KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

INSTITUTE OF DISTANCE LEARNING

(MSc. ENVIRONMENTAL SCIENCE)



MANAGEMENT OF LEACHATE FROM WASTE ROCK DUMP: A CASE STUDY AT NEWMONT GHANA GOLD LIMITED – AHAFO KENYASI

A THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE MASTER OF SCIENCE(MSC.) DEGREE IN ENVIRONMENTAL SCIENCE

BY

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DECLARATION

I hereby certify that this thesis being submitted is my original research work carried out at Newmont Ghana Gold Limited, Ahafo Kenyase. Except for references to other peoples work which has been duly acknowledged, this research consist of my own work under the supervision of Dr. Bukari Ali of the Geological Engineering Department, KNUST and that it has neither been whole or in part submitted for another degree elsewhere. This is therefore submitted in partial fulfillment for the award of MSc. Environmental Science.



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ABSTRACT

Concentrations of heavy metals -i.e. Fe, Mn, Cu, As, Zn, Ni and Cd- and physical parameters in surface and ground waters at some controls and compliance points within the NGGL's concession at Ahafo South were assessed. Water samples were taken from seven sampling locations within the mining area between the months of October 2011 and March 2012. Heavy metals' concentrations were determined using the AAS whilst those of physicochemical parameters were determined using standard methods for examination of water. Mean concentrations of the heavy metals in rainfall samples were 0.02, 0.02, 0.00, 0.003, 0.003, 0.00 and 0.00 mg/L respectively, and those in groundwater were respectively 0.197, 0.280, 0.00033, 0.064, 0.0067, 0.00 and 0.0012mg/L. Surface water recorded 0.470, 0.041, 0.002, 0.0017, 0.00, 0.00 and 0.00003 mg/L, respectively. Mean manganese and arsenic concentrations in groundwater at two control points exceeded EPA Ghana standards of 0.1mg/L for mining water discharge. The mean values of the physico-chemical parameters in surface and ground waters were within acceptable limits of EPA Ghana standards; sulphate in surface water just at the threshold. The study indicates that pyrite oxidation from the waste rock is evident, causing high concentrations of sulphate, above the Ghana standards, to leach directly from the waste rock. However, there is no potential for acid generation due to the high carbonate content of the rocks acting as a buffering material.

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ABBREVIATIONS

EPA	Environmental Protection Agency
WRD	Waste Rock Dump
TSF	Tailings Storage Facility
AMD	Acid Mine Drainage
NGGL	Newmont Ghana Gold Limited
GGMPP	Ghanaian-German Mineral Prospecting Project
RAB	Rotary Air Blast
RC	Reverse Circulation
DD	Diamond Drilling
NSW	Ntotroso Surface Water
KSW	Kenyase Surface Water
GWSD	Groundwater Characterisation-Deep
ECD	Environmental Control Dam
ATSF	Apensu Tailings Storage Facility
AAS	Atomic Absorption Spectrometer
IFC	International Finance Corperation
ANOVA	Analysis of Variance
TSS	Total Suspended Solids
TDS	Total Dissolved Solids
DO	Dissolved Oxygen
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CHAPTER ONE INTRODUCTION

1.1 BACKGROUND

Mining of ore requires the striping of large volumes of waste rock to uncover ore; waste rock dumps are created, and these are potential sources of pollution of water bodies from the generation of leachate. Waste rock normally has a high variability in particle size distribution and a very high permeability as placed in the dumps since the waste rock is not crushed before disposal. This allows convection air transport in the heap and increases reaction rate, especially if the dumps contain reactive chemical agents creating the potential for acid rock drainage and other soluble metals leach (European Union, 2004).

Waste rock dumps generate leachate of varying composition depending on the geochemical and physical characteristics of the waste rock. The physical and geochemical nature of the dump is determined by the physical configuration, geochemical distribution, temperature and transport of air and water through the dump. The characterization, in terms of the distribution of physical and geochemical properties within the dump is critical to its particle size, permeability, density and porosity. The particle size distribution of the waste rock, to a large extent, controls the movement of air and water through the dump, and this will depend on the original fabric of the rock, breakage by blasting and extraction, transportation and deposition in the dump (Broughton et al., 1991).

The particle size distribution within the dump is a function of how the material breaks down from in situ to after deposition in the waste rock dumps. Geochemical description of the pile describes the characteristics of the various waste rock types in terms of the source. This may include acid-base account, mineralogy, metal content and leach ability as a function of both the tendency to oxidize and physical characteristics. An estimate of dump composition may be derived from geological, mine planning and production records. The waste rock materials may be classified by their mineralogy and geochemistry as primarily either acid producing or acid consuming (Broughton et al., 1991).

In view of the varying composition of leachate from waste rock dumps, it needs proper management to prevent adverse environmental impacts, promote post-mining beneficial land use and reduce liabilities. This requires the interception of leachate generated from the dumps by the use of cut-off ditches to minimize surface water inflow under the heap. Seepage collection ditches at the toe of the dump is channelled to appropriate sediment and water control dams as well as monitoring of surface and groundwater bodies upstream and downstream of the waste rock dump

1.2 JUSTIFICATION

Waste rock management as a best practice effort is a fundamental indicator in environmental management, especially in a gold mining company. The management of the waste rock is also a regulatory requirement (EPA Akoben, 2008) and to this end gold mining companies are obliged to demonstrate best practice, taking cognizance of the requirements enshrined in the various regulatory documents. This work seeks to encourage the compliance with environmental regulations.

There are several perceptions about the adverse impacts of Newmont's activities on water bodies in the Project area. This study will also help document the real state of activities and provide appropriate responses to some of these perceptions.

1.3 OBJECTIVES

The main objective of this project is to assess present waste rock leachate management at Newmont in meeting legal compliance limits of downstream water bodies.

The specific objectives are:

- i. To measure the concentrations of heavy metals and other relevant physico-chemical parameters in the leachate and the recipient water bodies.
- ii. To measure the concentrations of the parameters in (i) in controls (rainfall, groundwater and surface waters).
- iii. To conduct an environmental audit on the present management systems by looking:
 - at drainage diversion around the waste rock dumps,
 - for evidence of discolouration of drainage from the waste rock dumps (i.e. presence of acid rock drainage)
 - at whether dumping of waste rock is done within approved areas and the control of unauthorised dumping at the dumps,
 - for evidence of leachate ponding around the embankment/ outside the reservoir,

- for evidence of fish kill and odour around the water dam,
- for evidence of aquatic weeds on water,
- at status of valves on discharge pipes, and
- making other observations as may be necessary.



CHAPTER TWO LITERATURE REVIEW

2.1 WASTE ROCK DUMP DEVELOPMENT

Waste rock dump is usually the most visible landform left after open pit mining. They are the most prone to erosion together with the tailings storage facility. It is therefore essential that careful planning before and during its construction produces cost efficient and effective rehabilitation to a safe, stable and non-polluting landform with an agreed post mining land use (Department of Mines and Petroleum, 2001). The development of a waste rock dump (WRD) goes through the following phases:

Planning, Design, Approval, Construction & Operation and Closure (Durham, 2004).

2.1.1 Planning

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The planning process of a waste dump must identify the relevant regulatory planning instruments and specifically the requisite approvals, and this should be done as early as possible. This is particularly important where the construction of the WRD will or has the potential to impact adversely on sensitive biota or ecosystems. Commitments to closure criteria are often made in project approval documentation (Notice of Intent). It is important that all closure criteria and commitments are realistic, achievable and meet the objective of a low risk to the environment, health and safety impact. The planning must include the characterisation of top soil removal from the footprint of the proposed WRD as well as local natural landforms in which the WRD is to be constructed. Environmental baseline data should be collected prior to the commencement of the WRD in accordance with environmental monitoring guidelines. The baseline data may include rainfall data, which is central in designing stable landforms with effective drainage systems (Durham, 2004).

2.1.2 Design

The key objectives of WRD design are to ensure that the facility is safe, stable and aesthetically acceptable during construction and closure. The facility is considered safe if the contents will not be released in an uncontrolled manner and cannot pollute the surrounding environment or harm anyone in the proximity of the closed facility. It is said to be stable if they release materials in a controlled manner. The facility is aesthetically acceptable if the visual impact of the finished WRD is minimised and acceptable to the relevant regulatory authority and interested parties. All WRDs should be planned and designed as engineered

structures by competent mining and geotechnical engineers (Durham, 2004). The following should be considered during WRD design.

2.1.2.1 Site Selection

In the selection of a site for a waste rock dump, there is the need to take into account tenement boundaries and any other natural feature of the landform. There should not be interruption of any significant drainage lines, and the location should not be in the way of any possible future cut back or any other development (Department of Mines and Petroleum, 2001)

The location of waste rock dumps should be considered along siting of the tailings storage facility (TSF) and if possible should be located near or adjacent the TSFs to ensure a nearby source of suitable materials for TSF rehabilitation and to reduce closure cost The design process should specifically address the suitability of the waste rock location in order to:

- Minimize the haulage distance from the pit
- Minimize adverse impact on any residential area including company living areas
- Minimize visual impact
- Minimize destruction of existing vegetation and natural landforms
- Minimize rehabilitation cost.

2.1.2.2 Natural Surface Drainage Requirement

The site selection process for the proposed waste rock dump shall give due regard to the natural surface drainage conditions within and adjacent the potential zone of influence of the proposed site. The WRD should not be positioned such that water courses are likely to erode the structure's toe. In particular, the need for water courses diversions or damming is avoided where possible. Where diversion or damming of water course is considered necessary, a risk assessment must be completed to consider the potential impact on sensitive biota or ecosystem and potential for subsidence.

2.1.2.3 Topsoil capture

All topsoil resources within the footprint of the WRD shall be recovered prior to the commencement of construction (dumping of waste rock). If the available depth of harvested topsoil material exceeds about 15cm, the material should be allocated topsoil and subsoil classifications and stockpiled separately. Subsoil may be an appropriate rehabilitation medium particularly where there is topsoil deficiency. The stockpile should not be more than two

meters in height in other to retain the maximum amount of mycorrhizae stored in it. The stockpile should be located as near as possible to the area it is to be used to minimise handling cost.

2.1.2.4 Geometry of WRD

The design process should specifically address the geometry of the WRD. The maximum height, area and shape of the WRD should be designed with regard to the area of land available and as far as practicable the geometry of the surrounding natural landforms. Where appropriate and as a general guideline, the WRD should have a geometry that is irregular. The geometry and design should be optimised not only for construction, but also rehabilitation and re-vegetation costs. The design of the facility should employ a geometry that minimises run-off velocity and potential for erosion gullies.

Where the area is steeper and re- contouring is required, consideration should be given to cutting to a shallower angle, which is dependent on the availability and suitability of the cover material and the benefits obtained from slope flattening. Slope flattening should not be carried out if it will negatively affect the engineering properties of the embankment material and hence the stability of the slope. All completed surfaces of the WRD should be stable and able to resist long term erosion (Durham, 2004).

2.1.3 Approval

WRD design requires internal approval as well as external by regulatory authorities. Prior to submission to regulatory authorities for approval, the design/ plans must be signed off by the appropriate General Manager and retained within the sites document management systems and all significant design amendment shall be subject to the same process.

The Mine manager in conjunction with the site environmental specialist/manager is responsible for acquiring the required approvals and licences. The approval documentation shall include the closure strategy for the facility including defined closure criteria. The ability to meet any commitments made within approval documentation as well as conditions attached to approvals must be considered carefully as they represent legal obligation.

2.1.4 Construction and Operation

The Mine manager shall ensure that the WRD is constructed to design. This can be achieved by:

- Ensuring that all supervisors(staff or contract) engaged in managing the construction of the WRD are familiar with and competent in the type of work to be carried out and manage the work to ensure that construction is carried out in accordance with the design drawings and specification provided by mining engineers.
- > Ensuring that the facility is subject to frequent surveys and inspections.

As a consequence of these inspections, the facility design may require modification to accommodate variations between predicted and actual construction. Design modification shall comply with the regulatory requirements as stated in the management plan and appropriately scheduled to avoid any negative from design non-conformance.

The site is required to review and conformance with the requirements of the WRD design guideline on an annual basis. The review plan may be included as a section within the WRD development plan and the review period should be selected so that remedial work required is carried out before seasonal rain events. A copy of the report should be given to the regulatory body for review and documentation.

2.1.5 Closure

Within 5years of planned site closure, completion criteria established during the planning phase should be reviewed with consideration to the findings of actions undertaken as part of the closure strategy. Formal stakeholder agreement on the completion criteria should be obtained in accordance with the required standards. In order to develop meaningful completion criteria, closure trials should be carried out early in the operational phase of the site and this will facilitate more effective design, planning and construction of safe, stable and aesthetically pleasing landforms and has the potential to reduce rehabilitation costs at closure

Environmental monitoring must be established for the purpose of determining the sites progress towards meeting the defined closure criteria to include the completion of ecosystem functioning analysis in accordance with the Environmental Monitoring Guidelines. The site general Manager shall ensure that an appropriate schedule of external review is developed for implementation following closure. The external review shall include a Safety and Geotechnical Assessment which will report all potential danger areas to be isolated and appropriate barriers and warning signs erected to prevent unauthorised personnel entering potentially unsafe areas, slope levels, changes in geometry and surface conditions as well as structural stability. A summary of the findings of the external review shall be provided to the Project Manager of the closure strategy and any major findings shall be reported in according with Environmental Standards (Durham, 2004).

2.2 WEATHERING OF ROCKS

Weathering is the breakdown and alteration of rocks and minerals at or near the surface of the earth into products that are in equilibrium with conditions found in the environment. Most rocks and minerals are formed deep within the earth's crust where temperatures and pressures differ greatly from the surface. Physical and chemical nature of materials formed in the earth crust are in disequilibrium with conditions occurring on the surface and because of the disequilibrium, materials occurring on the surface are easily attached, decomposed and eroded by various chemical and physical surface processes. The product of weathering are a major source of sediments for erosion and deposition forming sedimentary rocks which are composed of particles that have been broken down, eroded, transported and terminally deposited in basins. Weathering also contributes to the formation of soil by providing mineral particles like sand, silt and clay elements and compounds extracted from the rocks and minerals (Piwdwimy, 2006).

The process of weathering can result in three outcomes on rocks and minerals

- Complete loss of particular atoms or compounds from the weathered surface
- Addition of specific atoms or compounds to the weathered surface
- A breakdown of one mass into two or more masses with no chemical change in the mineral or rock.

The residue of weathering consists of chemically altered and unaltered materials. Many of the chemically altered products of weathering become very simple small compounds or nutrient ions. These residues can then be dissolved or transported by water, released to the atmosphere as gas or taken up by plants for nutrition. Some of the weathered products which are less resistant become clay particles; others are reconstituted by sedimentary or metamorphic processes to become new rocks and minerals (Piwdwimy, 2006).

There are three broad categories of mechanism for weathering: physical, chemical and biological weathering.

