KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

COLLEGE OF ENGINEERING

DEPARTMENT OF MATERIALS ENGINEERING

EVALUATION OF LAND RECLAMATION WITH MPTs AT ANGLOGOLD ASHANTI: A CHRONOSEQUENCE APPROACH.

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(BSC. NATURAL RESOURCES MANAGEMENT)

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ABSTRACT

Mining generally destabilizes environments and the entire ecosystem. To ensure that mining activities co-exist harmoniously with the human and physical environment, guidelines have been developed which all mining companies are obliged to comply. Reclamation is a desirable and necessary remedy to return the mined areas to an acceptable environmental condition whether for resumption of the former land use or for a new use. The research was carried out at Anglogold Ashanti, Obuasi Mines Ltd to evaluate land reclamation with MPTs. The study was in two parts: a sociological survey and a field evaluation. The survey was conducted in 3 communities namely: Binsere, Sansu and Kunka using semi-structured questionnaires, focus group discussions and personal observations. Eighty – one respondents were interviewed comprising of environmental experts of the mining company, the Community Relation Officer, Chiefs/Opinion leaders and selected households. The field experiment was carried out on four reclaimed sites of the ages of 3, 6, 9 and 12 years and a cocoa farm which has never been mined as the control. Soil samples were taken at three depths of 0 – 20, 20 - 40 and 40 – 60 cm from the four reclaimed sites and the control with a hand held auger and analysed for soil fertility parameters and selected heavy metal contaminants. The study revealed high community participation in the land reclamation exercise ranging from weed and fire control, supply of local seeds, seedling establishment and maintenance of reclaimed sites. Multipurpose trees: *Gmelina spp, Cedrella odorata, Cassia siamea, Cassia mangium, Anegreila robusta, Daniella ogea, Mansonia and Terminalia superba, Terminalia ivorensis, Khaya ivorensis, Triplochitin scleroxylon* and *Entandrophragma utile* were used in reclaiming mined out sites. The company uses the following reclamation processes and procedures to rehabilitate the disturbed sites: earthworks/slope battering, spreading of oxide material, spreading of top soil, construction of crest drains and broadcasting of cover crops to control run-off and erosion, tree planting and field maintenance. It was observed that land reclamation had significant effect on the pH of the soil. The 12 year old reclaimed site recorded the highest percentage base saturation of 87.9% with the lowest of 61.8% recorded on the 9 year reclaimed site. Soil total nitrogen and SOC content were higher in the top 0 – 20 cm depth than the 20 – 40 and 40 – 60 cm depth. Exchangeable acidity ranged from 0.71 to 1.08. Soil Arsenic content was highest in the 3 year old site (9.44 $mgkg^{-1}$) and least in the control site (0.48 $mgkg^{-1}$). Highest lead concentration of 1.45 $mgkg^{-1}$ was recorded on the 3 year old site and the lowest of 0.67 $mgkg^{-1}$on the control site. Copper was highest in the 3 year reclaimed site and the depth of 0 – 20 cm also recorded the highest value. The highest micronutrients were recorded on the 3 year old reclaimed site thus there was drop in the soil micronutrients with increase in years of reclamation.

DECLARATION

I hereby declare that except for references to other people's research which have been duly cited, this thesis submitted to School of Graduate Studies, Kwame Nkrumah University of Science and Technology, Kumasi for the degree of Master of Science in Environmental Resources Management, is my own investigation.

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CHAPTER ONE

1.0 Background to the Study

Land is one of the most important resources on which human beings depend. The rate of consumption of mineral resources is continuously increasing with the advancement of science and technology, economic development, industrial expansion, acceleration of urbanization and growth of population (Sheoran, 2008).

Mining is traditionally regarded as the world's oldest and the most important activity after agriculture. Throughout history, mining activities have made tremendous and significant contributions to the world's civilization. The United Nations Environment Programme (UNEP) explains mining as a process that begins with exploration for and discovery of mineral deposits and continues through ore extraction and processing to the closure and rehabilitation of mined-out sites (UNEP, 2000). It is also defined as the process of extracting coal or other minerals like gold, bauxite and diamond from underground (New Mont, 2007).

In terms of benefits, the mining sector is undoubtedly one of the most important sources of foreign exchange particularly in many sub-Saharan African countries. Mining has a long history in Ghana, for instance Anglo Gold Ashanti Company Limited at Obuasi is on record to have mined gold for more than hundred years (New Mont, 2007). Mining has played and continues to play a very important role in the economy of Ghana in terms of export earnings. For instance in September 2000, the country realized US$400 million within six months, by 2002 mining accounted for 25% of GDP and in 2005 contributed 34% of the total national income. Also in 2007, export of minerals and metals made up 43% of Ghana's total export revenue having produced 83.6 tonnes of gold alone (Adoboe, 2010). Mining also employs about 115394 workers (Ghana Statistical Service, 2012). Most of these earning were realized form surface mining, which became pronounced in the 1990s (Gyima, 2004).

However, all these benefits have been offset by considerable negative impacts on the environment and on the health and safety of mine workers and mining communities. Surface mining is perhaps the greatest agent of land destruction, utilizing over 13% out of the 240,000 km^2 of the remaining forest in Ghana for mining activities (Awotwi, 2003). In the early 1990s, the government of Ghana promulgated the surface mining operations law as a way of boosting the economy. The legalization of surface mining, which is relatively less expensive to operate, attracted small, medium and large-scale foreign mining companies into the country. Unlike deep cast mining, surface mining is destructive and environmentally `unfriendly as flora, fauna and associated top soil are removed prior to extraction of the mineral.

The methods employed in the extraction and the chemicals used for processing also pollute soil, water bodies and negatively affect human health. The top soil especially gets seriously damaged during extraction (Sheoran, 2008). Where mining takes place, the land is usually cleared of all vegetation, the landscape drastically altered and the ecosystem totally disrupted. If inappropriately managed, it can have significant off – site impacts particularly from the discharge of drainage contaminated with sediments, chemicals, metals or altered acidity. The operations can also introduce pests, predators and diseases into natural ecosystems and can also open up isolated areas to further human – induced disturbances (Elliot *et al*., 1996). It has been widely recognized since the late 20th century that reclamation is desirable. The necessary remedy to return the mined areas to an acceptable environmental condition whether for resumption of the former land use, for a new use (Redgwell, 1992), or to allow such lands to achieve their optimum economic value as much as possible (Bastida, 2002). In addition, reclamation is generally considered as an on - going programme because of progressively growing environmental effects as mining evolves through the different stages of development (Walde, 1993). According to Lamb (2001), reclamation is widely used to refer to re –

vegetation of highly degraded site such as mined or salt-affected lands. It aims to recover productivity of a degraded site mostly using exotic tree species. The original biodiversity is not recovered although the protective function and many of the ecological services may be re-established. According to Tetteh (2010), some of the reclamation processes and procedures used to rehabilitate the disturbed sites at Anglogold Iduapriem, Tarkwa mine are: earthworks/slope battering, spreading of oxide material, spreading of top soil, construction of crest drains and broadcasting of cover crops to control run-off and erosion, tree planting and field maintenance.

Mining is a temporary use of land and mine land reclamation is clearly justified from the perspective of sustainable development. Thus, it has become important part of the sustainable development strategy in many countries (Gao *et al*., 1998).

Currently, most mining companies employ various reclamation techniques to enhance conservation values of degraded sites in anticipation of returning some pre-disturbance functions. It has therefore become necessary for governments, regulatory agencies, local communities and the industry itself to adopt strategies attributing landscape, flora and fauna properties to ensuring the functionality of reclaimed ecosystems (Elliot *et al*., 1996). Central to the process of sustainability of reclaimed sites is the integration of socioeconomic and ecological values of communities into mine design, planning and extraction consistent with the desired end used objectives.

These developments have made it imperative for mining companies to undertake rehabilitation activities as part of their mine closure activities. In view of these effects, mining companies are required by law to enter into agreement with the Environmental Protection Agency (EPA) to document and to commit them to adhere to environmental management responsibilities.

Legislative Instrument 1652 of 1990 and Act 490 of 1994 commit all mining companies to register and describe the impact of their activities on the environment and how it will be mitigated.

In addition, the company is obliged to pay a reclamation bond to the Environmental Protection Agency. This is a security or guarantee which could be used to rehabilitate a mining site in case a company fails to honour this arduous obligation. Mining licenses are granted only after a company had fully complied with these requirements.

Although these regulatory bodies conduct audits and checks to ensure that the rehabilitation is done according to their specifications, the questions is, are these rehabilitation practices effective in terms of land suitability for agriculture and accessibility of lands for other land users? It is therefore important to assess the potential of the rehabilitated areas in relation to the uses they could offer to the communities.

1.1 Problem Statement

Many mining companies do not fully comply with community and environmental requirement prescribed by the Mining and Mineral guidelines. The non-adherence to the guidelines results in soil degradation, water and air pollution, unemployment, poverty as well as social unrest in the adjacent communities. Though mining has a lot of advantages, it also comes along with associated problems dominant among them being the loss of land to the local communities. Land that is used for farming is taken over by mining companies thus reducing land available for the local people. Mining companies also try to address these problems by rehabilitating the mined lands. However, the rehabilitation practices used by these mining companies are not clearly established. The main focus of the mining company is to restore disturbed lands into safe, stable and sustaining condition without any adverse impact to community. The success of the rehabilitation must be confirmed by the regulatory agencies that prescribes the modalities for completion. Anglogold Ashanti, Obuasi Mines had adopted some processes in reclaiming the disturbed sites but how early are these lands reclaimed before making it available to the community?

1.2 Justification

Mining inevitably causes alterations to the environment which can never be restored to its original status. Consequently, mining may culminate in the reduction of fertile lands for farming in the area with the resultant food shortages. The pits created in the course of mineral prospecting posed a great danger and acted as death traps to people and fauna in the vicinity. The medium and small open pits collect rain water during precipitation predisposing the surrounding community to high incidence of malaria and other waterborne diseases. The degraded lands are bare and devoid of vegetation and in most cases provided a corridor that accelerated windstorm momentum with subsequent erosion.

Notwithstanding the effectiveness of methods for prospecting and processing, a sizeable amount of poisonous chemicals used for gold processing and discharged into contained facilities occasionally seeps to pollute soil and nearby water bodies. Frequent demonstration and agitation about cyanide spillage and other environmental degradation calls for an assessment of the entire process so that guidelines could be recommended for such activities in future. However, if the best rehabilitation practices are carried out after life of the mine, the local community can benefit immensely from the land. Against this background, research that seeks to assess the improvement in fertility of the land and reduction of heavy metal contaminants after reclamation will be beneficial to the local community and also enhance management decisions.

1.3 Aim and Objectives

This study is based on the hypothesis that, the longer the number of years of trees on the reclaimed land, the higher the soil fertility status. The main objective of this study is to evaluate land reclamation with MPTs at Anglogold Ashanti, Obuasi Mines.

The specific objectives are:

i To identify reclamation practices adopted in AngloGold Ashanti mine Ltd, Obuasi.

ii, To determine the effect of reclamation on soil fertility indicators namely Nitrogen, Phosphorus, Potassium and Soil Organic Carbon.

iii To determine the effect of reclamation on some soil micro nutrients: As, Fe, Pb and Cu.

CHAPTER TWO

LITERATURE REVIEW

2.1 MINING AND METALLURGIC HISTORY OF THE OBUASI MINE

Gold has been mined in the Obuasi area for over a century. The gold was discovered and worked mechanically from alluvium and friable quartz of reefs long before the arrival of Europeans in 1895 (Kumi, 1998). Early mining was from quartz vein outcrops on the surface, which were later accessed by adits and shafts. The first shaft was sunk in 1905 (Ayensu, 1996). This method of mining was changed to conventional cut-and-fill in stopes through sub-level caving in 1969 and then to full-scale mechanisation in 1986. The transformations greatly increased the extraction of ore tonnages (Anon, 2002). Waste generated during the process of mining development is used as stope back-fills, thus limiting fresh underground waste rock from being exposed entirely to the surface conditions.

Open pit activities and major re-treatment of old tailings around the Pompora Treatment Plant (PTP) area evolved massively in the 1980s (Anon 1992). From 1947-1992, sulphide pretreatment was solely by pyro-metallurgy, which gradually came to a halt in 2000. Pyrometallurgical pre-treatment method in the extraction of gold from sulphide is highly diversified and takes advantage of the relative abundance of iron in the ore. Iron (II) compounds are oxidised to iron (III), which is a potential impurity, and the application of lime (as neutraliser) enhances the process in a carbothermal reaction that proceeds at a relatively low temperature (Rankins, 1987). Sulphur oxides to sulphur dioxide, and then hydrolyses in the presence of water to soluble sulphates, while arsenic (III) oxidises to arsenic (V). The sulphate precipitates as stable solids of iron (III) and arsenic (V) prior to disposal (Marsden, 1992).

Hydrometallurgical pre-treatment involving the use of natural bacteria, and used to catalyse mineral oxidation reaction was first introduced in 1992, and gradually developed to full capacity in 2000. Under hydrometallurgy, Thio- and ferro-oxidan thiobacilli, at a set of temperature-pH conditions, oxidise sulphur and iron species to break down sulphides

(Marsden, 1992). The principal mineral extraction method is by the autoclave-carbon in leach (CIL) electro-winning process. An Oxide Treatment Plant (OTP) was installed for the treatment of oxide ore, a Heap Leach Plant (HLP) treated low-grade sulphide, while Tailings Treatment Plant (TTP) was installed for tailings reclamation.

2.2 The mining industry of Ghana

In Ghana gold continuous to be the main focus of Ghana's mining industry although the country possesses other mineral reserves which include bauxite, diamond and manganese (EIU, 1999). Ghana is Africa's second largest gold producer and has been the leading exporter since the 6th century (Morris, 1996; Grubaugh, 2002). The mineral industry has been the leading recipient of foreign direct investments (Boocock, 2002).

Mining activities dates as far back as the 5th century as the main indigenous economic endeavors in Ghana (Grubaugh, 2002). Just before independence however, Africa's share by value of world mining output declined steadily from 23% to 10% as a result of poor policies, political interference, poor investment climates, weak institutions, inadequate indigenous technical and processional manpower, as well as poor infrastructures (Allaoua and Atkin, 1993; Quashie, 1996).

Governments in many African countries including Ghana were consequently stressed with finance in fuelling the economic potential of the industry and no new mine was opened in

Ghana over the past four decades until 1980 (Aryee, 2001).To remedy the situation, Ghana's mineral industry became state controlled immediately after independence to prevent mine closure, protect employment, increase state revenue as well as access the foreign currency generated from the mines (Tsikata, 1997).

Aside technological innovations, specific mineral and mining legislations had been promulgated in resuscitating the financial and institutional framework of the industry (Akabzaa and Darimani, 2001). The policy reforms bordering on tax breaks, tax exemption, labor policy, assets transfer, personal remittance quota, as well as reduction of imports duties had been vigorously effected (Campbell, 2003).

The implementation of these reforms had impacted positively on investment and production in the sector, attracting huge Foreign Direct Investment (FDI) in Ghana (Pigato, 2001). In 1999, a total of 19 operating companies and 128 local and foreign companies with exploration licenses were registered in Ghana (Coakley, 1999). Productivity has subsequently increased steadily in Ghana over the past decade. The sector's contribution for instance, to the national Gross Domestic Products grew progressively from 15.6%, through 27% to 46% in 1986, 1990 and 1995 respectively (Minerals Commission, 2000). Gold production experienced the most rapid growth accounting for over 2.5 million ounces in 1999 alone. Although the sector contributes to the socio economic development in the country, the reputation of the industry had been slipping over the past decade (Boateng, 1997). Public concern had over the years centered on health, safety, changes in non-renewable natural resources, habitat of flora, fauna, topography, hydrology as well as the stability of the landscapes resulting from the activities of the industries (Mulligan *et al.*, 1999). Reported cases of cyanide spillage into various water bodies including Angonaban in 1996 and Huni in 2001 streams, increased land use conflicts as well as the liquidation and closure of Bonte mines and its implications in March, 2004 are some of the developments that had created bad legacy for the industry (Ayeboafo, 2005). These negative developments had necessitated the establishment of various legislative instruments to ensure that natural resources in the mining concessions and the local communities are well protected. The implementation of Environmental Management Plan (EMP) during mining operation encourages self regulation, compliance and the development of practical approach to environmental legislation and impact prevention (Acquah, 1995).

In Ghana as in many countries, the EPA Act (Act 490) and the LI (1652) contain provisions for mandatory environmental management plan in all undertakings. Companies are required by law to submit an EMP within one or every three years for a new and already existing undertaking respectively, again, proponents or companies whose activities are covered by EMP or Environmental Impact Statement (EIS) are also expected to submit annual environmental report, as well as copies of audits undertaken to the Environmental Protection Agency of Ghana for auditing. Although, the audit reports are unavailable to the public under the present legislation, it demonstrates companies' compliance with sound environmental protocols and also improves relations with regulators, neighbours and employees (Acquah, 1995). As a means of promoting self regulation and good environmental stewardship, the chamber of mines, a non-governmental mining advisory council has been created in Ghana to educate the public on mining laws and to promote the welfare of members.

2.3 SURFACE MINING AND ITS ENVIRONMENTAL IMPACTS

The impact of the mining industry in the environment has been a public concern following the growing appreciation of the natural environment and the possible harmful effects that the industry's activities can cause. Although the activities of the mining industry occupy a relatively small part of the land surface, the scale and significance of environmental impacts had been more severe than other disturbances of the earth (Danielson and Lagos, 2001). Interestingly, environmental impacts occur in all the phases of mine development (Farell and Kratzing, 1996).

The nature and extent of impacts can range from minimal to significant depending on various factors ranging from the nature of ore, type of technology, extraction methods and the sensitivity of the local environment to the mining operation. Mining is responsible for the destruction of fauna and flora habitats, changes in topography, hydrology and landscape stability (Danielson and Lagos, 2001). In the absence of lay down environmental regulations, mining activities can induce water and wind erosions of non stabilized waste rocks, tailing dams, air and water pollution, predation, pest and disease infestation (Knight, 1998).

In addition to waste management issues, mines also oppose environmental and social challenges due to potential disruptions to ecosystems and local communities. Mining requires access to land and other natural resources which have the tendency to compete with other land uses including agriculture (Ashton *et al*., 2002). Mining companies are often limited by the location of economically viable reserves some of which may overlap with sensitive ecosystems or traditional indigenous community lands.

Despite the introduction of various technologies at reducing the various environmental impacts, mining still exerts strong pressure on the conservation of water, biodiversity and landscape ecosystems (Brooks, 1997).

2.3.1 Biodiversity and mining

Biological diversity describes the variety of organisms from the genetic, species, genera, families as well as higher taxonomic levels of ecosystem, interacting within particular habitats and the physical conditions under which they live. Despite its innumerable environmental services at the local, national and global levels (Doherty *et al*., 2000), losses to biological wealth had been a recurrent global issue in recent times.

In some conservation circles, the loss is related to developmental projects, land use changes, as well as variations in knowledge and application of biodiversity concepts .To other scientists, the decline results from the segregation of biodiversity legal frameworks from protected areas and other legislations.

Consequently, mining activities are sometimes permitted in protected and theory environmentally sensitive areas in some countries which conflicts principles underlying the conservation of biological diversity. In Ghana, for instance, government had lifted the moratorium placed in 1996 to pave way for forest zones mining within the forest reserves of

Subri, Supuma, shelterbelts, Oponmansi, Tanosuraw, Ajenjua, three points and Atewa range (Tassells, 2001).

Mining however within these forest reserves is likely to impact negatively on rivers; Densu, Ayensu, Birim, Bonsa, Ankobra and others considered to be biologically significant zones.

Some mining companies, many conservationists and non-governmental organizations have initiated various measures to safeguard biodiversity in the face of the continuing onslaught on ecosystems. Apart from declaring the protected zones as 'no – go areas' (Batini, 1997) in many countries, many scientists view the involvement of local communities in all phases of mining as the best way in protecting biological wealth in the industries.

2.3.2 Vegetation clearance and fragmentation

Indisputably, vegetation clearance presents one of the most significant threats to the conservation of biodiversity. It is estimated that, about 40% of the global terrestrial vegetation had been exchanged for mineral exploration, exploitation, and infrastructural development (Myers *et al.*, 2000). In Ghana, mining together with other anthropogenic disturbances is believed to be responsible for annual loss of 22,000 hectares of the existing forest cover (EPA, 1996).

Vegetation clearance has devastating consequence on soil ecosystems. Apart from exposing the soil to higher temperatures, vegetation clearance depletes the soil nutrient levels ironically required for the growth of vegetation (FAO, 1993).

Despite various efforts at arresting deforestation; frequent clearance and non-sustainable conversion of forests to other forms of land use, including mining unabatedly threatens many ecosystems (FAO, 1993). Apart from the destruction of key ecological processes including habitat, soil fertility, hydrological functions, pollination, dispersal and species richness (ITTO, 2002), vegetation clearance promotes forest and habitat fragmentation into isolated, smaller habitat patches.

2.3.3 Mining and species invasion

The degree to which ecosystems respond to species invasion has been a major challenge to many ecologists (Lavorel *et al*., 1999). In fact their spread has been described as the ranging biological wildfire (Dewey *et al*., 1995). Plant species invasion according to Hall (2003) is defined as those species that have or are likely to spread into native plant communities causing environmental harm by developing self sustaining populations and disrupting other systems. Species invasion is influenced by many biotic and abiotic factors reflecting ecosystem properties, attributes of invading species and propagules pressure (Lonsdale, 1999). In general, site disturbances including mining activities that change habitat conditions and /or disrupt resource availability of ecosystems is known to facilitate or predispose ecosystem to species invasion (Perrings *et al*., 2002).

