KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, - KUMASI

FACULTY OF CHEMICAL AND MATERIALS ENGINEERING

THESIS REPORT

TOPIC:- A STUDY OF SEDIMENTATION MANAGEMENT SYSTEMS AT NEWMONT GHANA GOLD LIMITED

PROJECT REPORT SUBMITED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE M.Sc (ENG.) DEGREE IN ENVIRONMENTAL RESOURCES MANAGEMENT

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DECLARATION AND CERTIFICATION

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

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ABSTRACT

Many mining communities in Ghana continue to complain about the muddling and pollution of their water bodies as a result of mining activities.

It is therefore in this light that the research is undertaken to investigate the erosion and sedimentation management systems of Newmont Ghana Gold Limited within its Ahafo operations, to asses the effectiveness of the systems put in place and determine whether or not the discharges from the mine do not pollute the receiving Tano River which in many cases serves as source of drinking water for communities living along it.

To achieve the set objective, sedimentation control practices of the mine were studied, runoffs in the environmental control dams were monitored for a period of 106 days (between August and November) to determine the quality of runoff that are being discharged into the environment, samples were taken upstream and downstream of streams draining the mine area to assess the quality of runoff entering the mine area as well as the quality of those leaving it. Samples were also collected at the inlet points of the various Environmental Control Dams (ECDs) to asses the effects of mining on the streams by monitoring sediment build up during rainy days.

Analyses of the results established the fact that although the mining activities generate a lot of sediment into the runoffs, yet the sedimentation dams are able to reduce the sediment loads by 92% to 95% and therefore making discharges from the sedimentation dams to the Tano River to be within the allowable discharge limit of 50mg/l.

In conclusion, the activities of the mine do not appear to have adverse effect on the receiving Tano River in terms of sedimentation and therefore recommend this type of sedimentation management system to other mining companies.

ACKNOWLEDGMENT

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The late lecturer, Emmanuel Owusu Adjei cannot be forgotten for sowing the seed of pursuing a further course in me, the necessary guidance, encouragement and assistance I received from him. May his Soul rest in perfect peace.

Mention must be made of Mrs. Brem and children who were my host during the period of my course work and all Newmont workers especially Director James Badu, of Newmont Environmental Department, Geoffrey Kakati, Paul Dawson, Anthony Loh, Josiah Cole, Emmanuel Trebi just to mention a few, for their assistance in diverse ways during the data capturing and the write up. I am very thankful to you all.

Finally, I thank my wife Conny and our children Gloria, Christlove and Godson as well as those of our household for their continued support.

DEDICATION

This thesis work is lovingly

dedicated to the most important people in my life:

my wonderful wife Connie,

and our three precious children

Gloria, Christlove and Godson.

You are my joy.

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CHAPTER ONE: INTRODUCTION

1.1 Background Information

The problem of erosion and sedimentation control has plagued society for years. Damage from erosion and sedimentation directly or indirectly affects all walks of life. Erosion and sedimentation results in:

Loss of fertile topsoil

Clogged ditches, culverts and storm sewers that increase flooding

Muddy or turbid lakes and streams

Damage to plants and animal life

Filled in ponds, lakes and reservoirs

Damage to aquatic habitat and reduce recreational value and use

Structural damage to buildings, roads, and other structures (Mikula and Croskey, 2005)

Early land clearing, logging and farming activities have resulted in the exposure of land surfaces to erosion in man parts of the world. This has impacted negatively on streams and rivers. However, in certain nations such as United States, nationwide soil conservation movements have greatly reduced the problem of agricultural erosion. Today, a typical farm conservation plan often reduces soil loss from 15 to 25 or more tons per acre per year, to less than five tons per acre per year (Mikula and Croskey, 2005).

Human activities such as construction have caused serious erosion and sedimentation problems. With modern equipment and technology, vast networks of highways, sprawling subdivisions, large industrial parks, and massive shopping centers are created. Similarly, the activities of mining bring about the exposure of large surfaces of land that invariably ends up in land degradation. In many cases, these activities results to severe erosion and sedimentation damage to land and water resources.

In many mining setups large tracks of land is cleared for constructional activities or for the purpose of mining ore. These activities lead to clearing of vegetation which result in exposing the land and later become compacted. The compacted land decrease infiltration of runoff and catalyze the activities of erosion. This causes the wearing and tearing of various soil layers, which become mobilized and transported along by running water or wind.

The operations of the mining industries have generally been considered as environmentally degrading in the eyes of the general public. In a period of increasing public, and non governmental organizations (NGOs) awareness of environmental issues, mining companies can no longer afford to disregard the views of these stakeholders. Mining companies have therefore developed strategies to mitigate the impact of their activities in an attempt to address public concerns. Under the auspices of regulatory bodies, companies have committed themselves to sustainable development which embodies protection of human health, the natural environment and the economy (Anon, 1996). In achieving these goals, mining corporations have implemented environmental management systems. These systems outline the organizational structures, responsibilities, practices, procedures, processes, and resources for implementing environmental management (Anon, 1994).

Many mining communities have complained about the muddling and pollution of their water bodies as a result of mining activities. The activities of surface mining involve the removal of surface cover and the creation of huge waste dumps some of which rise far above the normal topographic elevation of the surrounding land. These surfaces readily supply runoff with the load which with increasing velocity accelerates removal of earth. These loaded runoffs end up in streams, rivers and other water bodies where the eroded materials result in increase in turbidity of water and deposition of silt. This affects plants and animal life as the quality of the water is degraded and in extreme cases leads to plant and animal loss. This persistent problem of the pollution of water courses, many of which provide drinking water for communities downstream require the implementation of measures that will mitigate the impact. In some cases companies have supplied wells with pumps for drinking water to affected communities but this is no solution to the problem as this does not address the aspect of fauna and other animals which also depend on these waters as part of the general ecosystem build up. The responsibility for maintenance cost of the wells and pumps has also become an issue in many communities and has caused many of them to fall back on the nearby water bodies.

Good environmental practices that provide for the proper management systems for water bodies are specifically required of mining companies by both the Ghana Minerals Commission and Environmental Protection Agency of Ghana. As part of its water management systems mining companies have incorporated sedimentation systems in the form of control dams, sumps etc, which are sited at strategic locations, to ensure that sediments from erosional grounds do not end up in the various water bodies. In spite these incorporations, concerns of individuals, communities and various organizations on the destruction of water bodies from the activities of mining companies have been on the increase. This has led to many instances of clashes between mining companies and pressure groups. In recent times the people of Prestea have been in dispute with Biliton Bogosu Gold mine now called Golden Star Resources Bogosu Prestea Limited in respect of their mining operations in the area. Similarly there has been a long-running dispute over water between communities and Anglo-Ashanti in the Sansu surface mine in Obuasi, Ghana.

In the light of these problems it become important and necessary to study the sediments control systems applied on the mine and assess their effectiveness or otherwise. The selected study area as a case study is the Newmont Ahafo Project located at Kenyasi in the Brong Ahafo Region, Ghana.

1.2 Objectives of the Study

The objectives of the study are to:

1) Examine sediment capture in the various sedimentation basins and determine the sediments characteristics

2) Estimate potential drops in sediment loads at the control dams that could have been deposited into the water bodies.
3) Determine the efficiency of the current Sedimentation Management Practices of the mine by assessing runoffs and discharges from the sedimentation dams.

1.3 An Over View of Proceeding Chapters

Chapter 2 is a literature review on impact of mining to the environment especially to the water bodies. It also provides overview of acceptable standards of discharges into water bodies. Chapter 3 deals with the location, climatic conditions, local geology of the study area as well as a general description of the mine and facilities put in place by Newmont to control erosion and sedimentation. Chapter 4 discusses the methodology employed in the study, data collection and monitoring of the environmental control dams. Chapter 5 deals with discussing the results and interpretation of the data as well as an assessment of practices put in place to control runoffs on the mine. Chapter 6 concludes the study and offers some recommendations.

CHAPTER TWO: LITERATURE REVIEW

2.1 The EPA of Ghana and Public Environmental Awareness of Mining Impacts

From the onset of mining operations in Ghana, mining companies operated with little regard for environmental considerations. Mine wastes were dumped into various water bodies and mine leachate was openly allowed to join drainage network of an area with very little consideration for its environmental implications. In like manner, sediments from operating and abandoned mines impacted on nearby rivers as well as affect nearby farmlands. No serious effort was made to contain these sediments. This phenomenon of mining companies paying little or no attention to the impact of their activities on the environment continued until sometime in 1994 when the Environmental Protection Agency (EPA) was established by an Act which empowered it to come out with legislation, rules, guidelines and standards for the industry and regularize their operations in the country (Vormawor and Awuku-Apaw, 1996).

In Ghana the Ministry of Mines and Energy supervises the mining industry. The environmental aspects of mining are directly regulated by the Environmental Protection Council Decree of 1974 and Mining Regulations of 1970. The Minerals and Mining Law of 1986 makes provision for environmental protection and pollution prevention (Acquah, 1995). Under the 1996 Minerals and Mining Law the Minister of Mines and Energy is responsible for regulations restricting mining activities near water bodies, preventing water pollution amongst other things. The 1994 Mining and Minerals Regulation are meant to prevent permanent environmental damage by mining and encourage sound stewardship (Vormawor and Awuku-Apaw, 1996). The regulation has three parts including guidelines for exploration, mining, processing and decommissioning, guidelines for preparation of an EIA for new projects and guidelines for preparing an Environmental Action Plan (EAP) for existing projects.

With the coming into force of the EPA, mining companies were required to operate within guidelines set up by the regulatory agency. The operations of the EPA has with time called the activities of recalcitrant companies to order and even though it has not been able to totally curb the menace of mining companies polluting the environment it has gone a long way to reduce it. Today, the EPA maintains close contact with operating mines and conducts regular site inspections to ascertain prevailing conditions in these mines. The fact that companies are required to obtain an environmental permit before they can operate and the fact that they can loose these permits if they do not meet the requirements that allow these permits to be issued to them has gone a long way to inculcate a sense of responsibility in the industry.

Newmont Ghana Gold was granted an environmental permit to operate in the Ahafo area. The permit requires that the company incorporates sediment control structures that will ensure that all effluents leaving the operational area meet required standards before being discharged into the environment.

2.2 History of Mineral Exploration and Mining in the Project Area

The current gold resource in the Ahafo Lease area was identified through exploration by various interests that were consolidated by Newmont Ghana Gold Limited (NGGL) following a merger with Normandy Mining Ltd. and purchase of Moydow Mines International Inc.'s interests in Rank Mining in 2002. As a result, NGGL holds mining Licenses LVB 7523/2001 Area A, LVB 523/2001 Area B, and LVB 7524/2001; Prospecting license PL 151; and prospecting licenses Dekyem, Goa, and Bonsu, all of which cover approximately 270km² needed for development of the Ahafo Project. The Ahafo Project includes the area covered by these leases, which grants NGGL the right to mine and extract gold over a period of 30 years. The government of Ghana granted mining leases to Normandy and Rank Mining which subsequently transferred the leases to NGGL as the mergers and acquisitions occurred.

In April 1999, Centenary Gold Mining Company Ltd. submitted a Scoping Study and Draft Terms of Reference for the Sefwi Belt Gold Project to the Ghana EPA. The Scope of Study and Draft Terms of Reference for the EIA were accepted by the EPA. A Draft EIS was submitted in March 2000 (Anon, 2000a). Public meetings were held in the northern and southern portions of the concession, and a Final EIS was prepared to address concerns raised during those meetings. Environmental Permit No. 0043 was issued in October 2000. In November 2000, Rank Mining submitted a Scoping Study and Draft Terms of Reference for the Ntotroso Gold Project to the Ghana EPA. Rank submitted an EIS to the EPA in December 2000 (Anon, 2000b). Environmental Permit No. 0041 was issued to Rank Mining by EPA in February 2001. NGGL acquired these two projects (Sefwi Belt and Ntotroso Gold Projects) via merger with Normandy Mining Company (parent company of Centenary Gold Mining Company) and Rank Mining Company in 2003. In March 2004, the Ghana EPA informed NGGL that changes arising from integration of these two projects would require submittal of a new EIS. An EIS addressing these changes relative to the southern portion of the lease area was submitted to EPA in September 2004.

NGGL's mine planning to incorporate the two projects into one permit for the Ahafo Project was initiated with consolidation of mine and mill design in the southern portion of the Ahafo Lease area. An EIS covering development of the southern portion of the lease was submitted to EPA in September 2004 with plans to submit an updated EIS covering development of the northern portion of the lease in the foreseeable future after further mine planning and feasibility studies were completed.

Construction work began on the project area in the Ahafo South area in 2004 leading to the commencement of surface mining in 2006. The first gold was poured in 18th July, 2006 and the mine was officially opened by the president of Ghana on 17th November 2006. Currently the mine is mining at a rate of 500,000 ounces a year with an estimated life span of over 30 years.

2.3 The Impacts of Mining on Water Bodies in the Project Area

The development of mine pits, surface disruptions associated with mine development and facility construction such as grading, road construction, impoundment construction, foundation preparation, soil stripping, and pipeline and power line construction strictly known as disturbance activities have greatly impacted on the ecological balance of the area. These disturbance activities increase the potential for surface or ground water impact by exposing mineralized rock, disturbing native soils and vegetation, altering slope angles, and modifying watershed and aquifer characteristics. Mine pits, adits, shafts, and open cuts that expose mineralized rock have the potential to produce increased loadings of metals, dissolved solids, suspended solids, and acidity to surface waters. The construction of roads, utility lines, and facility foundations and stripping activities associated with the development of mine pits and the construction of mine processing, disposal, and water management facilities increase the potential for sediment contamination. These activities alter natural watershed characteristics by increasing runoff, decreasing soil cohesion and infiltration, and increasing susceptibility to erosion (EPA, 2006). Similarly, the project has necessitated the institution of a number of waste disposal activities which include the construction and operation of waste rock dumps, overburden piles, tailings impoundments, and slag piles and other process wastes. Some support activities such as those actions required for day to-day operation of the mine such as equipment maintenance, fuel storage, wastewater treatment, and laboratory analysis if not properly handled can seriously impact on the project area. The types of constituents that can be released during or following disturbance activities depend on the nature of the mineralization and the mining operation. Milling disturbances may increase the concentrations of suspended particles and metals (e.g., Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Hg, Ni, Se, Ag, Zn), major cations (e.g., NH4, N, Ca, Mg, K, Na), and anions (e.g., nitrate, sulfate, chloride, carbonate) that form a large portion of the total dissolved solids in surface waters. Constituent concentrations can be increased through dissolution or retransport of naturally occurring compounds or by the dissolution of reagents, such as blasting residues that are used during disturbance activities. Importantly, surface and underground disturbances can result in the production of acid drainage. This phenomenon, referred to as acid mine drainage or acid rock drainage, results when iron sulfide minerals (pyrite and marcasite), which commonly occur in mineralized zones, are exposed to the oxidizing environment of the atmosphere. The acidity produced from exposed pit walls and underground workings can impact surface water quality for many years after mining ceases by lowering pH and increasing the amount of metals leached from exposed surfaces and maintained in solution. Disturbance activities release contaminants to surface and ground waters primarily through precipitation runoff, releases of mine water, or disruption of aquifers and their confining layers (Viessman and Hammer, 1993).