2.2.1 Physical Weathering

Physical weathering is the breakdown of rocks into pieces with no change in the chemical composition of the weathered material having the same properties as the original and this occurs mainly by temperature and pressure changes (Piwdwimy, 2006). There are several forms of physical weathering;

• Abration

Water carrying suspended rock fragments has a scouring action on surfaces Examples are the grinding action of glaciers, gravel, pebbles and boulders moved along and constantly abraded by fast- flowing streams

• Freezing and Thawing

Water penetrates into rock and reacts with their constituent minerals. When water is trapped in the rock, repeated freezing and thawing results in forces of expansion and contraction. When water freezes, the increase in its volume is about 9%

• Thermal expansion and contraction of minerals

Rocks are composed of different minerals. When heated by solar radiation each different mineral will expand and contract at a different amount at a different rate with surface temperature fluctuation. With time the stresses produced are sufficient to weaken the bonds along grain boundaries and thus flaking of fragments. For instance, difference in temperature in desert environments or mountain regions may range from 30-50 degrees between day and night. Rock are heated and cooled from the outside by change in solar radiation which results in high temperature gradients inside and outside of the rocks.

• Crystallization

In arid environments, water evaporates at the surface of rocks and crystals formed from dissolved minerals. Over time, the crystals expand their volume and exert a force great enough to separate mineral grains and break up rocks.

• Action of organisms and plant roots

They aid in physical disintegration of rocks. Pressure exerted by roots during growth is able to rupture rock (Robinson and Williams, 1994). Trees and plant roots often push rocks apart especially when they grow in areas of little topsoil.

2.2.2 Chemical Weathering

Chemical weathering is the breakdown of rocks by chemical agents with the chief chemical agent being water. Minerals in rocks dissolve in rainwater or changed from one mineral into

another. Chemical weathering happens quickly in warm, moist environment because water is needed for the chemical changes and warmth speeds up in the process. Chemical weathering is dependent on available surface for reaction and the presence of chemically active fluids Smaller particle size weather by chemical means more rapidly than large particles due to an increase of surface area (Piwdwimy, 2006) Most chemical weathering processes include:

• Hydration

Ions have the tendency to hydrate when H_2O is present and dissociate. This kind of weathering happens in arid environments where salts are present. Example, Chlorides and sulphates weather due to hydration. In general, ions with the same charge but smaller ion radius has a larger layer of H_2O ions and therefore do not tend to adsorb tight.

• Oxidation-Reduction

Several primary minerals contain Fe^{2+} and Mn^{2+} . If there are oxidizing environmental conditions the Fe^{2+} is oxidized to Fe^{3+} (precipitation as an insoluble oxyhydroxide usually either ferrihydrite or the stable mineral geothite) and Mn^{2+} to Mn^{3+} or Mn^{4+} partly inside the mineral which results in a positive charge and the mineral becomes unstable. This charge imbalance is neutralised by a loss of some oxidized iron and manganese ions and/or some cations dissociate from the mineral. The precipitation may form a coating over the mineral surface which slows down the subsequent rate of hydrolysis. Oxidation of Fe^{2+} to Fe^{3+} according to

 $Fe^{2+} + 2 H_2O + 1/2O_2 < --> Fe(OH)_3 + H^+$

is an acidifying reaction (acid solution weathering). The H⁺ produced by this reaction will generally accelerate the rate of hydrolysis.

• Complexation

Metals released from primary minerals such as Fe, Mn and Al, build complexes with organic components such as fulvic acids and humic acids which are very stable (Nahon, 1991).

2.2.3 Biological Weathering

Biological weathering is the breakdown of rocks and minerals due to chemical and/or physical agents of an organism. These organisms range from bacteria to plants and animals. Biological weathering involves processes that can either be chemical or physical in character (Piwdwimy, 2006). Plants and trees can work their way into crevices of rocks forcing it apart and ultimately causing it to fracture. Some plants give off organic acids that can chemically

break down rock minerals. When plants and animals decay, they release carbon dioxide into the air. When the carbon dioxide mixes with water, it forms carbonic acid which can break down the minerals in the rocks Worms, termites, gophers and prairie dogs can all be responsible for biologically weathering rocks and particles. They physically break rocks apart during physical activities such as boring (Thompson and Jonathan, 1998).

Lichens which are made up of algae and fungi which live together in a symbiotic mutual relationship (an interaction in which two organism depend on each other). The algae provide food for the fungi and the fungi provide water and protection for the algae. Lichens produce a dilute acidic solution that slowly causes some minerals in rocks to decompose. (AGI, 1972). Lichens play an important role in weathering because they are rich in chelating agents which trap the elements of the decomposing rock in organo-metallic complexes. Some lichens anchor themselves to the surface of a rock and break it down either chemically or physically. They can either release various organic acids that will break down rock minerals or they can grow into pores and cracks of the rock making it vulnerable for rupture (Thompson and Jonathan, 1998).

2.2.4 Characterization of Waste Rock Pile

Waste rock dump is composed of heterogeneous mine waste material excavated from underground or surface workings for the purpose of exposing and excavating ore. Bureau of Mines (1968) dictionary defines waste as barren or sub marginal rock or ore which has been mined but is not of sufficient value to warrant treatment. The rock fragment in a dump are a product of mechanical processes such as drilling, blasting and ripping designed to disaggregate a massive body of in-situ rock in order to excavate and transport the materials (Phillip and Douglas, 2001). Important factors controlling rock pile stability are geometry of the rock piles, weight of waste rock; shear strength, pore pressure and foundation conditions

However the mineralogy and chemistry of the rock pile material and of the discharging water is important in determining the acid drainage potential. The acid drainage potential could ultimately affect the slope stability by changing the composition (i.e. weight and shear strength) of the rock pile. A typical rock pile characterization program involves field and laboratory measurement to determine the physical, hydrological, geological, and geochemical and geotechnical properties of the rock pile and the material within it (Virginia and Samuel, 2009)

2.3 LEACHATE FORMATION FROM WASTE ROCKS

Leachate is any liquid material that drains from land or stockpiled material and contains significantly elevated concentrations of undesirable material. The production and flow of leachate from waste rock piles is controlled by wetting and drying cycles. The waste piles are intermittently wetted by meteoric water and seasonal run-off, dried by drainage and evaporation. The time taken to complete the entire wetting- drying cycle is dependent upon porosity, permeability and climatic factors. A complete wetting-drying cycle for a waste rock pile located in a region of moderate to high rainfall with distinct seasons consist of four sequential stages;

- 1. Sulphide oxidation and formation of secondary minerals
- 2. Infiltration of water into dumps
- 3. Drainage of water from dump
- 4. Evaporation of pore water

The first stage represents the atmospheric oxidation of sulphides which results in the destruction of sulphides and the formation of secondary minerals. The second stage is the infiltration of meteoric water and seasonal run-off. Pores are wetted to the extent that weathering of minerals occurs. The third stage involves drainage of water from the pore spaces. Solutes dissolved in the pore water are transported to the water table or are channelled to surface seepages. Air replaces the pore water during drainage and a thin pore water film is left behind coating individual grains. The fourth stage is the evaporation of the water film during the drying cycle. During drying, the relative importance of drainage compared to evaporation is determined by the physical properties of the waster rock pile such as hydraulic conductivity. The drying results in the precipitation of secondary minerals that may coat the sulphide mineral surfaces. If drying continues, some of these minerals may dehydrate, crack and spall from the sulphide surfaces exposing fresh sulphides to atmospheric oxygen (Perkin, 1997).

In arid regions there are no percolating waters present and the flow of water through a waste rock is greatly reduced. In such locations, sulphide oxidation occurs and the secondary salt generated from the limited available moisture resides within the waste. As a result, sulphide oxidation and formation of secondary minerals, evaporation of pore water of the wetting – drying cycle may only be important. In an arid environment, sulphide destruction does not necessarily lead to drainage from waste rock piles. However during high rainfall events, excess moisture is present and the secondary weathering products are dissolved and transported with the water moving through the material to the saturated zone or surface seepages. The waters may then emerge as a significant first flush that contains elevated contaminant concentrations. The position of water table in mine waste has an important role in influencing the composition of drainage waters. This is because the water table elevation fluctuates in response to seasonal conditions forming zones of cyclic wetting and drying. Such fluctuations provide optimal conditions for the oxidation of sulphides and associated secondary weathering products (Perkin, 1997).

Mature dumps have three distinct domains i.e. the outer unsaturated zone, inner unsaturated zone and the saturated lower zone reflecting the different distribution of oxidation sites and chemical reactions. This implies that the types and rates of reactions and resulting products are different in the individual zones. The outer zone of a mature waste pile is expected to have low levels of sulphide minerals. It is rich in insoluble primary and secondary minerals and can be depleted in readily soluble components. In contrast, the unsaturated inner zone is enriched in soluble and insoluble secondary minerals. In this zone oxidation of sulphides should occur along a front slowly moving down towards the water table of the dump (Paktunc, 1998). Stratified waste rock profile on the other hand is rejected by some authors and has argued that sulphide waste are heterogeneous and that any infiltration rainwater would follow potential flow preferential flow paths acting as hydraulic conduits. Such discrete hydrogeological channels would limit water-rock interactions. In addition, local seeps from a single waste dump are known to have substantially different water qualities which support the hypothesis of preferential flow paths in waste piles. Also the abundance and distribution of acid producing and acid buffering minerals vary from one particle to another. Waste parcels with abundant pyrite, free movement of air and impeded movement of water are expected to develop higher acidities than equal volumes that contain less pyrite or that are completely saturated with water. Physical and chemical conditions within waste rock dumps vary even on a microscopic scale. The resulting drainage water is a mixture of fluids from a variety of dynamic micro-environments within the dump. Consequently the water quality in different parts of waste dumps exhibits spatial and temporal variations (Lottermoser, 2010)

2.3.1 Changes in Waste Dump Seepage

When mine waste is exposed to weathering processes some soluble minerals go readily into solution whereas other minerals take their time to weather at different rates. The drainage chemistry of readily soluble minerals remains constant over time as only a limited, constant amount of salt is able to dissolve in water. Such static equilibrium behaviour is commonly found in secondary mineral salts such as silicates and sulphides which weather and dissolve slowly over time. Their reactions are strongly time dependent hence the drainage chemistry of these minerals changes through time. Kinetic or equilibrium chemical weathering and dissolution of different minerals within mine waste have an important influence on the chemistry of mine waters. The different weathering processes cause or contribute to the chemical load of waters draining them. In particular, kinetic weathering processes determine changes to mine water chemistries over time because acid producing and acid neutralizing minerals have different reaction rates. These different weathering and dissolution behaviours of minerals have an influence on the temporal evolution of mine water chemistries. The drainage water chemistry of a dump or tailings evolves with time as different parts of the material starts to contribute to the overall chemical load. Generally the chemical load reaches a peak after which the load decreases slowly with time. When altered, weathered or oxidized wastes are subjected to rinsing and flushing, the pore water will be flushed first from the waste. Then easily soluble alteration minerals, weathering and oxidation products and secondary efflorescence will dissolve and determine early rates of metal release and seepage chemistry, in particular, the soluble and reactive minerals will contribute to equilibrium dissolution at an early stage. Finally weathering kinetics of sulphides and other acid neutralizing minerals will take over and determine the drainage chemistry (Lottermoser, 2010).

Mine drainage quality prediction cannot be based on the assumption that 100% of waste material experiences uniform contact with water. Water moving through an unsaturated portion of waste contacts waste briefly whereas water of the saturated zone has a longer contact time with the waste. In addition some material may have a very low permeability allowing very little ground water to flow through it. These waste portions contribute little to the chemistry of drainage waters. In order to understand the chemistry of drainage waters emanating from waste rock dumps, it is important to determine what waste portions are contacted by water and what the nature of this contact is (Hawkins, 1998)

2.3.2 Environmental Impacts of Leachate from Waste Rocks

Drainage water from tailings dam, mine waste dumps, heap leach pads and ore stockpiles may contain suspended solids and dissolved contaminants such as acids, salts, heavy metals, metalloids and sulphate. Such waters should not be released from a mine site without prior treatment. The uncontrolled discharge of mine waters with elevated contaminant concentration into the environment may impact on surrounding surface waters, aquatic life, soil, sediments and ground waters. Investigation of the environmental impacts of mine waters requires an assessment of the concentration of elements in waters of background and contaminated sample population.

2.3.2.1 Surface Water Contamination

The release of AMD waters with their high metal and salt concentration impact on waters for fishing, irrigation and drinking water supplies. Metals, metalloids and acidity levels may exceed aquatic ecosystem toxicity leading to diminished aquatic life (Seal et al., 2008). Irrigation of crops with stream water that is affected by AMD effluents may be inappropriate if the impacted stream has metals and metalloid concentrations above threshold values that are considered to be phytotoxic to crops. Portable water supplies can be affected when national drinking water quality guidelines are not met. Poor water quality also limits its reuse as process water at the mine site and may cause corrosion to and encrustation of the process circuit. In general the severity of surface water contamination decreases downstream of the contamination source due to mixing with non-contaminated stream which causes the dilution of elements, compounds and the neutralization of acidity. Mineral precipitation, adsorption and coprecipitation may also remove elements from solution leading to lower dissolved contaminant concentrations in impacted waterways. High concentrations of acidity, metals and increased conductivity, total dissolved and suspended solids and turbidity can be observed in mine seepage and runoff waters at the beginning of the wet season or spring (Lottermoser, 2010)

2.3.2.2 Impact on Aquatic Life

High acidity waters can destroy the natural bicarbonate buffer system which keeps the pH of natural waters within a distinct pH range. The destruction of the bicarbonate system by excessive hydrogen ions will result in the conversion of bicarbonate to carbonic acid and then to water and carbon dioxide. Photosynthetic aquatic organisms use bicarbonate as their inorganic carbon source and loss of it will have an adverse impact on these organisms. They

will not be able to survive in waters below a pH of less than 4.3 (Brown et al., 1991). Heavy metals and metalloids at elevated concentrations can be lethal to aquatic life and of concern to animal and human health. Moreover the methylation of dissolved mercury and other metals and metalloids is favoured by a low pH which turns the elements into more toxic forms. The impact of contaminated waters and sediments containing high concentrations of metals and metalloids on aquatic ecosystem and downstream plant and animals can be severe; a reduction of biodiversity, changes in species, depletion of numbers of sensitive species, or even fish kills and death of other species (Lottermoser, 2010)

2.3.2.3 Sediment Contamination

Improper disposal of contaminated water from mining, mineral processing and metallurgical operations releases contaminants into the environment. (Herr and Gray 1997). If mine waters are released into local streams, the environmental impact will depend on the quality of the releases effluent. Precipitation of dissolved constituents may result in abundant colourful mineral coatings in stream channels. Originally dissolved elements may be removed from solution through mineral precipitation, adsorption and coprecipitation. This may cause soils as well as floodplains, streams, and lake sediments to become contaminated with metals and metalloids and salts. Transport and deposition of waste particles will also add contaminants to soil sediments in a solid form. Consequently metals and metalloids may be contained in various sediments fractions (Lottermoser, 2010). However, metals and metalloids are not necessarily captured and stored in the deposited sediments. Contaminated sediments may be transported further and deposited in downstream environments. Also changed in water chemistry may cause the contaminated sediment to become a source of metals and metalloids in the stream water. (Butler, 2009).

