

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF ENVIRONMENTAL SCIENCE

COLLEGE OF SCIENCE

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IMPACT OF CHIRANO GOLD MINES OPERATIONS ON LEVELS OF

As, Pb, Hg AND Cd IN THE SURAW RIVER AND THE POSSIBLE

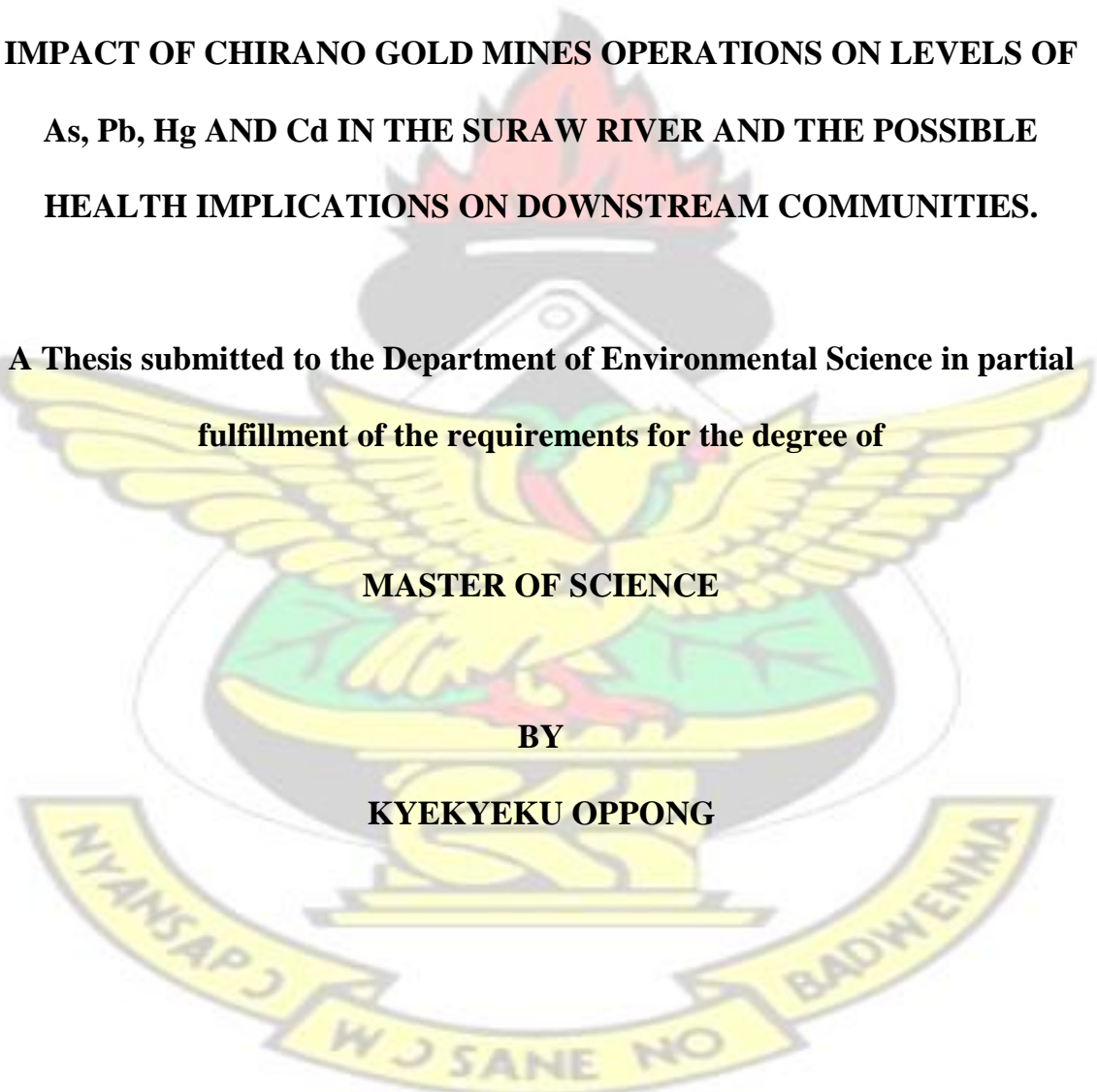
HEALTH IMPLICATIONS ON DOWNSTREAM COMMUNITIES.

**A Thesis submitted to the Department of Environmental Science in partial
fulfillment of the requirements for the degree of**

MASTER OF SCIENCE

BY

KYEKYEKU OPPONG



Institute of Distance Learning

JULY, 2011

DECLARATION

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

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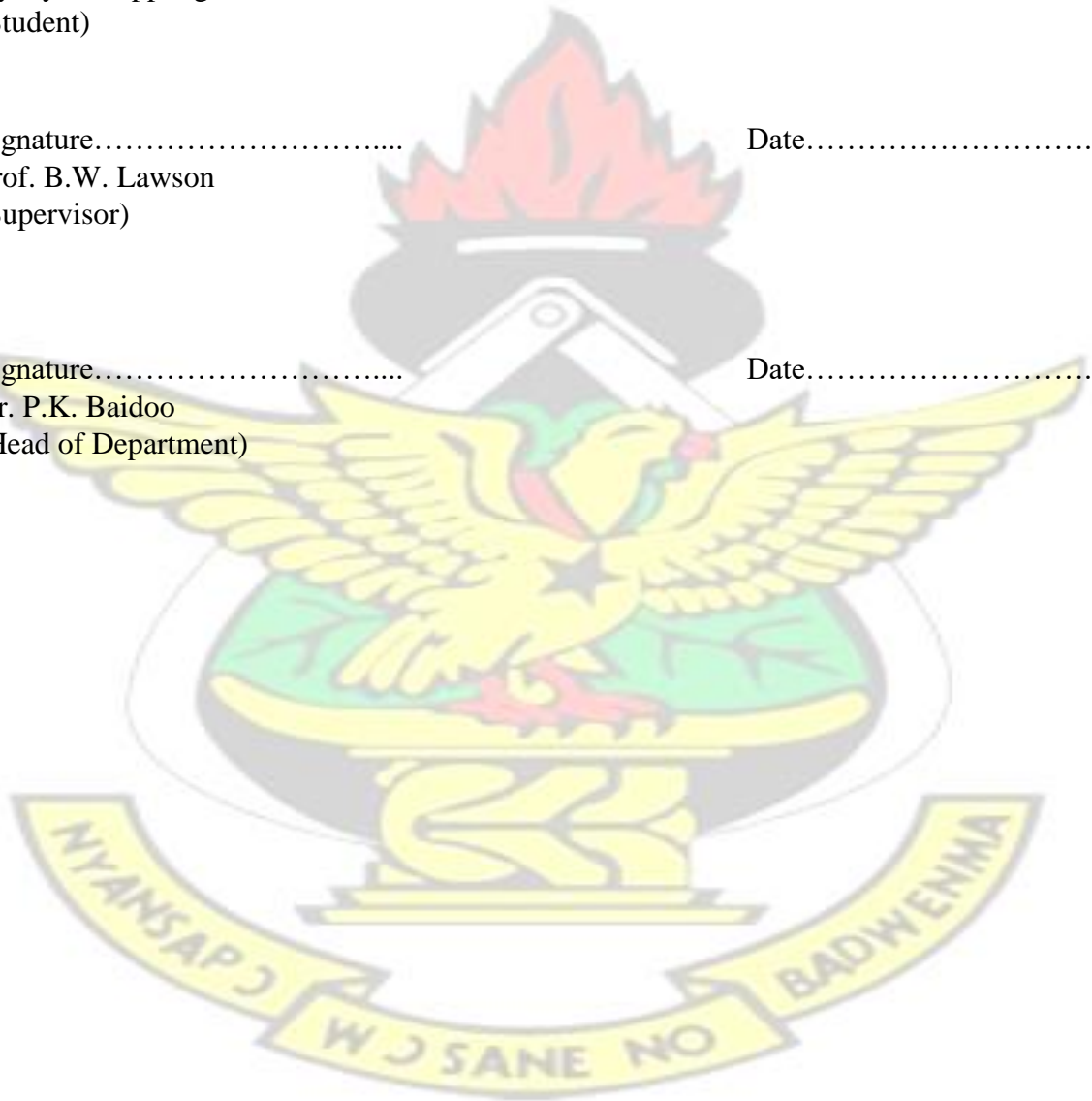
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ABSTRACT

Suraw River water quality awareness and preference survey conducted in five immediate downstream communities indicated that the residents were very much aware of the changes that have occurred since the commencement of active mining by CGML last quarter in 2004. Notwithstanding the residents overwhelming preference for the borehole water for their basic water needs including drinking, some people still rely on the River water when they go to their farms. Suraw River which principally drains the surface waters of Chirano Gold Mines operational area was investigated to assess the levels of As, Cd, Pb and Hg in the River water, bottom sediments and community borehole water using Atomic Absorption Spectrophotometer and Inductively Coupled Plasma - Optical Emission Spectroscopy (ICP – OES) for the water and sediments respectively. The results of the study generally showed low to below laboratory detection levels for the four heavy metals under investigation. The occurrence of Arsenic in more than half of the sampling sites in both the Suraw River and the community boreholes and particularly its detection at S1 in the surface water samples are most probably as a result of natural background levels. Except Cadmium which exceeded the Lowest Effect Level (LEL) in the sediment samples, the concentration of As, Pb and Hg were below the LEL of toxicity. The concentration of Cd also exceeded the Threshold Effect and the Probable Effect Levels but lower than the Severe Effect Level of sediment toxicity at five of the six sampling sites. The study has shown that the concentration of the four heavy metals investigated in both the Suraw River and the community borehole water were lower than expected compared with WHO/GWCL Drinking Water Standards and were within acceptable limits for potable water and therefore do not pose any immediate health risk to residents and settler farmers who still depend on the River water for their basic water needs. Apart from the concentration of Cd in the River sediments which showed consistent increase along the course of the River, concentration of the rest of the heavy metals investigated were all below the LEL and do not have any detrimental ecological impact on freshwater flora and fauna.

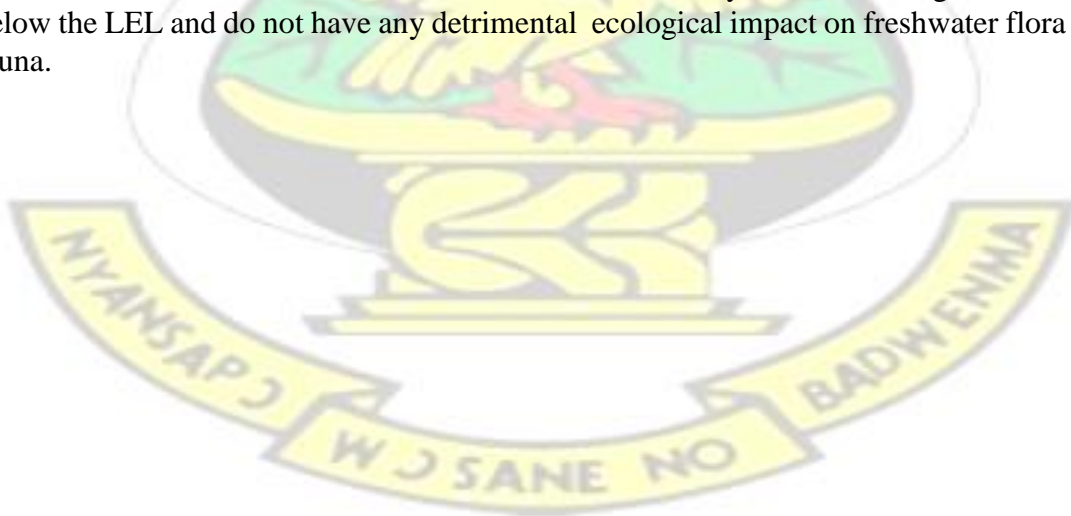


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LIST OF ABBREVIATIONS

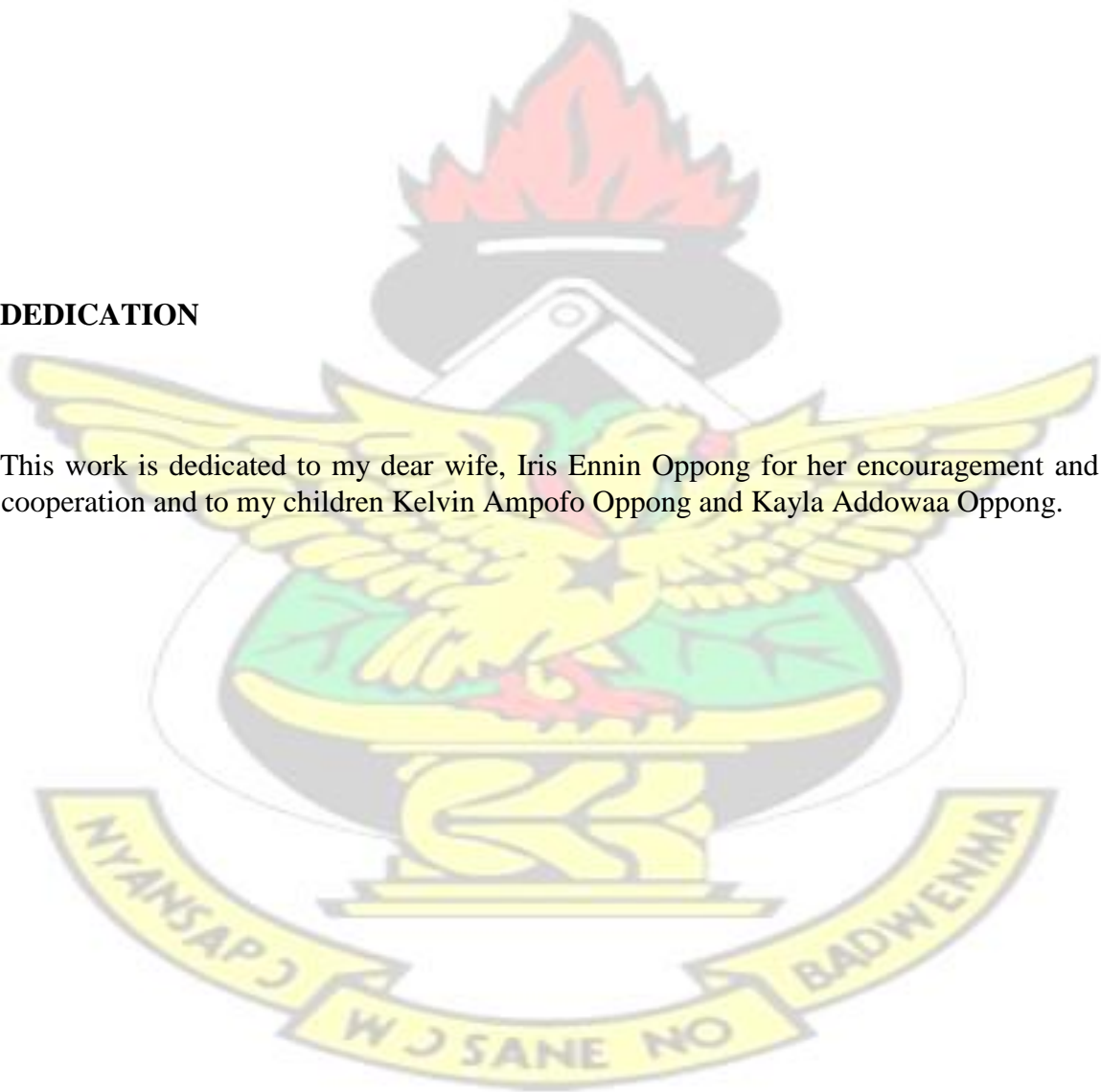
CGML	Chirano Gold Mines Limited	WACAM	Wassa
Association of Communities Affected by Mining	NRC		United States
National Research Council	LOAEL	Lowest Observed Adverse Effect	
Level	NOAEL	No Observed Adverse Effect Level	IARC
International Agency for Research on Cancer	ASTDR		United States
Agency for Toxic Substances and Disease			Registry
Lowest Effect level	TEL	Threshold Effect Level	PEL
Probable Effect Level	SEL	Severe Effect Level	EIS
Environmental Impact Statement	AERC	Africa Environmental	
Research and Consulting Company		Limited	
NOAA	National Oceanic and Atmospheric Administration		
AAS	Atomic Absorption Spectroscopy		
TDS	Total Dissolved Solids		
GPS	Global Positioning System		
ICP – OES	Inductively Coupled Plasma – Optical Emission Spectrometry		
g/t	Gramme per ton of the ore		



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DEDICATION

This work is dedicated to my dear wife, Iris Ennin Oppong for her encouragement and cooperation and to my children Kelvin Ampofo Oppong and Kayla Addowaa Oppong.



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CHAPTER ONE

1.0 INTRODUCTION

Access to safe and adequate water supply is essential to the existence of man and indeed all living things. Water is a cross-cutting element of the Growth and Poverty Reduction Strategy

(GPRS II) of the Republic of Ghana and is linked to all Eight of the Millenium Development

Goals. Ghana's long term plans outlined in the GPRS and other related development priorities give focus to improved rural water supply, sanitation, health and the control and eradication of water-borne diseases (National Water Policy, 2007). According to Gyampoh *et al.* (2008), about 65% of the Ghanaian population lives in rural areas with no access to pipe borne water.

The inability of rural dwellers in getting access to potable water makes them depend on streams and rivers for their basic water needs. Rural settlers have therefore relied on these sources of water for their survival. But for those who find themselves in mining territories, the problem they sometimes face is the pollution of the water-bodies by mining companies, and by their own illegal mining activities. . Chirano Gold Mines Ltd

(CGML) is located in the Bibiani Ahwianso Bekwai District Assembly (BABDA) and Sefwi Wiawso District Assembly (SWDA) Administrative areas. The mine operates both the conventional open cut and underground mining.

The operational area of Chirano Gold Mines Limited (CGML) is principally drained by the Suraw River which is one of the major tributaries of the Tano River. The Suraw River takes its source from the Tano Suraw Forest Reserve (TSFR) and flows through the mines

and some communities where it serves as drinking water for inhabitants of settlements located near its banks and is also used for a number of economic activities such as construction and watering of crops among others (Chirano Gold Project EIS, 2004). The use of the river especially by inhabitants of settlements for their water needs including drinking makes this project crucial for determining the health outcomes of downstream users.