Another issue of critical importance relates to processing activities in the project area. The processing activities ongoing in the project area include the construction and operation of crushing and milling facilities; flotation concentrators; smelters; vat and tank leach plants; water treatment facilities; and carbon stripping, zinc precipitation. Processing activities increase the potential for surface water impact by creating facilities in which metals are concentrated to values significantly above those in the ore, dissolving metals into solution, grinding metal-rich ore into fine particle sizes, and storing and using large quantities of reagents that can potentially degrade surface-water quality. Depending on the type of milling and concentrating process employed, a mine may construct ore stockpiles to assure consistent feed to a mill. Pad and dump leaching facilities have associated impoundments to store barren and pregnant leach solutions, pipelines to transfer solutions between storage ponds and leach pads, and leachate and seepage collection facilities (U.S.EPA, 1994).

Contamination from processing facilities can occur in many forms that depend on the type of ore being processed, the type of on-site processing, and the specific mine design. Consequently, the list of chemicals used at a mine site can be extensive and may include flotation reagents, frothing and collection agents, scale inhibitors, flocculants, thickeners, leach solutions, and leachate neutralizing solutions. Processing activities can release contaminants to surface waters in a variety of ways that include spills of reagent materials or processing fluids (e.g., pipeline ruptures), leaks at processing facilities (e.g., liner tears), storage pond overflows (e.g., during storm events), and facility failures (e.g., slope failure of a leach dump). Contaminant pathways can be direct (release directly to surface waters) or indirect. Examples of indirect contaminant pathways include infiltration to ground water that exchanges with surface water, seepage to soil or bedrock which discharges to surface water, and seepage through or below impoundment dams and berms (Montgomery, W. 1996).

Waste disposal activities increase the potential for surface water impact by creating permanent features in which waste materials are stored. Waste materials can serve as sources of leachable metals, acidity, cyanide or other toxic constituents, and fine-grained sediment for many years after mining ceases. Examples of these facilities include waste rock dumps, impoundments, and spent ore piles. Waste disposal facilities can impact receiving waters through the release of sediment, metals, and other contaminants. In part, the types of contaminants available to the environment depend on the character of the waste materials (e.g., grain size and mineralogy); the means by which these materials were processed (e.g., cyanide leach). Fine-grained materials such as tailings piles are a significant source of erodible sediment that potentially can be mobilized and redeposited in stream beds by surface runoff. Over the long term, waste rock clumps, tailings impoundments, and spent ore piles that contain sulfide-bearing material can contribute acidity to receiving waters through the oxidation of pyrite and marcasite (Simovic et al, 1985).

Contaminants can be released to surface waters in a variety of ways that include physical failure (e.g., breach or sloughing of a tailings impoundments), seepage (e.g., below an impoundment dam), saturation and overflow of lined facilities (i.e., the “bathtub” effect), and erosion by wind and water (e.g., gully formation during storm events). Contaminant pathways can be direct (release directly to surface waters) or indirect. Examples of indirect contaminant pathways include infiltration to ground water that exchanges with surface water, seepage to soil or bedrock which discharges to surface water, and seepage through or below impoundment clams and berms (Anon, 2003).

2.4 Water Quality and Pre-Mining Disturbances in the Project Area

The Tano River is a vital source of potable water for the Brong Ahafo region and people from Sunyani and several small towns and hamlets located within and around the project area utilize the river. Water from the river is pumped and treated through small to medium size treatment plants operated by Ghana Water Company Limited (GWCL).

Most of the water bodies in the project area are devoid of major chemical pollution problems. This may be attributed to the fact that the Tano River and its tributaries are largely undisturbed by activities such as artisinal mining (galamsey) or any intensive fishing where people would be tempted to use chemicals. Although used as a source of potable water by settlements located along their banks, concentrations of indicator microorganisms show that surface waters of the Project Area are contaminated by both total and faecal coliforms and hence not fit for human consumption without prior treatment. These coliforms may have several origins:

1) poor or non-existent sewage systems for the villages,
2) extensive bathing in the streams and
3) zoological (Anon, 2005)

2.5 Soils of the Project Area

As part of Newmont baseline data collection, the company conducted a study on the soils of the area. The soil resources inventory and assessment exercise encountered 19 soil types at the soil series level. The development of the soil has been affected mainly by the prevailing environmental conditions of climate of high and constant temperatures and rainfall, vegetation units, rolling and undulating nature of the landscape and the varied parent material of the project area.

Under the tropical environmental conditions, most of the soil have developed into matured stages and have various morphological characteristics. Most of the soils on summits of low-lying uplands and ridges to middle slopes are well to moderately well drained, brownish to reddish color, moderately deep to very deep, loam to silty clay, granular to sub angular blocky with very few to abundant concretions, gravel and stones. These soils have fair to good moisture retention capacity as the result of their sub soil eluvia clay contents. Summits and slopes of steep-sided inselbergs and mountains carry hallow and highly concretionary stony and gravely soils, that becomes droughty soon after rains, and susceptible to severe erosion, and poor in plants nutrients. The soils of the valleys are deep to very deep, imperfectly to poorly drained, mostly gray in color with mottles. They are liable to flooding and water logging during the wet seasons. Their textures range from sandy to clayey, and have problems of water management (Anon, 2005).

The soils of the project area have been leached off the bases rendering them acidic and are low in plant nutrients. The soils have been subjected to intensive practices, rendering them impoverished. Deforestation and other practices have also affected the morphological characteristics of the soils. Iron pan formations in the soils are very common. Poor performances of crops are common in the Project area. Effective fertilization and anti-erosion methods are needed if the soils are to be used for prolonged agricultural production (Anon, 2005).

2.6 Land Use in the Project Area

The Project Area occurs within the cocoa based system of the semi-deciduous forest zone of Ghana. Agricultural land use dominates with the majority of the people depending on farming as the source of livelihood and the principal means of employment. Shifting cultivation is the primary practice. The major agricultural land uses are: a) cocoa farming, b) food crop farming c) rice farming in inland valleys and d) bush fallows. The non-agricultural land uses include: (i) human settlements in towns, villages and hamlets (ii) undeveloped inland valleys with swamp vegetation and tarred roads, (iii) feeder roads and tracks (Anon, 1998).

2.7 EPA Requirements on Erosion and Sediment Control

The Environmental Protection Agencies have set guidelines and standards which they require mining companies in Ghana to comply with. The requirements for erosion and sedimentation control and discharge to water bodies postulate the following according to Ghana's Mining and Environmental Guidelines (Anon, 1994):

- Mining companies shall endeavour to carry out land clearance in the dry season and should schedule construction progressively so that no land cleared of vegetation more than twelve months in advance of when it is required. In the company's Environmental Impact Assessment (EIA) or Environmental Assessment Program (EAP), it should indicate when construction and land clearance would take place.

- At large disturbed areas, the company shall, where appropriate
  - Provide adequate drainage to roads and tracks
  - Minimize clearance of vegetation.
  - Divert upslope drainage around those areas to be disturbed
  - Leave as much as possible of the vegetation downslope of the disturbed area to act as a natural sediment trap.
  - Where earthworks on steep slopes are unavoidable, the company shall sidecast spoil uniformly. Where spoil material is concentrated in the valley, steps should be taken to stabilize the spoil
  - Minimize disturbance to land around stream crossings.

2.7.1 Discharges to Water Bodies

The discharges to water bodies require that:

- Where discharge of water to the natural drainage is unavoidable, the company shall report the quality and quantity of the discharge in the EIA or EAP.
- Uncontaminated drainage may be discharged untreated.
- If the discharge water is contaminated, the company shall treat the water to a standard to be agreed between Environmental Protection Agency (EPA) and the company before discharging to the receiving waters.
- Treatment of contaminated waters requires a designated treatment pond or vessel so that the treated water can be monitored prior to discharge to the natural drainage. The EIA and EAP will specify the treatment, monitoring and the method of discharge.

- During discharge, the company shall undertake regular in-stream monitoring to confirm that acceptable water quality is maintained downstream. The EIA and EAP will specify the extent and frequency of monitoring (Anon, 1994).

CHAPTER THREE: SITE DESCRIPTION

3.1 Study Area

3.1.1 Location and Access

The study area is located in the Brong Ahafo region of the Republic of Ghana and bounded by latitude 6.9074° and 7.1454° north and longitude 2.2925° and 2.4535° west, Fig. 3.1. It is approximately 300km northwest of Accra, the national capital, 107 km northwest of Kumasi the second largest city and 40 km southeast of the regional capital Sunyani. The main access to the mine is by the Kumasi-Sunyani highway, branching off at the Tepa junction and following 10 km of paved road from Hwidiem to Kenyasi. Travel time to the license from Accra is approximately 6 hours. Accessibility within the study area is good. There are several footpaths, tracks and few laterite roads that interconnect the various settlements and farmlands within the study area

3.1.2 Physiographic Climate and Vegetation

The topography of the site consists of low rounded hills with a maximum elevation of about 540m. The project area is drained by a number of seasonal streams and rivers that flow generally southeast and feed into the upper basin of the Tano River, which is perennial. From the project area, the Tano River flows southwards forming a section of the border between Ghana and Cote d'Ivoire before discharging into the Atlantic Ocean. The study area falls within the wet semi-equatorial climatic zone of Ghana (Walker, 1962). It is characterized by an annual double maxima rainfall pattern occurring in the months of May to July and from September to October. (Anon, 2005)

Mean monthly rainfall records range from between 176 mm (at Sunyani station) and 208mm (at Goaso station) for June and 169mm (at Goaso station) and 171 mm (at Sunyani station) for October. Typically, minimum rainfall is experienced from December

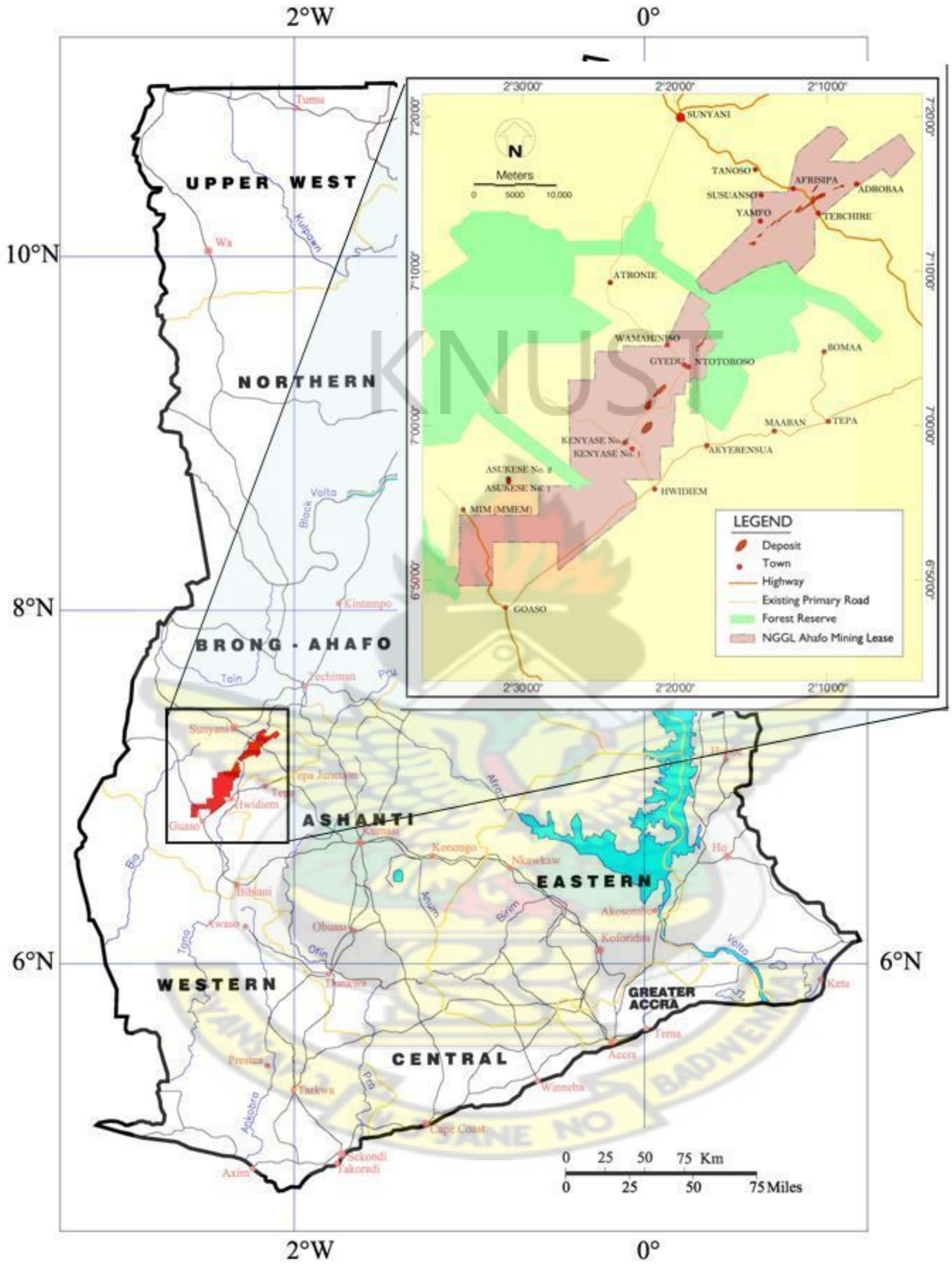

Figure 3. 1: Location of the study area

to the end of February, with January as the driest month. Mean monthly rainfall figures for January ranges between 5.6mm (at Goaso station) and 5.7mm (at Sunyani station). Mean monthly temperature within the area ranges from 23.9°C to 28.4°C. In general, March is the hottest month of the year with a mean temperature of 27.8°C. August is the coolest month with a mean temperature of 24.6°C. (Anon, 2005).

The project area is entirely rural and ambient air quality is good. There are no specific sources of gaseous or particulate emissions except from local and project traffic along the untarred roads of the concessions and the area in general. As a characteristic of this geographical part of the continent, the area is under the influence of the dust-laden harmattan winds. This seasonal particulate pollution occurs principally during the three months of the dry season, from December to February.

The project area lies within the semi-deciduous agro-ecological zone of Ghana and belongs to the Celtis-Triplochiton Association as classified by Taylor (1952). In a more recent classification, Hall and Swaine (1981) included the area under the moist semi-deciduous zone northwest sub-type. This is characterized by a three-storey structure with emergent tall trees often exceeding 50 m in height. The upper canopy consists of a mixture of deciduous and evergreen species, sometimes with gregarious under storey. Ordination analyses based on species composition (Hall and Swaine, 1976) reclassified the Project area and placed it in the Dry semi-deciduous zone type.

Species comprising trees, shrubs, herbs, grasses and climbers were identified within the project area.

3.1.3 Local Geology

The concession overlies approximately 300 km² of Birimian metasedimentary and metavolcanics sequences intruded by the granite plutons. The regional contact between the southeastern Sefwi Belt and northwestern sedimentary Sunyani basin trends for 80 km northeast through the concessions. This regional contact is interpreted to be over-turned thrust fault and is broadly associated with all deposits identified to date. Lateritic weathering is ubiquitous; hence most knowledge of underlying local geology is based on drill samples and geophysical images.

