KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

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COLLEGE OF SCIENCE

DEPARTMENT OF ENVIRONMENTAL SCIENCE

EVALUATION OF SOIL QUALITY AND HEAVY METALS IN *Manihot esculenta* and *Musa paradisiaca* GROWN ON RECLAIMED MINED LANDS IN THE BOGOSO/PRESTEA AREA, GHANA

A THESIS SUBMITTED TO THE DEPARTMENT OF ENVIRONMENTAL SCIENCE COLLEGE OF SCIENCE, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE

BY

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I

DECLARATION

I hereby declare that this thesis submitted to School of Graduate Studies, Kwame Nkrumah University of Science and Technology, Kumasi, is my own work towards the award of Master of Science degree in Environmental Science and thus all references and quotations cited in support of the results and the associated arguments have been duly acknowledged.

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ABSTRACT

The study was conducted at Golden Star Bogoso/Prestea Ltd. catchment to evaluate soil quality and heavy metals in cassava and plantain grown on reclaimed mined lands. Soil and crop samples were collected from four reclaimed sites of ages 1, 5, 12 and 15 years and two reference sites. The samples were analysed for physico-chemical parameters (pH, conductivity, organic matter, organic carbon, nitrate, phosphate, sulphate, chloride, exchangeable bases) and heavy metals (Cu, Zn, As, Cd, Pb, and Hg) using standard methods. It was observed that age of reclamation significantly influenced chloride, conductivity, exchangeable base, nitrate and soil pH. Sulphate was highest (23.6 mg/kg) in the 5 year site and least (5.5 mg/kg) in the 12 year site. Conductivity and chloride were observed to be lowest (95.0 µS/cm and 3.9 mg/kg) in the 1 year site while the reference site recorded the highest of (333.3 µS/cm and 10.3 mg/kg) respectively. Exchangeable bases ranged from 18.8 - 1.6 meq/100g for the 12 year and 1 year site respectively. The older reclaimed sites both recorded the highest pH of 7.3. Arsenic content ranged from 5.1 - 21.4 mg/kg for the 12 and 15 year sites respectively. The reference site registered the highest cadmium of 3.5 mg/kg, while copper ranged from 53.7 – 83.9 mg/kg for the sites. Zinc and manganese levels of 331.7 mg/kg and 256.5 mg/kg were highest in the 12 year and 15 year sites respectively. Heavy metals in crops were within maximum WHO/FAO permissible threshold except iron (24.5-25.8 mg/kg). Arsenic, cadmium, lead and mercury were not detected.

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CHAPTER ONE

INTRODUCTION

1.0 Background

The mineral extraction industry has historically been of great importance to the economic development of Ghana (Akabzaa, 2000; Agbesinyale, 2003), with the pre-independence name, Gold Coast, depicting the significance of the mining sector to the country. Ghana is endowed with mineral deposits and was ranked tenth in the world and second in Africa on the list of World Gold producing countries for 2013 and 2014 (Gold Fields Minerals Services (GFMS) Gold Survey, 2015). The mining sector continues to be a leading source of fiscal revenue to Ghana, contributing GH₵1.24 billion to the national purse or 16.2 % of total direct tax in 2014 (Ghana Chamber of Mines, 2014). The fiscal proceeds mobilized by the Ghana Revenue Authority (GRA) from the mining sector comprised GH₵ 441.2 million, GH₵ 416.5 million and GH₵ 259.4 million in corporate taxes, royalties, and pay as you earn (PAYE), respectively. Also, the producing members of the Chamber invested nearly US$ 21 million in financing a variety of livelihood enhancing projects primarily in the education, health and road sectors. In 2014, the producing members of the Chamber employed a total workforce of 12,148 Ghanaians. Consequently, mining towns such as Tarkwa, Obuasi, Prestea, Bogoso and Kenyasi have experienced positive changes in their economy due to the profitable nature of the sector.

Despite the huge contributions of mineral resources to Ghana's economic and social development, mining often exerts devastating impact on both the natural environment and the operated communities (Tauli-Corpuz, 1997; Li *et al*., 2012). Surface mining is known to disrupt the aesthetics of the landscape, soil components, microbe populations, and nutrient cycles. As demonstrated by several researchers, the complete removal of the vegetation cover during the mining process eventually results in the loss of some essential plant nutrients which are needed for sustaining healthy ecosystems (Kundu and Ghose, 1997; Amegbey, 2001). Overburden waste rock dumps often generate high heavy metal availability in soil. Compaction of acidic rocks to serve as impermeable medium to rainfall infiltration increases sand content, reduces moisture and organic matter in the mined soils. Acidic rock dumps contain sulphidic materials, and can also lead to the generation of acid-mine drainage (Ghose, 2005). Ultimately, mine waste contributes to loss of economic affluence due to multiple effects arising from pollution of air and water sources, biodiversity loss, increased toxicity and environmental disasters (Wong, 2003; Sheoran *et al*., 2008).

The scrapping of topsoil and subsoil with heavy machinery for the purpose of grade control exposes unfavourable bedrock which has no essential nutrients suitable for agriculture (Bonsu and Quansah, 1992). Between 1990 and 2005, for example, the Food and Agriculture Organization estimated that gold mining activities in Ghana resulted in a loss of 26 % of the forest cover and 15-20 % of arable land at mining communities such as Bogoso, Tarkwa and Ayanfuri (FAO, 2006). The degradation of soil can dampen economic growth, especially in Ghana where agriculture is the mainstay of the economy.

In recognition of these devastating impacts and as a response to the increasing environmental awareness by host communities and the establishment of environmental regulations, companies in the mining industry appear to be making conscious efforts to regulate the impacts of their activities on the environment and on the host communities (Cheney *et al*., 2002; Hilson, 2011).

Reclamation - the process by which highly degraded lands are returned to productivity and some measures of biotic function and productivity are restored - is one such effort carried out by mining companies to mitigate the environmental impacts of their operations. Reclamation is a key requirement of the Environmental Protection Agency (EPA) and Minerals Commission of Ghana. These agencies require that, reclamation be carried out in a manner that supports the next land-use by ensuring that features of the reclaimed lands are compatible and comparable either to the surrounding environs, or the pre-mining state (Mchaina, 2001). Reclamation of mined soils is critical to returning the pristine ecological integrity and the agricultural productivity of the soils. The process, over time, helps improve soil physical properties and the availability of major nutrients particularly, N, P, and K that enhance the fertility and productivity of the soil (Frimpong *et al*., 2014).

According to Sheoran *et al*. (2010), the re-vegetation strategy is widely accepted for mined soils reclamation as the re-vegetated soils become protected against the effects of accelerated erosion, which reduces soil nutrient concentrations through increased soil loss. Once the re-vegetation process commences and plant species have been established, the reclaimed soils need to be frequently assessed to establish their ability to support crop production in terms of major soil nutrient element availability since the duration of reclamation (Frimpong *et al*., 2014). Wetlands, arable agriculture, fish pond and grazing lands are among the potential uses of reclaimed mined sites (Cao, 2007). Evaluation of the nutrient status and the heavy metal contents of the reclaimed soil is, thus, important to assess the effectiveness of reclaimed mine lands to support food production.

1.2 Problem Statement and Justification

The Minerals Commission (2010; 2012) and the Environmental Protection Agency (EPA, 1999) require mining companies to carry out viable post-mining closure that incorporates the provision of sustainable alternative livelihood to the local people. A healthy and wellrehabilitated mined land could serve as recreational areas, grazing lands and for arable agricultural development by the local people in order to sustain their livelihoods. The expansion of surface mining operations within the Bogoso/Prestea catchment, for example, necessitated the acquisition of viable farm lands from the local people, and this also implies cumulative degradation of arable land, hence, a massive reduction in availability of fertile farm lands for food crop production. The inhabitants therefore expect that, their lands are returned similar to its productive and pre-mining condition, to support agriculture. Meeting this expectation, however, has become a major challenge to many mining companies in the country, despite efforts by some mining companies to reclaim the degraded lands. Another major limitation in the entire process is the nutrient accounting for the soil for the purpose of sustainable crop production.

While optimum amounts of nutrients are required for production of wholesome food crops, several studies in Ghana have revealed wide variations in nutrient levels of reclaimed mined soils, high heavy metal availability in these soils and the bioaccumulation of heavy metals in crops harvested from reclaimed lands and farmlands in mining communities (Hayford *et al*. 2008, Antwi, 2009; Tetteh, 2010; Adu, 2012). Hence, reclaimed soils need to be frequently assessed for ecological, physico-chemical, micro-biological and climatic environments (Frimpong *et al*., 2014).

Within the Bogoso/Prestea environs, lands under reclamation are mostly encroached by the community for the purposes of arable agriculture. However, there is a universal notion that, crops planted on these reclaimed lands are not suitable for cropping and even if crops flourish, they accumulate toxic residues that render the crops unwholesome to consumers. There is lack of data and education to confirm this perception for reclaimed lands within one of the pioneer locations where surface mining commenced. There is therefore, the need to assess soil quality of lands under reclamation and the measure of heavy metals accumulated in crops in the area.

This study seeks to provide information on the soil quality in terms of physico-chemical properties of reclaimed mined lands for sustainable food crop production within Bogoso/Prestea catchment areas. The study would also consider the assessment of heavy metals in staple crops *Manihot esculenta* (cassava) and *Musa paradisiaca* (plantain) harvested from the reclaimed lands.

1.3 Aims/Objectives

The main aim of this study was to evaluate soil physico-chemical properties of reclaimed mined lands. A secondary goal was to determine wholesomeness in terms of heavy metals in crops harvested from reclaimed lands in the Bogoso/Prestea mining environs.

1.4 Specific Objectives

The specific objectives were;

1. To quantify soil physico-chemical properties (pH, conductivity, organic matter, organic carbon, nitrate, phosphate, sulphate, chloride, exchangeable bases - calcium, magnesium, sodium and potassium) of reclaimed sites.
2. To assess the effect of reclamation age (i.e., the time since reclamation began) on the soil physico-chemical properties.
3. To determine the effect of reclamation on trace metals (Cu, Zn, As, Cd, Pb, and Hg) in soil and food crop (mainly cassava and plantain).

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In Sub-Saharan Africa, the mining sector contributes the largest foreign exchange in many countries across the continent (Ethan and Rene, 2011). In the works of Awotwi (2003), the mining sector in Ghana contributes over 40 % towards the country's foreign exchange earnings. The sector over the years has had great impact on the economy especially in the context of socio-economic development, i.e. provision of employment, attraction of foreign direct investment aimed at poverty reduction and improvement in the standards of living (Minerals Commission, 2000). Despite these positive repercussions of the mining sector especially its impact on the economy, mining activities pose severe dangers to environmental quality (BIRD, 2009). According to Araujo *et al*. (2015), there is an increasing trend of anthropogenic degradation of the land surface from mining.

2.2 Historical Synopsis of the Mining Industry in Ghana

The development of Ghana's gold mining industry dates back to the pre-colonial period, colonial period and later to post -independence period up to 1982. Different governments over the years developed different policy directions which have had a considerable influence on the industry (Yelpaala, 2004).

2.2.1 Pre-Colonial and Colonial Periods

Oral tradition and access to some archival sources reveal that, gold mining especially in its small scale began in some 2000 years ago (Yelpaala, 2004). In 1471, gold mining in Ghana started with the indigenous people in Gold Coast. Gold mining contact were initially made with the Portuguese when they first landed near the estuary of the Pra River under the command of Juan do Santarem and Pedro de Escobar at Elimina (Anin, 1994). Diego d' Azambuja later made the second expedition to the Gold Coast to trade gold around 1482. One significant issue in these transactions was their involvement and negotiations with the local people to determine the mode and content of the trade. This is hardly done in modern day and even if done terms and conditions were covertly and overtly abused (Kesse, 1985).

The process of Gold digging according to Winkle (1901), was characterized by "hazardous, tedious and back-breaking" processes. On the account of Meredith (1912), gold trade between the indigenous Gold Coasters and the Europeans was done by barter or what was considered as "silent trade". Some of the commodities exchanged included but not limited to clothing, iron, pewter basins, brass, pots and pans, salt, drinks, guns, gun-powder among others from their countries in exchange for gold dust.

2.2.2 Colonial Period

A study conducted by Akabzaa and Darimani (2001), revealed that, the formulation of mineral policy and its implementation during the colonial period began around the 19^{th} century. They emphasized that those policies were specifically aimed at establishing a legal framework and administrative procedures to regularize the operations of the mining industry.

