Ankobra River was carried out in four communities within the Amenfi East District of the Western Region, an area where the activity is highly prevalent. Samplings were carried out at six different points in four communities within the District, and analyses were done to determine the physico chemical parameters and heavy metal concentrations present in the water using the atomic absorption spectrometer.

The study showed that most of the physico-chemical parameters recorded at sections of the river where small scale activities were carried out were above standard limits. Similar observations were made for the concentrations of heavy metals analysed from the river; there were relatively higher concentrations of the heavy metals, especially mercury, at the small scale mining regions of the river as compared to analysed samples from the source. Effects of small scale mining activities on water course (direction), water level and the rate of flow (water current) were found to be negatively affected. The vegetation at the bank was also negatively affected.

The study revealed that, despite the economic boost provided by small scale mining activities, the processes involved have enormous negative effect on the Ankobra River and the environment at large. It is, therefore, recommended that there be instituted by regulations, law enforcement agencies to strictly monitor such activities.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE **PAGE**

LIST OF TABLES

CHAPTER ONE

1.0 INTRODUCTION

1.1 BRIEF BACKGROUND INFORMATION ON GHANA

Ghana is a free state, having attained independence on 6th March, 1957, and a republican status on 1st July, 1960 under its founder and first president, Osagyefo Dr. Kwame Nkrumah.

The nation is an African state, and is located within the West African sub region. It is bounded to the north by Burkina Faso, to the south by the Gulf of Guinea in the Atlantic Ocean, to the east by the Republic of Togo, and to the west by the Republic of Côte D'Ivoire.

From an initial population of about 5 million people at her independence in 1957, the nation's population has steadily increased to approximately 22 million people according to the 2000 population census (Ghana Population and Housing Census 2000).

Accra, the nation's capital, serves as her main commercial, legislative and judicial centre, alongside other important regional capitals such as Kumasi in the central part of the country, Tamale in the northern part, Koforidua in the eastern corridor, and Sekondi Takoradi, an important oil city in the west.

Until 1992 when the nation was ushered into democratic governance under the then military leader, Flt Lt. Jerry John Rawlings, the nation went through unstable political periods through several military coups, since her independence. These political turbulences affected her economy immensely, until a smooth transition to a constitutional rule in 1992.

The nation's premier university, the University of Ghana, situated in Legon in the nation's capital, is a cent of academic excellence. The Kwame Nkrumah University of Science and Technology (KNUST) in Kumasi is another very important educational centre along with very important colleges and research centres, contributing to the training of large numbers of skilled labour, especially in the Sciences for the country and the West African sub region at large. The University of Cape Coast established by the country's premier president, Dr. Kwame Nkrumah in 1962, is an important institution mainly responsible for training the nation's professional teachers (but lately giving training in other job sectors).

The *cedi* is the nation's currency of exchange. Over 60% of the active working population is engaged in subsistence farming, and the remaining working population is involved in both formal and informal employments. The informal sector, to which the small scale mining industry belongs, plays very important role in sustaining the nation's economy.

With a stable political arena and economically thriving environment, the nation has witnessed a tremendous growth in its economy since the Fourth Republic begun in 1992.

With a total gross domestic product (GDP) of 44 billion Ghana cedis (or 30 billion US dollars), and with a growth rate of 9% per annum, and an income per capita of 1, 225 US dollars, the nation witnessed an accelerated growth, and was thus, declared a middle income nation in 2011 (Ghanaweb, 2010)

The nation appears to have one of the best literacy rate records on the African continent. It has a literacy rating of 67% (Ghanaweb, 2010), and subsequent governments take huge interest in focusing on the development of its human resources through education.

The nation is endowed with great reserves of minerals, especially gold, in her soils, hence was rightly named by the British Colonial Government as the Gold Coast. There are several formalized mining firms in the nation, the most recognized ones being the AngloGold Ashanti, with its operational centres in the mining town of Obuasi, Goldfields Ghana Limited at Tarkwa in the Western Region, and Newmont Ghana Limited in Kenyasi in the Brong

Ahafo Region. These mining firms, together with other small scale mining industries, play a major role in Ghana's foreign exchange earnings, and in stabilizing the nation's economy.

As true as this realization may be, the nation is recently bridled with complex environmental problems as a result of the impact of increase in such activities as mining and other related activities on the environment. For example, within a few decades, the nation's forest belt reduced drastically from over 8 million to less than 2 million hectares in 2010. This estimation offers a rightful insight to the nation's environmental status, a situation which calls for a far greater concern and enlightenment on environmental issues than is presently known.

1.2 WORLD OVERVIEW OF SMALL SCALE MINING

Mining is the extraction of minerals and precious metals from the earth. These minerals and metals include manganese, tantalum, copper, tin, silver, diamonds and gold.

Mining may be considered in two forms: large scale mining and small scale mining.

Large scale mining usually employs large number of people and produces huge tonnes of gold. Examples of these are the Minas Serra Pelade Mines in Brazil which employed about fifty thousand workers and yielded twenty nine thousand tonnes of gold between 1980 to 1986 (Dickson and Eakin, 2008).

Small scale mining is a form of mining that is done at small levels and mostly employs relatively a low number of people (Appiah, 1998). It is generally engaged in by local people within the area where these activities occur, and comes along with it the influx of people from other areas.

There are two main forms of small scale mining; these are land dredging and river dredging. In the former, miners use generators to dig large holes in the ground to expose the gold bearing layer of the sand and clay. The slurry is then pumped into a sluice box which collects the gold particles. The tailings flow into an adjacent tailings dam or a mining pit in adjacent area, usually a forestland. With the river dredging, miners move along the river on a platform or in a boat. A hydraulic suction hose then suctions the gravel and mud along the river. These go through a tailing, and gold fragments are collected on felt mats. The remaining wastes may be released into the river, thereby causing enormous environmental damage to the water body (Pulles *et al.*, 2002).

Generally, in the modern trend of small scale mining activities, tools used include such simple machines as pick axe, shovels and pans to more complex machines such as grinders, excavators and trucks. Small scale mining activities started a long period before this modern era. The process begun as early as human civilization was recorded. This was because ancient civilization, prominent among which were those of Mesopotamia, Egypt, Jewish, Babylonians and the Greek, had exploited and used such minerals as copper, silver and gold extensively mainly in architectural works and as media of exchange for other goods and services. This was especially so when the Arabs trooped to Africa in the seventh and eighth centuries to trade other materials for gold (Botchway, 1995).

Yet mining activities in this period, generally considered as small scale, had very little impact on the environment and water bodies as they had no need of employing dangerous chemicals for extraction processes. This realization is diametrically different from the modern trend of small scale mining activities which do the environment vast harm (Rambaud *et al.*, 2001).

Small scale mining may be legal (registered) or illegal (not registered). Where they are registered there is some level of supervision, hence moderate consideration for environmental concerns (Iddirisu and Tsikata, 1998). Nevertheless, much destruction is done to the environment in the sense that activities done here are more vigorous and relatively higher. In situations where small scale activities are not registered, there is no monitoring, hence these miners are left unchecked, and the degraded environment receives no remediation. Environmental media mostly affected are water bodies such as rivers, streams and lakes, the soil and vegetation (Dzigbodi-Adjimah and Bansah, 1995).

In Brazil, the largest of all rivers in the world, the Amazon is not left out of the negative impact small scale mining activities have on the world's river system. Although largely considered unexploited, recent developments have indicated that human developments are beginning to have huge negative impacts on the Amazon. The Brazilian government, in an attempt to open the thick and remote Amazon Forest for development, has constructed road networks across the vast vegetation, thereby permitting the interference of external players. These intruders are mainly interested in mining and agricultural exploitations. These developments put the Amazon River in serious pollution threats. Indeed, a current study (Odell, 2008) have indicated that the Amazon River dolphins, which live in the Amazon and the Orinoco basins of South America and were previously considered untouchable, are now killed for their organs as good luck species.

Small scale mining activities occur in many regions within the African continent close to rivers and other water bodies. Major rivers in Africa where these activities occur in include the Nile River (the longest river in the world), the Moulouya river in northern Africa, the Orange and Okavango rivers in southern Africa, Lake Tanganyika and the Limpopo and Lualaba rivers in eastern Africa, the Volta and Niger rivers of estern Africa, and the Blue Nile and Chari rivers of central Africa. The pollution level and negative effects of small scale mining on most of these important river bodies are quite well known.

In Ghana, the effects of small scale mining activities are very enormous. Major rivers in the country which have been affected by small scale mining processes include the Volta River (the largest river in the country) formed from the confluence of the Black and White Voltas and its two tributaries, the Oti and Afram rivers, the Densu River, the Birim River, Pra, Tano, Ankobra and the Offin rivers, (Owusu, 2008) all of which empty into the Gulf of Guinea within the Atlantic Ocean, south of the country. In one way or the other, the state of each of these rivers has been tempered with by human related activities, paramount and most disturbing one being small scale mining activities, especially for gold, such as in the Ankobra River in the country's Western Region, and diamonds, as observed in the Birim River in the Kwaebibirem District of the Eastern Region.

In spite of all these negative impacts, one cannot ignore some of the positive effects of small scale mining activities. For instance, it provides jobs for many people. In some communities it constitutes the main job for people within and even those outside its catchment areas. The International Labour Organisation estimated that the activity provided employment for about 13 million people throughout the world (ILO, 1999). It may also serve as important source of income for the government, among many other benefits.

1.3 MAIN OBJECTIVE

The main objective of this study was to determine the effects of small scale mining activities on the Ankobra River.

1.3.1 SPECIFIC OBJECTIVES

The specific objectives were to

- determine the effects of small scale mining activities on the water quality of the Ankobra River based on such physical and chemical parameters as the pH, turbidity, electrical conductivity, salinity, dissolved oxygen and total dissolved solids.
- determine the presence and concentrations of the following heavy metals: copper, lead, cadmium, arsenic and mercury in the Ankobra River due to these activities.

- determine the seasonal changes of these parameters during the mid, dry and rainy seasons.
- determine the effects of small scale mining activities on the water course, water depths and the rate of flow (current) at specific sections of the Ankobra River.
- determine the impacts in the vegetation cover along the banks of the Ankobra River as a result of small scale gold mining activities.

1.4 JUSTIFICATION

Many rivers in Ghana are highly threatened by human interferences and unmonitored activities. Of these activities the quest of mining for precious metals and minerals seems unabated, as unemployment records continue to shoot up, and more people, especially the youth actively seek for jobs.

This unemployment situation has resulted in unprecedented and unscrupulous mining activities in many areas and on many rivers in Ghana. Among them, the Ankobra River basin is much affected as it is famous for its abundant deposits of alluvial gold. Many people from far and near, as well as foreigners (especially Chinese) have actively engaged in these destructive mining activities which have immensely affected the environment badly. This chain of developments also has direct influence on the many communities which depend largely on the Ankobra River as their source of drinking water and for other domestic purposes.

The study would therefore bring to light the effects of small scale mining activities on the Ankobra River, and suggest means to reduce the impact of the activities.

CHAPTER TWO

2.0 LITERATURE REVIEW

Small scale mining activities are done all over the world. The activities contribute significantly to economic growth of the individuals who engage in the industry and their communities. It is estimated that small scale mining activities job for some thirteen million people around the world (ILO, 1999). Over the last decade, small scale mining activities have been on the increase, as people seek economic relief in the face a constantly increasing unemployment rate.

As a result of this development, the activities of small scale miners have been very rigorous and rampant in several regions all over the world, and more so in developing countries such as Ghana.

2.1 HISTORICAL BACKGROUND OF SMALL SCALE MINING IN GHANA

Small scale mining, also called artisanal or subsistence mining have been engaged in by the native people of Ghana well over 1500 years now. According to Agyapong (1998), "vestiges of alluvial gold extraction and winning have been found that as far back as the sixth century" in the shores and forest belts of the Gold Coast. He asserted there were evidences that precious metals recovered from regional artisan activities attracted Arab traders to certain areas of the country as early as the seventh and eighth century AD, and that gold deposits in the Western Sahara were largely responsible for the wealth and strength of ancient Ghana empires and cultures. Thus by the fifteenth and sixteenth centuries, at the acme of European colonial exploration, the country was agreeably labeled the *Gold Coast*. Small scale mining in Ghana had been treated as an informal sector up until the 1980s, and this resulted in the decline of mineral production, as observed by (Botchway, 1995).

Small scale mining is often done by local people as well as nomadic immigrants who move from place to place for greener pastures. Nevertheless, this trend has taken a new dimension as the industry has now largely attracted foreigners, especially of Chinese origin, who undertake small scale mining activities not only with improved local machines, but also with complex forms which are imported purposely for the operations (Appiah, 1998). This is especially true in developing countries such as Ghana where activities of Chinese citizens have called for much concern. More often, the foreigner may hide under the auspices of one or very few but highly influential citizens within the local setting to carry out such an obnoxious task with incomparable environmental pollution and related damages.

Until the beginning of the new millennium, the activities of small scale miners were much minimal, relative to large scale miners. Gold was mainly mined in large quantities by the colonial masters in most parts of Southern Ghana.

Small scale mining activities which have gained much popularity in recent years had only had a major turn at the beginning of the 21st century. It comes as a huge solution and indeed relief to the increasing number of unemployment in most developing countries and the world at large (Appiah, 1998).

More often than not, small scale mining activities within a geographically defined region may be associated with a water body. Water is used in washing away the dirt (mostly soil) from which pure gold is extracted. As a result of this realization, small scale mining activities have always had a major toll on water bodies from which their activities are carried out.

The process is most detrimental to major water bodies which serve as the main recipient for other smaller streams and rivers which empty their contents into these large rivers. Among the major destructions caused are water pollution by chemicals such as mercury, cadmium, arsenic, copper and lead, and damage to vegetation cover.

As a result of the nation's favourable geographical setting, which makes precious minerals available in most sections of the Ghanaian soil, small scale mining of minerals, especially gold, is scattered across sections of the nation ((Mineral Commission, 2000).

2.2 AN OVERVIEW OF THE MODERN GHANAIAN SMALL SCALE MINING INDUSTRY

The abundance of gold in the Ghanaian soil has been attributed mainly to tectonic processes several years ago, which resulted in folds and faults, as well as a series of metamorphic and igneous, sedimentary and erosion activities (Lunt *et al*, 1995). Erosion activities have resulted in the spread of rich soils which cover sizable portion of the nation.

Several gold belts cover Ghana's land surface. The first belt, covering about 15-40km in width, contains the Birimian gold. Birimian gold is found in supracrustal West African rocks extending from Ghana to as far as Burkina Faso in the north, and Senegal and Mauritania in the western parts of the region. The belt contains such fine gold as proterozoic greenstone-type lobe gold deposits. This is variably complex, and occurs as quartz-filled shear zone and altered shear zone forms (Leube *et al.*, 1990).

The Tarkwaian gold is found in the second gold belt. About 90% of this gold belt comprises Vein-quartz-pebbles and auriferous pebble seposits. Quartzite and phyllite particles constitute the remaining 10% (Hammond and Tabata, 1997).

Due to the mineral rich contents of the Ghanaian soil, huge monies are accrued from the modern Ghanaian small scale mining industry. Good amount of gold either in fine particle forms or lump forms, are mined from small scale mining sites across the nation (Appiah, 1998).

Generally, wealthy persons buy some acres of land after prospects are made on them to assess the level of their gold mineral deposits. The mineral is very costly. A small part of it may sell millions of cedis. Hence the vigorous involvement of the youth.

The prospectors then high men and pay them wages (daily, weekly or specified days interval). Currently, a minimum average daily wage may support an unmarried young man or a woman's moderate expenditure for at least four days, though the specific amount paid may differ widely from place to place. However, small scale miners hardly economize. Thus, a day's wage may be spent on that particular day with very little or no amount kept. It is worth noting though, that few people involved enter this business with specified aims.

Another important factor that makes the modern small scale mining a lucrative business is the high demands for gold and golden products both on the local and international markets (Hilson, 2001).

2.3 ORGANISATION AND MAJOR PROCESSES IN SMALL SCALE MINING ACTIVITIES

A licensed operator may employ between five to twenty groups of tributes made up of between five to ten workers. Each group excavates the ore to process the mineral. Usually the tributers keep two-thirds of the profit and give the remaining one-third to the concessionaire (Appiah, 1998).

Small scale mining activities in Ghana employs very simple implements and devices such as pick-axes, shovels, mattocks, sluice boxes and cutlasses. In some few instances, mechanized machineries such as washing plants, Honda water pumps and explosives are employed (Hilson, 2001). Nonetheless, small scale mining sites of such mechanized machineries operate largely rudimentarily.

Generally, the processes involved in small scale gold mining are crushing the ore into pebbles or powder under various stages, washing the crushed sediments with washing blanket or hands along riverbanks to separate the mineral, and panning (Hilson, 2001). Mercury is used in the panning process, and the amalgamated gold is roasted on charcoal fire in the open air (Babut *et al.*, 2001).

2.4 SOCIO - ECONOMIC EFFECTS OF SMALL SCALE MINING ACTIVITIES

Small scale mining activities have immense contributions within the communities where they are operated (Davidson, 1993).The impacts may be both positive and negative. These influences are realized in the increase in population in the area of work, due to increased employment opportunities, boost in economic activities and reduction in crime. Negative influences resulting from small scale mining activities include child labour, promiscuity and high cost of living.

2.4.1 INCREASE IN POPULATION

Small scale mining activities bring about the influx of people to the areas of operation (Davidson, 1993). These people are mostly young men and women who are aggressive in making quick money. Some of these people are apprentices in various vacations who may previously be learning one form of trade or the other. Students who fend for themselves or have minimal support from home are also sometimes involved.

These people who come to the region of small scale mining activities to work also take women, especially teenagers from the area and befriend them. This interaction often results in teenage pregnancy and birth to more children, most of whom do not receive the necessary support and parental guidance. Subsequently, this results in population increase (ILO, 1999).

People, who previously farmed, also see the small scale mining of gold as a quick form of acquiring wealth. Thus, farmers also abandon their farming activities and move to *galamsey* sites in search of quick wealth.

2.4.2 EMPLOYMENT OPPORTUNITIES AND BOOST IN ECONOMIC ACTIVITIES

Small scale mining activities provide employment opportunities to the people within the area of operation, favourably in very remote settings where there is less or no formal job opportunities (Davidson, 1993). In developing countries, where employment is very much limited, and where farming is viewed as a job for the aged, the uneducated and the less active in the community, small scale mining activities are seen as huge sources of alternative employment for the youth and the more active within the society.

A United Nations' *Report on Small Scale Mining Activities* (UN, 1996) indicated that more than over thirteen million or 20% of the world's mining population was involved in small scale mining operations. This was confirmed by a research carried out by the International Labour Orginisation which stated in its *Global Report on Artisanal and Small Scale Mining,* that the number of the world's population directly involved in small scale mining activities was over thirteen million (ILO, 1999).

Besides the direct job opportunities to people, small scale mining activities create alongside many other employments through the boost in marketing activities (Noetstaller, 1993). Women who were previously jobless now acquire a form of job through petty trading or running errands at the sites of operation. Thus, all forms of population structure are at least able to meet their economic needs from the job opportunities created by the mining operation.

Whilst it is not capital intensive, small scale mining activities require sufficient manpower. Intensive- small scale mining operations are economically beneficial; investment cost per job is estimated to be 10-12 percent the costs in large mining operations (UN, 1992).