Rock types encountered include greywacke, siltstone, minor volcaniclastics, minor chert horizons, and graphitic zones in the footwall at Kenyasi/Amoma deposits. The rocks are distributed in the northwestern portions of the concessions, in the footwall of the regional shear zone. Rock units have undergone regional folding and metamorphism to green schist and occasionally lower amphibolite facies.

Volcanic units occur in southern and northern thirds of the concession area separated by a central Dixcove granite intrusion. Volcanic lithologies are generally scarce in deposits identified to date, and their distribution is interpreted from magnetic data and limited drilling. Basic volcanics predominate, and have been metamorphosed to green schist and amphibolite facies.

The central portion of strike within the concession area is dominated by a Dixcove granite intrusion which forms the hanging wall at Kenyasi/Amoma deposits. The granite is foliated adjacent to the regional shear.

Pre and post mineralization dykes intrude the sequence. These dykes are characterized by quartz and pink potassic feldspar at certain localities. Post mineralization feldspar porphyry dykes up to 2 m width are common in the northern portion of the license.

3.1.4 The Mine Area

The mining lease area extends over an area of 45 km from the Kenyasi area in the south to the Subenso area in the north. The lease area has been divided into two main blocks by the Bosumkese Forest Reserve and they are generally referred to as Ahafo South and Ahafo North Areas as shown in Fig.3.2. The Ahafo North Area is the northern half of the property and covers mainly areas to the north of the Bosumkese forest and the areas in and around Yamfo south, Susuanso, Terkyere and Adroba communities. The total tonnage defined over the Ahafo North Project Area is estimated as 32 Mt at 3.2 gm/t containing 3.2 Moz of gold. No mining or construction work has been undertaken in this area at the time of the study. The Ahafo South covers mainly areas to the south of Ntotroso community, areas in and around Kenyasi No 1 and Kenyasi No 2. Mining and related operational activities are currently concentrated at this half of the lease hence the study was limited to this portion of the license.

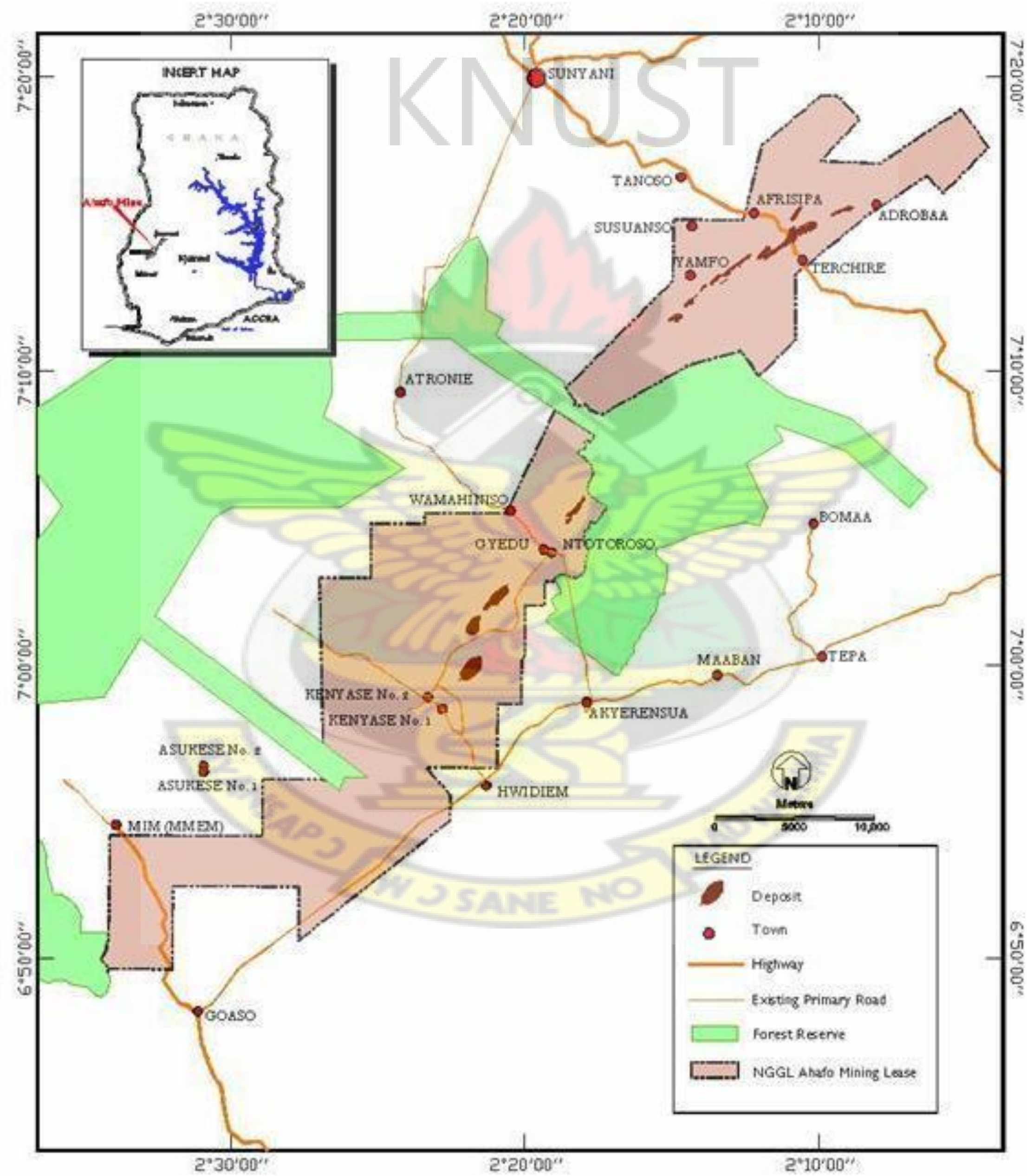

Figure 3. 2: The Ahafo License Area.

The Ahafo mine comprise facilities and services for mining and processing of approximately 137 million tonnes of ore being extracted by open pit mining. This is the first phase of the project and targets a mineable resource estimated at the time of the research work to be 105 Mt at 2.02 grams per tonne (gm/t) containing 6.8 million ounces (Moz) of gold. This is to be mined from four pits (Subika, Apensu, Awonsu and Amoma pits), of which two, the Subika and the Apensu pits are currently being mined.

3.2 Project Site Description

3.2.1 Drainage System of Project Area

The project area is drained by a number of seasonal streams and rivers, which feed into the upper basin of the Tano River as shown in Fig.3.3. The streams drain from the northwest where they take their source to the southeast into the Tano River that flows from the north to the south. The seasonal streams and rivers divide the project area up into a number of smaller sub-basins including the Subri, Awonsu, Subika and Amama.

3.2.1.1 The Tano River

The Tano River as the principal river receives inflows from a number of streams that drain the project area. It is conspicuously the largest water body in the concession area. The river is perennial and flows through a well drained channel protected by a canopy of tall trees. It has a rich aquatic ecology that supports large numbers of fishes and crocodiles. The Tano is a vital source of water for the region and beyond. The people of Sunyani and several small towns and villages located within and around the project area depend on the river as their source of drinking water. Water from the river is pumped at a number of stations and treated through small to medium size treatment plants operated by Ghana Water Company Limited (GWCL). One of such stations is located at Akyerensua and serves communities such as Akyerensua, Hwidiem, Kenyasi 1, Kenyasi 2 and New Dormaa.

3.2.1.2 The Subri Stream

The Subri stream takes its source near the Asukese Forest reserve and it is the largest sub-basin in the project area. It has a stream length of 25 km and covers a catchments area of approximately 129 km². Its channel is generally well defined though it passes through several swampy areas, particularly after it has crossed the Kenyasi-Ntotroso road.

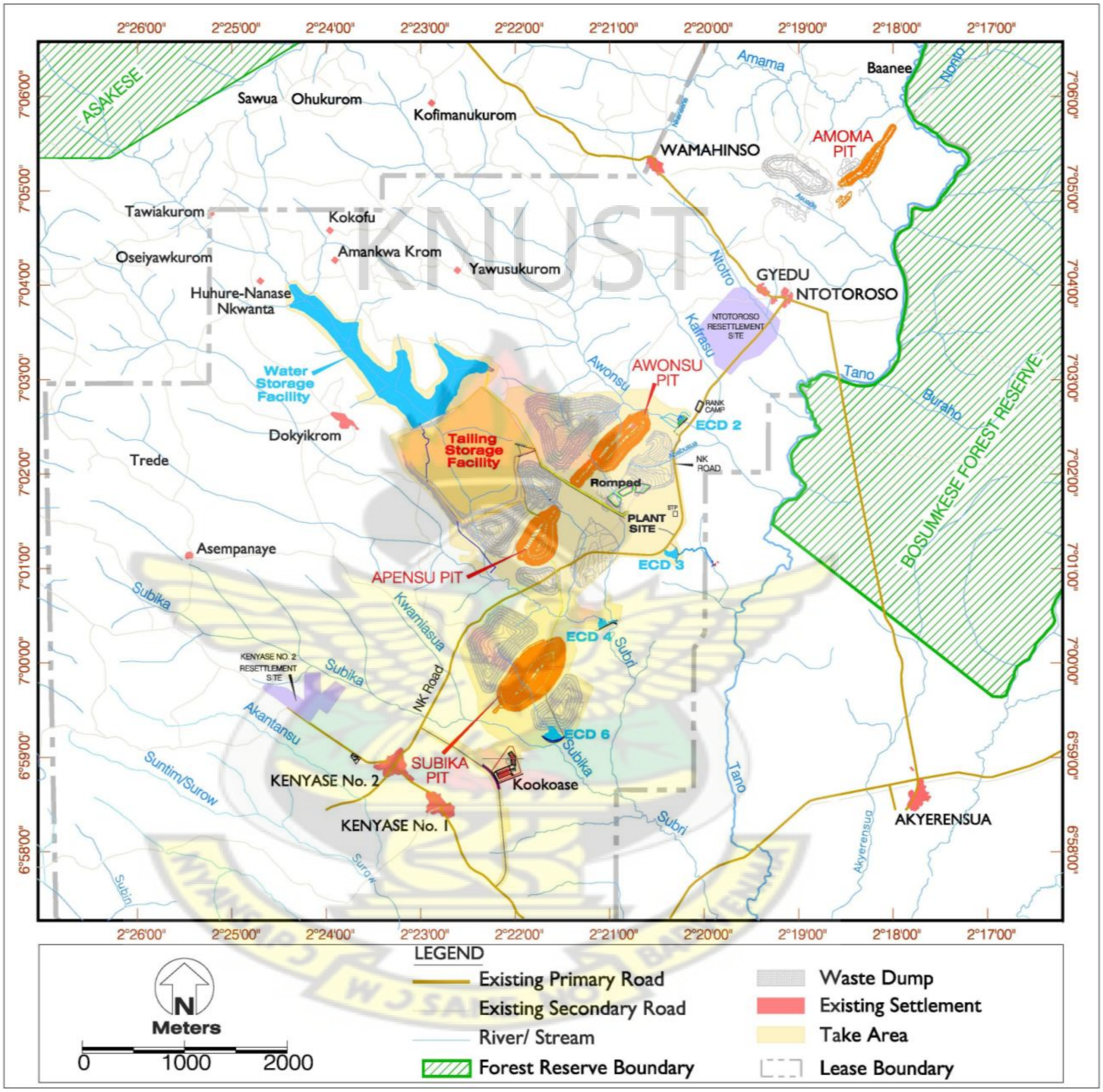

Figure 3. 3: Drainage Map of the Area Showing Mine Layout

The Subri has a number of tributaries. Its major tributaries are the Asandua and Subika. All these water bodies together with the Subri are seasonal in character and virtually dry up from November to April.

Several hamlets are located within the Subri catchments area. These hamlets rely totally or partially on the streams for their domestic water requirements. During the dry season, the inhabitants of these hamlets get their water requirements from small dugouts created in the stream channel.

3.2.1.3 Subika Stream

The Subika stream covers about 25% of the Subri basin and has a stream length of approximately 12 km. Several reaches of the stream are protected by a good canopy of trees.

3.2.1.4 Awonsu Stream

The Awonsu stream drains the valley immediately to the north of the Subri basin. It has a stream length and catchments area of approximately 14.8 km and 38.5 km² respectively. It flows in a southeastwards direction and joins the Tano River some 2 km after intersecting the Kenyasi-Ntotroso road. Like the Subri, the Awonsu is highly seasonal and it is a source of water supply for the population living in the small hamlets spotted within it catchments area.

3.2.1.5 The Amama Stream

The Amama stream drains the northern corner of the project area and flows generally eastwards to link the Tano River. Only a small part of the southern section of the Amama catchments falls within the project area.

3.2.2 Mine Pits

The deposits being mined occur along two shear structures that extend over the length of the mining licenses. The mine has four deposits, Subika, Apensu, Awonsu and Amoma pits (Fig.3.3). Ore extraction is currently ongoing from the Subika and the Apensu pits. The various mining pits and infrastructure are situated within the different sub-basins of the project area. Subika pit lies within Subika sub-basin of the Subri catchments, whilst the Apensu pit, falls within the Subri sub-basins and Apensu sub-basin. The Awonsu pit on the other hand, lies partly within the Subri sub-basin and partly within the Awonsu sub-basin and the Amoma pit in the Amama sub-basin is close to Amama-Tano confluence.

3.2.2.1 The Subika Pit

The Subika pit is hosted within granodiorite and extends over an ore strike length of 1,978 m and covers a surface area of 88 ha. The pit at 4.8:1 stripping ratio of waste to ore is estimated to produce 34.7 Mt of ore, 166.6 Mt of waste and yield 2.5 ounces of gold at the grade of 2.21g/t. Pit depth at the end of mining is estimated to be 378 m and volume of void to be created is 93,200 m^3.

The weathered profile over this pit is relatively shallow. Exploration activities are ongoing to develop this pit into an underground mine in the near future.

The immediate surroundings of the pit drains southeastwards, into the Subika stream which then joins the Subri stream and finally into the Tano River. Sediments from this environment are expected to be trapped by the Environmental Control Dam 6 (ECD6).

3.2.2.2 The Apensu Pit

Unlike the Subika, the Apensu pit is reported to be situated across metavolcanics and granitoids and extends over an ore strike length of 1,337 m. The pit margin extends over a surface area of 74 ha and is projected to a maximum depth of about 260 m. An opening of 69,500 m^3 would be created on completion. With a striping ratio of waste to ore at 3.89:1, the pit is estimated to produce 34,776,966 tonnes of ore and 135,219,697 tonnes of waste, from which 2.4 M ounces of gold at the grade of 2.18g/t would be extracted. This pit has a top layer of friable saprolitic material that extends to a depth of over 40 m.

3.2.2.3 The Awonsu Pit

The Awonsu pit falls partly within the Subri and partly within the Awonsu catchments. Like the Apensu pit, the Awonsu pit contains ore that is located within the contact between metavolcanics and granitoids.

With a striping ratio of waste to ore at 1.45:1, the pit is estimated to produce 24,113,445 tonnes of ore and 35.1 Mt of waste, from which 1.2 M ounces of gold at the grade of 1.60 gm/t would be extracted. Once completed, the pit will cover approximately 52 ha, with a volume of 24,500 m³ and be at depth of 210 m.