In the view of Anin (1994) and Songsore *et al*. (1994), the gold mining industry experienced rapid growth particularly in the Tarkwa District which was described as the Apinto District of Wassa. Kesse (1985), reported that Monsieur Pierre Bonnet, who is described as the "father of gold mining in Ghana", formed a French company, the African Gold Coast

Company at Axim in 1877, and later opened up the Abosso, Tamso, Effuanta and Awudua mines. The opening up of many mines and development of economic activities made the Colonial Government appoint a District Commissioner to the Tarkwa District to assist the chiefs in local administration in 1881 (Anin, 1994).

In 1932, the Mercury Ordinance was passed as a result of native reluctance to work for the Europeans. It was therefore considered as illegal for natives to use mercury in extracting gold. The situation before the enactment of the ordinance was that the indigenous people found themselves acquainted with the main chemical for extracting the gold. This in effect, resulted in an increase in gold production and the country officially reached its highest level of production in 1933-34 (Kesse, 1985).

2.2.3 Post-Independence

Ghana's gold mining industry was controlled by the state from 1957 to 1986. The government later established the State Gold Mining Corporation (SGMC) after independence in 1961 to take over operating mines such as Bibiani, Tarkwa, Prestea, Konongo and Dunkwa from the British (Coakley, 1999).

According to Walde (1983), access to foreign currency was one of the major reasons the government acquired these mines and also to protect employment because the prevailing policy aimed at maximizing revenue and controlling resources. In spite of the above policy, Akabzaa and Darimani’s (2001), observed that, the mining sector suffered from the lack of capital investment, maintenance and exploration. Capital became increasingly scarce rendering the state-run mines uncompetitive except Ashanti Goldfields Company (AGC) and Ghana Manganese Company (GMC). The State Gold Mining Corporation later closed down its mines at Bibiani and Konongo because they were not making profits.

Between 1958 and 1964, annual gold output rose. However, the mining industry stagnated and annual gold output fell throughout from 1965 to 1986 except in 1980 when the country's gold output rose marginally (Akabzaa and Darimani, 2001). In assigning reasons for the decline of output, the World Bank (1995) and Akabzaa and Darimani (2001) reported that, the lack of foreign exchange to sustain and rehabilitate the mines; inadequate capital; and investment for mining skills were some of the main reasons.

2.3 Mining Laws and Environmental Regulations

Various enactments have been passed since the colonial era to serve as regulatory or legal framework with regard to the mining industry and provide high level approach to environmental protection. Four mineral laws which constitute the core of all the enactments made on the mineral industry in recent times include: The Minerals Act, 1962 (Act 126), The Minerals and Mining Law, 1986 (PNDC Law 153), Environmental Protection Agency Act, 1994 (Act 490) and The Minerals and Mining Act, 2006 (Act 703).

2.3.1 Administration of Lands Act, 1962 (Act 163)

In brief, this Act was ratified to consolidate with enactments and amendments relating to the administration of the mineral industry, mineral resources, stool and other lands in

Ghana. The Act vested ownership of minerals in the President who may grant license for prospecting for minerals, dredging rivers, winning minerals and obtaining water or diverting streams for mining purposes and declare land for mining purposes. Under the Act, prospecting licenses were limited to 60 square miles and to a period of 2 years. In addition, any grant of any mining rights was not to exceed 60 years and mining rights could not aggregate more than 60 square miles for anyone applicant (Administration of Lands Act, 1962, Act 123).

2.3.2 The Minerals and Mining Law of 1986 (PNDC Law 153)

PNDC Law 153 is said to be one of the measures that have provided the framework for the resurgence of the mining sector. The law which has the underlying aim of creating a positive enabling climate for both local and foreign investment in the industry, provided for numerous incentives and benefits for mining companies as well as safeguarding the environment. Among others, mining companies were to pay royalties on gold production ranging between 3 % and 12 % depending on the rate of returns. A mining lease attracted an income tax of 45 %, but should the rate of returns exceed certain agreed levels, the company paid an additional profit tax. A holder of a mining lease in an investment year qualified for 75 % capital allowance on the capital expenditure incurred and 50 % in later years. Mining companies under the Act were also granted allowances on capitalization expenditure for reconnaissance and prospecting. Gold export according to the Act was done directly by the producers, giving investors more control over the marketing of their output (Minerals and Mining Law of 1986, PNDC Law 153).

The Law under Clause 72 offers remarkable environmental protection which states that; "The holder of a mineral right shall in the exercise of his rights under the licence or lease have due regard to the effect of the mineral operations on the environment and shall take such steps as may be necessary to prevent pollution of the environment as a result of such mineral operations". Also, under Clause 83, the Secretary responsible for the implementation of the Minerals and Mining Act is empowered to make regulations for; the restriction of prospecting operations and/or preventing the pollution of water resources, ensuring the safety and welfare of the public as well as persons employed in mines and the carrying on of mineral operations in a safe, proper and effective manner.

Ghana's Mining and Environmental Guidelines were released in 1994 and formed part of the basis for Environmental Regulations under the Minerals and Mining Law (1986). The Guidelines required that mining companies prepare a conceptual Decommissioning Plan as part of the Environmental Impact Assessment (EIA). Mining companies are required to prepare a Reclamation plan to achieve the following minimum standards/objectives;

- The reclamation objective for restorable land will be to chemically and physically stabilize the land and leave it in a safe condition and return it to the same land capability as prior to mining and
- For non-restorable land, reclamation should chemically and physically stabilize the land and leave it in a safe condition and encourage re-vegetation.

2.3.3 Environmental Protection Agency (EPA) Act (Act 490) 1994

Act 490 of the EPA was promulgated in December, 1994. The Act allows the Minister of Environment to make regulations, which may provide for various matters including: "standards and code of practice relating to the protection, development and rehabilitation of the environment." The EPA brought its Environmental Impact Assessment procedures into force, and in 1997, the EPA made available for public comment a draft of the sector specific environmental guidelines being developed for industry for effluent discharges into natural water bodies that were subsequently approved in 1999. Also in 1999, the Environmental Assessment Regulations (L.I. 1652) were established. Specifically, the regulations set out the requirements for environmental permitting, Environmental Impact Assessment (EIA), the production of Preliminary Environment Reports (PERs) and subsequent Environmental Impact Statement (EIS), environmental certificates, Environmental Management Plans (EMPs) and reclamation bonding.

2.3.4 The Minerals and Mining Act, 2006 (Act 703)

Act 703 is currently the act which regulates the administration of the mineral industry and mineral resources in Ghana. The purpose of the Act is to review the already existing Minerals and Mining Law, 1986 (PNDC Law 153) and consolidate the Small-scale Gold Mining Law, 1989 PNDCL 218 to reflect on new developments in the mining industry.

On the ownership of minerals, like the Minerals and Mining Law of 1986 (Provisional

National Defence Council (PNDL) Law 153), the Minerals and Mining Act, 2006 (Act 703) vests every mineral in its natural state in Ghana in the President in trust for the people of Ghana and the Minister responsible for mines on behalf of the President. The Minister, on the recommendation of the Minerals Commission may negotiate, grant, revoke, suspend or renew mineral rights in accordance with this Act. Under the Act, mining activities require a mineral right and a person must be granted a mineral right before he/she engages in the search, reconnaissance, prospecting, exploration or mining activities. The holder of a mineral right is also required to obtain relevant permits and endorsement from regulatory agencies such as Forestry Commission, Environmental Protection Agency (EPA) and the Water Resource Commission (WRC) to ensure

protection of natural resources, public health and the environment.
In respect of fees, royalties, and rentals, mining companies are obliged to pay the following: a prescribed application fee; annual ground rent to the owner of the land or successors; annual mineral right fees; and royalties between 3-6% of the total revenue of minerals obtained by the holder. A fee, royalty or other payment which falls due under this Act is a debt owed to the Republic and recoverable in the Court. In addition to managing the large scale mining industry, the Act has made provision for the establishment of Small-Scale Mining Committees at the District level. It is important to emphasize on the expected benefits or economic gains from the improved (investorfriendly) legal regime on the economy of Ghana. The consequence of the new mining regime according to Vieta (1994), was the rapid expansion in existing mines, reactivation of abandoned mines and escalation of new exploration sites.

2.4 Impacts of Surface Mining on the Environment

Despite numerous contributions of the mining sector to livelihoods and other benefits that it creates, the sector continues to pose numerous environmental problems. Some of these problems are; destruction of forest cover, destruction of farms, disturbance of the natural habitats of game species, air and water pollution, and land degradation (Offei-Aboagye *et al*., 2004). To Aryee *et al*., 2003; cited in; Offei-Aboagye *et al*. (2004), the environmental impacts of surface mining activities in Ghana are put into one of three major categories including damage that are caused to the lithosphere, the hydrosphere and the atmosphere.

Damage to the lithosphere in mining communities in Ghana includes destruction of tracts of agricultural land which induces soil erosion.

Yelpaala (2004), contends that surface mining is strongly associated with widespread degradation of land which leads to deforestation, loss of biodiversity and natural resources. Besides, dug out surface mining are not reclaimed, and previously vegetated areas are degraded, an act which consequently induces erosion and subsequent siltation of water bodies (Donkor *et al*., 2006). In typical mining communities in Ghana, lands which are virtually devoid of vegetative cover after mining operations are quite common to be found in many mining zones throughout the country (Hilson, 2001). Akabzaa and Darimani (2001), argued that, extensive areas of land and vegetation in Tarkwa mining area have been cleared to pave way for surface mining activities. It has been observed that, about 70% of total land spaces in Tarkwa have been allocated to surface mining companies in the form of concessions used for developing open pits and other facilities. At the end of mining operations, it is estimated that, about 40-60 % of the total land take/concession would have been used for developing tailings storage facilities, open pits and waste rock dumps, mine camps, roads, and relocation for affected communities (Akabzaa and Darimani, 2001). This explains why land as a natural asset is considered essential in the mining activity. It is without doubt that surface mining activity has caused significant damage to the landscape on which these activities take place.

In support with the above studies, Schueler *et al*. (2011), assessed the actual impacts and changes to land use systems in the Western region of Ghana arising from surface gold mining. They used Landsat satellite images from 1986 - 2002 to examine how mining affects land use systems and land cover changes. Farmers were also interviewed to ascertain the implications of mining related land cover changes on their livelihoods. The results from their study indicated that, surface mining operations accounted for 58 % of deforestation whereas 45 % of farmlands were loss within mining concessions, including known spill-over effects such as farming in the forests.

Surface mining is also known to disrupt the aesthetics of the landscape, soil components, microbe populations, and nutrient cycles. As presented by Amegbey (2001), the vegetative covers of lands are removed completely during surface mining activities depriving the site of essential plant nutrients. These nutriens which are essential for sustaining a healthy ecosystem are destroyed by mining operations (Kundu and Ghose, 1997).

Recent studies for example (Tieguhong *et al*., 2009; Mehta, 2002) observed that, surface mining impacts the external environment with emphasis on air and water pollution, especially the accumulation of mercury, cyanide and arsenic, land degradation, wildlife and fishery habitats, associated health hazards and human displacement. The Commission on Sustainable Development at the United Nations have observed that the use of mercury, cyanide or the mixture of both constitute a serious environmental concern (Spiegel and Hoeung, 2011).

2.5 Impact of Surface Mining on Food Crop Production

The Food and Agriculture Organization discovered that, mining towns such as Tarkwa, Ayanfuri, Dunkwa, Esaase and Bogoso significantly lost about 26 % and 15-20 % of forest cover and arable land respectively to mining operations between 1990 and 2005 (FAO, 2006). Both large scale surface mining and illegal small scale mining plays massive roles in degrading farm lands in mining areas. Also, a study conducted in the Obuasi Municipality by Osei-Bagyina (2012), to assess the impact of mining on the land use systems and livelihoods in the mining communities showed that, farmers who depended on water bodies within the areas where illegal mining were operated for crop irrigation, detected several negative effects on their crop productivity comprising; yellowing and dying of crops before maturity, low yields, stunted growth and rotting of crops before maturity. The study showed that the negative externalities of small scale mining have caused reduction in crop yields. The study also showed that an estimated average annual yield of cocoa reduced from 207.25 kg/ha to 98.03 kg/ha whiles average annual yields of citrus also reduced from 4707.77 kg/ha to 3883.09 kg/ha over an average period of 12 years (Osei-Bagyina, 2012).

Armstrong (2008), also reiterated that surface mining activities results in large scale deforestation, soil fertility loss, and soil erosion which contributes to the very low level of agricultural productivity, “with current average yields about 40 % of achievable yields”. This has adversely impacted rural communities by contributing to a decline in the productivity of agricultural lands.