The following Table, as provided by the ILO's *Global Report on Artisanal and Small Scale Mining 11*, provides an overview of countries and their active populations involved in this business.

Table 2.1: World employment statistics on small scale and artisanal mining (ILO, 1999)

Country	**Total Number in Thousands**
Bolivia	72
Brazil	10
Burkina Faso	100-200
China	3000-15000
Ecuador	92
Ghana	200
India	500
Indonesia	109
Malawi	40
Mali	200
Mozambique	60
Peru	30
Philippines	185.4
PNG	50-60
South Africa	10
Tanzania	550
Zambia	30
Zimbabwe	350

No direct figures are available for the number of people involved in artisanal mining in Ghana, but it is estimated that at least two hundred thousand of the nation's population could be involved in this operation and other accessories. Appiah (1998) asserted that over six thousand illegal and 117 registered artisanal gold mines occur only in the Western Region mining town of Tarkwa, Ghana.

2.4.3 GENERATION OF REVENUE

It is estimated that one-sixth of global mineral output is accumulated from small-scale mining, and the generation of revenues from the small-scale mining industry in Ghana has heightened after its complete legalization (Hilson, 2000). Table 2.2 presents the amount of gold raised from small scale gold mining businesses in Ghana between the years 1990-1997, and the revenues accumulated over this period (Agyapong, 1998).

Table 2.2: Small scale gold production in Ghana between 1990-1997 (Agyapong, 1998).

Year	In ounce	Revenue in US$ (000s)
1990	17,234	6,257
1991	8,493	3,800
1992	10,867	7,714
1993	33,647	11,480
1994	89,520	36,090
1995	127,064	53,540
1996	112,240	43,340
1997	107,093	33,094

2.4.4 REDUCTION IN CRIME

Since small scale mining activities provide employment for people, there is reduction in crime (which some youth see as an alternative job at extreme needs) in the regions where the operations are carried out. Small scale mining activities are mostly jobs for the active population such as the youth. Since most youth see the operation as a quick means of making money, they often go into it rather than any other alternative job. By this, organized crimes such as armed robbery, rape and organized community/house stealing are avoided.

2.4.5 LOCAL USES OF MINERALS

Part of the minerals obtained from small-scale mining activities is used locally by blacksmiths and jewellers in manufacturing products such as bracelets, gold chains and watches (Asante, 2000). These locally manufactured products are very costly and fetch enough income for the people engaged in this business whilst it fetches income for the government from revenue collections.

This gives opportunity for local craftsmen to utilize and explore their talents in making local jewelleries for public consumption. This is in sharp contrast to large scale gold production where the gold produced is exported in totality to foreign countries for foreign exchange (Coackley, 1999).

2.4.6 CHILD LABOUR

One serious negative influence of small-scale gold mining operation on the community is its influence on young people within the society (ILO, 1999).

The term became catchy in several years back, when Columbia experienced its worst form in its coal mining industry and caught international press attention, a move which led to a ban on the nation's coal export.

An International Labour Orginisation (ILO) Convention 182, sought to eliminate all forms of child labour, including child labour in mining operations through the International Programme on the Elimination of Child Labour, from the society ILO, 1999). Child labour in small-scale mining sites has serious repercussions on young people, among which are dropping out of school, and health effects.

The issue of child labour is particularly serious in developing countries. For example, the ILO *Global Report on Artisanal and Small Scale Mining 24* (ILO, 1999) indicated that out of the over 8000 small scale miners in Bolivia's small scale mining industry in the towns of Cerro Rico and Potosi, at least half of these people were children and teenagers of school going ages.

In parts of Africa such as Tanzania, Niger, Guinea, Burkina Faso and Ghana, worst forms of child labour occur. Children as young as five or less are seen in such activities as breaking rocks, carrying loads to be washed or running errands for workers on site (UN, 1996).

In Ghana, it is not uncommon for small-scale miners to send very young people to the mining site to carry loads or run one form of errand or another. In some instances, mothers who carry loads to be washed, send their school-going children to carry their siblings whilst they as parents got involved in more active labour.

Children as young as twelve are reportedly seen involved in active small-scale mining sites vigorously doing underground work just as adult miners (Traore, 1994).

2.4.7 INCREASE IN PROMISCUITY

Due to the quick money made from small-scale mining activities, most people engaged in the business often get themselves involved in scandalous and unacceptable societal lifestyles.

Such excess indulgences include teenage sexual abuses, womanizing, drunkenness, over excessive spending and indiscipline.

Akabzaa (2000) reported that teenage pregnancy is prevalent in small-scale mining activity areas than in regions where they are absent.

A recent research carried out in the western part of the country (Ghana) indicated that teenage pregnancy was more common in small-scale mining operational sites than in areas where this business was absent. Again, sexual promiscuity and drunkenness were common vices which confronted communities where small scale mining activities occurred (Akabzaa, 2000).

2.4.8 HIGH STANDARD OF LIVING

The cost of living in small scale mining regions is often very high (UN, 1996).This is because the operation fetches relatively much quicker money for its workers.

Small - scale-miners are often spindrifts. This is because they hardly plan ahead, and since the business is very fetching, they always have enough to spend.

Traders in the area of operation sell their goods at very high prices, and this makes the cost of living very high for the ordinary people living in the area.

Small-scale gold mining is a continuously growing business, very attractive to the young and active populations (Hilson, 2000). Since these groups of people would prefer this business to farming, food cost is often very high as only fewer and less active people get involved in the production of crops. While the standard of living has very minimal effects on those engaged in small - scale mining due to the money earned, it adversely affects the vulnerable and inactive, native population who are not involved in this business.

2.5 ENVIRONMENTAL CONCERNS IN SMALL SCALE MINING ACTIVITIES

Small scale mining activities come along with many environmental issues (Babut et al., 2001). These may culminate in an increase in the level of certain chemicals in the environment. These chemicals, mainly heavy metals increase in levels either by direct use of the chemical or its availability as a result of vigorous processing activities of the sand or the rocks which are washed for the mineral (Noetstaller, 1993).

In water bodies, small scale mining activities also largely affect such parameters as the pH, turbidity, salinity, dissolved oxygen and total dissolved solids.

2.5.1 HEAVY METALS IN THE ENVIRONMENT

The presence of heavy metals in the environment has adverse effects on ecosystems (N.S.R., 1994).

2.5.1.1 SOURCES AND OCCURRENCE OF HEAVY METALS

Minute amounts of heavy metals available in the environment are basically due to the *weathering* of rocks. This is the process by which rocks break down into pieces to generate soil. Like all metals, heavy metals circulate within the environment, and are eventually assimilated by plants and animals. Table 2.3 shows some data on the sources of naturally occurring cadmium in the environment (Hutchinson and Meema, 1987).

Table 2.3: Levels of naturally occurring cadmium in the environment (Hutchinson and Meema, 1987).

Medium	**Level of cadmium (µg/m^3)**
Atmosphere	0.1-5
Earth’s crust	0.1-0.5
Marine sediments	1.0
Sea water	0.1

However, the alarming increase of certain heavy metals such as arsenic and mercury are mainly due to anthropogenic activities such as gold mining, quarrying and sand winning. The local gold mining activity, *galamsey* which is mainly carried out in many places of the country including the communities in the Prestea - Huni Valley and the Amenfi East Districts within the Ankobra River appears far destructive than conventional gold mining processes in polluting the environment with heavy metals. Other sources of heavy metals are pesticides and fertilizers produced by industrial processes and applied in agricultural activities.

A group of heavy metals called *trace elements* are, however beneficial and are taken up by both aquatic and terrestrial plants and animals in minute quantities as nutritional essentials for active metabolic processes. Such trace elements include zinc, copper, iron and chromium (Akoto, 2009).

Arsenic occurs in the form of arsenical iron ($FeAS_2$) arsenical nickel (NiAs), cobaltite (CoAsS), and its important minerals, are arsenical pyrites/mispickel (FeAS), orpiment (As_4S_6), reaglar (As_4S_4) and nickel glance (NiAsS) (Soni, 1993).

Cadmium occurs as the principal constituent of a mineral only in the rare greenockite. It is obtained as a by-product in the refining of zinc ores (Hutchinson and Meema, 1987). Its separation from zinc is done by fractional distillation and electrolysis.

2.5.1.2 USES OF HEAVY METALS

Heavy metals have several uses for humans. Their most important applications are found in industrial and agrochemical fields.

For example, cadmium is used in nickel/cadmium batteries, as rechargeable or secondary power sources, as cadmium coatings to provide good corrosion resistance in high stress environment such as marine and aerospace, as pigments, stabilizers for PVC and in electronic components (Hutchinson and Meema, 1987). For agrochemical purposes, cadmium is used in phosphate fertilizers.

Arsenic has a variety of uses. The metal is used in flame retardant glass making. It is also used in eliminating green colour caused by impurities of iron compounds. It can also be added to lead to harden it. In defence, arsenic is used in military poison gases as lewisite and adamsite. In medicine, arsenic is used in minute quantities together with other medicinal components to treat syphilis. The element is used in lead arsenate, calcium arsenate and Paris green in the manufacture of insecticides (Damoah, 2007). In electronics, the metal is used in the manufacture of semiconductors and laser materials. It is also used in the manufacture of pesticides for agriculture purposes (Griffith, 1992).

Lead is another heavy metal with a variety of uses. It is used in storage batteries, in sheathing electric cables in lining tanks and pipes and in X-ray apparatus. Lead is also used as protective shielding for radioactive materials and in alloys such as solder and type metal. It is also used in paints and in pigments (Hutchinson and Meema, 1987).

Copper is another important heavy metal with many uses to the modern technological industry. Due to its distinct properties (high conductivity of heat and electricity and high resistance to corrosion) the element finds many important applications in the electrical and mechanical industries (Soni, 1993). It is also used for economic purposes as in coin making, in the manufacture of cooking utensils and in making vats and ornamental objects.

Mercury is mostly used in the manufacture of thermometers since its coefficient of expansion is nearly constant; that is, the change in its volume per each degree of rise or fall in temperature is constant (Mackay *et al.*, 1995). Mercury also finds important applications in the manufacture of vacuum pumps, barometers, electric rectifiers and switches. The element is also used in the manufacture of batteries and mercury thermometers (Kruus and MacCaw, 1991). Other important applications of mercury are found in the pharmaceutical and agrochemical firms, and in dentistry, although its use in these sectors is highly reduced due to its high level of toxicity (Babut *et al.*, 2001). In extraction, the element combines with common metals (except iron and platinum) to form alloys called amalgams. The mercury is later separated from the metal by distillation.

2.5.1.3 BEHAVIOUR OF HEAVY METALS IN FRESHWATER

Heavy metals have many serious effects in water and other environmental media (Alloway and Aryres, 1993). Being natural components of the earth's crust, they are available in minute and insignificant amounts within water bodies and in other environmental media as a result of natural processes such as rock weathering and volcanic eruptions.

Traditionally, the commonest anthropogenic source of heavy metal presence in freshwaters has been through pollution of water bodies as a result of mining processes (Ferguson, 1990). Mining firms at all levels use acid mine drainage system to release heavy metals from their ores since these metals are very soluble in acid solutions. After the drainage process, the acidic solution, usually containing high levels of the metals is dispersed into the environment (Akoto, 2009).

The solubility of metals is affected by pH; their solubility is inversely proportional to the pH of water. Thus, a fall in water pH indicates higher levels of dissolution and hence greater mobility. The phenomenon explains why metals are mostly toxic in soft water (Waldron, 1980).

Heavy metals and their organo-metal forms cannot be degraded into less poisonous forms; they are persistent in the environment. By the process of bioaccumulation (The process of increase in concentration of a chemical in a biological entity over time), these metals and their organo-metal forms are built up in food chains (Ferguson, 1990). Bioaccumulation results when the rate of intake or consumption of a particular chemical is higher than its rate of metabolism.

2.5.1.4 TRANSFORMATION OF HEAVY METALS IN FRESHWATER

The transformation of metals in water depends on three major processes, namely physical, chemical and biological processes (Kruus and McCaw, 1991).

Physical factors which affect this transformation include the rate of flow, turbulence of the water, advection and diffusion of the chemical.

Chemical reactions leading to the transformation include hydrolysis, substitution, elimination, and oxidation and reduction reactions (Fei-Baffoe, 2010). Factors such as the presence of reactants, availability of other pollutants, oxidation state of available chemicals, temperature, pH and sorption influence these chemical processes (McKinney and Scotch, 1996).

Biological processes are mainly initiated by microbial metabolism. Micro-organisms such as bacteria from the genera *Pseudomonas*, *Flavobacterium*, *Arthrobacter*, *Azotobacter* and certain species of fungi assist in altering the nature of heavy metals in water (Nathanson, 1997).

Natural transformations and environmental pathways are very complex and hugely affected by local conditions (Akoto, 2009). The best way of understanding the reactions and fate of heavy metals in the environment is to examine the biogeochemical interactions on the basis of their metal concentrations in their physical, chemical and biological states (Rambaud *et al.*, 2001).

In the case of mercury, methylation- demethylation reactions occur in the environment when the oxidized or mercuric species (Hg^{2+}) gains a methyl group (CH_3). The methylation of Hg^{2+} is a biological process producing a highly toxic and bioaccumulative emethylmercury

($MeHg^+$) and a volatile dimethylmercury compounds (Me_2Hg). Many other microorganisms, especially methanogens and sulpher-producing bacteria are involved in the conversion of Hg^{2+} to $MeHg^+$ under anaerobic conditions particularly in river sediments (Hutchinson and Meema, 1987). Mythylation readily occurs in low pH aquatic environments with high concentrations of organic matter as indicated below:

$$HgCl_2 \xrightarrow{\text{methylcobalamin}} CH_3HgCl + Cl^-$$

The methyl agent, methylcobalamin (vitamin B analog), which transforms inorganic mercury into organic mercury is produced as an intermediate in the synthesis of methane (Akoto, 2009).

2.5.1.5 BIOACCUMULATION OF HEAVY METALS IN FRESHWATER BODIES

Bioaccumulation is the tendency of a chemical to accumulate in a living organism to levels higher than in the surrounding environment of the organism (Connell *et al*., 1999). A number of factors determine the passive or active intake of chemicals exposed to an organism within a fresh water environment. At equilibrium however, a living organism would contain higher levels of the toxicant in its tissue than in its immediate environment such as water or soil sediments in the water basin (Klassen *et al.*, 1986).

Bioaccumulation occurs in food chain. For instance, mercury in water may be taken up by single-celled organisms such as zooplanktons. These may in turn be fed on by smaller fishes. Humans and other higher organisms feed on these fishes and accumulate the chemical in their body tissues (Walker *et al.*, 2006).

Two important factors with profound influence on the consequence of the process are bio-concentration and biological magnification (Adam and Lawson, 2010). Bio-concentration is the build-up of smaller amounts of potentially dangerous chemicals in the body tissue of an organism. The process eventually leads to biological magnification, which is the increase in the concentration of a chemical in an organism through the food chain.

2.5.1.6 TOXICITY OF HEAVY METALS IN FRESHWATER

The toxicity of heavy metals in freshwater and other environmental media is estimated by the absorption of aquatic organisms (aquatic plants and animals). Other living things (including humans) which directly or indirectly depend on the water as a source of drink or feed on aquatic organisms in the water body also play a role in the process (Hodgson and Levi, 1987). Plant and animal species differ widely in their sensitivity to heavy metals, and many other factors modify the response to the toxic dose (Alloway and Ayres, 1993). Some individuals are genetically adapted to tolerating anomalously high concentrations of certain metals. Homeostatic mechanisms in animals frequently involve special proteins such as metallothioneins, which bind to heavy metals, rendering them relatively inactive. Similar compounds called phytochelatins are found in plants. These make it difficult to generalize about the toxicity of heavy metals (Damoah, 2007).

The toxicity of heavy metals in vertebrates has often been measured as a median lethal dose fifty (LD50): This is the quantity of a chemical compound or the dose of the chemical per unit weight that will kill fifty percent of the particular animal exposed to the chemical under defined conditions (Adam and Lawson, 2010). LD_{50} values for cadmium and arsenic providing indication of relative mammalian toxicity of heavy metals are given in the Table below (Bowen, 1979).

Table 2.4: Relative mammalian toxicity of cadmium and arsenic as injected doses and diets (Bowen, 1979).

Element	Acute lethal dose injected into mammals (mg/kg bodyweight)	Dose in human diet (mg/day)
cadmium	1.3	3-330
Arsenic	6.0	5-50

The table shows that doses of 1.3mg/kg bodyweight and 6.0mg//kg bodyweight of cadmium and arsenic are generally harmful to mammals. In humans, a range of 3-330mg of cadmium and 5-50mg of arsenic in diets could prove fatal to the body.

Generally, the ionic forms of heavy metals are more toxic since they form toxic compounds with other ions, and electron transfer reactions that are connected with oxygen may lead to the production of oxy- radicals, a toxicity mechanism of considerable importance to plants and animals (Akoto, 2009).

Two important factors which affect the toxicity of heavy metals within the environment are bioconcentration and biological magnification (Walker *et al.*, 2006).

2.5.1.7 TRANSPORT OF HEAVY METALS IN FRESHWATER BODIES

The transport of heavy metals in the environment and its subsequent deposition has been a global issue. For instance, it has been observed that there are elevated levels of mercury in the remotest parts of surface waters away from local sources such as small-scale mining sites in water bodies (Hutchinson and Meema, 1987).

Two main physical processes govern the transport of all chemical pollutants from their local sources; that is, either point or non - point source (Fei-Baffoe, 2010). These two processes are advection and diffusion.

Advection occurs when the distribution of chemicals in the river body follows the course or direction of flow of the medium, and with the same velocity as the medium in which the pollutants flow. The direction of flow only changes when the pollutant changes from one phase to another. For instance, the direction of movement of particulate matter or aerosols in water changes as these pollutants accumulate and form residues to be deposited as sediments at the shores of the water body.

With diffusion, the molecules of chemical pollutants are evenly distributed as concentration gradient levels off (Hawken, 2008).

Pollution of surface waters and the means of control are subject by themselves. The description is complicated due to such factors as velocity of flow, turbulence, and the volume of water present. Thus, pollutants present in a water or river body may eventually be removed by natural means over a period of time through the interactions by these factors. The process is called *stream self-purification*, and it is most effective in removing decomposed organic pollutants from rivers and streams (Fei-Baffoe, 2010).

A fraction of the pollutants is also removed by the riverbanks as some are adsorbed by particles which gravitate down to sediments. Heavy metals such as cadmium or mercury which gravitate down into riverbeds may eventually end up in groundwater. As the chemicals are transported in the direction of flow of groundwater the water particles usually crawl through pores of the soil and are partially blocked by rock particles (Jackson and Jackson, 2000). The chemical pollutant is then adsorbed onto the soil particles as the water flows.

The ease of transport or movement of chemicals in a medium may be evaluated based a parameter called *permeability,* which is commonly related to the hydraulic conductivity of the material (Fei-Baffoe, 2010).

2.5.1. 8 EFFECTS OF HEAVY METALS ON HUMANS

Heavy metals in the environment pose serious health challenges to humans (Walker *et al.,* 2006). In water bodies, these chemicals taken up in food chains eventually end up in the human body, creating health complications. The effect may not be noticed at the initial stage. Eventually however, victims suffer complicated health problems as the chemicals build up in the body (Hutchinson and Meema, 1987).