According to Glanze (1996), there are 35 metals which are of interest as far as occupational or residential exposure is concerned; 23 of these are the heavy metals. However, some heavy metals such as iron, copper, manganese and zinc are nutritionally essential for a healthy life and play irreplaceable roles in the functioning of critical enzyme systems. Other metals are xenobiotics and play no useful role in human physiology and most other living organisms (Hu, 2002). At high concentrations, as occurs in contaminated environment, heavy metals present public health problems. Heavy metal toxicity can result in damaged or reduced mental and central nervous function, lower energy levels, and damage to blood composition, lungs, kidneys, liver, and other vital organs. Long term exposure may result in slowly progressing physical, muscular, postural instability and neurological degenerative processes that mimic Alzheimer's disease, Parkinson's disease, muscular dystrophy, and multiple sclerosis (International Occupational Safety and Health Information Centre, 1999)

In Ghana, the mining industry has been blamed for significant degradation of the environment particularly pollution of water bodies within their operational areas. Among environmental pollutants, metals are of particular concern due to their potential toxic effect and ability to bioaccumulate in aquatic ecosystems (Censi *et al.*, 2006). The presence of

heavy metals in aquatic ecosystems is the result of two main sources of contamination; natural processes or natural occurring deposits and anthropogenic activities. The main sources of heavy metal pollution to life forms are invariably the result of anthropogenic activities (Kennish, 1992; Francis, 1994). There are a number of activities on the mines whose by product eventually find their way into the surface waters. As water passes through and over geologic formations, heavy metals in the form of minerals dissolve making them mobile than where they existed naturally. Other processes and activities that could release heavy metals in surface waters on the mine include tire wears from heavy duty trucks, accidental or occasional spills of lubricating oil and grease, bearing wear, improper storage and disposal of wastes, run off through waste rock dumps, mineral processing waste spills, air conditioning coolants, auto body rust, improper handling of hazardous waste and burning of waste containing heavy metals. This is true because, air and soil contaminations ultimately end up in the aquatic system via local precipitation, water runoff and leaching of rocks and solid waste (Obodo, 2002).

Another potential source of heavy metal releases into the environment is the Tailings Storage Facility (Tailings Dam). The tailings dam contains high levels of heavy metals and chemicals added during the milling process which are much better available for dispersion into the environment than in the original ore. The mechanical stability of the tailings mass is very poor due to its small grain size and the usually high water contents. According to the Environmental Impact Statement, Chirano Gold Project (2004), the main conclusion of the geochemical characterization of the waste rock from the Project was that all of the waste rock samples were classified as Non-Acid Forming. This finding rules out the possibility of acid mine drainage phenomenon occurring.

However, Arsenic was detected in some water samples as reported in the water quality report in the baseline Environmental Impact Assessment Data. Stream bottom sediments collected in the main streams and rivers of the project area were generally low in As, Pb and Cd except mercury (approximately 10 times higher) with respect to Ghana Water and Sewerage Company (GWCL) drinking water standards. Arsenic and Mercury have been detected in the stream sediments in the main streams and rivers of the project area (Lycopodium Pty Ltd, 2003).

The communities within and around the mine's lease areas complain about the impact of mining on their water supply sources. These communities are typically rural and the major occupation is farming. They depend on surface and ground water (boreholes) sources for their water needs (Chirano Gold Project EIS, 2004). Heavy metal concentrations in aquatic ecosystems are usually monitored by measuring their concentrations in water, sediments and biota (Camusso et al., 1995).

The present study has been undertaken to compare the current levels of As and Hg in addition to Pb and Cd with the WHO/GWCL Drinking Water Standards. The scope of this study therefore focused on the level of Arsenic (As), Lead (Pb), Mercury (Hg) and Cadmium (Cd) in the Suraw River in the mining lease of Chirano Gold Mines Ltd.

1.1 AIM OF STUDY

The study aimed at determining the current levels of some heavy metals in the Suraw River to establish the possible impact of the mining operations on the river and the health implications on downstream communities

1.2 SPECIFIC OBJECTIVES

- The specific objectives were to :
- determine some physicochemical water quality parameters such as Temperature, pH, TDS and Conductivity at the six water and sediment sample collection sites.
- determine the levels of As, Cd, Pb and Hg in selected community boreholes.
- undertake survey in five of the Suraw River downstream communities to assess their level of awareness of the River water quality



CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 BACKGROUND OF CHIRANO GOLD MINES OPERATION

2.1.1 Introduction

Chirano Gold Mine Limited (CGML), a subsidiary of Kinross Gold is a Canadian company based in Vancouver, Canada. The Chirano Project is based on a granted mining lease (PL2/56) from April 8, 2004 which covers an area of 36.34 square kilometres valid for a period of 15 years. In the mid 1930s two concessions covered the Chirano area: one held by Gold Coast Selection Trust and one by Anglo-African Goldfields Ltd. No reports of work at this time survived, but some small pits have been found which may date from this period (Hugh, 2007). Modern era exploration within the prospecting license is known to have started in 1993 and exploration is still in progress in search of more deposits.

There are ten deposits that currently comprise the Chirano Project: Akwaaba, Suraw, Akoti South, Akoti North, Akoti Extended, Paboase, Tano, Obra South, Sariehu and Mamnao. The first gold pour was achieved in October, 2005 after commissioning of the process facilities in September, 2005 (Anon, 2009).

2.1.2 Location and Accessibility

The Chirano Gold Mine is situated 100 kilometres south-west of Kumasi, which is Ghana's second largest city. The township of Bibiani, the site of an existing large gold mine, lays 15 kilometres north-north-east of the project area (37 kilometres by road). Access to the Project from the capital Accra is, by plane then via a sealed highway from Kumasi running south-west towards Bibiani and onwards to Sefwi-Bekwai. The final approach is either by a 22 kilometre gravel road from Tanoso Junction (15 kilometres south of Bibiani) or by a 13 kilometre gravel road whose junction is approximately 9 kilometres beyond Sefwi-Bekwai (Anon, 2009).

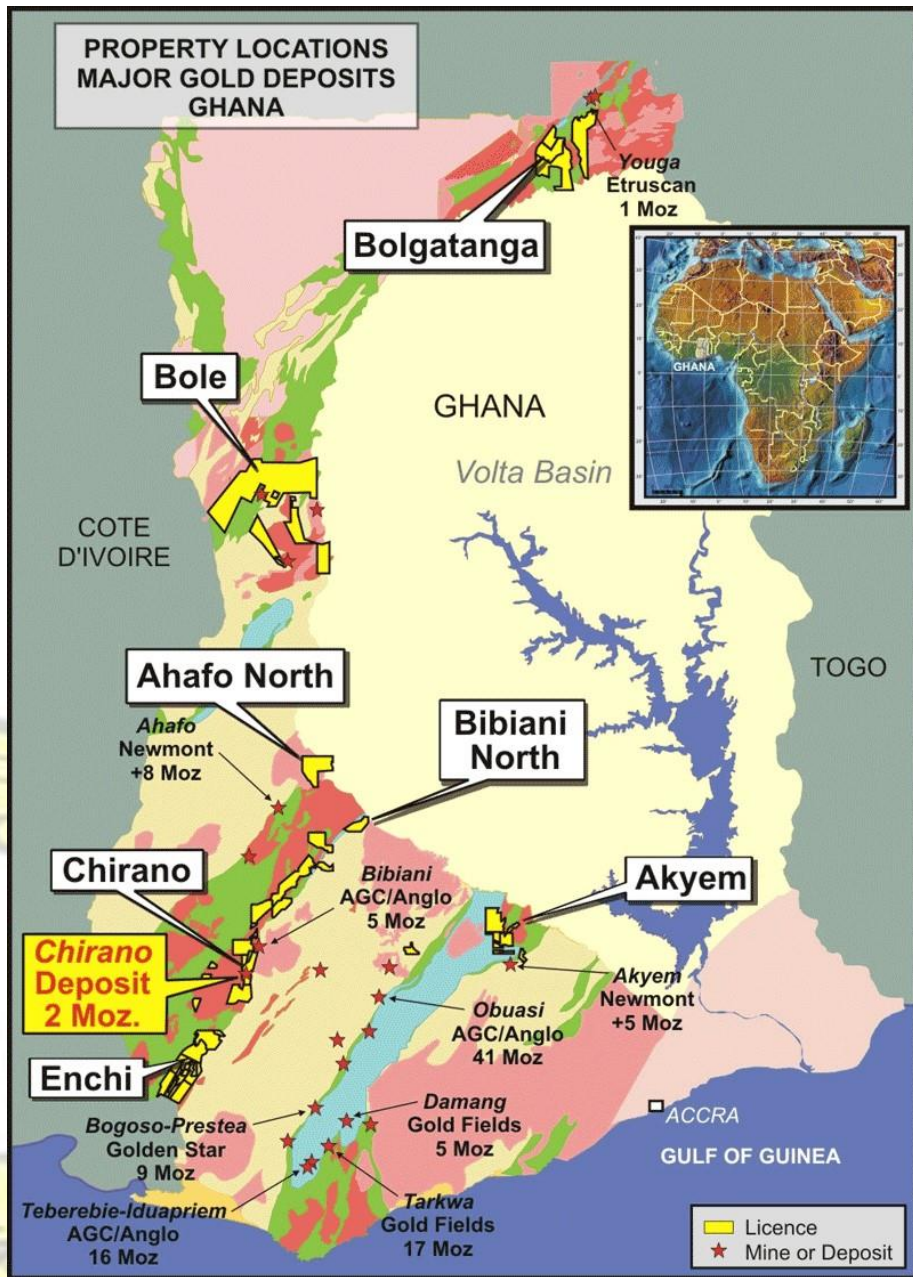


Fig 2.1 Location of Chirano Mine Relative to the Rest of Ghana

2.1.3 Climate and Vegetation

The climate at the Chirano Gold Mine area is fairly typical of that for southern inland Ghana, with a dry seasons extending from November to February. A humid season extends from March to April, with high temperatures, high humidity and occasional moderate rain, followed by a wet season extending from May to October with peaks in May to June and September to October.

The mine area has a mean annual rainfall of 1,420 mm. The highest average monthly rainfall is in June with 222 mm precipitation. January is typically the driest month. Annual evaporation is about 1,500 mm. Average relative humidity ranges from a low of 64% in January to a high of 85% in July.

The study area is bordered on the west by the south Bibiani Range which forms a major range of hills. This runs roughly north-south and the Chirano gold deposits lie halfway up its steep eastern slope, such that the open pits have high western walls and low eastern walls. The range rises from a height of about 250 meters above sea level to about 550 meters at its crest. The slopes are steep, commonly 15° to 25° and locally up to 35°. Part of the mining lease (42%) lies within forest reserves, and is covered by tall, primary, semi-deciduous rain forest (Anon, 2009).

2.1.4 Geology and Mineralization

The Chirano project area lies within the Proterozoic terrain of southwest Ghana, along a major structure separating the Sefwi Belt to the west from the Kumasi Basin to the east known as the Bibiani Shear zone. The belt and basin architecture comprises rocks of Birimian age, with the belts being dominated by mafic volcanics and the basins typified by fine grained, deep marine sediments. Both are intruded by granites (Anon, 2009).

2.1.5 Regional Geology

The project area straddles the boundary between the Sefwi volcanic belt to the west and the sedimentary Kumasi Basin to the east. Throughout the rest of south-western Ghana this boundary generally trends north-easterly, but the section surrounding Chirano has a northerly trend. In a regional perspective, this change in trend is one of the most obvious characteristics of the Chirano goldfield, and is almost certainly an important factor in the location of the mineralization. It is not certain whether this unusually oriented section of the belt-basin contact reflects a flexure (jog) in the contact, or is a north-south fault which offsets the contact. A regional digital terrain model shows a prominent north-south topographic lineament passing through Chirano, and also the Bibiani and Ahafo (Yamfo) gold deposits. This lineament can be traced for several hundred kilometres across the whole of Ghana

2.1.6 Local Geology

All the known Chirano gold deposits are hosted by the Chirano granite. The granite is flanked on its western side by mafic rocks ranging from fine grained basalts to medium grained dolerites. The granite is flanked to the east by Tarkwaian sediments, comprising arkosic sandstones, siltstones and minor conglomerates. The granite itself is a composite body, incorporating numerous thin but extensive sheets of mafic rock. The granite is generally thin, and strikes north-northeast, but includes a thicker section with a northerly trend, termed the Paboase Bulge. This bulge may be considered to be a major sinistral jog affecting both the granite and the Chirano Shear. The eleven known gold deposits occur along a single mineralized horizon. They are centred on the Paboase Bulge, but extend for several kilometres to the north and south (Anon, 2009).

2.1.7 Mining Operations

The mining operations include drilling and blasting, loading and hauling, dewatering, and haul road maintenance which are currently contracted to African Mining Services (AMS). CGML provides management, mining technical services and all other non-mining functions.

2.1.7.1 Grade Control

Grade control drilling is carried out independent of blast hole drilling, and employs the sampling of material from reverse circulation drill rigs. Grade control drilling is carried out on an 8 m x 10 m grid. As ore mining is carried out on 3 m vertical flitches, grade control drilling utilizes 24 m angled drill holes oriented grid east dipping at 60°. Grade control drill holes are sampled on 1.5 m intervals. The 1.5 m sample is split to 2 kg at the rig. At the laboratory the entire 2 kg split is pulverized such that 90% of it would pass through 75 microns. A 50 gram sample is collected and assayed. Routine quality control is conducted on sampling, sample preparation and laboratory analysis. Some are:

- Standard samples of known grades are added to the samples and sent along side with the unknown ones to the laboratory to check whether or not the samples are truly analyzed.
- Blank sample of less than 0.01 g/t Au is sent together with the unknown ones to the laboratory to confirm the accuracy of the results.
- When a sample is listed but not submitted and a result is received from the laboratory, a notification is sent to inquire about the result.
- A duplicate sample after every 15 m sampled is labelled and sent, with the expectation that the two will be the same and if not is taken as a sign of inaccuracy of the results.

2.1.7.2 Density Sampling

Density sampling is done in the pits within the ore, and waste zones. A sample of the insitu material from the pit floor is taken on a grid of 10 m x10 m within the ore and 20 m x 20 m in the waste. Transported materials are not used because they are mixed together and do not give a true representation of the material of the bench. The samples taken are sent to the laboratory for the determination of their specific gravity. The specific gravity obtained is used to calculate the tonnage of the ore block.

2.1.7.3 Drilling and Blasting

Pantera drilling rigs are used in drilling production holes with a bit diameter of 115 mm. Vertical holes are normally drilled. Depending on the rock type, 102 mm or 89 mm diameter bits are used for drilling batter holes at an angle of 75°. The drilling pattern used is the staggered pattern with burden and spacing being 3.5 m x 4.0 m.

Maxam Ghana Limited supplies the explosives for AMS to carry out the blasting operations. Ammonium Nitrate Fuel Oil (ANFO) and emulsion are used for the blasting. The ANFO is only used in dry conditions because of its physical nature. The emulsion is used in wet conditions because of its water resistance. The explosive density used is 1.15 g/cc.

2.1.7.4 Loading and Hauling

Excavators employed for loading are the Liebherr 994, 250 t hydraulic excavator with 14 m³ bucket and Liebherr 984, 110 t hydraulic excavator with 7 m³ bucket loading 90 t Caterpillar 777D trucks. The mining fleet on site includes the requisite ancillary equipment (dozers, graders and water trucks) for haul and pit access road construction and maintenance, waste dump and ROM pad maintenance and rehabilitation.

A bench height of 6 m comprising of two 3 m flitches are mined. The top flitch is mined first and subsequently the bottom flitch. The benches are mined in flitches so the available excavators can be used. In the process of mining the bottom flitch, a laser, receiver and a

staff are regularly used to check the level of the floor with respect to a given TBM (Temporary Bench Mark) provided by the surveyors.

2.1.7.5 Blast Monitoring

Every blast is monitored to ensure that the noise and ground vibration do not exceed the acceptable threshold values. The acceptable threshold values are 115 decibels (dbl) for noise and 5 mm/s for ground vibration.

2.1.7.6 Pit Dewatering

Relatively high rainfall is experienced during the two rainy seasons each year. In-pit groundwater and run-off water is collected in sumps for pumping to a water dam using diesel powered pumps.

2.1.8 Ore Processing

The treatment plant processes combinations of oxide and primary ores from the various pits at a rate of 3.5 Million Tonnes per annum (Mtpa) (Anon, 2009).

2.1.8.1 Run of Mine (ROM) Pad

ROM ore is delivered by haul trucks and dumped on the ROM pad. There are no stockpiles maintained at the pit and provision has been made for a ROM stockpile to allow blending to optimise plant performance. The ROM pad has been constructed with mine waste.

2.1.8.2 Crushing

ROM ore is loaded into a 200 ton capacity bin [10-BN-01] by a front end loader. ROM ore is loaded into the ROM bin in a particular ratio that is based on the grade and the mineralogy of the ore. The ROM bin incorporates a grizzly screen with an aperture size of 700mm by 700mm which prevents plus 700mm particles from entering the jaw crusher. Particles with size less than 700mm pass through the grizzly screen. Any oversize rocks that build up on the grizzly are removed and stockpiled for subsequent breakage using a rock breaker.

The undersize of the grizzly screen is fed onto a 1219mm wide by 9000mm long primary apron feeder [10-FE-01] through a chute. The primary apron feeder feeds the ore directly into a single toggle jaw crusher [10-CR-01] which is the primary crusher. The jaw crusher is a 1400mm wide by 1070mm long crusher which crushes the ore to a particle size passing 150mm [-150mm].

A variable speed apron feeder (10-FE-01) (which is like a steel conveyor), is installed at the base of the ROM bin. The apron feeder takes the ore from the bin and feeds it directly into the single toggle primary jaw crusher.

The jaw crusher reduces the size of the ROM ore to a product size of ± 150 mm. The crushed ore that discharges from the jaw crusher falls directly on to 10-CV-01 (which is first crushing conveyor belt).

10-CV-01 discharges directly onto 10-CV-07 which in turn feeds two double deck vibratory screens. The oversize material from the top deck reports to a single secondary cone crusher via 10-CV-08; the product of the secondary crusher then reports to 10-CV-07. The undersize of the top screen deck reports to the bottom deck of the screen. The oversize material from the bottom deck reports to the three tertiary cone crushers.

The product of the tertiary crushing also reports to 10-CV-07 via 10-CV-12. The undersize material (final product) from the bottom deck of the classification screens then reports to 10-CV-17 via 10-CV-13 and 10-CV-14. 10-CV-17 feeds the surge bin with the final crushed product. The surge bin has a capacity of 90 tonnes and the retention time of ore in

the bin is dependent on processing rate. Ore from the surge bin is delivered either to the grinding circuit or an overflow chute to allow excess crushed ore to report to an emergency stockpile via the stockpile feed conveyor (10-CV-03).

The maximum storage capacity allocated to the emergency stockpile area is approximately 100,000 tonnes. The crushed ore stockpile serves as a storage facility between the crushing and grinding circuits so that when the crushing circuit is shut down for repairs the grinding circuit can continue operating.

A reverse pulse dust collector (10-DC-01) is installed on 10-CV-01 near the crusher to remove dust particles generated during crushing operations. This is a dry collection system with reverse pulse cleaning, dumping back onto 10-CV-01 jaw crusher discharge conveyor. A wet dust scrubber is also installed in the secondary and tertiary crushing circuits (Anon, 2009).