3.2.2.4 The Amoma Pit

The Amoma pit is located along the main mineralized structure as the Apensu and the Awonsu pits and is also hosted by metavolcanics and intrusive granitoids. The pit is expected to produce 12.0 Mt of ore at 1.84g/t to yield 0.7 M ounces of gold. The pit would generate 23.2 Mt of waste and stripping ratio of waste to ore at 1.93. Pit depth at the end of mining will be 184 m and volume of void to be created is 15,000 m³ The Amoma pit will cover an area of 36 ha.

3.2.3 Waste Dumps

Large tonnages of waste rock are being generated from the various mine pits. To ensure the proper management of the waste a number of waste dumps have been created adjacent to the various mining pits. A total of six waste dumps have been planned for the Southern Deposits and these are as follows:
Subika waste dump
Apensu waste dump
Awonsu waste dump
Amoma waste dump

3.2.3.1 The Subika Waste Dump

Two waste dumps, have been sited adjacent to the Subika pit. One is at the west and the other at the east. The West Waste Dump is located at the footwall of the pit and covers a surface area of approximately 179 ha. It is estimated to hold up to 71.1 Mm³ of waste and reach a height of 72 m when mining is completed. The East Waste Dump is located on the hanging wall of the pit and covers a surface area of 97 ha. It is expected to grow to a total height of 66 m and volume of about 31.2Mm³ by the close of the mine.

3.2.3.2 Apensu Waste Dump

Wastes from the Apensu pit are being dumped at two sites, the Apensu West waste dump and the Apensu South waste dump. The Apensu West waste dump is located west of the Apensu pit, close to the tailings dump. This waste dump would cover an area of 93 ha and would rise to a maximum height of 54 m upon completion.

The Apensu south waste dump on the other hand is sited south of the Apensu pit and covers an area of 43 ha. It is expected to grow to a total height of 42m and volume of about 18.2 Mm^3 by the close of the mine. These two waste dumps are all within the Subri sub basin.

3.2.2.3 The Awonsu Waste Dump

The Awonsu waste dump is sited at the western side of the Awonsu pit. The waste dump is estimated to cover an area of 165 ha and would be expected to rise to a maximum height of 83 m upon completion of the pit.

3.2.2.3 Amoma Waste Dump

The Amoma waste dump is located at the southeastern side of the Amoma pit. The pit is estimated to cover an area of 73 ha and would be expected to reach a maximum height of 48 m upon completion of the pit.

3.2.3 Water Storage Dam

The company meets its water requirements for the processing of ore and other general mine use from a dam constructed (water Dam) on the upper course of the Subri stream about 3.6 km west of plant location. At full capacity, the dam covers an area of approximately 280 ha with a reservoir length of about 5 km. Aside from the water supplied to the dam by the Subri and its associated tributaries the company has constructed a pumping system that links the Tano River to the dam. This is used to pump some water from the Tano into the dam when the Tano is in high flood. The dam has also been stocked with various species of fresh water fish.

3.2.4 Tailings Storage Facility (Tailings Dam)

A tailings dam has been constructed to the immediate south of the water dam covering an area of 460 ha of the Subri water course. The tailings dam is separated from the water dam by a huge wall of compacted lateritic embankment. Water from the tailings dam is also re-circulated to the plant to supplement intake from the water dam.

3.2.5 Processing Plant and Operational Services Infrastructure

A processing plant together with an associated service infrastructure, and a number of blocks of building which serve as operational services infrastructure has been constructed over a large continuous block of land covering an area of about 35 ha. The different blocks of operational services infrastructure include maintenance and services block, administrative block, fueling station, stores, apartments, laboratory facility, sewage treatment plant, messing, accommodation etc. These facilities are located adjacent to the Ntotroso-Kenyasi road, some 5.0 km from Ntotroso.

3.2.6 Sedimentation Dams (Environmental Control Dams)

As part of its environmental controls on sediment movement the company has constructed a number of sedimentation dams referred to as Environmental Control Dams (ECDs) at vantage points on watercourses that run through disturbed areas within the property to intercept all runoff from the various workings and remove materials above a fine to medium silt size. Four environmental control dams namely ECD2, ECD3, ECD4, and ECD6 as shown in figure 3 are currently in place. ECD2 (131,000 m3 in size) is sited downstream of the Awonsu stream to trap runoff from the Awonsu pit and the waste dump. ECD3 (26,500 m3 in size), is situated on a small tributary draining the catchments area hosting the treatment plant and the Run of Mine (ROM) pad. ECD4 (223,000 m3 in size), is situated on a small tributary whose watershed contain the runoffs of the treatment plant and Apensu pit. ECD6 (80,000 m3 in size) is located on the Subika stream to trap runoff from the Subika excavation. The statistics of the ECDs are as shown in the Table 3.1.

Table 3. 1: Statistics of Environmental Control Dams (ECDs)

ID	Height (m)	Basin Area (ha)	Basin Volume (m^3)	Catchment Area (ha)	Storage Capacity (m^3)
ECD2	3	19	131,000	3,000	180,000
ECD3	3	2.4	26,500	140	56,000
ECD4	4.5	21	223,000	3,371	330,000
ECD6	3	6	80	297	110,000

CHAPTER FOUR:- METHODOLOGY

The methodology employed to collect information to meet the objectives of this research is grouped into four categories:

1. Desk study and Familiarization Visits to the Study Area.
2. A study of sediment control systems as implemented in the project area.
3. Evaluation of sediment loads in streams entering the mine area and sediment loads entering the control dams as well as the monitoring of discharges from the ECDs into the Tano River.
4. Analytical work on water in the control dams

The details of the procedure of the research are presented below:

4.1 Desk Study and Familiarization Visits to the Study Area

4.1.1 Literature Acquisition and Study

Topographic maps covering the research area were purchased from the Survey Department in Accra and available aerial photos of the study area were acquired from Newmont Ghana Gold Ltd. These were studied to determine the general topography of the area, the location of stream channels, flow directions and how the various streams are networked. Specific notification was made of locations where streams made entries into project site and locations where streams flow out from the project area.

Various maps, plans and documents of the mine area were also acquired from the Mine's Environmental and Mining Departments for study. This was to determine how the various infrastructures have been laid out in the mine area, where the environmental control dams have been sited and plan where the samples for the research work was to be collected from, as well as provide an insight into the mining and environmental management practices and setups of the mine.

The EPA office in Accra was visited to acquire information on what the EPA's acceptable requirements of discharges into water bodies in Ghana are.

4.1.2 Site Visitation and Interaction with Personnel

A reconnaissance site visit was made to the mine to ascertain the general outlay of the mine and its workings, so as to gain an overview of the area, the nature of the ore that is being mined and to assess the various activities of the mine that have the potential in terms of erosion and sedimentation to negatively impact on the water bodies in the area. The occasion was also used to identify the locations of the various mine workings and where the environmental dams have been sited.

The various locations of the sedimentation dams were picked with the Etrex-Garmin GPS, plotted and compared with the topographic map of the area to determine whether the sedimentation dams have been well sited or not, considering the drainage pattern of the area in relation to the mine setting. The plotting of the picked GPS points was achieved by downloading the picked points from the Etrex onto a laptop using the Map source software. An excel file was created for the exported data, which was later converted into a tab file and plotted onto an electronic map of the area using Maplnfo software.

The reconnaissance visit also granted the opportunity to check on the accessibility to the planned sample points and modify selected positions where necessary. The various workings (mining pits, waste dumps, run of mine pad etc) and constructional areas of the mine were toured on different occasions, in order to make an assessment of how these various sub-basins are being impacted by different activities of the project in terms of vegetation clearance and sediment release from the environment. This was then compared with the measures that have been put in place to minimize sediments generation and to determine whether adequate controls have been put in place to check on sediment release into the basins.

Verbal discussions with various technocrats from the mining and the environmental units were made to understand the mining activities, and environmental practices that have been put in place to mitigate erosion and sedimentation problems, gain insight into monitoring exercises, and the research conducted on soils and streams of the area that led to the adoption of a particular design of the ECDs etc.

These discussions gave an insight into the reason why there are different waste dumps e.g. waste dump for the top soil and waste dumps for the fresh rocks, why some of their activities are scheduled, why certain control measures are adopted, the type of materials used to reduce erosion, the type of monitoring equipment being used and how the monitoring activities are conducted.

4.2 Study of Various Erosion and Sediment Control Systems Applied on the Mine

The various erosion and sedimentation control measures being practiced on the mine were studied to determine how efficient these measures are, and to assess whether adequate control measures have been put in place to check erosion and sedimentation problems resulting from the mining activities. This objective was achieved by monitoring these control measures and involved visiting some of these sites, especially during and after runoffs. The selected sites include the check dams, re-vegetated areas, mulched areas and drilling sites.

4.3 Assessment of Sediment Quality of Water

Environmental control measures with regards to erosion and sedimentation systems, put in place for the various basins were studied. The studies involved monitoring the inflow of runoff into sedimentation dams as well as the outflow of discharge from these dams. The purpose of this was to provide a picture of how the mine was impacting on the area, and also to assess how efficient these measures were by determining the quality of water, in terms of Total Suspended Solids (TSS) that were discharged from the Environmental control dams.

To achieve the set objective, thirteen (13) sampling points on five major streams were selected. The selection of these points as shown in Figure 4.1 was based on the layout of the mine structures and the drainage net work of the area. Two of these points were sited on the Tano River tentatively referred to as the upstream and downstream points respectively. The upstream point provided data on the status of the Tano River prior to it entering the mine area whiles the data capture from the downstream provided information on the nature of the river after effluent from the mine had emptied into the Tano River.

Four sampling points were also sited downstream of the control dams to capture information on the nature of discharges from the various sedimentation dams that emptied into the Tano River. Four other points were sited on the inlets of the control dams. The essence of the data from these points was to provide information on the amount of sediment loads in the runoff prior to their entry into the control dams. The other sampling points were sited upstream at locations that determined the quality of the runoff prior to their entry into the mine area. These points are not under the influence of the disturbance of the mine and hence can be considered as control points.

The monitoring exercise was undertaken between August and October 2006, a period when much of the second season rainfall was experienced. Daily TSS values were measured from the various environmental sedimentation dams as well as the upstream and downstream points of the receiving Tano River. Within the period samples were taken on some rainy days to determine the sediment built up in the runoffs. This objective was achieved by taking TSS readings at hourly intervals within a period of six hours during and after heavy downpours.

At the various ECDs, TSS readings were taken near or around the decant tower where the impact of any water flow on the settled solids is minimal, with TSS values expected to be the lowest and access to the sampling found to be relatively safe. When water is discharged from the sedimentation dams, TSS readings were taken at three (3) hour intervals to ensure that what was released from the dam met the compliance level of 50 ppm. At both the upstream and the downstream sampling points of the Tano River, TSS values were taken from the middle of the river. Figure 4.1 is a map of the area showing the various sampling points.

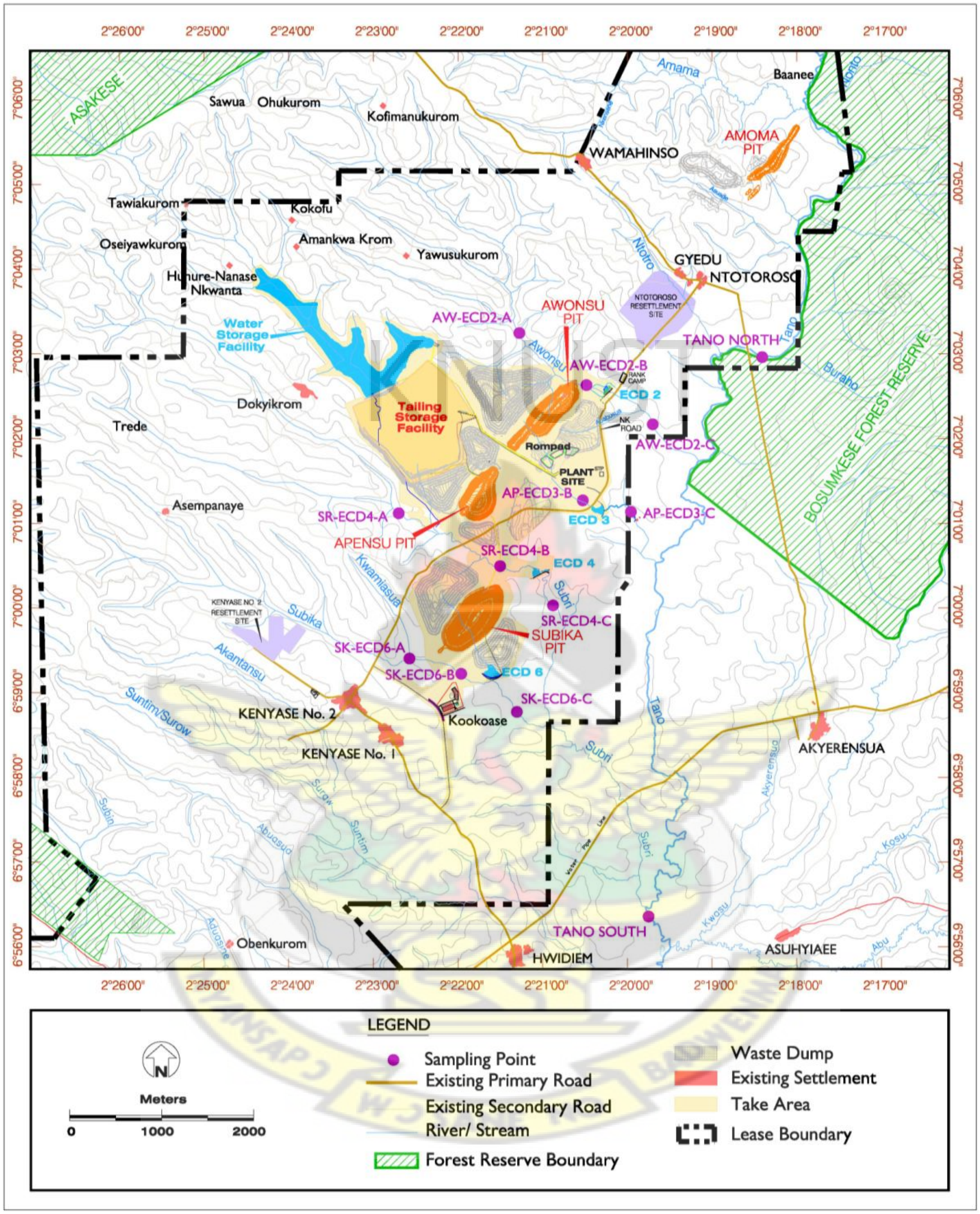

Figure 4. 1:- Sampling Location Points for Sediment Quality Monitoring

4.3.1 Measurements of TSS Values

In the measurement of TSS values, the TSS meter was first standardized to read 0 mg/l. This was achieved by calibrating the meter to read zero in deionised water. To achieve this, the probe of the meter was well cleaned and rinsed with deionised water, and then switched on. The probe of the meter was then dipped into deionised water and allowed to stabilize on 0 mg/l.

After stabilization had been achieved, the probe was then removed from the deionised water and dipped into the sample/water to a depth that ensured that the entire probe was submerged below the surface of the water before recording the TSS value. Usually this was done at a depth of 0.6 m. The depth of 0.6 m had been measured and marked on the cord connecting the probe to the meter. The most stable value registered on the meter was captured as TSS reading for the measurement. Thereafter the probe was rinsed with distilled water and cleaned with lint free cloth.