2.5.1.8.1 Effects, Treatments and Prevention of Copper Poisoning in Humans

Levels of copper in natural water ecosystems are generally low, usually 4 micrograms of the chemical in one litre of water (4µg/1.0L) or even less. Nonetheless, much more of copper may dissolve in drinking water, causing the level to be higher than expected. Higher levels of copper occur when corrosive water comes in contact with copper plumbing and copper-containing fixtures in distributing systems (DNR, 2011). In this situation, copper levels may exceed 1000 µg/L).

Copper poisoning occurs when daily copper consumption exceeds 1300 µg /L, according to the US- EPA. This may result in such symptoms as nausea, vomiting, diarrhoea, and stomach cramps, and the seriousness of these symptoms get higher with greater concentrations of the chemical.

Children below one year are more prone to copper poisoning than adults. Long term exposure of copper in drinking water with concentrations very high in values beyond 1000 µg/1.0L are found to cause kidney and liver damage in very young children (Hall and Shannon, 2007).

The most effective way of avoiding copper poisoning is to stop drinking or cooking with water which is determined to contain exceeding levels of the metal. Purchasing of bottled water with good standards also reduces copper poisoning.

2.5.1.8.2 Effects, Treatment and Prevention of Lead Poisoning in Humans

Lead is toxic when taken in any of its forms. The effects are usually felt when the chemical builds up in the body over a period of time (Boggess, 1977).

Lead poisoning leads to such complications as anaemia, constipation, body weakness and paralysis of the wrist and ankles. Lead poisoning reduces intelligence, delay motor development and causes hearing problems and troubles in body balancing. It also leads to impairment in memory, increased blood pressure and kidney problems in people (Akoto, 2009). Children that play with toys coated with lead –based paints are exposed to massive lead poisoning, as the lead flakes off. Levels above 10 micrograms per deciliter of blood are considered potentially harmful in young people (Boggess, 1977).

Current treatment of lead –poisoning include administering calcium disodium ethylene diamine tetra-acetate (EDTA). The heavy metal is removed from the body by displacing the calcium in EDTA and forming a stable complex that is excreted in the urine (Damoah, 2007).

2.5.1.8.3 Effects, Treatment and Prevention of Cadmium Poisoning in Humans

Cadmium is always found in association with zinc (Hutchinson and Meema, 1987), an essential micro plant nutrient within the earth's crust. The toxicological properties of cadmium are derived from this association with zinc.

The chemical is bio-persistent, and remains resident for many years once incorporated into the body system of an organism. Eventually though, it may be excreted (Akoto, 2009).

Cadmium concentrations of 2.0 ppm (parts per million) in the hair and 0.15 ppm in the blood are considered normal and harmless to the human body. Beyond these levels, however, the heavy metal poses serious health challenges to the body (Damoah, 2007).

Exposure to cadmium among humans leads to such complications as renal dysfunction, lung sicknesses including cancer, osteomyelitis/osteoporosis (bone defects), increased blood pressure and other myocardial effects. High levels of cadmium may also result in increased incidences of calcium kidney stones, and very high accumulations may result in heart diseases (Schroeder, 2006). They may also result in depression of some immune functions by reducing host resistance to bacteria and viruses.

Though cadmium has no useful biological importance, it competes with zinc for essential body functions, hence inhibiting enzymatic reactions and utilizing nutrients present in the host's body. It may also be a catalyst to enzymatic reactions, thereby generating free radical tissue damage (Akoto, 2009).

Treatment of cadmium levels in humans include administering intravenous EDTA (ethylenediaminetetra acid) chelation (Hutchinson and Meema, 1987). However, this is done at high levels of toxicity. Other treatment methods include the intake of zinc and selenium to protect the body cells and prevent the cells from greater absorption of cadmium.

The best way of tracing cadmium levels in the human body is through hair analysis, and two ways of avoiding its toxicity are to minimize cadmium exposure and maintaining good zinc levels in the body by eating foods such as whole grains, legumes and nuts (Boggess, 1977).

2.5.1.8.4 Effects, Treatment and Prevention of Arsenic Poisoning in Humans

Arsenic accumulates in body parts such as the skin, hair, nails and internal organs. Arsenic levels of 10-20 mg or 7-10 ppm is realized in the body, and this is tolerable. Beyond this level the chemical poses serious health problems and their associated effects.

Effects of arsenic exposure include hair dermatitis, diarrhoea, gastrointestinal illnesses, fatigue, headache, confusion, muscle pains, red and white blood cell problems, neurologic effects, liver and kidney damages (Ferguson, 1990).

Exceeded limits also increase cancer levels. It is suggested that prostate cancer which is the second leading cause of death in men in the United States is linked to chronic exposure to arsenic (Damoah, 2007).

One form of the metal, trivalent arsenic is not easily cleared from the human body system. Build up of this can occur with regular exposures, and this generates into chronic problems. (Brady and Holum, 1996).

Treatment of arsenic toxicity includes administering dimercaprol, which is given within the first 24 hours after high level exposures. Chelation therapy with EDTA also clears some levels from the body. Vitamin C may somewhat protect the body from arsenic effects (Hutchinson and Meema, 1987).

The only known prevention of arsenic toxicity is the avoidance of contamination from arsenic sources (Brady and Holum, 1996).

2.5.1.8.5 Effects, Treatment and Prevention of Mercury Poisoning in Humans

In vapour form and in water-soluble salts, mercury is highly hazardous and corrodes body membranes (Akoto, 2009).

Individuals exposed to mercury concentrations as low as 0.005mg/L - 0.01mg/L may face such complications as vomiting, gum bleeding and stomach-ache (Rambaud *et al.*, 2001). Relatively higher concentrations of mercury above these result in irreversible brain damage, liver and kidney destruction.

Mercury builds up in the body of organisms by the processes of bio-concentration and bioaccumulation through food chains and drinking water sources. This occurs over a period of time since removal is very difficult once it reaches the body (Cornell *et al.*, 1999).

One memorable event of mercury poisoning occurred in Japan in the 1950's – the Minamata Bay mercury poisoning incidence. Residents of the area experienced unusual symptoms of numbness, vision problems, and convulsions. Many people died in this incidence, and it was later discovered to be mercury poisoning which resulted from the dumping of mercuric toxic waste by a local industry into the Bay, resulting in poisoning of fishes and the death of thousands of people (Sonni, 1997).

2.5.2 CHARACTERISATION OF WATER BODIES ON THE BASIS OF SPECIFIED PARAMETERS

Water bodies in all forms are characterized by three broad factors; physico-chemical factors, biological features and hydrodynamic/hydrological factors. Small scale mining operations have strong influences on all these factors.

For a reliable assessment of water quality parameters, there should be a comprehensive monitoring and evaluation of these factors (Heath *et al.*, 2004).

2.5.2.1 EFFECTS OF SMALL SCALE MINING ACTIVITIES ON THE PHYSICO-CHEMICAL PARAMETERS OF THE ANKOBRA RIVER

Physico-chemichal factors are both physical and chemical factors such as pH, turbidity, salinity, dissolved oxygen and total dissolved solids which have certain effects on the state of the water body. These parameters are determined by combinations of geochemical, climatic and geomorphological factors specified in the particular water body (Heath *et al*, 2004).

Usually, the amount of soil cover per cent of global freshwaters depends on the variable of interest. The amount of soil cover per cent of freshwater has natural chemical concentrations suitable for aquatic lives and human consumptions. These natural concentrations are however, usually altered by anthropogenic sources (Fei-Baffoe, 2010).

Due to the rigorous washing activities and the use of chemicals in small scale mining activities, there is immense influence on such physico-chemical factors as the acidity or alkalinity of the water, its salinity, its clarity, the amount of oxygen dissolved in the water and the total dissolved solids or substances in the water (Kowalkowski *et al.*, 2006).

2.5.2.1.1 Effects on pH of Water bodies

pH is the measure of the acidity or alkalinity of a system. In water bodies, pH values are measured from 0-14 on the pH scale. Values above 7 indicate alkalinity, whereas values below 7 indicate acidity. In natural water systems, pH is almost neutral (that's 7 or close to 7). pH has immense effect on the life of aquatic plants and animals.

In clean and unpolluted water bodies, the pH is guided by the concentration of carbon dioxide. The exchange or dissolution of carbon dioxide from the atmosphere into water bodies depends on the temperature of the water body. Carbon dioxide concentration in water is directly proportional to the temperature of the system (Kowalkowski *et al.*, 2006).

At high water temperatures, dissolved carbon dioxide is converted to carbonic acid. This lowers the water pH below 7, making it more acidic. Organic decomposition, resulting in the formation of humic acids may also increase the acidity of water system.

Hydrolysis of salts of metals, for instance iron and aluminium may also affect the acidity of natural water bodies as most metals turn to be more soluble at lower pH. Acid rain, corroding structures, makes available such metals as zinc, copper and cadmium which are washed into water bodies (Schwarzenbach *et al.*, 2003). The availability of these metals in water bodies adversely affects the lives of aquatic organisms.

In water bodies, alkalinity is influenced by the concentration of hydroxide ions present, and these in turn is influenced by the concentrations of carbonates and bicarbonates causing a shift in equilibrium from more hydrogen ions ($H^{+)}$ to more hydroxide ions (OH^{-}).

In the presence of alkaline earth metals, solubilisation of carbon dioxide results in the formation of carbonates and bicarbonates which interact with the metals to shift the pH above 7. This makes the water body more alkaline.

pH status of natural water systems offers an important insight into the level of water pollution, photosynthetic activities by aquatic plants and respiration activities by algae and other micro-organisms.

Continuous pH monitoring in water bodies is necessary for checking the health of aquatic organisms, water quality for domestic uses and drinking purposes, for checking the suitability for recreational purposes and for checking the level of industrial discharges into the water body.

2.5.2.1.2 Effects on Water Salinity

The salinity of drinking water is 1000 ppm or less (Schwarzenbach *et al.*, 2003). That is, freshwater may be described water with salinity of 1000 ppm, but drinking water is more palatable at a salinity 600 ppm. The concentration of salts in water is generally affected by the volume of water available. During the dry seasons, evaporation of water may result in increased salinity as water molecules are removed to concentrate the salt molecules.

Sea water with a salinity of about 35000 ppm tends to be more salty than other water bodies. Water bodies, such as ponds and lakes used in the production of salt may have concentration of salts as high as 264,000 ppm above that of sea water.

The effects of small scale mining on the salinity of water may not be direct and immediate, eventually, however, minimal influences are felt as the operations directly or indirectly result in a decrease of water volume.

Monitoring water salinity is necessary to checking the status of salt water ecosystems and the use of such water for domestic and drinking purposes, and for agricultural uses (Schwarzenbach *et al.*, 2003).

2.5.2.1.3 Effects on Turbidity and Total Suspended Solids (TSS)

Turbidity describes the clarity of the water. Cloudy waters are considered to be more turbid, whilst transparent water is considered less turbid (Pulles *et al.*, 2002). On the turbidity scale, natural water systems measure turbidity ranging from 1.0 NTU to as high as 2000 NTU. Electronic turbidity sensors measure the backscatter of infrared light to determine the turbidity of water bodies in situ; the backscatter is due to the presence of suspended particles in the water. The more particles there are in the water, the greater the level of scattering. Manually, a Secchi disc and a calibrated line may be used to measure turbidity of water.

Total suspended solids (TSS) are suspended materials on the surface and within the water which contribute to its cloudiness or the light scattering ability of the water. Suspended solids are composed of very fine and smooth materials such as clay, silts, aggregate of organic and inorganic substances, microorganisms and planktons. The size of a TSS may range between. 10 µm to -0.1 mm (BGL, 2001).

In laboratory exercises, TSS is more accurately described as materials which cannot be filtered through a 45µm strainer or filter.

Figure 2.1: Effects of small scale mining activities on the turbidity of the Ankobra River.

The turbidity and total suspended solids of natural water systems are immensely affected by small scale mining activities. The operations deal with the washing of soil and waste chemicals into the water. As a result of this, water bodies affected by these mining activities are mostly very turbid, and could hardly meet standardized monitoring (Kuma and Young, 2004). Nonetheless, most mining workers as well as the natives in the regions of operation often depend heavily on these same water bodies for both domestic and agricultural purposes, and indeed in some instances, for drinking purposes (Akabzaa, 2000).

Persistent monitoring is necessary to ensure that environmental standards are met.

2.5.2.1.4 Effects on Total dissolved Solids (TDS) of Water bodies

The amount of total dissolved solids in water bodies generally differs greatly as a result of different soil or mineral composition within the region where the water flows. Principal components of total dissolved solids are inorganic salts such as calcium, magnesium, potassium, sodium, chlorides, sulphates and bicarbonates. Occasionally, the components may include very minute levels of dissolved organic matter.

Whilst reliable sources may not be available for guidance on TDS for drinking purposes and subsequent health effects, it is of the view that high levels of TDS in waters used for human consumption may be detrimental and unacceptable (Schwarzenbach *et al.*, 2003).

2.5.2.1.5 Effects on Electrical Conductivity

This is the measure of the water's ability to conduct electricity, mostly as a result of dissolved salts such as potassium and sodium chlorides. Electrical conductivity of freshwater systems is between 0.001 S/m - 0.1 S/m (Siemens per meter). There is a direct correlation between EC and TDS, and this is expressed mathematically as TDS (mg/L) $\approx$ EC (mS/cm) X 640. In some instances the two are used interchangeably. In fact, field measurement of EC is an indication of total dissolved solids (TDS) and/or salinity in natural water systems. At an EC of 0.3S/m, aquatic organisms and certain terrestrial plants may be critically affected by the salinity of the aquatic medium (Schwarzenbach *et al.*, 2003).

Inorganic ions influencing salinity include calcium, sodium, potassium and magnesium cations, and anions such as sulphate and carbonate anions. These positive and negative ions are held firmly together by chemical bonds. As molecules, the ions arrange themselves in an orderly fashion to form a crystal lattice with a zero net charge (Kowalkowski *et al.*, 2003).

In water, dissolution causes the breakdown of this crystal lattice, and the molecules are separated into their respective positive and negative ions. These separated ions move haphazardly in the solution, and are responsible for the conduction of electric current in aqueous solutions.

2.5.2.1.6 Effects on Dissolved Oxygen (DO) of Water bodies

The concentration of dissolved oxygen in water bodies is generally as a result of biological interactions, mainly photosynthetic activities. Heightened aquatic plant photosynthetic activities during the day increase the level of dissolved oxygen in water. The reverse occurs at night, when photosynthesis reduces due to reduction or total absence of light concentration.

Dissolved oxygen of unpolluted water is about $10 mgL^{-1}$, at a temperature range of 0^0C to 25^0C.

Eutrophication also has immense influence on dissolved oxygen in water (Fei-Baffoe, 2010). Both treated and untreated organic wastes contain huge proportions of inorganic plant nutrients, mainly phosphorous and nitrogen. When available in water bodies, these nutrients cause excessive growth of benthic aquatic plants such as musk grass and arrowheads, and phytoplankton such as diatoms and *Cyanobacteria*. When these organisms die, microbial activities initiate decomposition and consume a lot of oxygen. Eventually, dissolved oxygen concentration in the water decreases drastically. Other pollutants released into water bodies include chemicals in petroleum wastes, fertilizers and faeces, and these are directly fed on by microbes (Pulles *et al.*, 2002).

These microbial processes affect dissolved oxygen by reducing its concentration, as greater percentage of the dissolved oxygen is used for the microbial processes. Aquatic plants and animals are adversely affected, since dissolved oxygen is essential for all forms of life and a healthy ecosystem (Fei-Baffoe, 2010).

In small scale mining operations, the water is massively polluted by waste materials directly discharged into water bodies (Kuma and Young, 2004). The decomposition of these substances at the expense of oxygen dissolved in the water results in massive reduction of the concentration of dissolved oxygen.

2.5.2.2 EFFECTS OF SMALL SCALE MINING ACTIVITIES ON BIOLOGICAL PARAMETERS OF WATERBODIES

The description of biological factors of a particular water body is based on a combination of both qualitative and quantitative assessments of the system (Akabzaa, 2000).

Aquatic plant and animal growth is intensely influenced by the production of organic materials, and this is less in rivers and streams relative to lakes and ponds.

Monitoring based on biological parameters may broadly be categorized into two forms; the response of the biological species to changes in its surroundings and the sensitivity of the biological community to environmental changes.

Biological assessment of water bodies takes relatively a longer period, since it integrates together other quality parameters, both physico-chemical and hydrological.

Small scale mining activities have enormous effects on the biological factors of water bodies, especially rivers due to the disturbances and instabilities created in the water ecosystem.

2.5.2.2.1 Effects on Soil and Agricultural Activities

It has been observed that the removal of soil from river banks and lands closer to rivers for small scale mining activities has often resulted in the washing away of the soil, eventually resulting in decrease in water depth and volume. This process, called erosion, affects negatively the fertility of otherwise very fertile soil lands of swampy vegetation (Warrick, 2003), thereby affecting agricultural production of the area.

2.5.2.2.2 Effects on Flora

Aquatic plants play very important role in the food chain of aquatic animals. Most of these plants in the water serve as a source of food for some aquatic organisms. Some aquatic flora also provide shelter for some of these aquatic organisms. Their absence results in the disruption of the energy flow and provision of shelter to these aquatic organisms.

Again, the continuous removal of vegetation covers along the banks of rivers at all regions where small scale mining activities are practiced has adverse effects on both the soil and the animals in these swampy areas. As a result, there is loss of vegetation at all times, and such huge important plant species as mahogany, *odum*, *sapele* and raffia plants may be destroyed. These plants which previously beautified and provided shade at the banks of the river are no longer realized in most regions which have had continuous human contacts as a result of these mining activities.

Changes in such water quality parameters as pH, salinity, turbidity, dissolved oxygen and increase in concentration of heavy metals have adverse effects on some sensitive aquatic plants.

2.5.2.2.3 Effects on Fauna

Animal life, both aquatic and terrestrial, is negatively affected by small scale mining activities. Aquatic animals are affected as their food chain is altered due to interference in aquatic plant systems. In most instances, aquatic animal populations are drastically reduced, and in certain developments, the species may be totally extinct from the river.

Another serious effect of small scale mining activities on aquatic animal life is the use of chemicals for mining (Akabzaa, 2000). Chemicals such as mercury, arsenic and cyanide used in mining activities are very toxic, and sometimes destroy huge aquatic populations when overused.

Also, change in pH, salinity, turbidity, dissolved oxygen and concentrations of heavy metals disturb aquatic animals as these find it difficult to accommodate the new changes.

Terrestrial animals occupying swampy forests (forestlands at the banks of rivers and streams) are either killed or move to other locations to find new shelters. Such groups of animals as reptiles, birds and mammals such as monkeys which were previously seen on top of tress or under trees closer to river banks are no longer observed.

2.5.2.3 EFFECTS OF SMALL SCALE MINING ON THE HYDROLOGICAL FEATURES OF WATERBODIES

The hydrological cycle connects all water bodies on the earth. It is the cycle responsible for circulation of water on the globe. It combines atmospheric, oceanic and surface and ground waters to constantly make available water for biotic consumptions (Kowalkowski *et al.*, 2006).

The three types of water bodies are groundwater, lakes and rivers, and these classifications are based on certain defined parameters such as rate of flow, mixing ability and turbulence (*US Geological Survey*, 1986).