2.1.8.3 Pebble Crushing

The pebble crushing circuit includes a Symond's 4.25 standard fine head cone crusher directly fed by conveyor with pebbles recovered as oversize from the Primary mill discharge trommel screen. Scats from the Primary Mill discharge onto scats recycle conveyor, 30-CV-04, installed with a self cleaning tramp magnet, static magnet and a metal detector, prior to reporting to the recycle crusher. The tramp magnets and a metal detector are both suspended types and located on 10-CV-04 in a cross belt position.

The metal detector detects any residual tramp material on the recycle conveyor and actuates a deflector gate to bypass the crusher for a predetermined duration. Scats from 30-CV-04 will transfer to 30-CV-05 pebble crusher feed conveyor. Material reporting to the recycle cone crusher will discharge back onto the primary mill feed conveyor 10-CV02 via the recycle crusher discharge conveyor 30-CV-06. The deflected tramp material will report onto the primary mill feed conveyor.

The main aim of the recycle crusher operation is to provide continuous choke feed to the crusher. As the mill discharge grate wears, (i.e., the pebble tonnage and reduction ratio increase) it may be necessary to increase the closed side setting on the crusher to maintain crusher throughput (minimum CCs 16mm) (Anon, 2009).

2.1.8.4 Grinding and Classification

Grinding or Milling and Classification are the last stages of the comminution process. Grinding is a comminution process where a combination of impact and abrasion is used to reduce the particle size of ore to an economic optimum mesh of grind whilst Classification is a method of separating a mixture of particles into two or more products on the basis of the velocity with which they fall through a fluid medium.

After grinding and classification, sufficient liberation of gold-bearing material is achieved for the leaching and adsorption process.

Feed from the crushing circuit is transferred to the milling circuit via the Primary Ball Mill feed conveyor [10-CV-02] into the Primary Ball Mill [20-ML-01] for grinding. Water serves as the grinding medium and is added to the feed spout.

The ground ore [pulp] flows through the discharge grates into the mill discharge hopper where it is pumped to the cyclone feed hopper. The oversize from the trommel is transferred via a 600mm wide Primary Ball Mill Discharge Conveyor [30-CV-04] onto a 600mm wide Pebble Crusher Feed Conveyor [30-CV-05] into a Pebble Crusher [30-CR01]. The crushed product is transferred onto the Primary Ball Mill Feed Conveyor via a 600mm wide Pebble Crusher Discharge Conveyor [30-CV-06]. Tramp magnets are placed above the discharge end of the Primary Mill Discharge Conveyor and the feed end of the Pebble Crusher Feed Conveyor to remove any steel balls and scrap metal from the conveyor using the principle of magnetic susceptibility.

The pulp in the cyclone feed hopper is pumped to a cyclone nest. Classification is effected by the centrifugal motion of the slurry in the hydrocyclones. The coarse material spirals down the walls of the hydrocyclone as the underflow and this flows into the split underflow feeding the Secondary Ball Mills No. 1 and 2 (45% and 55% into Secondary Ball Mill number 1 and 2 respectively).

The cyclone nest is configured to direct split underflow to each mill. Nine cyclones operating on the left side feed Secondary Ball Mill number 1 and eleven cyclones operating on the right side feed Secondary Ball Mill number 2. Total number of cyclones on the nest is 22. Two other positions on the nest are on standby.

The fine material in the overflow from the classification process flows by gravity to two trash screens, with one of them feeding the thickener and the other feeding the leach feed hopper (Anon, 2009).

2.1.8.5 Pre-Leach Thickener

The Thickener Circuit is the third processing stage in the gold processing circuit. The Thickener operator is responsible for the smooth and safe operation of the circuit. The purpose of the Thickener circuit is to thicken the slurry from the grind circuit in preparation for leaching in the CIL circuit.

Cyclone underflow gravity flows into the trash screen distribution box onto the two trash screens. The oversize of the trash screens reports into the trash basket (normally consisting of wood, grit etc.). The feed to the thickener reports to the thickener well where flocculant is added to thicken the feed. Thickened solids are pumped from the bottom of the thickener by variable speed duty or standby Thickener Underflow Pumps, operating under the control of a bed mass detector and controller which maintains a constant bed mass in the thickener. There is a recycle pump that can be used to recycle the underflow during plant maintenance or shutdowns.

The Pre-Leach Thickener Area Sump Pump is provided to assist with cleaning up any spillage (Anon, 2009).

2.1.8.6 Leach and Adsorption Circuit

Leaching is the chemical process of liberating gold into solution by using lixivants in the presence of oxygen. Cyanide is the commonest lixiviant used in the leaching process.

Adsorption is the process of gold extraction from solution with activated carbon. An **overall** summary reaction is as follows:



At the Chirano Gold Mines Ltd processing plant, the Carbon-In-Leach [CIL] process is employed in the leaching and adsorption of gold. In the CIL process the activated carbon is transferred counter current to the flow of the leach feed. The activated carbon is added to the pulp in the adsorption tanks as cyanidation takes place so that adsorption of gold by carbon takes place simultaneously with gold dissolution. In the leaching and adsorption circuit there is one [1] leach tank and nine [9] adsorption tanks. These tanks are interconnected with launders for slurry flow. The nine adsorption tanks have two intertank screens and an agitator fitted in each of them. The leach tank is equipped with only an agitator.

The feed from the thickener is pumped into the leach feed distribution box where 25% Sodium Cyanide [NaCN] is added via a dosing pump. The resultant mixture gravity flows to the leach tank, where the dissolution of gold commences. The gold forms a complex in the presence of oxygen in the leach tank. The agitator helps to stir the pulp in the tanks thereby preventing the slurry from settling. The slurry in the leach tank gravity flows to adsorption tank 1 and moves sequentially to the other adsorption tanks and finally to adsorption tank 9. The intertank screens fitted in the adsorption tanks prevent the carbon in the tanks from flowing back downstream.

Activated carbon is progressively air lifted from adsorption tank 9 to 8 and finally to adsorption tank 1, thus the carbon transfer is counter current to the flow of slurry. The loaded carbon in adsorption tank 1 [carbon concentration of 9g/t or more] is pumped to the desorption circuit for gold recovery by desorption. Fresh carbon or recycled carbon spillage is loaded into adsorption tank 9 via an overhead gantry crane through the carbon conditioning tank (Anon, 2009).

2.1.8.7 Stripping Plant and Gold Room Operations

The following operations are carried out in the stripping and gold room areas:

- Acid washing of carbon.
- Stripping of gold from loaded carbon using the Zadra method.
- Electrowinning of gold from pregnant solution.
- Smelting of electrowinning products.

The stripping and gold room area operates 7 days per week, with the majority of loaded carbon preparation and stripping occurring during day shift. The Zadra stripping circuit is operated automatically and contains a separate rubber lined mild steel acid wash column and 2 stainless steel elution columns.

Acid Wash

Loaded carbon is received into the 5 tonne capacity acid wash column. Transfer, fill and acid wash operations are controlled automatically.

During acid washing dilute hydrochloric acid solution of about 2-3% strength is pumped through the bottom strainers inserted in the column to remove contaminants, predominantly carbonates, from the carbon. This process improves the elution efficiency and has the beneficial effect of reducing the risk of calcium-magnesium slagging within the carbon during the regeneration process.

A metered 0.6 bed volumes of dilute acid solution is pumped into the acid wash column and after the predetermined soaking period the loaded carbon is rinsed with water. Water rinsing consists of pumping 4 bed volumes of raw water through the column in order to displace any residual acid from the loaded carbon. Dilute acid and rinse water is disposed of to the tailings hopper. Acid washed loaded carbon is hydraulically transferred from the acid wash column to any of the two elution columns (Anon, 2009).

Zadra Elution Circuit

Strip solution is prepared prior to stripping each new batch of carbon. Sodium hydroxide and sodium cyanide are pumped from the respective storage and mixing tanks into the strip solution tank and mixed with raw water to the required concentrations of cyanide (0.2 w/v %) and caustic soda (2.0 w/v %).

The strip solution is pumped from the strip solution tank through the reclaim heat exchanger and then the inline strip solution heater and injected into the base of the column at a temperature of 110°C. In the Zadra stripping method the gold is continuously eluted from the loaded carbon and the pregnant strip solution fed to the electrowinning circuit. The strip solution is pumped through the carbon in the stripping column and then passed through eluate filters and the reclaim heat exchanger before entering the flash vessel. The pregnant strip solution gravitates from the flash vessel to the electrowinning cells.

Electrowinning and Gold Room

In the Zadra system the elution and electrowinning are integral and continuous operations. When the stripping solution exits the electrowinning cells it gravitates into the strip solution tank and then recirculated to the elution column. The strip solution is recirculated continuously for a designated time of 12 to 16 hours or until the gold level of the strip solution exiting the elution column reaches a desired level. At that stage the barren carbon level should be less than 100 g/t of gold. After the completion of every three elution and electrowinning the strip solution is directed to the CIL feed distributor, allowing any residual gold to be recovered in the CIL circuit.

The electrowinning cells are of polypropylene construction with lockable lids and sloping floors and are located within the security area of the gold room. Rectifiers, one per cell, are located in a non-secure area allowing operators and maintenance access without going through security checks. Elution circuit 1 utilises three electrowinning cells in series and Elution circuit 2 uses only a single, larger electrowinning cell.

The four electrowinning cells are fitted with stainless steel anodes and stainless steel wool cathodes. A direct current is passed through the cells between the electrodes and the electrolytic action causes the gold in solution to deposit on the cathodes. The gold is removed from the stainless steel wool cathodes by high pressure water blasting and the sludge filtered in a pressure filter. The concentrate is then placed in an oven for further drying and calcination prior to smelting.

Overhead electric chain hoists are provided to assist with handling of cathodes as necessary.

Gold Barring

The filtered gold sludge recovered from the cathodes of the carbon elution / electrowinning circuit is directly smelted with fluxes in a diesel-fired furnace to produce doré bars.

Fume extraction equipment removes noxious and other harmful gases from the electrowinning cells and barring furnace.

Carbon Regeneration

After completion of the elution process, the barren carbon is transferred from the elution column to a dewatering screen prior to entering the feed hopper of one of the two horizontal carbon regeneration kilns. In the kiln feed hopper any residual and interstitial water is drained from the carbon before it enters the kiln. Kiln off-gases are used to dry the carbon prior to entering the kiln.

The carbon is heated to 650 - 750°C and held at this temperature for 15 minutes to allow regeneration to occur. Regenerated carbon from the kiln discharges to a single deck carbon sizing screen located above Ads tank 6. The carbon sizing screen is fitted with a 1.0 mm square aperture woven wire screen cloth. Carbon reporting to screen oversize is returned to Ads tank 9 and the fine carbon reporting to screen undersize is discharged directly to the tailings hopper (Anon, 2009).

Tailings Disposal

Tailings gravitate from the final adsorption tank (Ads tank 9) to the tailings hopper via the carbon safety screen and are pumped with variable speed pumps to the tailings dam. The tailings dam comprises of a cross-valley storage located towards the eastern boundary of the Chirano tenement, approximately 1 km east-south-east of the plant site. The tailings

contained within the basin by four zoned embankments constructed using mine waste and fill sourced from within the facility basin or adjacent to the facility.

Tailings is discharged into the facility using sub-aerial deposition methods, through a combination of banks of conventional spigot type discharges at regular intervals, and also single point discharges from the heads of valleys. This will generate and maintain a supernatant pond near the centre of the facility where a perforated concrete tower equipped with a submersible pump is located. The supernatant water is pumped back to the process water pond.

The design incorporates a partial basin under drainage system to reduce seepage, and a drain located at the upstream toe of the embankment to lower the phreatic surface passing through the embankment. The toe drain and the under drainage system drain by gravity to a collection sump located at the downstream toe of the main tailings storage facility embankment. This under drainage water is pumped back into the tails dam (Anon, 2009).

2.1.8.8 Reagents

Lime

Provision has been made for quicklime to be delivered in bulk 35 tonne road tankers. The road tankers are pneumatically unloaded directly to the 58 tonne silo in the crushing plant. Quicklime is metered via a rotary valve directly onto the Primary Mill feed conveyor CV-02 for circuit pH control.

Cyanide

Cyanide is delivered in 1.1 tonne bulk bags. The bulk bags are lifted by monorail hoist to an enclosed bag breaker above a cyanide mixing tank. Cyanide is mixed to a 20% w/v solution with process water and then transferred to a cyanide solution storage tank.

Cyanide is added to the leach feed distributor by duty and standby fixed speed, centrifugal distribution pumps. Cyanide is dosed into the strip solution tank during preparation and mixing of the strip solution via a dedicated variable speed, positive displacement pump.

Caustic

Caustic is delivered in 1000kg bulk bags and is added to the caustic mixing tank using an overhead chain hoist. The tank is initially filled with water and sodium hydroxide is added to the tank from the bulk bags via a bag splitter. Caustic is dosed into the strip solution tank during preparation and mixing of the strip solution via a dedicated variable speed, positive displacement pump.

Hydrochloric Acid

Hydrochloric acid is delivered in 1000 litre IBC drums. The tank is initially half filled with raw water. The concentrated hydrochloric acid (32% w/w) is then dosed into the tank directly from the 1000 litre IBC drum. A solution concentration of 3% w/w HCl will be achieved. The diluted acid is delivered to the acid wash column by the dedicated centrifugal magnetic drive pump.

Activated Carbon

Fresh activated carbon is delivered in 550 kg bulk bags. The bulk bags are lifted by the CIL gantry crane to the carbon conditioning tank on top of the CIL deck.

Flocculant

Flocculant is received in 25kg bags and manually lifted into the feed hopper on the mixing plant. It is blown into a cyclone mixer and mixed to solution strength of 0.25% w/v with raw water and then aged in the mixing tank. It is transferred to a storage tank from which it is distributed to the thickener feed well by metering pump. The solution is further diluted with raw water to solution strength of 0.025% w/v prior to the thickener (Anon, 2009).

2.2 HEAVY METALS

Heavy metals are metallic elements which have a high atomic weight and a density much greater (at least 5 times) than water. There are more than 20 heavy metals, but four are of particular concern to human health: lead (Pb), cadmium (Cd), mercury (Hg), and inorganic arsenic (As). According to the U.S. Agency for Toxic Substances and Disease Registry, these four heavy metals are four of the top six hazards present in toxic waste sites. They are highly toxic and can cause damaging effects even at very low concentrations. They tend to accumulate in the food chain and in the body and can be stored in soft (e.g., kidney) and hard tissues (e.g., bone). Being metals, they often exist in a positively-charged form and can bind on to negatively-charged organic molecules to form complexes (http://tuberoze.com/Heavy_Metal_Toxicity.html). Some well-known toxic metallic elements with a specific gravity that is 5 or more times that of water are arsenic, 5.7; cadmium, 8.65; iron, 7.9; lead, 11.34; and mercury, 13.546 (Lide, 1992).

There are 35 metals that concern us because of occupational or residential exposure; 23 of these are the heavy elements or "heavy metals": antimony, arsenic, bismuth, cadmium, cerium, chromium, cobalt, copper, gallium, gold, iron, lead, manganese, mercury, nickel, platinum, silver, tellurium, thallium, tin, uranium, vanadium, and zinc (Glanze, 1996).

Interestingly, small amounts of these elements are common in our environment and diet and are actually necessary for good health, but large amounts of any of them may cause acute or chronic toxicity (poisoning) (International Occupational Safety and Health Information Centre, 1999). Heavy metals are also common in industrial applications such as in the manufacture of pesticides, batteries, alloys, electroplated metal parts, textile dyes, steel, and so forth. (International Occupational Safety and Health Information Centre 1999). Many of these products is in our homes and actually adds to our quality of life when properly used.

2.3 TOXICITY OF HEAVY METALS

One reflection of the importance of metals relative to other potential hazards is their ranking by the U.S. Agency for Toxic Substances and Disease Registry (ATSDR), which lists all hazards present in toxic waste sites according to their prevalence and the severity of their toxicity. The first, second, third and sixth hazards on the list are heavy metals: lead, mercury, arsenic and cadmium respectively (ATSDR, 1999).

Several of the metals are essential to the human body. The metals are mainly utilized in enzymes to make them function properly. But we only need the metals in small quantities (WHO, 1996). Some of them we need as trace elements and some are non-essential for us. Calcium, sodium and magnesium are essential metals and cobalt, molybdenum, selenium, chromium, nickel, vanadium and silicon are added as trace metals. Mercury and cadmium are examples of non-essential metals (Walker and Sibly 2001). Heavy metals important in environmental and health issues are for example Arsenic, Lead,

Cadmium, Copper, chromium, Mercury, Zinc, Cobalt, Nickel, Tin and Vanadium (SEPA, 2003). Those are not normally a part of the human body and are more poisonous to us than other metals (WHO, 1996). Many metals can be stored in living tissue and remain there for a long time (SEPA, 2003). If a metal acts as a pollutant or becomes harmful to our health depends on both the properties of the metal and the environment it is acting in. Both humans and plants exhibit a big variation concerning both the need of essential metals and the sensitivity to non-essentials metals and to high levels of essential metals and trace metals. Some metals are harmful mostly to plants, for example zinc, nickel and chromium, and some mostly to animals, for example cadmium and molybdenum (Pettersson, 1994).

Heavy metals become toxic when they are not metabolized by the body and accumulate in the soft tissues. Heavy metals may enter the human body through food, water, air, or absorption through the skin when they come in contact with humans in agriculture and in manufacturing, pharmaceutical, industrial, or residential settings. Industrial exposure accounts for a common route of exposure for adults. Ingestion is the most common route of exposure in children (Roberts, 1999). Children may develop toxic levels from the normal hand-to-mouth activity of small children who come in contact with contaminated soil or by actually eating objects that are not food (dirt or paint chips) (Dupler, 2001).

2.4 COMMON ROUTE OF EXPOSURE OF HEAVY METALS

The three major routes of entry of toxic chemicals into the human body are: inhalation, skin absorption and ingestion. The oral route (or ingestion) is usually thought to be a minor pathway for workplace exposure but since most of the effluents from the mines

contaminate surface and underground water bodies, in this case, ingestion becomes a significant route by which toxic chemicals from the mines enter the body of residents in the study area (Obiri, 2009).

A very important route for the absorption of toxicants into the body is through the gastrointestinal tract. Metals such as lead, arsenic, cadmium, etc are absorbed into the cells lining the intestinal tract by

- Passive or facilitated diffusion.
- Specific transport processes.
- Active transport (Guidotti, 1976).