Among the contaminants encountered with mining is arsenic (As). Arsenic generally originates from natural parent sources or anthropogenic activities (Chaturvedi, 2006). The effect of arsenic pollution in Ghana is mainly seen in gold mining towns where sulphide ore is treated. For example, arsenic pollution in and around Obuasi has resulted in wilting and discoloration of leaves of both tap-rooted and fibrous-rooted plants in the area, which has had a serious adverse effect on agricultural activities particularly the production of cocoa, oil palm, cassava, plantain, cowpea and rice (Yirenkyi, 2008). Due to withering of vegetation, soil erosion also tends to be severe in these areas (Chaturvedi, 2006). The high pH of cyanide discharge from treatment plants, does not allow vegetation to flourish in areas where these cyanide-rich tailings are located as can be seen at Obuasi (Yirenkyi, 2008).

Similar study conducted by Boateng *et al*. (2012), at Atiwa district in relation to the effect of small scale illegal mining on cocoa production revealed that, a number of challenges encountered by farmers include pollution of water resources from point sources, land degradation and pollution of air from the use of heavy machines. Cocoa farms located closer to these mining sites exhibited dropping of immature pods at the early stages, low yield and yellowing of leaves. This shows that, small scale mining indeed affects food crop production in areas where the mining activities are taking place. In addition, a study conducted by Adjei (2007), on Impact of Mining on Farmers in the Wassa Mining Region, Ghana, showed that, the takeover of viable farm lands from the local people leads to high rent and unfavorable land tenure. Farming is drastically reduced in these areas, chemical induced soils results in low yields, eventually food shortages emerge leading to high cost of living.

2.6 Reclamation

Reclamation has been characterized as the restoration of disturbed lands resulting from the operations of surface or underground mining (Yelpaala, 2004). Bradshaw (1996), characterizes reclamation as a procedure of making a piece of aggravated area suitable for cultivation. Tetteh (2010), considers reclamation as an alluring and essential solution for return mined territories to worthy natural condition either for resumption of the previous use or for another use. Its fundamental target is to re-set up vegetation cover, stabilize the soil and water conditions at the site and restore the ecosystem (Yelpaala, 2004; Bradshaw, 1996). Although reclamation is frequently used interchangeably with rehabilitation, and restoration to cover enormous collection of activities involved with ecosystem repairs, a concise understanding in relation to these terminologies is necessary. Ecological restoration refers to the re-establishment 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 outlines progressive efforts towards the reinstatement of original ecosystems (Johnson and

Tanner, 2004). In addition, reclamation describes several activities aimed at improving the quality of the ecosystem by influencing some valuable ecosystem functions essential to communities, government and individuals (Bradshaw, 2000).

Reclamation Council (1992), considered reclamation as the procedure of reconverting troubled land to its past or other profitable uses. This requires the evacuation of structures, decontamination and surface restoration, for example, contouring, soil substitution and re-vegetation. Sheoran *et al*. (2010), noticed that, reclamation includes the procedure to restore the natural uprightness of distressed mine land zones. It incorporates the management of a wide range of physical, chemical and biological unsettling influences of soils, for example, soil pH, productivity, microbial community and different soil supplement cycles that makes the degraded soil productive.

In the view of Verma (2003), reclamation is a management practice that is typically connected with asset extraction. It is the procedure of returning harmed area to its unique condition or to a worthy condition through area smoothing and basic territory planting. Reclamation can be accomplished through natural recovery, assisted restoration or a combination of the two. Natural recovery requires enough time and can be hastened if assisted (Bradshaw, 1996). The procedure of reclamation is an on-going activity (Tetteh, 2010), takes time and effort; somewhere around 5 to 10 years to accomplish any critical impact (Bradshaw, 1996). Wampler *et al*. (1997), however, supports combination of assisted and progressive reclamation. Progressive reclamation is most preferred and appropriate for small and large scale surface mining in Ghana. Also, it enables reclamation to commence in an area where mining has been completed while mining at other areas are ongoing. It is considered cheaper in the sense that, waste materials from active mining pits can be transported and used at current reclamation sites.

Polster (2009), observes that soils that have been radically disturbed are extremely hard to re-vegetate fundamentally in light of absence of rich topsoil which is expected to give nutrients, moisture, and a substrate for growth of plants. Reclaiming of lands is aimed at enhancing soil fertility, particularly by improving nutrient levels such as nitrogen in order to sustain plant life (Bradshaw, 1996). This is best accomplished through the availability of fertile topsoil, introduction of nitrogenous fixing legumes and tree plants. The success of reclamation within an acceptable period is largely dependent on topsoil rich in nutrients in addition to application of best practices targeted at sustaining fertility (Bradshaw, 1996).

Along these lines, the reason behind reclamation as a major aspect of mining operations is with the goal of leaving the mined area in a working environmental (to the degree possible), and physically-chemically stable state, accordingly making it accessible for future land uses. Reclamation of mined zones is vital to re-build up the ecological balance of the ecosystem and keep up a self-maintained ecosystem where all vital natural procedures happen (Verma, 2003).

2.6.1 Objectives of Mining Land Reclamation

Although mining is viewed as an urgent financial action around the world, mining has a critical negative effect on environment. Because of its tendency, particularly surface mining leads to serious degradation on ecological and visual values of the landscape. At the point when the extraction of the reserve is over, the altered landscape must be recovered so as to ease the harming impacts of surface mining and restore the landscape and its environment (Kuter, 2013).

It must be observed that, recovery of post-mining landscape is an exceptionally difficult assignment due to the fact that, there is no one specific procedure for such landscapes, and it profoundly relies on the site-unique qualities. In this manner, successful reclamation requires interdisciplinary methodology leading to coordinated and effective proposal to restore environmental, hydrological, aesthetic, recreational and different elements of the post-mining landscape. Diverse reclamation strategies and procedures have been proposed by a few disciplines, for example, environmental and mining engineering, forestry, archeology and social sciences.

In the view of Kuter (2013), a recognized objective of reclamation is aimed at creating a stable landscape that is aesthetically and environmentally compatible with surrounding environment, taking into account the needs of future generations. In general, the guideline for remediation of a contaminated land consists of minimization of actual or possible environmental threat, or the reduction of potential risks to acceptable levels. Cao (2007), observes that, the main objective of the mine reclamation is to ensure mitigation of adverse impact in the post mining scenario. Hilson and Murck (2000), aver that, reclaimed sites have a wide range of potential functions such as pasture, hay land, recreational areas, wildlife habitat, wetlands, fishing ponds, and swimming pools. Hilson (2011), made an observation that, due to recent development in the mining sector, such as the enactment of legislation and regulatory frameworks, provide incentives and guidelines for these mining companies to reduce their impacts on the environment and host communities. Reclamation is one of the awareness and goals of sustainable mining.

2.6.2 The Reclamation Process

The reclamation process starts when mineral resources have been exhausted. The decision to commence reclamation is backed by planned programmes, cost allocations and available equipment. Earth works are then initiated and conducted in such a way to blend with surrounding topography. Slopes are made stable and battered to maximum angle of 30˚. Growth medium and topsoil should be supplied in bulk after the filled out area is sufficiently settled. Topsoil is required and spread at a depth of 150 mm, allowing a settlement differential of about 50-75 mm (Sangakkara *et al*., 2008).

A period of about two weeks should be allowed before the planting of suitable cover crops with nitrogen fixing ability. To FAO (2011), perennial crops which produce abundant biomass are preferred to annual crops. Cover crop should be planted using seeds broadcasted evenly over the entire site (Sangakkara *et al*., 2008). The process may be repeated over areas which experienced poor germination to maintain continuous cover for the site. To improve or enhance soil fertility for the cover crops, it is sometimes necessary to apply a nitrogen fertilizer to the soil.

2.6.3 Re-vegetation of Mined Site

Re-vegetation in reclamation activities according to Yelpaala (2004), is highly effective in areas where multiple native species are mainly used since they are well adapted, and can sustain a greater biodiversity. Reclaimed sites must have a better nitrogen status to support plant growth, therefore, interventions that serves to promote soil and plant health should be key (Diver *et al*., 2008). To achieve this, leguminous cover crops that have the capacity to serve as pioneering herbaceous species like *Centrosema pubescens*, *Crotalaria juncea* should be broadcasted on the prepared land. This also serves as a soil cover to prevent erosion (Sangakkara *et al*., 2008).

Natural re-generation should be encouraged because it is beneficial in areas where native woody plant species naturally re-vegetate the site in tandem with the transplanted exotic tree seedlings. This can be achieved particularly where top soil rich in local tree seeds is obtained from adjacent boundary to the excavated site. Also, in case the site is close to a natural habitat, seed dispersal from the neighboring site will ensure fast colonization (Handel, 2009). In a situation where the excavated site is located far from any natural habitat, the best option will be to use mainly exotic tree plants.

2.6.4 Completion Criteria

Success indicators are usually established by regulatory agencies. However, the projected use of the land and site specifics agreed upon by the communities and mining company plays significant roles for any reclamation success story (Johnson and Tanner, 2004; Elliot *et al.*, 1996). In the view of Hobbs and Norton (1996), despite mining companies meeting the expectations of host communities and regulatory agencies, the basis for establishing reclamation success criteria had been widely criticized in recent times (Walker and Moral, 2003). In the past, reclamation success indicators were based on onset of narrow vegetation parameters measuring only early stages on re-vegetation.

Current indicators however, incorporate approaches encompassing self-regularity, impact mitigation, probability as well as socially relevant components of the reclaimed ecosystems (Ludwig *et al*., 1997). In general, reclamation success should be judged on actual demonstration of regular monitoring of change associated with ecosystem processes (Bell, 1996). Reclamation is only deemed successful and agreed upon when the site can be managed for its designated next land use without any further management input compared to other lands used in the same way (Laurence, 1999).

2.6.5 Monitoring and Reclamation Success

The main aim of environmental monitoring in many mine sites is the incorporation of mitigation activities into mining and reclamation towards good environmental stewardship (Asher and Bell, 1999). Frequent monitoring of flora and fauna on both reclaimed and adjacent undisturbed areas permit authorities to understand annual variation in species diversity and abundance. Environmental monitoring of reclaimed mined sites provides response mechanism with regards to the success and maintenance of mitigation measures as well as evaluation of the overall EIA processes (EPA-Ghana, 1996). At closure, monitoring contributes massively towards the success of ecosystem recovery (Asher and Bell, 1999). Monitoring builds the frame for identifying changes in environmental and land properties related to the implementation of reclamation plan (Viljoen, 1998). At highly sensitive and significant sites in Ghana, monitoring is deemed mandatory (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.

2.7 Reclaimed Lands Fertility and Support for Agriculture

Mining subsequently brings about intense changes in land use patterns, as mined lands preceding mining operations might have been utilized for forestry, agriculture and other beneficial purposes. This is for the most part accomplished through reclamation which incorporates the refilling of the removed overburden and has been fruitful as a rule. According to the Ghana Food and Agricultural Policy (2012), soils of mined sites can be enhanced to 70 % of its pre-mining potential. Kumar and Kumar (2013), contended that, mine spoils, constitute parent rocks and subsoils which are insufficient in plant supplements due to the absence of biologically rich top soil. Viability of reclaimed mine lands to support any productive venture and in the case of agriculture is incumbent on a variety of factors and conditions. This includes but not limited to the period for the reclamation, the type of mining method and mineral mined, the chemicals and intensity of machinery used and the extent of damage caused to the landscape through the various operational activities (Chaubey *et al*., 2012).

Ghose (2004), in his study on the impacts of opencast mining on soil fertility claimed that, topsoil is a fundamental factor in relinquished mined land for development of vegetation and must be reserved for post-mining land reclamation. There is a long time interval between stripping of topsoil to finally laying of the same soil over the reclaimed lands hence, the nutrient levels of stockpiled topsoil may reduce and become biologically unproductive. The excavated overburden materials from pits are shaped into huge dumps deficient in plant nutrients. This goes to affect its ability to support the growth and sustainability of plants. Soil is polluted due to disposal of mining wastes, wet and dry deposition from the atmosphere, infiltration of contaminated water and acid mine drainage (Aswathanarayana, 2003). This results in several changes occurring in the physical, chemical and microbiological properties of soil and soil fertility gradually deteriorates by the years (Singh and Singh, 2004; Horvat *et al.*, 2003).

2.8 Heavy Metals in Soil

Several studies have been conducted on heavy metal pollution within mining communities in Ghana dating back to the last few decades (Carboo and Serfo-Armah, 1997; Hilson, 2002; Adimado and Amegbey, 2003; Manu *et al.*, 2004; Essumang *et al.*, 2007; Obiri, 2007; Yidana *et al.*, 2008; Armah *et al.*, 2010; Nude *et al.*, 2011).

In the view of Wild (1994), the term heavy metal is considered as any chemical component with a specific gravity that is not less than five times the specific gravity of water and is harmful or toxic at higher sums. Usually, heavy metals are related to industrial release of metalloids such as arsenic, cadmium, copper, lead, mercury and zinc into the environment. The European commission recognizes these metals as the most serious threat to plant and animal life.