Studies by the United States Geological Survey revealed that groundwater usually has a steady movement with the water flowing through porous aquifers within the earth (*US Geological Survey*, 1986). The flow rate ranges from 1.0m/s to about 10m/s. There is poor mixing due to less turbulence, and the porous ability is guided by the geological constituent of the region of flow.

Lakes have average rate of flow between 0.001-0.01m/s with their currents being multi-directional. There is occasional stratification and vertical mixing, but these are mainly determined by the depth of the lake as well as the climatic conditions of the region where the lake is located.

Rivers move in only one direction (that's, movement is unidirectional) and have average flow rate ranging between 0.1 to 1.0m/s, though there is a wide variation in flow rate of different water bodies, and this depends largely on climatic factors and drainage patterns. There is vertical mixing of the water due to persistent currents and turbulence, and lateral mixing occasionally occurs downstream at major confluences.

Water quality assessments are incomplete without a thorough understanding of the hydrological parameters of the water body (Kowalkowski *et al.*, 2006).

Small scale mining activities have huge influences on these parameters mainly due to the interference with the water course, water depth and water current.

2.5.2.3.1 Effects on Water Course

- Small scale mining activities massively affect water courses. Most of the washed sand is not taken out of the river course. As a result these huge 'loads' of sand block the path of water movement. The water, moving under high pressure, takes a different course, thereby changing its original course.

In some instances, miners divert the water from its original course. This is done so as to control the amount of water needed for the washing process, or to allow the miners take loads of soil from the original course (Mensah, 1997).

2.5.2.3.2 Effects on Water Depth and Water Current

Water depth is largely affected by small scale mining activities as a result of the heaps of soil either removed from the river or left in the river (Mensah, 1997). In areas where soil is removed from the water belt, there is an increase in the depth of the river since the removed soil is mostly not refilled. This also reduces the rate of flow/water current as the area the water occupies expands.

When the soil heap is left in the water, the washed heaps reduce the depth of the water whilst it, at the same time, increases the water current. Two situations occur: In one instance, the soil is removed from one part of the river belt and washed at another part of the river. This results in an increase in the depth of the water where the soil is removed, but reduction in the depth of the water where the soil is washed and the heap is left. In another instance, the soil is washed at the region where it is removed. Both the current and water course are affected in this instance.

2.6 REGULATIONS ON MINING ACTIVITIES IN GHANA

Mining activities in Ghana are regulated by a number of legal frameworks (Noetstaller, 1994). That mining activities are not properly monitored cannot be attributed to the lack of regulations on mining processes. Rather, this can be attributed to the fact that there are weaknesses in existing laws, and also the lack of commitment on the part of environmental agencies to enforce these laws. Environmental agencies may sometimes also lack the necessary equipment for monitoring. This makes monitoring very difficult, and the agency becomes limited in its mandates (Iddrissu and Tsikata, 1998).

Some important mining regulations enshrined in the constitution of Ghana are reviewed here.

2.6.1 MINERAL AND MINING LAW 1986 (PNDCL 153)

Section I

"***All minerals are the property of the Republic of Ghana, and the Government has power to acquire compulsorily any land which may be required to secure the development or utilization of any mineral resources***".

This law makes the Government of Ghana the legal owner of minerals taken from the Ghanaian soil, and all lands suitable for mining processes.

Section 14 subsection 2 (PNDCL 153, 1986)

"***The Secretary (now the Minister) for Lands and Natural Resources shall, on behalf of the Republic, have power to negotiate, grant, revoke, suspend or renew any mineral right under this law".***

This makes it possible for the Minister of Lands and Natural Resources, on behalf of the Government of Ghana, to enact by-laws, and prevent any such move or mining activity deemed detrimental to the environment, and ultimately citizens of the nation.

PNDC Law 153 also makes it possible for mining organisations to have inspectors and monitors who sample materials and systems such as soil, tailings and water bodies in and around the site of work, so as to ensure that environmental standards are met.

2.6.2 THE MINERAL COMMISSION LAW 1986 (PNDCL 154)

The law was enacted to establish the Minerals Commission. The Minerals Commission is responsible for the formulation of policies regarding mineral exploration and its mining on Ghanaian soils. The Commission therefore has contractual obligation with proponents in the country.

Individuals holding the chairmanship, as well as the Chief Executive Officer of this Commission are appointed by the Government.

2.6.3 SMALL SCALE GOLD MINING LAW 1989 (PNDCL 218)

Section I

"No person shall engage in or undertake any small scale mining operations unless there is existence, in respect of such operation, a license and granted by the Secretary (now the Minister) for Lands and Natural Resources or by an officer auditioned in that behalf".

It is evidently clear from this law that small scale mining operations without permits are not allowed to operate. The story, however, differs from current observation, as almost all small scale mining activities across the nation either operate illegally or have not adequately followed due processes to acquire permit.

This law does not make it possible for non-Ghanaians to have license to operate, as stated in Section 2 of this regulation, except that such Ghanaians are 18 years and above. Nonetheless they may participate in such operations where Ghanaian citizens are the majority stakeholders, as directed by the firm's code.

Section 13 of the law forbids using explosives in small scale gold mining operations. It states,

"No small scale gold miner shall use any explosive in his operations…"

Unfortunately, lack of adequate supervision and monitoring has resulted in this aspect of the law being highly compromised.

The purchase and use of mercury is however permitted, as specified in section 14 of this law.

2.7 LEGAL FRAMEWORK FOR SMALL SCALE MINING ACTIVITIES IN GHANA

An important move was made by the PNDC Government in 1989 to officially allow the mining of important minerals such as gold. This legalization of small scale mining activity was an important landmark over previous regulations, which only permitted the small scale mining of diamonds. Three important mining laws were passed as follows:

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

2.8 PROCESSESS OF APPLICATION FOR SMALL SCALE MINING PERMIT/LICENSE

Firstly, a notification is given to the Officer responsible for small scale mining in the district. The Officer then follows up to the region to assess how suitable it would be for the activity before demarcating the site.

The prospective miner prepares a site plan, and a notice of the intention is published at the Assembly, the local information centre and the magistrate's court for 21 days.

After the 21 days, and if no contrary opinions are expressed, the applicant completes an application form to fulfil other requirements of the Mineral Commission. Recommendations are submitted to the Secretary or Minister for Mines and Energy who then approves or rejects the application.

A successful applicant is handed a code of environmental safety practices, and these include safety precautions at work places (protection at work places), land surface protection and general environmental protection guidelines.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 STUDY AREA

The study was carried out in four rural communities in the Amenfi East District of the Western Region. These villages were Adansi, Konkorso, Dikoto and Nsuaem. Adans is 7 km, Konkorso, 9 km, Dikoto, 10 km, and Nsuaem, about 15 km away from Wassa Akropong, the capital of the Amenfi East District. The Amenfi East District comprises many rural and satellite communities. The district capital, Wassa Akropong, serves as the main commercial centre for these rural communities. The inhabitants are mainly crop farmers. Crops cultivated include cocoa (the main cash crop produced), cassava, plantain, yam and cocoyam. Other nearby towns of commercial importance are Bawdie, Bogoso and Tarkwa in the Western Region and Dunkwa -on- Offin in the Central Region.

The Ankobra River has its source at Anhwiaso, a town near Sefwi Bekwai in the Western Region. It then passes in or near towns such as Sefwi Wiawso in the Sefwi area. The river then continues its course in and around some towns and villages such as Ankwaoso, Beposo and Prestea, all in the Wassa area, before it finally drains into the Atlantic Ocean in the Nzema area, all in the Western Region.

There were six sampling points in all, located in four different communities of the Amenfi East District (Figure 3.1). The four communities are Adansi, Konkorso, Dikoto Junction and Nswaem, all in the Amenfi East District. The sampling points were labeled as

1. Adansi North Sampling Point
2. Adansi South Sampling Point
3. Konkorso North Sampling Point
4. Konkorso South Sampling Point.
5. Dikoto Sampling Point.
6. Nsuaem Sampling Point.

Figure 3.1: A map showing the Ankobra River (in blue) and the sampling points (in red dots).

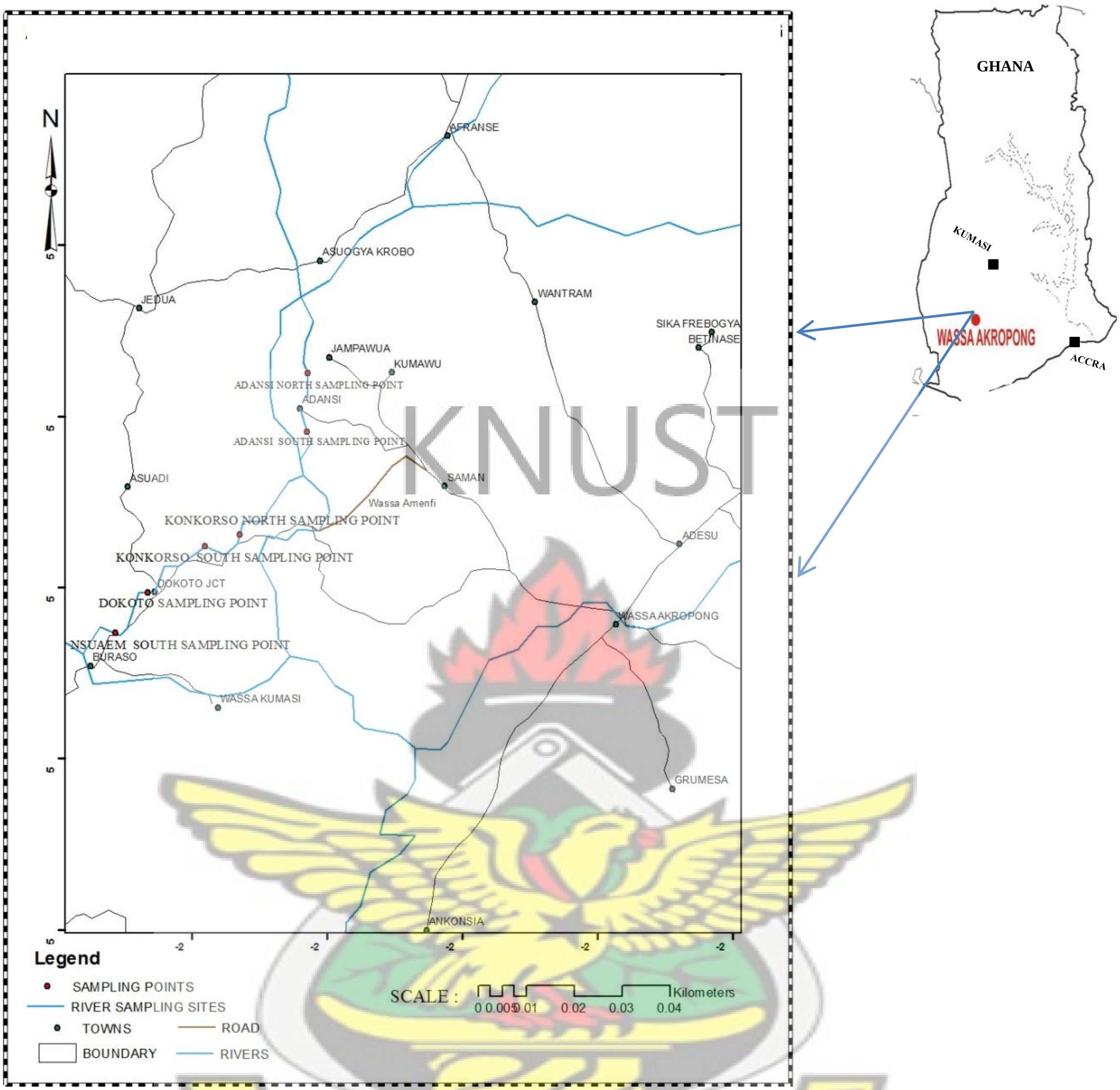

Figure 3.1: A map of the Ankobra River Showing the study area.

These sampling points were listed in the order from the upstream (the source) to the downstream of the river.

The Adansi North sampling point was located in the midst of a deep valley very close to the Adansi village. A newly constructed bridge was recently built across the river at this sampling point. The river was located about 50m below the bridge. One side of the bank was very sloppy, and one could only descend into the river from this section by carefully moving on step-like path created on this side. The bank of the river on the other side was very steep;

there was no passage way on this side of the bank that led into the river below the bridge. The water depth was very deep, and the rate of flow was generally slow, although this pattern changed during the rainy season. A lot of vegetation was found around the river banks; nonetheless, sunlight falls directly on the river bed during the day time. There were no human activities at this sampling point due to the dangerous nature of the river in this region.

The Adansi South sampling point was located downstream the Adansi North sampling point. The depth of the river in this region was relatively shallow. A lot of bamboo vegetation was found in and around the river. The bamboo vegetation stretched to cover the river belt, thereby providing shade and a very serene environment around this sampling point. The rate of flow at this point was relatively low, but was largely influenced by the season in which the sampling was done. There were minimal levels of human influences such as sand winning at this point.

The Konkorso North sampling point was located some five kilometres away from the Adansi South. The vegetation cover at this point was completely cleared as the region was highly affected by human-related activities, mainly gold mining and sand winning. The depth of the water was irregular in this region. The rate of flow was mainly determined by the season; generally it was low at the dry and mid seasons but moderately swift in the rainy seasons. The rate of flow was also lowered by the heaps of soil left in the middle of the river by illegal miners, and this also diverted the water course.

The Konkorso South sampling point was located about two kilometres away from the Konkorso North sampling point. This region also had most of its vegetation cover cleared. There were a lot of mining activities at this sampling point. The river course was diverted and massively reduced, and this made the rate of flow very swift and turbulent in this region.

The Dikoto sampling point was chosen under the Dikoto bridge, which was less than two kilometres away from the Konkorso South Sampling point, and further downstream. The banks of the river were mainly covered with a lot of grassy vegetation interspersed with few bamboo plants. The grass vegetation had developed as a result of massive small scale mining activities in this region which resulted in the clearing of the original vegetation cover. The water was relatively deeper in this region, and flowed lowly in the dry season but swiftly in the rainy season.

The Nsuaem sampling point was the last and furthest sampling point. The river banks had a lot of vegetation cover, and this stretched to cover the river belt, thereby given this sampling point a very shady region. Although there were no mining activities in this region, operations further upstream affected massively such parameters as the turbulence, rate of flow and turbidity of water in this region. Nonetheless, this sampling point served as the main source of drinking water for the community. The water depth was also found to be relatively deeper as canoes rifts were used to cross the river from one side to the other.

3.2 TIME OF STUDY

The studies spanned over a period of nine months, between November, 2010 to July, 2011. The choice was made to suit three different seasons at which small scale mining activities were moderate, immense or minimal, and at periods with different water depths and currents. These were the mid-season (November, December, and January), dry season (February, March, April) and the wet season (May, June, July)

3.3 SAMPLING

Sampling involves many factors and processes such as choosing the sampling points, labelling, treatment of bottles, technique for sampling and sample preservation.

3.3.1 SAMPLING POINTS AND LABELLING

Studies were done at six different sampling locations along the Ankobra River; these were Adansi North and South, Konkoso North and South, Dikoto Junction and Nsuaem, as shown in Figure 3.1.

The first three sampling points constituted the upstream of the Ankobra River, and the last three points, the downstream. These samples were appropriately labelled with the name of the community where they were picked, and in some cases, the geographical position (either north or south region) of the community where they were picked.

3.3.2 TREATMENT OF SAMPLING BOTTLES

Eighteen (18) clean white plastic bottles of volume 1000 mL (1.0L) each were used in sampling, one at each sampling site over the three different seasons. In each sampling season, the bottles were soaked in 3% nitric acid (3% NHO_3) for twenty four hours. These were then rinsed three times with de-ionised water, dried and stopped. The bottles were then kept in an ice container containing pieces of ice blocks. These were then carried to the sampling sites.

3.3.3 TECHNIQUES FOR WATER SAMPLING

During the sampling processes, each bottle was rinsed three times with the same sample to be fetched. A sample was then picked in such a way as to avoid bubbles of air from entering the bottle. This was then tightly closed and quickly transferred into an ice container with pieces of ice block.

pH measurement was done in situ. This was to prevent variation in original pH value of the sample as changes in temperature could have effected a change in sample acidity or alkalinity during the transfer process (Akoto, 2009).

3.3.4 SAMPLE PRESERVATION

At the chemical laboratory, such parameters as turbidity, salinity and electrical conductivity were determined immediately after arrival.

To preserve the samples for the heavy metal analyses, high purity, but very minute calculated amounts of hydrochloric acid (HCl) were added to each sample based on the specific volume of the test sample needed for a heavy metal analyses. A chain of custody (or sample) records was kept for each sample. These samples were kept in a refrigerator for analyses in due time.

3.4 SAMPLE TREATMENT FOR HEAVY METAL ANALYSES

The heavy metals analysed were copper (Cu), lead (Pb), cadmium (Cd), arsenic (As) and mercury (Hg). The digestion technique was used, and the analytical instrument used was the Spectra AA - 110/220/880 Varian. The samples were filtered through 0.5mµ membrane filters and 1.0mL concentrated hydrochloric acid was added to each 1000mL filtrate; 1.0g of potassium iodide was then weighed and added each 1000mL. The contents were well mixed. The treated samples were then allowed to stand for about one hour and then analysed.

The flame atomic absorption spectra device was used. The sample was aspirated and mixed as an aerosol with combustible gases (acetylene mixed with air). The mixture was then ignited in a flame through which radiation of the selected wavelength was set. During this combustion processes, atoms of the specific heavy metal in the sample were reduced to the atomic state. A light beam from a lamp whose cathode was made of the element being analysed was passed through the flame into a monochronometer and detector. The free unexcited ground state atoms of the element then absorbed light at characteristic wavelengths. The reduction of the light energy at the analytical wavelength was a measure of the amount of the element sample. The results were then amplified and transmitted to a signal processor.

During the detection process, the background correction was achieved by fixing a deuterium lamp.

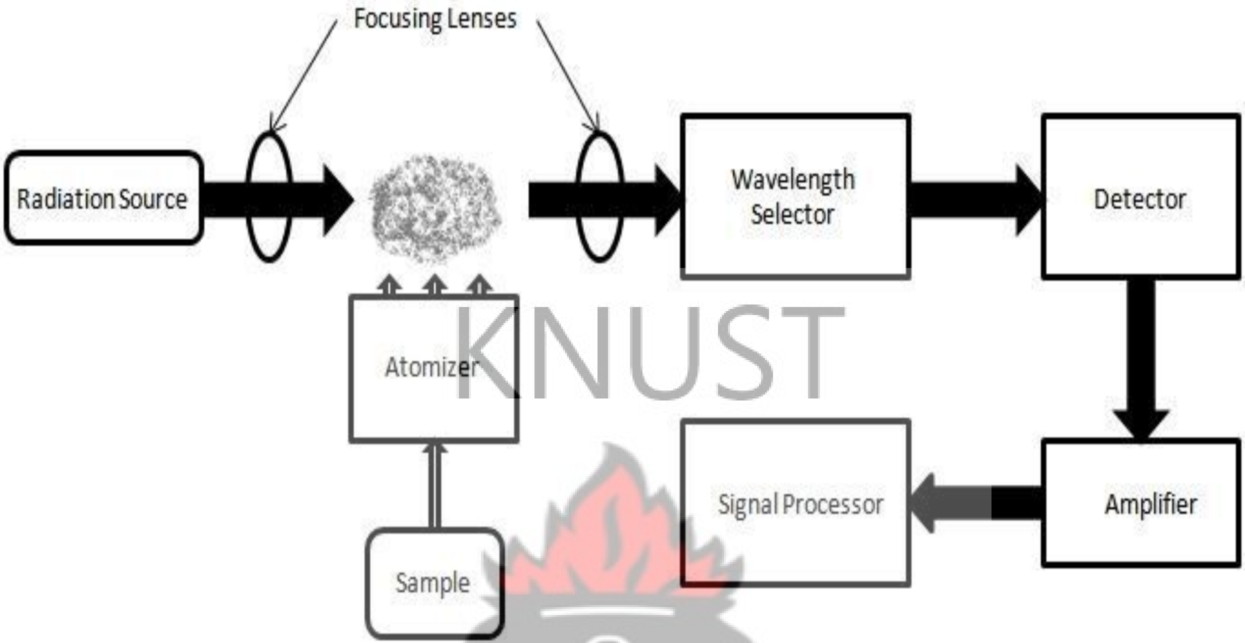

Figure 3.2: Flow chart for Spectra AA – 110/220/880 Varian methodologies (Source: BGL, 2001).