In many places of the world, the characteristics and use of exotic species for improving environmental value and restoration programme had impacted negatively on native biodiversity (Maron and Connor, 1996; GISP, 2001).The use of nitrogen fixing plants in restoration programme had been shown to facilitate the development of structures required for successful species invasion (Lonsdale, 1999). For instance, the high reproductive abilities as well as the vigour of many exotic species such as *Leucaena leucocephala, Casuarina equisitifolia, Chromolaena odorata,* are known to invade and modify community structure of many ecosystems (Ambika, 1996).

2.4 Mining Laws and Community Considerations

Mining lands have alternative uses and therefore compete with other land practices. For instance, the surface mining law which was promulgated in 1986 by PNDC L 153 causes land degradation and water, air and noise pollution. Fertile farm lands are normally taken by the mines and compensations paid are not sustainable. In this regard there have been a lot of enactments and regulations in the mining and minerals laws which aim at streamlining the activities of mining companies in such a way that there will be harmony between companies and the mine communities. Mining and minerals law PNDC L 153 of 1986, Section 17 Sub section (3) obliges a mining lease holder to submit an application and a site plan of the area earmarked for mining to the secretary of the minerals commission. This document should be signed by the chief and three elders of the mine community. Copies of this document are then forwarded to the Minerals Commission, Lands Commission, Forestry Commission, and the Public Agreement Board for their information and necessary action. Mining and Minerals Act 703 of 2006 Section 13, Sub section 3a, 3b requires the Minister of Mines to give notice in writing of mining rights in respect of land applied for mining to the chief or allodia owner and the District Assembly. This notice shall state the boundaries and published in acceptable customary manner to the area concerned, gazetted and exhibited at the District Assembly Office. Every mining lease holder is mandated to put in place a joint mines and community committee. This Committee from Act 703, Section 72 425 and 72 (1) (2) and (3) and PNDC L 153 Section 71 (1) and (2) shall be responsible for negotiating for compensations and other social obligations to the communities. Section 73 (4) obliges a mining leaseholder to resettle a community as a result of being displaced by a proposed mining operations. Localization policy of PNDC L 153 Section 54 (1), mining and minerals Act 703 Section 11 (d), Section 50 (1) (2) and (3), PNDC L 153 Section 36 (b) (d) requires a mining leaseholder to offer employment and training of Ghanaian personnel, preferably people form the mining communities for services which are not beyond their capabilities and also consistent with safety, efficiency and economy.

2.5 Mining Laws and Environmental Considerations

Kesse (1985) reported about 60 Acts, Ordinances and regulations that have been enacted since 1900 to regulate mining activities in Ghana. The Mining regulation of 1950 was in force before independence and focused on levelling and fencing of excavations and pits to improve landscape and prevent accidents. Further, it called for protection of water bodies from pollution and public safety at mine sites. Mining Regulation of 1970 L I 665 Section 52 requires mining companies to cut down all trees near the top of side or surface to prevent danger from falls, however, no provision was made for replacement.

Mining and minerals Law PNDC L 153 of 1986 Section 46 Sub section 4 (b) recommends programmes that take environmental safety factors into consideration before a mining lease is granted. Section 72 obliges the holder of mineral rights to prevent pollution of the environment as a result of its operations. It again makes provision for water protection. Section 50 (d) requires the stacking or dumping of any mineral or waste product in a manner approved by the Chief Inspector of Mines. Environmental Protection Agency Act of 1994 Act 494 Section 12 empowers the Environmental Protection Agency to demand Environmental Impact Assessment (E.I.A.) for any undertaking or project. Section 13 recommends that when an undertaking poses a serious threat to the environment or public health, the Agency may notify the person responsible to prevent or stop the activity. Section 15 Sub section 2 and 3 empowers an inspector to enter any premises to ensure compliance.

Environmental Assessment Regulation of 1999, LI 1652 empowers the Environmental Protection Agency to demand from companies before granting environmental permits the following:

i) Annual Environmental Reports (Regulation 25) ii)
Environmental Management Plans (Regulation 24) iii) An
environmental certificate for the operation phase and iv) Provision
of financial security/insurance bond/reclamation bond.

PNDC L 153 of 1986 Section 17 sub sections (2) a and b empower the secretary of the Mines Commission to request for particulars of financial and technical resources, account of money planned to be spent on the operations and programme of proposed mineral operations before granting or renewing mineral rights. Mining and minerals Act 2006 Act 703 Section II Sub section a, b and c also makes provision for the already mentioned requirements for granting minerals rights.

2.5.1 Effect of Mining on Biophysical Environment

Mining activities in most cases result in the loss of farmlands due to the large tracts of hectares mining companies acquire. Gyimah (2004) reported that one of the issues which normally cause confrontation between mining companies and the mining communities is the loss of farmlands which the communities depend on for their livelihoods. Farming activities are most often not allowed in the concession. In November 1996, the people of Wassa Fiase demonstrated against Prestea Gold Mining Company, for taking their fertile farm lands as their concessions (Friends of the Earth Magazine, 2000).

Both cash and food crops are also destroyed and compensation paid not commensurate and therefore not sustainable (CEPIL, 2004). Micro organisms and burrowing animals which improve soil physical and chemical conditions for instance, earth worms and termites are destroyed during surface mining operations.

Erosion becomes a serious menace as the vegetation and valuable top fertile soil is removed, thus exposing the soil surface. Allan and Leonnel (1996) stated that the effect of erosion increases on bare land as the chemical and physical constituents are carried away and thereby reduces the capacity of soil to support plant growth. Landscape is also adversely affected, wastes produced in the course of mining operations are usually heaped up and this creates an uneven landscape. Excavations also develop pits and trenches, which also pose serious problems for the development of site (Bennett, 1983). Blay (1997) pointed out that surface mining negatively affects soil properties through its effect on nutrients, soil temperature, water infiltration and surface run off. Young (1997) stated that the removal of topsoil results in deficiencies in nitrogen, phosphorus and potassium; such soils are normally characterized by shortage of organic matter and low pH.

2.5.2 Contribution of Mining to Air and Water Pollution

2.5.3 Water Pollution (Surface and ground water pollution)

Many mines have an active programme to reduce the water table or divert major
Water courses away from the mines. This exercise has disruptive outcomes for the quality and availability of surface and ground water (Akabzaa and Darimani, 2001).

The main concern of the communities has been potential cyanide contamination of surface and ground water resources by large-scale mining operations and mercury contamination from small scale and galamsey operations. But chemical pollution could also come from explosives mishandling and sulphur dioxide fumes from the companies. Apart from these chemicals, heavy metals from mining operations find their way to streams and also percolate into ground water (Vinorkor and Syme, 2006).

Desu (1970) reported that chemicals used in the processing of ores, for instance cyanide and mercury are extremely toxic to man, animals and aquatic life. Gyimah, (2004) also stated that suspended solids from dredging and effluents from washing and treatments also pollute water bodies. Nemeron (1978) observed that the discharge of chemicals and other wastes makes streams unsuitable for recreation, fish breeding, aquatic wild life and human consumption. Contamination of water resources also occurs through the leaching of heavy metals and other elements by percolating rainwater (Mitchell, 1990). This results in high concentration of dissolved metals in ground water. In 1996, cyanide spillage at Teberebe Gold Mine released 36 million liters of cyanide solution that destroyed cocoa, food crops and aquatic life (Wassa communities affected by Mining, 2004).

In Ghana, the concentration of mining operations in Tarkwa has been a chief cause of both surface and groundwater pollution. Four main problems of water pollution have been identified in Tarkwa mining areas. These are chemical pollution of ground water and streams, siltation through increased sediment load, increased faecal matter and dewatering effects (Akabzaa and Darimani, 2001).

Furthermore, a tailings dam burst at Tarkwa Gold Mines contaminated river Asumin killing aquatic organisms and polluted the drinking water of thousands of people (Wassa communities affected by Mining, 2004). For instance in 1993, in the Summitville Gold Mine in United States of America, the tailings dam was detected to contain about 6,500,000 cubic metres of toxic materials that could be washed into soil and streams that feed the Rio Grand rivers (Edward, 2001).

2.5.4 Air and Noise Pollution

Air pollution resulting from the activities of mining and mining support companies emanates mainly form high airborne particulate matter, black smoke, noise and vibration resulting from blasting activities. The main sources of airborne particulate matter (respirable dust, sulphur dioxide (SO_2), Nitrogen dioxide (NO_2), Carbon monoxide (CO) and black smoke) include the following activities: site clearance and road building, top soil stripping and dumping, open pit drilling and blasting, stripping, loading and haulage, vehicular movement, ore and waste rock handling, and leap leach crushing by companies doing heap leach processing. Others include fumes from roasting of sulphide ores by Assay laboratories and Prestea mines and refining processes. This has resulted in the high incidence of bronchitis in the area (Park, 1987).

High Sulphur dioxide (SO_2) content in the atmosphere given rise to acid, as it subsequently produces sulphuric acid (H_2SO_4). According to Park (1987), at toxicity limits of -0.5-1g/1, there are no visible effects on health, but toxicity greater than 1.5g/1 can result in breathing difficulties and from 200g/1 and above can cause great discomfort. Its harmful effects include asthmatitis, bronchitis respiratory disorders, lungs, eyes and heart disorders.

The discharge of airborne particulate matter into the environment -- principally minute dust particles of less than 10 microns -- poses health threats to the people in the mining area. All fine dust at a high level of exposure has the potential to cause respiratory diseases and disorders and can exacerbate the condition of people with asthma and arthritis. Dust from gold mining operations has a high silica content which has been responsible for silicosis and silico-tuberculosis in the area (Akabzaa and Darimani, 2001).

Unfortunately, the mining companies have not laid down adequate measures to prevent harmful emissions of dust into the ambient air. Measures to reduce dust emission are restricted to occasional spraying of roads within the premises of the mining concessions. This seems to be a misplaced effort because road dust does not appear to be the main source of dust pollution. Furthermore, the EPA acknowledged that dust suppression on the haulage roads is ineffective and the frequency of spraying is inadequate, particularly in the case of TGL12. Black smoke from fuel burning, fumes from the assay laboratories and ore roasting at Prestea make up additional sources of airborne pollutants in the Tarkwa mining district. There were cases where the values recorded for smoke exceeded the acceptable and tolerable levels of the EC, WHO and EPA. The uppermost value recorded was 207 gm-3 as against the tolerable levels of 100 gm-3 for the EC, 85 gm-3 for the WHO and 40 gm-3 for EPAGhana (Akabzaa and Darimani, 2001).

Metallurgical gases that escape into the atmosphere through extracting and smelting of metals usually affect vegetation and human beings (Asante, 2002). Evans (1990) reports of about 7000 acres of forest at Tennessee copper basin which was completely destroyed from sulphur dioxide damage and further 17000 acres were replaced by grass. The main gaseous pollutants are arsenic and oxides of carbon, and sulphur. Dusts generated by drilling, blasting excavation and crushing of rock materials cause pollution (Gyimah, 2004). Dust from mining operations contains high concentrations of silica, which can penetrate lung tissues and causes tuberculosis (Bergman, 2004). Mullins and Norman (1994) reported of potential metal uptake through inhalation of windblown particles from mine waste piles, tailings and smelting byproducts.

2.5.5 Effects of Mining on Forest and Forest Resource

Mining operations cause serious threats to forest in certain areas of the country. These forests are the habitat or house of more than 50 endangered species of plants, mammals, butterflies and birds. Ironically, areas like Atewa range, Cape three points, Opon Mansi and Tano Offin are the most priorities for protection. About 10,000 – 12,000 people depend on the forest for their food and livelihood and millions of people from both urban and rural areas depend on the river that flows through the reserves as source of drinking water (WACAM, 2004).

Iron ore extraction around Awaso led to the destruction of large hectares of forest land. In the 1960s and 70s bauxite mining in Atewa and Tano Offin were seriously threatened (Hall and Swaine, 1991). Gold mining in recent times poses a great threat to reserves in and near the genetic hot spots of the wet evergreen zone. A large-scale surface mining operation has been established in Neung forest reserve, one of Ghana's outstanding botanical hot spot (Bergman, 2004).

Surface mining is obviously very detrimental to forest, not only is forest biomass removed, but also soil and wildlife habitat destroyed (AngloGold Ashanti Limited Journal, 2000). The associated pollutants especially arsenic oxide and sulphur dioxide destroy forest vegetation. Economic timber species and medicinal plants which traditional herbalists use in curing diseases locally are also destroyed. This reduces foreign earnings as the quantity of timber species for export reduces and a great amount of foreign currency is used by the Government to import drugs (Friend of the Earth magazine January-March, 2000). Non timber forest products like chewing stick, snails, wrapping leaves, pounding stick which forest fringe communities depend on for their livelihood are also adversely affected or destroyed.

2.5.6. Degradation of Land and Vegetation

According to Akabzaa and Darimani (2001), extensive areas of land and vegetation in Tarkwa have been cleared to make way for surface mining activities. Currently, open pit mining concessions have taken over 70% of the total land area of Tarkwa. It is estimated that at the close of mining a company would have utilized 40-60% of its total concession space for activities such as siting of mines, heap leach facilities, tailings dump and open pits, mine camps, roads, and resettlement for displaced communities (Akabzaa and Darimani, 2001). This has momentous adverse impact on the land and vegetation, the main sources of livelihood of the people. There is already a scramble for farmlands in Atuabo and Dumasi. In most parts of Tarkwa, the environment is undergoing rapid dreadful conditions and its immense economic value is dwindling from year to year, due mainly to the heavy concentration of mining activities in the area. Agricultural lands are not only generally degraded, but the loss of land for agricultural production has also led to a shortening of the fallow period from 10 - 15 years to 2 - 3 years. The traditional bush fallow system, which sufficiently recycled substantial amounts of nutrients and made the next cycle productive, can no longer be practised due to insufficiency of land. Large-scale mining activities generally continue to diminish the vegetation of the area to levels that are vicious to biological diversity (Akabzaa and Darimani, 2001).

The deforestation that has emanated from surface mining has long – term effects even when the soil is replaced and trees are planted after mine decommissioning. The new species that might be introduced have the potential to influence the composition of the topsoil and then determine soil fertility and fallow period for certain crops. In addition to erosion when surface vegetation is depleted, there is deterioration in the viability of the land for agricultural activities and loss of habitat for birds and other animals. This has degenerated into destruction of the luxuriant plant life, biodiversity, cultural sites and water bodies (Akabzaa and Darimani, 2001). It is predictable that by the time the four companies - GAG, TGL,

GGL, and AGL-would have mined out all their concessions, a total of 16 ridges ranging between 120m and 340m high would have been twisted into huge craters (Akabzaa and Darimani, 2001).

2.6 MINING AND HEALTH

Health can be defined as a state of complete physical, mental and social well being of an individual, and not merely the absence of disease and infirmity (World Health Organisation, 1997). An alteration in the living cells of the body which jeopardizes survival in the environment results in diseases. Health problems arise from a variety of man's activities including industrialisation, farming, mining, migration and others.

Available literature examines the impact of mining on the health of both mine workers and the people within the surrounding communities of the mines. According to Stephens and Ahern (2001), mining remains one of the most perilous occupations in the world, both in terms of short term injuries and fatalities, but also due to long term impacts such as cancers and respiratory conditions such as silicosis, asbestosis and pneumoconiosis.

Studies of mining and health by type of mine process are divided into deep and open cast mines. Deep mines produce severe harms for employees in terms of their risks of high blood pressure; heat exhaustion; myocardial infarction and nervous system disorders. Studies of surface mining focus on coal, granite and rock mining and health risks related to dust breathing. In all levels of mining health risks occur with dust exposure (Stephens and Ahern, 2001).

Respiratory impacts are the most studied and problematic of health impacts for mine workers. Injuries have declined in importance but continue to be an important safety issue in mines. Long-term effects include cancers, mental health impacts and some proof of impacts on genetic integrity of workers. The heated discussion on the impact of the mining and minerals sector on both worker and community health is polarized. On the one hand the industry tends to underscore the supposed benefits of the sector, whilst on the other, community groups and NGOs suggest that the sector is injurious to health and sustainable development (Stephens and Ahern, 2001).

Further, the mining sector has been affected by the world-wide epidemic of HIV/AIDS, and this is apparent in the studies of South African mines. Several studies (Jochelson *et al.*, 1991; Campbell 1997; Campbell and Williams, 1999; Campbell 2000; Corbett *et al.*, 2000) have focused on the condition of the gold mines of South Africa. Migrant labour plays a vital role in the mining sector of South Africa, and these migrants are believed to play an important role in the transmission of HIV/AIDS. In terms of how the mining industry has dealt with this problem one study (Campbell and Williams, 1999) reports that "many mines made substantial efforts to establish HIV- prevention programmes relatively earlier on in the epidemic, but these appear to have had little impact".

Meanwhile, Corbett *et al.*, (2000) investigated the combined effects of HIV infection and silicosis on mycobacterial disease in a South African gold mine, and concluded that the danger of silicosis and HIV infection combine in a multiplicative manner. This indicates that tuberculosis (TB) remains as much a silica-related occupational disease in HIV-positive as in HIV-negative miners, and HIV- positive silicotics have by far higher TB prevalence rates than those reported from other HIV positive Africans. The increasing impact of HIV over time may indicate epidemic TB transmission with swift disease development in HIV-infected miners.

There were relatively few studies of policy initiatives by Stephens and Ahern (2001).

According to them, health and safety improvements in mines have been developed over a long period of negotiation and struggle. Laws have come after union and management activities. Governments have supported organized labour in the improvements.

Moreover, Stephens and Ahern (2001) stress that scientific evaluation of long-term impacts has grown. Employees have been able to use scientific evidence for improved “hazard visibility” and for shifts in health and safety legislation. However, much of the small-scale mining sector falls outside formal legislative shield or scientific analysis. Companies have provided a range of community initiatives including vaccination programmes and health services. These have mixed results. Companies have seldom addressed the community claims for damage made against them internationally. Communities have worked with scientists to understand some of the impacts associated with living near mines. Unions have scarcely played an overt role in support for community claims (Stephens and Ahern, 2001).

In Ghana, available literature on effects of mining on health is reviewed as follows.

Biostatistics obtained from Obuasi hospital in a survey by Friends of the Earth-Ghana (FOEGhana) showed a high prevalence of upper respiratory tract infection (URTI) in the area which medical experts linked to the mining activities and associated pollution (Awudi, 2002). Clinical symptoms similar to arsenic poisoning have been observed in patients in AGC hospital at Obuasi and have been associated with aerial pollution from mineral procession by the AGC (Awudi, 2002).

In Tarkwa area, with the initiation of mining investment, mining impact related diseases such as malaria, diarrhoea, upper respiratory tract infections, skin disease, acute conjunctivitis and accidents constitute the top ten diseases in the area according to biostatistics, obtained by FOE – Ghana in Korle-Bu Hospital in a survey in 2001. The area has the highest incidence of malaria in the Western Region and the country as a whole. Skin rashes are widespread particularly among communities living along rivers and streams which regularly receive leaked cyanide waste waters and other mining wastes within concessions and in many places in the world, dust with silicon content had been linked to high prevalence rates of Silocosis and Silico-tuberculosis (Akabzaa and Daramani, 2001; Avotri, 2001).

The World Health Organization (WHO) adopted a strategy on health and environment in Africa with the cardinal objective of stimulating the development of health policies towards sound management of environmental determinants of health. In responses to this policy, many mining institutions have formulated safety policies to reduce the potential health hazards in the industry. In addition health posts have also been established at various work places to deal with issues on site.

2.7 Heavy metals contamination in Mining

Mining and smelting operations are important causes of heavy metal contamination in the environment due to activities such as mineral excavation, ore transportation, smelting and refining, and disposal of the tailings and waste waters around mines (Dudka and Adriano, 1997; Navarro *et al*., 2008). Adverse environmental impacts from excessive heavy metals dispersed from mine and smelter sites include contamination of water and soil, phytotoxicity, soil erosion, and potential risks to human health (McLaughlin *et al*., 1999; Adriano 2001; Pruvot *et al*., 2006). Heavy metal contamination of agricultural soils and crops in the vicinity of mining areas has been regarded as a great environmental concern (Wcisło *et al*., 2002; Liu *et al*., 2005a; Kachenko and Singh, 2006).

Several studies in China, South Korea, and the USA have shown that water (Lin *et al*., 2007), vegetables (Chang *et al*., 2005; Zheng *et al*., 2007), rice (Yang *et al*., 2006), and even fish (Schmitt *et al*., 2007) are often contaminated by heavy metals dispersed from mining and smelting operations. Li *et al*., (2006b) found that Chinese cabbage growing in the vicinity of non-ferrous metals mining and smelting sites in Baiyin, China, contain high concentration of Cd exceeded the maximum permitted levels (0.05 mg kg-1) by 4.5 times. In the vicinity of a Pb/Zn mine in Shaoxing, eastern China, it was reported that the respective Pb and Cd concentrations of some vegetables were 20 and 30 times higher than the permitted standards (Li *et al*., 2006a). Clearly, not only the ingestion or inhalation of contaminated particles, but also the ingestion of plants produced in the contaminated area is another principal factor contributing to heavy metal of exposure for population. It has been recognized that food crops can be an important source of heavy metals for humans and animals (Dudka and Miller, 1999). Both heavy metal uptake via roots from contaminated soils and surface water, and direct deposition of contaminants from the atmosphere onto plant surfaces can lead to plant contamination by heavy metals.