4.3.2 TSS Analytical Methods

The sample analyses were done by electrochemical method (using meters and electrodes) where electricity generated is related to the chemistry or chemical concentration of the sample. The procedure involves placing electrodes in a water sample and measuring electric potential (voltage) in millivolts or currents in milliamperes, which is related to the concentration of the analyate.

4.4 Data Capture and Data Processing

The field measurements made were recorded on a field data sheet. The information captured included:

- Date and time of measurement, including any site condition, observations or concerns.
- ECD impounded water level - read from a staff gauge
- Number of decant rings in operation and the elevation of the top ring, measured via a drop tape.

- TSS levels within the discharge flow at varying depth for example at 0.6 and 1.0 meter depths - measured with the TSS meter.
- Overflow spillway discharge - no flow / flow. If flowing, the flow depth of the spillway is recorded.
- Site precipitation within the last 24 hours at the time of inspection.

The field data captured was later entered into the computer to generate an electronic database (Appendix 3).

4.5 Size Fractions and Rate of Settlement of Suspended Solids

As part of the study, samples were collected for laboratory test to determine the various size characteristics of the suspended solids as well as determine the settling rates of the sediments to provide an idea of how long sediments or runoff could be confined in the various ECDs to determine the required discharge levels.

4.5.1 Methodology for the Size Fraction

Samples of settled sediments from the ECDs were collected at the end of the rains when the volume of water in the dams was reduced. The samples were weighed and then wet sieved into different size fractions at the Newmont Laboratory at Kenyasi. The various size fractions were weighed with a digital electronic balance. From the results the various size percentages were then determined.

4.5.2 Methodology for Rate of Settling

To determine how long runoff could be impounded in the various dams before discharging into receiving streams, samples with different TSS levels were collected and allowed to settle over a period of time. Runoff samples were collected after different rainy days at the inlet points of the dams into 250 cubic meter containers and the rate of settling monitored for the different occasions. TSS levels of these samples were read at twelve (12) hour intervals over a period of ninety six (96) hours.

CHAPTER FIVE:- RESULTS AND DICUSSIONS

5.1 Introduction

There are four major streams of importance that flow through the project area. These are Subika, Subri, Apensu and Awonso streams. These streams and their tributaries define the drainage pattern of the project area. It is on these streams that the Environmental Control Dams (ECDs) are sited. During rainy days layers of soil are gradually torn off as particles of soil or are detached from the ground as rain come against the soil surface as a result of exposed soil surfaces from construction activity. The detached soil particles are mobilized and washed off by runoff into various drainage channels and subsequently into the network of streams in the study area. Consequently the Subika, Subri, the Apensu and Awonso streams carry eroded soil materials from areas off project domain as well as those from the project area. To achieve the objectives of the project work therefore, these streams were sampled at predetermined points and analyzed

5.2 Results

The results of the study of sediment build up during rainy days in the upstream sampling points of Awonsu, Apensu, Subika and Subri streams are presented below in Table 5.1. Similarly the results of sediments build up of these streams at the ECDs inlets are shown in Table 5.2.

Table 5. 1: Rainy days TSS Results of Upstream Sampling Points

DATE/	**Sampling Points**			**Rainfall**
Sampling Periods	**AW-ECD2-A/mg/l**	**SR-ECD4A/-mg/l**	**SK-ECD6-A/mg/l**	**Average**
30-Aug-06	100	115	113	66mm
1hr	115	155	140	
2 hr	344	352	370	
3hr	360	340	363	
4hr	280	290	259	
5hr	200	200	199	
6hr	125	115	118	

DATE/ Sampling Periods	Sampling Points			Rainfall
	AW-ECD2-A/mg/l	SR-ECD4A/-mg/l	SK-ECD6-A/mg/l	Average
31-Aug-09	130	142	136	19mm
1hr	190	187	202	
2hr	467	430	429	
3hr	402	430	439	
4hr	278	250	244	
5hr	190	201	191	
6hr	101	120	107	
3-Sep-06	130	122	126	25mm
1hr	291	287	301	
2 hr	640	592	622	
3hr	625	615	620	
Or	478	470	465	
5hr	270	285	290	
6hr	134	124	144	
18-Sep-06	35	43	38	4mm
1hr	190	201	187	
2 hr	472	477	460	
3hr	430	445	433	
Or	390	385	374	
5hr	269	266	276	
6hr	192	190	194	
10-Oct-06	12	28	25	44mm
1 hr	190	209	185	
2 hr	275	270	280	
3hr	390	404	383	
4hr	280	255	260	
5hr	198	189	177	
6hr	205	170	160	
14-Oct-06	30	45	36	11 mm
1 hr	213	200	220	
2 hr	465	442	422	
3hr	456	460	462	
4hr	301	289	276	
5hr	281	277	291	
6hr	212	202	198	
15-Oct-06	98	102	104	10mm

DATE/	Sampling Points			Rainfall
Sampling Periods	**AW-ECD2-A/mg/l**	**SR-ECD4A/-mg/l**	**SK-ECD6-A/mg/l**	**Average**
1hr	180	189	185	
2 hr	439	438	448	
3hr	445	430	441	
4hr	571	544	555	
5hr	473	472	455	
6hr	367	378	370	
18-Oct-06	137	132	141	62mm
1hr	370	365	373	
2 hr	519	522	534	
3hr	614	596	600	
4hr	554	563	541	
5hr	448	430	467	
6hr	317	328	321	

Table 5. 2: Rainy days TSS Values entering the ECDs

DATE/	Sampling Points				Rainfall
Sampling Periods	**AW-ECD2-B/mg/l**	**AP-ECD3-B/mg/l**	**SR-ECD4-B/mg/I**	**SK-ECD6-B/mg/l**	**Average**
30-Aug-06	100	405	364	207	66mm
1hr	151	678	539	389	
2 hr	340	984	722	556	
3hr	347	840	664	448	
4hr	289	702	513	306	
5hr	209	516	303	201	
6hr	130	219	180	126	
31-Aug-06	120	208	115	4	19mm
1hr	190	446	399	350	
2 hr	478	909	710	701	
3hr	399	734	622	598	
4hr	278	522	488	456	
5hr	198	208	247	257	
6hr	101	120	134	127	
3-Sep-06	120	200	160	67	25mm

DATE/	Sampling Points				Rainfall
Sampling Periods	AW-ECD2-B/mg/l	AP-ECD3-B/mg/l	SR-ECD4-B/mg/I	SK-ECD6-B/mg/l	Average
1hr	299	378	348	357	
2 hr	640	895	706	690	
3hr	629	705	654	570	
4hr	480	502	497	432	
5hr	289	312	339	354	
6hr	134	143	145	123	
18-Sep-06	35	160	45	37	4mm
1hr	193	251	204	172	
2 hr	477	789	699	483	
3hr	430	690	603	404	
4hr	382	501	468	397	
5hr	279	450	378	300	
6hr	202	302	310	261	
10-Oct-06	12	12	68	38	44mm
1hr	190	444	399	341	
2 hr	275	875	710	712	
3hr	399	1122	890	835	
4hr	278	942	872	759	
5hr	198	765	557	575	
6hr	205	707	564	488	
14-Oct-06	24	60	55	15	11 mm
1hr	213	415	424	356	
2 hr	478	857	766	435	
3hr	456	734	740	588	
4hr	309	549	472	456	
5hr	287	557	409	386	
6hr	212	473	367	327	
15-Oct-06	102	160	162	143	10mm
1hr	189	255	201	167	

DATE/	Sampling Points				Rainfall
Sampling Periods	AW-ECD2-B/mg/l	AP-ECD3-B/mg/l	SR-ECD4-B/mg/I	SK-ECD6-B/mg/l	Average
2 hr	438	690	609	528	
3hr	430	699	615	498	
4hr	544	789	704	599	
5hr	472	709	659	487	
6hr	378	409	436	413	
18-Oct-06	141	160	163	129	62mm
	373	579	462	433	
	534	801	699	704	
	600	1094	877	794	
	541	928	800	902	
	467	708	642	601	
	321	573	449	470	

5.2.1 Discussions of Results

5.2.1.1 Results from Subika Stream

The Subika stream and its tributaries are important network of drainage in the project area. The importance of the Subika and its tributaries to the project is the fact that its catchments area includes the Subika West waste dump, Subika East waste dump, South Waste dump and the Subika pit area as can be found on Fig.4.3. It is on the lower course of this stream that the Environmental Control Dam six (ECD6) is located. The ECD6 is therefore tentatively receiving sediments from the Subika pit area and its associated waste dumps. The essence of the three sampling points that were sited on the stream can be outlined as follows:

1. SK-ECD6-A was to assess sediment levels in areas on the upper course of the stream outside the project area,
2. SK-ECD6-B was to assess the level of suspended sediments of runoff or stream inflows into the control dams during a rainy day,

3. SK-ECD6-C was to provide a measure of the suspended material in the discharge from the environmental control dam six (ECD6).

At sample point SK-ECD6-A of the Subika stream, which provided a measure of sediment loads from catchments off the project area the maximum TSS values recorded during a period of six hours after or during a downpour ranged between 370 mg/1 and 622 mg/1 averaging 486 mg/l (Table 5.1). TSS readings of sample point SK-ECD6-B, located downstream of the former and which assesses discharges from the project area had values that ranged between 483 mg/l and 902 mg/1 (Table 5.2) with an average value of 669 mg/1. Comparing the two values, that is SK-ECD6-A and SK-ECD6-B it is evident that the TSS values recorded for the SUB-ECD6-B are relatively higher than those registered for the upstream sample point SK-ECD6-A. There is therefore an addition to the sediment load of the Subika stream as it flows through the project area. The higher TSS values of SK-ECD6-B as shown in Figure 5.1 can be due to the runoff from the Subika pit area, associated waste dumps and other disturbed areas due to the mining activities.

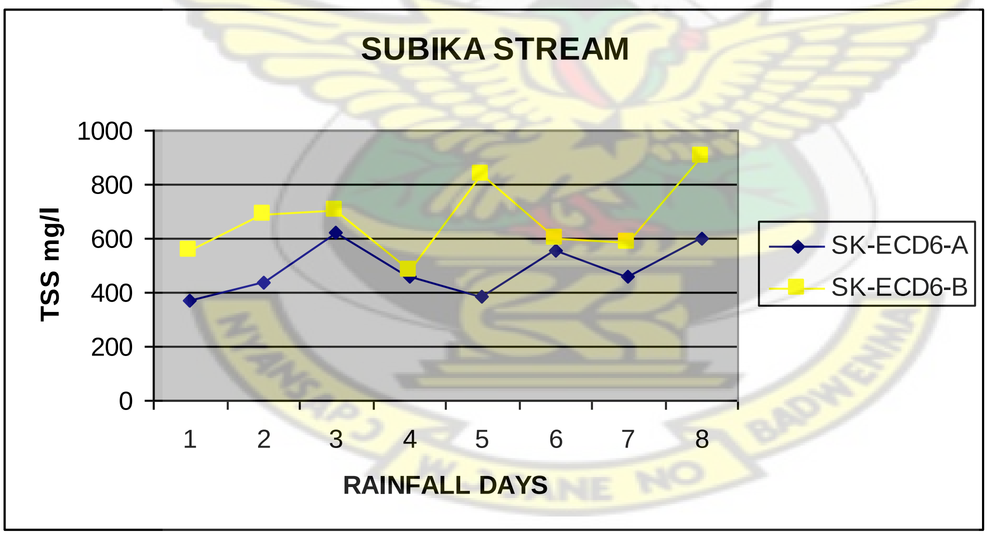

Figure 5. 1:- Graph of TSS Values of Subika Sampling Points SK-ECD6-A and SK-ECD6-B

5.2.1.2 Results from Subri Stream

The Subri stream is an important major stream in the project area. Together with it's tributaries the Subri accounts for about fifty percent (50%) of the project area. The Apensu pit area together with three waste dumps associated with the pit are drained by

Subri and its tributaries. The environmental control dam four (ECD4) is located on the lower course of the Subri and therefore receives the sediment inflows from runoff of the above mentioned areas.

Three important sampling points were sited on this stream, and these are

1. SR-ECD4-A, which was sited to observe sediment buildup in the stream prior to its entry into the project area, and served as a control point.
2. a sediment basin inlet point SR-ECD4-B which assessed sediments inflow into the control dam.
3. and SR-ECD4-C which measured the amount of sediments in the discharge from the control dam.

The upstream sampling point SR-ECD4-A is considered as a control point and measures the natural sediment build up in the stream from drainage in an unconstructed area. In the period of study the upstream sampling point of Subri stream (SR-ECD4-A) recorded maximum TSS values that ranged from 352 mg/I to 615 mg/1 (Table 5.1). On the other hand the TSS results from the environmental control dam inlet point SR-ECD4-B registered values that range from 699 mg/1 to 890 mg/l (Table 5.2). Comparing the two sampling points it is evident that the SR-ECD4-B registered higher TSS values than those of SR-ECD4-A. This suggests that sediment loads from upstream of Subri stream has further increased as the stream flows through the project area. The increase in the TSS values is as a result of sediment transport from the Apensu Pit and the associated waste dumps. The stream is also impacted by erosional material from the southern margins of the Subika pit and waste dumps. This therefore accounts for the relatively high values of the TSS values. A plot of the results from the first two sampling points is indicated in Figure 5.2. It is evident that the project has significantly increased the amount of sediment that is carried by the stream in view of the operational activities in the area.

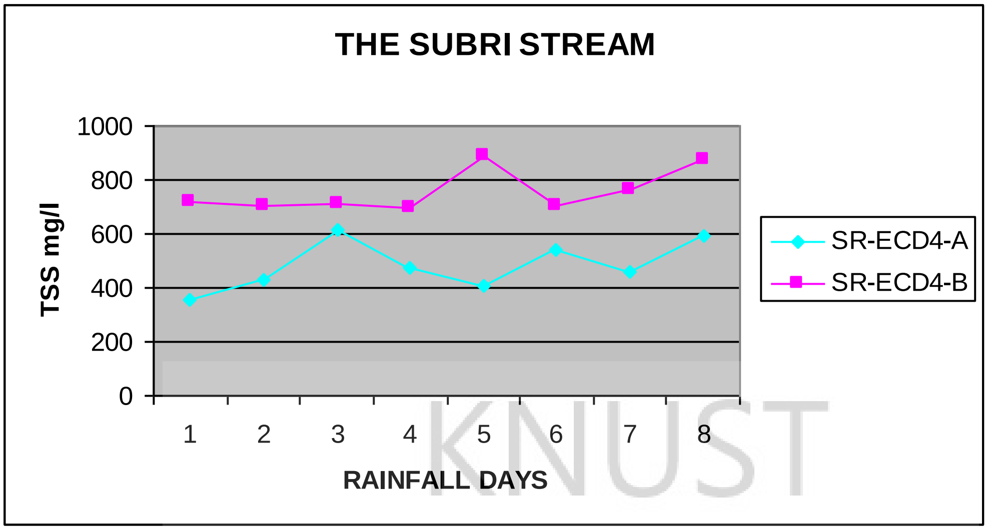

Figure 5. 2:Graph of TSS Values of Subri Sampling Points SR-ECD4-A and SR-ECD4-B

5.2.1.3 Results from Apensu Stream

The Apensu stream is a small stream that takes its source entirely from within the project area. Its catchment area includes the northern margins of the Apensu waste dump area, the large extensive and continuous block of land on which is sited the processing plant, ROM pad, administrative blocks, maintenance area and staff residential blocks. It is on the lower course of this stream that the Environmental Control Dam three (ECD3) is situated. Two important sampling points were sited on this stream, namely

1. AP-ECD3-B that was sited at the inlet section of the ECD3 assessed the sediments loads that was generated from the project area
2. The sample point AP-ECD3-C provided an idea of the amount of suspended particles in the discharge from the dam.