3.5 CALIBRATION OF SPECTRA AA – 110/220/880 VARIAN FOR HEAVY METAL ANALYSES

The lamp for the heavy metals to be analysed was fixed into the instrument, and the device was switched on. The specific wavelength for each metal was rotated and displayed. After this setting, readings for the blanks were taken digitally on-screen. Table 3.1 gives the instrumental parameters for cadmium and arsenic.

Table 3.1: Instrumental Parameters for Spectra AA - 110/220/880 Varian for cadmium and arsenic (Source: BGL Lab Manual, 2001)

Element	Lamp current (Am)	Wavelength (nm)	Spectral bandwidth	Background correction	Flame condition
Cadmium	8	228.8	0.5	On	Airflow-13.50 Air/acetyl-2.0
Arsenic	10	193.7	0.5	Off	Airflow-13.5 Air/acetyl-12.0

3.6 DETERMINATION OF WATER COURSE, CURRENT AND DEPTH

The current (velocity) of the water was determined by allowing a cork to float between the distance of two points. The time taken for the object to move from one point to the other was recorded, and the measured distance in meters was divided by the recorded time in seconds for each of the sampling points over the three seasons. An average of this was determined, and this gave the mean current in meters per second (m/s) of the river at that sampling point.

The depths were determined by immersing a thin iron bar into the river such that it touched the bed. The level was noted and recorded with a tape measure in situ. This was done for all the seasons at all the six sampling points, and their averages were recorded.

3.7 CHANGE IN VEGETATION

The changes in vegetation around the Ankobra River were determined by visual observation of the mangrove vegetation around the river. Brief but concise descriptions were given as observed at the sampling regions.

CHAPTER FOUR

4.0 RESULTS

4.1 pH, TURBIDITY, ELECTRICAL CONDUCTIVITY, SALINITY, DISSOLVED OXYGEN (DO) AND TOTAL DISSOLVED SOLIDS (TDS)

Results for these parameters were recorded in the tables below.

Table 4.1 Results for water quality parameters at the upstream of the Ankobra River during the mid-season.

Sampling point	pH	Turbidity (NTU)	Electrical conductivity (µS/cm)	Salinity (ppm)	Dissolved oxygen (mg/L)	Total dissolved solids (mg/L)
Adansi North	6.65	175	127	510	4.54	405
Adansi South	6.62	210	121	525	6.29	412
Konkorso North	6.65	532	125	557	5.22	480
Mean value	**6.64**	**305.67**	**124.33**	**530.67**	**5.35**	**432.33**
EPA standard	**6 - 9**	**75**	**1500**	**600**	**5***	**500**

**EPA standard value of 5mg/L for dissolved oxygen was adopted from chart a chart drawn by the World Health Organisation (WHO, 1997*).

During the mid-season, all the averages recorded for the parameters at the upstream were below or within the EPA standards, the only exception being turbidity with its mean of 305.6 NTU, as compared to the EPA standard value of 75 NTU.

Table 4.2: Results for water quality parameters at the downstream of the Ankobra River during the mid-season.

Sampling point	pH	Turbidity (NTU)	Electrical conductivity (µS/cm)	Salinity (ppm)	Dissolved oxygen (mg/L)	Total dissolved solids (mg/L)
Konkorso South	6.67	456	120	506	5.36	458
Dikoto Junction	6.68	396	126	543	4.86	462
Nsuaem	6.68	126	120	509	4.64	418
Mean value	**6.68**	**326**	**122**	**519.33**	**4.95**	**446**
EPA standard	**6 - 9**	**75**	**1500**	**600**	**5***	**500**

**EPA standard value of 5mg/L for dissolved oxygen was adopted from chart drawn by the World Health Organisation (WHO, 1997).*

At the downstream of the mid-season, mean turbidity of 326 NTU also exceeded the standard turbidity of 75 NTU accepted by the EPA. The other parameters; pH, electrical conductivity, salinity, dissolved oxygen and total dissolved solids had averages which were below or within the accepted EPA standards.

Table 4.3: Results for water quality parameters at the upstream of the Ankobra River during the dry season.

Sampling point	pH	Turbidity (NTU)	Electrical conductivity (µS/cm)	Salinity (ppm)	Dissolved oxygen (mg/L)	Total dissolved solids (mg/L)
Adansi North	6.32	212	130	552	5.45	420
Adansi South	6.57	165	134	584	6.20	433
Konkorso North	6.32	694	133	621	4.35	527
Mean value	**6.40**	**357**	**132.33**	**585.70**	**5.33**	**460**
EPA standard	**6 - 9**	**75**	**1500**	**600**	**5***	**500**

**EPA standard value of 5mg/L for dissolved oxygen was adopted from a chart drawn by the World Health Organisation (WHO, 1997).*

At the upstream of the dry season, two parameters exceeded the EPA standard values. These were turbidity with a mean value of 357 NTU as against EPA's standard of 75 NTU, and dissolved oxygen of mean 5.33 mg/L as against the EPA standard of 5 mg/L. The other four parameters; pH, electrical conductivity, salinity and total dissolved solids were below or within the standards.

Table 4.4: Results for water quality parameters at the downstream of the Ankobra River during the dry season

Sampling point	pH	Turbidity (NTU)	Electrical conductivity (µS/cm)	Salinity (ppm)	Dissolved oxygen (mg/L)	Total dissolved solids (mg/L)
Konkorso South	6.50	577	129	549	6.36	515
Dikoto Junction	6.35	490	132	688	4.16	502
Nsuaem	6.75	167	126	526	4.64	392
Mean value	**6.53**	**411.33**	**129**	**587.70**	**5.05**	**469.70**
EPA standard	**6 - 9**	**75**	**1500**	**600**	**5***	**500**

**EPA standard value of 5mg/L for dissolved oxygen was adopted from a chart drawn by the World Health Organisation (WHO, 1997).*

At the downstream of the river during the dry season, the highest mean turbidity of 411.33 NTU was recorded. Also the dissolved oxygen of 5.05 mg/L was recorded. Both parameters were higher than the EPA accepted standard. The mean salinity also came to its closest of 587.70 mg/L as against the EPA standard of 600mg/L. The other parameters were within accepted limits.

Table 4.5: Results for water quality parameters at the upstream of the Ankobra River during the rainy season.

Sampling point	**pH**	**Turbidity (NTU)**	**Electrical conductivity (µS/cm)**	**Salinity (ppm)**	**Dissolved oxygen (mg/L)**	**Total dissolved solids (mg/L)**
Adansi North	6.87	143	171	458	6.50	388
Adansi South	6.88	190	167	493	6.89	395
Konkorso North	6.79	350	182	511	6.32	480
Mean value	**6.85**	**227.67**	**173.33**	**487.33**	**6.57**	**421**
EPA standard	6 - 9	75	1500	600	5*	500

**EPA standard value of 5mg/L for dissolved oxygen was adopted from a chart drawn by the World Health Organisation (WHO, 1997).*

At the upstream river during the rainy season, the mean turbidity of 227.67 NTU was still higher than the EPA's standard of 75 NTU. Mean dissolved oxygen was 6.57 mg/L, and this was the highest mean among all three seasons recorded for this parameter. The averages for pH, electrical conductivity, salinity and total dissolved solids (TDS) were all within the EPA standards. TDS recorded its lowest value o (421 mg/L) in all the three seasons at the upstream during this season.

Table 4.6 Results for water quality parameters at the downstream of the Ankobra River during the rainy season.

Sampling point	pH	Turbidity (NTU)	Electrical conductivity (µS/cm)	Salinity (ppm)	Dissolved oxygen (mg/L)	Total dissolved solids (mg/L)
Konkorso South	6.82	327	163	474	6.68	481
Dikoto Junction	6.82	308	175	522	6.35	462
Nsuaem	6.90	120	160	489	6.64	367
Mean value	**6.85**	**251.67**	**166**	**495**	**6.56**	**436.67**
EPA standard	**6 – 9**	**75**	**1500**	**600**	**5***	**500**

**EPA standard value of 5mg/L for dissolved oxygen was adopted from a chart drawn by the World Health Organisation (WHO, 1997).*

At the downstream of the river, during the rainy season, the lowest turbidity of 251.67 NTU was recorded. Nonetheless, this was still higher than the EPA standard of 75 NTU. The highest mean for dissolved oxygen was recorded was 6.56 mg/L. The other four parameters recorded averages within EPA standard values.

4.2 THE HEAVY METAL ANALYSES

Results on the heavy metal analyses (copper, lead, cadmium, arsenic and mercury) for the upstream and downstream river over the three seasons have been given below.

Table 4.7: Results for water quality parameters (heavy metals) at the upstream of the Ankobra River during the mid-season.

Sampling point	**Concentration**	**Of Heavy**	**Metal**	**(mg/L)**	
	Copper	**Lead**	**Cadmium**	**Arsenic**	**Mercury**
Adansi North	0.013	0.29	<0.005	0.012	0.008
Adansi South	0.011	0.300	<0.005	0.012	0.006
Konkorso North	0.030	0.055	<0.005	0.020	0.010
Mean value	0.018	0.215	<0.005	0.015	0.008
EPA standard	1.00	0.1	0.1	0.01	0.005
Laboratory blank	<0.005	<0.010	<0.005	0.001	<0.005
Standard buffer reading	0.998	1.009	0.197	0.010	0.005

As observed in Table 4.7, two of the metals analysed from the upstream recorded concentrations above the EPA permissible/ standard limits during the mid-season. These metals were lead and mercury with averages of 0.215 mg/L and 0.008 mg/L respectively. The EPA standard for lead is 0.215 mg/L whilst that for mercury is 0.005 mg/L. Copper and arsenic recorded averages below the EPA standard values. Cadmium was theoretically absent as it concentration was less <0.005 mg/L.

Table 4.8: Results for water quality parameters (heavy metals) at the downstream of the Ankobra River during the mid-season.

	Concentration	**Of**	**Heavy Metal**	**(mg/L)**	
Sampling point	**Copper**	**Lead**	**Cadmium**	**Arsenic**	**Mercury**
Konkorso South	0.022	0.058	<0.005	0.017	0.011
Dikoto Junction	0.018	0.144	<0.005	0.016	0.010
Nsuaem	0.008	0.190	<0.005	0.014	0.007
Mean value	0.016	0.131	<0.005	0.016	0.009
EPA standard	1.00	0.100	0.100	0.010	0.005
Laboratory blank	<0.005	<0.010	<0.005	0.001	<0.005
Standard buffer reading	0.998	1.009	0.197	0.010	0.005

At the downstream river, the average concentrations recorded for lead and mercury were 0.131 mg/L and 0.009 mg/L respectively. Both two concentrations were above the EPA permissible limits. Arsenic with its concentration of 0.016 mg/L also exceeded the EPA's arsenic standard of 0.010 mg/L. Copper concentration was below standard. Cadmium was absent also at the downstream.

Table 4.9: Results for water quality parameters (heavy metals) at the upstream of the Ankobra River during the dry season.

Sampling point	Concentration	Of	Heavy Metal	(mg/L)	
	Copper	**Lead**	**Cadmium**	**arsenic**	**Mercury**
Adansi North	0.092	0.351	<0.005	0.019	0.008
Adansi South	0.090	0.350	<0.005	0.018	0.009
Konkorso North	0.134	0.420	0.011	0.033	0.015
Mean value	0.105	0.374	<0.005	0.023	0.011
EPA standard	1.00	0.10	0.10	0.01	0.005
Laboratory blank	<0.005	<0.010	<0.005	0.001	<0.005
Standard buffer reading	0.998	1.009	0.197	0.010	0.005

At the upstream, during the dry season, the average concentrations of both lead and mercury increased considerably to 0.374 mg/L and 0.011 mg/L respectively, both two values which exceeded the EPA standards. Arsenic with an average of 0.023 mg/L also exceeded the EPA standard of 0.01 mg/L. Copper concentration also exceeded the EPA's 1.00 mg/L with a difference of 0.005 mg/L. Significantly, a cadmium concentration of 0.011 mg/L was recorded during this season, although this value is far below the EPA standard of 0.10 mg/L for cadmium, it was the first time this heavy metal was detected, and relatively the highest for both the upstream and downstream over all the three seasons.

Table 4.10: Results for water quality parameters (heavy metals) at the downstream of the Ankobra River during the dry season.

Sampling point	**Concentration Of Heavy Metal (mg/L)**				
	Copper	**Lead**	**Cadmium**	**arsenic**	**Mercury**
Konkorso South	0.097	0.380	0.009	0.023	0.013
Dikoto Junction	0.089	0.340	0.007	0.026	0.011
Nsuaem	0.091	0.300	<0.005	0.021	0.009
Mean value	0.092	0.340	<0.005	0.023	0.011
EPA standard	1.00	0.1	0.1	0.01	0.005
Laboratory blank	<0.005	<0.010	<0.005	0.001	<0.005
Standard buffer reading	0.998	1.009	0.197	0.010	0.005

At the downstream of the river, during the dry season, lead and mercury recorded the mean concentrations of 0.340 mg/L and 0.011 mg/L respectively. The same concentration of mercury was recorded at the upstream, and this was the highest in all the seasons. Arsenic recorded a value of 0.023 mg/L, the same concentration which was recorded at the upstream. Cadmium recorded minute concentrations at two sampling regions, the Konkorso South and Dikoto Junction regions, and these were far below the EPA standard for this metal. Copper concentration was also below EPA standard, although quite closer.

Table 4.11: Results for water quality parameters (heavy metals) at the upstream of the Ankobra River during the rainy season.

Sampling point	Concentration Of Heavy Metal (mg/L)				
	Copper	Lead	Cadmium	Arsenic	Mercury
Adansi North	<0.005	0.013	<0.005	0.011	0.005
Adansi South	<0.005	0.110	<0.005	0.010	0.006
Konkorso North	0.015	0.015	<0.005	0.016	0.010
Mean value	<0.005	0.046	<0.005	0.0123	0.007
EPA standard	1.00	0.1	0.1	0.01	0.005
Laboratory blank	<0.005	<0.010	<0.005	0.001	<0.005
Standard buffer reading	0.998	1.009	0.197	0.010	0.005

In Table 4.11, at the upstream during the rainy season, the mean concentration of lead reduced considerably to 0.046 mg/L, a value which was well below the EPA standard value of 0.1 mg/L in drinking water. Mercury level also reduced to 0.007 mg/L, but this still exceeded the EPA's standard of 0.005 mg/L for this metal. Mean arsenic concentration reduced significantly to 0.0123 mg/L, yet this exceeded the EPA standard for arsenic. Copper was almost absent while cadmium was not determined altogether.

Table 4.12: Results for water quality parameters (heavy metals) at the downstream of the Ankobra River during the rainy season.

Sampling point	Concentration	Of Heavy	Metal	(mg/L)	
	Copper	**Lead**	**Cadmium**	**Arsenic**	**Mercury**
Konkorso South	<0.005	0.054	<0.005	0.014	0.009
Dikoto Junction	<0.005	0.019	<0.005	0.016	0.007
Nsuaem	<0.005	0.016	<0.005	0.008	0.008
Mean value	<0.005	0.029	<0.005	0.013	0.008
EPA standard	1.00	0.1	0.1	0.010	0.005
Laboratory blank	<0.005	<0.010	<0.005	0.001	<0.005
Standard buffer reading	0.998	1.009	0.197	0.010	0.005

At the downstream, during the rainy season, average lead concentration reduced further to 0.029 mg/L below the standard value. Mean mercury level increased slightly to 0.008 mg/L, which still exceeded the permissible limit. Mean arsenic also increased slightly at the downstream to 0.013 mg/L, which was also above the EPA standard of arsenic in drinking water. Copper and cadmium were not realized at the downstream during this season.

4.3 RESULTS FOR WATER CURRENT AND DEPTH

Table 4.13: Mean currents of the Ankobra River during the mid, dry and rainy seasons.

Season	Adansi North	Adansi South	Konkorso North	Konkorso South	Dikoto Junction	Nsuaem
Current at mid-season (m/s)	0.143	0.140	0.100	0.330	0.083	0.166
Current at dry season (m/s)	0.100	0.083	0.071	0.201	0.064	0.097
Current at rainy season (m/s)	0.200	0.200	0.167	0.500	0.200	0.230
Mean	**0.148**	**0.141**	**0.113**	**0.344**	**0.116**	**0.164**

Table 4.14: Mean depths of the Ankobra River during the mid, dry and rainy seasons.

Season	Adansi North	Adansi South	Konkorso North	Konkorso South	Dikoto Junction	Nsuaem
Depth (m) in mid-season	2.300	1.300	1.100	0.500	1.500	1.800
Depth (m) at the dry season	2.100	1.250	0.800	0.300	1.200	1.500
Depth (m) at the rainy season	3.300	3.000	2.010	2.00	2.600	2.300
Mean depth (m)	**2.567**	**1.850**	**1.303**	**0.933**	**1.767**	**1.867**

CHAPTER FIVE

5.0 DISCUSSION

5.1 pH, TURBIDITY, ELECTRICAL CONDUCTIVITY, SALINITY, DISSOLVED OXYGEN AND TOTAL DISSOLVED SOLIDS

These were discussed based on the level of effects of the mining activity in a particular sampling area. Their seasonal averages at the upstream and downstream were then considered based on the level of small scale mining effect on the specified parameter.

5.1.1 pH AT THE UPSTREAM AND DOWNSTREAM OF THE RIVER

With respect to the sampling areas, the highest pH was recorded at the Adansi South sampling region during the rainy season, whilst the lowest was recorded at both Adansi North and Konkorso North during the dry season. Results for the mid-season fell between the highest and lowest pH values recorded.

At the downstream, the highest pH of 6.90 was recorded at Nsuaem during the rainy season. The lowest pH of 6.35 at the downstream was recorded at Dikoto Junction (see graphs at appendix)

In all, the highest average pH (6.85) was recorded at both the upstream and downstream regions of the river during the rainy season. The lowest average pH of 6.40 was recorded at the upstream region during the dry season.

During the rainy seasons, volume of water bodies increase. This results in dilution of water bodies which have relatively higher acidic concentration, thereby reducing their acidity and making them neutral or alkaline. On the other hand, water bodies reduce in volume at dry seasons, thereby increasing their acidic concentration and make them more acidic.