Lead and Cd are considered potential carcinogens and are associated with etiology of a number of diseases, especially cardiovascular, kidney, blood, nervous, and bone diseases (Jarup, 2003). Although Zn and Cu are essential elements, their excessive concentration in food and feed plants are of great concern because of their toxicity to humans and animals (Kabata-Pendias and Mukherjee, 2007). Cultivation of crops for human or livestock consumption can potentially lead to the uptake and accumulation of these metals in edible plant parts with a resulting risk to human and animal health (Gupta and Gupta, 1998; Lim *et al*., 2008). Serious systemic health problems can develop as a result of excessive dietary accumulation of heavy metals such as Cd and Pb in the human body (Oliver, 1997). Lacatusu *et al*., (1996) reported that soil and vegetables polluted with Pb and Cd in Copsa Mica and Baia Mare, Romania, significantly contributed to decreased human life expectancy within the affected areas, reducing average age at death by 9–10 years. In France (Pruvot *et al*., 2006) and Brazil (Bosso and Enzweiler, 2008), it was reported that children living around a former smelter had high blood Pb levels. Turkdogan *et al*., (2002) suggested that the high prevalence of upper gastrointestinal cancer rates in the Van region of Turkey was related to the high concentration of heavy metals in the soil, fruit, and vegetables. Dietary intake is the main route of exposure for most people, although inhalation can play an important role in highly contaminated sites (Tripathi *et al*., 1997). Thus information about heavy metal concentrations in food products and their dietary intake is very important for assessing the risk to human health.

In China, there are over 9,000 state-owned and 30,000 private mining companies, and large amounts of hazardous wastes are released from base-metal mining and smelting operations annually. Cumulative use of land by mining was approximately 1,500,000 ha by 2006, with 60% of this area impacted by mine tailings. Metal ore processing usually leads to multimetal contamination of the environment, and topsoil in the vicinity of mines and smelters contains elevated concentrations of heavy metal (Dudka and Adriano, 1997). Dabaoshan mine area (Guangdong, southern China) has been confirmed to have soils and waters severely pollution by heavy metals (Zhou *et al*., 2007; Lin *et al*., 2007). Mining activities during the past four decades have generated large quantities of mine waste materials without any proper treatment. It has been reported that mining activities polluted approximately 83 villages, 585 ha of paddy fields and 21 ha of ponds around this mine. In the vicinity of Dabaoshan mine area, the number of cancer cases (oesophageal cancer, liver cancer, etc.) is about nine times above the normal incidence of cancer, and the mortality rate approaches 56% (Liu *et al*., 2005b). Environmental surveys conducted by the Ministry of Health have shown that children living around the mine area had higher blood lead levels than those living in non contaminated sites (Liu *et al*., 2005b). This exposure has been probably attributed to the consumption of drinking water and crops contaminated by mining activities.

The use of hazardous chemicals in mining operation constitutes a major source of pollution to both surface and underground water bodies. Chemicals leaching from waste rocks, tailings dams and the surface of open pits often create long term effects of acid mine drainage. Acid mine drainage (AMD) occurs when sulfide bearing minerals, such as pyrite or pyrrhotite, are exposed to oxygen or water rock piles, mine openings, and pit walls. Apart from altering the pH of soil and water bodies, AMD is responsible for the release of more common pollutants including iron, manganese, aluminum, zinc, cadmium, lead and other metals, sulfate, acids, nitrate and suspended solids (Younger, 2000).

While small amounts of heavy metals are considered essential for the survival of many organisms, higher levels of these metals are toxic to many organisms and often cause avoidance behavior in fishes as well as death in birds, fishes, man and some micro invertebrate communities in many places of the world. The use of cyanide and mercury in beneficiation processes is known to pose serious health and safety threats to many communities. Despite its high ore recovery rate and rapid decomposition (Kelly, 1998), cyanide complexing with other metals for mineral processing is believed to adversely affect fishes, birds and humans. Moreover, traces of mercury used in amalgamating gold particles during the beneficiation processes has been found in some plant and animal tissues in some aquatic ecosystems (Hilson, 2002). Once stored in tissues, it can be passed on to offspring; often producing anorexia, lethargy, muscle ataxia, visual impairment and other central nervous system disorders in young birds, fishes and man (Hilson, 2002). To address these impacts, many countries including

Ghana have put in place legislations to ensure compliance with water quality standards or guidelines in many industries including the mining sector.

2.7.1. Toxicity of metals in soil

The presence of metals in water and soils can pose a significant threat to human health and ecological systems. Heavy metal toxicity represents an uncommon, yet clinically significant, medical condition. If unrecognized or inappropriately treated, heavy metal toxicity can result in significant morbidity and mortality. Many metals are essential to biochemical processes in correct concentrations but at higher doses, heavy metals can cause negative health effects such as irreversible brain damage. Some metals such as lead and mercury easily cross the placenta and damage the brain (Levine *et al*., 2006).

Metals have the potential to be toxic to living organisms if present at availability above a threshold level. This threshold varies between taxa and metal speciation. Most urban and industrial runoff contains a component of trace and heavy metals in the dissolved or particulate form (Defew *et al.*, 2004). Since heavy metals cannot be degraded biologically, they are transferred and concentrated into plant tissues from soils and pose long-term damaging effects on plants. Nevertheless, different plants react differently to wastewater irrigation; some are more resistant to heavy metals. The ability of mangrove plants to tolerate heavy metals in wastewater is not clear and the impact of wastewater on plant growth must be understood before the system can be employed for removing heavy metal from wastewater. Heavy metals that accumulate in soils not only exert deleterious effects on plant growth, but also affect the soil microbial communities and soil fertility. Yim & Tam (1999) found that microbial biomass and enzyme activities decreased with increasing heavy metal pollution, but decreases vary depending on the types of enzymes. The potential hazard to the marine environment of pollutants depends mostly on their concentration and persistence. Persistence pollutants, such as heavy metals, can remain in the environment unchanged for years and thus may pose a threat to man and other organisms.

Many of the heavy metals are toxic to organisms at low concentrations. However, some heavy metals, such as copper and zinc are also essential elements. Concentrations of essential elements in organisms are normally homeostatically-controlled, with uptake from the environment regulated according to nutritional demand. Effects on the organisms are manifest when this regulation mechanism breaks down as a result of either insufficient (deficiency) or excess (toxicity) metal (Duffus, 2002).

Copper is one of several heavy metals that are essential to life despite being as inherently toxic as non-essential heavy metals exemplified by Lead (Pb) and Mercury (Hg) (Scheinberg, 1991). Plants and animals rapidly accumulate it. It is toxic at very low concentration in water and is known to cause brain damage in mammals (DWAF, 1996). Interest in these essential metals which are required for metabolic activity in organisms lies in the narrow "window" between their essentiality and toxicity (Skidmore, 1964). Non-essential metals like Aluminium (Al), Cadmium (Cd) and Lead (Pb) exhibit extreme toxicity even at trace levels (Merian, 1991).

Cadmium (Cd) has been found to be toxic to fish and other aquatic organisms (Rao and Saxena, 1981; Woodworth and Pascoe, 1982). The effect of Cd toxicity in man includes kidney damage (Friberg, *et al*., 1986; Herber *et al*., 1988) and pains in bones (Tsuchiya, 1978). Cd also has mutagenic, carcinogenic and teratogenic effects (Fischer, 1987; Friberg *et al*., 1986, Kazantzis, 1987, Heinrich, 1988).

Lead is defined by the United States Environmental Protection Agency (USEPA) as potentially hazardous to most forms of life, and is considered toxic and relatively accessible to aquatic organisms (USEPA, 1986). Lead is bioaccumulated by benthic bacteria, freshwater plants, invertebrates and fish (DWAF, 1996). The chronic effect of lead on man includes neurological disorders, especially in the foetus and in children. This can lead to behavioral changes and impaired performance in IQ tests (Lansdown, 1986; Needleman, 1987).

2.7.2 Mobility and Speciation of Metals in Water and Soil

Understanding the environmental behaviour of a metal by determining its speciation, mobility and occurrence is of paramount importance. The term speciation is related to the distribution of an element among chemical forms or species. Heavy metals can occur in several forms in water and soil (Maiz *et al.*, 2001). Based on this information the most appropriate method for soil and water remediation can be determined (Garrido *et al.,* 2005).

Soils are significant sinks for metals, while water represents an important pathway for the dispersion of metals over extremely large areas (Gabler, 1997). The mobility of a metal in soil and water depends significantly on the chemical form and speciation of the metal. The mobility of metals in ground-water systems is hindered by reactions that cause metals to adsorb or precipitate, or chemistry that tends to keep metals associated with the solid phase and prevents them from dissolving. These mechanisms can retard the movement of metals and also provide a long-term source of metal contaminants. While various metals undergo similar reactions in a number of aspects, the extent and nature of these reactions varies under particular conditions (Mulligan *et al.*, 2001, Shen *et al.,* 2005). Studies on the mobility of heavy metals in soils have shown that the mobility is strongly influenced by several factors, e.g. pH redox potential, clay mineral content, organic matter content and water content. Various processes, e.g., adsorption-desorption, complex and ion-pair formation or activities of micro organisms are also involved (Gabler, 1997). Simple and complex cations are the most mobile, exchangeable cations in organic and inorganic complexes are of medium mobility and, chelated cations are slightly mobile (Kelly *et al.,* 2003, Gabler, 1997). Metals in organic particles are only mobile after decomposition or weathering. Precipitated metals are mobile under dissolution conditions (e.g. change in pH) (Kelly *et al.*, 2003).

2.8 Influence of Soil Properties on Mobility of Heavy Metals

Chemical and physical properties of the contaminated matrix influence the mobility of metals in soils and groundwater (Gäbler *et al.,* 1997). Contamination exists in three forms in the soil matrix: solubilized contaminants in the soil moisture, adsorbed contaminants on soil surfaces, and contaminants fixed chemically as solid compounds. The chemical and physical properties of the soil influence the form of the metal contaminant, its mobility, and the technology selected for remediation (Garrido *et al.*, 2005)

2.8.1 Chemical Properties

The presence of inorganic anions (carbonate, phosphate, sulphide) in the soil water can influence the soils ability to fix metals chemically (Garrido *et al.,* 2005). These anions can form relatively insoluble complexes with metal ions and cause metals to desorb and precipitate in their presence. Soil pH values generally range between 4.0 and 8.5 with buffering by Al at low pH and by CaCO3 at high pH. Metal cations are most mobile under acidic conditions while anions tend to sorb to oxide minerals in this pH range. At high pH, cations precipitate or adsorb to mineral surfaces and metal anions are mobilized. The presence of hydrous metal oxides of Fe, Al, and Mn can strongly influence metal concentrations because these minerals can remove cations and anions from solution by ion exchange, specific adsorption and surface precipitation (Gäbler *et al.,* 1997).

Sorption of metal cations onto hydrous oxides generally increases sharply with pH and is most significant at pH values above the neutral range, while sorption of metal anions is greatest at low pH and decreases as pH is increased. Cation exchange capacity (CEC) refers to the concentration of readily exchangeable cations on a mineral surface and is often used to indicate the affinity of soils for uptake of cations such as metals. Anion exchange capacity (AEC) indicates the affinity of soils for uptake of anions, and is usually significantly lower than the CEC of the soil. In addition to hydrous oxides, clays are also important ion exchange materials for metals. The presence of natural organic matter (NOM) has been shown to influence the sorption of metal ions to mineral surfaces. NOM has been observed to enhance sorption of Cu^{2+} at low pH, and suppress Cu^{2+} sorption at high pH (Gäbler *et al.*, 1997).

2.8.2 Physical Properties

Particle size distribution can influence the level of metal contamination in a soil. Fine particles (<100μm) are more reactive and have a higher surface area than coarser material. As a result, the fine fraction of a soil often contains the majority of contamination. The distribution of particle sizes with which a metal contaminant is associated can determine the effectiveness of a number of metal remediation technologies, for example, soil washing (Martinez *et al.*, 2006). Moisture influences the chemistry of contaminated soil. The amount of dissolved minerals, pH and redox potential of the soil water depend on the soil moisture content. Soil structure describes the size, shape, arrangement and degree of development of soils into structural units. Soil structure can influence contaminant mobility by limiting the degree of contact between groundwater and contaminants. It has been demonstrated that the speciation of trace metals in natural soils depends on the physical and chemical characteristics of the soil. Soil pH, redox, organic, carbonate, clay and oxide contents all influence metal speciation and mobility. A study by Maturi and Reddy (2006) showed that zinc and cadmium in soil are mostly associated with exchangeable, water soluble and organic fractions. Copper is mainly organically bound and exchangeable, whereas, lead is slightly mobile and bound to the residual fraction (Maturi and Reddy, 2006). After discharge to an aquatic environment, metals are partitioned between solid and liquid phases. Within each phase, further partitioning occurs among ligands as determined by ligand concentrations and metal-ligand bond strengths. In solid phases, soil, sediment, and surface water particulates, metals may be partitioned into six fractions: (a) dissolved, (b) exchangeable, (c) carbonate, (d) ironmanganese oxide, (e) organic, and (f) crystalline (Khan *et al.*, 2004). Partitioning is affected strongly by variations in pH, redox state, organic content, and other environmental factors.

The dissolved fraction consists of carbonate complexes, whose abundance increases with pH, and metals in solution, including metal cation and anion complexes and hydrated ions whose solubilities are affected strongly by pH and tend to increase with decreasing pH.

Exchangeable fractions consist of metals bound to colloidal or particulate material (Khan *et al.*, 2004). Metals associated with carbonate minerals in soil constitute the carbonate fraction, which can be newly precipitated in soil (Davydova, 2005). The iron-manganese oxide fraction consists of metals adsorbed to iron-manganese oxide particles or coatings.

The organic fraction consists of metals bound to various forms of organic matter. The crystalline fraction consists of metals contained within the crystal structure of minerals and normally not available to biota. Hydrogen ion activity (pH) is probably the most important factor governing metal speciation, solubility from mineral surfaces, transport, and eventual bioavailability of metals in aqueous solutions. pH affects both solubility of metal hydroxide minerals and adsorption-desorption processes. Most metal hydroxide minerals have very low solubilities under pH conditions in natural water (Davydova, 2005). Adsorption, which occurs when dissolved metals are attached to surfaces of particulate matter (notably iron, manganese, and aluminium oxide minerals, clay, and organic matter), is also strongly dependent on pH and, of course, the availability of particulate surfaces and total dissolved metal content. Metals tend to be adsorbed at different pH values, and sorption capacity of oxide surfaces generally varies from near 0 percent to near 100 percent over a range of about 2 pH units (Bourg *et al.*, 1988, Elder, 1989). The adsorption edge, the pH range over which the rapid change in sorption capacity occurs, varies among metals, which results in precipitation of different metals over a large range of pH units. Consequently, mixing metalrich acidic water with higher pH metal-poor water may result in dispersion and separation of metals as different metals are adsorbed onto various media over a range of pH values. Cadmium and zinc tend to have adsorption edges at higher pH than iron and copper, and consequently they are likely to be more mobile and more widely dispersed. Adsorption edges also vary with concentration of the complexing agent thus, increasing concentrations of complexing agent increases pH of the adsorption edge (Bourg *et al.,* 1988). Major cations such as Mg^{2+} and Ca^{2+} also compete for adsorption sites with metals and can reduce the amount of metal adsorption. Particulate size and resulting total surface area available for adsorption are both important factors in adsorption processes and can affect metal bioavailability (Louma, 1989). Small particles with large surface-area to-mass ratios allow more adsorption than an equivalent mass of large particles with small surface-area-to-mass ratios. Reduced adsorption can increase metal bioavailability by increasing concentrations of dissolved metals in associated water. The size of particles released during mining depends on mining and beneficiation methods. Finely milled ore may release much smaller particles that can both be more widely dispersed by water and wind, and which can also serve as sites of enhanced adsorption. Consequently, mine tailings released into fine-grained sediment such as silty clays found in many places can have much lower environmental impact than those released into sand or coarse-grained sediment with lower surface area and adsorption (Mitchell *et al.,* 1999). Temperature exerts an important effect on metal speciation, because most chemical reaction rates are highly sensitive to temperature changes (Louma, 1983). An increase of 10 ºC can double biochemical reaction rates, which are often the driving force in earth surface conditions for reactions that are kinetically slow, and enhance the tendency of a system to reach equilibrium. Temperature may also affect quantities of metal uptake by an organism, because biological process rates (as noted above) typically double with every 10 ºC temperature increment (Mulligan *et al.*, 2001). Because increased temperature may affect both influx and efflux rates of metals, net bioaccumulation may or may not increase (Mulligan *et al.*, 2001).

2.9 Review of the studied metals

2.9.1 Copper

Copper (Cu) is mined as a primary ore product from copper sulphide and oxide ores. Mining activities are the major source of copper contamination in groundwater and surface waters. Other sources of copper include algicides, chromated copper arsenate (CCA), pressure treated lumber and copper pipes. Solution and soil chemistry strongly influence the speciation of copper in ground-water systems. In aerobic conditions, sufficiently alkaline systems, $CuCO_3$ is the dominant soluble copper species (Kelly *et al.*, 2003). The cupric ion, Cu^{2+}, and hydroxide complexes, $CuOH^+$ and $Cu(OH)_2$, are also commonly present. Copper forms strong solution complexes with humic acids (Khan *et al.*, 2004). The affinity of Cu for humates increases as pH increases and ionic strength decreases. In anaerobic environments, when sulphur is present CuS(s) will form. Copper mobility is decreased by sorption to mineral surfaces. Cu^{2+} sorbs strongly to mineral surfaces over a wide range of pH values (Mulligan *et al.*, 2001).The cupric ion (Cu^{2+}) is the most toxic species of copper. Copper toxicity has also been demonstrated for $CuOH^+$ and $Cu_2(OH)_2^{2+}$ (Mulligan *et al.*, 2001).

2.9.2 Arsenic

Arsenic (As) is a semi metallic element that occurs in a wide variety of minerals, mainly as As_2O_3, and can be recovered from processing of ores containing mostly copper, lead, zinc, silver and gold. It is also present in ashes from coal combustion. Arsenic exhibits fairly complex chemistry and can be present in several oxidation states (-III, 0, III, V) (Chapman, 1996). In aerobic environments, As (V) is dominant usually in the form of arsenate (AsO_4^{3-}) in various protonation states: H3AsO4, H2AsO4-, HAsO42-, AsO43-. Arsenate and other anionic forms of arsenic behave as chelates and can precipitate when metal cations are present. Metal arsenate complexes are stable only under certain conditions. As (V) can also co-precipitate with or adsorb onto iron oxyhydroxides under acidic and moderately reducing conditions (Gäbler, 1997). Coprecipitates are immobile under these conditions but arsenic mobility increases as pH increases. Under reducing conditions As(III) dominates, existing as arsenite (AsO33-) and its protonated forms: H3AsO3, H2AsO3-, HAsO32-. Arsenite can adsorb or co-precipitate with metal sulfides and has a high affinity for other sulfur compounds. Elemental arsenic and arsine, AsH3, may be present under extreme reducing conditions. Biotransformation (via methylation) of arsenic creates methylated derivatives of arsine, such as dimethyl arsine HAs(CH3)2 and trimethylarsine As(CH3)3 which are highly volatile. Since arsenic is often present in anionic form, it does not form complexes with simple anions such as Cl- and SO42-. Arsenic speciation also includes organometallic forms such as methylarsinic acid (CH3)AsO2H2 and dimethylarsinic acid (CH3)2AsO2H. Many arsenic compounds sorb strongly to soils and are therefore transported only over short distances in groundwater and surface water. Sorption and co-precipitation with hydrous iron oxides are the most important removal mechanisms under most environmental conditions. Arsenates can be leached easily if the amount of reactive metal in the soil is low. As(V) can also be mobilized under reducing conditions that encourage the formation of As(III), under alkaline and saline conditions, in the presence of other ions that compete for sorption (Gäbler, 1997).

2.9.3 Lead

Lead released to groundwater, surface water and land is usually in the form of elemental lead, lead oxides and hydroxides, and lead metal oxyanion complexes. Most lead that is released to the environment is retained in the soil. The primary processes influencing the fate of lead in soil include adsorption, ion exchange, precipitation, and complexation with sorbed organic matter. These processes limit the amount of lead that can be transported into the surface water or groundwater. The relatively volatile organo-lead compound tetramethyl lead may form in anaerobic sediments as a result of alkyllation by micro organisms (Mulligan *et al.,* 2001, Garrido *et al.,* 2005). The amount of dissolved lead in surface water and groundwater depends on pH and the concentration of dissolved salts and the types of mineral surfaces present. In surface water and ground-water systems, a significant fraction of lead is undissolved and occurs.