Heavy metals enter our bodies by means of sustenance, drinking water and air. Some substantial metals such as copper, selenium and zinc are vital to keep up to maintain the metabolism of the human body. Nonetheless, at higher concentrations, they can result into poisoning that may cause acute or chronic toxicity. Heavy metals are risky on the grounds that they tend to bioaccumulate. Bioaccumulation implies an increase in the concentration of a chemical in a biological organism over a period, contrasted with the chemical's concentration in the environment. Compounds accumulate in living organisms whenever they are taken up and stored faster than metabolized or excreted. In the view of Wild (1994), all foods and water comprise of metals and non-metals that at high concentrations, whether from natural or industrial sources can become harmful. The exposure of the general population to heavy metals in many part of the world has reached levels that are significantly high to cause some effects among sensitive groups of the general population. The major basic organs for environmentally exposed populations are the central sensory system of the creating foetus or child (lead and mercury) and the kidney (cadmium) (Bernard, 1995).

Numerous metals and metalloids are available in minute (trace) qualities in the soil water. Thus, these trace elements occur naturally due to rock weathering. They can be leached into surface water or ground water, taken up by plants, released as gases into the atmosphere or bound semi-permanently by soil components such as clay or organic matter. Even in smaller quantities, a lot of these trace elements (e.g. nickel, boron, copper and zinc) are crucial for plant development. However in higher sums they might diminish plant growth. To Dai *et al*. (2004), elements such as arsenic, cadmium, lead and mercury are of concern basically due to their potential adverse effect to soil organisms, animals and man. The effect of heavy metals on soils hinges on numerous factors, for example, pH, organic matter, cation exchange capacity and species of metals.

A high percentage of the gold bearing ore in the mining communities is embedded in mineralized dyke and schist (pyrite and arsenophyte) associated with arsenic and sulfur. The extraction of the gold includes broiling which discharges airborne particles and huge amounts of arsenic into the atmosphere (14-19 tons daily in Obuasi). Both past and present large scale and illegal small-mining activities have affected water resources in satellite communities. Stream water is altogether contaminated by As, Hg, Fe, and, to some degree, Cu, Ni and Zn (www.sciencedirect.com). Pb, Cd and Hg are the three most pollutant heavy metals. Cd, As, Cr and Hg are highly toxic, Pb, Ni, Mo and F are appreciably toxic whiles B, Cu, Mn, Zn and Fe are low in toxicity (Brady, 1990).

2.9 Heavy Metals in Food Crops

The issue of plant pollution is of interest or concern due to two fundamental reasons. In the first place, pollutants may have direct phytotoxic impacts on the plants themselves, leading to a reduction in crop returns and threatening food supplies. The second concern is that, plants may act as media through which heavy metals enter the food chain. For instance, high levels of Cd may be stored in plant tissues that may be in excess and dangerous to the plants themselves and even greater consequences to animals that feed on the plants.

The issue of food chain contamination by heavy metals has become serious in recent years because of their possible accumulation in biosystems through contaminated water, soil and air. The major sources of heavy metals to crops are their growth media (soil, air, nutrient solutions) from which these heavy metals are taken up by the roots or foliage (Lokoshwad and Chandrappa, 2006). A variety of diseases can be caused, triggered or exacerbated by heavy metal toxicity. Included are lead and mercury as well as arsenic, cadmium, copper, iron and manganese. Surplus of these elements and compounds in the environment leads to increased levels in human body tissues, thus decreasing their ability to remain healthy.

Established in the samples in Obuasi were high concentrations of arsenic in soils, water, plants, selected food items, and human hair (Amasa, 1975; Amonoo-Neizer and Busari, 1980). The lowest arsenic content of 0.07 mg/kg was recorded for oranges whereas pepper recorded the highest value of 0.97 mg/kg wet mass in Kumasi. At Obuasi, cocoyam leaves accumulated the least arsenic levels of 0.14 mg/kg and plantain samples registered the highest arsenic levels (1.86 mg/kg wet mass) (Amonoo-Neizer and Amekor, 1993).

2.10 Soil Properties and Fertility

Fertile soils contain in readily available forms all chemical and biological constituents such as mineral (inorganic) matter, organic matter, water, air and organisms essential for plant growth. The chemical composition is greatly determined by the nature of parent materials from which the soil was formed and by the processes that it has undergone over time. Reclaimed soils are not monoliths of unchanging composition but rather characterized by large spatial variability in both vertical and horizontal spheres. In order to support plant growth, reclaimed lands must have the necessary and sufficient nutrients. These soils most often lack the adequate amount of such nutrients in question due to the heavy chemicalization of these soils during excavation (Plaster, 2009).

2.10.1 Potassium

According to Zublena (1997), Potassium is one of the most important nutrients needed in the process of photosynthesis, water transport, sugar transport, protein synthesis and starch formation. Apart from nitrogen which is needed in large amount especially in crop production, potassium is a mineral nutrient that is required by plants in sufficient amounts (Marschner, 1995). Soils that contains the right amount of this mineral in quest improves disease resistance, tolerance to water stress, winter hardiness, tolerance to plant pests and efficient uptake of other nutrients.

2.10.2 Nitrogen

In order to update soil quality after heavy mining activities, the presence of nitrogen becomes of essence to crop production. Nitrogen is required to guarantee optimum crop quality as protein content of crops is directly related to nitrogen supply (Grant and Flaten, 1998). It is a part of all plant proteins and component of DNA and RNA. Available nitrogen is taken up by plant roots in the form of (NO_3^-) and (NH_4^+). The available forms of nitrogen are very water soluble and move rapidly through the soil profile with rainfall and irrigation. From the stand point of environmental sustainability, nitrogen leached as nitrate reduces water quality as well as N_2O released into the atmosphere contributes to greenhouse gas effect and global warming (Campbell *et al.*, 1995).

2.10.3 Phosphorus

Phosphorus is a mineral needed by the plant to convert solar energy into chemical energy relevant for the synthesis of sugar, starch and proteins. Generally, the energy dynamics of the plant is premised phosphorus (P) content of the soil which is taken up by plant mostly as $H_2PO_4^-$. To maximize crop yield and effective production, nutrients such as phosphorus, potassium and nitrogen need to be present in balanced quantities (Halvorson and Black, 1985).

2.10.4 Exchangeable Cations

The cation exchange capacity (CEC) of a soil maybe defined as the amount of negatively charged sites on surface of the soil that can electrostatically retain positively charged ions (cations). Calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+) and potassium (K^+) constitute the core of the positively charged ions. A high CEC does not necessarily exhibit more soil fertility since soil CEC could be occupied by acidic hydrogen (H^+) and aluminum (Al^{3+}). CEC is however a standard indicator of soil quality and productivity.

According to Hesse, 1998, calcium is a macronutrient that is highly used by plants in relatively large amounts. It is a secondary element since it is indirectly added to the soil during the application of primary fertilizer elements - NPK. Magnesium is essentially involved in energy metabolism in the plant, protein formation and important part of chlorophyll (Zublena, 1997).

2.10.5 Soil pH and Acidity

Soil pH plays a major factor for the presence of essential plant nutrients (Rahman and Ranamukhaarachchi, 2003). Weak acidic conditions help the uptake of nitrates and phosphates. It was observed by Fageria and Baligar (1998) that, soil pH and base saturation are important soil properties that stimulate nutrient availability and crop growth. Also, soil pH determines the fate of soil-microorganisms interactions and later affects both organic matter decomposition and nutrient availability (Mengel and Kirkby, 1982). Slightly acidic soil pH (5.5) enhances fungal activity and at alkaline levels makes bacterial more abundant. The rate of nitrification process promoted by *Nitrosomonas* and *Nitrobacter* bacteria depends largely 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). Generally, the rate of bacteria growth is more sensitive to low pH than fungal growth (Walse *et al.*, 1998). Donelly *et al. (*1990), reasons that, the biomass and lignin decomposition by microbes appears insignificantly impacted by soil acidity at pH range of 4.5-6.5. However, in acidic pH (less than 4.5), microbial activity as well as nutrient turnover is greatly reduced (Santa, 2000).

2.10.6 Organic Matter

Organic matter is defined as the portion of soil that includes animal and plant remains at various stages of decay. Organic matter improves soil conditions by increasing soil water and nutrient holding capacity and forming soil aggregates which improves tilth (Plaster, 2009). According to Barber (1995), the chemical composition of organic matter fluctuates but mainly consists of about 50 % carbon, 5 % nitrogen, 0.5 % phosphorus, 39% oxygen and 3 % hydrogen. In addition, soil organic matter increases cation exchange capacity over time.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of Study Area

The study was conducted at Bogoso/Prestea, located in the Prestea-Huni Valley District, on the western border of the Ashanti Gold Belt in Ghana. Extensive commercial-scale mining activities have occurred within the Bogoso/Prestea area dating back to 1930s, involving several mining companies such as Marlu Gold Mining Areas Ltd., Canadian Bogoso Resources Limited (CBRL), Billiton Bogosu Gold Limited (BGL), and more recently (since 2001) Golden Star Resources (GSBPL, 2015). As outlined in the GSBPL Environmental Management Plan (GSBPL, 2015), the study area (Bogoso concession) is located approximately 35 km northwest of Tarkwa while the Prestea lease is located approximately 15 km south of Bogoso in the Prestea-Huni Valley District in the Western Region of Ghana (GSBPL, 2015) (Figure 1).

The predominant topography of the concessional areas is characterized by a series of northeast-southwest trending sub-parallel ridges, including low, steep-sided hills and ushaped valleys while some areas within the concessions have significant changes in elevation (GSBPL, 2015). The Bogoso/Prestea area is located in the wet, semi-equatorial climatic zone of Ghana mainly determined by the movement in the Inter Tropical Convergence Zone (ITCZ).

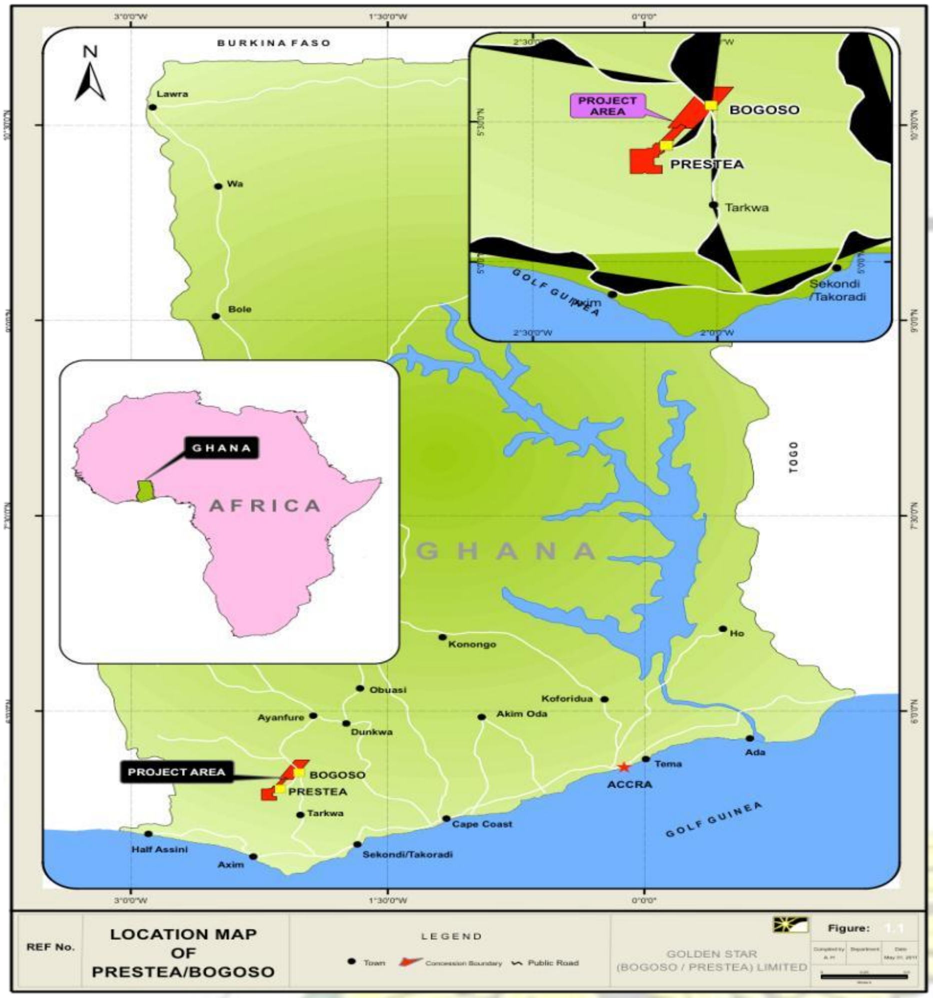

Figure 1: Map showing Bogoso/Prestea (source: GSBPL, 2015)

Rainfall data gathered at Bogoso from 1995-2015 indicate a mean monthly rainfall ranging from 23.2 mm in January to 286.7 mm in June and a mean annual rainfall of 1626.4 mm. About 58 % of rainfall occurs from April to July whiles approximately 29 % occur from September to November. Mean monthly temperatures range from 28 ˚C to 38 ˚C. Relative humidity is fairly constant throughout the year, ranging from 70 % to 90 % (GSBPL, 2015). The geology of the Bogoso/Prestea area is divided into three main lithostructural assemblages; the Tarkwaian litho-structural assemblage, the tectonic breccia (volcanic rocks) and sparse Tarkwaian sedimentary slivery. Three distinct styles of mineralization are found on the Bogoso/Prestea area. The most extensive is the sulphiderich and sheared graphitic zones. The second style consists of laminated, fault-fill quartz veins and the third style consists of sulphide-rich, brecciated and volcanic lenses (GSBPL, 2015).

