KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

FACULTY OF RENEWABLE NATURAL RESOURCES

THE ASSESSMENT OF THE REHABILITATION OF A DEGRADED MINE SITE

A CASE STUDY OF COMMUNITY INVOLVEMENT

IN AMANSIE RESOLUTE LIMITED SITE

THESIS SUBMITTED TO THE DEPARTMENT OF AGROFORESTRY

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KUMASI

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MASTER OF PHILOSOPHY IN AGROFORESTRY

BY

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DECLARATION

I hereby declare that this submission is my own work towards the Master of Philosophy in Agroforestry and thus all references and quotations cited in support of the results and the concomitant arguments have been duly acknowledged.

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DEDICATION

This research is dedicated to my wife, Lucia Adwoa Bonsu for her encouragement, support and tolerance and to all my children; Ignatius and Rosemary and to Tina who was born whilst I was undertaking this study.

ABSTRACT

Mining generally destabilizes environments and the entire ecosystem. To ensure that mining activities co-exist harmoniously with the human and physical environment, guidelines have been developed which all mining companies are obliged to comply. This study was undertaken to evaluate the impact of communities' involvement in pre-mining, mining and post mining activities towards the restoration of degraded mine site. The research was conducted in the Amansie Resolute Mining Site and three adjacent mining communities through socio economic, field botanical surveys, soil sampling and analysis. The socio economic survey was carried out through administration of semi structured questionnaires to chiefs and opinion leaders at Koninase, Kwankyiabo and Manso Nkran. The Mines Department – Kumasi, Environmental Protection Agency, Kumasi, Environmental Officer of Amansie West District Assembly were also interviewed. Botanical studies were carried out in the re-forested waste and tailing dump sites, non forested waste and tailing dump sites and on secondary forest. Trees were randomly selected from each hectare, plot, among the study sites, height, diameter and volume determined; mean species diversity dominance and evenness were also estimated. Litter in-situ and turn-over ratio were compared among the sites. Multiple soil samples were collected and mean nutrient parameters determined through recommended laboratory methods. The result from the socio-economic studies revealed that the mining company pursued the laid down procedures for land acquisition employed some people in the communities, provided some social amenities and restored the degraded mine site. The mean heights of trees were 17.0 m, 16.5 m, 2.5 m, 1.5 m and 48 m for reforested waste and tailing dumps, non forested waste and tailing and secondary forest respectively. The mean diameter measurements were 0.076 m^2, 0.075 m^2, 0.03 m^2, 0.25 m^2 and 0.30 m^2 in similar order, whilst the mean volume measurement were 0.771 m^3, 0.072 m^3, 0.070 m^3, 0.001 m^3 and 3.390 m^3. The mean litter ratios were 1:5, 1:2.3, 1:2.43 and 1:4.5 respectively. There were no significant differences in species diversity dominance and evenness among the sites. Soil nutrient levels did not show significant differences at 5% ($P < 0.05$) using Duncan's Multiple Range Test. A limited number of people were employed through the spectrum of the mining company's activities. There were above average coverage of trees in restoration sites and soil fertility levels highly competitive among study sites.

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TABLE OF CONTENTS

CHAPTER **PAGE**

1.0	**INTRODUCTION**	**1**
1.1	**Background to the Study**	1
2,0	**LITERATURE REVIEW**	**5**
2.1	Historical perspective of Mining in Ghana	5
2.2	Methods of Mining	7
2.2.1	Underground Mining	7
2.2.2	Solution Mining	8
2.2.3	Surface Mining	8
2.2.4	Placer Mining	8
2.3	Mining Materials	9
2.3.1	Waste Rock	9
2.3.2	Mill Tailings	9
2.4	Mining laws and Community Consideration	10
2.5	Mining laws and Environmental Consideration	11
2.5.1	Effects of Mining on Biophysical Environment	13