In spite of the slight variations in the pH at the upstream and downstream in the three seasons, there is very little or no effect of small scale mining activities on the pH of the Ankobra River, since all recorded values for pH fall within the Ghana Environmental Protection Agency's (EPA's) standard pH of 6-9 for water bodies.

5.1.2 TURBIDITY AT THE UPSTREAM AND DOWNSTREAM OF THE RIVER

At the upstream the highest turbidity value of 694 NTU was recorded at Konkorso North during the dry season, while the lowest of 143 NTU was recorded at the Adansi North during the mid-season. The highest average of 532 was recorded at the dry season, and the lowest average of 227.67 NTU was recorded during the rainy season.

At the downstream, the highest turbidity value of 577 NTU was recorded at the Konkorso South during the dry season, and the lowest value of 120 NTU was recorded at Nsuaem during the rainy season.

The highest average of 411.33 NTU was recorded at the downstream during the dry season, while 227.67 NTU as the lowest average was recorded at the upstream during the rainy season.

Generally, values recorded for the mid-season were higher than those recorded for the rainy season but lower than values for the dry season for both the upstream and downstream. The downstream was more turbid than the upstream, and this may be attributed to stream flow activities in which the downstream becomes the recipient of all activities from the north or upstream. With the EPA's standard value of 75 NTU, all the values recorded for turbidity in the communities were far beyond acceptable turbid limits. The high turbidity of the Ankobra River may be attributed to the active *galamsey* activities carried out at both the upstream and downstream sections of the river – a major cause for concern.

Also, the dry season had the highest averages for both the upstream and downstream river because small scale mining activities generally increase at the dry seasons when the flow is low or the water becomes stagnant.

5.1.3 ELECTRICAL CONDUCTIVITY AT THE UPSTREAM AND DOWNSTREAM OF THE RIVER

The highest electrical conductivity recorded at the upstream was 182 µS/cm at the Konkorso North, and this was during the rainy season. The lowest value recorded was 120 µS/cm at the Konkorso South during the mid-season. The highest and lowest averages were 173.33 µ S/cm during the rainy season and 124.33 µS/cm during the mid-season respectively.

At the downstream, the highest value of 175 µS/cm was also recorded at the Dikoto Junction during the rainy season, and the lowest value of 120 µS/cm was recorded at both the Konkorso South and Dikoto Junction. The highest mean recorded at the downstream was 166 µS/cm during the rainy season, and the lowest mean of 122 µS/cm during the mid-season.

In all, the upstream had the highest average, and this was recorded during the rainy season. During the rainy season, high current flow allows the transfer of electrically charged particles to be transferred from one part of the river to the other. That the upstream recorded relatively high values than the downstream may be as a result of the presence of oppositely ions which at upstream of react and partially neutralize any other ions carried from the upstream to the downstream.

In spite of these analyses, small scale mining activities have very little or no effect on the quality of the water in the Ankobra River: The EPA's standard value for drinking waters is 1500 µS/cm, and all the discussed values are far below this standard.

5.1.4 SALINITY AT THE UPSTREAM AND DOWNSTREAM OF THE RIVER

At the upstream, the highest salinity recorded was 621 ppm at the Konkorso North during the dry season, and the lowest was 458 ppm at the Adansi North during the rainy season. The highest average at the upstream was 585.70 ppm, recorded during the dry season, while the lowest average was 487.33 ppm, recorded during the rainy season.

At the downstream, the highest salinity recorded was 688 ppm at the Dikoto Junction, and the lowest was 474 ppm at the Konkorso South. The highest and lowest averages at the upstream were 585.70 ppm during the dry season and 487.33 ppm at the rainy season.

At the downstream, the highest average of 587.70 ppm was recorded at the dry season, while 495 ppm was the lowest average recorded, and this was during the rainy season.

Hence the downstream was more salinized than the upstream, a condition which may be due to the downstream being at the receiving end of chemical activities of the river.

During the dry season, the level of water reduces as a result of increased evaporation. This causes the volume of water to reduce, thereby increasing the concentrations of dissolved salts present in the water. At the rainy seasons, the reverse is realised when rainfall increases and evaporation decreases resulting in increased in water volume. These cause the dilution of dissolved salts and consequently reduce their concentrations.

Although the overall averages recorded values lower than the EPA's standard salinity value of 600 ppm, salinity levels in the Konkorso North upstream of the Ankobra, and Dikoto Junction at the downstream of the river were higher above the allowable standard salinity for drinking water, and this calls for concern.

Thus, small scale mining operations in the Ankobra River contribute to the increased in salinity levels in some communities where the river serves as a source of drinking water.

5.1.5 DISSOLVED OXYGEN (DO) AT THE UPSTREAM AND DOWNSTREAM OF THE RIVER

At the upstream, the highest dissolved oxygen value recorded was 6.89 mg/L at the Adansi South during the rainy season, and the lowest was 4.35 mg/L at the Konkorso North.

The highest average value at the upstream was 6.57 mg/L during the rainy season, and 5.33 mg/L lowest average was recorded during the dry season.

At the downstream, the highest dissolved oxygen value recorded was 6.68 mg/L at Konkorso South during the rainy season. The lowest value recorded was 4.16 mg/L at the Dikoto Junction during the dry season.

The highest average value recorded at the downstream was 6.56 mg/L during the rainy season, and the lowest was 4.95 mg/L, recorded during the mid-season.

Averagely, dissolved oxygen concentration was found to be slightly higher at the upstream than at the downstream. This may be attributed to the fact that decay and eutrophication were more frequent at the downstream since a lot of dead plants were found in the waters here due to clearing of vegetation at the river banks. This was particularly so during the mid-season. Consequently, this resulted in quick consumption of dissolved oxygen, causing eutrophication.

EPA Ghana adopts and accepts the World Health Organisation's standard value of 5.00 mg/L for drinking water. It was observed that samples from the upstream contained enough of dissolved oxygen healthy for human consumption, the only exceptions being samples from Adansi North during the mid-season, and Konkorso North during the dry season. The reason may be attributed to the fact that vigorous small scale mining activities assisted in the dissolution of air (oxygen) in the river. These activities include removing soil from the river -

belt, washing the soil in water for the pure gold, and constant disturbances within the water as a result of these vigorous processes. The lowest over-all average of 4.95 mg/L was recorded at the downstream during the mid-season, a direct consequence of decay of dead plants found in the river during this season.

5.1.6 TOTAL DISSOLVED SOLIDS (TDS) AT THE UPSTREAM AND DOWNSTREAM OF THE RIVER

At the upstream the highest value for total dissolved solids recorded was 527 mg/L, and this was recorded at the Konkorso North sampling point during the dry season. The lowest TDS recorded was 388 mg/L at the Adansi North during the rainy season.

The highest mean recorded was 460 mg/L at the dry season, while the lowest average value of 321 mg/L was recorded at the rainy season.

At the downstream, the highest TDS was 515 mg/L at the Konkorso South during the dry season, while the lowest value of 367 mg/L was recorded at the Nsuaem sampling point during the rainy season.

The highest average recorded was 469.70 mg/L at the downstream during the dry season. The lowest average value was 432.33 mg/L recorded at the upstream during the mid-season.

Thus, TDS was found to be higher at the downstream than at the upstream, a situation that may be attributed to three reasons; that the downstream was more turbulent than the upstream, thereby contributing to dissolution processes; that the downstream contained more soluble solid substances than the upstream, hence more solids dissolved in the downstream than at the upstream; that the upstream drains into the downstream, thereby making it a recipient of stream-flow from the upstream.

The EPA's standard value for TDS in drinking water is 500 mg/L. Since some of the sampling regions recorded values that exceeded this, and since averages recorded at both the downstream and upstream were very close to the permissible standard, it is an indication that small scale mining activities has a significant effect on this parameter.

5.2 DISCUSSION ON HEAVY METAL ANALYSES

The heavy metals analysed included copper, lead, cadmium, arsenic and mercury. These were also discussed based on the season (mid, dry and rainy seasons), and as samples from the upstream and downstream regions of the river.

5.2.1 COPPER

The highest value recorded at the upstream sampling points for copper was 0.134 mg/L, and this was recorded during the dry season at the Konkorso North sampling point. An average value of 0.105 mg/L was recorded during this season. Values recorded at the mid-season were negligible. During the rainy season, most of the sampling points recorded a value of less than 0.005 mg/L (<0.005 mg/L), and this was an indication that copper was either absent or its concentration was negligible (insignificant).

At the downstream, the highest concentration recorded for copper was 0.097 mg/L, and this was recorded during the dry season at the Konkorso South sampling point. Here, values recorded during the mid-season were all insignificant in comparison with the standard EPA value of 1.00 mg/L. Values recorded at the rainy seasons in all the sampling points were less than 0.005 mg/L, indicating that copper concentrations were very insignificant during this season as the water volume increases and results in dilution. Again, both the mid and rainy seasons recorded seasonal averages which were far below permissible limits.

The EPA standard value for copper in drinking water is 1.00 mg/L. While a concentration of up to 1.00 mg/L was not recorded in any of the sampling points, and none of the seasonal averages recorded up to this concentration, it is important to note that concentrations of copper were always relatively high in the dry seasons at both the upstream and downstream sections of the river. This may be attributed to the reduction in water volume during the dry season, and also as a result of increase in small scale gold mining activities in the river during this season. There is the possibility of steady increase in the concentration of this heavy metal over a period of time which could result in concentrations higher than the EPA standard for copper in drinking water.

5.2.2 LEAD

At the upstream river, the highest concentration recorded for lead was 0.42 mg/L at the Konkorso North sampling point, and this was during the dry season. All the concentrations recorded at the upstream during the dry season exceeded the EPA standard concentration of 0.100 mg/L in drinking water. With the exception of the Konkorso North sampling point which recorded a concentration of 0.055 mg/L, all the concentrations recorded at the mid-season exceeded the EPA standard concentration for lead in drinking water. The Konkorso North sampling point also recorded the highest concentration in copper over the mid-season. The lowest concentration recorded was 0.013 mg/L, and this was at the Adansi North sampling point during the rainy season.

The highest mean value recorded for lead at the upstream was 0.374 mg/L during the dry season, while the lowest average was 0.046 mg/L recorded in the rainy season.

At the downstream, the highest concentration of lead was 0.38 mg/L, recorded at the Konkorso South sampling point during the dry season. The lowest was 0.016 mg/L, and this was recorded at the Nsuaem sampling point over during the rainy season. All values recorded during the mid and dry seasons exceeded the EPA standard concentration of 1.00 mg/L, the only exception being the Konkorso sampling point, which recorded concentrations of 0.058

mg/L during the mid-season. Concentrations recorded at the sampling points during the rainy season were all below the EPA standard value, and this may be attributed to dilution as a result of increase in water volume during this season.

The highest average concentration for lead at the downstream was 0.340 mg/L recorded during the dry season, and the lowest average was 0.029 mg/L recorded during the rainy season.

Lead concentration at the upstream was found to be a little higher than its concentration at the downstream, an indication that the upstream had greater proportion of this metal than the downstream. This may be due to vigorous small scale mining activities at the upstream, as was observed at the field. This occurrence may also be attributed partially by the fact that the geological composition the upstream basin contained relatively greater proportion of copper.

Concentrations of lead were of significant impact at both the upstream and downstream of the Ankobra River during the dry and mid seasons, since their seasonal averages exceeded the EPA standard value.

5.2.3 CADMIUM

Generally, cadmium was either absent or of negligible concentrations in both the upstream and downstream of the Ankobra River in all the three seasons. Recorded concentrations were less than 0.005 mg/L (which meant the heavy metal was absent) or a little above 0.005 mg/L. Konkorso South and Dikoto Junction at the downstream of the river recorded 0.009 mg/L and 0.007 mg/L respectively during the dry season, an indication that cadmium concentrations could be increasing steadily with time.

Generally, however, all recorded concentrations were negligible as they fell below the EPA's allowable concentration of 0.100 mg/L for cadmium in drinking water.

5.2.4 ARSENIC

The highest concentration of arsenic recorded at the upstream was 0.033 mg/L, and this was at the Konkorso North sampling point during the dry season. The lowest was 0.010 mg/L recorded at the Adansi South during the rainy season. Only the Adansi South recorded a concentration of 0.010 mg/L, which is also the EPA's standard value for arsenic in drinking water. All other sampling points, regardless of the season, recorded concentrations above 0.01 mg/L.

At the downstream, the highest concentration of 0.026 mg/L was recorded at the Dikoto Junction sampling point, and this was during the dry season. The lowest concentration recorded was 0.008 mg/L, recorded at Nsuaem during the rainy season.

Values recorded at the five other sampling points, regardless of the season were all above the EPA standard value of 0.01 mg/L.

The seasonal averages were 0.015 mg/L for the mid-season, 0.023 mg/L and 0.0123 mg/L for the dry and rainy seasons respectively. All these averages exceeded the EPA's standard limit of 0.01 mg/L.

Comparing the seasonal averages of the upstream and downstream sampling points, arsenic was found to be more concentrated at the downstream section of the river. This may partly be attributed to the fact that the downstream section of the river usually serves as the recipient of the polluted water from the upstream. That the samples from the dry seasons recorded higher concentrations may also be explained by increase in small scale activities during this season, and decreased in water volume as a result of evaporation.

5.2.5 MERCURY

Concentrations of mercury were found to be high at both the upstream and downstream of the Ankobra River.

At the upstream, only the Adansi North sampling point recorded 0.005 mg/L, the same value used as a standard in drinking waters by the EPA. Concentrations at the other two sampling points and in all the seasons exceeded this. The highest concentration was 0.015 mg/L, recorded at the Konkorso North sampling point during the dry season. The lowest was 0.005 mg/L at the Adansi North during the rainy season.

The highest seasonal average at the downstream was 0.011 mg/L recorded during the dry season. The lowest seasonal average was 0.007 mg/L recorded during the rainy season.

At the downstream, the highest concentration was 0.013 mg/L, recorded at the Konkorso South during the dry season. The lowest was 0.007 mg/L recorded at the Dikoto Junction sampling point during the rainy season. All the other values recorded at the downstream in the three seasons, including the seasonal averages of 0.009 mg/L for the mid, 0.011 mg/L for the dry and 0.008 mg/L for the rainy seasons exceeded the EPA standard of 0.005 mg/L.

Generally, the chemical was more concentrated at the downstream than was known at the upstream. Mercury is widely used during extraction processes in the small scale mining of gold. Waste water containing used mercury often drained into river bodies (in this case, the Ankobra River). This polluted water then ended up at the downstream as it was drained from the upstream. Hence the above occurrence.

Among all the five heavy metals analysed, mercury is the most toxic, and thus with very lethal effects. However least its concentration may be above the EPA standard, grievous short and long term effects may result in humans and within the environment. Nonetheless, this heavy metal was the most concentrated in the Ankobra River when assessed against EPA standards. This is an indication of how widely the chemical is used in small scale mining operations, and thus, has polluted river bodies in areas where these operations were very prevalent.

5.3 HYDROLOGICAL FEATURES

Many observations were made regarding the water course, water current and water depth of the Ankobra River. The assessment was based on general comparison with unaffected courses of the Ankobra from source, and comparison made with the six sampling points along the mining regions of the Ankobra in the Amanfi East District.

5.3.1 CHANGE IN WATER COURSE

In some regions of the Ankobra, the water course was massively influenced by heaps of sand which blocked the original path of the river. This was more prominent in the Konkoso North, Konkorso South and Dikoto Junction, where miners left huge heaps of soil in the Ankobra water belt, thereby diverting the course to another path. In some instances, this development led to increase or decrease in the water current based on the diameter and depth of the created course. Where the new course had a greater diameter, the depth was often shallow, and the current reduced. The reverse was true in situations where the diameter was narrow. This realisation very known at the Konkorso North and Konkorso South.

The other three sampling points; Adansi North, Adansi South and Nsuaem were either unaffected or very minimally affected in this regard.

5.3.2 CHANGE IN WATER CURRENT

The water current was greatly affected in two areas, and minimally influenced in a third community. These areas were Konkorso North and Konkorso South, both two areas running concurrently, and the water current massively altered, and a third site, the Dikoto Junction sampling area, which was minimally affected. The change in water current in these areas was mainly due to huge heaps of sand which blocked the water course, and also deep holes created in the water belt as soils were removed to be washed ashore for gold. While water current was very swift at the Konkorso South, there appeared to be a general decrease in current in its northern component (Konkorso North) and the Dikoto Junction at its south.

The Adansi North, Adansi South and Nsuaem sampling regions were almost unaffected in terms of current assessment. The water, though highly turbid, was generally calm and moved smoothly during all the three seasons.

5.3.3 CHANGE IN WATER DEPTH

The most affected sampling regions were the regions where small scale mining activities were heavily affected. The Konkorso North, Konkorso South and the Dikoto Junction areas were the most affected. The depths were very much irregular as some sections of the water in these regions were very deep whiles others were quite shallow. The situation was more pronounced in these three regions, and in the case of the Dikoto Junction sampling site, very irregular depths were created some two to ten meters outside the watercourse around the banks. These depths almost ate into the main water body, a situation quite hazardous to people who plied on this side of the river.

The Adansi North, Adansi South and Nsuaem regions were unaffected. While the Adansi North and Nsuaem regions were originally deep, the Adansi South appeared was relatively less deep and permitted the crossing of people from one side of the river to the other side during the dry season. Rifts and canoes were used for crossing of people especially at the rainy season. These three areas generally maintained their original depths.

The highest average depth was recorded at the Adansi North. The lowest was recorded at the Konkorso North; both two areas located at the upstream.

5.4 REMOVAL OF VEGETATION COVER

In all the sampling regions where small scale mining was practiced, the vegetation covers were hugely cleared. In some areas such as the Konkorso North, Konkorso South and Dikoto Junction, the destruction of the mangrove vegetation run into acres of land.

The destruction of the flora at the banks of the river resulted in subsequent destruction of fauna through endangering and extinction processes; food chains were massively affected, thereby threatening the existence of some plant and animal species, a situation very unhealthy for the sustenance of the Ankobra ecosystem.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

Among the parameters studied, turbidity of the Ankobra River was most affected, and the turbid level was found to be very high during the dry seasons when small scale mining activities were high.

Dissolved oxygen was found to be above the EPA standard. The concentration of dissolved oxygen was high at the upstream than the downstream. While this may be considered as a positive sign, the occurrence may largely be due to the rigorous small scale mining activities within the river. During the rainy season when the water current and turbulence were high, the level of dissolved oxygen increased.

Parameters which were not affected included pH, electrical conductivity and total dissolved solids (TDS). The seasonal averages recorded for these parameters were below standards of the EPA. While these may be considered as positive signs, regular monitoring is necessary to ensure that standards are kept.

With the heavy metals, mercury was found to be excessively high in all the small scale mining sites of the Ankobra River, and its concentration was slightly higher at the downstream than at the upstream. This was closely followed with lead and arsenic which recorded average concentrations above the EPA standards. Their levels were found to be especially higher during the dry season. The rainy season recorded relatively less concentrations (although some of these concentrations were above the EPA standards).

The concentrations of these heavy metals in the samples over the period of study were high and very significant. These mean that citizens of Adansi, Konkorso, Dikoto and Nsuaem could be poisoned by these heavy metals over a period of time, as the bio-concentration and subsequent bio-accumulative effects of these heavy metals over a period of time become more pronounced. The enormous health effects these metals have on the communities dependent on the river in these areas cannot be over-emphasized.