The natural soils in the project area are formed by the *in situ* weathering of the underlying base rock, namely the Tarkwaian, Upper Birimian, and Lower Birimian formations.
Factors such as topography give rise to numerous soil series, including the Atukrom, Atewa, Asikuma, Ansuma, Kakum, Kokofu, Nsuta, Piki, and Temang series. The soils are described in broad terms as ferrasols and oxisols, respectively. In general, the soils are strongly acidic, experience high rates of leaching due to the high rainfall regime and are generally nutrient-poor, as they lack nitrogen, phosphorous and exchangeable basic cations (GSBPL, 2015). The predominant land uses in the area include agriculture, residential, forest and mining. As per 2010 census analysis, approximately 35,760 and 10,000 populations reside in Prestea and Bogoso respectively and about 52 % of the households engage in some form of agriculture.

3.2 Sampling Design

Four sites within the Bogoso/Prestea concession of GSBPL, representing four reclamation chronologies, were selected for the study (Table 1). These sites were one (1)-year old (1.3 ha), five (5) - year old (25.9 ha), 12-year old (5.0 ha), and 15-year old (1.0 ha) reclaimed sites (Figure 2). In addition, two adjacent un-disturbed lands were used as reference sites. The 1-year site was used by GSBPL as a temporary ore stockpile and reclamation commenced in 2015. The 5-year old site was a revegetated waste rock dump, but currently has been encroached and used to cultivate crops by the community. The 12 and 15-year old sites were waste dump and pit-waste dump, respectively. The land use criteria and post monitoring of these sites have been completed and are actively utilized for agricultural production.

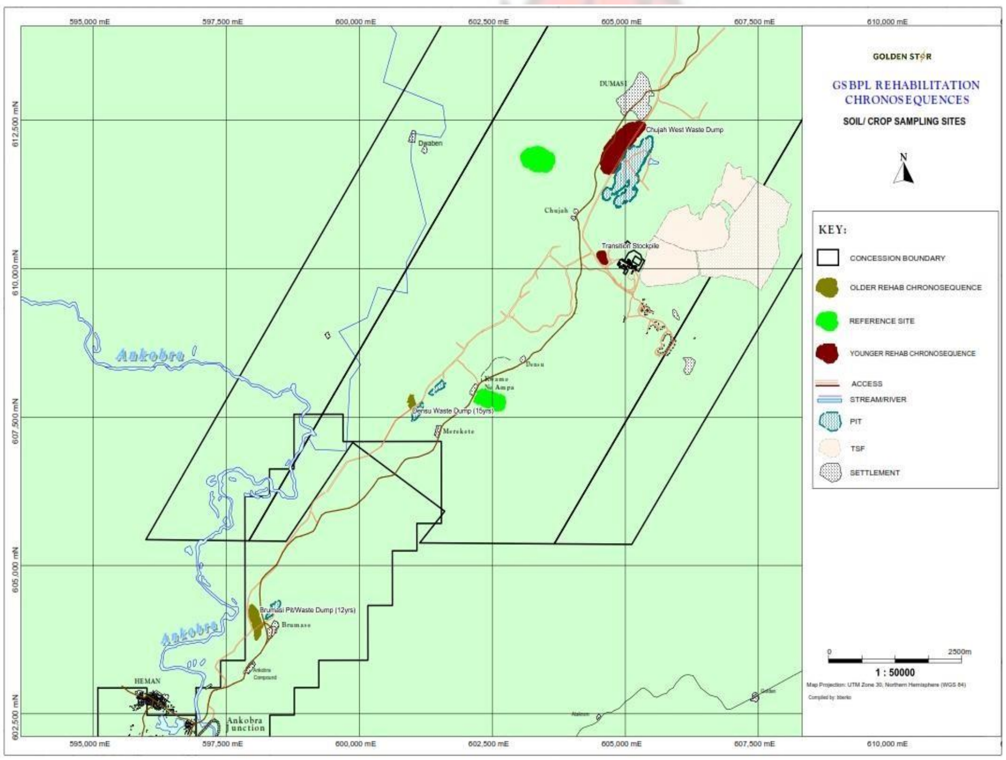

Figure 2: Map of GSBPL reclamation chronosequence and reference sites

Each study site was divided into subplots depending on the size and topography, as shown in (Table 1). A total of 46 composite soil samples were collected from the subplots.

Table 1: Selected study sites with their corresponding number of subplots

Site	Subplots

1-year (1.3 ha)	6
5-year (10.3 ha)	16
12-year (5.0 ha)	5
15-year (2.0 ha)	10
Reference site (6.0 ha)	9
Total	**46**

3.3 Soil and Crop Sampling

Generally, 12-20 sub-samples composited into one sample provide a reasonable representation of a relatively uniform 32 ha field (Miller, 2011). Twenty (20) grab soil samples were randomly extracted at a depth of 0-30 cm using a spud bar, hand trowel and/or spade. Each of about 15-20 grab samples fetched for a subplot were placed in a transparent polybag and shaken vigorously to homogenize from which about 2 kg composite sample was obtained (Plate 1). The composite samples were placed into plastic-lined sampling bags which were clearly labelled with the name of the site, and date/time of sampling. Soil samples were stored at temperature of 4 ºC to prevent microbial action on soil.

Plate 1: Soil sampling at the 5-year old waste dump

Three grab samples were randomly collected separately for fresh cassava tuber and plantain fruits from each study site except the one (1) year old with the aid of a sharp knife. A range of 3-5 grab samples (depending on the size of the farm) of matured cassava tuber were collected and labelled as one composite for each farmland. The same process was repeated for sampling matured plantain fruits (Table 2). A total of seventeen (17) cassava tuber and eighteen (18) plantain fruit composite samples collected were labelled with the name of the site, date/time of sampling and crop name. The crop samples were washed with double deionised (DDW) water, air-dried, packaged and submitted to SGS laboratory, Tema for heavy (trace) metal analysis (As, Cu, Mn, Cd, Fe, Pb, Hg).

Table 2: Number of cassava and plantain composite samples

Study Site	Cassava	Plantain
5-year	5	4
12-year	4	4

15-year	2	4
Reference site	6	6
Total	**17**	**18**

Plate 2: Sampling of plantain fruit from the reference site

Plate 3: Collection of cassava tuber samples from the 5 year old site

3.4 Laboratory Analysis

Soil samples were analysed at GSBPL Environmental laboratory. The soil samples were air dried, pulverized and sieved with 85 % passing 75 µm mesh to obtain the test samples.

3.4.1 Preparation of Soil Samples for Chemical analysis

Hundred gramme (100 g) of each test sample was weighed, transferred to 250 ml stopper conical flask and was shaken with 100 ml of deionized distilled water (1:1 ratio). The samples were allowed to stand in the extractant and then were shaken with a magnetic stirrer for 30 minutes (Korndorfer *et al*., 1995; Mussa *et al*., 2009). The suspension was allowed to settle and the extract were analysed.

3.4.2 Soil pH and Conductivity

Soil pH and conductivity were determined using Mettler Toledo multi parameter meter in a suspension of soil and water. The pH-conductivity meter was calibrated with pH buffer 4.01 and 7.01 and conductivity buffer 1413 µS/cm, 5000 µS/cm and 12880 µS/cm solutions. The pH and conductivity were measured in-situ by immersing the electrodes into the upper part of the suspension.

3.4.3 Water Extractable Nitrate, Phosphate, Sulphate and Chloride

The extracts from soil-water suspension were filtered through a cellulose nitrate filter paper, 0.45 µm. The filtrate were analysed for nitrate, phosphate and sulphate using manufacturer's specific test kits and spectrophotometer (HACH 5000 DR) developed from USEPA and Standard Methods (4500-P-E). Filtered water samples were poured into 10 mL sample cells (cuvettes) for each of the parameters. In determining nitrate, sulphate and phosphate, test kit powdered reagents NitraVer.5, SulfaVer. 4, and PhosVer. 3 were added to the samples respectively and shaken for 30 seconds while the samples were left to stand for 10 minutes. For chloride, 1 ml mercuric thiocyanate and 0.5 mg ferric ion solution were added to 10 ml of the extract. The same procedure was followed for blanks and standards before the actual samples were analyzed. Readings of the samples were taken with the HACH DR 5000 spectrophotometer at wavelengths of 450 nm, 500 nm, 890 nm and 455 nm for sulphate, nitrate, phosphate and chloride, respectively.

3.4.4 Soil Moisture

The standard test method for laboratory determination of water (moisture) content of soil, rock, and soil-aggregate mixtures (ASTM D 2216) was employed. The mass of moist soil was dried at a temperature of 105 ^oC for 24 hours. The dried content was allowed to cool to room temperature before the final mass was measured. The procedure was repeated until there was no change in the mass of the dry weight. Moisture content was calculated as follows:

Mass of soil solids, $Ms = Mds - Mc$

Mass of pore water, $Mw = Mms - Mds$

Water content, $Wc = \frac{Mw}{Ms} * 100$

Where Mds is mass of dried soil, Mc is mass of empty dry container and Mms is mass of moist soil.

3.4.5 Soil Organic Matter and Organic Carbon

Soil organic matter was determined with the Loss on Ignition (LOI) method. The mass of an empty clean and dry porcelain dish was determined (Mp). A known amount of the dried soil Md (above) was placed in the weighed porcelain dish and the temperature of the oven was gradually increased to 450 ^oC and heated for four (4) hours (Cambardella *et al*., 2001). The porcelain was removed and allowed to cool to room temperature. The final weight was determined as Ma. The organic matter was calculated as follows;

Mass of the ashed (burned) soil, $Ma = Mpa - Mp$

Mass of organic matter, $MO = Md - Ma$

Organic matter (content), $OM\% = \frac{MO}{Md} * 100$

Organic carbon was determined on the test samples by the use of Carbon/Sulphur InfraRed analyzer (Leco analyzer). The samples were wet digested with nitric acid (HNO_3) on a hot plate to dryness in order to oxidize all inorganic carbons present. Two grammes (2 g) of the dried digest was placed in the Leco and analyzed.

3.4.6 Heavy Metals in Soil

Test soil samples were wet-digested by treating the soil samples with a 3:1 mixture of hydrochloric acid (HCl) and nitric acid (HNO_3) (EPA 3050B, 1996) and heated on a hot plate at a temperature of 120 ^oC for 15 minutes. The soil and solutions were each cooled to room temperature, transferred quantitatively to 100 ml volumetric flasks, filtered with 0.45 µm cellulose nitrate filter paper under suction and kept in clean sample rack before metal analysis. The total metal concentrations were determined by flame atomic absorption spectrophotometer (AAS 280FS). The concentrations of Mn, Fe, Cu, Zn, Cd and Pb were determined using Agilent AA280FS model of Atomic Absorption Spectrometer (AAS). The AAS was calibrated using certified reference standard solutions of the different metals under investigation. The concentrations of the metals were determined at wavelengths of 228.8 nm, 324.8 nm, 248.3 nm, 279.5 nm, 213.9 nm and 217 nm for Cd, Cu, Fe, Mn, Zn and Pb respectively. Ca, Mg, Na and K were analyzed at wavelengths of 422.7 nm, 285.2 nm, 589.0 nm and 766.5 nm respectively.

3.4.7 Determination of As

Potassium iodide (KI) was added to a portion of the digest samples to reduce arsenic from As (V) to As (III) respectively. Total arsenic was analysed using the hydride generation method coupled to AA280FS AAS at a wavelength of 193.7 nm.

3.5 Analysis of Heavy Metals in Cassava and Plantain Samples

A total of 35 composite crop samples were packaged and analysed at SGS laboratory at Tema for trace metal analysis for As, Mn, Cu, Cd, Fe, Pb and Hg. Cassava and plantain samples were cut and grinded into smaller pieces using quartz mortar and pistol for air drying. Two gramme (2 g) of samples were weighed into disposable digestion tubes and digested with aqua regia solution (1:1 HNO_3 and HCl) at 110 ^oC for a total of 1 hour on hot block. Digests were cooled and topped up with deionised water to 50 ml mark and analysed with Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) for As, Mn, Cu, Cd, Fe and Pb and Inductively coupled plasma mass spectrometry (ICP-MS) for Hg.