2.10 Tailings

Tailings consist of ground rock and process effluents that are generated in a mine processing plant. Mechanical and chemical processes are used to extract the desired product from the run of the mine ore and produce a waste stream known as tailings. This process of product extraction is never 100% efficient, nor is it possible to reclaim all reusable and expended processing reagents and chemicals. The unrecoverable and uneconomic metals, minerals, chemicals, organics and process water are discharged, normally as slurry, to a final storage area commonly known as a Tailings Management Facility (TMF) or Tailings Storage Facility (TSF). Not surprisingly the physical and chemical characteristics of tailings and their ability to mobilise metal constituents are of great and growing concern (ICOLD and UNEP, 2001). Tailings are generally stored on the surface in retaining structures but can also be stored underground in mined out voids by a process commonly referred to as backfill. Backfilling can provide ground and wall support, improve ventilation, provide an alternative to surface tailings storage and prevent subsidence (EC, 2004). The challenges associated with tailings storage are ever increasing. Advances in technology allow lower grade ores to be exploited, generating higher volumes of waste that require safe storage. Environmental regulations are also advancing, placing more stringent requirements on the mining industry, particularly with regard to tailings storage practices. This ultimately places added pressure on the operators of a tailings facility who carry out the day to day roles of tailings discharge and water management.

The majority of historical tailings related incidents have been influenced by poor day to day management, which has resulted in the strengthening of regulations controlling tailings storage today. Tailings are a waste product that has no financial gain to a mineral operator at that particular point in time. Not surprisingly it is usually stored in the most cost effective way possible to meet regulations and site specific factors. Dams, embankments and other types of surface impoundments are by far the most common storage methods used today and remain of primary importance in tailings disposal planning (Vick, 1990). The particular design of these retaining structures is unique to a particular environment and mining operation. When considering the design of a tailings storage facility there are many parameters which impact on the optimum site selected and the storage and tailings discharge methods used (Ritcey, 2005). The environment is the most crucial parameter constraining tailings storage which ultimately affects the way a facility is designed, built, operated and closed. For this reason a range of alternate methods of tailings storage and discharge techniques need to be considered when designing a facility for a particular location.

2.10.1 Tailings and Acid Mine Drainage

The process of beneficiation of run of the mine ores and subsequent disposal to surface containment facilities exposes elements to accelerated weathering and consequently increases mobilisation rates. The addition of reagents used in mineral processing may also change the chemical characteristics of the processed minerals and therefore the properties of the tailings and waste rock (EC, 2004). Problems arise when this accelerated weathering process generates toxic levels that create short and long term tailings management challenges. The processing of hard rock sulphidic bearing ores is just one example of the potential problems associated with accelerated weathering. In this case the sulphide minerals more readily oxidise in the tailings facility as a result of the size reduction from milling increasing the surface area and thus exposure of the tailings to air and water. Acid generation and metal mobilisation occur that eventually find their way into the surrounding environment through runoff or seepage. This phenomenon is a well-known problem affecting the mining industry and is commonly known as Acid Mine Drainage (AMD) or Acid Rock Drainage (ARD) (Garcia and Ballester, 2005; Ritcey, 2005).

Globally, the release of Acid Mine Drainage (AMD) poses a great challenge to many restorationists. Currently, AMD managements in many companies entail strategies for preventing and / or containing processes of acid mine drainage. Surface mining companies operating on sulphidic areas usually rely on strategies that reduce water contact with waste rocks, tailings, exposed rocks as well as other potential acid generating materials.

In some companies, the establishment of surface water diversion structures including drainage and collection ditches, alkaline loading ponds, soil and plastic linings, installation of water pump, peripheral deep wells on or around the waste dumps and other acid generating materials are intended to decrease water contact and effect of AMD materials on down streams (Perrings *et al.*, 2002; Gentile and Duggin, 1997). Moreover, impounding or flooding acid generating rocks to reduce pyrite oxidation processes and metal contaminating and AMD effects had been employed in many places (Pedersen *et al.*, 1997).

In addition to recycling over 98% of water used for mineral processing, the existence of collection ditches and rapid revegetation techniques are intended to reduce the ingress of water and its consequent AMD discharged on the Waste dump within the concession of AngloGold, Iduapriem mine (pers. comm., 2009). Rapid revegetation controls erosion, enhances evapotranspiration, fauna abundance and soil fertility (Loch, 2000).

The disposal of tailings is commonly identified as the single most important source of environmental impact for many mining operations (Vick, 1990). This is not surprising when considering that the volume of tailings requiring storage can often exceed the in-situ total volume of the ore being mined and processed. Over the last century the volumes of tailings being generated has grown dramatically as the demand for minerals and metals has increased and lower and lower grades of ore are being mined. In the 1960's 10's of thousands of tonnes of tailings were produced each day and by 2000 this figure has increased to 100's of thousands (Jakubick and McKenna, 2003). Understanding the mineral processing techniques can help to determine how tailings are produced and the challenges associated with their storage.

2.11 Reclamation

Mining companies undertake reclamation of degraded areas to comply with state environmental regulations in many countries. Apart from adhering to the preparation and submission of the reclamation plan, mining companies are mandated in many countries to post a pre-mining financial assurance or security in the form of cash, letters of credit, surety bonds, or trust fund to cover the cost of environmental damages in circumstances of insolvency during the closure (Laurence, 1999). In the United States for instance, a bank surety or the operator itself guarantees funding sufficient for a regulatory authority to undertake or complete the mine reclamation obligation.

Generally, reclamation bonds are calculated and periodically reviewed to equilibrate operational cost, closure as well as addressing long term impacts to wildlife, soil and water quality (Laurence, 1999). Ghana's reclamation bond is reminiscent of the United State legislation. Act 490, the PNDC Law 153 as well as LI 1652, entrench reclamation of mined surface upon cessation of mining activities. Closure certificate as in many countries is issued only if the reclamation plan has been implemented to the satisfaction of the communities, and regulatory authorities. In pursuance of section 24 of the Environmental Assessment Regulations (1999), reclamation policies in Anglogold, Iduapriem mine had been implemented in tandem with mining in order to return the land to its pre-mining state. Policies bordering reclamation of pits, waste dumps, and rompads, tailing dams, water bodies, and the final land use objective had been set up (EPA, 2004).

2.11.1 Main objectives of mine land reclamation

Since the Brundtland Commission first put forward the concept of sustainable development, all industries have been seeking ways to perform in a more sustainable manner. The mining sector is no exception. The extraction of minerals can have a number of impacts, topographical, ecotoxicological and socio-economic, from operation to closure. To achieve sustainability, the mining industry should pursue ‘‘the combination of enhanced socioeconomic growth and development, and improved environmental protection and pollution control’’ (Hilson and Murck, 2000). Mine land reclamation constitutes an integral component part of mine sustainability, which is, as Morrey (1999) explains, to achieve

‘‘physical stability, waste management and acceptable land use’’, and as Kahn *et al*., (2001) add, to improve resilience, productivity and biodiversity of the land. The amelioration sometimes is both technically and economically difficult; therefore, the realistic objectives of land reclamation may differ significantly from the ideal goal of site rehabilitation. However, in the context of long-term land sustainability, reclamation may provide the potential for ecological adjustment or for practical reuse of mined land. Specifically, the principal objectives include but are not limited to the following (partly adopted from Warhurst and Noronha, 1999; Morrey, 1999):

- to eliminate health and safety hazards (e.g. dismantling all facilities and structures threatening human health and safety);
- to restore impacted land and water resources (e.g. revegetating progressively and stabilizing residues to reduce potential of acid mine drainage or water contamination);
- to eliminate off-site environmental impacts (e.g. cleaning up sites to conform to the community’s surrounding landscape);

- to ensure that post-mining land has a viable self sustaining future with respect to both environmental and socio-economic benefits (e.g. developing publicly owned land for recreation, historic purposes, conservation purposes, or open space benefits, or for constructing public facilities in communities);
- to encourage better use of energy and natural resources and to guarantee sustained mining operations.

Different mines have different rationales and methods for site rehabilitation, and it is not feasible to restore all mine sites, as restoring or backfilling very large pits may be very difficult and uneconomic. But, ultimately, all land disturbed by mining activities has some potential for economic, recreational and aesthetic use. So the core of reclamation is to identify the unique potential of mined land and to choose appropriate technologies and measures to transform this potential into a sustained capability (Morrey, 1999). Reclaimed sites have a wide range of potential functions such as pasture, hay land, recreational areas, wildlife habitat, wetlands, fishing ponds, and swimming pools. Some scholars insist that the achievement of sustainable mining requires proactive mine management (Hilson and Murck, 2000). Despite the validity of this argument, it is also imperative to have accompanying legislation and regulatory frameworks in place to provide the incentives and frameworks for these mining companies.

The absence of either of them would possibly lead to failure or at least lower effectiveness of the mine management, and would thus undermine the goals of sustainable mining. The following section examines the importance of legislation and regulatory frameworks to mine land reclamation.

2.11.2 Institutional frameworks on reclamation

Regulatory effectiveness over reclamation performance, to a large extent, is dependent on sound cooperation between authorities at all levels of government towards common reclamation objectives, and also by a clear definition of responsibilities. The early 1970s saw global efforts to control and mitigate environmental impacts through institutional reform, with a trend characterized by a shift from a dispersed obligation mechanisms towards the creation of separate environmental authorities with increasingly independent powers (Walde, 1993; Wagner, 1998). The US Environmental Protection Agency (EPA) was created in 1970, empowered to promulgate regulations for the implementation of environmental laws covering water, solid waste, air and radiation, pesticides and toxic substances, to minimize conflicts and inconsistencies, to facilitate compliance and regulatory enforcement, and to conduct environmental research on problems and their mitigation methods. Since then it has become the only regulatory agency in the federal environmental bureaucracy that reports directly to the President.

Developing countries have also founded their state environmental agencies. Venezuela first set up its Ministry of the Environment in 1977. This was followed by the creation of the Ministry of Sustainable Development and Environment in Bolivia, the Secretariat of Environment, Natural Resources and Fisheries in Mexico, the Secretariat of Natural Resources and Sustainable Development in Argentina and the Ministry of Environment in Colombia. Some Asian countries as China, Mongolia, Vietnam and Indonesia have also established their independent state environmental protection agencies. But unfortunately, some of these institutions are functioning poorly (Weber-Fahr *et al*., 2002) and it is rare for all environmental matters to be handled in these countries within the jurisdiction of a single agency as is the case of the US EPA. More often, multiple departments will be involved commonly with confused tasks. China's State Environmental Protection Agency (SEPA) was promoted to a ministerial status in 1998, but so far it has not been empowered to have a final say on key projects, nor had direct responsibility for the implementation of environmental laws and regulations.

Likewise, although tasked with overall monitoring and diagnosing environmental problems including mining issues, the capability of Zimbabwe's Department of Natural Resources has been limited to date (Hollaway, 2000). In this respect is the division of authority over environmental issues among a number of ministries: for example, water pollution falls to the ministry of water, reclamation to the ministry of land, and hazardous substances to the ministry of health. This results in either duplication and inefficiency or omission and nonimplementation. Weber-Fahr *et al*., (2002) have given a forcible illustration with the example of Peru where, within the Ministry of Energy and Mines (MEM), some groups are tasked with promoting the mining sector, while others have the authority to prevent environmental damage in the sector and to monitor performance.

It is clear that competent and independent institutions with balanced interests are needed. The process of institutional reform in many developing countries has been encouraging and impressive. But, at the same time, the complexity in jurisdiction and the regulatory frameworks has revealed more or less a contradictory ideology for objectives and benefits of various departments. As Otto *et al*., (1999) noted, these frameworks generally seek to reconcile the benefits between mining and the costs to control or mitigate resultant negative environmental effects.

In reality or in perception, different parties apply different measurements in calculating cost and benefit, therefore arriving at a different assessment of the balance (Andrews-Speed *et al*., 2002). The key to resolving the complexity lies in the assessment and the balance of the trade-offs between environmental protection and the various invested interests. It may indeed be utterly groundless to deny a sectoral approach to environmental management where technical expertise is easily accessible and issues involved are better understood. However, an integral approach is usually preferable with an environmental governance institution established detached from any specific sector but forming part of the overall development planning scheme (Weber-Fahr *et al.,* 2002).

2.11.3 Ecosystem Restoration strategies

Increased public concern for ecosystems destruction has led to the unprecedented interest in ecological restoration (Bradshaw, 2002). Though frequently used interchangeably with rehabilitation, reclamation and replacement to cover large array of activities involved with ecosystem repairs, a clearer understanding regarding these terminologies is necessary. Ecological restoration refers to the reinstatement of the original ecosystem that has the capacity to repair, enhance, capture and retain processes of energy, water, nutrient and species from the structural and functional perspectives (Hobbs and Norton, 1996).

Rehabilitation describes progressive efforts towards the reinstatement of original ecosystems (Johnson and Tanner, 2004). Also, reclamation describes various activities aimed at improving the quality of the ecosystem by impacting some valuable ecosystem functions desirable of communities, government and individuals and replacement is the creation of an alternative ecosystem of the original (Bradshaw, 2002). In simple terms, ecological restoration may be equated to primary succession or recovery of mined land when it is largely left to natural processes after disturbance (Johnson and Tanner, 2004).

In most places, technique for restoring degraded mine sites had relied on the priorities and objectives of the stakeholders, the cost, benefits as well as the socioeconomic and environmental values of land resources in their current and desired future states (Carnorgo *et al.,* 2002). Studies on abandoned mining areas had lent support to the recovery of ecosystems without intervention (Bradshaw, 2002). Though highly embraced in the industry, the sequence of successional trajectory associated with this technique is complex and unpredictable (Parker, 1997). In some places, the reclaimed site may yield a biodiversity different from the original ecosystems (Johnson and Tanner, 2004). Despite reducing biological wealth, there is an increasing interest in plantations techniques in harmonizing long term forest ecosystem restoration goals with near-term socio-economic development objectives (Lamb and Gilmour, 2003). Plantation is known to enhance soil moisture, litter accumulation, vegetation growth and temperature reduction, towards ecosystem recovery (Parrotta and Knowles, 1997). In practice however, the principal restoration option for highly disturbed sites involves the amelioration or reclamation towards site improvement and species adaptation in a way which seek to conserving biodiversity and ecosystems functions (Johnson and Tarmer, 2004).

2.11.4 Revegetation

According to Lamb (1994), techniques for revegetation depend on the priorities and objectives of the stakeholders, cost, benefits, and economic, social and environmental values of the reclaimed sites. At AngloGold Iduapriem, the initial revegetation or reclamation strategies involve the use of vetiver grass, centrosema, pluraria and other leguminous cover species to be proceeded with woody or shrub species which promote long term ecosystem processes. The establishment of the woody species stage is usually either left to the natural invasion of locally adaptable species or may be accomplished via direct seeding or transplanting techniques (Withes, 1999).

Known to be economical and reliable strategy for revegetation in many places, the success of direct seeding is contingent upon seed viability, supply and vigor (Parrotta and Knowles, 1997). Nonetheless, increased innovations in broadcasting and dormancy breaking techniques in recent times had contributed to the success of direct seeding in revegetation (Dixon *et al*., 1995,).

Decision to use local or wide range of provenances has become critical in global reclamation programme (Faulconer *et al*., 1996). Local provenance is known to preserve the genetic integrity representative of original ecosystems. In many places however, the cost of topsoil re-spread, as well as the physical and chemical properties of degraded sites necessitate the use of wide range of provenances.

2.11.5 Completion criteria and success indicators

Completion criteria have been defined as reclamation success objectives (Johnson and Tanner, 2004). The success indicators are usually generated on site specific basis to enable regulatory agencies, communities and mining companies to judge the success or otherwise of reclamation programme (Elliot *et al.*, 1996).

Despite meeting the expectations of communities and regulatory agencies (Hobbs and Norton, 1996), the scientific basis for establishing reclamation success criteria had been widely criticized in recent times (Walker and Del Moral, 2003). In the past, success indicators were based on narrow set of vegetation parameters measuring only early stages on revegetation.

Present indicators however integrate approaches embracing self regularity, impacts mitigation, predictability as well as socially relevant components of the reclaimed ecosystems (Ludwig et al., 1997). In reality, judging reclamation success is not amenable to hypothesis but depend upon actual demonstration of frequent monitoring of change associated with ecosystem processes (Bell, 1996). Reclamation is only deemed successful and agreed upon only when the site can be managed for its designated land use without any greater management input compared to other lands used in the same way (Laurence, 1999).

In AngloGold Iduapriem, reclamation success is measured by company’s performance regarding erosion control, canopy formation, species complexity, water quality, weed control, soil enrichments, and public safety issues alongside time, cost and benefits to the local communities (pers. comm., 2009)

2.11.6 Monitoring and reclamation success

The principal objective of environmental monitoring in many mine sites is the integration of mitigation actions into mining and reclamation activities towards good environmental performance (Asher and Bell, 1999). Regular monitoring of flora and fauna on both reclaimed and adjacent undisturbed areas enable environmental mangers to understand annual variation in species diversity and abundance which could otherwise be misinterpreted. During mining, monitoring provides feedback mechanism regarding the success and maintenance of mitigation measures, requirement for additional and /or corrective mitigation measures, as well as appraisal of the overall EIA processes (EPA-Ghana, 1996). At closure, monitoring contributes remarkably towards the success of ecosystem recovery (Asher and Bell, 1999). Monitoring creates the platform for detecting changes in water, air and land properties associated with the implementation of reclamation plan (Viljoen, 1998). In Ghana, monitoring is strictly mandatory particularly in areas with high environmental sensitivities and significance, where impacts are uncertain as well as fragile habitats (Fitzgerald, 1993; Allen *et al.,* 2004 EPA-Ghana, 1996).

Until recently, biodiversity monitoring programme in many companies had concentrated on few vegetation indices with no or few passing reference to fauna. In practice however, credible appraisal of biodiversity units measures complexity of species, resilience to fire, disease, and pest disturbances (Purvis and Hector, 2000).

Currently, mining companies employ monitoring techniques including Remote Sensing (RS), Regional Significance Analysis (RSA) and Ecosystem Functional Analysis (EFA) in assessing ecosystem composition (Kearns and Barnett, 2001)

Monitoring programme in AngloGold Iduapriem, include increases associated with diameter at breast height (dbh), leaf length, leaf area index, canopy cover, litter accumulation, water quality and soil fertility as well as ability of reclaimed sites to support plant growth (Addo, 2008). In assessing the progress towards soil fertility and its sustainability, a trial farm cropped with oil palm, banana, pineapple and cocoa had been established at some portions of the old tailings dam site within the concession to monitor the fertility level of the soil (Addo, 2008).

2.11.7 The level of community participation in reclamation success

The inclusion of the socioeconomic welfare of the local communities is an investment of critical importance in today's mining operations. To many, it is a process of concern revelation and door to success. The establishment of mining companies arguably in the rural areas comes along with it infrastructural developments, employment opportunities and building capacity of communities. In return for their investments, the mineral industry expects the local communities to assist in reclamation programme and other related closure activities.

Apart from land acquisition and payment of royalties, extensive consultations with the affected communities throughout the mine life assist in diagnosing potential points of conflict. This requires maintenance of constant dialogue with the public, informing them of planned mitigation measures and their inputs. Advance consultation prior to exploration or mining is a key not only to win community support, but promote positive corporate image, competitive advantage, and sustainable resource management for the mining companies. Consequences of poor consultation however, result in significant cost to humans, environment and the states. Usually, it escalates social ills including stealing, molestation, family disintegration, unnecessary confrontation as well as threat to desired objectives of reclamation. In September, 2003, for instance, equipment valued 5.5 million dollars belonging to KAS mining company in the Amansie West District of Ashanti were allegedly vandalized by the local communities as a result of perceived poor consultation.

Again, in 2002, the Peruvian community of Tambogrande voted to reject mining in their community due to the projected displacement of half of its residents as well as fears about the potential impacts on the community's traditional livelihood. According to a study, displacement may result in serious social problems, including marginalization, food insecurity, and losses of access to common resources, public services, and social breakdown (Digby, 2002).

As a step in reducing pressure on reclaimed sites, many mining companies currently employ local communities in various stages of their reclamation efforts. These include weed and fire control, supply of native seeds, seedling establishment and maintenance of trial farms and soil conservation research (Fitzgerald, 1993). In AngloGold Iduapriem, the local community is employed in various stages of their reclamation efforts. These include weed and fire control, supply of native seeds, seedling establishment and maintenance of trial farms (Addo, 2008).

In addition, communities are periodically consulted to make inputs into the current reclamation projects. Again, relinquishing unmined lands to landowners for farming as well as granting site access to indigenous people are additional steps towards ensuring the success of reclamation activity.

2.12 Soil chemical properties

The soils under the reclaimed sites must have the ability to support plant growth in order to satisfy the end-use objectives. The reclaimed sites must contain appreciable soil nutrients required to support plants growth so that the resource-poor farmer can do farming in a similar manner as the nearby undisturbed lands.

2.12.1 Nitrogen

Nitrogen (N) is the nutrient that is most frequently limiting to crop production and the nutrient applied in the greatest amounts (Campbell *et al.,* 1986). It is a part of all plant proteins and component of DNA and RNA. Nitrogen is required for assurance of optimum crop quality as protein content of crops is directly related to N supply (Grant and Flaten, 1998). It is also of major concern with regards to environmental sustainability because nitrate leaching can reduce water quality and N2O emission can contribute to the greenhouse gas effect and global warming (Campbell *et al.*, 1995). Reclaimed soils are therefore supposed to attain a very good nitrogen status to support plant growth.

2.12.2 Phosphorus

Phosphorus (P) is involved in energy dynamics of plants (Zublena, 1997). Without it, plants cannot convert solar energy into the chemical energy needed for the synthesis of sugars, starches and proteins. Phosphorus, Nitrogen and other nutrients need to be available to the 50 crop in balance to optimize crop yield and quality and efficiency of crop production (Halvorson and Black, 1985)

2.12.3 Potassium

Except nitrogen, potassium is a mineral nutrient plant require in the largest amounts (Marschner, 1995). Potassium (K) is involved in photosynthesis, sugar transport, water and nutrient movement, protein synthesis and starch formation (Zublena, 1997). It also helps to improve disease resistance, tolerance to water stress, winter hardiness, tolerance to plant pests and uptake efficiency of other nutrients.