2.5 FACTORS AFFECTING THE MOBILITY OF HEAVY METALS IN THE ENVIRONMENT

Besides the metals man have created through nuclear reactions the rest have been on earth since the planet was formed (Walker and Sibly 2001). The metals exist naturally in the bedrock and are released through weathering. In water, metals exist in different forms, both solved and suspended, depending on a number of different parameters. The solubility, transportation and toxicity differ between different metal species. The transportation of metals with groundwater is normally affected by sorption to solid aquifer material (Appelo and Postma, 1999). The most important chemical retention mechanisms are sorption

processes and precipitation (Espeby and Gustafsson, 2001). Other chemical processes of importance are redox reactions and complexation. An increased aqueous complexation often makes an element more soluble, but the form is often less toxic. The redox status decides the speciation of some redox-sensitive elements. Different redox species have different retention capacity and the redox status is important for transport (Espeby & Gustafsson 2001). These mechanisms and the mobility of metals are affected by a number of different parameters e.g. the oxidation state of the metal ion, pH and Eh (Appelo and Postma 1999). Determining the mobility of heavy metals is a very complex matter.

2.6 CONCENTRATION OF Pb, Cd, As and Hg in SURFACE AND GROUNDWATER

In some places groundwater is in hydraulic contact with rivers and recharge from them can also take place (Kortatsi, 2004). The groundwater composition varies widely and is a combined result of the composition of the water entering the groundwater reservoir and the reactions with minerals present in the rock that may modify the water composition. Some minerals dissolve quickly and significantly change the water composition, like carbonates, others dissolve slowly and have less effect on the water composition, like silicates. The retention time is also important in determining the water chemistry. Long residence times allow reactions to take place and these waters are likely to have higher concentrations of ions than water with short residence times (Appelo and Postma, 1999). Usually in unaffected environments the concentration of most metals is very low and is mostly determined by the mineralogy and the weathering (Espeby and Gustafsson, 2001). There are a few examples of local metal pollution through natural weathering but in most cases

metals become an environmental and health issue because of anthropogenic activity. Mainly mining and smelting plants release metals from the bedrock (Walker and Sibly, 2001). Soil concentration of adsorbing surfaces (oxide surfaces, clay mineral and humic substances) and the pH are very important parameters effecting the transportation of metals in the groundwater system (Espeby and Gustafsson, 2001).

Lead is the most common of the heavy elements, accounting for 13 mg/kg of the earth's crust. More than 80% of the daily intake of lead is derived from the ingestion of food, dirt, and dust. That means that an average of 5 $\mu\text{g/l}$ lead intake from water forms a relatively small proportion of the total daily intake for children and adults. Lead is possible human carcinogen (evidence inadequate in humans, sufficient in animals) and it is also a cumulative poison so that any increase in the body burden of lead should be avoided. A provisional tolerable daily intake is set to 3.5 μg of lead per kg of body weight for infants lead to a calculated guideline value of 0.01 mg/l. As infants are considered to be the most sensitive subgroup of the population, this guideline value will also be protective for other age groups (WHO, 1996).

Cadmium concentrations in unpolluted natural waters are usually below 1 $\mu\text{g/l}$. Median concentrations of dissolved cadmium measured at 110 stations around the world were less than 1 $\mu\text{g/l}$. The maximum value recorded being 100 $\mu\text{g/l}$ in the Rio Rimao in Peru. Food is the main source of cadmium intake. Crops grown in polluted soil or irrigated with polluted water may contain increased concentrations, as may meat from animals grazing on contaminated pastures. The estimated lethal oral dose for humans is 350-3500 mg of

cadmium; a dose of 3 mg of cadmium has no effects on adults. A guideline value for cadmium is calculated to 0.003 mg/l drinking-water (WHO, 1996).

The level of arsenic in natural waters generally varies between 1 and 2 µg/l. Concentrations may be elevated, however, in areas containing natural sources; values as high as 12 mg/l have been reported. In view of reducing the concentration of arsenic in drinking-water, a provisional guideline value of 0.01 mg/l is recommended. The guideline value has been derived on the basis of estimated lifetime cancer risk (WHO 1996).

Almost all mercury in uncontaminated drinking water is thought to be in the form of Hg²⁺. It is only the carbon-mercury bond in organic mercury compounds that are chemically stable. The solubility of mercury compounds in water varies. Mercury(II) chloride is readily soluble, mercury(I) chloride much less soluble, mercury sulphide has a very low solubility and elemental mercury vapour is insoluble. Some anaerobic bacteria are capable of mercury methylation. Methyl mercury can then easily enter the food chain as a consequence of rapid diffusion and tight binding to proteins. Environmental levels of methyl mercury depend on the balance between bacterial methylation and demethylation. Naturally occurring levels of mercury in groundwater and surface water are less than 0.5 µg/l. The WHO guideline value for total mercury is 0.001 mg/l (WHO, 1996).

2.7 SOURCES OF WATER FOR THE MINE FRINGE COMMUNITIES

The CGML Project Area lies partly within the Suraw sub-basin of the Tano river basin and partly in the main Ankobra basin. These two major rivers drain the southwestern parts of Ghana into the Atlantic Ocean. The Project Area is drained principally by the main Suraw

River and its tributaries. Smaller catchments include the Mamnao stream in the north and the Paboase stream to the south. The streams and rivers draining the Project Area receive flow contributions, which originate from sites where future mining activities will be developed. Therefore, the main mining area is comprised of headwaters for these tributaries. Within the Project Area, most of these water bodies are devoid of major pollution problems. They are used, mainly during the rainy season, as sources of potable water by the inhabitants of the settlements located near their banks (Chirano Gold Project EIS, 2004)

The immediate communities in and around Chirano Gold Mines mining lease area are Etwebo, Kwaokrom, Anyinasie and Surano all in the Bibiani- Anhwianso –Bekwai District and Akoti, Paboase in the Sefwi Wiawso District. In addition to these villages, there is a preponderance of scattered hamlets. To date, CGML has identified 21 hamlets occurring within the boundary of its proposed Mining Lease (Chirano Gold Project EIS, 2004).

Use of groundwater resources, mainly for domestic purposes, is common in the Bibiani Anwiaso-Bekwai District. Shallow wells have been dug down to about 20 ft (7 m). Deep wells have also been bored to provide potable water. All the main villages of the Project Area have access to at least one borehole equipped with hand-activated pump (Chirano Gold Project EIS, 2004).

Surface water quality is typical of rural areas in Ghana. The pH was generally near neutral to slightly acidic ranging from 5.2 to 7.4 and a mean of 6.5. Surface water analysis results obtained as part of the baseline survey showed high values for Apparent colour and turbidity for most of the samples and always exceeded the WHO guideline values. Levels

of suspended solids (TSS) were generally high, though a few samples had concentrations below the 20 mg/l quoted by the WHO guideline values. Very low concentrations of arsenic (As) were found in most of the samples and for all the sampling periods.

Results of groundwater analysis undertaken as part of the baseline survey exhibited values for pH ranging from 5.5 to 7.8. Of fifteen heavy metals analyzed, iron, manganese and zinc were detected in the majority (93%) of the samples analyzed. Arsenic was also detected in some of the samples (approximately 43%). Concentration of arsenic was generally well below GWSC and WHO guideline values (0.010 mg/l) (Chirano Gold Project EIS, 2004).

2.8 POSSIBLE EFFECTS OF MINING ON LOCAL WATER BODIES IN THEIR CATCHMENT AREAS

Mining by its nature consumes, diverts and can seriously pollute water resources. Negative impacts can vary from the sedimentation caused by poorly built roads during exploration through to the sediment, and disturbance of water during mine construction. Water pollution from mine waste rock and tailings may need to be managed for decades, if not centuries, after closure. These impacts depend on a variety of factors, such as the sensitivity of local terrain, the composition of minerals being mined, the type of technology employed, the skill, knowledge and environmental commitment of the company, and finally, the ability to monitor and enforce compliance with environmental regulations.

There are four main ways in which mining impact on water quality negatively. These are:

- Acid Mine Drainage (AMD) is a natural process whereby sulphuric acid is produced when sulphides in rocks are exposed to air and water. Acid Mine Drainage (AMD) is essentially the same process, greatly magnified. When large quantities of rock containing

sulphide minerals are excavated from an open pit or opened up in an underground mine, it reacts with water and oxygen to create sulphuric acid. When the water reaches a certain level of acidity, a naturally occurring type of bacteria called *Thiobacillus ferroxidans* may kick in, accelerating the oxidation and acidification processes, leaching even more trace metals from the wastes. The acid will leach from the rock as long as its source rock is exposed to air and water and until the sulphides are leached out – a process that can last hundreds, even thousands of years. Acid is carried off the mine site by rainwater or surface drainage and deposited into nearby streams, rivers, lakes and groundwater. AMD severely degrades water quality, and can kill aquatic life and make water virtually unusable.

- Heavy metal pollution is caused when such metals as arsenic, cobalt, copper, cadmium, lead, silver and zinc contained in excavated rock or exposed in an underground mine come in contact with water. Metals are leached out and carried downstream as water washes over the rock surface. Although metals can become mobile in neutral pH conditions, leaching is particularly accelerated in the low pH conditions such as are created by Acid Mine Drainage.
- Processing chemicals pollution occurs when chemical agents (such as cyanide or sulphuric acid used by mining companies to separate the target mineral from the ore) spill, leak, or leach from the mine site into nearby water bodies. These chemicals can be highly toxic to humans and wildlife.
- Erosion and sedimentation of rivers and streams in mining communities occurs during mineral development. Soil and rock are disturbed in the course of constructing and maintaining roads, open pits and waste impoundments. In the absence of adequate prevention and control strategies, erosion of the exposed earth may carry substantial

amounts of sediment into streams, rivers and lakes. Excessive sediment can clog riverbeds and smother watershed vegetation, wildlife habitat and aquatic organisms (Obiri, 2009).

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2.9 SOURCES AND TOXICITY OF Pb, Cd, As, AND Hg

2.9.0 Sources and toxicity of Lead

The dominant source of worldwide dispersion of lead into the environment (and into people) for the past 50 years has clearly been the use of lead organic compounds as antiknock motor vehicle fuel additives. Since leaded gasoline was introduced in 1923, its combustion and resulting contamination of the atmosphere has increased background levels everywhere, including the ice cap covering Northern Greenland where there is no industry and few cars and people (USEPA, 1986).

A number of factors can modify the impact of lead exposures. For example, water with a lower pH (such as drinking water stemming from the collection of untreated “acid rain”) will leach more lead out of plumbing connected by lead solder than more alkaline water (Moore, 1985). The general body of literature on lead toxicity indicates that, depending on the dose, lead exposure in children and adults can cause a wide spectrum of health problems, ranging from convulsions, coma, renal failure, and death at the high end to subtle effects on metabolism and intelligence at the low end of exposures (ATSDR, 1999). A plethora of well-designed prospective epidemiologic studies has convincingly demonstrated that low-level lead exposure in children less than five years of age (with

blood lead levels in the 5-25 $\mu\text{g/dL}$ range) results in deficits in intellectual development as manifested by lost intelligence quotient points (Banks et al., 1997).

2.9.1 Sources and toxicity of Cadmium

Cadmium is chemically similar to zinc and occurs naturally with zinc and lead in sulphide ores. Cadmium is a soft, ductile metal which is obtained as a by-product from the smelting of lead and zinc ores. It is also found in chalcophiles as a mineral called greenockite, CdS . Volcanic eruption is also another source of cadmium in the environment. Naturally, cadmium levels in the atmosphere are thought to be about 2ng/m^3 though high values are found near zinc smelters.

The anthropogenic sources of cadmium in the environment poses serious threat because of its surface input to soil system making the metal more accessible for plant and animal uptake. Cadmium is obtained mainly as a by-product during the processing of zinc-bearing ores and from the refining of lead and copper from sulphide ores. Cadmium is used primarily for the production of nickel-cadmium batteries, in metal plating, and for the production of pigments, plastics, synthetics and metallic alloys. Cadmium has been shown to be toxic to human populations from occupational inhalation exposure and accidental ingestion of cadmium contaminated food. Inhalation of cadmium dust in certain occupational settings may be associated with an increased incidence of lung cancer. Other symptoms include; irritation of upper respiratory tract, metallic taste in the mouth, cough and chest pains (Foulkes, 1986). Ingestion of elevated levels of cadmium has resulted in

toxicity to the kidney and skeletal system and may be associated with an elevated incidence of hypertension and cardiovascular disease.

2.9.2 Sources and toxicity of Arsenic

Arsenic is a naturally occurring element in the earth's crust. Arsenic is a metalloid, behaving more like a non-metal than a metal. It forms compound with oxygen. That makes As mobile in both oxidizing and reducing environments and it is mainly controlled by adsorption. That makes solid concentrations of oxides and hydroxides of Fe, Al and Mn essential parameters for controlling As transportation (Smedley and Kinniburgh, 2001). They are found alongside the gold ores such arsenopyrites (FeAsS) (Coakley, 1996). Arsenic is usually present in the environment in inorganic form. The inorganic arsenic easily dissolves and enters underground and surface waters. The presence of arsenic in the environment may be attributed to one of the following sources: residual arsenic from former pesticidal use, smelter emission from ores of gold such as arsenopyrites from the sulphur treatment plant. Arsenic in the study area is moderately high as reported by Africa Environmental Research and Consulting Company Limited during their studies on two water holding ponds which are fed by the Suraw River (Unpublished data, 2010). The U.S. National Research Council has recently concluded, based on epidemiologic studies that the evidence is now sufficient to include lung and bladder cancer, along with the skin cancers, as being caused by ingestion of inorganic arsenic (NRC, 2001). They further concluded that there is some indication that arsenic may induce cancers in other organs, although the evidence is not as strong. Chronic arsenic exposure has been

implicated in several noncancerous conditions, in particular, skin disease, diabetes mellitus, hypertension and cardiovascular disease, perturbed porphyrin metabolism, and irreversible noncirrhotic portal hypertension (NRC, 2001). It has been long known that arsenic exposure is associated with skin pathology, including hyper pigmentation, hyperkeratosis, and skin cancers. In the majority of cases in which an internal cancer has been ascribed to arsenic exposure, a dermatologic hallmark of arsenic poisoning was also identified (Tsai et al., 1999). Effects of arsenic on the liver have been suggested in a few case reports, although the pathology has not been well described. In addition to noncirrhotic portal hypertension (Nevens et al., 1990), other liver pathology has been described, including hepatic enlargement, hepatocellular carcinoma (Centeno et al., 2000), and liver angiosarcoma (Neshiwat et al., 1992). Franblau and Lillis (1989), reported two cases of sub – chronic (2 months) arsenic intoxication resulting from ingestion of contaminated well water (9 – 10.9mg/L), sporadically (once or twice a week) for about two months. Acute gastrointestinal symptoms, central and peripheral neuropathy, bone marrow suppression, hepatic toxicity and mild mucous membrane and cutaneous changes were observed. The calculated dose was between 0.03 – 0.08mg/Kg/day based on a body weight of 65kg and ingestion of arsenic from 238 to 475ml water/day. The effects observed for the short –term arsenic exposure (appearance of edema, gastrointestinal or upper respiratory symptoms), differ from those for long – term arsenic exposure (skin disorders and damages to the nervous system). Symptoms such as peripheral neuropathy appeared in some of the subjects or individuals even after cessation of the arsenic intake (USEPA, 1988). According to Tseng, et al., (1968), chronic dermal exposure to arsenic causes skin cancer. The prevalence of skin cancer is very high in areas where chronic exposure to inorganic arsenic is very high. Tseng noted that, hyperpigmentation, keratosis and possible

vascular complications were seen at LOAEL = 0.17mg/L (0.014mg/kg/day). The NOAEL = 0.009mg/L of water

(0.0008mg/kg/day).

According to (IARC, 1980), inorganic form of arsenic is classified as a class A Carcinogen (Human Carcinogen). This classification is based on sufficient evidence from human data. That is, increased lung cancer mortality was observed in multiple populations exposed to arsenic primarily through drinking of arsenic contaminated water. Again, an increased mortality from multiple internal cancers (liver, kidney, lung and bladder) and an increased incidence of skin cancer had been observed in populations consuming drinking water with high inorganic arsenic concentration.

2.9.3 Sources and toxicity of Mercury

Elemental mercury is a silvery metallic liquid that is volatile at room temperature. Mercury is found in soil and rocks typically as an ore known as cinnabar, consisting of insoluble mercuric sulphide. In Ghana, the presence of mercury in the environment may be attributed to the use of mercury in gold recovery processes where the inorganic form of the metal either is washed into rivers or is vaporized readily into the atmosphere (Obiri, 2005; Essumang *et al.*, 2007). Mercury compounds are also used as germicides and fungicides, and as industrial catalyst in the manufacture of plastics, pulp paper, paints, cosmetics, batteries, etc. Mercury is a non essential element, a neurotoxin and has teratogenic effects. It also affects the renal system, nervous system, gastrointestinal tract and the respiratory system. It is responsible for the death of 52 people in Minamata, Japan in 1952 through eating of contaminated fish (Lee, 1994). Mercury has been shown to be toxic to human

populations because of occupational exposure and accidental ingestion of mercury-contaminated food. The nature of mercury toxicity depends on its chemical form. For example, methylmercury is very toxic as compared to inorganic mercury. The methylmercury is of special concern because of its enhanced lipophilicity, bioaccumulation and volatility as compared with the inorganic mercury. For this reason, it is able to cross biological membranes more easily and enters the brain, spinal cord, the peripheral nerves and the placenta. The foetus in the uterus may show symptoms of cerebral palsy through mercury intoxication, even though the mother may not show symptoms of mercury poisoning (Kpekata, 1974; W.H.O., 1990). Accidental ingestion exposure to high levels of organic mercury compounds has produced developmental toxicity in humans. Aryl mercury compounds are even more dangerous and cause brain damage giving numbness, loss of vision, deafness, madness and death (W.H.O., 1990). The USEPA has classified both mercuric chloride and methylmercury as possible human carcinogens (Group C), based on the absence of data in humans and limited evidence of carcinogenicity in animals, whereas elemental mercury is in Group D, i.e., not classifiable due to inadequate data (Barregard, 1990). Exposure to mercury (II) fumes or ions in water body contaminated with both inorganic and organic mercury causes respiratory damage, damage to the brain and may result in death after long period of exposure.

2.10 HEAVY METALS IN STREAM BOTTOM SEDIMENTS OF THE PROJECT AREA.

Stream bottom sediments collected in the main streams and rivers of the Project Area are generally below the optimum guideline values proposed by the New Dutch List with the exception of mercury (approximately 10 times higher). These relatively high

concentrations of mercury in sediments may have resulted from past alluvial galamsey activities or old mine workings which took place within the Project Area at the beginningth of the 20 century. All the samples have concentration of major metals well below the level set by the New Dutch List for cleaning action (Chirano Gold Project EIS, 2004). African Environmental Research Company (AERC) (2009) conducted an assessment of water and sediment quality and evaluation of heavy metal in two water holding ponds on the mine which are supplied with water principally from the Suraw River as part of the baseline survey. They reported concentrations in samples of the storage pond as follows: As: 0.22-0.18; Cd: <0.01-0.23; Cr: 1.4-3.0; Fe: 2327-2954; Pb: 2.4-4.4; and Zn concentration 5.1-41.3 mg kg⁻¹ were found. The heavy metal concentrations in the ponds decreased in the sequence of Fe > Zn > Pb > Cr > Cu > As > Cd. The sequence is virtually the same for the Suraw pond but with slightly higher concentrations of heavy metals. In comparison with the sediment screening guidelines, all the heavy metals with the exception of Fe were below the guideline of even the lowest effect level (LEL).