As the Apensu stream catchment area is entirely within the project area no sampling point could be located to assess any amount of sediments that is generated upstream of the project area and transported into the project area.

The results from sample point AP-ECD3-B indicate that the maximum TSS values recorded over a period of six hours after rains, ranged between 789 mg/l and 1122 mg/l. These values are relatively higher than those of Subika and Subri streams.

5.2.1.4 Results from Awonso Stream

The catchment area of the Awonso stream includes the Awonsu Pit which is yet to be developed and the Rank Camp area. The Rank camp is one of the mine camps in the project area. Three sampling points were sited on this stream during the study. These were:

1. an upstream point AW-ECD2-A, which assessed the amount of suspended particles that was generated off the project area,
2. AW-ECD2-B, which assessed the amount of sediment material that was generated and transported into the control dam, and
3. AW-ECD2-C that measured the amount of sediment in the discharge from the control dam.

At sample point AW-ECD2-A of the Awonsu stream, TSS values recorded during the period of the research work had peak values which ranged between 360 mg/l and 640 mg/l averaging 497 mg/I. TSS readings of sample point AW-ECD2-B located downstream of the same stream have values that ranged between 347 mg/l and 640 mg/I averaging 495 mg/l. Comparing the two sampling points, TSS readings are fairly close although there are occasional differential highs. This can be seen in Figure 5.3.

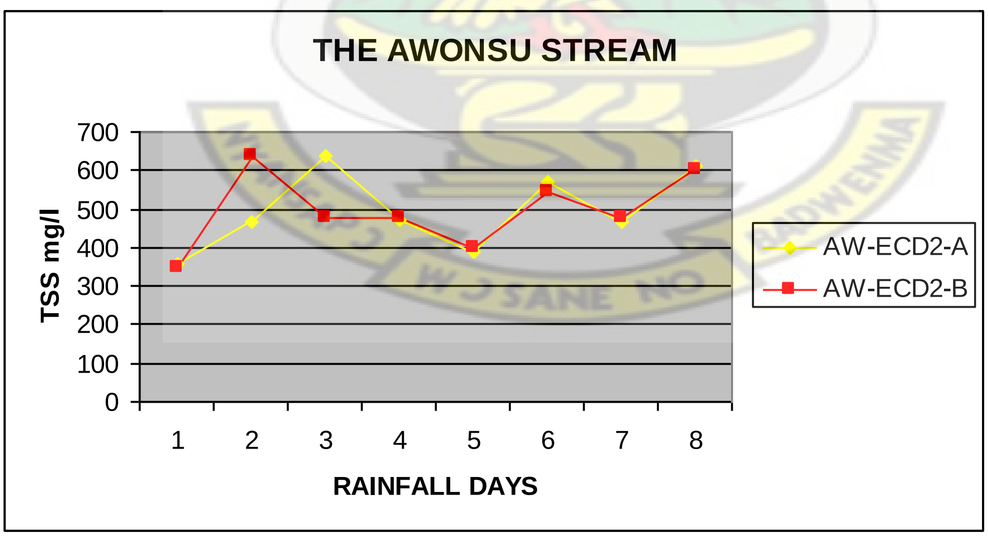

Figure 5. 3:- Graph of TSS Values of Awonso Sampling Points AW-ECD2-A and AW-ECD2-B.

Comparing sample point AW-ECD2-A and AW-ECD2-B it can be seen that although sample point AW-ECD2-B is located within the project area its values are fairly close to that recorded in the upstream point. This suggests that there is little influence of mining activity on the runoff from the area. This can be explained by the fact that there is currently no mining activity ongoing within the catchments at the time of the study. Further more considering the results from the two sampling points in respect of their location and catchment area, sample AW-ECD2-B covers a larger catchment area than sample point AW-ECD2-A. It may therefore be deduced that sediment loads in runoff depend not only on the size of its catchment area but also on the prevailing environmental conditions such as the amount of exposed areas and the intensity of prevailing erosional activity since topographically they are the same for the two.

5.2.1.5 Comparison of Sediments Inflow from Upstream

When the average maximum TSS values of the respective upstream sampling points of Subika, (SK-ECD6-A), Subri (SR-ECD4-A), and the Awonso (AW-ECD2-A) are compared it may be said that the TSS values for the three streams on the average are fairly close. This is evident from Figure 5.4

The upstream sampling points arc points that may be considered as control sampling points as these measure runoff from areas that come from outside the mining area and have seen very little or no constructional activities except for the few farms. These areas are generally highly forested grounds with good vegetation cover with little or no major human activity within their catchments.

This may account for the low TSS values as compared to the other streams and also the closeness of the values of the TSS readings of the runoffs. The closeness of their TSS values could therefore be likened to the same condition prevailing in the respective catchment areas.

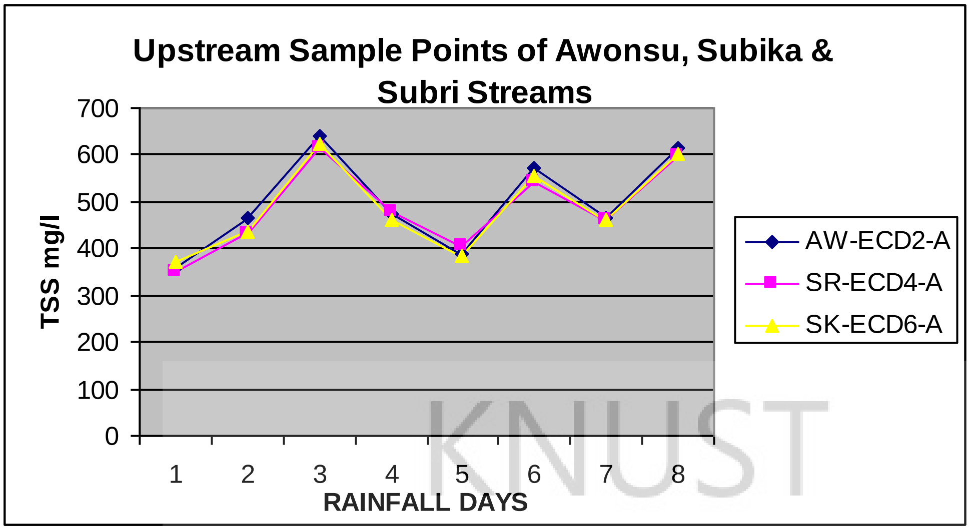

Figure 5. 4:- TSS Plots of Upstream Sampling Points of Subika (SK-ECD6-A), Subri (SR-ECD4-A and Awonsu (AW-ECD2-A)

5.2.1.6 Comparison of TSS Values of Sediment Inflow into the Various ECDs

When the maximum TSS values for each rainy day for the four inlet sampling points of the environmental control dams that is, Subri Sample point SR-ECD4-B, Subika sample point SK-ECD6-B, Awonsu sample point, AW-ECD2-B and the Apensu sampling point AP-ECD3-13 are compared, it is observed that the values of TSS registered in the Subika, Subri and Apensu are all higher than those registered in the Awonsu stream (Figure 5.5).

The TSS value from Apensu sampling point AP-ECD3-B is the highest of all the sampling points for a particular rainy day. This may be attributed to the fact that the Apensu stream takes up run off from the catchment that houses Processing Plants, ROM pad, administrative blocks, various maintenance areas and staff residencies as well as the Apensu waste dumps area. These areas are cleared of virtually all vegetation cover.

Besides, since the administrative area is the core of business, the fleets of cars that ply the area generate a lot of dust and loose material from un-tarred roads and parking sites that can easily be transported into the various channels causing the higher sediment loads in its runoff. Further to this the wide surface area that is virtually cleared of all vegetation allows layers of soil to be easily dislodged or detached from the surface layer as a result of rain splash and runoff activities. Hence the relatively high TSS value from the Apensu stream.

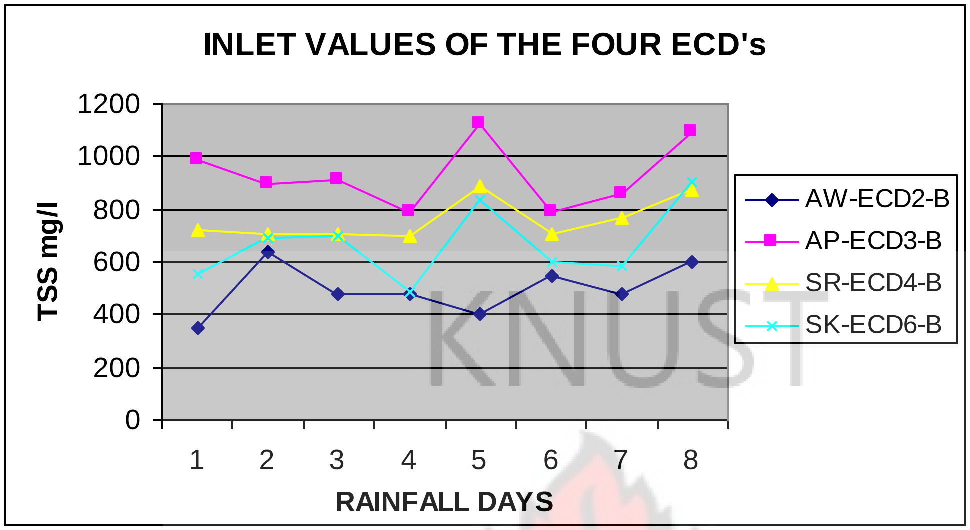

Figure 5. 5:- TSS Plots of ECD Inlet Sampling Points of Subika (SK-ECD6-B), Subri (SR-ECD4-B), Awonsu (AW-ECD2-B) and Apensu (AP-ECD3-B)

In respect of the Subri and Subika sample points, TSS values of the Subri are higher than the Subika. Although the two sampling points are supplied by runoff from ongoing mining pits and active waste dumps within their catchments, the differences in the respective loads can be explained as coming from the differences in the type of waste generated from their respective pits (excavations). The waste generated from the Subika pit is made up of fresh granitic rock with little erodability whereas the waste from the Subri excavation is composed of highly weathered mostly completely oxidized phyllitic rock. The phyllitic rock is generally made up of very fine size clay particle that can easily be transported by water at the least generated runoff compared to the waste generated from fresh granitic rock mass. Therefore the higher sediment loads in the Subri sample SR-ECD4-B than Subika sample SK-ECD6-B could be due to the finer clay size particle of its waste materials.

The TSS values recorded in the Awonsu ECD inlet is the least of the four. This can be explained to be coming from the fact that the catchment area of the Awonsu is yet to experience any major human disturbance and hence the difference. Figure 5.5 is a graph showing the trends for the various streams.

It can therefore be said that clearing vegetation and mining activities have seriously led to a major increase in sediment build up in the Apensu, Subri and Subika catchment areas though it may he said that the environmental control dams are serving as a check to the release of these materials into lower course of the streams.

5.2.1.7 Comparing Upstream Sample Values and ECDs Inlet Sample Values

From Table 5.1 and Table 5.2, the highest TSS values among the streams coming into the mine lease area as against the highest recorded TSS values entering the ECDs for a particular rainy day are as shown in Table 5.3 below.

Table 5. 3: Highest TSS Values Among Upstream points and ECDs Inlet Sample

	Day1 mg/L	Day2 mg/L	Day3 /mg/L	Day4 /mg/L	Day5 mg/L	Day6 /mg/L	Day7 /mg/L	Day8 /mg/L
Max. Upstream Values	370	467	640	477	404	571	465	614
Max. ECDs Inlet Values (ECD3)	984	909	895	789	1122	857	789	1094

The vast difference in the inlet values as compared to those coming from outside the mine area are therefore an indication that the mining activities generate sediments that can affect the water bodies in the area and therefore needs to be controlled.

Calculating the ratio of the upstream sediment loads to that of inlets loads, it was realized that it ranges between 1:1.4 and 1:2.7.

5.3 Discharges from the ECDs

The practice at the ECDs is to hold runoff that are captured in the dam till suspended sediments have settled out to a TSS value of 50 mg/l or below. To meet this objective the TSS readings are taken at each ECD daily at different depths to determine TSS levels at those depths so as to know the depth to which decantation could be done during discharge of captured runoff from the sedimentation dams. For a daily monitoring of the ECDs for a period of 106 continuous days, decantation from the 4 dams took place on 23 occasions/days as shown in Table 5.4.

Table 5. 4: TSS values recorded from the Tano River sampling points

DATE	AW-ECD2-C/mg/l	AP-ECD3-C/mg/l	SR-ECD4-C/mg/I	SK-ECD6-C/mg/l	Tano South/mg/l	Tano North/mg/l
3-Aug-06	N	N	N	20	34	34
4-Aug-06	N	N	N	22	30	31
5-Aug-06	N	N	N	24	28	30
7-Aug-06	N	N	N	26	26	29
10-Aug-06	N	30	N	N	23	28
14-Aug-06	N	48	40	N	11	23
22-Aug-06	N	N	N	10	20	
23-Aug-06	N	N	N	7	15	
19-Oct-06	N	198	N	42	29	
20-Oct-06	N	304	N	40	14	
22-Oct-06	N	N	N	18	12	30
23-Oct-06	N	N	N	20	20	35
25-Oct-06	N	75	54	10	18	20
26-Oct-06	N	70	108	18	37	
27-Oct-06	N	67	40	N	29	
28-Oct-06	N	62	82	20	36	10
29-Oct-06	N	79	75	49	45	27
30-Oct-06	N	37	53	N	70	59
2-Nov-06	N	N	22	N	6	23
3-Nov-06	N	N	35	N	41	40
9-Nov-06	12	27	31	N	21	17
10-Nov-06	18	35	N	N	58	30
13-Nov-06	40	N	N	N	24	29

Note: N means No Discharge

Decantation from ECD2 (AW-ECD2-C) took place on only 3 occasions whilst decantation from the EDC3 (AP-ECD3-C), ECD4 (SR-ECD4-C) and ECD6 (SK-ECD6-C) occurred for 12 days, 10 days and 14 days respectively. TSS readings taken from the outlet points of the various ECDs during this period show recorded values that range between 7 mg/l and 304m g/l, generally about 67% of decantation giving values less than 49 mg/I.

TSS values recorded for ECD2 ranges between 12 mg/l to 40 mg/l whilst that of ECD3, ECD4 and ECD6 are 27 mg/l to 304 mg/l; 22 mg/1 to 108 mg/l and 7 mg/1to 49 mg/1 respectively.

It could be realized from Table 5.4 above that, on certain days within the period of 19th to 30th October 2006, TSS values recorded from ECD3 and ECD4 outlets were above the allowable discharge limit of 50 mg/l. This is because apart from 21st and 24th October, it rained every day: causing a continuous flow of runoff into the dams. Therefore, the runoff into the dams exceeded the dams' holding capacities resulting in spill overs. In effect the TSS values recorded during these periods were not in reality, an intentional decantation from those dams. Ignoring these values therefore, it would be realized that all the TSS values measured from the four streams during decantation are all less than 50gm/1.