The levels of copper and cadmium were found to be far below the Ghana Environmental Protection Agency's guideline limits in drinking water. Hence their effects were insignificant, though not completely ignorable.

Thus, at the end of this enormous study, it has been shown that small scale mining activities in the Ankobra River have serious repercussions on the river and its conservation as these activities mainly impacted the river negatively. There must be collectively a comprehensive effort to curtail these effects.

6.2 RECOMMENDATIONS

Based on the findings in this study, I submit the following recommendations to help control and minimise the impacts of small scale mining on the Ankobra River:

- There should be strict regulations of all small scale mining activities by aurthorised agencies and organizations such as the Environmental Protection Agency and the Minerals Commission in all sections of the Ankobra River where small scale mining activities are carried out.
- Such parameters as turbidity and heavy metal concentrations should be continuously monitored to ensure that standards are kept for human health reasons, and the conservation of the Ankobra River ecosystem.
- Due to the high levels of some heavy metals (especially mercury and arsenic) and the high turbid nature of the Ankobra River, the Amenfi East District Assembly, together with well-meaning Ghanaians, responsible ministries and NGOs should be on top of

the situation by providing healthy sources of drinking water (for example making bore holes) for communities which depend on the Ankobra as their source of drinking water and for other domestic uses.

- There should be some levels of reclamation activities in and around areas of the Ankobra River where small scale mining activities are practiced.
- Ministries and NGO's should pursue the agenda of vigorously educating people involved in small scale mining activities and people around the Ankobra River of the possible health hazards and risks involved in their activities on the river.
- Further studies should be carried out on dependents of the Ankobra River and mine workers to find out possible health problems these face as a result of small scale mining activities in the river.

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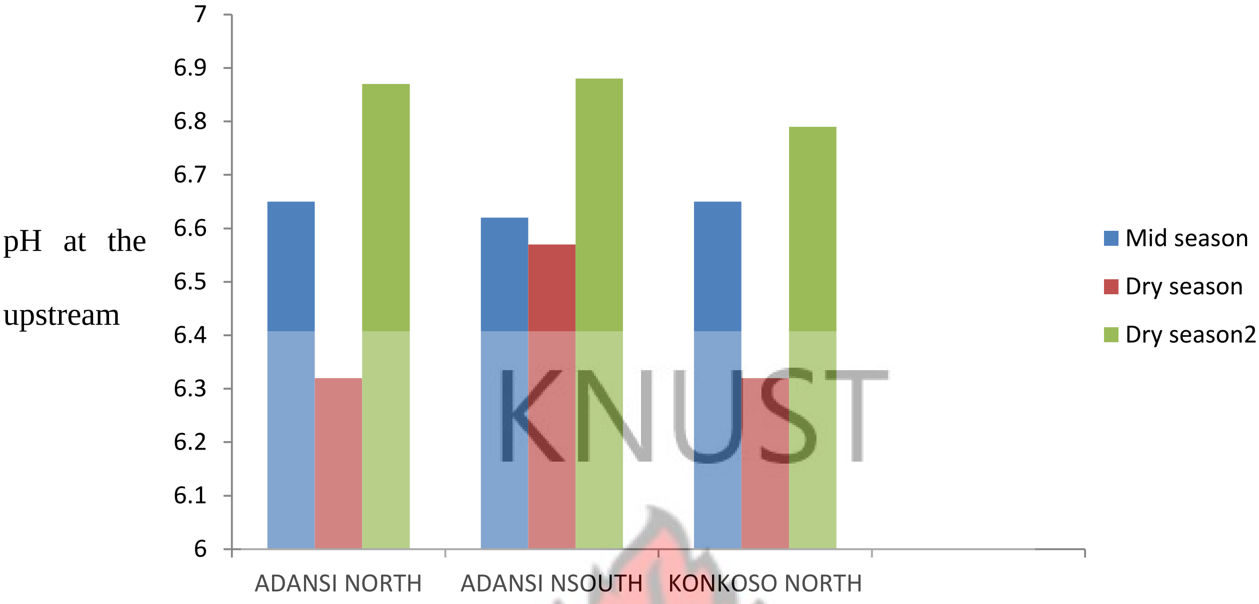
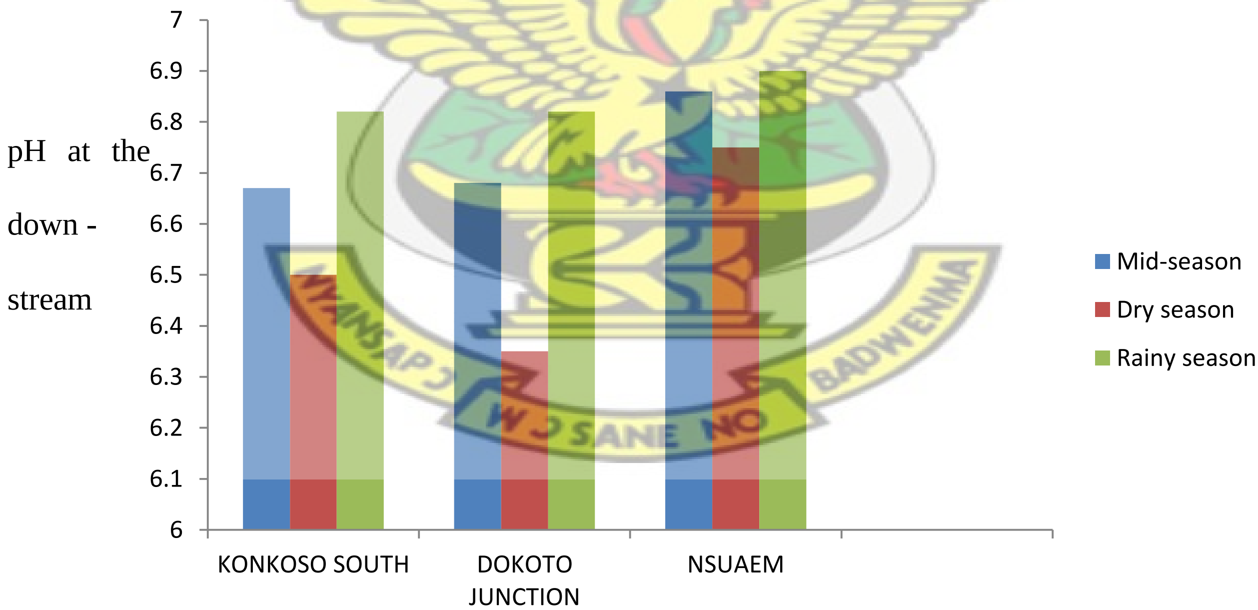
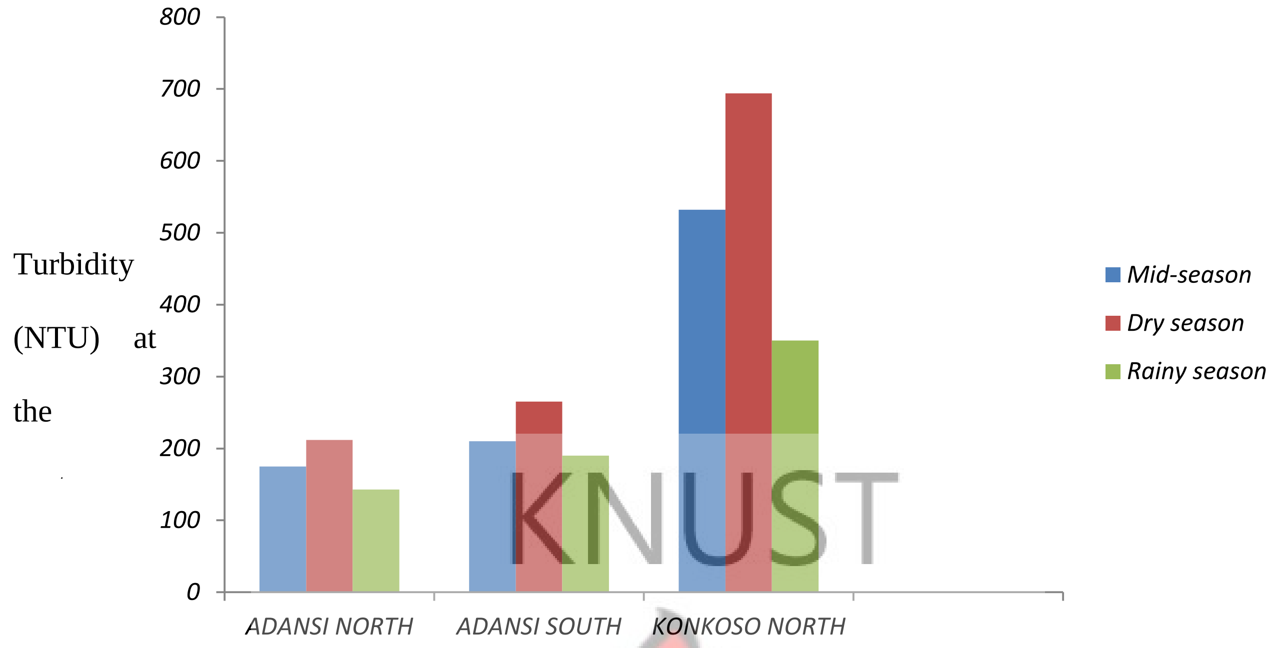
APPENDICES



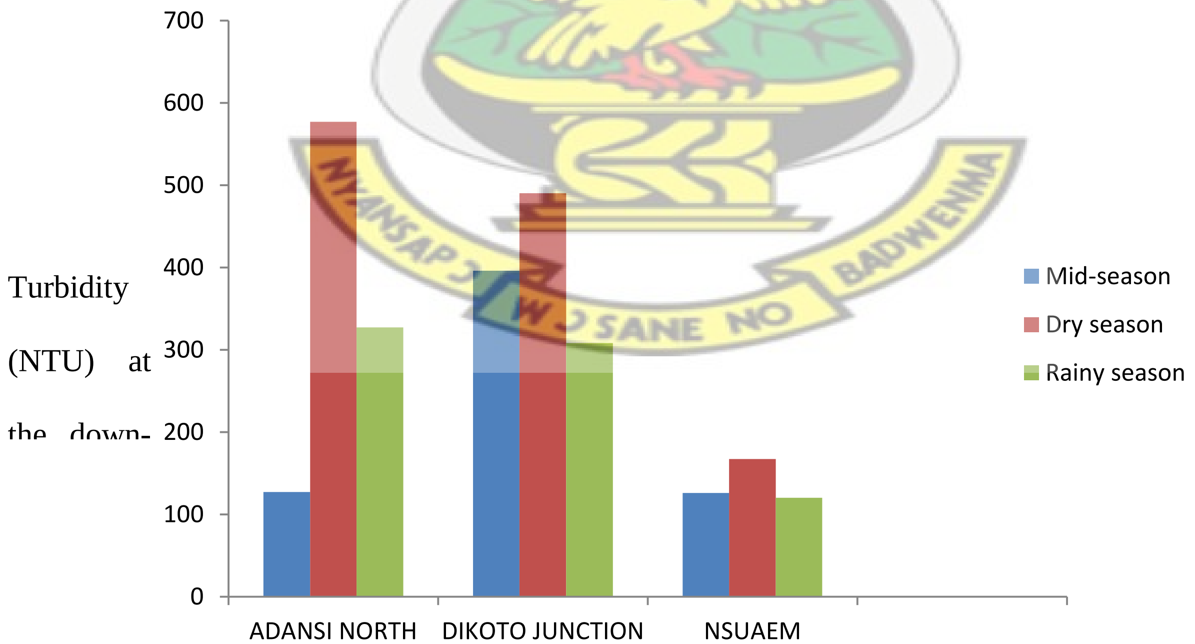
Appendix 1: A graph of pH at the upstream of the Ankobra River during the mid, dry and rainy seasons.



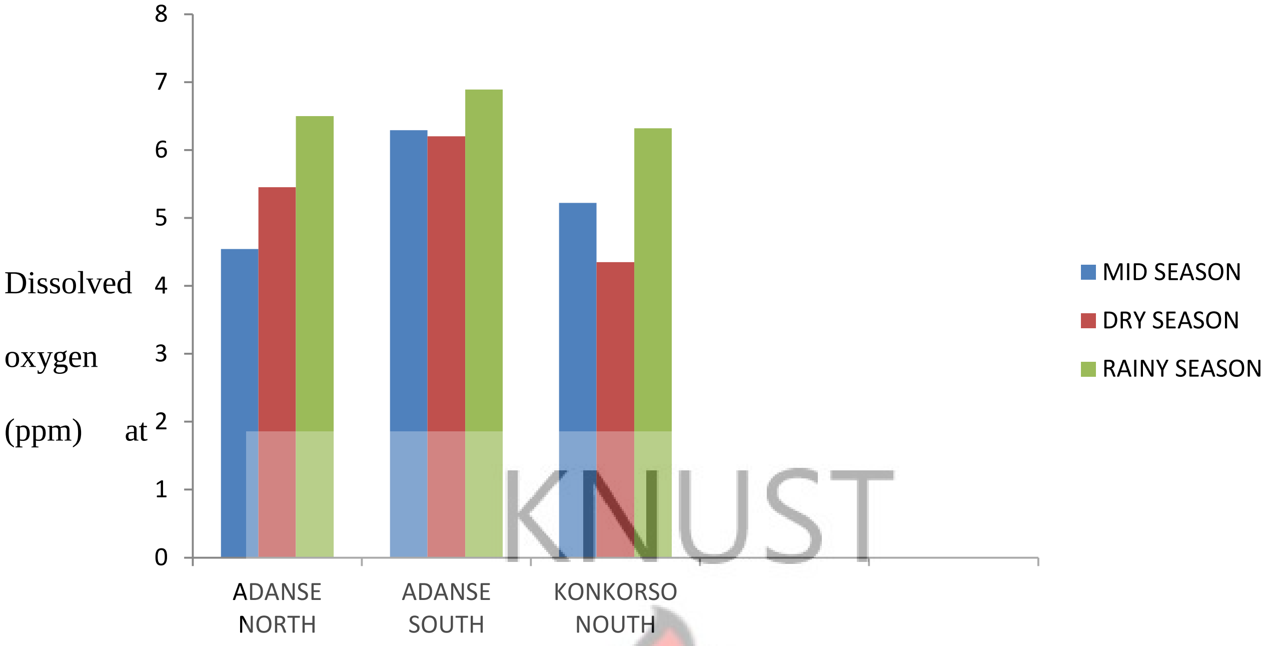
Appendix 2: A graph of pH at the downstream of the Ankobra River during the mid, dry and rainy season.



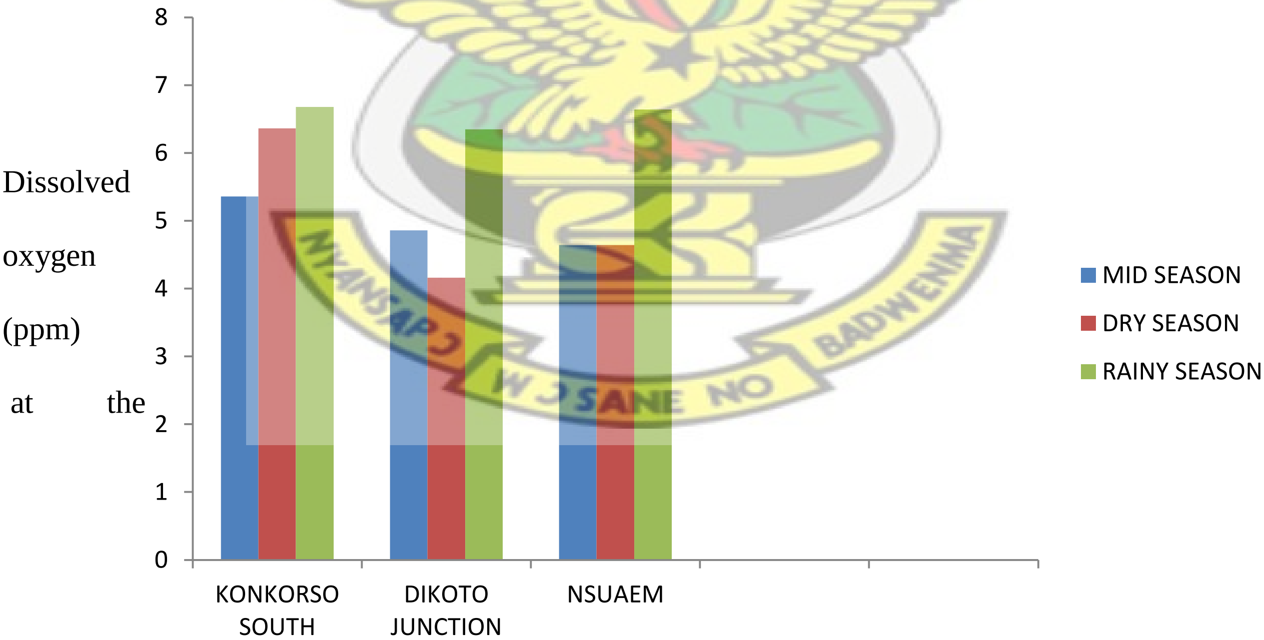
Appendix 3: A graph of turbidity at the upstream of the Ankobra River during the mid, dry and rainy seasons.



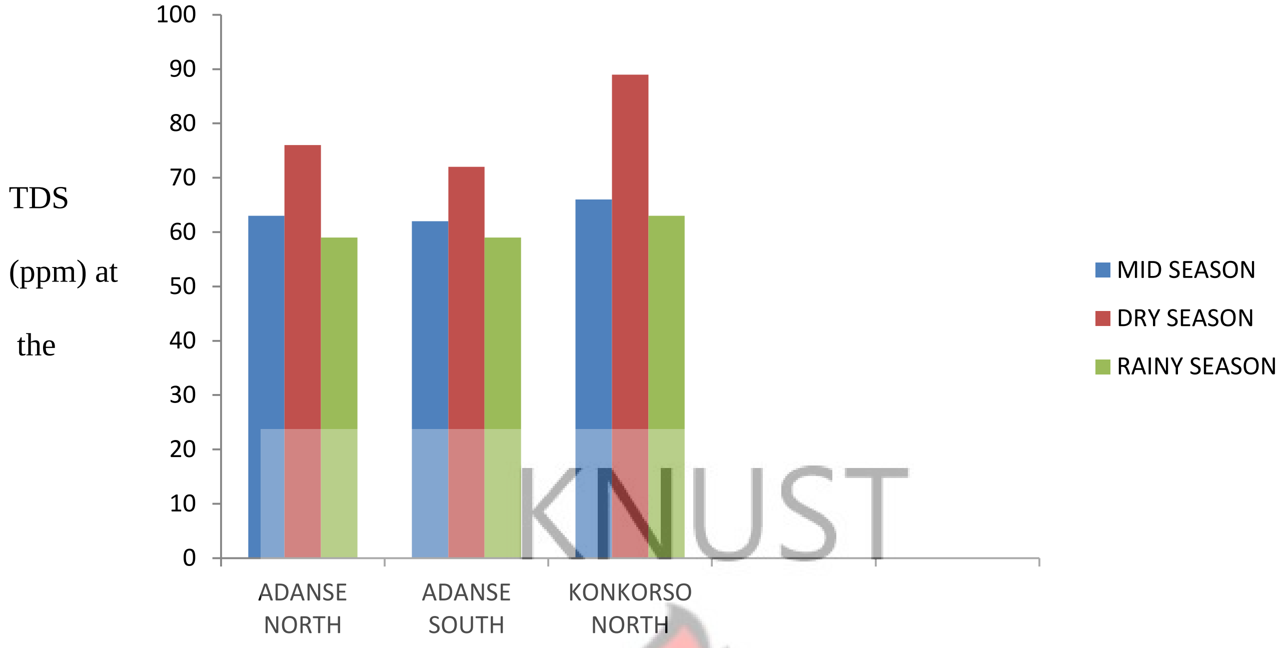
Appendix 4: A graph of turbidity at the downstream of the Ankobra River during the mid, dry and rainy seasons.