2.3.2.4 Ground water Contamination

The release of mine waters impacts more frequently on the quality of ground waters than on that of surface waters. Mining derived contaminants may enter waters of the unsaturated or saturated zone or become attenuated at the ground water –surface water interface. (Gandy et al, 2007). Ground water contamination may originate from mine workings, tailings dam, waste rock piles, heap leach pads, ore stockpile, coal spoil heaps, ponds and contaminated soils. Contaminated water may migrate from waste source into aquifers, especially if the waste repository is uncapped, unlined and permeable at its base or if the lining of the waste source has been breached. Again, the flooding of underground workings may impact on the

chemistry of mine waters and local ground water. Waste rock reaction in open pits may also lead to the dissolution of contaminants. At such sites water and dissolved contaminant may leak from the mine workings or the waste repository into the underlying aquifer. Significant concentrations of sulphate, metals, metalloids and other contaminants have been found in ground water plumes migrating from mine workings and waste repositories and impoundments at metal sulphide mines (Lottermoser, 2010).

The migration rate of such a plume is highly variable and dependent on the physical and chemical characteristics of the aquifer or waste material. General sulphate, metals, and metalloid concentration in the ground water define a leachate plume extending down gradient of acid mine drainage source. Contaminant level depends on the interaction between the soil, sediment or rock through which the contaminated water flows and the contaminant in the water. Conservative contaminants move at ground water velocities, however, reactive contaminants move more slowly than the ground water velocity and a series of different pH zones may be present in the contaminant plume. The occurrence of these zones is attributed to the successive weathering of different pH buffering phases in the aquifer. Such attenuation processes in the aquifer including pH changes can reduce the constituent concentrations to background levels in the pathway of the subsurface drainage. Neutralizing minerals such as carbonates may be contained in the aquifers and these minerals buffer acidic ground waters. Depending on the neutralizing property of the aquifer through which the water moves, it could be many years before significant impact on ground and surface water quality is detected. In the worst case the neutralizing minerals are completely consumed before the acid generation is halted at the source then the acidic ground water plume will migrate down gradient and can eventually discharge to the surface (Lottermoser, 2010).

2.3.3 Leachate Management Strategies

At mine sites, containment of all contaminated water is to be ensured using proper management strategies. These strategies aim at protecting aquatic environments and to reduce the water volume requiring treatment. Depending on the waste and water characteristics, location or climate of the mine site, different strategies are applied. Various strategies can be used to reduce mine water volumes;

- Interception and diversion of surface waters through construction of upstream dams
- Diversion of run-off from undisturbed catchments
- Maximizing of recycling or reuse of water

- Segregation of water types of different quality
- Controlled release into nearby waters
- Sprinkling of water over dedicated parts of the mine site area
- Use of evaporative ponds
- Installation of dry covers over sulphide waste in order to prevent infiltration of meteoric water.

Releasing waste waters during periods of high rainfall or peak river flow may also achieve dilution and reaction of the effluent to pollutant concentrations below water quality standards (i.e. dilution is the solution of pollution). However in most cases such disposal is not politically and environmentally acceptable and treatment is required prior to their discharge. In many cases mining operations have to discharge mine waters to streams outside their operating license areas. The release of water from the mine site has to conform to statutory directives, which the quality of discharge water has to meet a specified standard comprising a list of authorised levels of substances. National water quality guidelines are commonly used as a basis for granting a mining license and allowing discharge of mine waters. They are designed to protect downstream aquatic ecosystems, drinking water, and water for agricultural use. Water quality guidelines for metals in aquatic ecosystem are commonly based on total concentrations, however, the bioavailability of metals (i.e. the ability to pass through a biological cell membrane) and the toxicity of metals to aquatic organisms are dependent on the chemical form, which is the speciation of these metals. Metals present as free ions are more bioavailable than metals adsorbed to colloids or particulate matter. Consequently, guidelines which are based on total metal concentrations are overprotective since only a fraction of the total metal concentration in water will be bioavailable (Lottermoser, 2010).

CHAPTER THREE MATERIALS AND METHODS

3.1 STUDY AREA

Newmont Ghana Gold Limited (NGGL), Ahafo Project is one of the two Greenfield developments in Ghana being sponsored by Newmont Ghana. It is located in the Brong-Ahafo Region of Ghana, approximately 300km northwest from the capital, Accra; 107 km northwest of Kumasi and 40 km south east of the regional capital of Sunyani (Figure 3.1). The currently known reserves and resources at Ahafo, as well as significant extensions to the strike length of the Ahafo mineralized zones, are secured by the Yamfo - Kenyase Mining Lease and the Rank Mining Lease. In addition, a number of Reconnaissance and Prospecting Licenses cover areas immediately towards the west and east of the main mineralized structure.



Figure 3.1: Map of Ghana showing Newmont tenements (NGGL Ahafo. Technical, 2006)

The area features low rolling hills and receives modest to fairly high annual rainfall (1,250 - 2,000mm) and lies in the general headwaters of the Tano River Basin. Access to the Ahafo Project is good via several paved and laterite roads. The northern part of the area is served by the main. Kumasi-Sunyani Highway (yellow trace in Figure 3.1). Extensive timbering in the past has degraded much of the primary forest cover although several sizeable Forest Reserves remain nearby (NGGL Ahafo. Technical, 2006)

3.1.1 Geology of Newmont Ghana Gold, Ahafo Mine

The Newmont, Ahafo Mine lies within the Birimian rocks of early Proterozoic Age, between 2.1 and 1.8 Ga. The Birimian units have been classified as Birimian metasedimentary and metavolcanic rocks. The latter is composed of metamorphosed tuffs and lavas, calc-chlorite schists, metadiorites amphibolites and greywackes. The Birimian metasedimentary rocks are composed of greywackes with impure quartzites, phyllites, schists and hornstone. These are mainly steeply dipping, isoclinally folded and sheared metasediments, lavas and tuffs. The rocks are in general cut by quartz veins stringers In general, dips of both bedding and foliations are in the range of 30° to 80° in the southeast direction. The Birimian Supergroup in south-western Ghana, comprises several narrow north-east-trending belts of volcanic and volcaniclastic rocks of tholeiitic to acidic composition that are separated by broad sedimentary basins (Wright et al., 1985)

The Ahafo projects are located in the Sefwi Belt, one of the five Birimian volcanic belts in Ghana and have pyrite as the main sulphide. To date, no arseno-pyrite has been observed in the Ahafo deposits. Alteration commonly consists of intense silicification, chlorite and carbonate alteration with sericite, albite and minor feldspar (NGGL Ahafo. Technical Report, 2006). The Sefwi Belt is bounded to the northwest by the Sunyani Basin and to the southeast by the Kumasi Basin, which are preserved structural remnants of larger basins. The Belt-type granitoids or "Dixcove suite" intrude the contact and predominate in the metavolcanic rocks forming more or less elongate bodies parallel to the regional strike. Basin-type granitoid (formerly known as Cape Coast suite) intrusions are found in the southern-most part of the project area (Wright et al., 1985).

Regionally, the sedimentary succession consists mainly of fine to medium-grained lithologies (argillites and greywackes) with variable amounts of volcanoclastic material. The Basin-type granitoids intrude the metasediments. The volcanics are mainly basaltic and have been metamorphosed to varying degrees from Lower Greenschist to Amphibolite Facies. The Belt-type granitoids intrude the volcanic areas (Wright et al., 1985). The main structural feature in the area is the north-east to south-west trending regional shear zone that separates the Sefwi Belt from the Sunyani Basin, locally referred to as the Kenyase Thrust. The known Ahafo District gold resources currently consist of twelve discrete deposits that are localized along multiple northeast-striking structural zones. All of the deposits appear to be part of the same

mineralised system and are "shear zone" hosted mesothermal type. (NGGL Ahafo. Technical Report, 2006).

3.2 SELECTION OF SAMPLING SITES

Sampling sites were selected from both Control points (monitoring points that are upstream of the mine-take area or in areas where there are no mining activities) and Compliance points (Points that are located where water leaves the mine-take area and enters the environment). Other sites were leachate trench at the base of the waste dump and rainfall samples collected around the mine take area. A test was to be carried out to compare the concentrations of heavy metals as well as physical parameters of the waters as they move from upstream to the downstream. Control points selected were NSW 10 (Ntotroso Surface Water 10) at the Tano River Pumping Station, KSW16 at Dokyikrom (Kenyase Surface water 16), GWC5D at Tailorkrom, and GWC8D at Dokyikrom. Compliance points selected were ECD4 at Kantinka (Environmental Control Dam 4) and GWC7D at Kantinka as well as trench sample called Apensu Tailings Storage Facility (APTSFI) as shown in (Figure 3.2).

Six samples each were collected from all selected sites monthly between October 2011 and March 2012. Water samples were collected into 250ml plastic bottles as shown in (Plate 3.1 and 3.2). Concentrations of physical parameters were measured in the field whilst those for heavy metals, sulphate and alkalinity were transported to the laboratory in an ice chest to keep them within a required temperature.

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Figure 3.2 Map of Ahafo showing Water Monitoring Location Sites



Plate 3.1 Surface Water Sampling at NSW10-Tano River pumping Station



Plate 3.2 Groundwater Sampling at GWC5D, Tailorkrom.

3.3 FIELD AND LABORATORY ANALYSIS

Water samples taken were analysed for temperature, conductivity, pH ,total dissolved solids(TDS), total suspended solids(TSS), dissolved oxygen(DO), turbidity, sulphate, alkalinity and heavy metals (dissolved metals) i.e. Arsenic (As), Iron (Fe), Copper (Cu), Zinc (Zn), Manganese (Mn), Cadmium (Cd) and Nickel (Ni).

3.3.1 pH, Temperature, Conductivity, DO and TDS, TSS

pH, temperature, conductivity, dissolved oxygen and total dissolved solids were measured using the Orion-4 star pH-conductivity meter in the field. The meter was first calibrated with pH buffers 4.00, 7.00 and 10.00. It was then calibrated with conductivity buffers, 1413 and 12. 19μ s/cm. The concentrations of the parameters were measured using the probes placed in the water samples collected in 1000ml beaker as shown in (Plate 3.3)



Plate 3.3 Determination of physical parameters in the field

The HACH 2100Q Spectrophotometer was used in the determination of turbidity in the water samples. The machine was calibrated using standard solutions of 20, 10, 100 and 800 NTU.

20ml of the water sample was placed in the spectrophotometer and the reading recorded in the field sampling book.

3.3.2 Sulphate Determination

The HACH DR 2800 Spectrophotometer was used in the determination of sulphate in the water sample. A sample cell was filled with 10ml of the water sample; the contents of the SulfaVer 4 Reagent Powder Pillow added to the sample and swirled vigorously to dissolve the powder. The instrument timer was started for a five- minute reaction time with the cell undisturbed. Test results are measured at 450nm. The spectrophotometer measures the turbidity which is proportional to the sulphate concentration

3.3.3 Alkalinity Determination

A 100ml of the water sample was poured into an Erlenmeyer flask and five drops of mixed indicator bromocresol green–methyl red was added to the sample and the initial titre value was recorded. It was then titrated with 0.02N HCL to end-point. The final titre value was recorded and the titration volume in ml determined. Total alkalinity was calculated as follows:

Alkalinity (as mg/L CaCO₃) = $\frac{V \times N \times 1000 \times 100}{\text{ml sample x 2}}$

Where V= titration volume in ml

N= normality of the acid solution

100= molecular mass of CaCO₃ (Standard Methods, 1992).

3.3.4 Dissolved Metals

The metal concentrations of arsenic, iron, copper, zinc, manganese, cadmium, and nickel were determined using Atomic Absorption Spectrometer (AAS), 55B model. The machine was calibrated using the standard solutions of the various metals. 200ml of the filtered sample was measured into a bottle and 1ml of concentrated HCL added, shaken and allowed to stabilise for about an hour for digestion to take place. The concentrations of the metals were determined using the following wavelengths: As (193.7nm), Fe (248.3nm), Cu (324.8nm), Zn (213.9nm), Mn (279.5nm), Cd (228.8nm) and Ni (232.0nm) (Perkin, 1997)

3.4 COMPLIANCE LIMITS

Compliance limits are achieved through a set of standards. Legal Compliance Limits which is applicable in Ghanaian laws and regulation and any associated licenses and permits including Ghana EPA General Environmental Quality Standards. It is also achieved through the commitments made in NGGL's loan agreement with the International Finance Corporation (IFC) which is termed as Loan Commitment Limits, which is applicable to the World Bank Environment, Health and Safety Guidelines: Mining and Milling- Open Pit (August 1995), to satisfy IFC lending commitments (NGGL, 2008. Site Specific Water Quality Criteria). Table 3.1 shows the various standards applicable at NGGL, Ahafo Project area

Parameter	Unit	Ghana EPA	IFC (WB)	NGGL
pH	-	6-9	6-9	6-9
Temperature	°C	<3 above ambient	<5 above ambient	<3 above ambient
TSS	mg/l	50	50	50
TDS	mg/l	1000	-	1000
Conductivity)	µS/cm	1500		1500
Colour	TCU	20	21-1	20
Turbidity	NTU	75	1 A A A A A A A A A A A A A A A A A A A	75
Ammonia	mg/l		Sold Free	1
Aluminium	mg/l	5	more -	5
Antimony	mg/l	1.5	-	1.5
Arsenic, total	mg/l	0.5	1	0.5
Arsenic, diss.	mg/l	0.1	3	0.1
Cadmium	mg/l	0.1	0.1	0.1
Copper	mg/l	2.5	0.3	2.5
Flouride	mg/l	10	0	10
Iron	mg/l	10	2	10
Lead	mg/l	0.1	0.6	0.1
Manganese	mg/l	0.1	-	0.1
Nickel	mg/l	0.5	0.5	0.5
Silver	mg/l	0.1	-	0.1
Sulphate	mg/l	300	-	300
Zinc	mg/l	5	1	5
Cyanide, free	mg/l	0.1	0.1	0.1
Cyanide, total	mg/l	1	1	1
Oil and Greese	mg/l	10	20	10

Table 3.1: Comparison of water quality guidelines for legal discharge of water

CHAPTER FOUR RESULTS

This Chapter presents the results of some water quality analysis at some controls and compliant points within the NGGL Ahafo Mine take-area and an environmental audit conducted with their concerns.

4.1 PHYSICAL PARAMETERS

Results of the water quality analysis pertaining to the physical parameters conducted on the various points are presented. In these, the means are used for simplicity; however, a summary of the details results are presented in (Table 4.1) whereas the full details may be found in the Appendices.