Table 2.1 The proposed New Dutch List of sediment target and intervention values

Contaminant (Heavy metal)	Target value (mg/kg dry wt)	Intervention value (mg/kg dry wt)
Pb	85.0	530.0
Cd	0.8	12.0
As	29.0	55.0
Hg	0.3	10.0

Source: Target and intervention values – Soil Quality Standards issued by the Ministry of Housing, Planning and Environment, Netherland (2001).

Table 2.2 Freshwater sediment Guideline by NOAA, 2009 for the four metals investigated

Heavy Metal	Pb	Cd	As	Hg
LEL (mg/kg) (Lowest Effect Level)	31.000	0.600	6.000	0.200
TEC (mg/kg) (Threshold Effect Concentration)	35.000	0.596	5.900	0.174
PEC (mg/kg) (Probable Effect Concentration)	91.300	3.530	17.000	0.486
SEL (mg/kg) (Severe Effect Level)	250.000	10.000	33.000	2.000

Source: National Oceanic and Atmospheric Administration (NOAA), U.S.A (2009).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 STUDY AREA

Chirano Gold Mines Ltd is a Kinross company located in the Bibiani-Anhwiaso-Bekwai (BABDA) and Sefwi Wiawso Districts (SWD) of the Western Region, which lies

between Latitude 6°00'00" N and 6°24'75" N and Longitude 2°21'33" W and 2°24'33" W. The project is about one hundred kilometers (100 km) south-west of the city of Kumasi and fifteen kilometres (15km) south- southwest of the township of Bibiani. The mine has a lease area of about 36 km².

The project lies within the wet-semi-equatorial climatic region of Ghana. The project area is characterized by an annual double maxima rainfall pattern occurring in the months of March to July and from September to mid-November. Approximately 55% to 60% of the total rainfall is recorded during the first rainy season. The mean annual rainfall varies widely from year to year with a mean of 1472.7 mm and a range of 1056.2 mm to 1929.0 mm. The mining company lies partly within the Suraw sub-basin of the Tano River and partly in the main Ankobra basin (Chirano Gold Project EIS, 2004).

3.2 GEOLOGY OF CHIRANO GOLD MINE

Chirano Gold Mines lies within the Proterozoic terrain of southwest Ghana, along a major structure separating the Sefwi Belt to the west from the Kumasi Basin to the east known as the Bibiani Shear zone. The belt and basin architecture comprises rocks of Birimian age, with the belts being dominated by mafic volcanics and the basins typified by fine grained, deep marine sediments. Both are intruded by granites. The project area straddles the boundary between the Sefwi volcanic belt to the west and the sedimentary Kumasi Basin to the east. Throughout the rest of south-western Ghana, this boundary generally trends north-easterly, but the section surrounding Chirano has a northerly trend. In a regional perspective, this change in trend is one of the most obvious characteristics of the Chirano goldfield, and is almost certainly an important factor in the location of the mineralization. A regional digital terrain model shows a prominent north-south topographic lineament passing through Chirano, and also the Bibiani and Ahafo (Yamfo) gold deposits. This lineament can be traced for several hundred kilometres across the whole of Ghana. All the known Chirano gold deposits are hosted by the Chirano granite. The granite is flanked on its western side by mafic rocks ranging from fine grained basalts to medium grained dolerites. The granite is flanked to the east by Tarkwaian sediments, comprising arkosic sandstones, siltstones and minor conglomerates. The granite itself is a composite body, incorporating numerous thin but extensive sheets of mafic rock. The granite is generally thin, and strikes north-northeast, but includes a thicker section with a northerly trend, termed the Paboase Bulge. This bulge may be considered to be a major sinistral jog affecting both the granite and the Chirano Shear.

The gold deposits occur along a single mineralized horizon. They are centred on the Paboase Bulge, but extend for several kilometres to the north and south (Chirano Gold Project EIS, 2004).

3.3 SELECTION OF SAMPLE SITES

Samples were taken at the locations specified in Tables 1.1 and 1.2 as depicted in Figure 3.1. Six sampling sites were chosen for the analysis of As, Cd, Hg and Pb in surface water, and bottom sediments along the Suraw River on the mine. Water samples from boreholes were also taken at five communities downstream of the Suraw River as it flows from the mine. The width of the river along which the experimental sites were selected ranged from about 2.4 m to 6.5 m at the control point and about 6.5 m at the exiting point from the mine respectively. Similarly, the depth was between 0.3 m and about 2.1 m (Appendix 1). S1 is a control site which is upstream and outside the zone of impact of the mining operations. Sampling sites S2 and S3 were drainages from Obra and Tano waste dumps for studying the effects of mining wastes on the River water. S4 was chosen to determine the anthropogenic impact from Akoti and Etwebo communities on the Suraw Rive. S5 sample was collected from the Kolia and Gyae streams which are tributaries of the Suraw River and are considered as part of the upper catchment of the Suraw River. S6 sample was selected as compliance point where the stream leaves the mine take area and enters the environment.

Sampling sites were located with an *eTrex* GPS unit which has accuracy within 3.0 to 6.0 metres. Sample co-ordinates are given in WGS-84 Northern Hemisphere projection.

Table 3.0 GPS location of surface water sampling sites

Sample ID	Northings	Eastings	Site Description
S1	699115.5	569220.5	S1 is the control point outside the zone of mining impact. It is about 1,250m to WD1
S2	697702	568760	S2 is the Suraw River drainage through Obra waste dump
S3	696705.9	568400.5	S3 sample was collected from the Suraw River at the base of the Tano waste dump and about 970 m from S2.
S4	695225	568482	S4 was sampled from the Suraw River after Akoti and Etwebo but before it joins Kolia and Gyae tributary. It is about 1,590 m from S3 sampling site
S5	694982.4	568514.3	S5 is a sample collected from Kolia and Gyae streams which join the Suraw River before it leaves the mine lease area. The sample was taken at a distance of about 340 m from S6

S6	694861.4	569238.5	S6 sampling point is compliance site where the Suraw river exits the mine take area.
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Table 3.1 GPS location of community boreholes

Sample ID	Northings	Eastings	Site Description
G1	695542	567981	G1 is a community borehole at Akoti and about 300 m from G2
G2	695542	567981	G2 is a community borehole at the old Market Centre at Etwebo
G3	694663	569855	G3 is at Kwaokrom community about 2,200 m from Akoti.
G4	693038	570871	G4 is a community borehole at Anyinasie DC Primary School that serves the community with potable water.
G5	692395	571199	G5 is a borehole at Surano community which is about 1,000 m from Anyinasie.

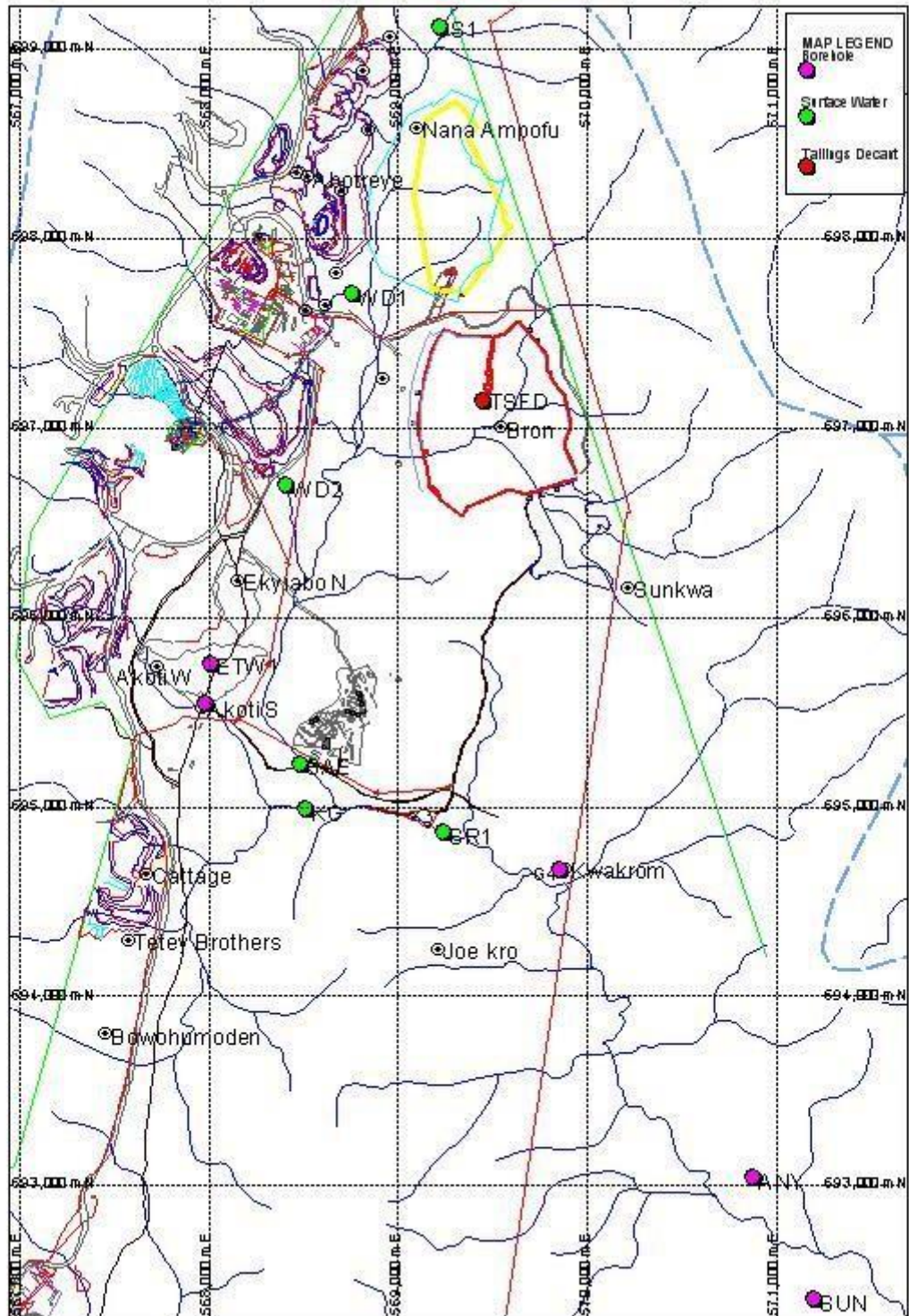


Fig3.1: Map showing locations of sampling points.

3.4 SAMPLE COLLECTION

The equipment used in both the water and the sediment sampling were washed and rinsed with 10% nitric acid and then rinsed with deionized water. Physical parameters such as Temperature, pH, TDS and Conductivity were measured in situ with probes and recorded as Appendix 2 - 3. Two water samples were taken at each site; one unfiltered for total metals and one which was filtered by a peristaltic pump with 0.45 micron filter for the dissolved metals in December 2010 and February 2011. Water samples were collected into one litre polyethylene bottles using the subsurface grab method.



Plate 3.1 Sampling site on the Suraw River at S6.



Plate 3.2 Akoti community borehole sampling site (G 2).

According to Harvey (2002), rapidly flowing streams, rivers and shallow lakes (<5 m) are usually well mixed and show little stratification with depth. Water sampling was done in the middle of the River bed and immediately acidified with concentrated nitric acid to pH less than 2. The samples were then kept below 5°C in an ice cooler. Two duplicate and a reagent blank samples were taken in each batch of sampling for quality control purposes.

The sediment sampling was done in a river flow conditions with a garden trowel in a thick polyethylene bag. About 100g of the bottom sediment were taken at three points from each sampling location and then homogenized into a single composite sample. At each sampling site, the depth and the width of the stream were measured and recorded (Appendix 1). One duplicate sample (SD8) and two additional sediment samples SD9 and SD10 were taken at

a depth of 20 cm at the central point of the river at S3 and S6 sampling stations. These two samples were collected as reference to determine whether the heavy metals have leached below a depth of 15 cm in the river bottom sediment. Heavy metals such as Pb, Cu, Ni and Zn are usually deposited in sediments not deeper than 15 cm (Ochsenbein *et al.*, 1983; Santos Bermejo *et al.*, 2003)

3.5 LABORATORY ANALYSIS

3.5.1 Determination of sediment pH, conductivity, TDS and Temperature

The pH, Temperature, TDS and Conductivity of each sediment sample was determined using probes. About 10g of the wet sediment was mixed with 50 ml of deionized water in a beaker and stirred continuously until it became a uniform mixture. They were labeled and allowed to stand for about 30 minutes after which the readings were taken and recorded (Appendix 4). The pH meter was standardized using standard buffers of pH 4.0 and 7.0.

3.5.2 Digestion of Cd, Pb, As in sediments

The sediment samples were dried in an oven for 48 hrs until constant dry weight readings were attained. They were then pulverized and sieved through a 2 mm stainless steel mesh.

For Cd and Pb $2.00 \pm 0.10\text{g}$ (1.900 – 2.100 g) of the resulting homogenous sample was weighed into a 50ml Digestion tube. 2.5 ml of concentrated HCl (aq) and 2.5 ml of concentrated HNO₃ (aq) were added and waited until effervescence ceased. The content of the tube was mixed by swirling and allowed to stand until any more effervescence had ceased.

The digester block was preheated to 110 ± 4 °C. The temperature was monitored using a calibrated thermometer. Sample was digested at 110 °C for 40 minutes, digestion tube was

then removed from the block and 10mL distilled water was added, and further digested for 20 minutes. Digestion tube was removed from the block and allowed to cool. It was made up to 50.0 ml mark with distilled water, then the cover was placed on and mixed by inverting 3 -4 times. It was allowed to settle for approximately 30 minutes. The clear sample digest was decanted into a clean 10ml plastic tube and submitted for Inductively Coupled Plasma- Optical Emission Spectrometer (ICP-OES) analysis

For As one ml aliquot of the digested sample was dropped into a 25.0 ml volumetric flask to it was added 2.5 ml of concentrated HCl and 10% KI. The resulting solution was allowed to stand for one hour. A few drops of ascorbic acid AR powder were added to discharge any yellow colour of iodine. It was then made up to volume with distilled water and immediately submitted for arsenic analysis by Atomic Absorption Spectrometry.

3.5.3 Determination of Mercury

One gramme of the finely ground and sieved homogenous sediment sample was placed into a 50.0 ml digestion tube. Ten millilitres of (10.0 ml) distilled water, 2.0 ml conc.H₂SO₄, 1ml conc.HNO₃ were added onto the sample and mixed between each addition. 10.0 ml 5% Potassium Permanganate solution was added to the tube. Once the reaction had subsided 2.0 ml of 5% Potassium Persulphate was added. The digestion block was preheated to 95 ± 4 °C and the temperature monitored using a calibrated thermometer. The sample was digested at 95 ± 4 °C for 30 minutes

In Hg preparation and analysis, the digest was cooled and 5.0ml 10% Hydroxylamine Hydrochloride -Sodium Chloride Solution was added to reduce excess KMnO₄. The digest was made up to volume with distilled water and sonicated for 10 minutes. The sample was

submitted for analysis by cold Vapour Atomic Absorption Spectrometry (AAS) within 24 hours of the addition of Hydroxylamine Hydrochloride -Sodium Chloride solution.

3.5.4 Preparation and analysis of the water samples

3.5.4.1 For As

25mL aliquot of the sample was transferred into a 50.0 ml digestion tube, 20.0 ml conc. HCl was added and heated in a digestion block at $105 \pm 4^\circ\text{C}$ for 30 minutes and cooled. Five millilitres (5.0 ml) of 10% KI was added and left to stand for at least 1 hour. A minimum amount of Ascorbic acid powder was added to discharge any yellow colour of iodine. The sample was made up to the 50.0 ml volume with distilled water and immediately submitted for analysis by Hydride Generation AAS.

3.5.4.2 For Hg

25.0 ml of sample was transferred into a 50.0ml digestion tube. Two milliliters (2.0 ml) of conc. H_2SO_4 and 1mL of conc. HNO_3 were added, mixing after each addition.

10 ml 5% potassium permanganate solution and 2.0 ml 5% Potassium Persulphate solution were added to the tube and mixed. The sample was digested for 2 hours in the digestion block maintained at $95 \pm 4^\circ\text{C}$. The sample was cooled and 5.0 ml 10% hydroxylamine hydrochloride -sodium chloride solution was add to reduce excess KMnO_4 .

The sample was made up to the 50ml volume with distilled water. The sample was sonicated for 10 minutes and submitted for analysis by cold Vapour Atomic Absorption Spectrometry.

3.5.4.3 For Cd and Pb

50.0ml of sample was transferred into a 50.0ml digestion tube and 5ml of conc. HNO₃ was added.

The sample was covered with plastic watch glasses and digested for 2½ hours in the digestion block maintained at 95 ± 4 °C then allowed to cool to room temperature. Any condensation on the watch glass was rinsed onto the sample tube and the sample was made up to the 50ml volume with distilled water. The sample was submitted for analysis by ICP-OES.

3.6 SURVEY ON COMMUNITY AWARENESS ON SURAW RIVER QUALITY

The five downstream communities selected for the study were Etwebo, Akoti, Kwaokrom, Anyinasie and Surano based on their proximity and the history of their dependence on Suraw River water. The target population was mostly women and family heads in the households in view of their cultural role of providing water for the household. Households in the five communities were used in the simple random sampling technique instead of individual persons due to the influx of people from other regions into the area in search of mining jobs. There were a total of 780 households in the five communities. Of these, 258 constituting 33% of the total households were selected for the survey (95%CI).