2.12.4 Exchangeable calcium and magnesium

Calcium (Ca) is one of the essential elements obtained from the soil by plants and used in relatively large quantities. It is a macronutrient and also a secondary elements since it is usually added to the soil indirectly during the application of materials containing the primary fertilizer elements - NPK (Hesse, 1998). Magnesium (Mg) is an essential part of the chlorophyll molecule. It is also involved in energy metabolism in the plant and is required for protein formation (Zublena, 1997). According to Hesse (1998), Mg occurs in soils, principally in the clay minerals, being common in micas, vermiculites and chlorites. Welte and Werner (1963) investigated the uptake of Mg by plants as influenced by hydrogen, calcium and ammonium ions. They found that hydrogen ions suppressed Mg uptake most and with a strongly acid substrate, Mg deficiency could be remedied by applying

Mg and the pH raised. Zublena (1997) state that depletion of Ca and Mg reserve in the soil by crop removal is rarely a problem in limed soil because of the large quantity of these nutrients that are present in liming materials. However, some crops, such as peanuts, may require more Ca than the crops can remove.

2.12.5 Soil pH and Acidity

Soil pH is the deciding factor for the availability of essential plant nutrients (Rahman and Ranamukhaarachchi, 2003). Nitrates and phosphates are taken up at higher rates in weak acidic conditions (Mengel and Kirkby, 1982). Fageria and Baligar (1998) found the soil pH and base saturation are important soil chemical properties that influence nutrient availability and crop growth. The soil pH influences the occurrence and the activities of soil microorganisms and eventually affects both organic matter decomposition and nutrient availability (Mengel and Kirkby, 1982). Although temperature, soil moisture and the quality of carbon and nutrients determine the overall organic carbon turnover in soil, soil matrix characteristics (such as clay content, Al and Fe content and soil pH) moderate carbon turnover in soil (Dalal, 2001). Soil pH less than 5.5 promotes fungal activity and at higher levels makes bacterial more abundant (Trolldenier, 1971). The nitrification process and its rate brought about by *Nitrosomonas* and *Nitrobacter* bacteria depends considerably on soil pH because these bacteria prefer more neutral soil conditions. In strongly acidic soils the native nitrate content is therefore, extremely low (Mengel and Kirkby, 1982). Bacterial growth rates are generally more sensitive to low pH than fungal growth rates (Walse *et al.*, 1998). Microbial biomass and lignin decomposition appears to be not significantly affected by soil acidity at pH range of 4.5-6.5 (Donelly *et al.*, 1990). However, in acidic pH less than 4.5, microbial activity as well as nutrient turnover is greatly reduced (Santa, 2000). The combined impact of H+ and Al3+ on microbial activity and organic matter decomposition could be modelled with ion exchange expression, such as vanselow expression (Walse *et al.*, 1998). Acidic soil pH dissolves Al and other metals from the mineral soil surfaces, which enter the soil solution. In podosols, Al is mobilized in the alluvial horizons under the predominant influence of organic acidity, and then leaches down the profile as organically bound to bidentate organic sites (Nissinen *et al*., 1999).

2.13 Soil physical properties and soil fertility relationship

Soil texture is the most fundamental attribute of soil fertility. Farmers around the world recognized that soil fertility increases with clay content and that high clay soil are prone to drought in dry areas and to flood in wet areas (Woomer and Swift, 1994). The quantity of ions that a soil can retain against leaching is determined by the magnitude by the ion exchange capacity. The ion exchange is located on soil organic matter (SOM) and clay surface. SOM also follows a linear relationship with clay content. Most of the N in terrestrial ecosystems and a large part of the P is found within the SOM. The soil properties that contribute to the formation and stabilization of macro aggregates include soil texture, clay and mineralogy, exchangeable cations, Fe and Al oxides, calcium carbonate as well as SOM (Le Bissonnais, 1996).

CHAPTER THREE

3.0 DESCRIPTION OF STUDY AREA AND METHODOLOGY

3.1 Climate, Soils, Vegetative Cover and Land Use

Obuasi is about 80 km south west of Kumasi, Ghana and is situated at latitude 6° 12' 00 North and longitude 1° 40' 00 West (Fig 3.1). It is geologically situated within the principal greenstone belt of Proterozoic (Birimian) age which consist of volcano-sedimentary and igneous formations. This belt extends over a distance of approximately 300 km in a northeast/south-west trend in south-western Ghana (Anglogold Ashanti Limited Journal, 2000). The vegetation in the area is mainly secondary forest, forbs re-growth and swamp.

There are two raining seasons, with the major reaching its maximum in May/June and the minor in October. The month of July, August and early September are generally much drier than the remaining months. The annual rainfall ranges from 1300 mm to 2300 mm/yr with temperature between 22°C and 32°C. The population of the Municipality is estimated at 168,641 using the 2010 Housing and Population Census as a base and applying a 4% annual growth rate (Ghana Statistical Service). The Municipality is scattered over many small to large villages throughout the area and is mainly drained by the Nyam and Jimi Rivers.

Besides mining, the majority of the people are farmers (Griffis *et al.*, 2002).

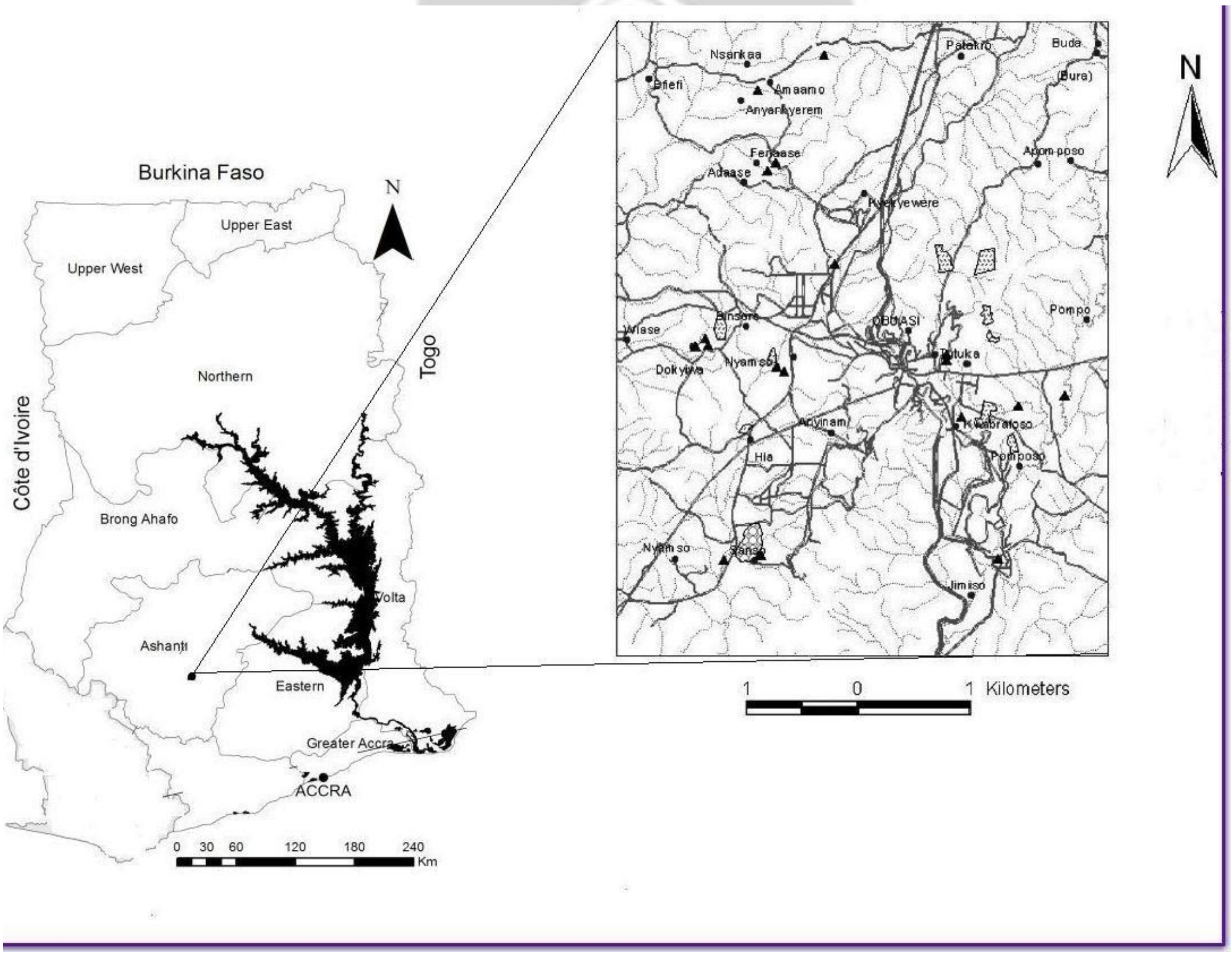

Figure 3. 1: Location map of study area and its environs

The Adansi West District lies within the Equatorial Climatic Zone of the country and is characterized by two rainfall maxima (May/June and October/November). Mean annual rainfall is between 1250 to 2000 mm and averages 1588 mm. Mean monthly temperature ranges from 24°C in August to 30°C between March and April and averages 27.9°C per annum. Average monthly relative humidity is highest (75-90%) during the two raining seasons and lowest (70-80%) during the rest of the year. Annual mean relative humidity is 78%. The natural vegetation of the concession area has been modified significantly by timber extraction, mining and farming. As a result, the vegetation is not typical of Moist Semi- Deciduous Forest zone of the equatorial rain forests of West Africa. Primary forest is restricted to the most inaccessible areas. Historically, trees like teak, mahogany, kapok and wawa have been selectively felled for use as underground shoring timber and wood fuel.

Seven soil associations occur on the concession and these vary in suitability for agriculture and forestry. Major land use is farming (staple and cash crops), although some firewood collection, logging and hunting are practiced on the concession.

3.1.1 Topography and Drainage

The Obuasi area has a topography, which ranges from gently undulating to distinctly hilly and mountainous. Two main ranges of hills cut across the town, giving rise to a series of low peaks, which are about 500m above sea level. Most of the mining operations are nestled on the lower slopes of a prominent range of hills which trend to the southwest of Obuasi. Elsewhere, the topography is mostly gently undulating with scattered hills with elevations of between 180 to 210m above sea level. The area has an extensive network of streams and rivers namely Pompo, Nyame, Akapori, Wheaseammo, Jimi and Kunka which drained the municipality. All these rivers are polluted by mining and other human activities (Yeboah, 2010). Most of these streams including the Jimi take their sources from the ranges of hills, some of which are mined by

AngloGold Company (AGC) and artisanal miners ("galamsey" operators). The AGC concession lies within the Jimi River catchments of the Offin River system. These streams also serve as sources of domestic water for a number of communities in the area.

3.1.2 Soil

Soils in the municipality are predominantly forest ochrosols developed under forest vegetation with rainfall between 900 mm and 1650 mm. They are rich in humus and suitable for both cash and food crops production. Crops grown include citrus, oil palm, cocoa, plantain, maize, cassava, vegetables. Total agriculture land area in the Municipality is about 93km², 60% of which is under cultivation and the remaining 40% undeveloped agriculture land (Table 3.1). Land under forest is the least (4%) of the land use system (Table 3.1).

Table 3. 1: Agriculture land and land under forest in the Obuasi Municipality

LAND USE	SIZE (km^2)
Agricultural Land Area	92.57
Land Under Cultivation	55.60
Undeveloped Agricultural Land Area	36.97
Land Under Forest	4.10
Others (Settlements & Degraded Lands)	65.73
Total Land Area	**162.4**

Source: OMAMTDP, 2006

Rocks in the Municipality are mostly of Tarkwaian (Pre-Cambrian) and Upper Birimian formation which are noted for their rich mineral bearing potentials. Areas around the contacts of the Birimian and Tarkwaian zones known as reefs are noted for gold deposits. The Obuasi mine (AngloGold Ashanti) which works on steeply dipping quartz veins over a strike length of

8km has since 1898 produced over 600 tons (18 million ounces) of gold from ore averaging about 0.65 ounces per ton (OMAMTDP, 2006).

3.2 Methodology

The study was conducted in two phases: a sociological survey and a field experiment. The sociological survey was conducted in three (3) communities within the catchment area of the mining concession namely Binsere, Sansu and Kunka (Table 3.2).

The field experiment was conducted on selected reclaimed site of the mining company. The selected sites were 3 year old, 6 year old, 9 year old, 12 year old reclaimed sites and a cocoa farm. The 3 year old reclaimed site was 2.5 ha, 6 year old 5.5 ha, 9 year old 8.3 and the 12 year old was 15.8 ha. One ha was demarcated at each reclaimed site and this was divided into

3 plots, to represent 3 replicates for each site. A hand auger was used to take the soil sample. Five samples were taken per plot, bulked and subsample to represent a replicate for the year group.

Soil samples were taken at 3 different depths of 0 – 20cm, 20 – 40cm and 40 – 60cm.

3.2.1 Sociological Survey

The survey was undertaken in the three communities involving workers of the Environmental Department of the mining company and the Community Relation Officer. Chiefs and Opinion Leaders were consulted and focus group discussions were also held within each community. The purpose of the survey was to identify the various land reclamation practices in the selected areas and how each was managed. Interviews were conducted on the following:

- Adopted reclamation practices
- Levels of communities participation in the reclamation
- The biological /tree species used in the reclamation exercise
- The processes involved in the reclamation of a mined out site.
- Identification of the success criteria/indicators in the reclamation of a site.
- Identification of the indigenous tree species before the mining commenced.

Determination of the benefits of land reclamation by the communities

• Level of perceived satisfaction of the reclamation exercise by the respondents

The interviews were carried out using semi – structured questionnaires (Appendix 1 and 2) during the 'rest days' (taboo days) in the communities and normal working days in the offices of the Environmental Department and the Community Relation officer. Participatory Rural Appraisal (Chambers, 1992) was used to interview the chiefs and opinion leaders. The focus group discussion covered all the three communities. Respondents from the communities were all workers on the reclamation sites. A total of 81 interviews were held (Table 3.2). Personal and field observations were made at the reclaimed sites and facts observed documented.

Table 3. 2: Number of respondents interviewed in each of the three communities and staff of Anglogold.

Communities	**Number of respondents**
Binsere	20
Sansu	20
Kunka	20
Community Relation Officer	1
Environmental Department	20
Total	81

3.3 LABORATORY/ ANALYTIC METHODS

3.3.1 Soil Analysis

The physico – chemical properties of the soils taken from the reclaimed sites were determined in the laboratory of the Soil Research Institute, Kwadaso, Kumasi.

3.3.2 Soil pH

Soil pH was measured in a 1:1 soil-water ratio using a glass electrode (H19017 Microprocessor) pH meter. Approximately 25 g of soil were weighed into a 50 ml polythene beaker and 25 ml of distilled water was added to the soil. The soil-water solution was stirred thoroughly and allowed to stand for 30 minutes. After calibrating the pH meter with buffers of pH 4.01 and 7.00, the pH was read by immersing the electrode into the upper part of the soil solution and the pH value recorded.

3.3.3 Soil organic carbon

Soil organic carbon was determined by the modified Walkley-Black method as described by Nelson and Sommers (1982). The procedure involves a wet combustion of the organic matter with a mixture of potassium dichromate and sulphuric acid. After the reaction, the excess dichromate is titrated against ferrous sulphate. Approximately 1.0 g of air-dried soil was weighed into a clean and dry 250 ml Erlenmeyer flask. A reference sample and a blank were included. Ten ml 0.1667*M* potassium dichromate ($K_2Cr_2O_7$) solution was accurately dispensed into the flask using the custom laboratory dispenser. The flask was swirled gently so that the sample was made wet. Then using an automatic pipette, 20 ml of concentrated sulphuric acid (H_2SO_4) was dispensed rapidly into the soil suspension and swirled vigorously for 1 minute and allowed to stand on a porcelain sheet for about 30 minutes, after which 100 ml of distilled water was added and mixed well. Ten ml of orthophosphoric acid and 1 ml of diphenylamine indicator was added and titrated by adding 1.0*M* ferrous sulphate from a burette until the solution turned dark green at end-point from an initial purple colour. About 0.5 ml 0.1667*M* $K_2Cr_2O_7$ was added to restore excess $K_2Cr_2O_7$ and the titration completed by adding $FeSO_4$ drop-wise to attain a stable end-point. The volume of $FeSO_4$ solution used was recorded and % C calculated.

Calculation:

The organic carbon content of soil was calculated as:

$$\% \, O.C = \frac{M \times 0.39 \times mcf \times (V_1 - V_2)}{s} \qquad \text{Equation 1}$$

Where

M = molarity of ferrous sulphate solution.

V_1 = ml of ferrous sulphate solution required for blank.

V_2 = ml of ferrous sulphate solution required for sample.

s = weight of air − dry sample in grams.

mcf = moisture correcting factor $\frac{(100 + \% \text{ moisture})}{100}$.

$0.39 = 3 \times 0.001 \times 100\,\% \times 1.3$ (3 = equivalent weight of carbon).

1.3 = a compensation factor for the incomplete combustion of the organic carbon.

3.3.4 Total nitrogen

Total nitrogen was determined by the Kjeldahl digestion and distillation procedure as described in Soil Laboratory Staff (1984). Approximately 0.2 g of soil was weighed into a Kjeldahl digestion flask and 5 ml distilled water added. After 30 minutes a tablet of selenium and 5 ml of concentrated H_2SO_4 were added to the soil and the flask placed on a Kjeldahl digestion apparatus and heated initially gently and later vigorously for at least 3 hours. The flask was removed after a clear mixture was obtained and then allowed to cool. About 40 ml of distilled water was added to the digested material and transferred into 100ml distillation tube. 20 ml of 40 % NaOH was also added to the solution and then distilled using the Tecator Kjeltec distiller. The digested material was distilled for 4 minutes and the distillate received into a flask containing 20 ml of 4 % boric acid (H_3BO_3) prepared with PT5 (bromocresol green) indicator producing approximately 75 ml of the distillate. The colour change was from pink to green after distillation, after which the content of the flask was titrated with 0.02*M* HCl from a burette. At the end-point when the solution changed from weak green to pink the volume of 0.02*M* HCl used was recorded and % N calculated. A blank distillation and titration was also carried out to take care of traces of nitrogen in the reagents as well as the water used.

Calculation:

The percentage nitrogen in the sample was expressed as:

$$\% \text{ N} = \frac{(\text{M} \times (\text{a} - \text{b}) \times 1.4 \times \text{mcf})}{\text{s}} \qquad \text{Equation 2}$$

where

M = concentration of hydrochloric acid used in titration.

a = volume of hydrochloric acid used in sample titration.

b = volume of hydrochloric acid used in the blank titration.

s = weight of air − dry sample in grams.

mcf = moisture correcting factor $\frac{(100 + \%\ \text{moisture})}{100}$

3.3.5 Bray's No. 1 Phosphorus (available phosphorus)

The readily acid-soluble forms of phosphorus were extracted with a HCl:NH_4F mixture called the Bray's no.1 extract as described by Bray and Kurtz (1945) and Olsen and Sommers (1982). Phosphorus in the extract was determined on a spectrophotometer by the blue ammonium molybdate method with ascorbic acid as reducing agent. Approximately 5 g of soil was weighed into 100 ml extraction bottle and 35 ml of extracting solution of Bray's no. 1 (0.03*M* NH_4F in 0.025*M* HCl) was added. The bottle was placed in a reciprocal shaker and shaken for 10 minutes after which the content was filtered through Whatman no.42 filter paper. The resulting clear solution was collected into a 100 ml volumetric flask. An aliquot of about 5 ml of the clear supernatant solution was pipetted into 25 ml test tube and 10ml colouring reagent (ammonium paramolybdate) was added as well as a pinch of ascorbic acid and then mixed very well. The mixture was allowed to stand for 15 minutes to develop a blue colour to its maximum.

The colour was measured photometrically using a spectronic 21D spectrophotometer at 660 nm wavelength. Available phosphorus was extrapolated from the absorbance read.

A standard series of 0, 1.2, 2.4, 3.6, 4.8 and 6 mg P/l was prepared from a 12 mg/l stock solution by diluting 0, 10, 20, 30, 40 and 50 ml of 12 mg P/l in 100 ml volumetric flask and made to volume with distilled water. Aliquots of 0, 1, 2, 4, 5 and 6 ml of the 100 mg P/l of the standard solution were put in 100 ml volumetric flasks and made to the 100 ml mark with distilled water.

Calculation:

$$P\ (\mathrm{mgkg^{-1}}) = \frac{(a-b)\times 35 \times 15 \times mcf}{s} \qquad \text{Equation 3}$$

where a = mg/l P in sample extract.

b = mg/l P in blank.

s = weight of air − dry sample in gram.

$$mcf = \text{moisture correcting factor } \frac{(100 + \%\ \text{moisture})}{100}$$

35 = volume of extracting solution.

15 = final volume of sample solution.

3.3.6 Exchangeable cations

Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined in 1.0*N* ammonium acetate (NH_4OAc) extract.