4.1.1 pH

The mean pH values at the various sampling points are presented in Figure 4.1,



Figure 4.1: Mean pH in all sampling locations with EPA upper and lower limits in red

Rainfall having a mean pH of 6.41 was relatively low compared to that of underground and surface waters. The mean pH of groundwater was also low ranging between 6.73 and 7.23 compared to that of surface water values ranging between 7.36 and 8.55 with GWC5D at Tailorkrom recording the highest pH of 7.23 and GWC7D at Kantinka recording the lowest
pH of 6.73. For surface waters, the highest pH value of 8.55 was recorded at ECD4 of Katinka and the lowest pH of 7.36 recorded at KSW16 of Dokyikrom (Table 4.1).

Statistically ($P \le 0.05$) there was a difference between rainfall and ECD4. Difference was also recorded between ECD and GWC8D, GWC7D. (Appendix I

4.1.2 Turbidity

The mean turbidity values at the various sampling points are presented in Figure 4.2, Mean turbidity level for rainfall was high compared to underground waters and relatively low compared to surface waters. The values of groundwater ranged between 2.12NTU and 3.67NTU with the highest value recorded at GWC8D at Dokyikrom .The values of surface water ranged between 7.28NTU and 61.03NTU with the highest value recorded at NSW10 at the Tano River pumping station (Table 4.1).

There was no significant difference in turbidity statistically ($P \le 0.05$) between rainfall and groundwater but recorded a difference between surface water at NSW10 and groundwater's at GWC5D, GWC8D and GWC7D. Again difference was recorded between rainfall and KSW16, NSW10 and finally between ECD4 and GWC7D (Appendix II).



Figure 4.2: Mean turbidity in all sampling locations with EPA limit in Red

4.1.3 Total Suspended Solids (TSS)

The mean total suspended solid values at the various sampling points are presented in Figure 4.3. Rainfall with a mean TSS of 6.25 was high compared to that of underground water and relatively low compared to surface water. Groundwater values ranged between 1.66 and 5.17 compared to that of surface water values ranging between 13.38 and 56.83 respectively with GWC5D at Tailorkrom recording the highest TSS of 5.17. For surface waters, the highest TSS value of 56.83 was recorded at NSW10 of Tano River pumping station (Table 4.1) Statistically ($P \le 0.05$) there was no significant difference between rainfall and groundwater values but differences were recorded between surface water at NSW10 and groundwater's at GWC5D, GWC8D and GWCD7D and also between KSW16 and GWC7D (Appendix III)



Figure 4.3: Mean TSS in all sampling locations with EPA limit in red

Sample	Sampla	Meen nH &	Moon Tomn	Mean	Mean	Meen Cond	Mean TDS.	Mean	Mean	Mean
Туре	Sitos	Derrer		Turb.(NTU	TSS.mg/L	with an Cond.	mg/L &	D.O. mg/L	Alkali.&	SO4 ² mg/L &
	Siles	Känge	C & Kallge	& Range	& Range	µs/cm & Kange	Range	& Range	Range	Range
Painfall		6.41	24.08	5.55	6.25	17.42	8.50	7.70	7.75	1.00
Kainjali		6.08-6.89	21.70-24.90	2.01-8.10	4.00-9.00	8.21-23.46	4.0-11.0	7.39-7.93	2.00-21.00	In Mean i.& SO4 ² mg/L & ge Range 5 1.00 1.00 0.00-1.00 00 1.00 238.00 0.00-3.00 70 0.17 253.00 0.00-1.00 30 21.00 172.00 13.00-24.00 50 1026.66 153.00 880.0-1140.0 57 1.67 73.00 0.00-4.00 00 0.00 125.00 0.00-0.00 50 133.30
	GWC5D	7.23	26.42	2.62	5.17	460.70	222.5	2.80	230.00	1.00
	GWCJD	7.19-7.40	25.90-27.20	1.11-5.57	1.00-21.00	433.00-495.00	212.0-231.0	1.87-3.83	225.00-238.00	0.00-3.00
Ground-	CWC9D	7.04	26.87	3.67	3.33	467.00	229.0	2.68	239.70	0.17
water	GWCoD	6.90-7.21	26.10-27.90	0.65-11.10	1.00-7.00	446.00-487.00	219.0-239.0	1.03-5.13	221.00-253.00	0.00-1.00
	CWC7D	6.73	25.95	2.12	1.66	374.30	181.17	3.28	155.30	21.00
	<i>GWC7D</i>	6.42-9.97	22.50-27.60	0.92- <mark>3.6</mark> 8	1.00-5.00	358.00-396.00	175.0-192.0	1.93-4.32	239.700.17221.00-253.000.00-1.00155.3021.00148.00-172.0013.00-24.00133.501026.66114.00-153.00880.0-1140.0	
	APTSFS	7.43	27.22	7.28	13.38	2444.00	1024.83	5.32	133.50	1026.66
	1	7.27-7.57	25.30-28.70	1.92-15.20	3.00-42.00	2009-2821	115.0-1382	2.73-7.51	114.00-153.00	880.0-1140.0
	NGW 10	7.52	26.18	61.03	56.83	197.00	101.0	5.37	56.67	1.67
Surface	INS W 10	7.06-8.17	25.40-26.80	14.2-156.0	5.0-161.0	93.00-501.00	51.0-273.0	3.04-7.76	38.00-73.00	0.00-4.00
water	VCW 16	7.36	25.18	40.12	30.33	300.80	140.92	5.28	113.00	0.00
	K3W 10	6.96-7.70	23.40-27.80	23.30-53.20	20.0-39.00	257.00-342.00	121.0-167.0	4.01-6.16	100.00-125.00	0.00-0.00
	ECD 4	8.55	30.07	22.81	14.48	871.80	456.83	6.88	114.50	133.30
	ECD 4	7.84-9.10	28.70-31.00	7.91-38.9	3.00-41.0	396.0-1109.00	194.0-721.0	4.96-8.50	58.00-186.00	52.00-330.00

Table 4.1: Mean and range of some water quality parameters (Appendix IV)

4.1.4 Total Dissolved Solids (TDS)

The mean total dissolved solid values at the various sampling points are presented in Figure 4.4. Mean total dissolved solids level for rainfall was relatively low compared to underground waters as well as to surface waters. The values of groundwater ranged between 229.0 and 222.5 with the highest value of 222.5 recorded at GWC5D at Tailorkrom .The values of surface water ranged between 101.0 and 1024.83 with the highest value of 1024.83 recorded at APTSFS1 (Table 4.1)

Statistically ($P \le 0.05$) there was a significant difference between rainfall and groundwater at GWC8D and with surface waters at ECD4 and APTSFS1.There was also a differences recorded between GWC7D and APTSFS1 Surface water also recorded differences between NSW10 and APTSFS1 as well as KSW16 and APTSFS1.(Appendix V).



Figure 4.4: Mean TDS in all sampling locations with EPA limit in red

4.1.5 Conductivity

The mean conductivity values at the various sampling points are presented in Figure 4.5 A rainfall with a mean conductivity of 17.42 was relatively low compared to that of underground water and surface water. Groundwater values ranged between 374.3 and 467. Compared to that of surface water values ranging between 197 and 2444 respectively with GWC8D at Dokyikrom recording the highest conductivity of 467. For surface waters, the highest conductivity value of 2444 was recorded at APTSFS1 (Table 4.1)

Statistically ($P \le 0.05$) there was a significant difference between rainfall and APTSFS1 and ECD4. Differences were also recorded between surface water at NSW10 and APTSFS1 as well as KSW16 and APTSFS1. (Appendix VI)



Figure 4.5: Mean conductivity in all sampling locations with EPA limit in red

4.1.6 Dissolved Oxygen (DO)

The mean dissolved oxygen values at the various sampling points are presented in Figure 4.6. Mean dissolved oxygen level for rainfall of 7.7 was relatively high compared to underground waters as well as to that of surface waters. The values of groundwater ranged between 2.8 and 3.28 with the highest value of 3.28 recorded at GWC7D at Kantinka .The values of surface water ranged between 5.28 and 6.88 with the highest value of 6.88 recorded at ECD4 (Table 4.1). Statistically ($P \le 0.05$) there was a difference between rainfall and groundwater at GWC8D and GWC5D.There was also a differences recorded between surface water at ECD4 and groundwater at GWC8D and GWC5D (Appendix VII).



Figure 4.6: Mean DO in all sampling locations

4.1.7 Alkalinity

The mean alkalinity values at the various sampling points are presented in Figure 4.7. Mean alkalinity level for rainfall value of 7.75 was relatively low compared to underground waters as well as to that of surface waters. The values of groundwater ranged between 155.3 and 239.7 with the highest value of 239.7 recorded at GWC8D at Dokyikrom .The values of surface water ranged between 56.67 and 133.5 with the highest value of 133.5 recorded at APTSFS1 (Table 4.1)

Statistically ($P \le 0.05$) there was a significant difference between rainfall and groundwater at GWC8D, GWC7D and GWC5D. There was also a differences recorded between surface water at NSW10 and groundwater at GWC8D and GWC5D (Appendix VIII).



Figure 4.7: Mean alkalinity in all sampling locations

4.1.8 Sulphate

The mean sulphate values at the various sampling points are presented in Figure 4.8. Mean sulphate level for rainfall value of 0.17 was relatively low compared to surface water and that of groundwater was also low compared to that of surface water. The values of groundwater ranged between 0.17 and 21 with the highest value recorded at GWC7D at Kantinka .The values of surface water ranged between 0 and 1026.66 with the highest value recorded at APTSFS1.(Table 4.1)

Statistically ($P \le 0.05$) there was a significant difference between rainfall and surface water at APTSFS1 and ECD4. There was also a differences recorded between surface water at KSW16, ECD4 and APTSFS1. Groundwater at GWC8D also recorded a significant difference with surface water at APTSFS1 (Appendix IX).



Figure 4.8: Mean sulphate in all sampling locations with EPA limit in red

4.2 DISSOLVED METALS CONCENTRATION

4.2.1 Iron (Fe) Concentration

Mean dissolved iron concentration in rainfall was low compared to both groundwater and surface water. The concentration in groundwater was also low with the highest value of 0.23mg/L recorded at GWC5D compared to surface water with the highest value of 1.05mg/L recorded at KSW16 (Table 4.2). Statistically ($P \le 0.05$) significant difference was recorded in dissolved iron concentration between rainfall and surface waters at NSW10 and KSW16. Differences were also recorded between surface waters at NSW10 and APTSFS1 as well as between KSW16 and APTSFS1 and ECD4. There was no difference recorded in groundwater. (Appendix X).



4.2.2 Manganese (Mn) Concentration

Mean dissolved manganese concentration in rainfall was low compared to groundwater and to that of surface water. The concentration in groundwater was high with the highest value of 0.67mg/L recorded at GWC8D compared to surface water with the highest value of 0.09mg/L recorded at KSW16. (Table 4.2).Statistically ($P \le 0.05$) no difference was recorded in dissolved manganese concentration between rainfall and surface water. Difference was recorded between surface waters at KSW16 and APTSFS1. Differences were also recorded between groundwater at GWC8D and surface waters at NSW10 and ECD4 (Appendix XI).



Figure 4.10 Mean Mn concentrations in all sampling locations with EPA limit in red

4.2.3 Copper (Cu) Concentration

Mean dissolved copper concentration in rainfall was low compared to both groundwater and surface water. The concentration in groundwater was low with the highest value of 0.001mg/L recorded at GWC7D compared to surface water with the highest value of 0.003mg/L recorded at KSW16. (Table 4.2).Statistically ($P \le 0.05$), difference was recorded in dissolved copper concentration between rainfall and surface waters at APTSFS1, KSW16 and ECD4. Differences were also recorded between groundwater at GWC5D and surface waters at APTSFS1, KSW16 and ECD4 as well as GWC8D and KSW16 (Appendix XII).



Figure 4.11Mean Cu concentrations in all sampling locations

Sample	Sample	Mean	Mean	Mean	Mean	Mean Ni(mg/L)	Mean As.	Mean Cd
Туре	Sitos	Fe(.mg/L)	Mn(mg/L)	Cu(mg/L) &	Zn.(mg/L)	& Range	(mg/L)	(mg/L)
	Sites	& Range	& Range	Range	& Range	& Kange	& Range	& Range
Dainfall		0.02	0.02	0.00	0.003	0.00	0.003	0.00
Rainfall		0.00-0.02	0.00-0.02	0.00-0.00	0.002-0.07	0.00-0.00	0.002-0.006	0.00-0.00
	CWC5D	0.23	0.12	0.00	0.00	0.00	0.03	0.003
	GWC5D	0.15-0.28	0.01-0.27	0.00-0.00	0.00-0.00	0.00-0.00	0.027-0.031	0.000-0.006
Ground-	CWC9D	0.22	0.67	0.00	0.02	0.00	0.16	0.0004
water	GWCoD	0.07-0.38	0.23-1.21	0.00-0.001	0.00-0.02	0.00-0.00	0.14-0.19	0.0002-0.0008
	CUUC7D	0.14	0.05	0.001	0.00	0.00	0.001	0.0003
	GWC/D	0.02-0.26	0.01-0.07	0.001-0.001	0.00-0.00	0.00-0.00	0.0005-0.0009	0.0002-0.0004
	APTSFS	0.06	0.04	0.002	0.00	0.00	0.002	0.0001
	1	0.03-0.08	0.02-0.07	0.001-0.002	0.00-0.00	0.00-0.00	0.0016-0.0028	0.000-0.0001
	NGW 10	0.67	0.015	0.001	0.00	0.00	0.0006	0.00
Surface	NSW 10	0.46-0.91	0.01-0.02	0.0007-0.0025	0.00-0.00	0.00-0.00	0.00-0.0006	0.00-0.00
water		1.05	0.09	0.003	0.00	0.00	0.002	0.00
	K3W 10	0.83-1.18	0.02-0.29	0.001-0.006	0.00-0.00	0.00-0.00	0.001-0.002	0.00-0.00
	ECD 4	0.16	0.02	0.002	0.00	0.00	0.002	0.00
	ECD 4	0.16-0.16	0.01-0.04	0.001-0.002	0.00-0.00	0.00-0.00	0.001-0.002	0.00-0.00

Table 4.2Mean and range of some dissolved metals (Appendix XIII)

4.2.4 Arsenic (As) Concentration

Mean dissolved arsenic concentration in rainfall was low compared to groundwater and high compared to surface water. The concentration in groundwater was high with the highest value of 0.16mg/L recorded at GWC8D compared to surface water with the highest value of 0.002mg/L (Table 4.2). There was statistically ($P \le 0.05$) a difference recorded in dissolved arsenic concentration between rainfall and groundwater at GWC8D. Difference was also recorded between surface water at NSW10 and groundwater at GWC5D and GWC8D. Groundwater recorded a difference between GWC5D and GWC7D as well as between GWC8D and GWC7D (Appendix XIV).



Figure 4.12 Mean As concentrations in all sampling locations with EPA limit in red

4.2.5 Zinc, Nickel and Cadmium Concentrations

Mean dissolved Zinc, Nickel and Cadmium concentrations were all low for all monitoring locations and statistically ($P \le 0.05$) showed no significant differences between rainfall, groundwater and surface waters in all sampling locations (Appendix XV and XVI).