5.3 Results from Tano River

The last two columns in Table 5.4 above show TSS values recorded from the Tano River sampling points.

These two sampling points were for the purpose of determining the TSS quality of the Tano River prior to its flow (Tano North sampling point) into the project area and also the level of suspended particle as the river flows off from the project area (Tano south sampling point). The Tano North sampling point which is to the north of the project area was located such that it is located above the confluence of all the streams that drain the project area. On the other hand the second sampling point, Tano South sampling point, was located such that it was below the confluence of the last stream on the downstream of the Tano River that flow through the project area. From the study it was evident that the sampling point to the north of the river (Tano north sampling point) recorded values that range from 10 gm/l to 59 gm/l. The downstream sampling point (Tano south sampling point) registered values that range from 11gm/l to 70gm/l. A plot of the two sample points is as shown in Figure 5.6.

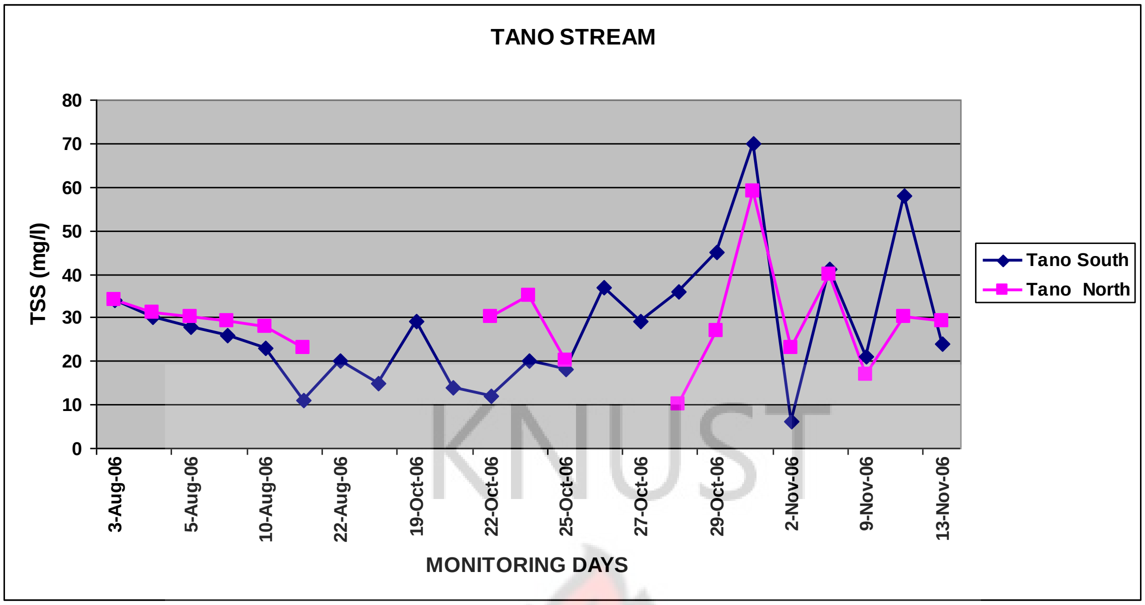

Figure 5. 6:- TSS Values of Tano South and Tano North.

A critical look at Figure 5.6 shows that for most of the observation days the TSS values of the southern sampling point recorded values that were fairly close to those that were recorded in the north sampling point, with the values of the southern point appearing on most occasions to be less than that of the northern values. This could be due to the fact that some of the suspended material probably settled out as the stream advanced downstream. Similarly it suggests that as streams from the mining area empty into the Tano River, it results in an increase in the volume of water and thereby leads to dilution of the amount of suspended solids in the river. This observation therefore implies that the discharges from the project area such as from the ECDs are not adding appreciable particulate loads to the Tano River as they link up with it. Therefore, the lower TSS values recorded at Tano South sampling points confirm that discharges from the mining lease area have lower sediment concentration.

One important high in TSS values of the south sampling points can be observed in the graph that is on the 30th October 2006. Incidentally it is evident that this was the period When ECD3 and ECD4 had exceeded its maximum volume and led to spill over because of the rains experienced at the time.

A second point of importance is the fact that on the 10th November 2006 as seen in Table 5.4, Tano South recorded a value of 58 mg/l whilst Tano North recorded 30 mg/l. The discharges from the ECDs for the period were between l8 mg/1 and 35 mg/l. Considering the TSS values of the discharges from the mining area into the Tano river, it can be said that the effluents from the control dams are not responsible for localized value of the south sampling point (that is comparing a value of 30 mg/1 to 5 8mg/1). Therefore the value 58 mg/I could be due to local activity within the Tano River which is the case when extensive swimming takes place in the river by the locals upstream, prior to the sampling period.

5.5 TSS Levels in Discharges from ECDs and Ghana EPA Standards

The EPA allowable standard for discharge of effluent into the environment or receiving streams is 50 mg/1.From the study it is observed that the levels of TSS in the discharges from the four environmental control dams studied were all below a value of 50 mg/1 at the time of discharges. The maximum sediment loads recorded to have entered the various sedimentation control dams, ECD2, ECD3, ECD4 and ECD6 (Refer to Table 5.2) are 640 mg/l, 1122 mg/l, 894 mg/I and 902 mg/I respectively. Considering these range of sediment loads and assuming a maximum decantation load of 50 mg/I as specified by the EPA, it can be said that the ECDs are able to reduce sediments loads by 92% - 95%; thus 92% by ECD2, 95% by ECD3, 94% by ECD4 and 94% by ECD6.

5.6. The Rate of Sediments Settlement in Runoff

Tables 5.5 and 5.6 show the total suspended solids values of three runoffs A, B and C Collected on three different rainy days from ECD3 and monitored over a period of four days at twelve hour intervals to determine the rate at which the sediments in the runoff would settle. For each sample two readings were taken at each monitoring period. Thus one reading is taken at the surface and the other taken at 1.0 m below the surface. Table 5.5 shows values that were taken at the surface whilst Table 5.6 shows TSS values recorded at one meter depth.

Table 5. 5:- TSS Values (in mg/l) Recorded from Surface of Confined runoffs

ID	0Hr	12Hrs	24Hrs	36Hrs	48Hrs	60Hrs	72Hrs	84Hrs	96Hrs
A	650	134	32	49	14	28	7	22	13
B	856	143	53	58	17	31	16	27	19
C	2010	154	56	63	18	36	16.7	29	22

Table 5. 6:- TSS Values (in mg/l) At 1.0 m Depth of Confined Runoffs

ID	0Hr	12Hrs	24Hrs	36Hrs	48Hrs	60Hrs	72Hrs	84Hrs	96Hrs
A	650	146	60	52	29	34	20	26	24
B	856	156	81	60	30	38	27	28	25
C	2010	170	85	64	31	-42	34	30	2

5.6.1 TSS Values at the Surface

Considering the Table 5.5 it is observed that at the end of the 96 hours (4 Days), TSS readings for samples A, B and C have reduced from 650 mg/1 to 13 mg/l, 856 mg/I to 19 mg/l and 2010 mg/I to 22 mg/1 respectively. A study of the table shows a general trend of reduction in TSS values at each subsequent reading although there are few fluctuations. However, considering the first twelve hours, there is a sharp drop in TSS values from 650 mg/l to 134 mg/l for sample A, from 856 mg/I to 143 mg/l for sample B and from 2010 mg/I to 154 mg/ sample C. These reductions show percentage drop in sediment loads within the period as 77.5% for sample A, 83.3% for sample B and 93.3% for sample C. Based on the results it can be said that within the first twelve hours, the runoffs are able to drop at least 77% of their sediment loads. A plot of the values is shown in Figure 5.7. After the first twelve hour period changes in the subsequent readings are gradual. It is observed in Figure 5.7 that after 38hrs, all the samples have sediments loads less than 50 gm/l.

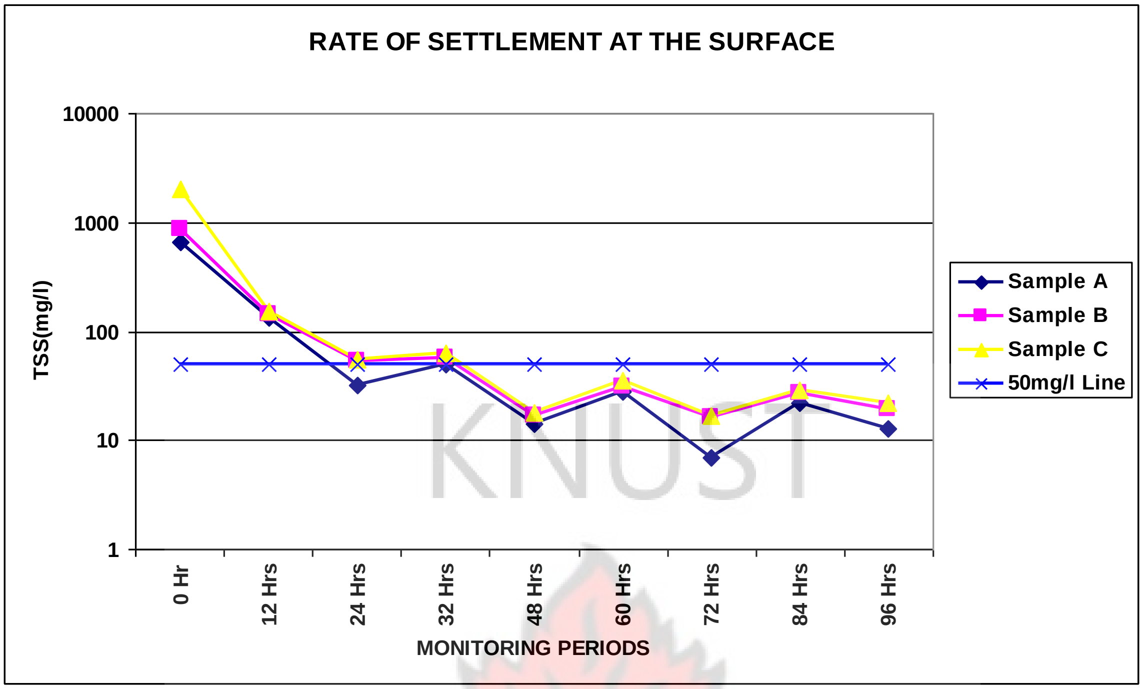

Figure 5. 7:-Graph of the TSS Values at the Surface

5.6.1 TSS Values at 1m below the Surface

Considering Table 5.6 it is observed that the samples at l m below the surface followed the same trend as the results observed from the surface. Sample A had values reduced from 650 mg/l to 24 mg/1 whiles sample B and C has values that range from 856 mg/1 to 25 mg/l and 2010 mg/I to 26 mg/l respectively. The Figure 5.8 shows the graphical representation of the behavior of the samples within the period. Within the first twelve hours TSS values reduced from 650 mg/l to 146 mg/l in sample A, 850 mg/l to156 mg/1 in sample B and 2010 mg/l to 170 mg/l in sample C representing percentage drops in sediment loads within the period as 77.5%, 81.8% and 91.5% respectively. Beyond the twelve hours the change in the TSS values tends to be gradual. From the graph (Figure. 5.8), at around 42 hrs all the samples, A, B and C have TSS values at 50 mg/l and below.

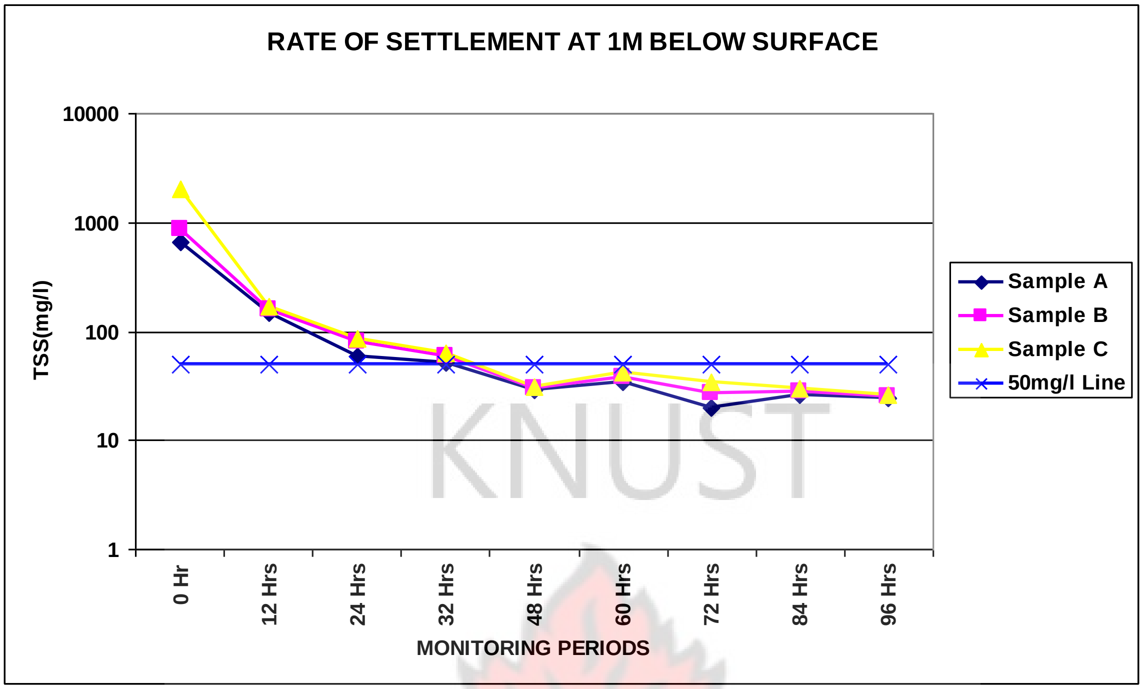

Figure 5. 8:- Graph of the TSS Values at 1m Below the Surface

5.6.3 Comparing TSS Values at the Surface and 1m below Surface

Comparing the results in Tables 5.5 and 5.8, it is observed that although the results are very close, yet those observed from lm below the surface are always higher than their corresponding values at the surface. The comparatively high TSS values at lower depth than at the surface show that sediment loads in runoffs are not uniformly distributed. This observation therefore indicates that at depth, TSS values are always higher than at the surface.

At the surface, the runoffs attained a value of 50 mg/l after about 38 hrs whilst at one meter depth it attained the 50 mg/I value after 42 hrs. The two results when combined suggest that after 42 hours the top 1 meter zone of runoff reduce its sediment loads to 50 mg/l. It can therefore be concluded from the study that when runoff gets into the sedimentation dams, after 42 hours, the top 1 meter of the runoff would reduce its sediment load to 50 mg/l and can therefore be decanted.

5.7 Size Fractions Analyses

The Tables 5.7 and 5.8 show the results of size fraction analyses on the samples collected from the environmental control dams. Samples D2 and D4 are samples taken from ECDs 2 and 4 whilst samples D3A and D3B are from ECD3 and D6A and D6B are from ECD6. Each sample was sieved into eight different size fractions. These are, +420µm; +210µm, +149µm; +105µm, +74µm, +53µm, 144µm and -44µm.