3.3.7 Extraction of the exchangeable bases

A 5 g soil sample was transferred into a leaching tube and leached with 100 ml of buffered 1.0*N* ammonium acetate (NH_4OAc) solution at pH 7.

3.3.8 Determination of calcium and magnesium

For the determination of the calcium plus magnesium, a 25 ml of the extract was transferred into an Erlenmeyer flask. A 1.0 ml portion of hydroxylamine hydrochloride, 1.0 ml of 2.0 per cent potassium cyanide buffer (from a burette), 1.0 ml of 2.0 per cent potassium ferrocyanide, 10.0 ml ethanolamine buffer and 0.2 ml Eriochrome Black T solution were added. The solution was titrated with 0.01*N* EDTA (ethylene diamine tetraacetic acid) to a pure turquoise blue colour. The titre value was recorded.

The titre value for calcium was subtracted from this value to get the titre value for magnesium.

Calculation:

Exchangeable Calcium (cmol of Ca (+) kg^{-1}soil) =

$$\left[\frac{V_1 - V_2}{V_3} \times V_4 \times N \times \frac{100}{w}\right] \times mfc \qquad \text{Equation 4}$$

where

V_1 = volume of EDTA required for sample aliquot titration, ml

V_2 = volume of EDTA required for blank titration, ml

V_3 = volume of aliquot taken, ml

V_4 = total volume of original NH_4OAc extracts, ml

N = normality of EDTA

w = weight of sample taken in g

mcf = moisture correcting factor $\frac{(100 + \%\ moisture)}{100}$

Exchangeable Calcium plus Magnesium (cmol of Ca + Mg kg^{-1} soil)

$$= \left[\frac{V_5 - V_6}{V_7} \times V_4 \times N \times \frac{100}{w}\right] \times mfc \qquad \text{Equation 5}$$

where

V_5 = volume of EDTA required for sample aliquot titration, ml

V_6 = volume of EDTA required for blank aliquot titration, ml

V_7 = volume of aliquot taken, ml V_4 = total volume of original NH_4OAc extracts, ml

N = normality of EDTA

w = weight of sample taken in g mcf = moisture correcting factor $\frac{(100+\%\ moisture)}{100}$

1ml 0.01 N EDTA = 0.2004 mg Ca^{2+} = 0.1216 Mg^{2+}

3.3.9 Determination of Calcium

A 25 ml portion of the extract was transferred to an Erlenmeyer flask. Hydroxylamine hydrochloride (1.0 ml), potassium cyanide (1.0 ml of 2 % solution) and potassium ferrocyanide

(1.0 ml of 2 %) were added. After a few minutes, 4 ml of 8*M* potassium hydroxide and a spatula of murexide indicator were added. The solution obtained was titrated with 0.01*N* EDTA solution to a pure blue colour. The titre value was again recorded.

3.3.10 Exchangeable potassium and sodium determination

Potassium and sodium in the percolate were determined by flame photometry. A standard series of potassium and sodium were prepared by diluting both 1000 mg/l potassium and sodium solutions to 100 mg/l. This was done by taking a 25 ml portion of each into one 250 ml volumetric flask and made to volume with water. Portions of 0, 5, 10, 15 and 20 ml of the 100 mg/l standard solution were put into 200 ml volumetric flasks respectively. One hundred milliliters of 1.0*N* NH_4OAc solution was added to each flask and made to volume with distilled water. The standard series obtained was 0, 2.5, 5.0, 7.5, 10.0 mg/l for potassium and sodium. Potassium and sodium were measured directly in the percolate by flame photometry at wavelengths of 766.5 and 589.0 nm respectively.

Calculations:

$$\text{Exchangeable K } (\text{cmolkg}^{-1}\text{soil}) = \frac{(\text{a}-\text{b}) \times 250 \times \text{mcf}}{10 \times 39.1 \times \text{s}}$$ Equation 6

$$\text{Exchangeable Na } (\text{cmolkg}^{-1}\text{soil}) = \frac{(\text{a}-\text{b}) \times 250 \times \text{mcf}}{10 \times 23 \times \text{s}}$$ Equation 7

where

a = mg/l K or Na in the diluted sample percolate.

b = mg/l K or Na in the diluted blank percolate.

s = weight of air − dry sample in gram.

$\text{mcf} = \text{ moisture correcting factor } \dfrac{(100 + \%\text{ moisture})}{100}$

3.3.11 Determination of available Potassium

Available potassium extracted using the Bray's no. 1 solution was determined directly using the Gallenkamp flame analyzer. Available potassium concentration was determined from the standard curve. Potassium standard solutions were prepared with the following concentrations:

0, 10, 20, 30, and 50 μg K / ml of solution. The emission values were read on the flame analyser. A standard curve was obtained by plotting emission values against their respective concentrations.

Calculation:

$$K\ (mg\ kg^{-1}) = \frac{(a-b)\times 35 \times mcf}{s} \qquad \text{Equation 8}$$

where

$a =$ μgK/ml in sample.

$b =$ μgK/ml in blank.

$s =$ weight of air − dry sample in gram.

$35 =$ volume of extracting solution.

$mcf =$ moisture correcting factor $\frac{(100 + \%\ moisture)}{100}$

3.3.12 Soil texture

The soil texture was determined by the Hydrometer method. Approximately 40 g of soil was weighed into 250 ml beaker and oven dried at 105 ^{0}C over night. The sample was removed from the oven and then placed in a desiccator to cool, after, which it was weighed and the oven dry weight taken. A 100 ml of dispersing agent commonly known as Calgon (Sodium Bicarbonate and Sodium Hexa-metaphosphate) was measured and added to the soil. It was then placed on a hot plate and heated until the first sign of boiling was observed. The content in the beaker was washed completely into a shaking cup and then fitted to a shaking machine and shaken for 5 minutes. The sample was sieved through a 50 microns sieve mesh into a 1.0 L cylinder. The sand portion was separated by this method while the silt and clay went through the sieve into the cylinder. The sand portion was dried and further separated using graded sieves of varying sizes into coarse, medium and fine sand. These were weighed and their weights taken.

The 1.0 L cylinder containing the dispersed sample was placed on a vibrationless bench and then filled to the mark. It was covered with a watch glass and allowed to stand overnight. The Hydrometer method was used to determine the silt and the clay contents. The cylinder with its content was agitated to allow the particles to be in suspension, it was then placed on the bench and hydrometer readings taken at 40 seconds and 24 hours intervals. At each hydrometer reading the temperature was also taken. Sand and clay portions were then calculated as percentage of quantity of sand used. Silt content was determined as difference between total soil used and that of sand and clay. The various portions were expressed in percentage and using the textural triangle the texture was determined.

$$\%Sand = \frac{\text{Weight of soil} - \text{40 seconds hydrometer reading}}{\text{Weight of soil}} \times 100$$

$$\%\ Clay = \frac{\text{24hour hydrometer reading} \times 100}{\text{Weight of soil}}$$

$$\%\ Silt = 100 - (Sand\ \% + Clay\ \%)$$

3.3.13 Effective Cation exchange capacity (ECEC)

This was calculated by summation of exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) and exchangeable acidity (Al^{3+} and H^{+})

3.4 DETERMINATION OF MICRONUTRIENTS (As, Fe, Pb and Cu)

Ten grams of soil sample was weighed into a 100 ml shaking bottle. Thirty (30) ml of 0.05 EDTA solution was then added to the sample and placed on a reciprocal shaker for 2 hrs. Sample was removed and filtered into a 50ml flask. Aliquots were then taken for the various micronutrients.

3.4.1 Estimation of micronutrients

Standard graphs of As, Fe, Pb and Cu were drawn on the AAS equipment with known standards, and the unknown samples extrapolated from the graph to obtain the concentrations. When dilutions were observed the final concentration was then multiplied by the dilution factor to obtain the actual results.

3.5 Data Analysis

Data obtained in this study on the physico – chemical properties of the soil was subjected to analysis of variance using SAS statistical software (Version 9) and results presented in bar charts where ANOVA indicated significant difference at $p \leq 0.05$ in treatment. Least significant difference was calculated and used to separate means.

The questionnaires were analysed using Statistical Package for Social Scientists (SPSS) to generate frequency tables from the data. Microsoft Excel was used to generate the charts from the frequency tables.

CHAPTER FOUR

RESULTS

4.1 Reclamation practices at AngloGold Ashanti, Obuasi mines.

Twenty respondents were interviewed from the Environmental Departmental and all the 20 (100%) respondents identified 16 sites that have been reclaimed by Anglogold Ashanti. The reclamation practices identified by the respondents were: the processes involved in reclaiming the disturbed sites, the tree species used and the communities' involvement.

4.1.1 Land reclamation processes at Anglogold Ashanti, Obuasi mines.

The 20 (100%) respondents of the Environmental Department of Anglogold identified the following as the processes involved in the reclamation: Earthwork/slope battering, spreading of oxide material, spreading of topsoil, construction of crest drains, raising of cover crops, tree planting, field maintenance, erosion control using vetiver grass, monitoring and measuring of success criteria.

4.2 Indigenous tree species before the mining started

A baseline survey by the Environmental Department of the Company identified the following tree species before the mining started; *Terminalia superba, Terminalia ivorensis, Ceiba pentandra.* The secondary forest was invaded by the exotic species especially *Cassia siamea.*

4.2.1 Tree species used in the reclamation exercise

The Environmental Department of the company mentioned that the tree species used in the reclamation process (Table 4.1) were due their ability to grow and establish fast and their economic value.

TAble 4. 1: Tree species used in reclamation at Anglogold Ashanti, Obuasi Mines

EXOTIC species	INDIGENOUS species
Gmelina sp	*Anegreila robusta* (Asanfena)
Cedrella ordorata	*Daniella Ogea*
Cassia siamea	Mansonia sp
Cassia mangium	*Terminelia superba* (Ofram)
	Khaya ivorenses (Mahogany)
	Triplochiton scleroxylon (Wawa)
	Entandrophragma utile (Edinam)
	Terminalia Ivorensis

4.3 Community participation in the reclamation process

Community participation in the reclamation included: weed and fire control, supply of local seeds, seedling establishment and maintenance of trial farms.

4.4 Perceived benefits of land reclamation by the Communities

Respondents from the three (3) communities agreed that restoration of land to owners, creation of employment, prevention of conflict and preservation of indigenous medicinal trees were the main benefits of land reclamation (Fig 4.1). Fifteen respondents each from Binsere and Kunka and 10 respondents from Sansu also claimed it serves as a safe play grounds. All the respondents from Binsere perceived aesthetic beauty as a benefit whiles 15 and 10 respondents from Sansu and Kunka respectively also asserted to land reclamation serving as aesthetic beauty (Fig 4.1).

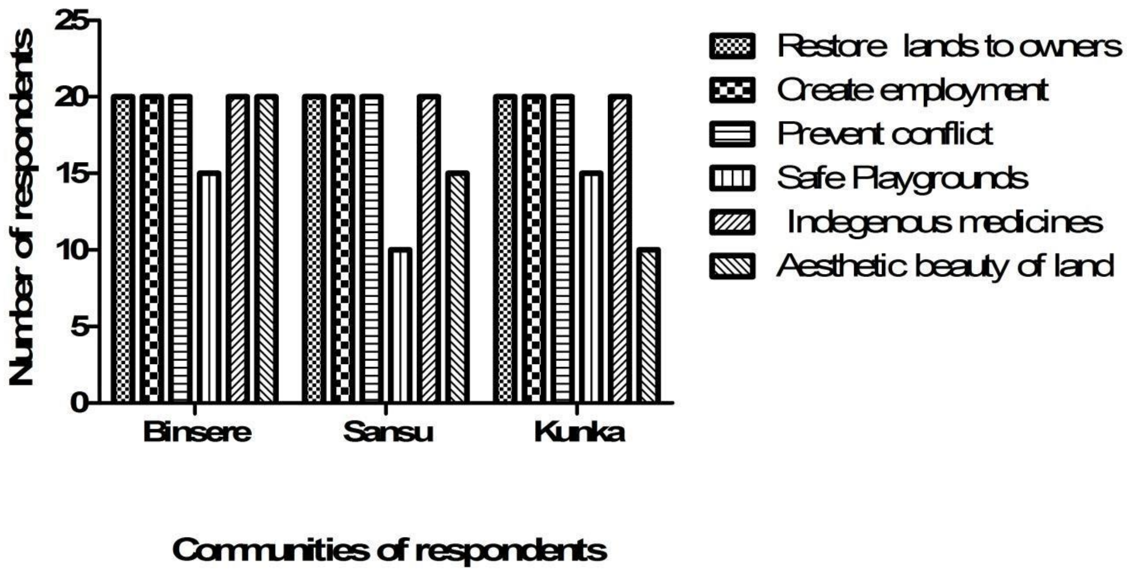

Figure 4. 1: Perceived benefits of reclamation in three Communities at Anglogold Ashanti.

4.5 Satisfaction level of reclamation by respondents

Ninety percent (90%) of respondents from Binsere and Sansu perceived the reclamation to be very satisfactory whiles 65% of respondents from Kunka also rated the practice as very satisfactory (Fig 4.2). With regards to satisfaction, 10% of respondents each from Binsere and Sansu also rated it as satisfactory. The Community Relation Officer (CRO) rates the practice as very satisfactory whiles 90 percent of respondents from the Environmental Department also rated it as very satisfactory. Only 5 percent of respondents from Kunka rated the practices as unsatisfactory (Fig 4.2).

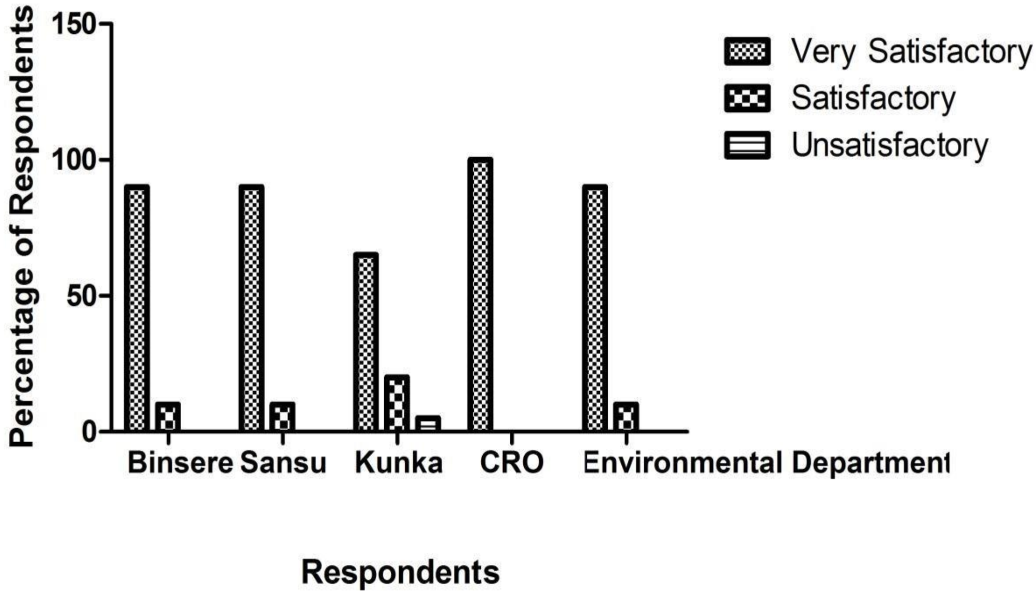

Figure 4. 2: Level of satisfaction of land reclamation perceived by the communities.

4.6 Soil chemical properties in the reclaimed sites at Anglogold Ashanti, Obuasi Mines.

Soil pH, Soil organic carbon, Nitrogen, Base saturation, Exchangeable acidity, Soil organic matter, Total exchangeable bases, Arsenic, Iron, Copper and Lead were not significantly influenced by the interaction between years of reclamation and the depth of sampling (Table 4.2).

Table 4. 2: Analysis of Variance of various soil parameters as influenced by years of reclamation and soil depth

	Soil pH	SOC	N	Na	Bs	EA	SOM	TEB	As	Fe	CU	Pb
←						Mean square						→
Years of reclamation	4.26*	0.19$_{ns}$	0.92^{ns}	1.99^{ns}	16.75**	4.44*	0.43^{ns}	2.76*	3.64*	4.54*	57.75**	3.78*
Soil depth (d)	0.13^{ns}	17.23^{ns}	23.55**	3.33*	2.82^{ns}	0.03^{ns}	9.47**	1.94^{ns}	2.68^{ns}	9.38**	32.60**	0.52^{ns}
Year *depth	0.28^{ns}	1.44^{ns}	0.97^{ns}	2.37*	0.77^{ns}	0.38^{ns}	1.81^{ns}	1.44^{ns}	0.55^{ns}	1.98ns	3.26*	0.91^{ns}
Residual	0.27	0.11	0.00082	0.0003	74.81	0.07848	0.4858	23.2262	30.7714	9323.42	1.99*	0.2151

* Means significant at $p \leq 0.05$
** Means significant at $p \leq 0.01$

4.6.1 Soil pH

Soil pH was significantly ($p = 0.0082$) influenced by years of reclamation. The pH ranged from 4.55 – 5.39 (Fig 4.3). The year 3, 6, and 9 were in the lower acidic range whiles year 12 and the control were in the optimum range. Soil depth however did not influence soil pH.

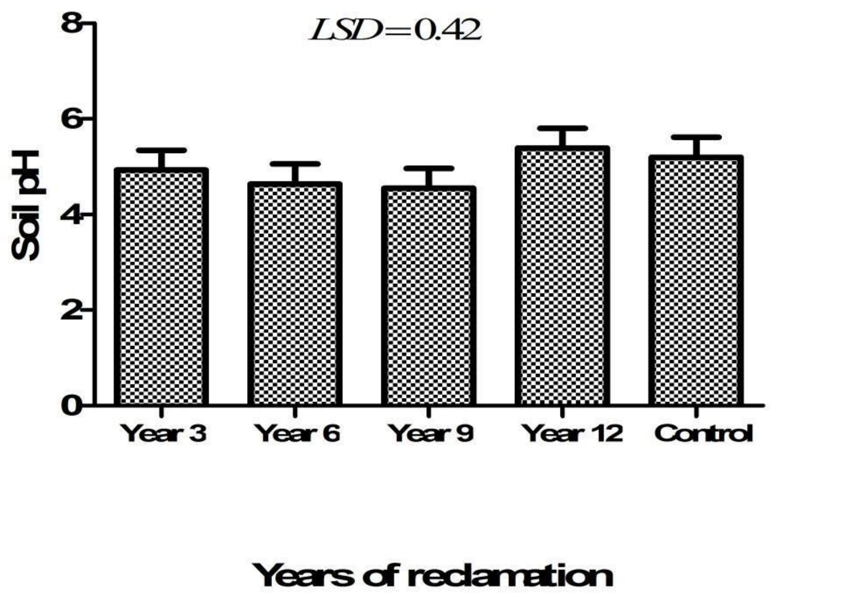

Figure 4. 3: Effect of years of reclamation on soil pH on reclaimed sites.

4.6.2 Soil Organic Carbon

Soil organic carbon (SOC) was significantly ($p = 0.0001$) influenced by sampling depth (Fig 4.4). Soil organic carbon content decreases with depth. The highest value of 0.96% was recorded at depth 0 – 20 cm which was significantly higher than SOC obtained at 20 – 40 cm and 40 – 60 cm. However, years of reclamation did not influence SOC.

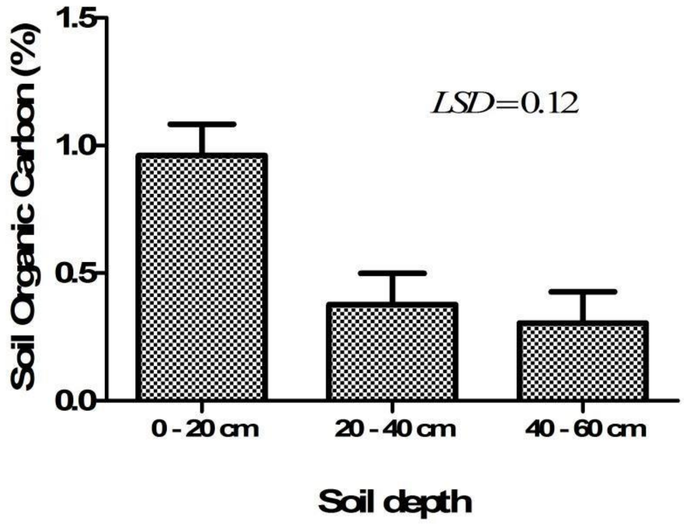

Figure 4. 4: Effect of sampling depth on soil organic carbon at Anglogold Ashanti.

4.6.3 Soil Nitrogen

Soil total nitrogen content was significantly (P = 0.0001) influenced by the sampling depth (Fig 4.5). Soil depth of 0 - 20 cm was significantly higher than depths 20 – 40 and 40 – 60 cm depth.

The least value of 0.02% was recorded at depth 40 – 60 cm. Though sampling depth was significant, years of reclamation however did not significantly influence soil total N.