4.3 INSPECTIONS

During the period of study, inspections were conducted on environmental control dams and water storage facilities to ascertain the appropriateness of the managed practices; some of the positive outcomes were:

- There was no evidence of spill on water;
- Aesthetically, water was clear and looked natural;
- No evidence of water ponding on the embankment;
- No evidence of fish kill on water;
- Water was odourless and colourless;
- No community members or any fishing/swimming activity around the dam; and
- No damage was done to the decanting tower.

However there were a few negative observations that needed to be corrected including:

- The immediate environment of the decanting tower was weedy and required clearing;
- Water in the dam was overflowing through the spill way as a result of heavy down pours from the previous days (Appendix XVII)



CHAPTER FIVE DISCUSSIONS

5.1 PHYSICAL PARAMETERS

Mean pH for all sampling points shows that they fall within the EPA standard limits however that of rainfall was low. The low pH of rainfall, making it more acidic compared to that of surface and groundwater is due to the fact that water reacts with carbon dioxide in the atmosphere to form a weak carbonic acid The values were neutral and/or basic. This behaviour of the water may be attributed to the fact that rocks within the area are more basic in nature with good neutralising ability.

Mean turbidity shows exceedance of the EPA standard limit at NSW10. Turbidity in water may be a function of factors such as agricultural or urban development, vegetation and precipitation events, eroded materials including clay, silt or mineral particles from soils or from natural organic matter created by decay of vegetation which can greatly influence raw water turbidity (USEPA Guideline, 1989). The turbidity of the surface waters at NSW10 showing exceedance of EPA standard maximum limits and KSW16 though high but not in exceedance may be due to the fact that they are outside the mine-take area and may be influenced by activities from the surrounding communities. NSW10 for example may be influenced by the raw water intake by the Tano GWCL.

Mean total suspended solids for all sampling points falls within the EPA standard limit. TSS measurement is balanced with relatively quick and easy turbidity measurement to develop a site specific correlation. Once correlation is established, turbidity can be used to estimate TSS from more the frequently measured turbidity. TSS is a function of turbidity and the higher the TSS level, the higher the turbidity (USEPA Guideline, 1989). From this correlation, surface waters at NSW10, KSW16 and ECD4 show high TSS making turbidity high for the same water points which may be due to the human activities, run-off from precipitation, operational activities among others.

Mean total dissolved solids shows exceedance of the EPA standard limit at APTSFS1. Total dissolve solids is a measure of the amount of material dissolved in water which represents the amount of ions in it. This material can include carbonate, bicarbonate, chloride sulphate,

phosphate calcium magnesium, sodium and organic ions. A certain amount of these ions in water are necessary for aquatic life but a high concentration of it may reduce water clarity, contribute to a decrease in photosynthesis, combine with toxic compounds and heavy metals and lead to an increase in water temperature (U.S Geological Survey, 1984). Sulphate is one of the major constituents of dissolved ions and from the data, there is a high level of sulphate in APTSFS1 making total dissolved solids also high at the same sampling location as a result of the pyrite oxidation from the waste rocks.

Mean conductivity shows exceedance of the EPA standard limit at APTSFS1. Conductivity, which is a measure of the ability of water to conduct electric current, is a function of the types and quantities of dissolved solids in water and their mobility. Groundwater normally has high electrical conductivity as a result of its ability to dissolve rock forming minerals forming the aquifers. APTSFS1 has a high electrical conductivity due to high levels of dissolved ions present in the water.

Dissolved oxygen, is a measure of how oxygen is dissolved in water. Oxygen enters the water mainly from the atmosphere and in areas where groundwater discharges into streams. This dissolved oxygen is breathed by fish and zooplankton and is needed by them to survive. Moving water tends to contain a lot of dissolved oxygen as a result of turbulence, which allows the water to mix with atmospheric gases; stagnant water is unable to mix well contains little DO. Bacterial can consume oxygen as organic matter decays and excess organic matter can cause eutrophic condition, which is an oxygen deficient situation not too suitable for aquatic lives. This is particularly so in stagnant waters with a lot of rotten organic material (U.S Geological Survey, 1984). Though EPA does not give specific figures of limits, it is important that DO levels in water are good enough to sustain aquatic lives. The introduction of excess organic matter may result in the depletion of oxygen in aquatic systems, and prolonged exposure to low DO levels (<5 - 6mg/L) may not directly kill an organism but exposure to levels below 2mg/L for up to four days may kill most of the biota in a system (Gower, 1980).

DO levels in the waters sampled were quiet high signifying that there are little or no organic matter decay competing with aquatic lives for oxygen; the biological oxygen demand may therefore be minimal if any at all.

Alkalinity is a measure of the buffering capacity of water or the capacity of bases to neutralise acids; it is therefore important in determining a channel to neutralise acid contamination from rainfall or wastewaters. These buffering materials are primarily the bases -bicarbonates (HCO_3^{-1}) and carbonates (CO_3^{-2}) and occasionally hydroxides. Waters with high alkalinity are able to resist major shifts in pH. As increasing amount of acids are added to the water body, the pH of the water decreases and the buffering capacity of the water is consumed. Though EPA is not specific on limits of alkalinity in water, levels of 20 - 200 mg/L are typical of fresh water. A total alkalinity level of 100 - 200 mg/L will stabilize the pH level in a stream or river. Levels below 10mg/L indicate that the system is poorly buffered and is very susceptible to changes in pH from natural and human causes (USEPA Guideline, 1989). Alkalinity values in all sampling locations were within requirement levels, which may be due to the fact that rocks within the area have enough carbonate levels for buffering with no acid rock drainage effect.

Mean sulphate values at the various sampling points shows exceedance of the EPA standard limit at APTSFS1. Weathering of metal sulphide minerals such as pyrite, pyrrhotite, charcopyrite, arsenopyrite, among others releases acid and heavy metals to the environment. Although it is a slow process, it can cause serious environmental problems in regions with large sulphide deposits. Acid mine drainage, which is a common source of pollution from mining activities, is the result of the natural weathering of metal sulphide that has been accelerated by human activities (Andre, 2009). High sulphate level at APTSFS1 is as a result of sulphur oxidation, particularly pyrite from the waste dump. Dilution which is said to be the solution to pollution whereby other water bodies interact with precipitation, and by natural activities, the level of pollution reduces as water gets to the ECD4 which is a compliance point.

5.2 DISSOLVED METALS

Iron concentrations in water depends on redox and light conditions, pH, the amount and type of dissolved organic matter. The highest dissolved iron concentrations have been measured in acid, nonhumic rivers contaminated by mine drainages. Large concentrations of iron in a river water occur particularly during storms and rapid floods During such floods, a larger portion of stream flow is derived from surface run-off hence the qualitative and quantitative properties of this surface run-off is likely to be of great importance in the concentrations of iron during flood (Vuori, 1995). At higher pH, the solubility of iron is reduced due to the formation of iron hydroxides. Iron concentration is independent of acidity neither is it related to alkalinity of groundwater and stream water (Kritzberg and Ekstrom, 2011). Concentrations of iron do not exceed the Ghana Environmental protection Agency maximum limit though quite high in surface waters at NSW10 and KSW16. Geochemical studies in the area shows that iron occurs mildly in the top and subsoil layers and not in the deep seated rocks. Surface run-off carries particle of sand and silt to surface waters making iron concentrations high in those two controls points which are outside the mine take area.

Manganese is one of the most abundant metals in the earth's crust usually occurring with iron. At concentrations exceeding 0.1mg/l, the manganese ions impart an undesirable taste to beverages and stains plumbing fixtures and laundry. At concentrations as low as 0.02mg/l, manganese can form coatings on water pipes that may later slough off as a black precipitation (Griffen, 1960). Anaerobic groundwater often contains elevated levels of dissolved manganese. It can be adsorbed onto soil and the extent of adsorption depends on the organic content and cation exchange capacity of the soil (ATSDR, 2000).

In aquatic systems, manganese solubility increases at low pH as well as under oxidationreduction potential. The presence of high concentrations of chlorides, nitrates and sulphates may increase manganese solubility raising both aqueous mobility and uptake by plants. The concentration of manganese under aerobic conditions typical of shallow aquifers and surface waters is generally low and as a rule do no reach detection limits. The reason is that in aerobic conditions, manganese is found in its stable oxidized form generally as MnO₂ which is highly insoluble In anaerobic conditions, manganese is released from minerals and reduced to its more soluble form (Nadaska, et. al., 1977). Manganese level in groundwater exceeds that of Ghana Environmental Protection Agency maximum limit. This may be due to the fact that ambient groundwater contains elevated concentrations of naturally occurring manganese which are present in Ahafo groundwater Copper levels in surface and groundwater is generally very low. High levels of copper may then get into the environment through mining, farming, manufacturing operations among others. Copper concentrations in all sampling locations were very low and did not exceed the maximum limit (2.5mg/l) of the Ghana Environmental Protection Agency. This may be due to the fact that copper is not much evident in the lithological structure of the area.

Arsenic occurs naturally in geologic materials. It may be present in one or more oxidation states depending on available oxygen. They are usually only present in anaerobic conditions where dissolved oxygen is absent (Ayotte, 2008). Several industrial and agricultural activities may add arsenic to groundwater and surface water. Mining, wood preservation, pesticide manufacturing and use may also release arsenic into the environment. It may also be a contaminant in phosphorous fertilizers (Chang et. al., 2004). Arsenic concentration in groundwater at the control point GWC8D exceeds the Ghana Environmental Protection Agency maximum acceptable limit and this may be due to the naturally occurring arsenic in the rock and the low oxygen levels since groundwater is not exposed to atmospheric oxygen. It may also be due to agricultural activities since it is within a farming community.

Mean dissolved Zinc, Nickel and Cadmium concentrations were all low for all monitoring locations and statistically ($P \le 0.05$) showed no significant differences between rainfall, groundwater and surface waters in all sampling locations (Appendix XV and XVI).



CHAPTER SIX CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

Pyrite oxidation in the waste rock is evidently causing high concentrations of sulphate above the Ghana EPA standards. High levels of total dissolved solids and conductivity were also recorded in the leachate from the waste rock of which sulphate is a major component of the increasing levels.

However, there is no potential for acid generation due to the fact that rock lithology in the mining area has high carbonate content acting as a buffering material to neutralise acids as they are added to the water. These buffering materials are primarily the bases of bicarbonates (HCO₃) and carbonates ($CO_3^{2^-}$), and occasionally hydroxides. Dissolved metals were within the required EPA limits except manganese and arsenic, which had high levels in groundwater due to the fact that it occurs naturally in groundwater as seen in the control points.

The study also showed that the concentrations of both physic-chemical parameters and dissolved metals were within the Ghana EPA maximum acceptable limits for water leaving the compliance points of the "mine-take" area to the surrounding water bodies. Again, inspections conducted proved that there were no violations whatsoever and that proper management practices were being followed to ensure that waste waters leaving the working area were environmentally sound and not causing any adverse effect on human and aquatic lives, and the ecosystem at large.

6.2 **RECOMMENDATION**

There is no doubt that mining operations release some concentrations of both dissolved and total metals into the environment which when not managed well will cause adverse effect on the environment, human and aquatic lives. There is therefore the need to continue with the good management practices and to be abreast with International best practice so as to arrest any adverse situation before it becomes a disaster. Even though water leaving the mine-take area does not exceed that of EPA requirements, monitoring should be as regular and stringent as possible so as not to give room for any sudden events. It is also recommended that further studies be carried out to study total metals concentrations.

REFERENCE

- AGI, (1972). Glossary of Geology. American Geological Institute, Washington D. C.
- Andre, J. B., (2009). Generation of acid mine drainage: reactive transport models incorporating geochemical and microbial kinetics, Ph.D. thesis, University of Colorado at Boulder.
- Agency for Toxic Substance and Disease Registry (ATSDR), (2000). Toxicology Profile for Manganese. US Department of Health and Human Services, Atlanta, 539 pp.
- Ayotte, J. D., Nielsen, G. M., Robinson, R. G. and Moore, B. R., (2008). Relationship of Arsenic, Iron and Manganese in groundwater to aquifer type. Bedrock Lithogeochemistry. USGS- Water Resource Investigation Report .61 pp.
- Broughton, L. M., Robertson, A. M. and Kirsten B. C., (1991). Modelling of Leachate Quality from Acid Generating Waste Rock Dumps. Steffen, Robertson and Kirsten (B.C.) Inc. Homby Street, Canada, pp8-11.
- Bureau of Mines, (1968). A dictionary of Mining, Mineral and Related Terms. U. S. Department of Interior Publishing.
- Brown, D. S., Allison, J. D. and Novo-Grada, K. J., (1991). A Geochemical Assessment for Environmental Systems. EPA/600/391/021. Office of Research and Development, U. S. Environmental Protection Agency, Athens.
- Butler, B. A., (2009). Effect of pH, Ionic Strength, Dissolved Organic Carbon, time and Particle size on metals release from mine drainage impacted streambed sediments. Water Research version 43. National Risk Management Research laboratory. pp1392-1402.
- Chang, A., Page, A. and Krage, N., (2004). Role of Fertilizer and Micronutrient Application on Arsenic, Cadmium and Lead Accumulation. Department of Environmental Sciences. University of California, Riverside, California.
- Durham, D. (2004). Waste Rock Dump Guidelines. Environment, Health and Safety Management System. WMC Resources Ltd. pp. 3-11
- Department of Mines and Petroleum (2001). Environmental Notes on Mining. Mineral House Publishing, Western Australia
- EPA, Ghana, Akoben, (2008). Environmental Rating Methodology for Mining Companies. Department of Mines and Petroleum, Western Australia, (2001) Environmental note on mining, 49pp.