Table 5. 7:- Sieved Fractions of the Samples

Source	Sample ID	Weight/mg	>420µm	>210µm	>149µm	>105µm	>74µm	>53µm	>44µm	<44µm
ECD6	D6A	368	40.15	49.22	41.25	36.05	27.02	12.22	0.16	161.19
ECD6	D6B	500	59.75	74.49	50.76	40.75	34.39	18.25	3.74	217.87
ECD2	D2	500	2.62	2.37	1.47	1.68	2.23	3.01	0.94	486.68
ECD4	D4	486	0.59	0.45	0.49	0.48	0.73	1.71	0.31	481.24
ECD3	D3A	500	0.88	0.38	0.19	0.19	0.40	1.60	0.36	496.00
ECD3	D3B	500	0.71	0.34	0.17	0.18	0.35	0.10	0.36	497.79

Table 5. 8:- Size Fraction Distribution (µm %) of the Samples

Source	Sample ID	>420µm	>210µm	>149µm	>105µm	>74µm	>53µm	>44µm	<44µm
ECD6	D6A	10.91	13.38	11.21	9.79	7.34	3.32	0.04	43.8
ECD6	D6B	11.95	14.9	10.15	8.15	6.88	3.65	0.75	43.57
ECD2	D2	0.52	0.47	0.29	0.34	0.45	0.6	0.19	97.14
ECD4	D4	0.12	0.09	0.1	0.1	0.15	0.35	0.06	99.02
ECD3	D3A	0.18	0.08	0.04	0.04	0.08	0.32	0.07	99.2
ECD3	D3B	0.14	0.07	0.03	0.04	0.07	0.02	0.07	99.56

A study of the results as presented in Tables 5.7 and 5.8 show that for all the samples, the <44µm size fractions form the greater portion of each sample whilst <44µm x <53µm size fractions are the least with the exception of sample D3B. The percentage composition of the <44µm size fraction ranges from 43.6% to 99.6% and that of >44µm x <53µm size fractions ranges from 0.04% to 0.75%.

For the other size fractions, +420µm, +210µm,+149µm, +105µm, +74µm, and +53µm, sample D6A and D6B have a fair amount of these size fractions within its samples mainly ranging between 3.3% to 14.9% whilst for samples D2, D4, D3A and D313 the percentage composition of these size fractions are all less than 1%.

A graph of the percentage compositions of the various size fractions as shown in Figure 5.9 indicates two sets of correlations. One set of correlation exist between samples D6A and D6B and the second group of correlation exist among the four samples D3A, D3B, D2 and D4. The first correlation is for samples from ECD6, whose sediments are made up of fairly amount of large size sediments.

The large size fractions of sediments in ECD6 could be due to the fact that besides the sediments carried off by the runoff, water from the Subika pit is pumped into ECD6. Since the pumping action exerts force greater than the normal runoff, it might be able to carry larger size fractions to the sedimentation dam. Hence the larger size fraction of sediments in ECD6 than the other ECDs.

The perfect correlation among samples D3A, D3B, D2and D4 which are sediments collected from ECD3, ECD2 and ECD4 respectively, therefore indicates that the particle sizes of sediments transported into the ECDs from the various catchments are similar because their catchments are underlain by the same rock units.

It would be realized that samples from ECD6 (sample D6A and D6B) have larger size fractions in their samples as compared to those from the other ECDs. This could be the reason why the samples from ECD6 could not correlate with those from the other ECDs.

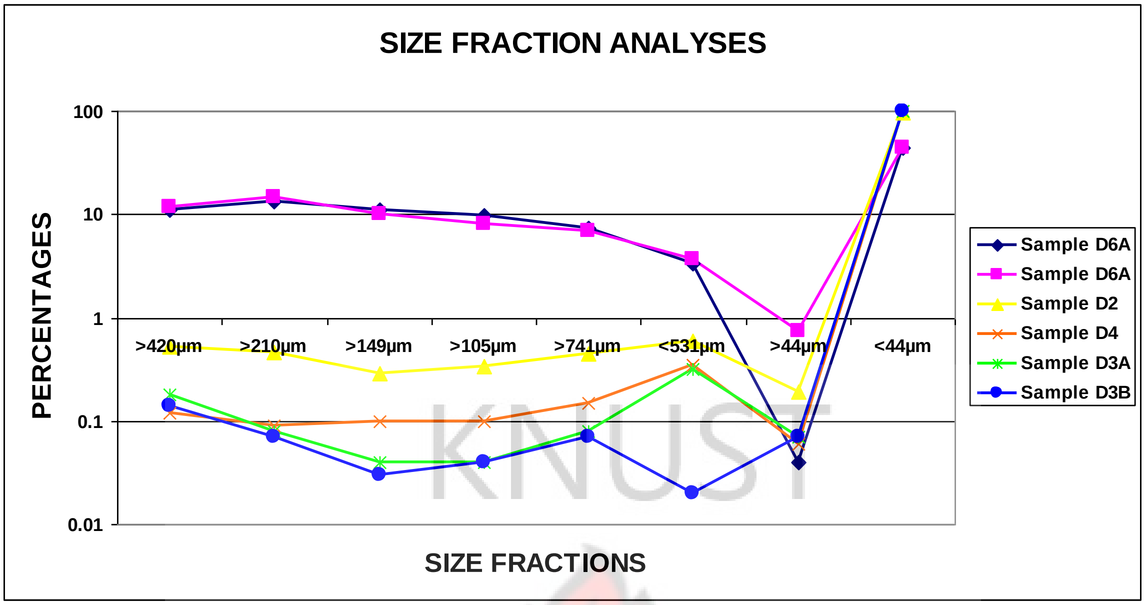

Figure 5. 9:- Percentage Composition of the Various Size Fractions

5.8 An Assessment of Practices to Control Runoff in the Ahafo Mine

The existing vegetation in the project area prior to the development of the mine consist of secondary forest, woodland-grassland with a high amount of elephant grass as observed in the adjacent lands of the project area. These grasses are naturally good checks on erosion in the area as they also act as sediment traps.

The development and operation of the mine in the study area has necessitated the clearance of large tracts of land. This activity has exposed large areas of land and has disturbed the general ecological balance of the site. Forested areas, open spaces, and other naturally vegetated areas have been permanently lost through clearing. At the mining sites large areas have been cleared for waste dumps and the excavation of mining pits and haulage tracts (Figure 5.10). These have resulted in the generation of large volumes of loose soils that can be easily carried by wind and rain as evidences on Figure 5.11.

Figure 5. 10- Cleared and Excavated Portion of the Apensu Pit Area.

Figure 5. 11:- One of the Dump site of Excavations from the Apensu Pit

Secondly the loss of ground cover coupled with grading, smoothing, and compaction of the land surfaces in these areas have greatly decreased surface water infiltration, and has resulted in increased sediment loads in storm water runoff and an acceleration of erosion activities. Groundtruthing of streams in the project area and on adjacent lands visually show an increase in sediment runoffs from project areas into streams and other water bodies. Evidently appreciable amounts of sediments are eroded from the mine area as indicated by the TSS values registered at the inlet points of the various ECDs. In the absence of a mitigating measure it would be expected that these sediments would be carried down the lower course of the various rivers and finally into the Tano River.

In order to reduce the continuous tearing and washing away of various soil layers a number of practices have been adopted by the mining company to ensure that the level of sediments in flight are greatly reduced before leaving the mine area into the receiving Tano River. These include the use of ECDs, check dams, seeding and the use of diversion Channels.

5.8.1 Terrain Evaluation of ECDs Sites

The sedimentation dams as shown in Figure 5.12 are linked to channel/side drains which serve to direct the runoffs into the sedimentation basins.

Figure 5. 12: Environmental Control Dams Six (ECD6)

The ability of the ECDs to efficiently capture and mitigate eroded material from the project sites depends on the proper sitting of the dams and the creations or the development of channels that will ensure that eroded material are transported into a prescribed ECD. The study of topographical maps and aerial photos on the project area coupled with ground-truthing enabled the study to evaluate the terrain suitability for the sitting of the ECDs.

An evaluation of the various ECD sites indicates that topographically the project area is located in gentle undulating lowland that converts into a flat terrain eastwards as one approaches the plains of the Tano River. Generally the gentle undulating grounds with the few elevated hills rarely exceeding 300 m will be expected to erode soil sediments and get deposited on the fairly flat section of the project area some of which are potentially swampy.

In the ground-truthing it was evident that the various ECDs on the margins of the gentle undulating fairly low lands are linked with drainage channels that are well developed to channel drainage from the project area into the ECDs. These locations were observed to be safe location relative to the flood plains of the Tano River flood plains where physical evidence indicates they could be destroyed in serious floods or when the Tano is in flood.

Of critically importance for the direction of run-off into the control dams are the side drains. There are net works of drainage channels constructed at various locations which ensure that various eroded material from the project area end up into the ECDs. In some locations these drains are lined with sorted rock materials derived from the mine pit and have rock cheek dams at intervals as shown on Figure 5.13. The essence of the rock lining is to reduce the erosion of the walls of the drains. In some locations these drains are planted with vertiver grass to filter the drain sediments.

Figure 5. 13:- One of the Channels Created to Direct Runoffs from the Administration Area, Camp A and Plant Site to Sedimentation Basin ECD3

5.8.2 Assessment of the Application of Check Dams

Check dams as shown on Figure 5.14 are built to reduce water flow to non-erosive velocities and to allow relatively large-sized particles to settle out of the water and be deposited or trapped upstream of the check dam. In the ground-truthing of the area it was evident that check dams are one of the major sediment control practices in the study area. These check dams are made from fragmented rocks of granitoids derived from the Subika pit.

Figure 5. 14:- Newly Made Check Dams on Camp A – Ntotoroso Road to Reduce Velocity of Runoffs and Aid Sedimentation.

There was however a problem with the manner in which the system was being practiced. The first issue had to do with the arrangement of' the check dams along the ditches. Normally checked dams are used in series and should be located or spaced so that the toe of the upstream check dam is at the same elevation as the lowest point of the top of the downstream check dam. Therefore the steeper the slope the closer the check dams are expected to be. This does not seem to be the case in most of the sites visited. Secondly, it is expected that for the proper functioning of the check dams as sediment trappers when larger size fractions of stones are used smaller size fractions of stones are placed immediately upstream of the check dams to filter sediments. This is not the case for most of the check dams. Thirdly, in the cleaning of depositional sediments, collected sediments are not taken away from the sites but are only collected and deposited about two meters from their original position. The end result is that these materials are washed back into the channels immediately during rainfall. This practice therefore renders the check dams ineffective in respect of trapping fresh sediments that are being carried down from upstream.

5.8.3 Diversion Channels

Field observations identified a number of diversion channels which have been put in to intercept runoffs which would have otherwise flowed into undeserved areas to create erosional and sedimentation problems. The slopes of most of these channels were observed to be sufficient to generate adequate runoff velocity.

5.8.4 Mulching and Seeding of sites

Mulching essentially involves the placing of materials on the soil to protect it from erosion and to provide a proper environment for the germination and growth of vegetation. Waste dump sites are areas where the company undertakes major revegetation exercises to reduce the effectiveness of runoff in conveying these loosely deposited materials into receiving waters. To achieve this, such sites are mulched by the use of locally generated wood fiber mulch blankets referred to as jute mats which serve as erosional control blankets as shown on Figure 5.15. These jute mats are spread over the entire surface area before seeding.

Figure 5. 15:- Covering Topsoil from the Subika Pit with Locally Made Jute Mat.

The jute mat serves to insulate the soil from erosive power of runoffs, insulates the soil from intense heat, and conserves moisture by limiting evaporation. By their nature they also enrich the soil as they decay. These blanket-covered grounds are then seeded and regularly watered by the use of a hydro seeder vehicle.

This study found these erosional control blankets as excellent materials for the steep slops associated with the waste dumps and for areas that show concentrated flows. It was observed that the practice seriously reduced the erosive potential of runoff in such areas. The company has adopted the practice of planting grasses at areas which have been laid bare as a result of the constructional activities as evidenced by the activities shown on Figure 5.16. Grasses such as Vertiva are usually planted in such areas. The grass serves to reduce the impact of rain on the soil thereby reducing the potential of soil particles being carried away. It also serves as sediment traps preventing suspended particles from being carried away. The study found this to be very effective in checking erosion of sediments in the project area.

Figure 5. 16:- Newmont Workers Planting Grasses to Prevent Erosion Around a Sedimentation Dam

In view of these practices the volume of materials that would have otherwise been transported into the various sediment basins are greatly reduced.

CHAPTER SIX:- CONCLUSION AND RECOMMENDATIONS

From the study conducted in the project area, the following conclusions have been drawn:

1. Surface water runoff from the mine are effectively captured in the various sedimentation dams (ECDs) that have been built by the mine
2. The ECDs in normal rainy days are performing efficiently as they are able to reduce suspended solids in runoff by ninety-two to ninety-five percent (92% to 95%) of the original total suspended solids value.
3. In terms of total suspended solids the activities of the mine is not threatening the Tano River as the mine's discharges to the Tano River are within environmental acceptable standards of the EPA.
4. One adverse finding of importance is the fact that the volumes of the ECDs particularly ECD3 and ECD4 had been underestimated and are not sufficiently large enough to handle the large volumes of runoffs from the mine area in certain times of the year. This has resulted in the overflow of runoff captured in the sedimentation dams leading to the release of' discharges that are above the recommended EPA limits into the Tano River. It is recommended that the ECDs are enlarged to avoid the situation of overflows.
5. It is evident that a most of sediments observed in runoff come from the catchments area of ECD3. This could not be from the waste dumps and the mining pit alone but from the large open grounds due to the placement of the process plant, administration block etc within its catchments. Since the soil types in the area is easily erodible as experienced by the results of ECD3, it is recommended that open areas within the plant and administrative areas be re-vegetated or cemented to reduce rain splash erosion.
6. The sizes of the stones used for the construction of the check dams and the ordering of the check dams do not meet the best practice methodology. Checked dams are used in series and should be located or spaced so that the toe of the upstream check dam is at the same elevation as the lowest point of the top of the downstream check dam. Therefore the steeper the slope the closer the check dams

is expected to be. The removal and dumping of trapped sediments in the vicinity of the check dams should be reviewed as these sediments are immediately washed back into stream with the least rainfall. To make the mine's erosion and sedimentation Control measures more effective, it is also recommended that the size of the boulders should be graded as well as sticking to the proper orderly arrangement of check dams. All sediments collected from check dam sites should be disposed off properly.

7. About 97% to 99.5% of sediment loads in the runoffs are of size fractions less than 44 microns (<44um).
8. When runoff gets into the sedimentation dams, it would be able to drop its sediments loads to the allowable discharge limit of 50 mg/I within a period of forty two (42) hours and the top one meter level can be decanted.
9. In some of the ECDs there is some level of leakage attributed to the stone baskets used in the construction of some sections of the control dams and suggests that the stone baskets construction should be improved to curtail such leakages.

In conclusion, the study revealed that in general, the sedimentation controls practices of the mine are effective and environmentally friendly. I therefore recommend this model to the other mines.

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APPENDICES

APPENDIX 1: Total Suspended Solids (TSS) data

APPENDIX 2: Environmental Control Dam (ECD) TSS monitoring records

APPENDIX 3: GPS coordinate points of the ECDs