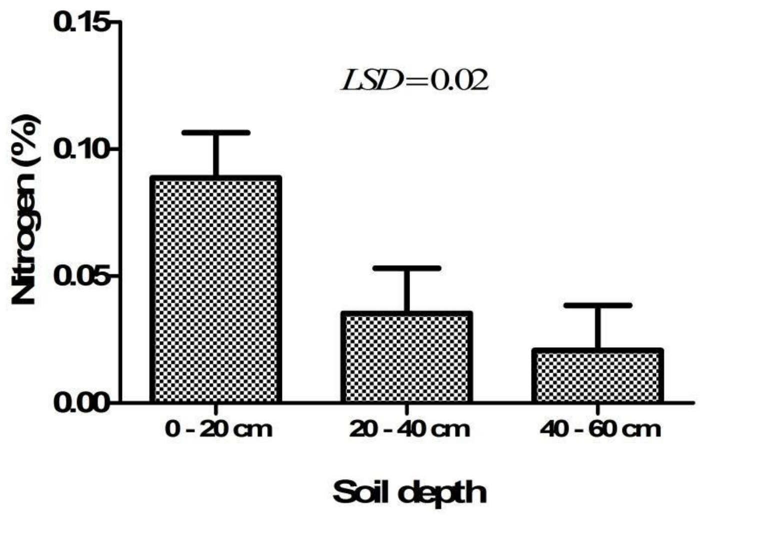

Figure 4. 5: Soil total nitrogen content at different soil depths at Anglogold Ashanti .

4.6.4 Sodium Concentration

Figure 4.6 shows that soil depth significantly (p = 0.004) influenced soil sodium concentration. There was no significant difference between depths 0 – 20 and 20 – 40 cm. However, 40 – 60 cm depth was significantly lower than depths 0 – 20 and 20 – 40 cm. Years of reclamation however did not influence exchangeable sodium concentration.

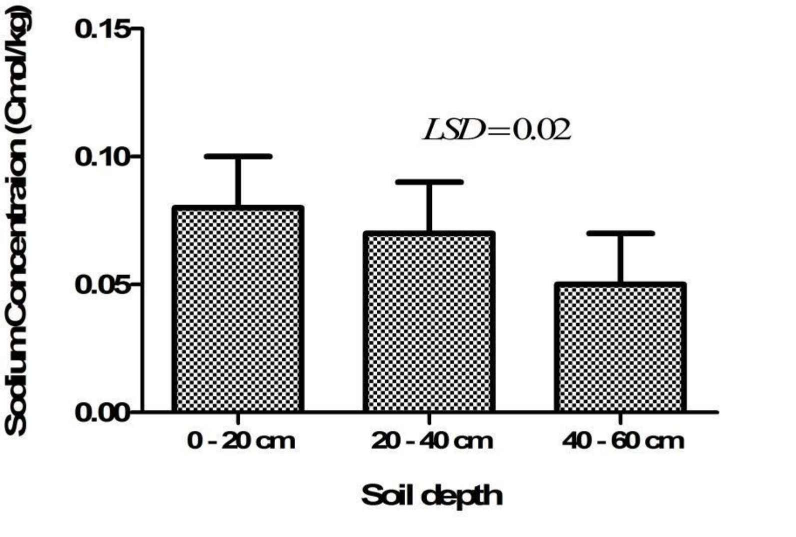

Figure 4. 6: Sodium Concentration at different soil depth at Anglogold Ashanti, Obuasi.

4.6.5 Base saturation of the soil

The years of reclamation had significant ($p = 0.0001$) effect on Percentage base saturation of the soil (Fig 4.7). Base saturation decreases from year 3 to 9 and increased in year 12 and the control. The highest value of 87.9% was recorded on year 12 reclaimed site and the least value of 61.8% on year 9 reclaimed site. There was no difference between year 3, 12 and the control, however, they were significantly higher than the year 6 and 9. Percent base saturation was not influence by sampling depth.

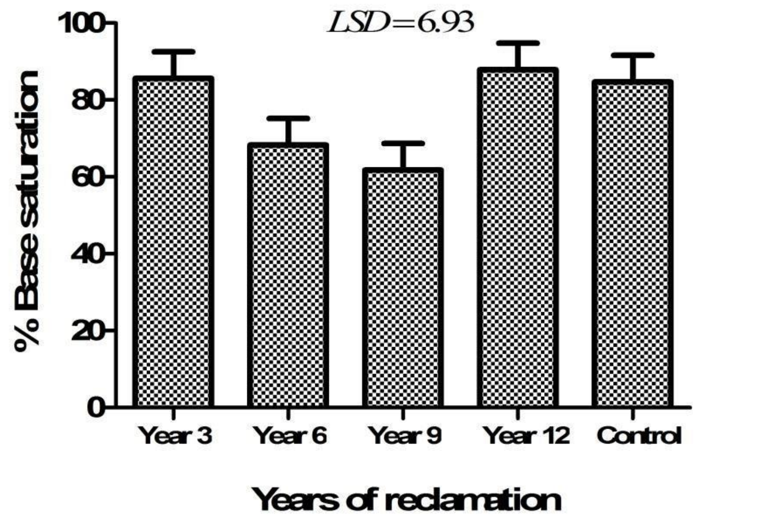

Figure 4. 7: Effect of years of reclamation on percentage base saturation of soil.

4.6.6 Exchangeable Acidity

Exchangeable acidity was significantly ($p = 0.0066$) influenced by years of reclamation (Fig. 4.8). The highest value of 1.08 was recorded on the 6 year reclaimed site and the lowest value of 0.71 on the control site. There was no significant difference between year 3, 6 and 9 sites. However, year 3, 6 and 9 sites were significantly higher than the 12 year site and the control site. Soil depth did not significantly influence exchangeable acidity.

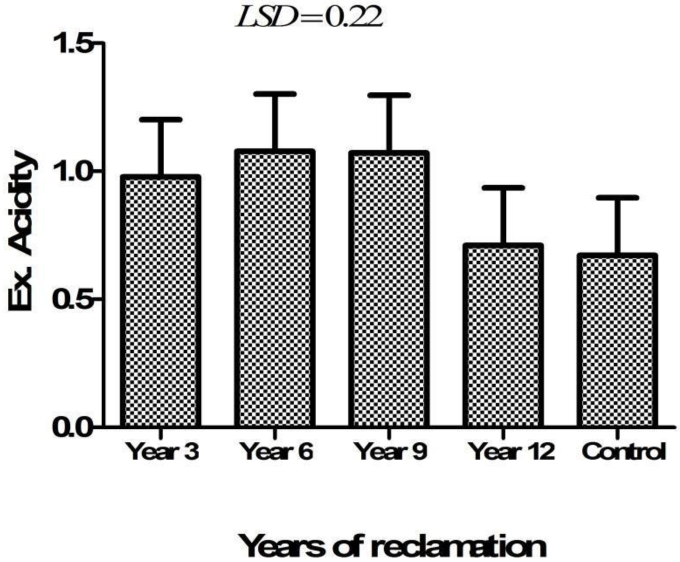

Figure 4. 8: Effect of years of reclamation on exchangeable acidity.

4.6.7 Soil Organic matter

The depth of sampling significantly ($p = 0.0007$) influenced soil organic matter content (Fig. 4.9). Soil organic matter generally decreased with depth. The least value of 0.63% was recorded at depth 40 – 60 cm and the highest value of 1.66% was recorded at depth 0 – 20 cm. There was marginal difference in SOM content between depth 20 – 40 and 40 – 60 cm. Even though sampling depth was significant, years of reclamation did not influence soil organic matter.

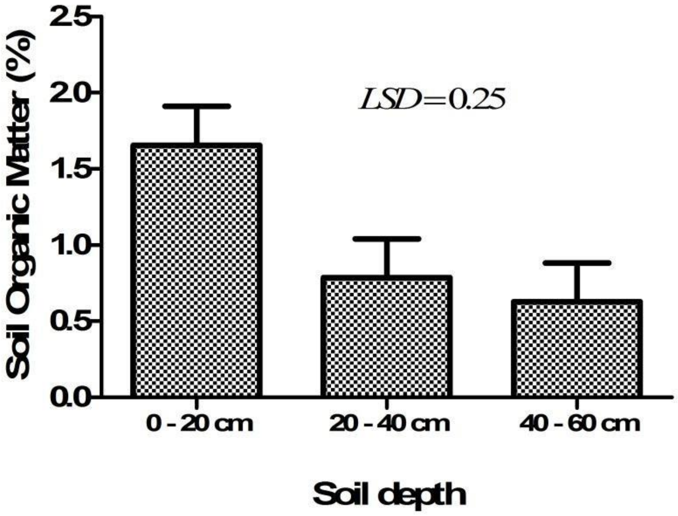

Figure 4. 9: Effect of depth of sampling on soil organic matter at Anglogold Ashanti.

4.6.8 Total Exchangeable Bases

Total exchangeable bases was significantly (p = 0.0047) influenced by the years under reclamation (Fig. 4.10). Total exchangeable bases decreased from year 3 to 9 and increased in the 12 year and the control. The lowest exchangeable base value of 1.89 was recorded on the year 9 old reclaimed site and the highest value of 8.24 on the control site. There was a marginal difference between 6 and 9 year old sites which were significantly lower than year 3, 12 and the control. However, depth of soil did not significantly influence total exchangeable bases.

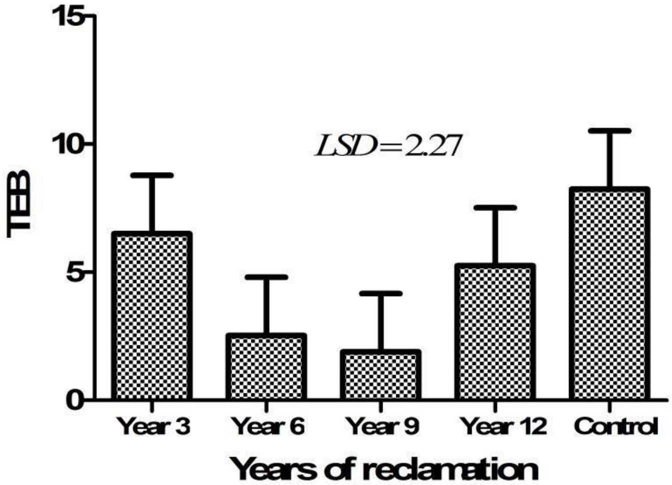

Figure 4. 10: Effect of years of reclamation on total exchangeable bases at Anglogold.

4.6.9 Exchangeable Magnesium

Figure 4:11 shows that exchangeable magnesium was significantly (p = 0.0005) influenced by the years of reclamation. Exchangeable magnesium did not follow a clear pattern. There was no significant difference between year 3, 12 year old site and the control however; these were significantly higher than that of 6 and 9 year old sites. The highest mean value was recorded on the 3 year old site and the least on 9 year old site. Exchangeable magnesium was not influenced by sampling depth.

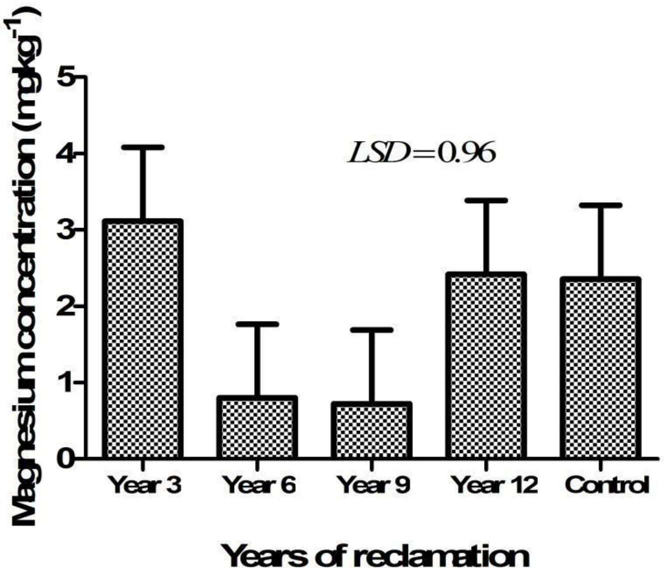

Figure 4. 11: Effect of years of reclamation on exchangeable magnesium at Anglogold.

4.6.10 Soil Particle Distribution

Table 4.3 shows the effect of years of reclamation and depth on soil particle. There was a decrease in sand and clay content with increasing year of reclamation.

Table 4. 3: Effect of different years of reclamation and depth on soil particle.

Years of reclamation	Soil Particle distribution (%)			
	Sand	Silt	Clay	Textural Class
Year 3	33.5	39.1	27.4	Clay loam
Year 6	32.3	55.3	12.4	Silt loam

Year 9	**24.1**	**65.5**	**10.4**	**Silt loam**
Year 12	**43.0**	**49.9**	**7.1**	**Silt loam**
Control	**16.6**	**66**	**17.4**	**Silt loam**

Sampling depth at 0 – 30 cm

4.7 Soil heavy metal content under land reclamation.

4.7.1 Soil Arsenic (As) content

Arsenic concentration was significantly ($p = 0.0165$) influenced by the years of reclamation (Fig 4. 12). The least value of 0.48 $mgkg^{-1}$ was recorded at the control site. The highest value of 9.44 $mgkg^{-1}$ was recorded on the 3 year reclaimed site. The 3 year old site was significantly higher than year 6, 9, 12 and the control. However, there was a marginal difference between year 6 and 9. Depth of soil did not affect soil arsenic content.

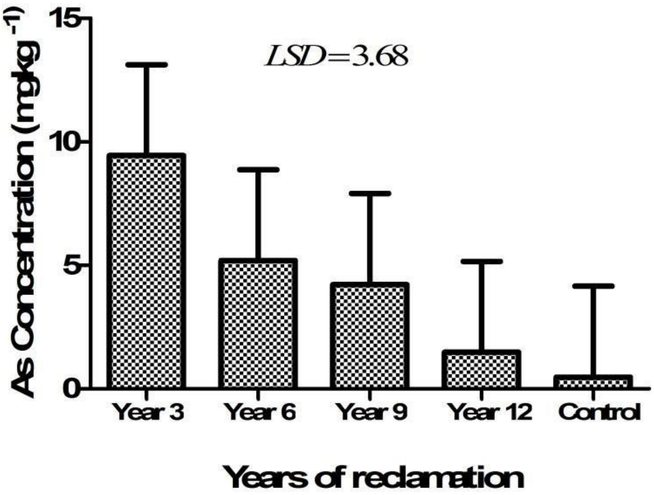

Figure 4. 12: Effect of years of reclamation on arsenic concentration at Anglogold.

4.7.2 Soil lead (Pb) content

Soil lead content was significantly (p = 0.0139) influenced by the years of reclamation (Fig 4.13). The lowest lead concentration of 0.67mgkg^{-1} was recorded on the control site and the highest value of 1.45 mgkg^{-1} on the 3 year old site. All the reclaimed sites had significantly lower Pb content than the 3 year old site. At the reclaimed sites, difference in Pb content in the 6 and 9 year site was not significant; however, they were significantly higher than what was obtained in the 12 year old site and the control. Soil Pb content was not influence by depth of soil sampling.

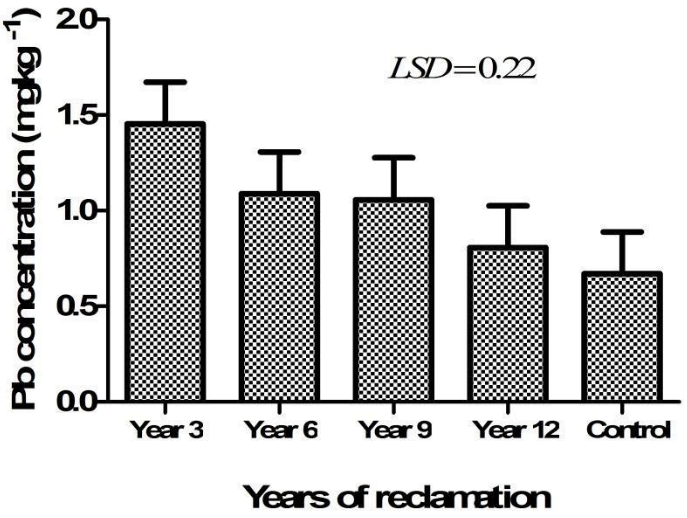

Figure 4. 13: Effect of years of reclamation on soil lead concentration at Anglogold.

4.7.3 Soil Iron (Fe) content

Depth of soil sampling significantly ($p = 0.0008$) influenced soil Fe concentration at the reclaimed sites (Fig. 4.14). Soil Fe concentration generally decreased with depth. The least value of 31mgkg^{-1} was recorded at depth 40 – 60 cm and the highest value of 177.7 mgkg^{-1} was recorded at depth 0 – 20 cm. However, years of reclamation did not affect the soil iron concentration.

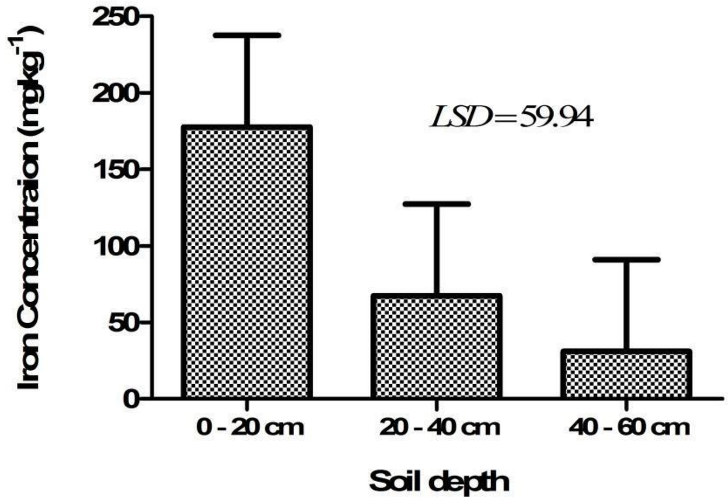

Figure 4. 14: Effect of soil depth on Iron concentration under the reclaimed sites.

4.7.4 Soil Copper (Cu) concentration

Copper concentration of the soil was significantly (p = 0.0009) influenced by both the years of reclamation (Fig 4.15a) and the depth of sampling (Fig 4.15b). Soil copper concentration did follow a clear pattern. The year 3 had a significantly higher copper concentration than year 6, 9, 12 and the control. However, there was no significant difference in copper concentration between year 6, 9, 12 and the control. With regards to the depth of sampling, copper concentrations decreases with depth (Fig 4.15b). Soil depth of 0 – 20 cm was significantly higher than soil depths of 20 – 40 and 40 – 60 cm.

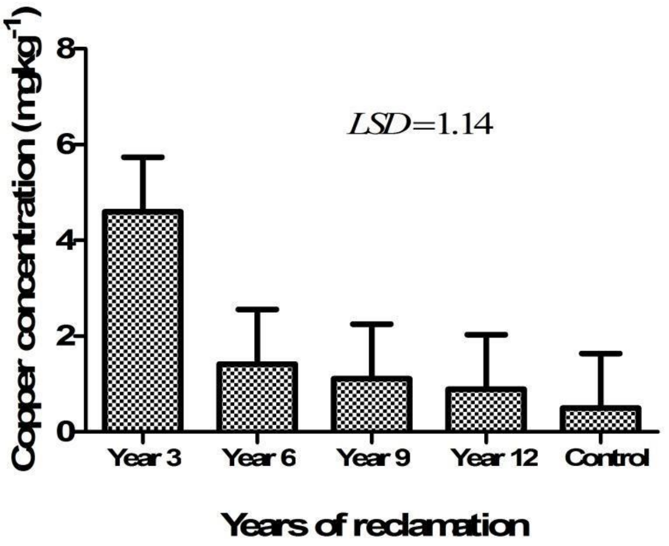

Figure 4. 15a: Copper concentrations under the different years of reclamation.

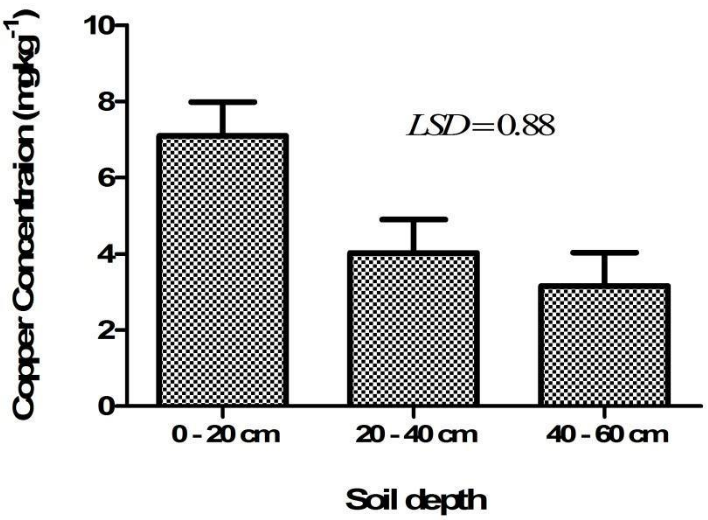

Figure 4. 16b: Copper concentrations at different soil depth at Anglogold Ashanti.

CHAPTER FIVE

DISCUSSION

5.0 Land reclamation processes at Anglogold Ashanti, Obuasi mines

At Anglogold reclamation site, Earthworks/Slope battering is done to get a visual blend of the disturbed area and the nearby undisturbed land (Tetteh, 2010). The slopes are buttered at an angle of not exceeding 30°. Immediately following the slope buttering, oxide material is spread to bind all the aggregate soil particles and to make the land surface stable. The top soil is then spread on the top of the oxide material to promote plant growth. Soil amendment like poultry manure is used to facilitate early succession. Fertilizer is applied as and when the need arises. Crest drains are then constructed to check run-off and control erosion. Vetiver grass is used as barrier approach to control erosion (Tetteh, 2010).