3.6 Data Management and Analysis

Data gathered on the physicochemical properties of the reclaimed soils, and heavy metals in soils and crops were managed with MS Excel. The data was subject to the Shapiro Wilk test for normal distribution and the Levene test for homogeneity of variances. The data set failed the normality and equality of variance tests and were therefore analysed with the non-parametric Kruskal Wallis test. Games-Howell and Kuskal Wallis post-hoc tests were used to compare the means, when a significant difference was present. All data received were statistically analysed at 95 % confidence level.

CHAPTER FOUR

RESULTS

4.1 Effects of Reclamation on Soil Physico-chemical Properties

Comparison of the soil physicochemical properties between the reference and reclaimed sites showed that reclamation significantly ($p < 0.05$) influenced soil chloride, conductivity, exchangeable base, nitrate and sulphate levels (Table 3). Exchangeable bases (9.1 meq/100g), nitrate (1.3 mg/kg), and sulphate (13.8 mg/kg) were higher at the reclaimed site compared to the values obtained for the reference site (3.3 meq/100g, 0.2 mg/kg and 5.8 mg/kg respectively). On the other hand, soil conductivity and chloride levels were higher at the reference sites (333.3 µS/cm and 10.3 mg/L, respectively) when compared to the values recorded at the reclaimed sites (182.7 µS/cm and 5.5 mg/kg). The mean cation constituent of the exchangeable bases for the reclaimed sites was in the order Ca>Mg>K>Na.

However, reclamation did not have any significant effects on percent organic carbon, percent organic matter, soil pH and phosphate concentrations ($p > 0.05$; Table 3). The mean organic carbon, organic matter, soil pH and phosphate concentrations recorded for the reclaimed soil were 1.0 %, 3.1 %, pH 5.9 and 0.10 mg/kg respectively.

Table 3: Mean concentrations of soil physicochemical properties compared for the reclaimed and reference sites within the studied area

Parameter	Mean ± standard deviation		P-value
	Reclaimed soil	**Reference soil**	
Chloride (mg/kg)	5.5 ± 2.33	10.3 ± 3.60	0.000
Conductivity (µS/cm)	182.7 ± 97.51	333.3 ± 89.16	0.000
Exchangeable bases (meq/100g)	9.1 ± 7.81	3.3 ± 1.13	0.030
Nitrate (mg/kg)	1.3 ± 0.86	0.2 ± 0.28	0.001
Sodium (mg/kg)	87.5 ± 30.05	45.5 ± 17.07	0.000
Sulphate (mg/kg)	13.8 ± 9.53	5.8 ± 7.24	0.022
Calcium (mg/kg)	1108.9 ± 1329.73	224.6 ± 100.99	0.054
Magnesium (mg/kg)	291.1 ± 175.97	178.0 ± 49.65	0.065
Organic carbon (%)	1.0 ± 0.84	1.0 ± 0.23	0.970

Organic matter (%)	3.1 ± 2.91	2.8 ± 0.89	0.764
pH (soil:water ratio 1:1)	5.9 ± 1.15	6.6 ± 0.46	0.116
Phosphate (mg/kg)	0.1 ± 0.16	0.1 ± 0.06	0.587
Potassium (mg/kg)	224.4 ± 100.18	175.3 ± 79.77	0.179

P value is significant at $p < 0.05$.

4.2 Variations in the Soil Physico-chemical Properties among Reclamation Chronosequences

Age of reclamation strongly influenced soil physico-chemical properties ($p < 0.05$; Table 4). Soil pH generally increased with the age of reclamation. Post-hoc multiple comparisons indicated significant differences in pH between the later reclamation chronosequences (1-year old and 5-year old) and the earlier reclamation chronosequences (12-year old and 15-year old). Soils from 1-year and 5-year chronosequences were generally acidic (pH 4.0-6.0) whilst those of the earlier chronosequences were slightly alkaline (pH 7.0-9.0). The pH of the reclaimed soils also differed from that of the reference soil, which was observed to be 6.6. Soil conductivity ranged from 95 µS/cm at the 1-year site to 332.0 µS/cm for the 12-year reclaimed site. The reference site recorded the highest value of 333 µS/cm. Conductivity appeared to show an increasing trend with the age of reclamation as the 1-year and 5-year old reclaimed sites showed significantly lower levels compared to the earlier chronosequence and reference sites ($p < 0.05$). However, the older chronosequence showed no variation in conductivity from the reference site. Similarly, percent organic carbon and organic matter increased with the age of reclamation. Organic carbon averaged 0.1 % at the 1-year old reclaimed site and 2.1 % at 15-year old reclaimed site. Percent organic mater ranged from 0.2 % at the 1year site to 6.8 % at the 15-year old reclaimed site. Notably, percent organic carbon and organic matter for the 1-year and 5-year old were much lower than the older chronosequence and the reference site. The reference site recorded mean organic carbon and organic matter of 1.0 % and 2.8 % respectively.

Table 4: Variations in soil physico-chemical properties in relation to age of reclaimed mined lands in study area

	Mean ± standard deviation								
Study site	**Chloride (mg/kg)**	**Conductivity (µS/cm)**	**Exchangeable bases (meq/100g)**	**Nitrate (mg/kg)**	**Organic carbon (%)**	**Organic matter (%)**	**pH (soil: water, 1:1)**	**Phosphate (mg/kg)**	**Sulphate (mg/kg)**
1-year	3.9 ± 0.45^{a}	95.0 ± 8.37^{a}	1.6 ± 0.45^{a}	1.5 ± 0.42^{a}	0.1 ± 0.01^{a}	0.2 ± 0.10^{a}	5.1 ± 0.26^{a}	0.1 ± 0.04^{a}	6.0 ± 1.55^{a}
5-year	5.2 ± 2.70^{a}	118.1 ± 23.44^{b}	3.9 ± 2.34^{b}	1.8 ± 0.98^{a}	0.4 ± 0.11^{b}	1.1 ± 0.43^{b}	5.0 ± 0.34^{a}	0.1 ± 0.03^{a}	23.6 ± 3.22^{b}
12-year	7.2 ± 1.83^{b}	332.0 ± 93.65^{c}	18.8 ± 3.59^{c}	0.8 ± 0.46^{b}	1.5 ± 0.43^{c}	5.4 ± 2.03^{c}	7.3 ± 0.34^{b}	0.4 ± 0.24^{b}	5.5 ± 2.38^{a}
15-year	6.2 ± 1.96^{b}	264.0 ± 30.26^{c}	17.3 ± 4.12^{c}	0.9 ± 0.69^{b}	2.1 ± 0.29^{c}	6.8 ± 1.19^{c}	7.3 ± 0.13^{b}	0.2 ± 0.10^{a}	6.0 ± 4.92^{a}
Reference	10.3 ± 3.60^{b}	333.3 ± 89.16^{c}	3.3 ± 1.13^{b}	0.2 ± 0.28^{b}	1.0 ± 0.23^{c}	2.8 ± 0.89^{c}	6.6 ± 0.46^{c}	0.1 ± 0.06^{a}	5.8 ± 7.24^{a}

Different superscripts in a column indicate significant difference at $p < 0.05$.

Chloride and nitrate concentrations responded differently to the reclamation. The younger chronosequence (1-year and 5-year sites) registered minimum chloride level of 4.9 mg/kg and maximum nitrate level of 1.7 mg/kg. On the contrary, the older chronosequence recorded minimum nitrate of 0.9 mg/kg and maximum chloride of 7.2 mg/kg. The reference site recorded the lowest soil nitrate of 0.2 mg/kg but the highest chloride level of 10.3 mg/kg. Nitrate and chloride levels for the reference site varied statistically from the younger chronosequence but were comparable to those of the older reclaimed sites. Phosphate levels also varied significantly ($p < 0.05$) between the younger sites (0.1 mg/kg) and the 12-year old site (0.4 mg/kg). Mean sulphate concentration was considerably higher for the 5-year old reclaimed site (23.6 mg/kg) than those from the remaining sites (5.5-6.0 mg/kg). Soil exchangeable bases were significantly influenced by reclamation age as levels in the older chronosequence were significantly ($p = 0.000$) higher than the younger chronosequence and the reference site. Exchangeable base concentrations ranged from 1.6 meq/100g (1-year site) to 18.8 meq/100g (12-year old site).

4.3 Heavy Metal Concentrations in Reclaimed Soils Compared to Reference Soil

Heavy metals in the reclaimed soil (except cadmium) did not vary statistically from the reference soil ($p > 0.05$; Table 5). In general, As (14.0mg/kg), Cu (61.9 mg/kg), Pb (27.0 mg/kg), Mn (195.8 mg/kg) and Zn (176.8 mg/kg) for the reclaimed sites were higher than the reference site. Mean cadmium concentration of 1.4 mg/kg was the lowest heavy metal concentration in the reclaimed soil whereas the highest accumulated heavy metal level of

195.8 mg/kg was obtained for manganese. Cadmium (3.5 mg/kg) and iron (70.2 g/kg) concentrations were however higher for the reference site compared to the reclaimed site (1.4 mg/kg and 61.6 g/kg respectively).

Table 5: Heavy metal levels compared for the reclaimed and reference soils at the Bogoso/Prestea area

Parameter	Mean ± standard deviation		P-value
	Reclaimed soil	Reference soil	
Cadmium (mg/kg)	1.4 ± 0.84	3.5 ± 1.05	0.000
Arsenic (mg/kg)	14.0 ± 8.51	8.2 ± 3.45	0.053
Copper (mg/kg)	61.9 ± 17.29	58.5 ± 34.12	0.669
Iron (g/kg)	61.6 ± 30.33	70.2 ± 18.06	0.422
Lead (mg/kg)	27.0 ± 46.26	1.0 ± 0.00	0.102
Manganese (mg/kg)	195.8 ± 93.77	156.3 ± 105.82	0.276
Zinc (mg/kg)	176.8 ± 137.41	117.0 ± 127.06	0.313

P value is significant at $p < 0.05$

4.4 Effects of Age of Reclamation on the Heavy Metal Levels in Reclaimed Soils

Like the soil physicochemical properties, heavy metals (except Mn) content in soils varied strongly ($p < 0.05$) among the reclamation chronosequences, and the reference sites (Table 6). Arsenic (As) concentrations, for example, was significantly higher for the 15-year old reclaimed site (mean concentration of 21.4 mg/kg) compared to the other sites. The 12-year old reclaimed site recorded the lowest mean arsenic value of 5.1 mg/kg. Copper concentration ranged from 53.7 mg/kg to 83.9 mg/kg for the 12-year site and 1-year old reclaimed sites respectively whilst the reference site recorded 58.5 mg/kg. The 1-year old site recorded significantly (p=0.033) higher concentration of Cu than the other reclaimed sites.

Cadmium levels for the reference site (3.5 mg/kg) was significantly (p=0.002) higher than the reclaimed sites whereas both 1-year and 15-year old reclaimed sites recorded the minimum value of 1.4 mg/kg. Mean iron levels recorded for the study area were generally high and typical of ferrasol and oxisol soils which constitute greatly to the geology of the area. Iron levels ranged from 38.0 g/kg (12-year old site) to 92.6 g/kg (1year old site). The reference site recorded mean iron concentration of 70.2 g/kg and was significantly different from the 5-year and 12-year old reclaimed sites.