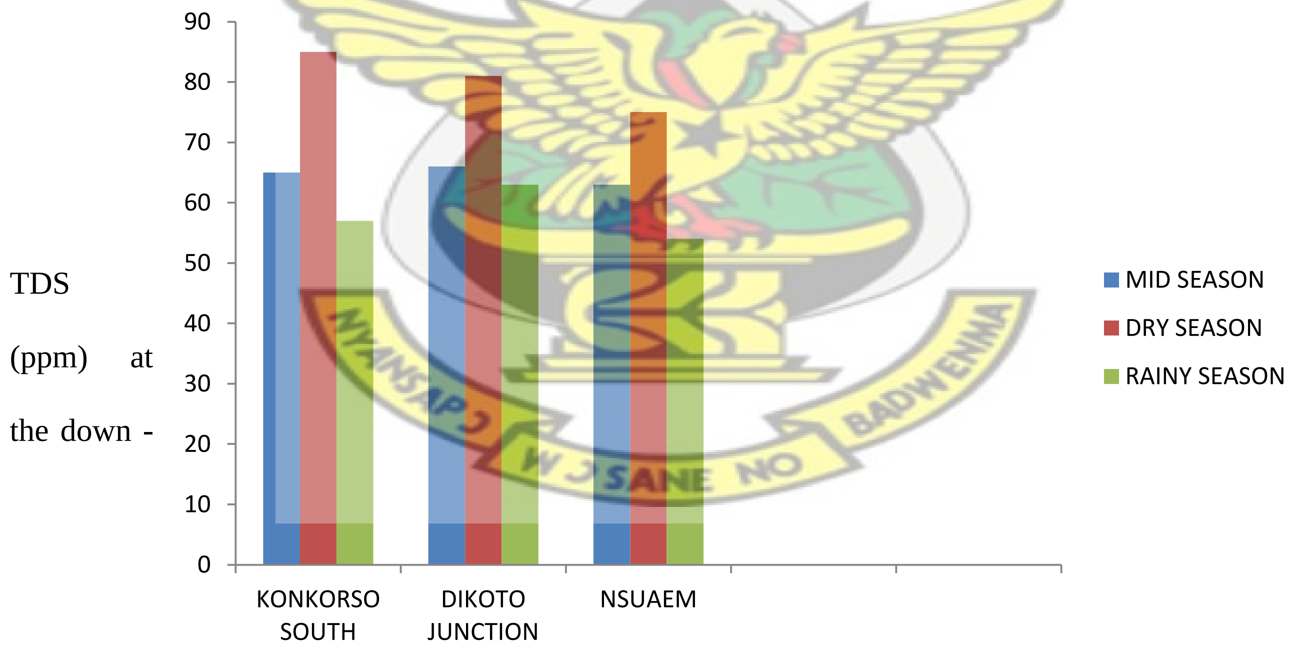
Appendix 5: A graph of dissolved oxygen at the upstream of the upstream of the Ankobra River during the mid, dry and rainy season.



Appendix 6: A graph of dissolved oxygen at the downstream of the Ankobra River during the mid, dry and rainy seasons.



Appendix 7: A graph of TDS at the upstream of the Ankobra River during the mid, rainy and dry seasons

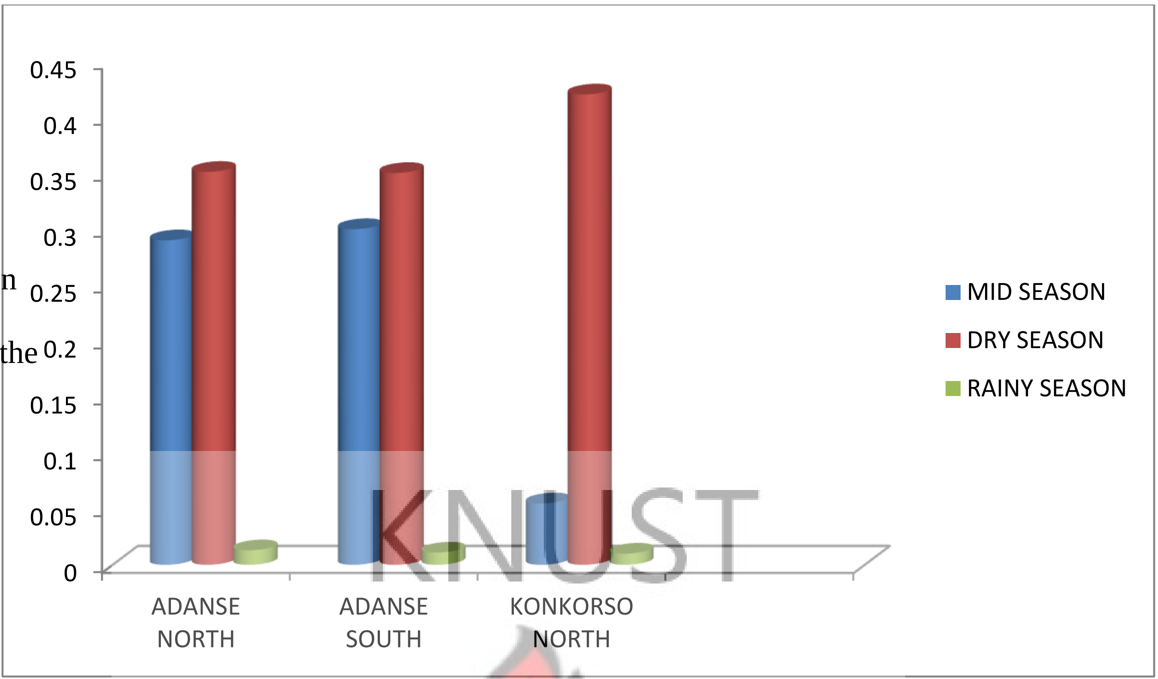


Appendix 8: A graph of TDS at the downstream of the Ankobra during the mid, dry and rainy season.

Lead

concentration

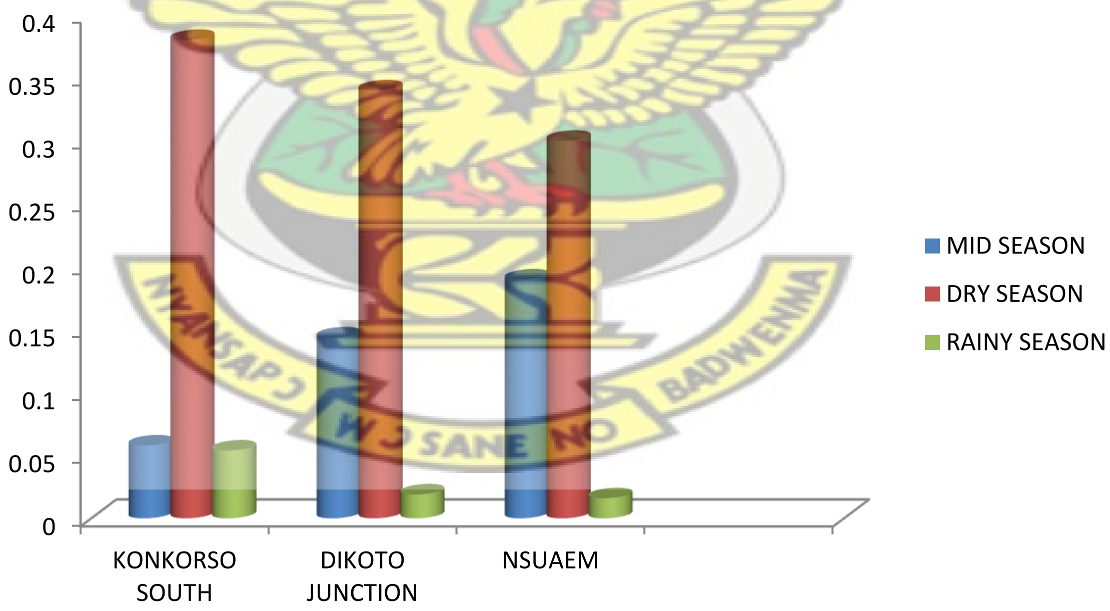
(mg/L) at the



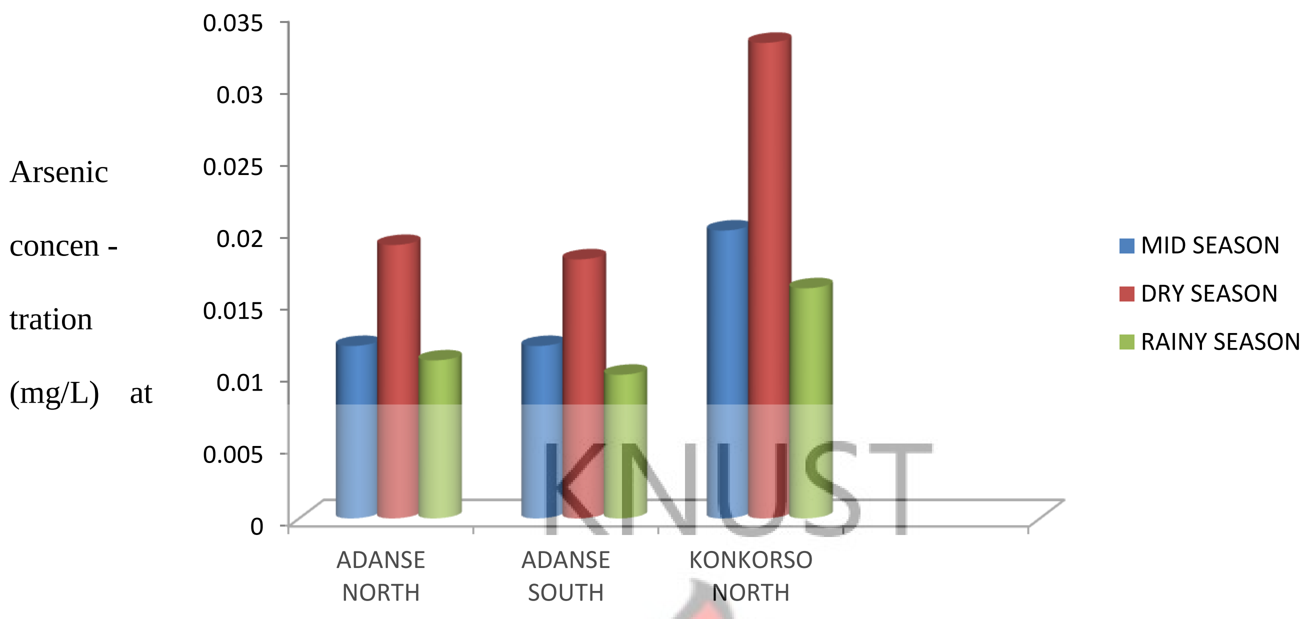
Appendix 9: Graphical representation of lead concentrations at the upstream of the Ankobra River during the mid, dry and rainy seasons.

Lead concent-

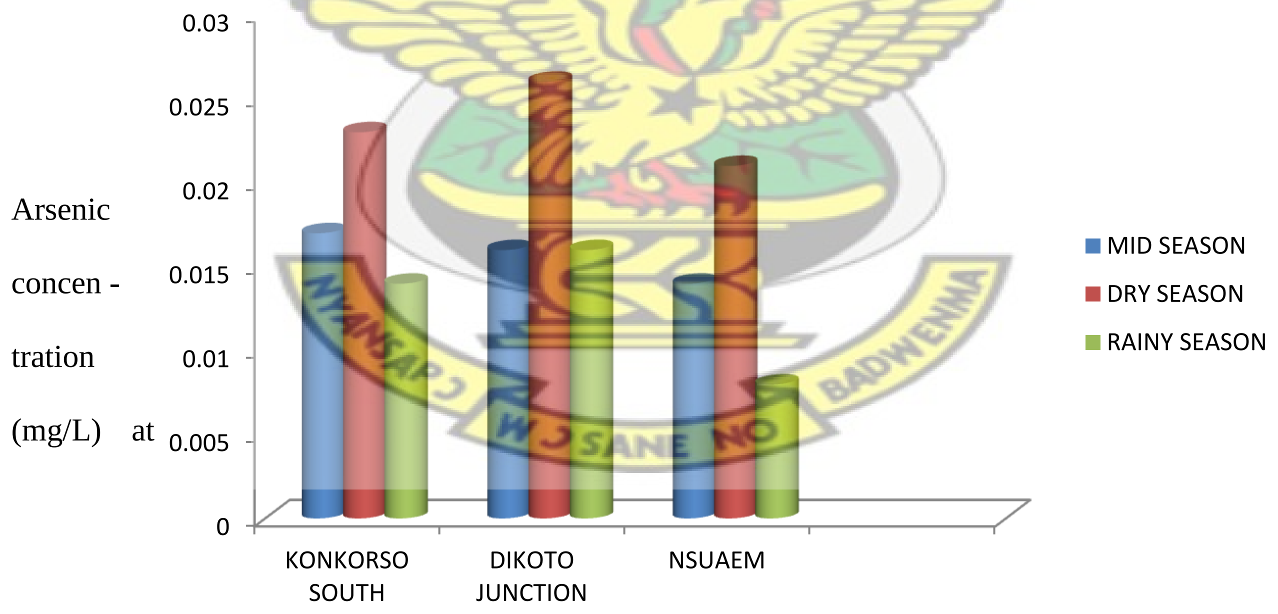
ration (mg/L)



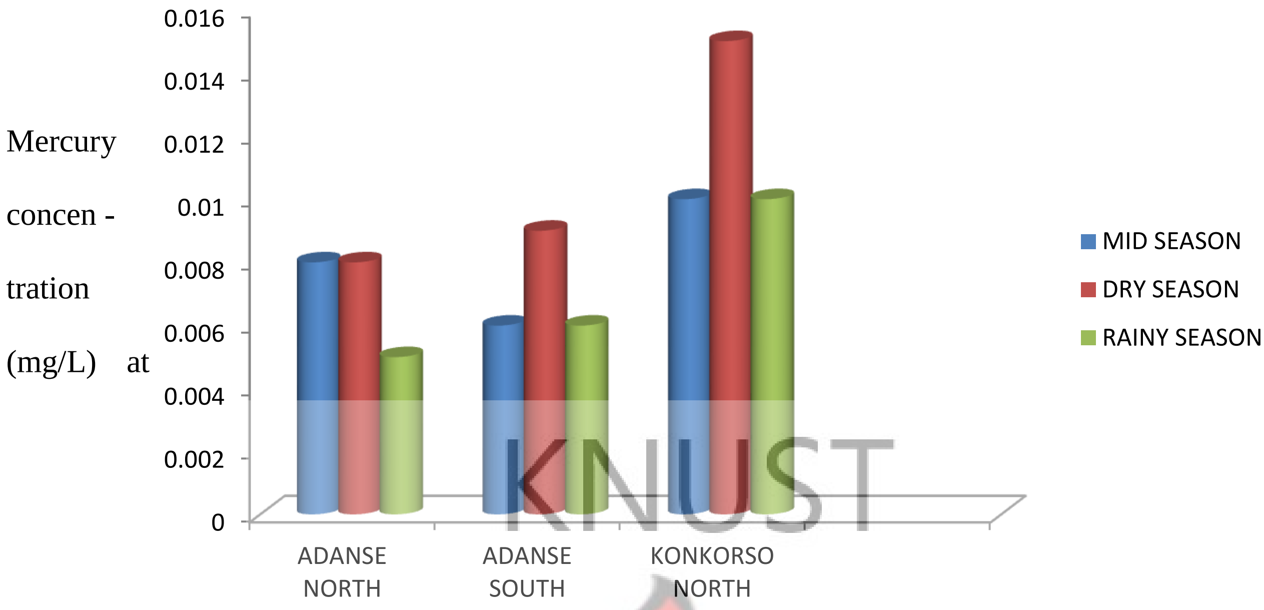
Appendix 10: A graph showing the concentrations of lead at the downstream of the Ankobra River during the mid, dry and rainy seasons.



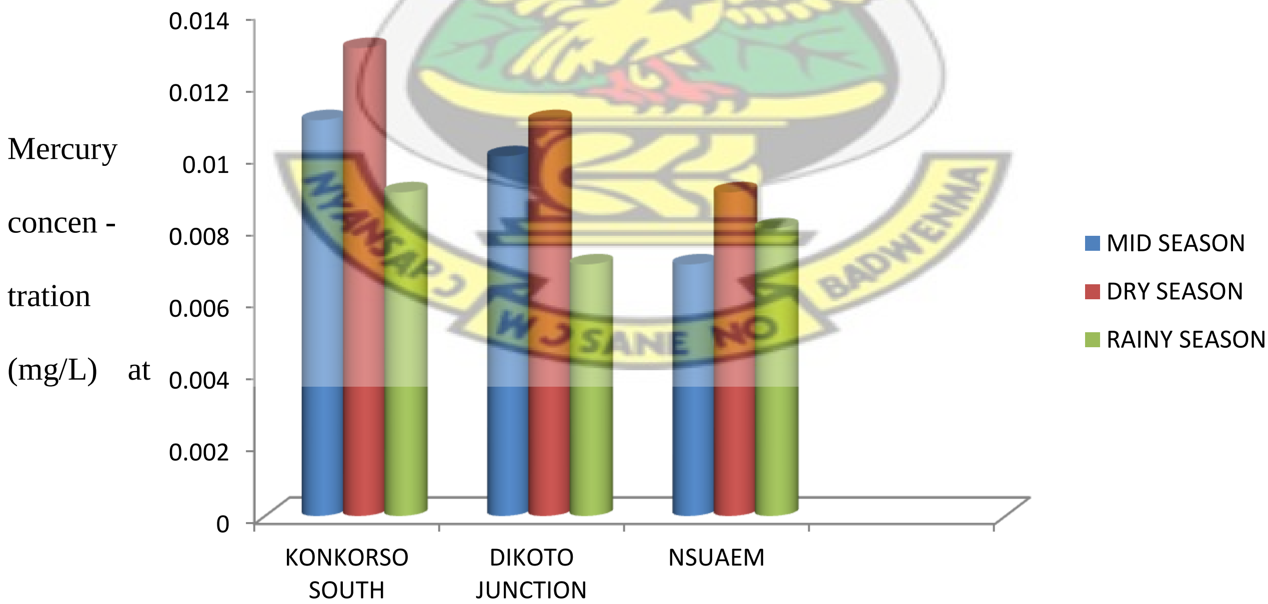
Appendix 11: A graphical representation of arsenic concentrations at the upstream of the Ankobra River during the mid, dry and rainy seasons.



Appendix 12: A graph showing the concentrations of arsenic at the downstream of the Ankobra River during the mid, dry and rainy seasons.



Appendix 13: A graph showing the concentrations of mercury at the upstream of the Ankobra River during the mid, dry and rainy seasons.



Appendix 14: A graphical representation of the concentration of mercury at the mid, dry and rainy seasons at the downstream of the Ankobra River.