Plate 4. 1: Vetiver grass for erosion control

The system of strips of vetiver grass (*Vetiveria zizanioides*) has been widely promoted as a vegetative barrier to runoff (Greenfield, 1988; National Research Council, 1993; Young, 1997).Vetiver grass grows under a wide range of climates, it is relatively non-invasive and non-competitive and can be established as narrow strips, 0.5 - 1.0m wide. It is a tufted perennial grass, which creates a dense physical barrier or filter to runoff. Cover crops such as brachiaria are then broadcast on the surface of the topsoil in order to further enhance erosion control.

Tree planting is the next process after the cover crops are broadcasted. Seedlings of *Gmelina spp, Cedrella odorata, Cassia siamea, Cassia mangium, Anegreila robusta, Daniella ogea, Mansonia and Terminalia superba, Terminalia ivorensis, Khaya ivorensis, Triplochitin scleroxylon* and *Entandrophragma utile* are planted in a mixed stand at 3m x 3m planting distance. The tree planting is followed by field maintenance where pruning, weeding and fertilizer application are done.

Success criteria and monitoring are the next processes climaxing the reclamation procedure and processes. The company monitors against Acid Mine Drainage (AMD) at the waste dump site. The company checks that the slopes are stable and free from failure. Monitoring detects changes in water, air and land properties associated with the implementation of reclamation plan (Viljoen, 1998). In Ghana, monitoring is strictly mandatory particularly in globally significant biodiversity areas, where impacts are uncertain as well as fragile habitats (Fitzgerald, 1993; Allen *et al*., 2004; EPA-Ghana, 1996).

Success criteria according to the company are based on the end-use objectives. For the purposes of agriculture/farming, the following were the completion criteria stipulated by EPA

(2004) for the company's reclamation:

i. Appropriate topsoil cover ii. Topsoil

cover should be 50 cm thickness iii. Soils stable and free from erosion iv.

Completion of three food crop cycle

v. Qualitative and quantitative analysis of vegetative cover vi.

Creation of conditions favourable for the return of fauna vii.

Planted cash crop species sustainable

A site is deemed to have a final completion of reclamation if it continues to retain the criteria for land use when no additional monitoring and maintenance are required after reclamation. Acid Mine Drainage occurs when the sulphide minerals more readily oxidise in the tailings facility as a result of the size reduction from milling, increasing the surface area and thus exposure of the tailings to air and water. Acid generation and metal mobilisation occur that eventually find their way into the surrounding environment through runoff or seepage. This phenomenon is a well known problem affecting the mining industry and is commonly known as Acid Mine Drainage (AMD). Where AMD phenomenon occurs, an area will be deemed to have a final completion when no additional monitoring and maintenance are required after reclamation works have been achieved after a period of not less than 7 years (EPA, 2004).

These are done according to Environmental Protection Agency L1 1652 of 1999 and Reclamation Security Bonds (RSA) that firms agree with the EPA. The LI 1652 makes it mandatory for all mining companies to rehabilitate the lands disturbed during their operations, to re-build soil fertility levels and restore the ecosystem resilience as close as possible to pre-mining conditions where practicable. Completion criteria have been defined as reclamation success objectives (Johnson and Tanner, 2004). The success indicators are usually generated on site specific basis to enable regulatory agencies, communities and mining companies to judge the success or otherwise of reclamation programme (Elliot *et al*., 1996).

5.1 Tree species used in the reclamation exercise

The following tree species were used in the reclamation: *Gmelina spp, Cedrella odorata, Cassia siamea, Cassia mangium, Anegreila robusta, Daniella ogea, Mansonia and Terminalia superba, Terminalia ivorensis, Khaya ivorensis, Triplochitin scleroxylon* and *Entandrophragma utile*. All the reclaimed sites were dominated by equal species diversity of these tree species. The reasons given to the choice of the tree species were that, they are fast growing, have the ability to establish and survive on degraded sites, have economic value when fell for timber and have adapted to the environment (Young, 1997). In addition to this, *Cedrella odorata* is a nitrogen fixing. Nitrogen-fixing tree species (NFTS) are an ideal class of trees for afforestation of degraded sites (Mac-Dickens, 1994) because they are able to establish and thrive in nitrogen deficient soils. Lawrie, (1981), noted that in addition to their nitrogen-fixing capacity, NFTS grow quickly and tolerate a variety of adverse soil conditions. It is widely believed that 75% of nitrogen is contributed by the root nodules of these leguminous plants. Legumes also have the ability to rehabilitate degraded land by improving the physical, chemical and biological characteristics of soil (Lawrie, 1981).

Van Noordwijk and Dommergues (1990) reported that when roots of nitrogen fixing trees are in close contact with roots of non- nitrogen fixing plants, greater number of nodules and the resulting N_2-fixation is stimulated in the N_2-fixing plants. This might indicate the ability of the *Cassia magium*, to survive and improve their nitrogen fixing ability in these mined out sites and hence their selection for reclaiming these degraded sites. According to Huan *et al.,* (1985) and Osinubi *et al.*, *(*1991), drought tolerance of woody plants has been shown to be improved by VAM colonization. Accordingly, Bethelfalvay *et al.*, (1988) reported that VAM plants can absorb soil moisture below the levels accessible to non-mycorrhizal plants and thus VAM association can be important during periods of drought-stress and/or on degraded lands.

5.2 Community participation in the reclamation practices

Communities are periodically consulted to make inputs into the current reclamation projects. Workshops and focus group discussions are organized for the communities and their traditional authorities to allow them determine the final land use which is incorporated into the decommissioning and closure cost document. All the casual workers were taken from the various communities. Some are engaged in activities such as weeding, collection of seeds, clearing and maintenance of the reclaimed sites.

Fitzgerald (1993) observed that as a step in reducing pressure on reclaimed sites, many mining companies employ local communities in various stages of their reclamation efforts. These include weed and fire control, supply of native seeds, seedling establishment and maintenance of trial farms and soil conservation research. This collaboration with the communities has brought peace between the company and the communities. Fitzgerald (1993) reported that, relinquishing reclaimed lands to landowners for farming as well as granting site access to indigenous people are additional steps towards ensuring the success of reclamation activity.

5.2.1 Benefits of land reclamation as perceived by the communities at Anglogold Ashanti, Obuasi mine.

The communities see the use of the same land for both agricultural purpose and also for the mineral exploitation as increasing the monetary value on the land. The perceived benefits by the communities are in conformity with the perceived views of land reclamation benefits reported by FESS (2007) at a Consultative Workshop on Land Reclamation and Alternative Land Use.

5.3 Overall satisfactory level of the reclamation practices by the various respondents

Generally, communities are fundamentally concerned with questions of flow of benefits and the limitation or redistribution of mining impacts (Wesley-Smith 1990; Banks, 2002). The views expressed by respondents represent the fact that the communities were always in contact with the company and as a matter of fact, the company goes about its duty as stipulated in the reclamation security agreement with the EPA (EPA, 2004). Majority of the community members have also been employed by the company as casual or permanent workers and the communities are always aware of what is going on. According to the respondents, none of the sites affected by the mining exercise have been left without reclamation. Also, the usual conflicts associated with mining between mining communities and mining companies are not prevalent. These reasons affected their rating on the level of satisfaction of the reclamation practice.

5.4 Soil chemical properties under the reclaimed sites

5.4.1. Soil pH

The optimum soil pH recorded on the 12 year reclaimed site and the control may be attributed to organic acids resulting from higher organic matter decomposition. The lower acidic content in the lower years could also be attributed to low organic matter content. Riha *et al*. (1986) observed that low pH found below canopies originated from organic acids from leaf litter and acidic stem flow and through fall. Gordon (2010), reported that some major causes for soils to become acid are: Acidic parent material, Organic matter decay and rainfall associated with leaching. Rainfall is most effective in causing soils to become acidic if a lot of water moves through the soil rapidly (Gordon, 2010). Therefore the general low pH could also be attributed to the heavy rainfall pattern of the study area.

5.4.2. Soil organic carbon (SOC)

The significantly higher SOC in the top soil could be attributed to high biomass production by the MPTs to the soil surface. Obeng (2000) observed that soils of the forest belt of Ghana have a greater accumulation of organic matter in the surface horizon resulting from the more abundant leaf – fall under forest vegetation and the slow rate at which humus is oxidized. In addition, fine root growth contributes more to soil organic carbon (Norby *et al.*, 2004). According to Binkley (1996), Binkley and Giardina (1998), tree species differ in their biomass production and tissue nutrient concentrations and in their effects on soil properties such as pH, nutrient cycling and biota. According to Young and Young, 2001, high SOC is attributed to the age of the tree species used in the reclamation which produced high biomass leading to high organic matter production. Soil Organic Carbon is closely related to the amount of organic matter in the soil (SOM) which on approximation is calculated as: SOC x 1.724 = SOM.

5.4.3 Soil total Nitrogen

Higher total N in the upper soil layer could be due to leguminous trees and/or mineralization of organic matter from leaf and root biomass in the soil. Most multipurpose trees of the tropics nodulate with effective rhizobia (Sprent and Parsons, 2000) whiles others nodulate freely. The introduction of legumes into forest ecosystems holds some promise for maintaining soil nitrogen without the use of inorganic nitrogenous fertilizer (Mishra and Prasad, 1980). Continuous nitrogen input from leguminous tree species used in the reclamation could have influenced the nitrogen content of the soil. This agrees with work done by Bino (1998), who reported an increase in mean nitrogen from 0.48% to 0.53% in the surface soil after nitrogen fixing trees (NFTS) were planted. This was also in agreement with Darmawan *et al.,* (2006), who found out that the nitrogen content in the soil was mostly accumulated in the surface soil layer, from plant biomass. The presence of N-fixing trees generally increases the N content of litter fall by 4-10 times (Binkley and Giardina, 1998). The nitrogen-fixing efficiency of the legumes provides a substantial amount of fermentable organic matter for satisfactory microbial activity (Perera *et al.*, 1992) and subsequently the release of N. It is also widely believed that 75% of nitrogen is contributed by the root nodules of leguminous plants (Lawrie, 1981).

The higher soil total nitrogen of the surface soil (0 – 20 cm) can be attributed to the higher level of soil organic carbon (SOC) in the surface soil since soil total N and SOM are positively correlated.

5.4.4 Percent base saturation of the soils.

The high base saturation value recorded on the 12 year old site is an indication that the exchange sites on such soil particles are dominated by the basic cations (Ca^{2+}, Mg^{2+}, K^+, Na^+). Since low pH could result in the availability of heavy metals in the soil, the higher percent base saturation recorded in the 12 year old reclaimed site could be attributed to its comparative higher pH. According to Tetteh (2010), soils from the reclaimed sites with high pH values also have high percent base saturation.

5.4.5 Exchangeable Magnesium

It was observed that magnesium decreased with increasing years of reclamation. This may be due to leaching which agrees with work done by Yasin *et al.*, (2010), who reported that standing pattern and canopy covering of trees affects the leach out of nutrients from the soil.

5.4.6. Exchangeable sodium concentration

The decrease in exchangeable Na^+ with soil depths could be attributed to nutrient recycling and was not in conformity with a study carried out by Mishra *et al*. (2003) who observed that exchangeable Na^+ is low in the upper layers as compared with lower soil depths. Adrien *et al*. (1998) observed that low soil pH with a corresponding increase in the solubility of aluminum outcompete base cations from the binding sites on the exchange complex. The basic cations are displaced from the exchange sites to the soil solution where they are bound by organic or mineral acid and transported to lower soil horizons.

5.5 Heavy metals under the reclaimed sites

Many metals are essential to biochemical processes in correct concentrations but at higher concentration, heavy metals can have negative health implications such as irreversible brain damage. Some metals such as lead and mercury easily cross the placenta and damage the brain (Levine *et al.,* 2006).

Soils are significant sinks for metals, while water represents an important pathway for the dispersion of metals over extremely large areas (Gabler, 1997).

Generally, high content of the heavy metal concentration in soils could be attributed to the pH status of the soil. This study showed that soil pH was influenced by years under reclamation. The equilibrium between metal speciation, solubility, adsorption and exchange on solid phase sites is intimately connected to soil pH (Olomu *et al*., 1973; Kalbasi *et al*., 1978; Cavallaro and McBride, 1984; Sauve *et al*., 1997). As a result of the strong influence of pH on metal solubility (McBride *et al*., 1997), anthropogenic processes which result in the lowering of substrate pH can cause metal toxicities, even if no extra metal has been added to the system (Fergus, 1954; Kelly *et al*., 1990; Robinson *et al.*, 1995). Studies on the mobility of heavy metals in soils have shown that the mobility is strongly influenced by several factors, e.g. pH redox potential, clay mineral content, organic matter content and water content. Various processes, e.g., adsorption-desorption, complex and ion-pair formation or activities of micro organisms are also involved (Gabler, 1997).

5.5.1 Soil Arsenic Content

The lowest Arsenic concentration recorded on the 12 year old site could be due the ability of the trees to remove arsenic from the soil. Arsenic is mobilised in the local environment as a result of the oxidation of arsenopyrite. High concentrations have been reported in soils (Amasa, 1975) and rivers (Smedley et al., 1996) close to the mining operations and ore processing plant. Arsenic levels can also be attributed to a combination of natural processes such as weathering reactions, biological activity and dispersal of tailings as well as through other anthropogenic activities. According to Ortiz - Escober, (2005) under typical soil – forming oxidations, the nature of soil As is controlled by the lithology of the parent rock materials, volcanic activity, weathering history, transport, biological activity and precipitation. It could also be due to the high degree of contamination by the processes of mining operations such as roasting of ore in the past, solid mechanical dispersal of primary minerals of arsenic as well as secondary minerals formed by weathering in the tailings and contaminated water effluents (Garcia – Sanchez and Alvarez – Ayuso, 2003).

5.5.2 Soil Copper Content

Soil copper concentration was found to decrease with depth which could be attributed to nutrient recycling and also decreased with years of reclamation which could also be attributed to the ability of the trees to remove copper from the soil. Copper forms strong solution complexes with humic acids (Khan *et al.*, 2004). The affinity of Cu for humates increases as pH increases and ionic strength decreases.

5.5.3 Soil lead content

The decrease in soil lead concentration with years of reclamation could be attributed to the ability of the trees to remove lead from the soil. With decrease in depth, it could be due to nutrient recycling. Most lead that is released to the environment is retained in the soil. The primary processes influencing the fate of lead in soil include adsorption, ion exchange, precipitation, and complexation with sorbed organic matter (Mulligan *et al.*, 2001, Garrido *et al.*, 2005).

5.5.4 Soil Iron Content

The higher value of Iron recorded in the top soil could be attributed to the parent material. Vanmechelen *et al.*, (1997) stated that iron in the mineral soil layers varies within a wide range of 100 to 100,000 µg/g. Kadovic and Knezevic (2002) noted that iron concentration in the mineral of forest soils layer in Serbia amounts to a minimum value of 80µg/g, and a maximum value of 10,442µg/g. This agrees with work done by Milan *et al.*, (2009), who found out that the concentrations of iron in the soil layer of 0-10 cm was 23,800 µg/g, and in the layer of 10 - 40 cm was 24,233 µg/g. Iron is the fourth most abundant element on earth mostly in the form of ferromagnesium silicates. Soils typically contain 1 – 5% total Iron. Iron availability is influenced by the soil pH, soil aeration and reactions with organic matter.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The study revealed that Anglogold Ashanti, Obuasi mines has reclaimed the disturbed sites using earthworks/slope battering, spreading of oxide material, spreading of top soil and construction of crest drains. Cover crops were raised to control run-off and erosion.

There is high community participation in the reclamation exercise ranging from weed and fire control, consultation, seedling establishment, security and maintenance of trial farms.

The company used the following tree species: *Gmelina spp, Cedrella odorata*, *Cassia siamea, Cassia mangium*, *Anegreila robusta, Daniella ogea, Mansonia and Terminalia superba, Terminalia ivorensis, Khaya ivorensis, Triplochitin scleroxylon* and *Entandrophragma utile* in reclaiming the disturbed lands. These trees are multipurpose in nature providing more than one function.

From the study it can be concluded that the highest micronutrient content was observed in the 3 year reclaimed site. Thus there was drop in soil micronutrient content with increase years of reclamation.

6.2 RECOMMENDATIONS

- Liming and phytoremediation of mined reclaimed soils is needed to raise the pH of the soils which are generally characterised as being acidic.
- Agroforestry multipurpose trees with nitrogen fixing ability would be ideal for mine land reclamation due to their ability to establish faster on degraded lands and also improve soil nutrient levels.
- Species such as alfalfa that are capable of extracting heavy metals from the soil should be included in reclamation practices that have agriculture as end use objective to avoid toxic level of heavy metals in the food chain.

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APPENDIX 1:

QUESTIONNAIRE FOR MINING COMPANY

The questionnaire for a research instrument for a master degree thesis on the topic ***Assessment of land reclamation practices at Anglogold Ashanti, Obuasi Mines*** and it is for academic solely exercise. All information collected will be used for the purpose for which it is intended.

Tick where appropriate

A. History of Mine site

1. How many years have you been in operation?

1 – 5 [ ] 6 – 10 [ ] 11–16 [ ] 17–21 [ ] other..

2. What was the land-use before the mining operation started?

Agriculture [ ] Forestry [ ]

Others..

3. What were the indigenous tree species?

....

B. RECLAMATION PRACTICES

C.

4 a. How many sites have you reclaimed?

....

4b. Name them with their corresponding ages

Site Age

....

5 a. Enumerate and give a chronological order of the adopted processes in the reclamation of a site

....

5 b. Give the ecological implications of the listed processes in 5a above

....

6 a. Which tree species are used in the reclamation exercise?

....

b. Why have you chosen this/ these species?

....
....

7. When do you expect the area under reclamation to be fully reclaimed or be viable to be put to its end use?

....

8a. Is the reclamation practice participatory? Yes [ ] No [ ]

8b. If yes how is the community involved?

....

8 c. If no why is the community left out?

....

9. How do you deal with heavy metal contaminants in your reclamation practice?

....

10. What is/are the end / final use of your land(s) under reclamation?

....

11. How do you deal with the problem of runoff and erosion?

[ ] 1. use of earth structures (terraces, ditch-and –bank structures, etc.)

[ ] 2. biological method

[ ] 3. combination of both [

] 4. Any other

....

12a. Do you add trees to support erosion control structures? Yes/no

....

12b. If yes, what type of trees do you use?

....

13a. Have you done any cultivation on any of your reclaimed site? .....Yes ( ) No ( )
13b. If yes, how old was the site used in the cultivation?

14. Which tree species was/ were used in that particular reclamation exercise?

....

15. Which crop/s was/were grown in that reclaimed site?

....

D. MANAGEMENT AND PERFORMANCE OF RECLAMATION PRACTICES

16. How do you maintain an area under reclamation (biological composition and ecological considerations)?

....

17. How do you monitor the performance of the reclamation practice?

....

18. How do you determine the overall success of a reclamation practice (measurable indicators)?

APPENDIX 2.

Questionnaire for the Communities

The questionnaire for a research instrument for a master degree thesis on the topic ***Assessment of land reclamation practices at Anglogold Ashanti, Obuasi Mines*** and it is for academic solely exercise. All information collected will be used for the purpose for which it is intended.

NAME OF COMMUNITY………………………… Que. No ………………

A) DEMOGRAPHIC INFORMATION OF RESPONDENTS

1. Name of respondent ……………………….
2. Age of Respondent…………………………….
3. Educational background of respondent

a. MSLC b. JHS c. SHS d. Technical/vocational e. Tertiary

4. Marital status of respondent

a. Married b. Single c. divorced d. widow/widower

5. Origin of respondent

a. Native b. Migrant

6. Number of people in household ………………………………………………
7. Occupation of respondent ………………………………………………
8. How long have you been living here? 1-3years [ ] 3-6years [ ] >6years [ ]
9. Were you here when this mining company started its operations? Yes [ ] No [ ] 10. Mention some of the pre-mining activities you people were engaged in?

....

....

....

11. Are you aware that Anglogold Obuasi mine is rehabilitating the disturbed Lands? Yes [ ] No [ ]

12. Have you been to any of the reclaimed sites? Yes [ ] No [ ]

13. If yes, which of the sites?

....

....

14.Can you enumerate some of the trees/shrubs

....

....
....

....

15. Do you have any idea why those trees/shrubs were planted?

....

....

....

16. How was the nature of the land?

(i)Eroded Yes [ ] No [ ] (ii) Fertile Yes [ ] No [ ]

(iii)Very steep Yes [ ] No [ ] (iv) Rocky Yes [ ] No [ ]

(v)Waterlogged Yes [ ] No [ ]

17a. Did you see any of the demonstration farms at the reclaimed sites? Yes [ ] No [ ] 17b.What crop/s was grown there?

....

18a. Do you think the reclaimed sites can support plant growth in future? Yes [ ] No [ ]. Explain

....

18b.If yes to the above, name crops you think can thrive well on the reclaimed sites and why?

....

....

19. In terms of labour and cost, how will you compare working on reclaimed lands to that of the natural lands?

20. Is reclamation very necessary and why? Perceived benefits of the reclamation

....

....

....

21. Is the community involved in the reclamation exercise? Yes [ ] No [ ]

22. If yes, how is the community involved?

(i) Casual labourers [ ]

(ii) Permanent workers [ ]

(iii) Seed collection for sale [ ]

(iv) All 0f the above [ ]

23. In general, how will you classify the reclamation practices at the mining site?

Satisfactory [ ]

Very Satisfactory [ ]

Not Satisfactory [ ]

Destructive [ ]