Table 6: Trends of Heavy Metal Levels in Study Soils due to Age of Reclamation

	Mean ± standard deviation						
Study site	**Arsenic (mg/kg)**	**Cadmium (mg/kg)**	**Copper (mg/kg)**	**Iron (mg/kg)**	**Lead (mg/kg)**	**Zinc (mg/kg)**	**Manganese (mg/kg)**
1-year	11.9 ± 2.71^{a}	1.4 ± 0.99^{a}	83.9 ± 8.37^{a}	92.6 ± 15.79^{a}	1.0 ± 0.00^{a}	52.3 ± 9.97^{a}	139.8 ± 57.77^{a}
5-year	12.9 ± 1.34^{a}	1.4 ± 0.79^{a}	59.8 ± 17.36^{b}	46.3 ± 16.96^{b}	1.0 ± 0.00^{a}	91.6 ± 77.54^{a}	173.5 ± 115.42^{ab}
12-year	5.1 ± 1.09^{b}	1.5 ± 0.78^{a}	53.7 ± 15.00^{b}	38.0 ± 6.74^{b}	27.2 ± 7.71^{b}	331.7 ± 10.62^{b}	225.6 ± 14.92^{ab}
15-year	21.4 ± 12.54^{a}	1.4 ± 0.98^{a}	56.2 ± 12.31^{b}	81.0 ± 36.70^{a}	90.5 ± 54.16^{c}	315.8 ± 51.47^{b}	256.5 ± 56.96^{b}
Reference	8.2 ± 3.45^{ab}	3.5 ± 1.05^{b}	58.5 ± 34.12^{b}	70.2 ± 18.06^{a}	1.0 ± 0.00^{a}	117.0 ± 127.06^{a}	156.3 ± 105.82^{ab}
Dutch/WHO Guideline	20.0	1.0-3.0*	50-100*	50*	50.0	200	2000

Different superscripts in a column indicate significant difference at $p < 0.05$; Method detection limit for lead is < 1.0 mg/kg

Dutch/WHO Guidelines: Figures with * indicate WHO guideline only

Lead concentrations were consistently below the method detection limits of 1.0 mg/kg for the study sites except for the 12-year and 15-year old reclaimed sites, which recorded levels of 27.2 mg/kg and 90.2 mg/kg, respectively. The lead content for the older chronosequence (12 year and 15 year sites) were significantly higher than the other sites. Zinc and manganese levels were affected by age of reclamation and increased from the younger to the older chronosequences. Zinc concentrations for the 12 year and 15 year chronosequence (331.7mg/kg and 315.8 mg/kg) were significantly (p=0.001) higher than the younger chronosequence (52.3 mg/kg and 91.6 mg/kg) and the reference site (117.0 mg/kg). The mean concentration of manganese followed an ascending order from 139.8 mg/kg (1-year old) to 256.5 mg/kg (15-year old) for the reclaimed sites but were not statistically different from the reference site (156.3 mg/kg), as p=0.080.

4.5 Heavy Metals in Cassava and Plantain Harvested from Reclaimed and Reference Soils

Generally, heavy metal levels in cassava sampled from the reclaimed sites did not vary from cassava sampled from the reference site ($p > 0.05$; Figure 3). Iron (Fe) was considerably the predominant heavy metals in the cassava samples, ranging from 16.325.0 mg/kg for the 12-year and reference site respectively. The highest Cu, Zn and Mn levels of 4.6 mg/kg, 22.0 mg/kg and 5.8 mg/kg were respectively accumulated in the cassava samples collected from the 15-year and 5-year reclaimed sites respectively. Corresponding values of these metals for the reference site were 3.1 mg/kg, 12.9 mg/kg and 5.6 mg/kg. Cd, Pb, As and Hg concentrations were all below method detection limits of 0.3 mg/kg, 0.1 mg/kg, 0.2 mg/kg and 0.1 mg/kg, respectively.

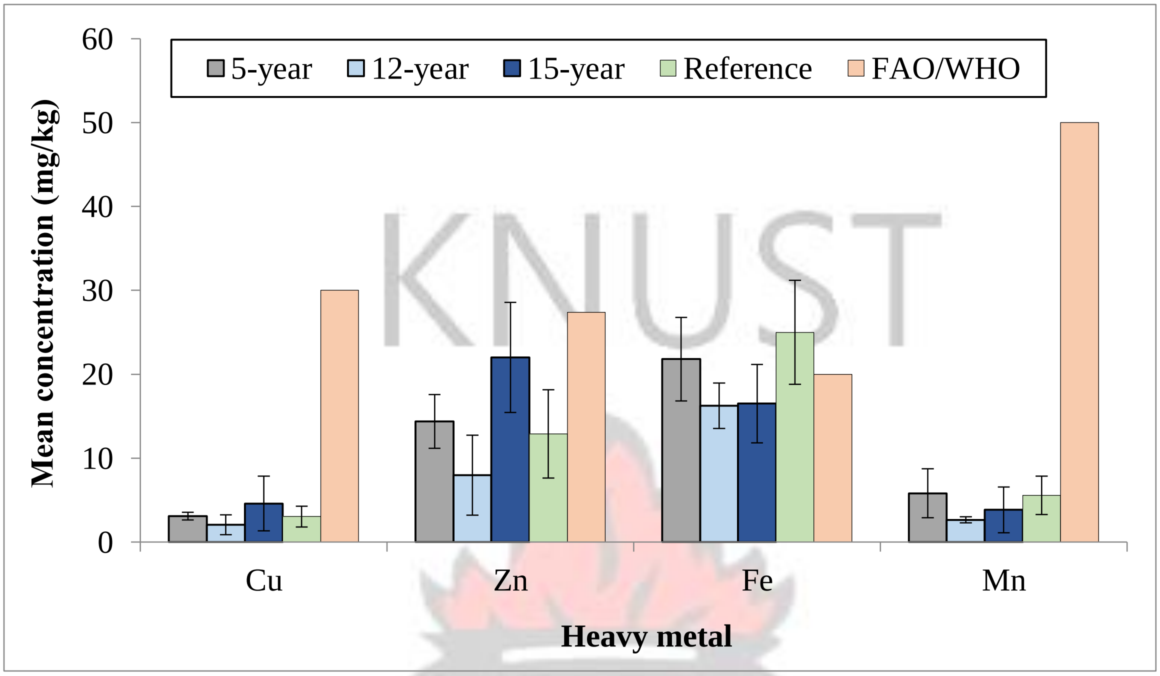

Figure 3: Heavy metals accumulated in *Manihot esculenta* (cassava) grown on the reclaimed and reference sites within the Bogoso/Prestea mining area

Similarly, Fe was the most accumulated heavy metal in the plantain samples followed by manganese. However, no statistical difference was observed for Fe in plantain between the reclaimed site and the reference site. Fe concentration for the reclaimed sites ranged from 15.8-36.0 mg/kg (12-year and 15-year sites respectively) whereas the reference site recorded 24.5 mg/kg. Cu and Zn mean concentration of 4.2 mg/kg and 6.7 mg/kg, respectively, were accumulated in plantain sampled from study sites. With the exception of Mn in the 5-year and reference site showing significant difference, the heavy metals in plantain crops did not vary ($p > 0.05$; Figure 4) between the reclaimed and reference sites. The plantain sampled from the reclaimed site especially the 5-year site contained significantly more Mn (24.0 mg/kg) than those from the reference site (15.3 mg/kg).

Arsenic, cadmium, lead and mercury were all below method detection limits.

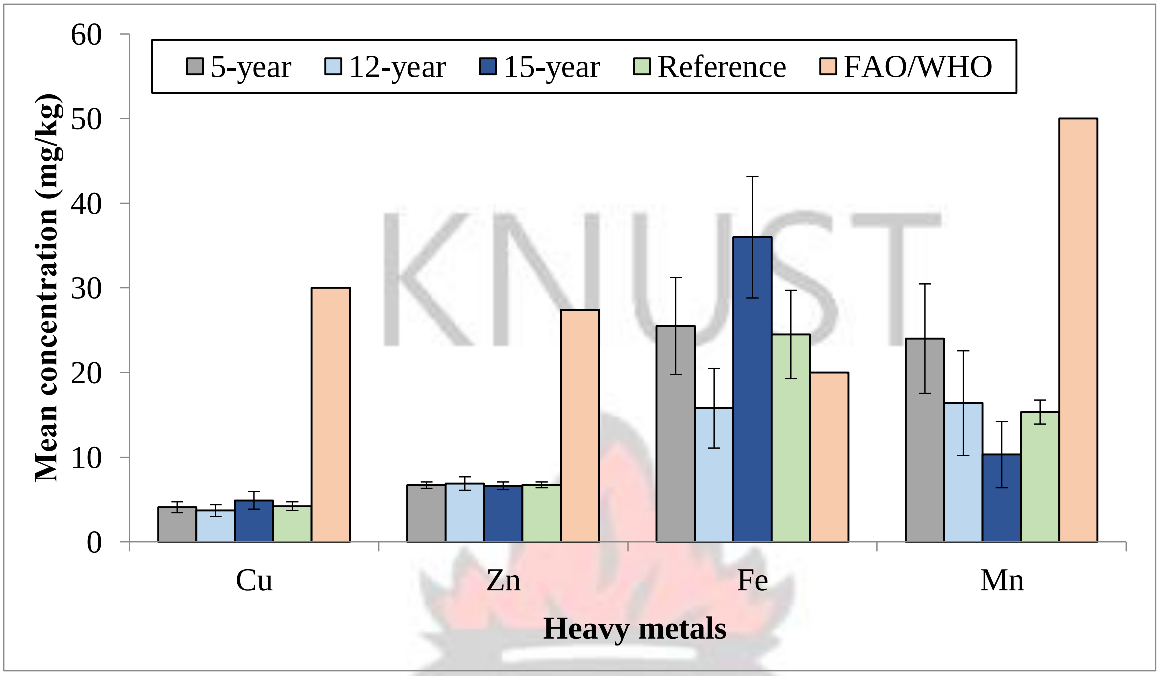

Figure 4: Heavy metals stored in *Musa paradisiaca* (plantain) grown on reclaimed and reference sites within Bogoso/Prestea concession

CHAPTER FIVE

DISCUSSION

5.1 Effects of Reclamation on Soil Physico-chemical Properties

Reclamation of degraded mine land is a prerequisite for undertaking sustainable postmining closure and is aimed at progressively improving the quality of land for profitable use by stakeholders. In this regard, the current study was undertaken to evaluate the effects of reclamation and age of reclamation of key soil physicochemical properties and heavy metal levels within the Bogoso/Prestea area. Results generally indicated significant influence of reclamation on soil properties such as pH and anions, with some parameters improved (organic carbon and organic matter) as age of reclamation increased. These findings are consistent with studies by Tetteh (2010), Ortiz-Escober (2005) and Eddy *et al.* (2006) which found varying responses of various soil physical and chemical parameters to reclamation within a mined out land.

Soil pH is a generally accepted indicator of mine soil quality and denotes the measure of active soil acidity or alkalinity. The pH range of 5.1 to 7.3 for the study sites falls within the optimum range of 5.2-8.0 for most agricultural plants (Lake, 2000). The relatively lower acidic content for the younger reclaimed sites could be attributed to acidic parent material such as pyrites (FeS_2) and rainfall-associated leaching. Pyrite parent materials, which are predominant in the study area, may oxidize to sulphuric acid and significantly lower soil pH (Lake, 2000). The neutral pH recorded for the older year sites, could be due to carbonate bearing minerals ($Ca/MgCaCO_3$) and high organic matter which tend to increase and buffer pH as they weather and dissolve (Sheoran *et al*., 2010).

Soil conductivity relates with soil properties that affect crop produce including soil texture, exchangeable cations, drainage conditions and organic matter levels (Grisso *et al*., 2009; Lund *et al*., 2000; Kitchen *et al*., 2003). The conductivity results indicate that the older reclaimed sites had high water soluble nutrients available for plant uptake. These sites, for example, were enriched with organic matter, which improves soil water holding capacity and cation exchange than the younger reclaimed site. High levels of precipitation could flush soluble salts out of the younger reclaimed sites (1-year and 5year old sites), which had no or limited vegetative cover and hence low conductivity levels. Generally, given the low conductivity values, the soils in this study area would be classified as non-saline ($0 < 2000$ µS/cm) according to the USDA Natural Resources Conservation Service (Smith and Doran, 1996). Non-saline soils improve seed germination, plant growth, water and nutrient uptake (Akbarimoghaddam *et al*., 2011;
Singh and Chatrath, 2001).

According to CSIR-SRI (2009) classification, the earlier chronosequences (1-year and 5year old) and the reference site were low in soil organic carbon (SOC < 1.5 %), whilst the older reclaimed sites (12-year and 15-year olds) were found to be within the moderate range (1.5 – 3.0 %). SOC improved with age of reclamation, probably as a result of the high biomass production and decay of organic matter over time from nitrogen-fixing tree species planted during reclamation. Studies conducted by Johnson (1992) and Cole *et al*.

(1995), revealed that, nitrogen fixing trees contribute 20-100 % more soil carbon than non-nitrogen fixing trees; this might have accounted for the higher soil organic carbon and organic matter at the older reclaimed sites relative to the sites at early stages of reclamation as well as the reference site.

The higher nitrate content of the reclaimed soils compared to the reference site could be explained by the use of leguminous species (eg. *Pueraria*, *Centrosema* and *Leucaena*) in reclamation and the mineralization of organic matter (Bino, 1998). Binkley and Giardina (1998), made a similar observation that, the presence of nitrogen-fixing trees increases soil nitrogen content. The nitrogen fixing efficiency of legumes provides a substantial amount of fermentable organic matter for satisfactory microbial activity (Perera *et al.*, 1992). Nitrogen, like phosphorus and sulphur, is an essential soil element that controls soil fertility and crop yield (Singh and Mishra, 2012). In a warm-aerated, slightly acidic to slightly alkaline soils, nitrogen exists as nitrate and is readily available for plant uptake. Thus, the higher nitrogen content of the reclaimed soil could positively influence plant growth and development at the reclaimed sites. The depletion of nitrate levels with age of reclamation may be attributed to the continuous tilling of the older reclaimed sites during farming without replenishing over the years which was also confirmed in a study conducted by Mesoppirr *et al*. (2014).