- European Union, (2004). Classification of Mining Waste Facility. Swedish Geotechnical Institute and University of Science and Technology, Krakow. pp6:52-54
- Gandy, C. J., Smith, J. W. N. and Jarvis, A. P., (2007). Attenuation of Mining-Derived Pollutants in the Hyporheic Zone: A review. Science of the total Environment 373.Newcastle University Publishing. Pp435-446
- Gower, A. M., (1980). Water Quality in Catchment Ecosystem. John Wiley and Sons Publishing, New York. pp89-109
- Griffen, A. E., (1960). Significance and removal of manganese in water supplies. Journal of the American Water Works Association. pp. 52:1326
- Hawkins, J. W., (1998). Hydrogelogic Characteristics of Surface Mine Spoil. Office of Surface Mining, Pittsburgh, PA 15220. pp 3:1-9
- Herr, C. and Gray, N., (1997). Metal Contamination of riverine sediments below the Avoca Mines, South East Ireland. Environmental Geochemistry and Health. pp2:73-82
- Kritzberg, E. S. and Ekstrom, S. M., (2011). Increasing iron concentration in surface waters-a factor behind brownification. Copernicus Publication on behalf of the European Geosciences Union, Sweden. pp 1-16
- Lottermoser, B.G, (2010). Mine Wastes Characterization, Treatment and Environmental Impacts. 3rd Edition. Springer- Verlag, Berlin Heideelberg, 400pp.
- Nadaska, G., Lesny, J. and Michalik, I., (1977). Environmental Aspect of Manganese Chemistry. Department of Biotechnology. University of Cyril and Methodius, Slovakia. pp 1-16
- Nahon, D. B. (1991). Introduction to Petrology of Soils and Chemical weathering, John Wiley and Sons Inc., New York. 313pp
- Newmont Ghana Gold Ltd, Ahafo (2008). Site Specific Water Quality Criteria. pp 2-9
- Newmont Ghana Gold Ltd, Ahafo, Technical Report (2006) Reserve and Resource Estimation version 3, pp3:11-35.
- Perkin, E. (1997). Analytical Methods for Atomic Absorption Spectroscopy, 4th edition. Perkin Elmer Corperation, United States of America, 299 pp.
- Phillip, R. M. and Douglas, J. C. (2001). Chemical Composition of samples collected from Waste Rock Dumps and other Mining-Related Features. Western U.S. pp1-8.
- Piwdwimy, M. (2006). "Weathering" Fundamentals of Physical Geography, 2nd edition. University of British Columbia. <u>www.physicalgeography.net</u>

- Paktunc, A. D., (1998). Characterization of Mine Waste for the prediction of acid mine drainage in Environmental Impacts of Mining activities, Springer-Verlag, Berlin. Pp425-431
- Robinson D. A. and Williams, R. B. G., (1994). Rock Weathering and Landform Evolution. John Wiley and Sons New York. 512pp
- Standard Methods for the Examination of Water and Wastewater, (1992). 18th Edition. pp 3:36-68
- Seal, D., Stapleton, F. and Dart, J., (2008). Possible Environmental Sources of Surface Water Contamination. J. Opthalmol Publishing, Britain. pp7:424-427
- Thompson, G. R. and Jonathan, T. (1998). 'Introduction to Physical Geology''. Frank Press and Raymond Siever. pp 6:94-106.
- U.S Geological Survey. (1984): Water Science School. URL: http://ga.water.usgs.gov/edu Howard Perlman Publishing
- USEPA Guideline Manual (1989). "Turbidity Provisions". Office of Water (4607). EPA-815-R-99-010. pp7:1-9
- Virginia, T. and Samuel, T. M. (2009). Characterization, Weathering and Stability of Rock Piles. New Mexico Bureau of Geology and Mineral Resources. pp.22 -30.
- Vuori, K. (1995). Direct and indirect effects of iron on river ecosystems. Finnish Zoological and Botanical Publishing Board. Joensua, Finland. pp 32:317-329.
- Wright, J. B., Hastings, D. A., Jones, W. B., and Williams, H. R. (1985). Geology and Mineral Resources of West Africa. George Allen and Unwin Publishers limited. London WCIA1LU, UK. pp 4:38-50
- World Bank Environment (1995). Health and Safety Guideline. "Mining and Milling-Open Pit. pp 1-4

APPENDICES

APPENDIX I

STATISTICAL ANALYSIS FOR RAINFALL, SURFACE WATER AND GROUNDWATER: A COMPARATIVE TEST ON pH FOR ALL SAMPLING SITES

Table Analysed

pН

Kruskal-Wallis test	
P value	P<0.0001
Exact or approximate P value?	Gaussian Approx.
P value summary	***
Do the medians vary signif. $(P < 0.05)$	Yes
Number of groups	
Kruskal-Wallis statistic	NUD 30.59

Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05? S	ummary
Rainfall vs NSW 10	-25.75	No	ns
Rainfall vs KSW 16	-23.00	No	ns
Rainfall vs ECD 4	-38.08	Yes	***
Rainfall vs GWC 5D	-17.92	No	ns
Rainfall vs GWC 8D	-9.417	No	ns
Rainfall vs GWC 7D	-8.083	No	ns
Rainfall vs APTSFS 1	-25.33	No	ns
NSW 10 vs KSW 16	2.750	No	ns
NSW 10 vs ECD 4	-12.33	No	ns
NSW 10 vs GWC 5D	7.833	No	ns
NSW 10 vs GWC 8D	16.33	No	ns
NSW 10 vs GWC 7D	17.67	No	ns
NSW 10 vs APTSFS 1	0.4167	No	ns
KSW 16 vs ECD 4	-15.08	No	ns
KSW 16 vs GWC 5D	5.083	No	ns
KSW 16 vs GWC 8D	13.58	No	ns
KSW 16 vs GWC 7D	14.92	No	ns
KSW 16 vs APTSFS 1	-2.333	No	ns
ECD 4 vs GWC 5D	20.17	No	ns
ECD 4 vs GWC 8D	28.67	Yes	**
ECD 4 vs GWC 7D	30.00	Yes	**
ECD 4 vs APTSFS 1	12.75	No	ns
GWC 5D vs GWC 8D	8.500	No	ns
GWC 5D vs GWC 7D	9.833	No	ns
GWC 5D vs APTSFS 1	-7.417	No	ns
GWC 8D vs GWC 7D	1.333	No	ns
GWC 8D vs APTSFS 1	-15.92	No	ns
GWC 7D vs APTSFS 1	-17.25	No	ns

APPENDIX II

STATISTICAL ANALYSIS FOR RAINFALL, SURFACE WATER AND GROUNDWATER: A COMPARISON TEST ON TURBIDITY FOR ALL SAMPLING SITES

Table Analysed

Turbidity

Kruskal-Wallis test	
P value	P<0.0001
Exact or approximate P value?	Gaussian Approx.
P value summary	***
Do the medians vary signif. ($P < 0$.05) Yes
Number of groups	8
Kruskal-Wallis statistic	KUUS 35.22

Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Rainfall vs NSW 10	-19.33	No	ns
Rainfall vs KSW 16	-17.83	No	ns
Rainfall vs ECD 4	-14.33	No	ns
Rainfall vs GWC 5D	8.833	No	ns
Rainfall vs GWC 8D	6.333	No	ns
Rainfall vs GWC 7D	11.50	No	ns
Rainfall vs APTSFS 1	-2.000	No	ns
NSW 10 vs KSW 16	1.500	No	ns
NSW 10 vs ECD 4	5.000	No	ns
NSW 10 vs GWC 5D	28.17	Yes	**
NSW 10 vs GWC 8D	25.67	Yes	*
NSW 10 vs GWC 7D	30.83	Yes	**
NSW 10 vs APTSFS 1	17.33	No	ns
KSW 16 vs ECD 4	3.500	No	ns
KSW 16 vs GWC 5D	26.67	Yes	*
KSW 16 vs GWC 8D	24.17	No	ns
KSW 16 vs GWC 7D	29.33	Yes	**
KSW 16 vs APTSFS 1	15.83	No	ns
ECD 4 vs GWC 5D	23.17	No	ns
ECD 4 vs GWC 8D	20.67	No	ns
ECD 4 vs GWC 7D	25.83	Yes	*
ECD 4 vs APTSFS 1	12.33	No	ns
GWC 5D vs GWC 8D	-2.500	No	ns
GWC 5D vs GWC 7D	2.667	No	ns
GWC 5D vs APTSFS 1	-10.83	No	ns
GWC 8D vs GWC 7D	5.167	No	ns
GWC 8D vs APTSFS 1	-8.333	No	ns
GWC 7D vs APTSFS 1	-13.50	No	ns

APPENDIX III

STATISTICAL ANALYSIS FOR RAINFALL, SURFACE WATER AND GROUNDWATER: A COMPARISON TEST ON TOTAL SUSPENDED SOLIDS FOR ALL SAMPLING SITES

Table Analysed

TSS

Kruskal-Wallis test	
P value	0.0001
Exact or approximate P value?	Gaussian Approx.
P value summary	***
Do the medians vary signif. ($P < 0$.05) Yes
Number of groups	8
Kruskal-Wallis statistic	KNUS 29.22

Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Rainfall vs NSW 10	-15.79	No	ns
Rainfall vs KSW 16	-13.46	No	ns
Rainfall vs ECD 4	-5.958	No	ns
Rainfall vs GWC 5D	9.292	No	ns
Rainfall vs GWC 8D	8.708	No	ns
Rainfall vs GWC 7D	14.96	No	ns
Rainfall vs APTSFS 1	-4.458	No	ns
NSW 10 vs KSW 16	2.333	No	ns
NSW 10 vs ECD 4	9.833	No	ns
NSW 10 vs GWC 5D	25.08	Yes	*
NSW 10 vs GWC 8D	24.50	Yes	*
NSW 10 vs GWC 7D	30.75	Yes	**
NSW 10 vs APTSFS 1	11.33	No	ns
KSW 16 vs ECD 4	7.500	No	ns
KSW 16 vs GWC 5D	22.75	No	ns
KSW 16 vs GWC 8D	22.17	No	ns
KSW 16 vs GWC 7D	28.42	Yes	**
KSW 16 vs APTSFS 1	9.000	No	ns
ECD 4 vs GWC 5D	15.25	No	ns
ECD 4 vs GWC 8D	14.67	No	ns
ECD 4 vs GWC 7D	20.92	No	ns
ECD 4 vs APTSFS 1	1.500	No	ns
GWC 5D vs GWC 8D	-0.5833	No	ns
GWC 5D vs GWC 7D	5.667	No	ns
GWC 5D vs APTSFS 1	-13.75	No	ns
GWC 8D vs GWC 7D	6.250	No	ns
GWC 8D vs APTSFS 1	-13.17	No	ns
GWC 7D vs APTSFS 1	-19.42	No	ns

APPENDIX IV

MEAN, RANGE AND STANDARD DEVIATION OF SOME WATER QUALITY PARAMETERS

								APTSFS
F	Rainfall	NSW 10	KSW 16	ECD 4	GWC 5	D GWC 8D	GWC 7D	1
6.40±0	0.37	7.52±0.38	7.37 <u>+</u> 12+0 14	£0.24	8.55±0.4	7 7.27±0.	.08 7	.04±0.11
лЦ	1.23±1	.34 /.4 : 00\ /7	43±0.14	16 06 7	(70)	7 94 0 10)		0)
рп (6.90-	(0.06-0 7 21)	(6 /12_0 07	.00-0.17) \ (7.27	(0.90-7 -7 57)	.70) (7.64-9.10)	(7.19-7.4	0)
(0.90-	7.21)	(0.42-9.97) (7.27	-7.37)				
Temp (°C)	24.08±	1.58 26	.18±0.54	25.18±	1.77 3	80.07±0.97	26.42±0.4	43
26.87	±0.74	25.95±1.8	7 27.22	2±1.28				
((21.70-	24.90) (2	5.40-26.80)) (23.40	-27.80) (3	28.70-31.00)	(25.90-27	7.20)
(26.10)-27.90)	(22.50-27.	60) (25.3	0-28.70)	~			
Turbidity (NT	J) 5.55±2	.56 61	.03±50.05	40.12±	12.07 2	22.81±10.47	2.62±1.3	2
3.67±	3.72	2.12±1.12	7.28±	4.47				
	(2.01-8	3.10) (14	4.20-156.00	0) (2 3.30-	-53.20) (7.91-38 .9)	(1.11-5.5	7)
(0.65-	11.10)	(0.92-3.68) (1.92	-15.20)				
TEE (mg/l)	6 25+3	22 56	02154 62	20.224	762 1	1 10+10 10		1
2 22+	0.25±2 2 3 3	1 66+1 63	.05±54.05 12 29	50.55± 2+1/1 27	7.05 1	14.40113.13	J.1/1/.0	L
3.331	2.33 (4.00-9	1.00 ± 1.03	00-161.00	(20.00)	.39.00) (1	3 00-41 0)	(1 00-21	00)
(1.00-	7.00)	(1.00-5.00) (3.00	-42.00)	35.00) (5.00 11.0)	(1.00 21.	00)
(,			SS.				
Cond. (µS/cm) 17.42±	7.05 19	7.00±153.4	10 300.80	±36.06 8	371.80±288.50	460.70±2	1.20
467.0	0±16.88	374.30±16	.06 2444	.00±286.5	0			
	(8.21-2	.3.46) (9	3.00-501.00	0) (257.00)-342.00)(396.00-1109.0	0) (433	.00-495.00)
(446.00-487.0	0) (358.0	0-396.00) (2	2009-2821)					
TDS (mg/l)	8 5+3 3	32 10	1 0+86 14	140 92	+19 58 4	156 83+183 00	222 5+6	11
229.0 ⁻	+8.17	181.17+6.	11 1024	.83+140.6	0	190.03-103.00	222.320.	
	(4.0-11	0) (5	1.0-273.0)	(121.0-	- 167.0) (1	194.0-721.0)	(212.0-23	31.0)
(219.0)-239.0)	(175.0-192	2.0) (115.	0-1382)		,		- /
DO (mg/l)	7.7±0.2	21 5.3	37±1.76	5.28±0	.75 6	5.88±1.38	2.81±0.84	4
2.66±	1.43	3.28±0.98	5.32±	1.66				
((7.39-7	'.93) (3.	.04-7.76)	(4.01-6	5.16) (<i>4</i>	4.96-8.50)	(1.87-3.8	2)
(1.03-	5.13)	(1.93-4.32) (2.73	-7.51)				
Alk (mg/l)	7.75±8	.92 56	.67±13.43	113.00	±10.64 1	14.50±49.29	230.00±4	.47
239.7	0±11.55	155.30±9.2	22 133.5	50±15.32				
	(2.00-2	.1.00) (3	8.00-73.00)	(100.00	0-125.00)(58.00-186.00)	(225.00-2	238.00)
(221.0	0-253.00)(148.00-17	72.00)(114.	00±153.0	D)			
SO₄ (mg/l)	0.17±0	.40 1.6	67±1.97	0.00±0	.00 1	33.30±106.50	1.00±1.2	7
0.17±0	0.41	21.00±4.0	5 1027	±102.50				
	(0.00-1	.00) (0.	.00-4.00)	(0.00-0).00) (.	52.00-330.00)	(0.00-3.0	0)
(0.00-	1.00)	(13.00-24.	00) (880.	00-1040.0	00)			

APPENDIX V

STATISTICAL ANALSIS FOR RAINFALL, SURFACE WATER AND GROUNDWATER: A COMPARISON TEST ON TOTAL DISSOLVED SOLIDS FOR ALL SAMPLING SITES

Table Analysed

TDS

Kruskal-Wallis testP<0</th>P valueP<0</td>Exact or approximate P value?GauP value summary***Do the medians vary signif. (P < 0.05) Yes</td>Number of groupsNumber of groups8Kruskal-Wallis statistic39.1