Table 3.2: Sample size used for the questionnaire administration

Community	N	n
Etwebo	160	53
Akoti	141	47
Kwaokrom	40	13
Anyinasie	76	25
Surano	363	120

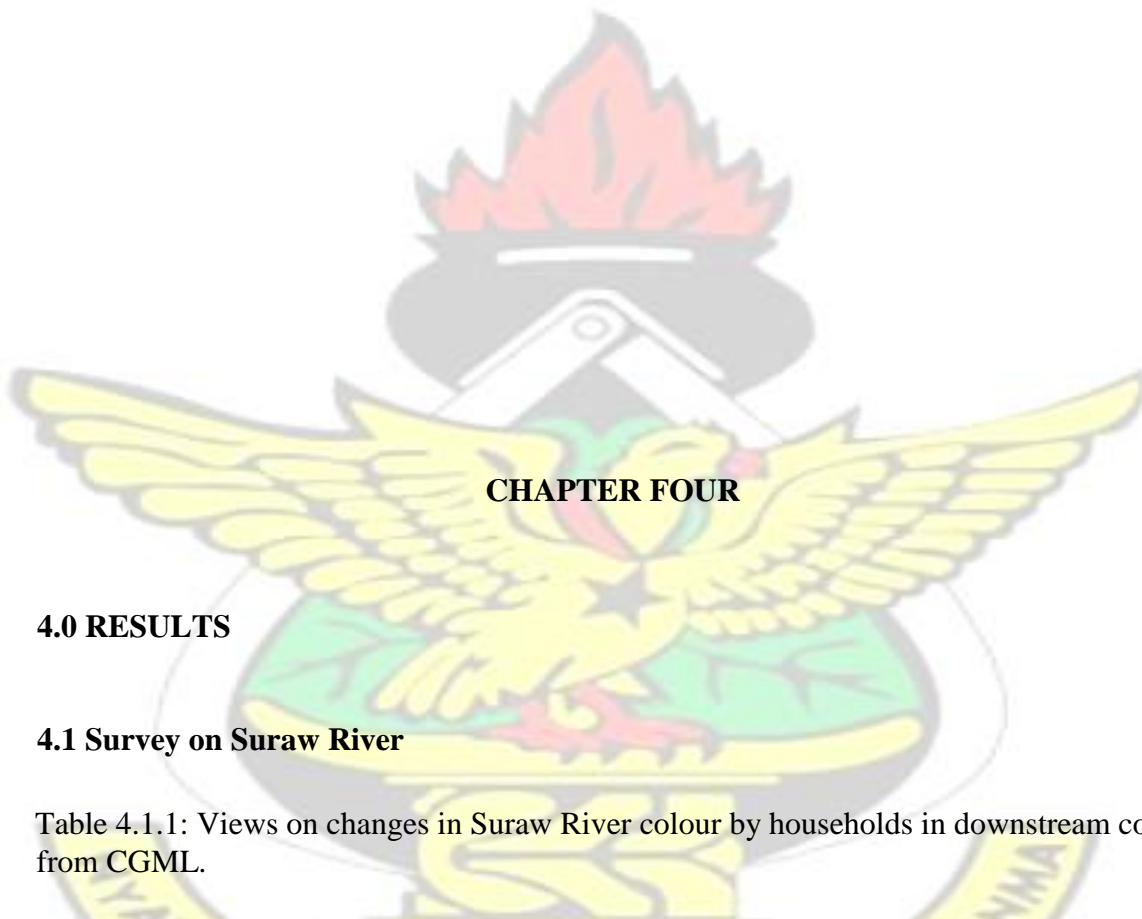
Total	780	258
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Source of the N: CMCP Baseline data (unpublished)

Legend: N: Total number of households in the community

n: Number of households sampled

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CHAPTER FOUR

4.0 RESULTS

4.1 Survey on Suraw River

Table 4.1.1: Views on changes in Suraw River colour by households in downstream communities from CGML.

Change in River colour	Akoti	Etwebo	Kwawkrom	Anyinasie	Surano
Number of Respondents	40	53	13	25	110
Percentage of Respondents	85.1%	100%	100%	100%	91.6%

Table 4.1.2: Views on changes in Suraw River level by households in downstream communities from CGML

Changes in River level	Akoti	Etwebo	Kwawkrom	Anyinasie	Surano
Number of Respondents	15	21	13	20	27
Percentage of Respondents	31.9%	39.6%	100%	100%	22.5%

Table 4.1.1 shows that 241 households representing 93.4% of the sample size had noticed change in the colour of the River. Table 4.1.2 also shows that 96 households which represent 37.2% of the total respondents were of the view that the level of the River has reduced after the commencement of active mining by CGML.

Table 4.1.3: Preference for borehole or Suraw River water by downstream communities.

Indicators surveyed	Akoti	Etwebo	Kwawkrom	Anyinasie	Surano
Number Preferring borehole	45	52	13	25	114
Percentage	95.7%	98.1%	100%	100%	95.0%
Number Preferring Suraw water	2	1	0	0	6
Percentage	4.3%	1.9%	100%	100%	5%
Total	47	53	13	25	120

From Table 4.1.2, 96.5% of the households surveyed preferred the borehole water to the Suraw River. Nine households chose the River water over the borehole. Six of these nine households were in Surano community, two in Akoti and one in Etwebo.

4.2 pH, Temperature, TDS and Conductivity of Suraw River and community boreholes

Table 4.2.1: pH, Temperature, TDS and Conductivity at six sampling sites on the Suraw River (December, 2010).

Station code	pH	Temp. °C	TDS (mg/l)	Cond. (µs/cm)
S1	6.60	26.2	96.80	213.00
S2	7.20	28.0	220.00	484.00
S3	7.40	26.3	381.00	802.00
S4	7.30	26.5	259.00	508.00
S5	7.60	24.7	269.00	547.50
S6	7.30	25.9	288.00	605.00

S1: Control point of the Suraw River in TSFR; S2: Drainage of the Suraw River from Obra waste dump; S3: Drainage of the Suraw River from Tano waste dump; S4: Suraw River across Akoti-Chirano road; S5: Kolia stream before joining Suraw River; S6: Suraw River at the exiting point from the mine

Table 4.2.2: pH, Temperature, TDS and Conductivity at six sampling sites on the Suraw River (February, 2011).

Station code	pH	Temp. °C	TDS (mg/l)	Cond. (µs/cm)
S1	6.70	20.90	94.50	181.70
S2	6.50	25.80	260.00	539.00
S3	7.40	23.50	303.00	605.00
S4	7.60	22.60	232.00	457.00
S5	7.60	22.00	269.00	522.00
S6	7.10	23.00	110.70	227.0

S1: Control point of the Suraw River in TSFR; S2: Drainage of the Suraw River from Obra waste dump; S3: Drainage of the Suraw River from Tano waste dump; S4: Suraw River across Akoti-Chirano road; S5: Kolia stream before joining Suraw River; S6: Suraw River at the exiting point from the mine

Table 4.2.3: pH, Temperature, TDS and Conductivity of selected community boreholes (December, 2010).

Station code	pH	Temp. °C	TDS (mg/l)	Cond. (µs/cm)
G1	6.10	26.30	326.00	328.00
G2	5.45	26.30	65.00	140.30
G3	5.50	27.10	57.40	127.80
G4	5.20	26.60	40.20	88.30
G5	5.70	26.60	26.50	58.10

G1: Borehole water at Akoti junction; G2: Borehole water at Etwebo old Taxi Station; G3: Borehole water at Kwaokrom close to Catholic Church; G4: Borehole water at Anyinasie DC Primary School; G5: Borehole water Surano

Table 4.2.4: pH, Temperature, TDS and Conductivity of selected community boreholes (February, 2011).

Station code	pH	Temp. °C	TDS (mg/l)	Cond. (µs/cm)
G1	5.96	26.00	303.00	304.00
G2	5.60	26.10	78.00	153.80
G3	5.50	27.00	68.40	130.40
G4	5.33	26.80	51.70	90.80
G5	5.64	26.70	23.70	65.10

The pH of the Suraw River at each the six sampling sites were higher than the pH of community boreholes. The pH of the River water ranged between 6.50 and 7.60 while the boreholes recorded pH ranges between 5.20 and 6.10 (Table 4.2.3 and Table 4.2.4).

The highest pH value of 7.60 was recorded at S5 in December 2010 and at S4 and S5 in February 2011 sampling batches respectively.

There was little variation in community borehole temperature (groundwater). It varied between 26.00 °C and 27.10 °C but there was much variation in the Suraw River (Surface water) between 20.90 °C and 28.00 °C (Table 4.2.1 and Table 4.2.2).

Total Dissolved Salts (TDS) of community borehole and Suraw River water samples from the six sites show that the River water values were generally higher than those of the

boreholes and ranged between 94.50 mg/l and 381.50 mg/l whilst it varied between 23.70 mg/l and 326.00 mg/l for the community boreholes. S1 recorded the lowest TDS values of 96.80 mg/l and 94.50 mg/l for December 2011 and February 2011 sampling respectively whilst S3 also registered the highest values for both sampling batches with a value of 381.00 mg/l and 303.00 mg/l for December 2010 and February 2011 samples. For the community boreholes, the least TDS value of 26.50 mg/l and 23.70 mg/l both occurred at G5 whilst the highest values of 326.00 mg/l and 303.00 mg/l were also recorded at G1.

Conductivity measured on both the River water and community boreholes water followed the same trend as TDS. The lowest values of 213.00 $\mu\text{s/cm}$ and 181.00 $\mu\text{s/cm}$ were obtained at S1 and the highest values of 802.00 $\mu\text{s/cm}$ and 605.00 $\mu\text{s/cm}$ were recorded at S3 during December 2010 and February 2011 sampling respectively. Similarly, for the community boreholes, G1 recorded the highest conductivity value of 328.00 $\mu\text{s/cm}$ and 304.00 $\mu\text{s/cm}$ and the lowest values of 58.10 $\mu\text{s/cm}$ and 65.10 $\mu\text{s/cm}$ at G5 for the two sampling regimes.

4.3 Heavy Metals in Suraw River water and community boreholes

Table 4.3.1: AAS analysis result of Suraw River samples (December, 2010).

Station code	Cd(mg/l) Dissolved	Cd(mg/l) (Total)	Pb(mg/l) Dissolved	Pb(mg/l) (Total)	Hg(mg/l) Dissolved	Hg(mg/l) (Total)	As(mg/l) Dissolved	As(mg/l) (Total)
S1	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	0.002	0.004
S2	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	<0.002
S3	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	<0.002
S4	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	<0.002
S5	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	<0.002
S6	<0.002	<0.002	<0.01	0.02	<0.001	<0.001	<0.002	<0.002

S1: Control point of the Suraw River in TSFR; S2: Drainage of the Suraw River from Obra waste dump; S3: Drainage of the Suraw River from Tano waste dump; S4: Suraw River across Akoti-Chirano road; S5: Kolia stream before joining Suraw River; S6: Suraw River at the exiting point from the mine.

Table 4.3.2: AAS analysis result of Suraw River samples (February, 2011).

Station code	Cd(mg/l) Dissolved	Cd(mg/l) (Total)	Pb(mg/l) Dissolved	Pb(mg/l) (Total)	Hg(mg/l) Dissolved	Hg(mg/l) (Total)	As(mg/l) Dissolved	As(mg/l) (Total)
S1	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	0.004	0.010
S2	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	0.004
S3	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	0.002
S4	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	<0.002
S5	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	<0.002
S6	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	0.004

S1: Control point of the Suraw River in TSFR; S2: Drainage of the Suraw River from Obra waste dump; S3: Drainage of the Suraw River from Tano waste dump; S4: Suraw River across Akoti-Chirano road; S5: Kolia stream before joining Suraw River; S6: Suraw River at the exiting point from the mine.

Table 4.3.3: AAS analysis result of borehole water samples from five downstream communities (December, 2010).

Station code	Cd(mg/l) Dissolved	Cd(mg/l) (Total)	Pb(mg/l) Dissolved	Pb(mg/l) (Total)	Hg(mg/l) Dissolved	Hg(mg/l) (Total)	As(mg/l) Dissolved	As(mg/l) (Total)
G1	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	0.002
G2	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	0.002
G3	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	0.006
G4	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	<0.002
G5	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	<0.002

G1: Borehole water at Akoti junction; G2: Borehole water at Etwebo old Taxi Station; G3: Borehole water at Kwaokrom close to Catholic Church; G4: Borehole water at Anyinasie DC Primary School; G5: Borehole water Surano

Table 4.3.4: AAS analysis result of borehole water samples from five downstream communities (February, 2011).

Station code	Cd(mg/l) Dissolved	Cd(mg/l) (Total)	Pb(mg/l) Dissolved	Pb(mg/l) (Total)	Hg(mg/l) Dissolved	Hg(mg/l) (Total)	As(mg/l) Dissolved	As(mg/l) (Total)
G1	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	<0.002

G2	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	<0.002
G3	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	0.004
G4	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	<0.002
G5	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	<0.002

G1: Borehole water at Akoti junction; G2: Borehole water at Etwebo old Taxi Station; G3: Borehole water at Kwaokrom close to Catholic Church; G4: Borehole water at Anyinasie DC Primary School; G5: Borehole water Surano.

S6 recorded total Pb concentration of 0.02 mg/l and dissolved arsenic concentration of 0.002 mg/l at S1 in December 2010. Total arsenic concentration of 0.004 mg/l also occurred at S1 in December 2011 sampling. In February 2011, dissolved arsenic concentration of 0.004 mg/l was detected at S1 whilst total arsenic concentrations of 0.010 mg/l, 0.004 mg/l, 0.002 mg/l and 0.004 mg/l were detected at S1, S2, S3 and S6 respectively. Apart from these observations, the concentrations of the four heavy metals under investigation were all below detection limits (Table 4.3.1 and Table 4.3.2).

Like the Suraw River water (surface water), only low total arsenic concentration were detected in community boreholes (groundwater) at G1, G2 and G3 (Table 4.3.3 and Table 4.3.4). Total and dissolved concentrations of the rest of the heavy metals were all below detection limits.

4.4 Heavy Metals in Suraw River bottom sediments

The concentrations of Cadmium, Lead, Mercury and Arsenic obtained from the six Suraw River bottom sediment samples were compared with Freshwater Sediment Screening Quality Guidelines (SQUIRT) by the National Oceanic and Atmospheric Administration (NOAA, 2009) Appendix 9. Table 4.4.1 below shows results of the Suraw River bottom sediments collected at the six sampling stations.

Table 4.4.1: Suraw River sediment digestion results using ICP – OES (December, 2010). Concentrations are reported in mg/kg dry weight

Station code	Cd (mg/Kg)	Pb (mg/Kg)	Hg (mg/Kg)	As (mg/Kg)
SD1	1.1	1.9	0.14	<0.05
SD2	4.8	3.1	<0.05	<0.05
SD3	5.2	3.5	<0.05	<0.05
SD4	6.3	1.9	<0.05	<0.05
SD5	6.8	2.2	<0.05	<0.05
SD6	7.6	2.1	<0.05	<0.05

SD1: Suraw River bottom sediment at S1, SD2: Suraw River bottom sediment at S2, SD3: Suraw River bottom sediment at S3, SD4: Suraw River bottom sediment at S4, SD5: Suraw River bottom sediment at S5, SD6: Suraw River bottom sediment at S6.

4.4.1 Comparison of the Concentration of Cd, Pb, Hg and As in Suraw River sediment at SD1 with NOAA, 2009 Freshwater Sediment Quality Guidelines (mg/kg dry weight)

For SD1, the concentration of Cd was higher than the Lowest Effect Level (LEL) and Threshold Effect Level (TEL) but significantly lower than the Probable Effect Level (PEL) and Severe Effect Level (SEL). However, the concentrations of Pb, Hg and As were all far lower than LEL, TEL, PEL and SEL as Figure 4.1 below depicts.

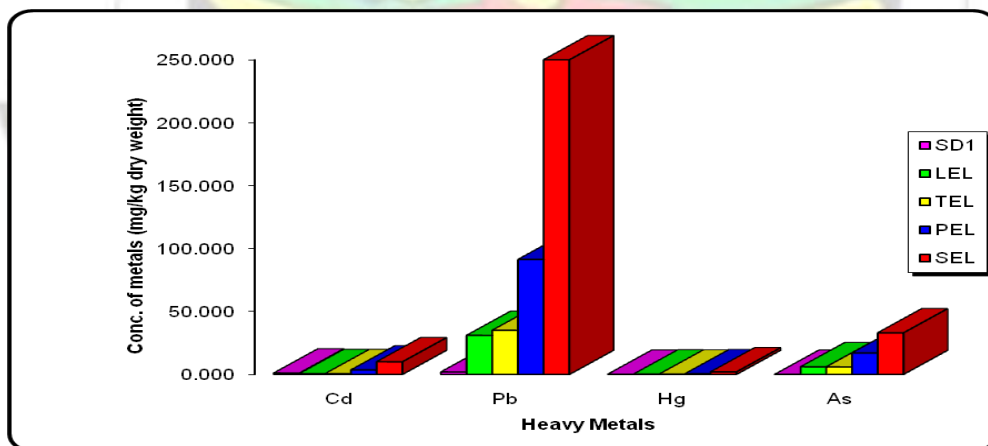


Figure 4.1 Concentration of Cd, Pb, Hg and As in Suraw River as detected at SD1 compared with NOAA, 2009 Freshwater Sediment Quality Guidelines.

4.4.2 Comparison of the Concentration of Cd, Pb, Hg and As in Suraw River sediment at SD2 with NOAA, 2009 Freshwater Sediment Quality Guidelines (mg/kg dry weight)

For SD2, concentration of Cd exceeded LEL, TEL and PEL but was however lower than the SEL. Pb, Hg and As levels were all significantly lower than the NOAA, 2009 Freshwater Sediment Quality Guidelines as shown in Figure 4.2 below.

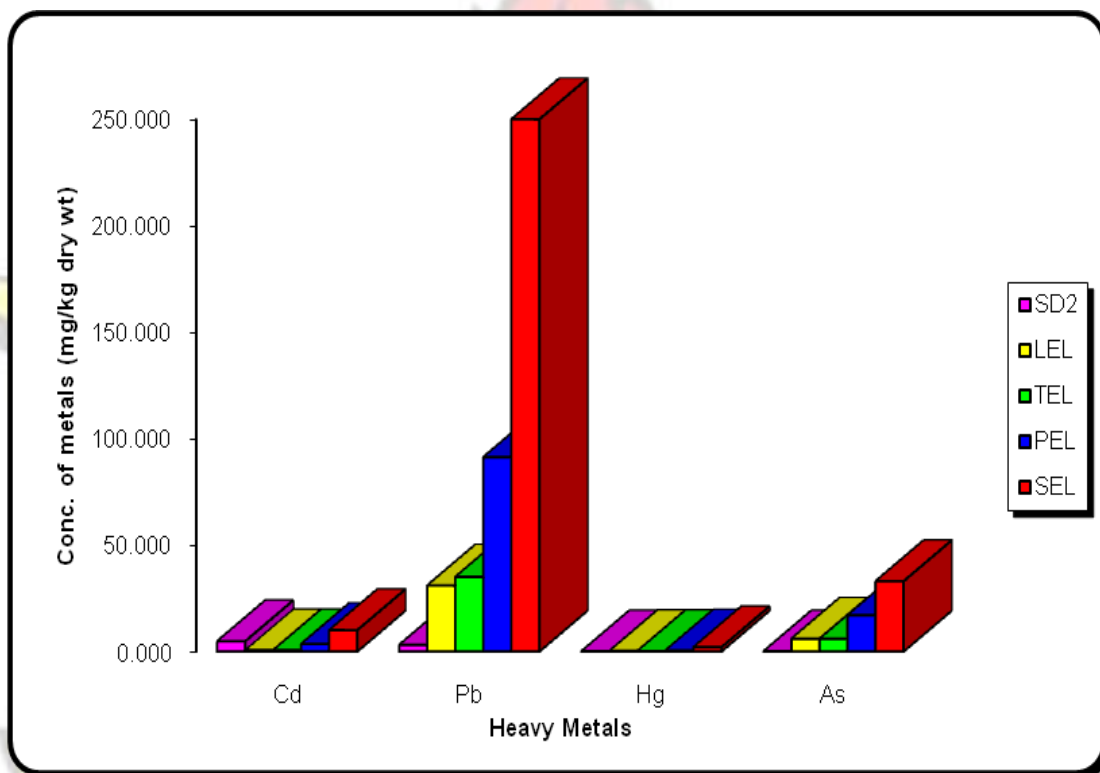


Figure 4.2 Concentration of Cd, Pb, Hg and As in Suraw River as detected at SD2 compared with NOAA, 2009 Freshwater Sediment Quality Guidelines.