The low phosphate levels recorded for the study sites (0.1 - 0.4 mg/kg) puts these soils in the ferralsols classification, according to the FAO soil classification (FAO, 1988; GSBPL, 2015). As observed by Hinsinger (2001), concentration of soluble phosphate in the soil solution <5 mg/kg is low considering the amount needed by plants and to the total P in soils. Mean sulphate value for the 5-year old reclaimed site was significantly higher than those of the other study sites. The oxidation of pyrite minerals (from elemental sulphur to sulphate) from the exposure of sulphidic waste rock materials to oxygen and moisture as observed by Stumm and Morgan (1996), Nordstrom and Alpers (1999), could explain for this difference.

Chloride is often highly soluble in water and very mobile in soil unless it is held by soil exchange sites. At early stages of reclamation (1 to 5-year old), soil chloride is leached as a result of rainfall on lands due to the establishment of good internal soil drainage systems. Huang *et al*. (1995), for example, observed that a large amount of chloride was washed to depth of 40-60 cm by water after one season of growing rice. In acidic soils (pH 5.0-5.5), chloride ion, functions as a nitrification inhibitor (Christensen *et al*., 1986), but this impact is much less in slightly acidic soils (pH 6.5-7.0; Xu *et al*., 2000). This may explain the inverse relationship between nitrate and chloride levels observed in the current study.

Generally, exchangeable base levels increased from the later reclaimed sites to the earlier reclaimed sites and maybe influenced by pH levels. This relationship was also observed by Tetteh (2010). It is widely accepted that SOM is responsible for 25-90 % of the total exchange sites of surface horizons of mineral soils (Oades *et al*, 1989; Oorts *et al*., 2003). Calcium accounted 76-77 % to exchangeable base levels for the earlier reclaimed sites and 36 % for the reference site followed by Mg, which contributed (11-13 %) exchangeable bases for the earlier reclaimed and reference sites (28 %). These values are consistent with assertions made by Troeh and Thompson (1993). They observed that, dryland soils generally have very high levels of total Ca which occupy about 75-85 % of the CEC sites. Research has indicated that a Ca:Mg ratio of 3-5 in the topsoil is optimal for most crops (National Soil Service (NSS), 1990). The Ca:Mg ratio for the reference site was lower (1.3) as compared with the reclaimed site (2.0), suggesting that the reclaimed site may be more suitable for crop production than the reference site. The low exchangeable cations in the lately reclaimed sites coupled with the low organic matter content, may result in low yield (Sanchez and Logan 1992). Sodium ions are less tightly held to soil particles than K, Ca or Mg. For this reason, Na is more easily leached from soil than the other cations (Marschner and Rengel, 2007); hence the low abundance in the reclaimed and reference sites compared to Ca, Mg and K. Ca, Mg, K and Na are known essential elements and important macronutrients, which are potentially important for the health and stability of ecosystems (Lucas *et al*., 2011).

5.2 Effects of Reclamation on Soil Heavy Metal Levels

Reclamation is deemed appropriate for returning mined lands to pre-mining state by improving soil quality geared towards the anticipated final land use. However, heavy metals in reclaimed soils remain a concern for lands apportioned to be used for agricultural purposes. Phytoremediation of heavy metals by the use of vetiver and other suitable plants are employed to avert the effects of heavy metal accumulation. Heavy metals (As, Cu, Fe, Pb, Mn and Zn) investigated for the study sites showed no significant variation. Arsenic levels for the reclaimed sites (except the 15-year site which recorded

21.4 mg/kg), although higher than that of the reference, were within the 20 mg/kg guideline value set by Netherlands (New Dutch list) (http://www.epd.gov.hk/eia/register/permit/latest/figure/vep159appendixa.pdf). The high arsenic level content of the reclaimed soil may be due to dispersal of parent minerals of arsenic as a result of mining operations. This hypothesis confirms assertion made by Ortiz-Escober and Cutler (2005) that, soil arsenic maybe controlled by the lithology of the parent rock materials, weathering history, transport, biological activity and precipitation. It is also worthy of note that the arsenic levels recorded for the reclaimed lands within the study area were generally low compared to values (127.6 mg/kg and 238.7 mg/kg) reported by Tetteh (2010) for a forest and a reclaimed site, respectively, at Tarkwa.

Copper levels for the study area were higher than the Netherland/FAO/WHO guideline value of 50 mg/kg but are consistent with levels reported by Boamponsem *et al*. (2010), about soil heavy metal concentrations in the mining areas of Tarkwa. The high copper values in the study area could also be attributed to the geology of the area as well as the migratory characteristics of this metal. Hu *et al*. (2003), in a research on the distribution characteristics of trace elements during fly-ash land reclamation, showed that, elements such as copper move slowly and gradually upwards in the soil as water evaporates. A significant observation made during the study was that cadmium levels for the reclaimed sites (1.5 mg/kg) were within the FAO/WHO guideline of 3 mg/kg but the reference (3.5 mg/kg) exceeded the guideline. The low cadmium level in the reclaimed site could be due to the accumulation of the element by the phytoremediation grasses vetiver

(*Chrysopogon zizanioides* (L.) Roberty), commonly used in reclamation (Truong and Baker, 1998; Chen, 2000). This plant species is also used to effectively control erosion (Truong *et al*., 1995). This assertion was supported by a study by Minh and Khoa (2009) which established a high removal efficiency of vetiver for cadmium (about 0.72) compared with 0.26 removal for Pb.

Iron availability is influenced by the soil pH, soil aeration and reactions with organic matter. Iron levels for the 1-year and 15-year old reclaimed sites as well as the reference site were higher than the 50000 mg/kg guideline set by the FAO/WHO whereas the 5year and 12-year old sites were within the guideline. The elevated concentrations of iron in the area for both the reclaimed and reference sites could be attributed to the availability of iron-rich laterite sub-soils which are classified by FAO as ferrasols and oxisols (GSBPL, 2015). Similar to observation made by Tetteh (2010), iron was found to be the most abundant heavy metal in comparison to the other heavy metals in the study area. Vanmechelen *et al.* (1997), stated that, iron in the mineral soil layers varies within a wide range of 100 to 100,000 mg/kg. According to Brady and Weil (1999), the general iron nutrient requirement of plants is about 100 mg/kg. By this claim, it can conveniently be assumed that all the study sites have sufficient amounts of iron available for use by plants that would be cultivated on them.

Available manganese content in soils is variable. Manganese levels from the reclaimed site ranged from 139.8-256.5 mg/kg and were within the recommended maximum permissible level of 2000 mg/kg set by the FAO/WHO. Organic matter, pH, and weather conditions tend to influence soil manganese. At lower pH (< 5.5), for example, oxides of manganese can easily be reduced in soil exchange sites (Kogelmann and Sharpe, 2006), but the dominant soluble manganese may be leached in soils with good drainage as with the later reclaimed sites. High pH and organic matter allows manganese adsorption into soil complexing sites, thereby increasing their availability (Fageria *et al*., 2002; Bradl, 2004).

Lead levels recorded for the later reclaimed sites and the reference sites were below method detection limit of 1 mg/kg. Lead levels for the study sites were within the Netherland guideline value of 50 mg/kg for lead except the 15-year old site but were however within the Dutch list intervention value of 530 mg/kg (http://www.epd.gov.hk/eia/register/permit/latest/figure/vep159appendixa.pdf). The use of portions of the earlier reclaimed sites as domestic dumpsites for the communities could be the reason for the elevated lead levels. Boadu (2014), reported a mean of 329.9 mg/kg at Abgogbloshie dumpsite, relatively higher than the reclaimed sites. The common sources of lead in dumpsite soils include lead-based paint, leaded gasoline, some types of pesticides, smelters, coal-based furnaces, and lead-acid batteries (Boadu, 2014).

Zinc levels for the reclaimed sites increased with increase in years of reclamation ranging from 52.3-331.7 mg/kg. Zinc levels for the later reclaimed and reference sites agree with the natural abundance range of 10-300 mg/kg in soils reported by Eddy *et al.* (2006), and the 2.5-150 mg/kg range preferred concentration for plant growth proposed by Rai (1977) and Robinson (1946). Zinc values for the earlier-reclaimed site were consistent with a value of 305 mg/kg reported at Tarkwa by Hayford *et al*. (2008). In addition, if the general zinc nutrient requirement of plants is 20 mg/kg as stated by Epstein (1965), then the soil in the study area has adequate store of zinc to meet the growth requirements of plants. The continuous effects of eluviation by rainfall and evaporation (Zhanbin *et al*., 2013) could account for the high zinc levels for the older reclaimed sites.

5.3 Heavy Metals in Cassava and Plantain

Generally, crops harvested from reclaimed lands are of food safety concern due to the possibility of heavy metal contamination. However, if reclamation is effective and the presence of heavy metals are within acceptable guidelines, agriculture in rural areas where mining operations dominate economic activities could be an alternative livelihood for the indigenes whose lands were compensated for mining. For this reason, samples of cassava and plantain harvested from the reclaimed lands and reference sites were analyzed for heavy metal accumulation.

Heavy metals recorded for crop samples were generally low and within acceptable guidelines. Iron levels were by far the most abundant heavy metal in the cassava and plantain samples. The abundance of iron levels in the crops agree with results from a study conducted by Idodo-Umeh and Ogbeibu (2010), who also observed high levels of iron in crops on reclaimed lands compared to other heavy metals. Plantain samples on the study sites except the 12-year site recorded iron concentrations (24.5-36.0 mg/kg) above the FAO/WHO permissible limit of 20 mg/kg (Afzal *et al*., 2011). Iron levels in cassava from the 12 and 15-year sites were within the FAO/WHO limit whilst those of the reference and 5-year sites were above the FAO/WHO threshold. Compared to the abundant occurrence of iron in soils, its content in plants is generally low, although, in most cases it is higher than that of other trace elements. Normal iron levels required by plant tissue ranges from around 25 to more than 500 mg/kg, dry weight, depending on plant part and species (FAO/WHO, 2011). The levels of manganese for both reclaimed and reference sites were within the maximum level of 80 mg/kg in foods as proposed by Pais and Jones (1997). Plantain samples were enriched with manganese levels than cassava. Adequate levels of manganese recorded for the crops aid in the digestion and absorption of food through peptidase activity, in the synthesis of cholesterol and fatty acids in humans while excess manganese may inhibit iron absorption (Moore, 1991).

Also, statistical difference occurred for zinc levels between the plantain (6.6-6.9 mg/kg) and cassava (7.9-22.0 mg/kg) samples. Cassava samples were enriched in zinc levels than plantain on both the reclaimed and reference sites but were within the FAO/WHO's recommended guideline of 50 mg/kg. Zinc levels for the crops were within sufficient levels to provide vital biological functions to indigenes who consume these crops (Kalagbor *et al.*, 2015). Similarly, copper levels were within acceptable FAO/WHO permissible limits of 30 mg/kg and therefore pose no threat to consumers.

Concentrations of arsenic, cadmium, lead and mercury were not detected in the crop samples. Consumption of these crops therefore poses no significant food safety threats to consumers within the catchment area. Levels of these toxic metals are low and arsenic values in this study are contrary to findings made by Amonoo-Neizer *et al.*, 1993, who observed average arsenic value of 1.86 mg/kg in plantain samples in Obuasi.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Reclamation is a widely accepted method for converting degraded mined lands to productivity. The results obtained in the study indicated that, reclamation employed within the Bogoso/Prestea mining area is an efficient means of returning lost soil fertility after the operational phase of mining. Age of reclamation aided in improving soil pH, organic carbon, organic matter, conductivity and exchangeable base levels. Reclamation reduced soil cadmium whilst iron, copper, lead, manganese and zinc levels for the reclaimed sites were comparable to the reference site. In addition, the presence of heavy metals in soils did not increase accumulation in cassava and plantain crops. Plantain samples as well as cassava sampled from the reference site accumulated high iron levels above the maximum FAO/WHO permissible limit. Copper, manganese and zinc levels accumulated in crops were below FAO/WHO maximum permissible limits whereas arsenic, cadmium, lead and mercury were not detected in the food crops.

6.2 Recommendations

- Strategies for reducing heavy metal contamination resulting from the mining activities should be intensified especially for reclamation practices that have agriculture objective as the next land use.
- Secondly, there is the need for regular and continuous monitoring of the level of heavy metals in the environment, particularly in soil as these metals continue to accumulate in the environment. They are not biodegradable.

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