P<0.0001 Gaussian Approx. ***

Number of groups	8		
Kruskal-Wallis statistic	39.10		
	RIVOJI		
Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Rainfall vs NSW 10	-9.167	No	ns
Rainfall vs KSW 16	-10.00	No	ns
Rainfall vs ECD 4	-32.83	Yes	**
Rainfall vs GWC 5D	-24.67	No	ns
Rainfall vs GWC 8D	-27.33	Yes	*
Rainfall vs GWC 7D	-16.00	No	ns
Rainfall vs APTSFS 1	-41.00	Yes	***
NSW 10 vs KSW 16	-0.8333	No	ns
NSW 10 vs ECD 4	-23.67	No	ns
NSW 10 vs GWC 5D	-15.50	No	ns
NSW 10 vs GWC 8D	-18.17	No	ns
NSW 10 vs GWC 7D	-6.833	No	ns
NSW 10 vs APTSFS 1	-31.83	Yes	**
KSW 16 vs ECD 4	-22.83	No	ns
KSW 16 vs GWC 5D	-14.67	No	ns
KSW 16 vs GWC 8D	-17.33	No	ns
KSW 16 vs GWC 7D	-6.000	No	ns
KSW 16 vs APTSFS 1	-31.00	Yes	**
ECD 4 vs GWC 5D	8.167	No	ns
ECD 4 vs GWC 8D	5.500	No	ns
ECD 4 vs GWC 7D	16.83	No	ns
ECD 4 vs APTSFS 1	-8.167	No	ns
GWC 5D vs GWC 8D	-2.667	No	ns
GWC 5D vs GWC 7D	8.667	No	ns
GWC 5D vs APTSFS 1	-16.33	No	ns
GWC 8D vs GWC 7D	11.33	No	ns
GWC 8D vs APTSFS 1	-13.67	No	ns
GWC 7D vs APTSFS 1	-25.00	Yes	*

APPENDIX VI

STATISTICAL ANALYSIS FOR RAINFALL, SURFACE WATER AND GROUNDWATER: A COMPARISON TEST ON CONDUCTIVITY FOR ALL SAMPLING SITES

Table Analysed

Conductivity

Kruskal-Wallis test P value Exact or approximate P value? P value summary Do the medians vary signif. (P < 0.05) Yes Number of groups Kruskal-Wallis statistic

P<0.0001 Gaussian Approx. ***

8 38.90

8

Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Rainfall vs NSW 10	-9.167	No	ns
Rainfall vs KSW 16	-10.00	No	ns
Rainfall vs ECD 4	-32.75	Yes	**
Rainfall vs GWC 5D	-25.50	No	ns
Rainfall vs GWC 8D	-26.50	No	ns
Rainfall vs GWC 7D	-16.08	No	ns
Rainfall vs APTSES 1	-41.00	Yes	***
NSW 10 vs KSW 16	-0.8333	No	ns
NSW 10 vs ECD 4	-23.58	No	ns
NSW 10 vs GWC 5D	-16.33	No	ns
NSW 10 vs GWC 8D	-17.33	No	ns
NSW 10 vs GWC 7D	-6.917	No	ns
NSW 10 vs APTSFS 1	-31.83	Yes	**
KSW 16 vs ECD 4	-22.75	No	ns
KSW 16 vs GWC 5D	-15.50	No	ns
KSW 16 vs GWC 8D	-16.50	No	ns
KSW 16 vs GWC 7D	-6.083	No	ns
KSW 16 vs APTSFS 1	-31.00	Yes	**
ECD 4 vs GWC 5D	7.250	No	ns
ECD 4 vs GWC 8D	6.250	No	ns
ECD 4 vs GWC 7D	16.67	No	ns
ECD 4 vs APTSFS 1	-8.250	No	ns
GWC 5D vs GWC 8D	-1.000	No	ns
GWC 5D vs GWC 7D	9.417	No	ns
GWC 5D vs APTSFS 1	-15.50	No	ns
GWC 8D vs GWC 7D	10.42	No	ns
GWC 8D vs APTSFS 1	-14.50	No	ns
GWC 7D vs APTSFS 1	-24.92	Yes	*

APPENDIX VII

STATISTICAL ANALYSIS FOR RAINFALL, SURFACE WATER AND GROUNDWATER: A COMPARISON TEST ON DISSOLVED OXYGEN FOR ALL SAMPLING SITES

Table Analysed

DO

Kruskal-Wallis testP<0</th>P valueP<0</td>Exact or approximate P value?GauP value summary***Do the medians vary signif. (P < 0.05) Yes</td>Number of groupsNumber of groups8Kruskal-Wallis statistic30.2

P<0.0001 Gaussian Approximation ***

8 30.20

Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Rainfall vs NSW 10	14.25	No	ns
Rainfall vs KSW 16	13.92	No	ns
Rainfall vs ECD 4	5.500	No	ns
Rainfall vs GWC 5D	31.92	Yes	**
Rainfall vs GWC 8D	31.83	Yes	**
Rainfall vs GWC 7D	28.25	Yes	*
Rainfall vs APTSFS 1	14.25	No	ns
NSW 10 vs KSW 16	-0.3333	No	ns
NSW 10 vs ECD 4	-8.750	No	ns
NSW 10 vs GWC 5D	17.67	No	ns
NSW 10 vs GWC 8D	17.58	No	ns
NSW 10 vs GWC 7D	14.00	No	ns
NSW 10 vs APTSFS 1	0.0000	No	ns
KSW 16 vs ECD 4	-8.417	No	ns
KSW 16 vs GWC 5D	18.00	No	ns
KSW 16 vs GWC 8D	17.92	No	ns
KSW 16 vs GWC 7D	14.33	No	ns
KSW 16 vs APTSFS 1	0.3333	No	ns
ECD 4 vs GWC 5D	26.42	Yes	*
ECD 4 vs GWC 8D	26.33	Yes	*
ECD 4 vs GWC 7D	22.75	No	ns
ECD 4 vs APTSFS 1	8.750	No	ns
GWC 5D vs GWC 8D	-0.08333	No	ns
GWC 5D vs GWC 7D	-3.667	No	ns
GWC 5D vs APTSFS 1	-17.67	No	ns
GWC 8D vs GWC 7D	-3.583	No	ns
GWC 8D vs APTSFS 1	-17.58	No	ns
GWC 7D vs APTSFS 1	-14.00	No	ns

APPENDIX VIII

STATISTICAL ANALYSIS FOR RAINFALL, SURFACE WATER AND GROUNDWATER: A COMPARISON TEST ON ALKALINITY FOR ALL SAMPLING SITES

Table Analysed

Alkalinity

Kruskal-Wallis testP<0</th>P valueP<0</td>Exact or approximate P value?GauP value summary***Do the medians vary signif. (P < 0.05) Yes</td>Number of groupsNumber of groups8Kruskal-Wallis statistic40.3

P<0.0001 Gaussian Approx. ***

Number of groups	8		
Kruskal-Wallis statistic	40.37		
	NINODI		
Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Rainfall vs NSW 10	-5.667	No	ns
Rainfall vs KSW 16	-14.83	No	ns
Rainfall vs ECD 4	-16.67	No	ns
Rainfall vs GWC 5D	-36.33	Yes	***
Rainfall vs GWC 8D	-39.67	Yes	***
Rainfall vs GWC 7D	-27.50	Yes	*
Rainfall vs APTSFS 1	-20.33	No	ns
NSW 10 vs KSW 16	-9.167	No	ns
NSW 10 vs ECD 4	-11.00	No	ns
NSW 10 vs GWC 5D	-30.67	Yes	**
NSW 10 vs GWC 8D	-34.00	Yes	***
NSW 10 vs GWC 7D	-21.83	No	ns
NSW 10 vs APTSFS 1	-14.67	No	ns
KSW 16 vs ECD 4	-1.833	No	ns
KSW 16 vs GWC 5D	-21.50	No	ns
KSW 16 vs GWC 8D	-24.83	Yes	*
KSW 16 vs GWC 7D	-12.67	No	ns
KSW 16 vs APTSFS 1	-5.500	No	ns
ECD 4 vs GWC 5D	-19.67	No	ns
ECD 4 vs GWC 8D	-23.00	No	ns
ECD 4 vs GWC 7D	-10.83	No	ns
ECD 4 vs APTSFS 1	-3.667	No	ns
GWC 5D vs GWC 8D	-3.333	No	ns
GWC 5D vs GWC 7D	8.833	No	ns
GWC 5D vs APTSFS 1	16.00	No	ns
GWC 8D vs GWC 7D	12.17	No	ns
GWC 8D vs APTSFS 1	19.33	No	ns
GWC 7D vs APTSFS 1	7.167	No	ns

APPENDIX IX

STATISTICAL ANALYSIS FOR RAINFALL, SURFACE WATER AND GROUNDWATER: A COMPARISON TEST ON SULPHATE FOR ALL SAMPLING SITES

Table Analysed

Sulphate

P<0.0001

8

39.73

Gaussian Approx.

Kruskal-Wallis test P value Exact or approximate P value? P value summary Do the medians vary signif. (P < 0.05) Yes Number of groups Kruskal-Wallis statistic

Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Rainfall vs NSW 10	-6.417	No	ns
Rainfall vs KSW 16	2.083	No	ns
Rainfall vs ECD 4	-25.92	Yes	*
Rainfall vs GWC 5D	-5.250	No	ns
Rainfall vs GWC 8D	0.0000	No	ns
Rainfall vs GWC 7D	-19.92	No	ns
Rainfall vs APTSFS 1	-31.92	Yes	***
NSW 10 vs KSW 16	8.500	No	ns
NSW 10 vs ECD 4	-19.50	No	ns
NSW 10 vs GWC 5D	1.167	No	ns
NSW 10 vs GWC 8D	6.417	No	ns
NSW 10 vs GWC 7D	-13.50	No	ns
NSW 10 vs APTSFS 1	-25.50	No	*
KSW 16 vs ECD 4	-28.00	Yes	**
KSW 16 vs GWC 5D	-7.333	No	ns
KSW 16 vs GWC 8D	-2.083	No	ns
KSW 16 vs GWC 7D	-22.00	No	ns
KSW 16 vs APTSFS 1	-34.00	Yes	**
ECD 4 vs GWC 5D	20.67	No	ns
ECD 4 vs GWC 8D	25.92	Yes	*
ECD 4 vs GWC 7D	6.000	No	ns
ECD 4 vs APTSFS 1	-6.000	No	ns
GWC 5D vs GWC 8D	5.250	No	ns
GWC 5D vs GWC 7D	-14.67	No	ns
GWC 5D vs APTSFS 1	-26.67	No	*
GWC 8D vs GWC 7D	-19.92	No	ns
GWC 8D vs APTSFS 1	-31.92	Yes	***
GWC 7D vs APTSFS 1	-12.000	No	ns

APPENDIX X

STATISTICAL ANALYSIS FOR RAINFALL, SURFACE WATER AND GROUNDWATER: A COMPARISON TEST ON DISSOLVED IRON FOR ALL SAMPLING SITES

Table Analysed	Fe		
Kruskal-Wallis test			
P value	P<0.0001		
Exact or approximate P value?	Gaussian Approx.		
P value summary	***		
Do the medians vary signif. ($P < 0.05$)	Yes		
Number of groups	8		
Kruskal-Wallis statistic	39.30		
Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Rainfall vs NSW 10	-28.42	Yes	**
Rainfall vs KSW 16	-33.75	Yes	***
Rainfall vs ECD 4	-0.8333	No	ns
Rainfall vs GWC 5D	-15.25	No	ns
Rainfall vs GWC 8D	-14.75	No	ns
Rainfall vs GWC 7D	-13.58	No	ns
Rainfall vs APTSFS 1	1.917	No	ns
NSW 10 vs KSW 16	-5.333	No	ns
NSW 10 vs ECD 4	27.58	Yes	*
NSW 10 vs GWC 5D	13.17	No	ns
NSW 10 vs GWC 8D	13.67	No	ns
NSW 10 vs GWC 7D	14.83	No	ns
NSW 10 vs APTSFS 1	30.33	Yes	**
KSW 16 vs ECD 4	32.92	Yes	***
KSW 16 vs GWC 5D	18.50	No	ns
KSW 16 vs GWC 8D	19.00	No	ns
KSW 16 vs GWC 7D	20.17	No	ns
KSW 16 vs APTSFS 1	35.67	Yes	***
ECD 4 vs GWC 5D	-14.42	No	ns
ECD 4 vs GWC 8D	-13.92	No	ns
ECD 4 vs GWC 7D	-12.75	No	ns
ECD 4 vs APTSFS 1	2.750	No	ns
GWC 5D vs GWC 8D	0.5000	No	ns
GWC 5D vs GWC 7D	1.667	No	ns
GWC 5D vs APTSFS 1	17.17	No	ns
GWC 8D vs GWC 7D	1.167	No	ns
GWC 8D vs APTSFS 1	16.67	No	ns
GWC 7D vs APTSFS 1	15.50	No	ns

APPENDIX XI

STATISTICAL ANALYSIS FOR RAINFALL, SURFACE WATER AND GROUNDWATER: A COMPARISON TEST ON DISSOLVED MANGANESE FOR ALL SAMPLING SITES

Table Analysed	Mn		
Kruskal-Wallis test			
P value	0.0003		
Exact or approximate P value?	Gaussian Approx.		
P value summary	***		
Do the medians vary signif. $(P < 0.05)$	Yes		
Number of groups	8		
Kruskal-Wallis statistic	26.91		
Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Rainfall vs NSW 10	4.000	No	ns
Rainfall vs KSW 16	-11.00	No	ns
Rainfall vs ECD 4	8.917	No	ns
Rainfall vs GWC 5D	-8.833	No	ns
Rainfall vs GWC 8D	-17.08	No	ns
Rainfall vs GWC 7D	-10.50	No	ns
Rainfall vs APTSFS 1	14.50	No	ns
NSW 10 vs KSW 16	-15.00	No	ns
NSW 10 vs ECD 4	4.917	No	ns
NSW 10 vs GWC 5D	-12.83	No	ns
NSW 10 vs GWC 8D	31.58	Yes	**
NSW 10 vs GWC 7D	-14.50	No	ns
NSW 10 vs APTSFS 1	10.50	No	ns
KSW 16 vs ECD 4	19.92	No	ns
KSW 16 vs GWC 5D	2.167	No	ns
KSW 16 vs GWC 8D	-6.083	No	ns
KSW 16 vs GWC 7D	0.5000	No	ns
KSW 16 vs APTSFS 1	25.50	Yes	*
ECD 4 vs GWC 5D	-17.75	No	ns
ECD 4 vs GWC 8D	-26.00	Yes	*
ECD 4 vs GWC 7D	-19.42	No	ns
ECD 4 vs APTSFS 1	5.583	No	ns
GWC 5D vs GWC 8D	-8.250	No	ns
GWC 5D vs GWC 7D	-1.667	No	ns
GWC 5D vs APTSFS 1	23.33	No	ns
GWC 8D vs GWC 7D	6.583	No	ns
GWC 8D vs APTSFS 1	-21.08	No	ns
GWC 7D vs APTSFS 1	25.00	Yes	*

APPENDIX XII

STATISTICAL ANALYSIS FOR RAINFALL, SURFACE WATER AND GROUNDWATER: A COMPARISON TEST ON DISSOLVED COPPER FOR ALL SAMPLING SITES

Table Analysed

Cu

Kruskal-Wallis test	
P value	P<0.0001
Exact or approximate P value?	Gaussian Approx.
P value summary	***
Do the medians vary signif. $(P < 0.05)$	Yes
Number of groups	
Kruskal-Wallis statistic	33.09

Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Rainfall vs NSW 10	-23.17	No	ns
Rainfall vs KSW 16	-23.17	No	ns
Rainfall vs ECD 4	-25.25	Yes	*
Rainfall vs GWC 5D	0.0000	No	ns
Rainfall vs GWC 8D	-2.000	No	ns
Rainfall vs GWC 7D	-8.833	No	ns
Rainfall vs APTSFS 1	-25.58	Yes	*
NSW 10 vs KSW 16	0.0000	No	ns
NSW 10 vs ECD 4	-2.083	No	ns
NSW 10 vs GWC 5D	23.17	No	ns
NSW 10 vs GWC 8D	21.17	No	ns
NSW 10 vs GWC 7D	14.33	No	ns
NSW 10 vs APTSFS 1	-2.417	No	ns
KSW 16 vs ECD 4	-2.083	No	ns
KSW 16 vs GWC 5D	23.17	No	ns
KSW 16 vs GWC 8D	21.17	No	ns
KSW 16 vs GWC 7D	14.33	No	ns
KSW 16 vs APTSFS 1	-2.417	No	ns
ECD 4 vs GWC 5D	25.25	Yes	*
ECD 4 vs GWC 8D	23.25	No	ns
ECD 4 vs GWC 7D	16.42	No	ns
ECD 4 vs APTSFS 1	-0.3333	No	ns
GWC 5D vs GWC 8D	-2.000	No	ns
GWC 5D vs GWC 7D	-8.833	No	ns
GWC 5D vs APTSFS 1	-25.58	Yes	*
GWC 8D vs GWC 7D	-6.833	No	ns
GWC 8D vs APTSFS 1	-23.58	No	ns
GWC 7D vs APTSFS 1	-16.75	No	ns

APPENDIX XIII

MEAN, RANGE AND STANDARD DEVIATION OF SOME DISSOLVED METALS CONCENTRATIONS

Rainfall	NSW 10 K	SW 16	ECD 4 GW	C 5D GWC 8D	APTSFS GWC 7D 1
Fe (mg/l) 0.02±0	0.00 0.67±	0.15	1.05±0.15	0.16±0.00	0.23±0.05
(0.00-((0.07-0.38)	0.02) (0.46- (0.02-0.26)	-0.91) (0.03-0	(0.83-1.18)).08)	(0.16-0.16)	(0.15-0.28)
Mn (mg/l) 0.02±0 0.67+0.47	0.004 0.015 0.05+0.02	±0.00 0.04+0	0.09±0.10	0.02±0.01	0.12±0.12
(0.00-0 (0.23-1.21)	0.02) (0.01- (0.01-0.07)	-0.02) (0.02-0	(0.02-0.29) 0.07)	(0.01-0.04)	(0.01-0.27)
Cu (mg/l) 0.00±0	0.00 0.001	±0.00	0.003±0.002	0.002±0.001	0.00±0.00
(0.00- (0.00-0.001)	0.00) (0.000 (0.001-0.001)	07-0.0025 (0.001-	5)(0.001-0.006) -0.002)	(0.001-0.002)	(0.00-0.00)
Zn (mg/l) 0.003: 0.02+0.00	±0.0 <mark>02 0.00±</mark> 0.00+0.00	0.00	0.00±0.00	0.00±0.00	0.00±0.00
(0.002 (0.00-0.02)	-0.07) (0.00- (0.00-0.00)	-0.00) (0.00-((0.00-0.00) 0.00)	(0.00-0.00)	(0.00-0.00)
Ni (mg/l) 0.00±0	$0.00 0.00 \pm 0.00 \pm 0.00$	0.00	0.00±0.00	0.00±0.00	0.00±0.00
(0.00-0.00) (0.00-0.00)	0.00) (0.00- (0.00-0.00)	-0.00) (0.00-0	(0.00-0.00) 0.00)	(0.00-0.00)	(0.00-0.00)
As (mg/l) 0.003:	±0.002 0.000	6±0.00	0.002±0.001	0.002±0.001	0.03±0.001
(0.002 (0.14-0.19)	-0.006) (0.00- (0.0005-0.000)	-0.0006))9)(0.0016	(0.001-0.002) 6-0.0028)	(0.001-0.002)	(0.027-0.031)
Cd (mg/l) 0.00±0	0.00 0.00±	0.00	0.00±0.00 +0.000	0.00±0.00	0.00±0.0.003
(0.0004±0.0003) (0.00-0) (0.0002-0.000)	0.00) (0.000 8)(0.0002-0.000	-0.00) -0.00))4)(0.000-	(0.00-0.00) -0.0001)	(0.00-0.00)	(0.000-0.006)

APPENDIX XIV

STATISTICAL ANALYSIS FOR RAINFALL, SURFACE WATER AND GROUNDWATER: A COMPARISON TEST ON DISSOLVED ARSENIC FOR ALL SAMPLING SITES

Table Analysed	As		
Rruskai-wains test	P~0.0001		
Exact or approximate P value?	Gaussian Approx		
P value summary	***		
Do the medians vary signif. ($P < 0.05$)	Yes		
Number of groups	8		
Kruskal-Wallis statistic	38.43		
Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Rainfall vs NSW 10	11.50	No	ns
Rainfall vs KSW 16	-4.750	No	ns
Rainfall vs ECD 4	-5.750	No	ns
Rainfall vs GWC 5D	-22.00	No	ns
Rainfall vs GWC 8D	-28.00	Yes	*
Rainfall vs GWC 7D	5.500	No	ns
Rainfall vs APTSFS 1	-12.50	No	ns
NSW 10 vs KSW 16	-16.25	No	ns
NSW 10 vs ECD 4	-17.25	No	ns
NSW 10 vs GWC 5D	-33.50	Yes	***
NSW 10 vs GWC 8D	-39.50	Yes	***
NSW 10 vs GWC 7D	-6.000	sy No	ns
NSW 10 vs APTSFS 1	-24.00	No	ns
KSW 16 vs ECD 4	-1.000	No	ns
KSW 16 vs GWC 5D	-17.25	No	ns
KSW 16 vs GWC 8D	-23.25	No	ns
KSW 16 vs GWC 7D	10.25	No	ns
KSW 16 vs APTSFS 1	-7.750	No	ns
ECD 4 vs GWC 5D	-16.25	No	ns
ECD 4 vs GWC 8D	-22.25	No	ns
ECD 4 vs GWC 7D	11.25	No	ns
ECD 4 vs APTSFS 1	-6.750	No	ns
GWC 5D vs GWC 8D	-6.000	No	ns
GWC 5D vs GWC 7D	27.50	Yes	*
GWC 5D vs APTSFS 1	9.500	No	ns
GWC 8D vs GWC 7D	33.50	Yes	***
GWC 8D vs APTSFS 1	15.50	No	ns
GWC 7D vs APTSFS 1	-18.00	No	ns

APPENDIX XV

STATISTICAL ANALYSIS FOR RAINFALL, SURFACE WATER AND GROUNDWATER: A COMPARISON TEST ON DISSOLVED ZINC FOR ALL SAMPLING SITES

Table Analysed	Zn		
Kruskal-Wallis test			
P value	0.1377		
Exact or approximate P value?	Gaussian Approx.		
P value summary	ns		
Do the medians vary signif. $(P < 0.05)$	No		
Number of groups	8		
Kruskal-Wallis statistic			
Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Rainfall vs NSW 10	8.167	No	ns
Rainfall vs KSW 16	8.167	No	ns
Rainfall vs ECD 4	8.167	No	ns
Rainfall vs GWC 5D	8.167	No	ns
Rainfall vs GWC 8D	4.333	No	ns
Rainfall vs GWC 7D	8.167	No	ns
Rainfall vs APTSFS 1	8.167	No	ns
NSW 10 vs KSW 16	0.0000	No	ns
NSW 10 vs ECD 4	0.0000	No	ns
NSW 10 vs GWC 5D	0.0000	No	ns
NSW 10 vs GWC 8D	-3.833	No	ns
NSW 10 vs GWC 7D	0.0000	No	ns
NSW 10 vs APTSFS 1	0.0000	No	ns
KSW 16 vs ECD 4	0.0000	No	ns
KSW 16 vs GWC 5D	0.0000	No	ns
KSW 16 vs GWC 8D	-3.833	No	ns
KSW 16 vs GWC 7D	0.0000	No	ns
KSW 16 vs APTSFS 1	0.0000	No	ns
ECD 4 vs GWC 5D	0.0000	No	ns
ECD 4 vs GWC 8D	-3.833	No	ns
ECD 4 vs GWC 7D	0.0000	No	ns
ECD 4 vs APTSFS 1	0.0000	No	ns
GWC 5D vs GWC 8D	-3.833	No	ns
GWC 5D vs GWC 7D	0.0000	No	ns
GWC 5D vs APTSFS 1	0.0000	No	ns
GWC 8D vs GWC 7D	3.833	No	ns
GWC 8D vs APTSFS 1	3.833	No	ns
GWC 7D vs APTSFS 1	0.0000	No	ns
APPENDIX XVI

STATISTICAL ANALYSIS FOR RAINFALL, SURFACE WATER AND GROUNDWATER: A COMPARISON TEST ON DISSOLVED CADMIUM FOR ALL SAMPLING SITES

Table Analysed	Cd		
Kruskal-Wallis test			
P value	0.0270		
Exact or approximate P value?	Gaussian Approx.		
P value summary	*		
Do the medians vary signif. $(P < 0.05)$	Yes		
Number of groups	8		
Kruskal-Wallis statistic	$(NUS^{15.80})$		
Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Rainfall vs NSW 10	0.0000	No	ns
Rainfall vs KSW 16	0.0000	No	ns
Rainfall vs ECD 4	0.0000	No	ns
Rainfall vs GWC 5D	-11.75	No	ns
Rainfall vs GWC 8D	-12.83	No	ns
Rainfall vs GWC 7D	-12.08	No	ns
Rainfall vs APTSFS 1	-3.333	No	ns
NSW 10 vs KSW 16	0.0000	No	ns
NSW 10 vs ECD 4	0.0000	No	ns
NSW 10 vs GWC 5D	-11.75	No	ns
NSW 10 vs GWC 8D	-12.83	No	ns
NSW 10 vs GWC 7D	-12.08	No	ns
NSW 10 vs APTSFS 1	-3.333	No	ns
KSW 16 vs ECD 4	0.0000	No	ns
KSW 16 vs GWC 5D	-11.75	No	ns
KSW 16 vs GWC 8D	-12.83	No	ns
KSW 16 vs GWC 7D	-12.08	No	ns
KSW 16 vs APTSFS 1	-3.333	No	ns
ECD 4 vs GWC 5D	-11.75	No	ns
ECD 4 vs GWC 8D	-12.83	No	ns
ECD 4 vs GWC 7D	-12.08	No	ns
ECD 4 vs APTSFS 1	-3.333	No	ns
GWC 5D vs GWC 8D	-1.083	No	ns
GWC 5D vs GWC 7D	-0.3333	No	ns
GWC 5D vs APTSFS 1	8.417	No	ns
GWC 8D vs GWC 7D	0.7500	No	ns
GWC 8D vs APTSFS 1	9.500	No	ns
GWC /D vs APTSFS 1	8.750	No	ns

APPENDIX XVII

INSPECTIONS

		Document No:	AHF-ENV-064-F01	
NEWMONT	AHAFO OPERATIONS	Version No.	1.0	
IVE WINDING	Form	issue Date:	July 2008	
		Fage No.	Page 1 of 3	

ECD_WSF_SCS Inspection Form

Inspectors: Lydia <u>Sefab</u> , Kwa	ame <u>Yebosh</u> Joyce	e <u>Kuai:Appiah</u> & Samuel Dan	quah	Environr	nent	ECD 4	2	Date:
Item / picture #	Issue	Conditions/ Observations	Correc Ri immedia	ctive Action equired ite/Permanent	Person Responsible	Estimated Date of Completion	Actual Date of Completion	Initials of Person Completion
	Evidence of Oil Spill/Sheen	No oil Spill on water			1000	24	78 -	-
Saleman (1985)	Is reservoir over spilling	The Water in the dam is overflowing through the spill way as results of heavy down pour the previous days.			J.		2-	12
	Aesthetics of water	Serene, clear and the water in the tank looks so natural	N.W.	SANE NO		-	-	
	Evidence of water ponding on the embankment	No evidence of water ponding on embankment		3	55	1.52	2 .	æ

Author	Sitis, Department	To Be Reviewed:	JULY 2008	
Approved by	X. Remsey	Print Date	25/06/2012 10:02:00 AM	

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-		Occurrent No:	AHF-ENV-064-F01	
NEWMONT	AHAFO OPERATIONS	Version No:	1.0	
IVE WINDIVI	Form	issue Date:	July 2008	
		Fage No:	Fage 2 of 3	

ECD_WSF_SCS Inspection Form

Item / picture #	Issue	Con <mark>ditions</mark> / Observations	Corrective Action Required immediate/Permanent	Person Responsible	Estimated Date of Completion	Actual Date of Completion	Initials of Person Completion
	Evidence of fish kill on water or spill way	No fish kill on wateror spill water.		ेन्	-	-	
	Evidence of fish stress e g gasping for breathon surface of water	No		8 4 0			e .
	Odor from the water reservoir	Water within the reservoir is odorless and coloureless.		- F	15	₹K.	153
	Is weeding required within immediate environs	Yes .weeding is required around the decanting tower and around the immediate environment.	Weeding Weeding	Macon March 1			
	Evidence of community members activities e.g. Fishing or swimming	No community member or any activity around the dam.	2 83 81 2 83	341	2		

Author:	50x. Department	To Be Reviewed	JULY 2008	2
Approved by:	K Remsey	Print Date:	25/08/2012 10:02:00 AM	

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<u> </u>		Document No:	AHF-ENV-064-F01
NEWMONT	AHAFO OPERATIONS	Version No:	1.0
GHANA	Form	Issue Date:	July 2008
		Page No:	Page 3 of 3

ECD_WSF_SCS Inspection Form

Item / picture #	Issue	Conditions/ Observations	Corrective Action Required immediate/Permanent	Person Responsible	Estimated Date of Completion	Actual Date of Completion	Initials of Person Completion
	Evidence aquatic weeds on water	Some water weeds growing on top of the water in the reservoir.		-	-	-	-
	Evidence of damage to decant tower cover or signage?	No Damage to the decant tower but the signage around the dam has faded.			-	-	-
	Status of Valve on discharge pipe?	The valve is intact.		-	-	-	-
	Other observation?	The water level in the dam is as high as 366cm and TSS level as low as 9 mg/l the dam needs decanting as any further rains can cause overflow on its banks.	W J SANE NO	Non-	-	-	-

Environmental Manager Signature:

A copy of the action form must be given to the person/department/contractor responsible

Author:	Spy, Department	To Be Reviewed:	JULY 2008
Approved by:	K. Ramsey	Print Date:	25/06/2012 10:02:00 AM

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