4.4.3 Comparison of the Concentration of Cd, Pb, Hg and As in Suraw River sediment at SD3 with NOAA, 2009 Freshwater Sediment Quality Guidelines (mg/kg dry weight)

For SD3, Cd concentration in bottom sediments was higher than LEL, TEL and PEL values according to NOAA, 2009 Freshwater Sediment Quality Guidelines but was lower than SEL levels. The rest of the three heavy metals under investigation were all lower than the Guideline values

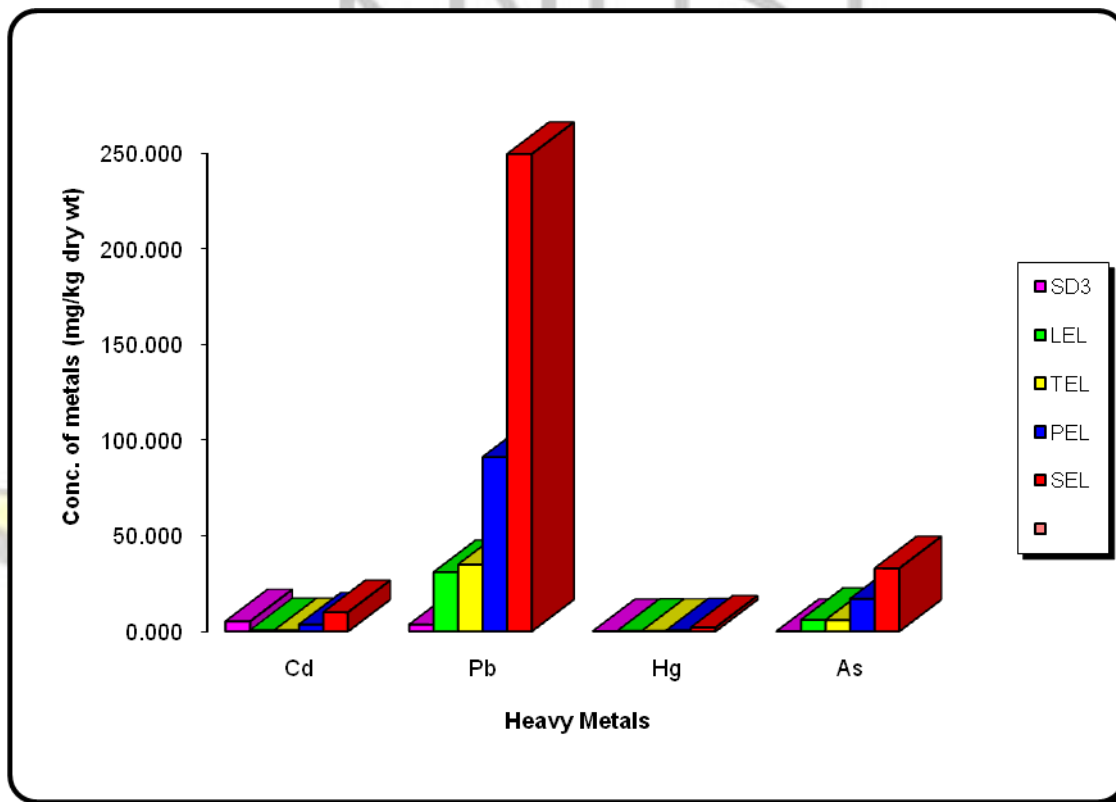


Figure 4.3 Concentration of Cd, Pb, Hg and As in Suraw River as detected at SD3 compared with NOAA, 2009 Freshwater Sediment Quality Guidelines.

4.4.4 Comparison of the Concentration of Cd, Pb, Hg and As in Suraw River sediment at SD4 with NOAA, 2009 Freshwater Sediment Quality Guidelines (mg/kg dry weight)

Concentration of Cd at SD4 continued to exceed LEL, TEL and PEL but was lower than SEL whilst Pb, Hg and As recorded levels which were far lower than the Guideline values.

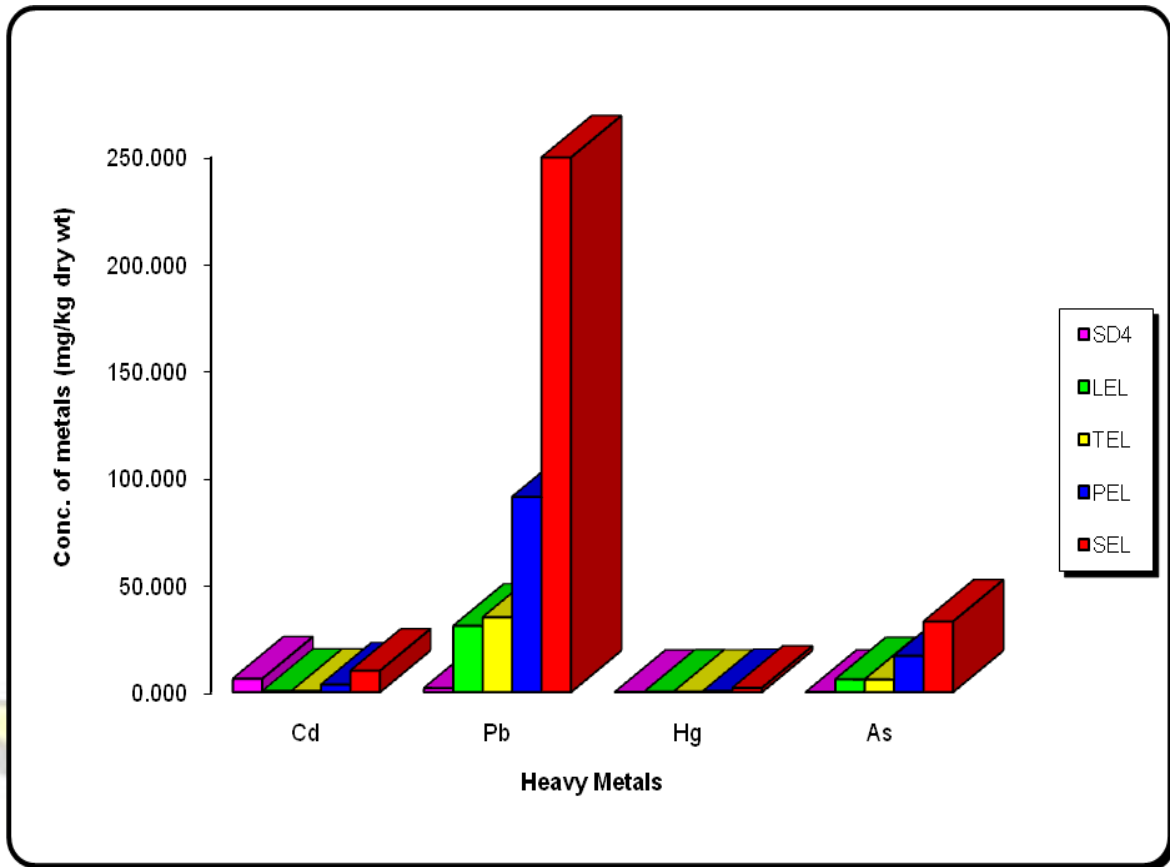


Figure 4.4 Concentration of Cd, Pb, Hg and As in Suraw River as detected at SD4 compared with NOAA, 2009 Freshwater Sediment Quality Guidelines.

4.4.5 Comparison of the Concentration of Cd, Pb, Hg and As in Suraw River sediment at SD5 with NOAA, 2009 Freshwater Sediment Quality Guidelines (mg/kg dry weight)

Cadmium recorded concentrations higher than LEL, TEL and PEL values but lower than SEL level. Concentrations of Pb, Hg and As all were significantly lower than the Guideline values.

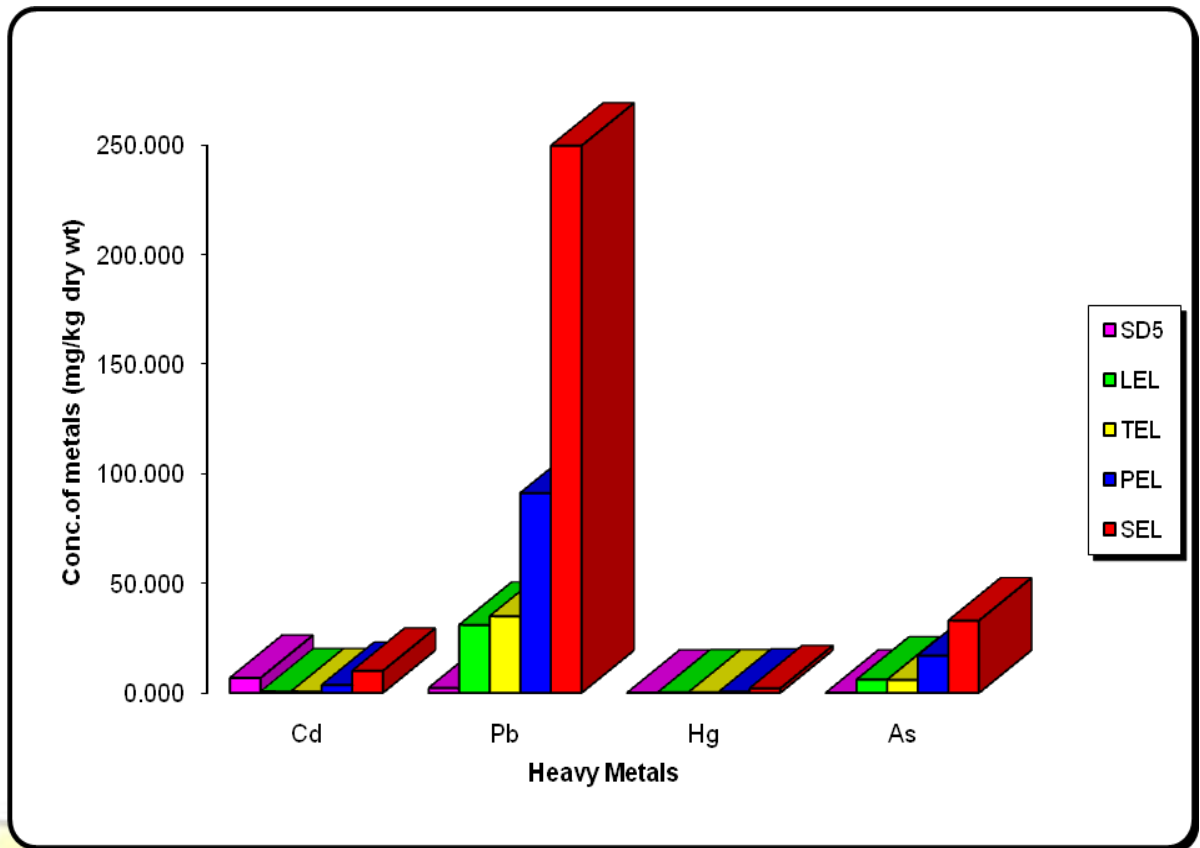


Figure 4.5 Concentration of Cd, Pb, Hg and As in Suraw River as detected at SD5 compared with NOAA, 2009 Freshwater Sediment Quality Guidelines.

4.4.6 Comparison of the Concentration of Cd, Pb, Hg and As in Suraw River sediment at SD6 with NOAA, 2009 Freshwater Sediment Quality Guidelines (mg/kg dry weight)

At SD6, concentration of Cd still exceeded the LEL, TEL and PEL but was lower than the SEL concentration. Concentrations of Pb, Hg and As were all lower than the Guideline values.

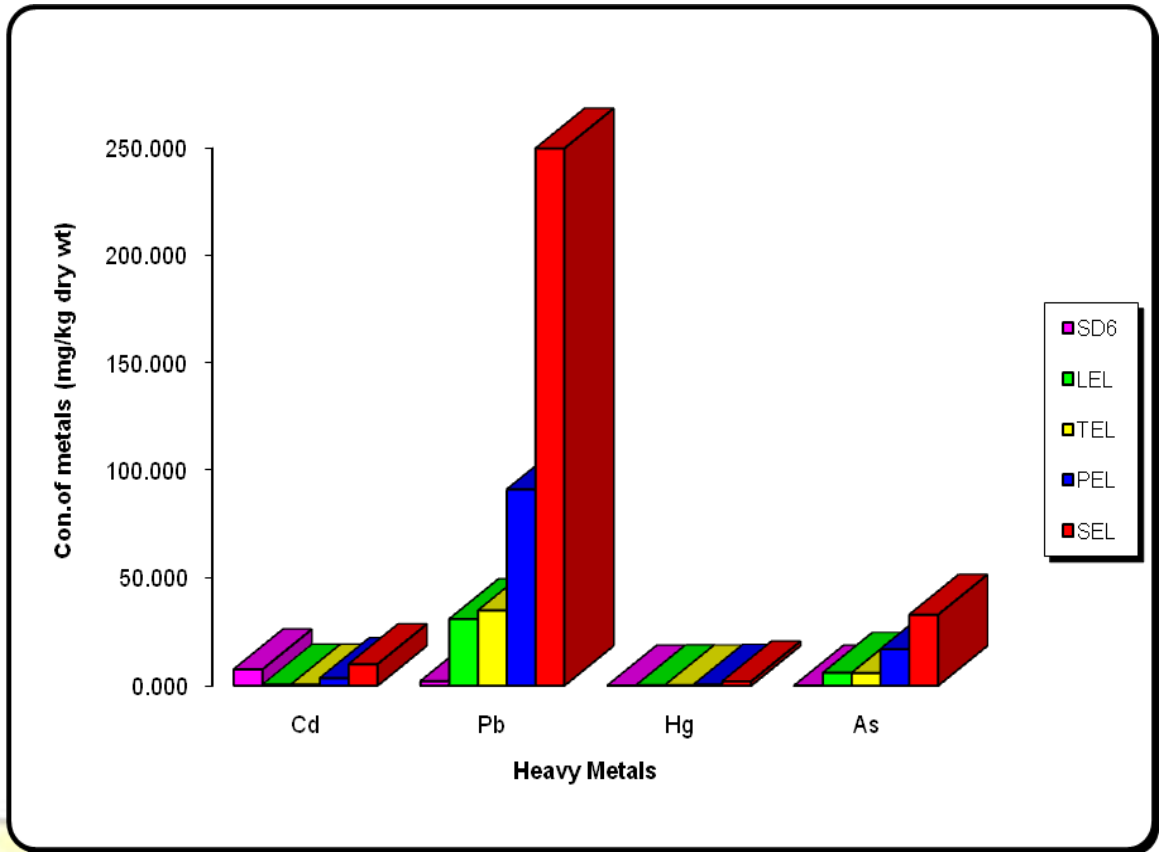
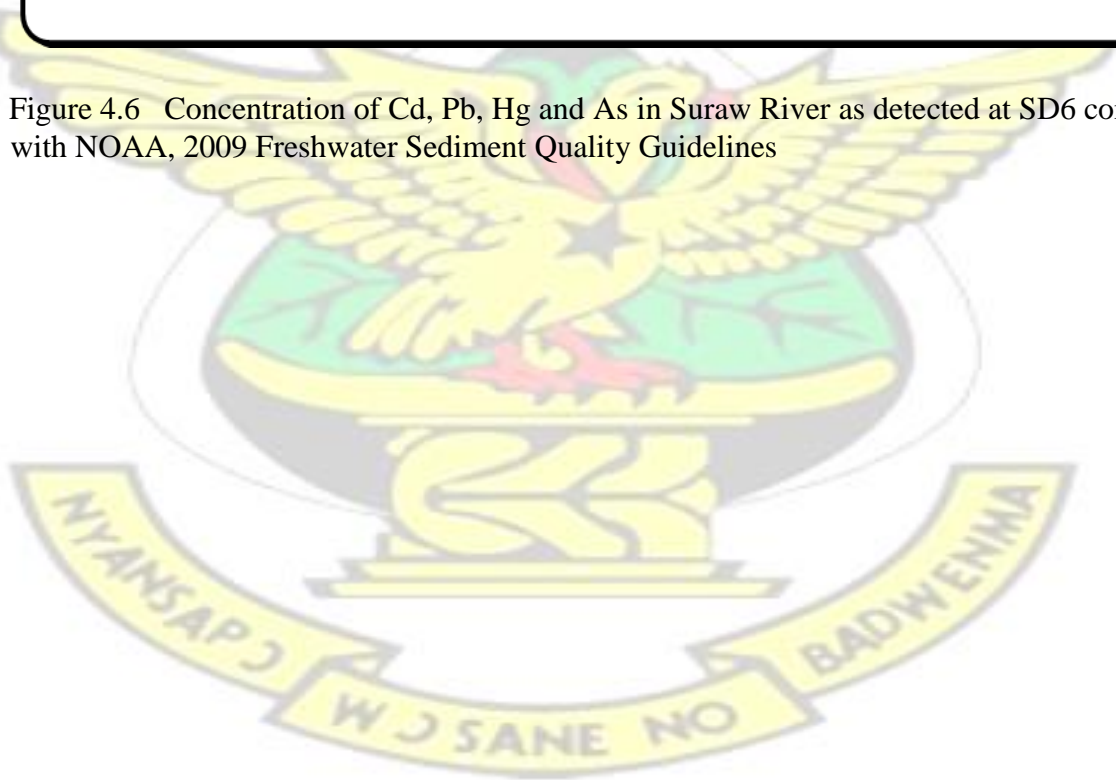


Figure 4.6 Concentration of Cd, Pb, Hg and As in Suraw River as detected at SD6 compared with NOAA, 2009 Freshwater Sediment Quality Guidelines



CHAPTER FIVE

5.0 DISCUSSION

5.1 Survey on the Suraw River

From the results of the survey shown in Table 4.1.1, it was found that out of the sample size of 258 households, 241 representing 93% had noticed a perceptible change in the colour of the Suraw River after active mining began in December, 2004. Ninety-six households which constitute about 37% were of the view that the River was shrinking and the level has also dropped compared to the volume/level some years back. An overwhelming 249 households representing about 96% of the households sampled preferred the borehole water to the Suraw River water whilst 9 households which account for 3.5% chose the Suraw River over the borehole. Of the 9 households that opted for Suraw River water in the five communities surveyed, 6 of the respondent households were in Surano. The change in colour of the Suraw River especially at Akoti and Etwebo portions of the River could be attributed to storm water from the waste rock dumps, exploration drilling pads, construction and grading of mine access road and haul roads and also partly from Akoti and Etwebo communities which have seen rapid development due to the influx of people seeking for jobs in the Mine. The silt laden storm water from these activities act in concert and adversely affects the clarity of the River. However, as the River flows for considerable distance downstream, it becomes clearer with reduced Total suspended Solid (TSS) levels and this explains why some inhabitants in Surano community are still depending on the Suraw River for their water needs.

5.2 pH, Temperature, TDS and Conductivity of the Suraw River samples and community boreholes

During field investigation, it was revealed that the pH values obtained from the six sampling sites on the Suraw River (Surface water) were higher than the values recorded on community boreholes (groundwater). This relatively low pH of community borehole water is consistent with the outcome of the baseline hydrogeological studies on the groundwater quality of the project area by Knight Piesold Pty Limited (2004). Temperature variation was wider in the Suraw River samples than in the borehole samples.

Total Dissolved Salts (TDS) showed strong correlation with conductivity for both the Suraw River and borehole water sampled. However, the surface water generally had higher TDS and conductivity values than the boreholes except at G1 where unusually high TDS and conductivity were measured both in December and January field investigation. The least TDS and conductivity values for both December 2010 and February 2011 field investigation occurred at S1 which is the Control point outside the zone of impact of the mining operation. High electrical conductivity in a river could be attributed to high mineral salt concentration which comes from the dissolution of minerals in the soil (Ntengwe, 2006) but could also come from industrial or mining effluent.

5.3 Heavy metals in Suraw River and community boreholes

Concentration of 0.02 mg/l of Pb (total) was detected at S6 in water samples collected in December 2010. S6 is the exiting point of the Suraw River from Akoti and Etwebo communities as well as the mine. The presence of Pb at this sampling site could be attributed to indiscriminate dumping of waste, from battery charging stations and other anthropogenic activities in the two communities. Arsenic concentration of 0.002 mg/l (dissolved) and 0.004 mg/l (total) were detected at S1 which is outside the zone of impact of the mining operations. Again, 0.004 mg/l of As (dissolved) and 0.010mg/l of As (total)

were present at S1; 0.004 mg/l, 0.002 mg/l and 0.004 mg/l at S2, S3 and S6 respectively in Suraw River samples collected in February 2011. The presence of arsenic in the surface water suggests that this metalloid occurs naturally in the surface waters of the CGML mining lease area and not as a result of anthropogenic activities. The levels of Arsenic found in this study confirmed earlier studies on Water Quality Assessment in two water holding ponds which are fed with Suraw River water by Africa Environmental Research and Consulting Company Limited (2009). They reported that Arsenic concentrations showed high and moderate levels at some stations with values either exceeding the acute levels or lower than the chronic level (Unpublished data).

Though Arsenic was present in some community boreholes in samples collected in December at G1, G2 and G3, it was also detected in samples collected in February at G3. Mercury and Cadmium might be present but were below detection limits. The presence of arsenic in some of the boreholes in the mining lease area confirms the report in Chirano Gold Mines Ltd Water Use Permit Report by Lycopodium Pty Ltd (2003) in accordance with Water Resources Commission Permit Conditions (WRC Form II). They reported that Arsenic was detected in some groundwater samples collected in the Project area (approximately 43%) with concentration generally well below GWCL and WHO Guideline values (0.010 mg/l).

5.4 Heavy Metals in Suraw River bottom sediments

Sediments constitute an essential environmental reservoir due to their capacity to retain and release different compounds from or to a river. Sediments have been reported to form the major repository of heavy metal in aquatic systems while allochthonous and autochthonous influences could make a concentration of heavy metals in the water high enough to be of ecological significance (Oyewo and Don-Pedro, 2003). These heavy metals generally exist

in low levels in water and attain considerable concentration in sediments and biota (Namminga and Wilhm, 1976). The higher elemental concentration of bottom sediments of Suraw River was in agreement with the concept that bottom sediments contain higher concentrations of metals than that of overlying water (Depinto and Martin, 1980).

The heavy metal concentrations obtained from the sediment samples were compared with Freshwater Sediment Screening Quality Guidelines (SQUIRT) by National Oceanic and Atmospheric Administration (2009). Cadmium was higher than both the Lowest Effect Level (LEL) and Threshold Effect Level (TEL) at SD1 but significantly lower than both Probable Effect Level (PEL) and Severe Effect Level (SEL). However, the levels of Lead, Mercury and Arsenic were all far lower than the Guideline values. From SD2 to SD6, Cadmium was higher than LEL and TEL values but was lower than the PEL and SEL values whereas the levels of other metals were drastically lower than the values of the rest of the Guideline values.

The sediment analysis result shows that apart from Arsenic, all the six bottom sediment samples collected in the Suraw River had one or the other of the heavy metals considered in this study. The heavy metal concentrations in the Suraw River sediment decreased in the sequence of Cd>Pb>Hg>As from S1 downstream to S6. The levels of Cadmium increased gradually from 1.1 mg/kg at the control sampling point (S1) which is outside the zone of impact of the mining operation to as high as 7.6 mg/kg at SD6 where the Suraw River leaves the mine take area. This consistent rise in the levels of Cadmium could be due to its release into the River from the waste rock dumps and anthropogenic load from Akoti and Etwebo communities.

Although levels of Lead in the Suraw River at the six sampling sites were appreciable, it did not show any consistent pattern. Mercury was detected only at the Control point (SD1) whereas the levels in the Suraw bottom sediments at the remaining sites were below

detection limits. The level of Mercury in sediments at the Control point in the Tano Suraw Extension Forest Reserve where the current pits are located is in line with the findings by Knight Piesold Pty Limited (2004) who reported high concentrations of Mercury in stream bottom sediments collected in the main streams and rivers of the project area. The report attributed the levels of Mercury to past alluvial galamsey activities or old mine workings which took place within the project area at the beginning of the 20th century.



CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The results obtained in this study show that the concentration of As, Pb, Hg and Cd in both surface Suraw River water and borehole water in the five communities were all within GWCL/WHO Drinking Water Standards. The heavy metal status in the Suraw River compared with the Ghana Water Company Ltd Drinking Water Standards shows no significant difference. CGML operations have therefore not affected the heavy metal status of the Suraw River and consequently have no apparent health threat to downstream communities though they now depend heavily on boreholes because of perceived risk of contamination by the mining company. The observed change in the Suraw River's channel morphology and sedimentation characteristics indicates that sediment storage within the

active channel has increased due to increased sediment load from mining development activities upstream.

The analytical results of the Suraw River water showed gradual increase in TDS from S1 to S6. This could be due to the dissolution of minerals in the water as the River traverses through rock drains at some point and also receive storm water from the waste dumps and flow contribution from active mine areas which are rich in minerals.

This study has also shown that the five communities downstream of the Suraw River within CGML's mining lease area are much aware of the water quality level of the Suraw River and hence their overwhelming preference for the borehole water sources provided by the Chirano Gold Mines Limited, the Bibiani –Anhwianso- Bekwai and Sefwi Wiawso District Assemblies.

All the respondent households in the five communities surveyed indicated that the Suraw River served their basic water needs until CGML started active mining. Notwithstanding the overwhelming preference for borehole water for their basic water needs, some of the respondents said the River water still serve their water needs including drinking when they are in their farms.

6.2 RECOMMENDATIONS

Mining operations along water courses remains inimical to the sustainable use of rural water resources. However, improved environmental management practices, treatment methods and acceptable discharge locations are crucial to abate the impact of mining activities on local water bodies.

The following recommendations are made as a result of the outcome of the present study;

1. Though the study has shown that the levels of As, Cd, Hg and Pb in the Suraw River water are so low to cause any public health problems, periodic sediment surveillance studies on the heavy metal status of the River is highly recommended to guarantee the health of the people in communities downstream.
2. Further studies should be conducted on the borehole at Akoti junction to unravel the unusually high TDS and Conductivity which were significantly higher than all the other community boreholes
3. Dewatering from the open pit and underground should be treated to reduce the sediment load before discharge into the local water courses.
4. Sediment ponds/Silt traps should be constructed downstream at the toe of all waste dumps and in storm water courses from active works areas to allow for settling before it enters local water courses.
5. Progressive rehabilitation/re-establishment of vegetative cover on disturbed lands should be encouraged to reduce run-off and consequently sediment load in local water courses.
6. Both the surface and ground water sampling in this study were carried out in the dry season between January and February. This study therefore did not consider the effect of seasonal variation on the release and availability of heavy metals in the Suraw River. It is therefore important that a similar study is conducted in the rainy season to determine the effect of seasonal variation on the release and availability of heavy metals in both surface and ground water resources of the CGML mining lease area.

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APPENDICES

Appendix 1: Suraw River average depth and width measurement taken at the six sampling sites (December, 2010).

Sample ID	Depth (m)	Width (m)
S1	0.30±0.01	2.40±0.30
S2	2.10±0.02	3.90±0.20
S3	0.90±0.01	3.60±0.01
S4	1.00±0.02	3.60±0.20
S5	0.80±0.01	3.20±0.10
S6	1.20±0.01	6.50±0.10

Appendix 2: Average pH, Temperature, TDS and Conductivity measured on the field (December, 2010).

Station code	pH	Temp. °C	TDS (mg/l)	Cond. (µs/cm)
S1	6.60±0.01	26.2±0.10	96.80±0.30	213.00±0.01
S2	7.20±0.01	28.0±0.30	220.00±0.20	484.00±0.02
S2D	7.10±0.03	28.50±0.10	222.00±0.10	486.00±0.02
S3	7.40±0.01	26.3±0.20	381.00±0.10	802.00±0.02
S4	7.30±0.01	26.5±0.10	259.00±0.20	508.00±0.02
S5	7.6±0.01	24.7±0.20	269.00±0.10	547.50±0.02
S6	7.30±0.02	25.9±0.10	288.00±0.30	605.00±0.01
TSFD	9.85±0.01	33.2±0.20	968.00±0.20	2260.000.01
STD	7.26±0.02	33.1±0.10	126.40±0.10	307.00±0.02

S1: Control point of the Suraw River in TSFR; S2: Drainage of the Suraw River from Obra waste dump; S3: Drainage of the Suraw River from Tano waste dump; S4: Suraw River across Akoti-Chirano road; S5: Kolia stream before joining Suraw River; S6: Suraw River at the exiting point from the mine; S2D: Duplicate of S2; TSFD: Supernatant recycling water at TSF; STD: Standard water (distilled)

Appendix 3: Average pH, Temperature, TDS and Conductivity measured on the field (February, 2011).

Station code	pH	Temp. °C	TDS (mg/l)	Cond. (µs/cm)
S1	6.70±0.01	20.90±0.30	94.50±0.10	181.70±0.02
S2	6.50±0.01	25.80±0.20	260.00±0.20	539.00±0.01
S3	7.40±0.02	23.50±0.10	303.00±0.20	605.00±0.02
S4	7.60±0.01	22.60±0.10	232.00±0.10	457.00±0.02
S5	7.60±0.01	22.00±0.20	269.00±0.10	522.00±0.02
S6	7.10±0.02	23.00±0.10	110.70±0.10	227.00±0.02
S6D	7.06±0.01	23.00±0.20	110.70±0.10	227.00±0.01
TSFD	10.46±0.02	27.10±0.20	222.00±0.10	504.00±0.01
STD	7.10±0.01	28.50±0.10	124.00±0.10	302.00±0.01

S1: Control point of the Suraw River in TSFR; S2: Drainage of the Suraw River from Obra waste dump; S3: Drainage of the Suraw River from Tano waste dump; S4: Suraw River across Akoti-Chirano road; S5: Kolia stream before joining Suraw River; S6: Suraw River at the exiting point from the mine; S6D: Duplicate of S6; TSFD: Supernatant recycling water at TSF; STD: Standard water (distilled)

Appendix 4: Average Measurements of sediment physical parameters

Sample ID	Temperature(°C)	pH	TDS(mg/L)	Conductivity(µS/cm)
SD1	27.40±0.20	6.48±0.01	59.40±0.20	128.30±0.04
SD2	26.10±0.20	6.47±0.01	239.00±0.30	506.00±0.03
SD3	28.30±0.20	7.03±0.01	180.40±0.10	399.00±0.03
SD4	28.60±0.30	6.53±0.01	133.40±0.20	298.00±0.04
SD5	28.00±0.10	6.52±0.02	128.40±0.20	284.00±0.03
SD6	28.20±0.20	6.57±0.03	109.40±0.10	243.00±0.03
SD7	28.30±0.20	6.45±0.02	129.10±0.20	287.00±0.01
SD8	28.40±0.10	6.44±0.03	240.10±0.20	107.80±0.02
SD9	27.60±0.30	6.47±0.02	105.50±0.20	231.00±0.02
SD10	27.30±0.10	6.48±0.03	111.70±0.10	244.00±0.03

SD1: Suraw River bottom sediment at S1, SD2: Suraw River bottom sediment at S2, SD3: Suraw River bottom sediment at S3, SD4: Suraw River bottom sediment at S4, SD5: Suraw River bottom sediment at S5, SD6: Suraw River bottom sediment at S6; SD7: Sediment taken at the beach of TSF; SD8: Duplicate sample at SD2; SD9: Sediment extracted at a depth of 0.20m at SD3; SD10: Sediment extracted at a depth of 0.20m at SD6.

Appendix 5: AAS analysis results of Quality Control samples (December, 2010).

Station code	Cd(mg/l) Dissolved	Cd(mg/l) (Total)	Pb(mg/l) Dissolved	Pb(mg/l) (Total)	Hg(mg/l) Dissolved	Hg(mg/l) (Total)	As(mg/l) Dissolved	As(mg/l) (Total)
TSFD	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	0.022	0.034
S2D	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	<0.002
STD	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	<0.002	<0.002

S2D: Duplicate of S2; TSFD: Supernatant recycling water at TSF; STD: Standard water (distilled)

Appendix 6: AAS analysis results of Quality Control samples (February, 2011).

Station code	Cd(mg/l) Dissolved	Cd(mg/l) (Total)	Pb(mg/l) Dissolved	Pb(mg/l) (Total)	Hg(mg/l) Dissolved	Hg(mg/l) (Total)	As(mg/l) Dissolved	As(mg/l) (Total)
TSFD	<0.002	<0.002	<0.01	<0.01	<0.001	0.002	<0.002	<0.002
S6D	<0.002	<0.002	<0.01	<0.01	<0.001	<0.001	<0.002	<0.002
STD	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	<0.002	0.004

S6D: Duplicate of S6; TSFD: Supernatant recycling water at TSF; STD: Standard water (distilled)

**Appendix 7: Sediment digestion results on Quality Control samples (December, 2010)
Concentrations are reported in mg/kg dry weight**

Station code	Cd (mg/Kg)	Pb (mg/Kg)	Hg (mg/Kg)	As (mg/Kg)
STSD	10.0	14.5	0.07	<0.05
DSD2	9.9	4.7	<0.05	<0.05
DSD3	5.2	3.2	<0.05	<0.05
DSD6	4.5	3.3	<0.05	2.28

STSD: Sediment at the tailings dam; DSD2: Duplicate sediment sample at SD2; DSD3: Control sediment sample taken at a depth of 0.20 m from the stream bottom at SD3; DSD6: Control sediment sample taken at a depth of 0.20 m from the stream bottom at SD6

Appendix 8: Industrial Effluent Discharge and Drinking Water Guidelines

	Effluent Guidelines		Drinking Water Guidelines	
	<i>WB/IFC Mining</i>	<i>EPA Ghana</i>	<i>WHO</i>	<i>GSB/GWC</i>
Pb	0.1	0.1	0.01	0.01
Hg	0.01	0.005	0.001	0.001
Cd	0.1	0.1	0.003	0.003
As	0.1	0.1	0.01	0.01

Source: Ghana Standards Board
 Water Quality Requirement for Drinking Water
 Ref. No. GS 175 Pt. 1:1997
 All concentrations are in mg/l or ppm

Appendix 9: Comparison of the concentration of Cd, Pb, As and Hg in the Suraw River sediment at the six sampling sites with NOAA, 2009 Freshwater Sediment Quality Guidelines.

Locality	Cd	Pb	Hg	As
SD1	1.100	1.900	0.140	<0.050
SD2	4.800	3.100	<0.050	<0.050
SD3	5.200	3.500	<0.050	<0.050
SD4	6.300	1.900	<0.050	<0.050
SD6	7.600	2.100	<0.050	<0.050
Lowest Effect Level (LEL)	0.600	31.000	0.200	6.000
Threshold Effect Level (TEL)	0.596	35.000	0.174	5.900
Probable Effect Level (PEL)	3.530	91.300	0.486	17.000
Severe Effect Level (SEL)	10.000	250.000	2.000	33.000

Appendix 10: Questionnaire for conducting the survey on Suraw River Water Quality

**Kwame Nkrumah University of Science and Technology, Kumasi Institute of Distance Learning
 Msc. Environmental Science**

Questionnaire for assessing the awareness of water quality in the communities/villages along the banks of the Suraw River.

All information provided will be treated as strictly confidential and for academic purpose only.

Details of Respondent

- Q1. Age of respondent.....
Q2. Sex: Male or Female.....
Q3. Occupation.....
Q4. Residency..... Q5.
Educational Background.....

Qualitative analysis of Suraw River

Q6. For how many years have you depended on the Suraw River for your water needs?
Specify.....

Q7. What do you use the Suraw River water for?

Drinking	
Cooking	
Washing	
Bathing	
Watering of crops	

Any others specify.....

Q8. Are there fishes in the Suraw River? Yes or No

Q9. If yes, is fishing done in the River? Yes or No

Q10. If no, have you observed any other life form(s) in the River?

Q11. If Yes, specify.....

Q12. Does the river water have any colour when first drawn? Yes or No

Q13. If water is clear when first drawn, does it turn coloured after staying overnight? Yes or No

Q14. Does the river water have any odour? Yes or No

Q15. If there is an odour in water when first drawn, is it gone after staying overnight? Yes or No
If yes, what is the colour of the precipitate?

Specify.....

Q16. Have you ever suffered from any water borne disease after drinking or cooking with water from the Suraw River? Yes or No

Q17. If yes specify.....

Q18. Have you noticed any changes in the water quality of the Suraw River after commencement of Chirano Gold Mines Ltd operations? Yes or No

Q19. If yes specify those change(s) observed.....

Q20. Have you noticed any changes in the level of the River over the past four to five years? Yes or No

Q21. If yes, state.....

Q22. Are there other sources of water in your community/village/hamlet?

Q23. How do the other sources of water compare with each other? Kindly explain in brief.

.....
.....
.....

THANK YOU FOR YOUR ASSISTANCE AND YOUR VALUABLE TIME