PAGE

2.5.2	Contribution of Mining to Air and Water Pollution	14
2.5.3	Water Pollution	14
2.5.4	Air Pollution	15
2.5.5	Effects of Mining on forest and forest resources	15
2.6	Restoration of Degraded Mine Sites	16
2.6.1	Methods of Rehabilitation	18
2.6.2	Problems in Rehabilitation of Degraded Mine Sites	19
2.7	Purpose of rehabilitation of degraded mine sites	20
2.7.1	Rehabilitation for Forestry/Agricultural Land	20
2.7.2	Rehabilitation for Pasture	23
2.7.3	Rehabilitation of degraded mine site for recreational purpose	24
2.8	Tree species for rehabilitation of degraded mine site	25
2.8.1	Stands growth and development in Rehabilitated mine site	25
2.8.2	Litter in-situ and turn-over under mixed stands	26
2.8.3	Natural species recruitment/regeneration under mixed stands	27
2.8.4	Natural re-colonization of mine sites	28
2.8.5	Diversity of regenerated species	29

		PAGE
2.9	Soil Amelioration under planted trees	30
3.0	**MATERIALS AND METHODS**	**33**
3.1	The Study Area	33
3.1.1	The original and present vegetation	36
3.2	Study Methodology	36
3.2.1	Socio-economic survey	37
3.2.2	Botanical survey	38
3.2.3	Sampling Methods	39
3.2.4	Methods employed for tree planting	41
3.2.5	Soil sampling and analysis	41
3.2.6	Laboratory analysis	42
3.3	Data analysis	43
3.3.1	Statistical Analysis	43
3.4	Limitation of the study	43
4.0	**Results**	**45**
4.1	Acquisition of mining rights	45
4.1.1	Communities interaction and acquisition of Environmental permit	45
4.1.2	Posting of reclamation security bond	46
4.1.3	Formation of joint mining and community Committees	46
4.1.4	Employment opportunity offered	47

PAGE

4.2 Mine site rehabilitation 48

4.2.1 Natural re-colonized species on non forested sites (non forested waste and tailings dumps) 48

4.2.2 Natural species recruitment under planted stands (Forested waste and tailings dumps) 48

4.2.3 The undergrowth or regenerated species under secondary forest 48

4.3 Mean growth rate of trees species under studied sites 54

4.3.1 Tree height 55

4.3.2 Diameter measurement 55

4.3.3 Volume measurement 57

4.4 Diversity, dominance and evenness of recruited/regenerated Species in the various sites 57

4.5 Litter in-situ and turn-over in the various sites 61

4.6 Soil nutrient levels 63

4.6.1 Potential hydrogen concentration 63

4.6.2 Percentage organic carbon 63

4.6.3 Percentage total nitrogen 64

4.6.4 Percentage organic matter 65

4.6.5 Exchangeable cations (calcium, magnesium and Potassium concentration) 66

4.6.6 Cation Exchange capacity 68

4.6.7 Available phosphorus 69

4.6.8 Available potassium 70

4.6.9 Percentage clay 71

		PAGE
5.0	**DISCUSSION**	**73**
5.1	Pre-mining commitments	73
5.1.1	Acquisition of mining rights	73
5.1.2	Reclamation Security Bond and environmental Management	74
5.1.3	Employment consideration	75
5.2	Performance of planted trees	76
5.3	Natural species re-colonization/recruitment diversity, Dominance and evenness under the various sites	77
5.4	Litter in-situ and turn-over	78
5.5	The chemical and physical properties of soil	79
5.5.1	The differences in nutrient levels between non forested, Reforested waste and tailings dumps and secondary forest	79
6.0	**CONCLUSION AND RECOMMENDATIONS**	**84**
6.1	**CONSLUSIONS**	**85**
6.2	**RECOMMENDATIONS**	**85**
	REFERENCES	**87**
	APPENDICES	**101**

LIST OF TABLES

TABLE **PAGE**

3.1	Relevant stakeholders interviewed	38
4.1	Employment opportunities	47
4.2	Mean growth measurements from studies sites	54
4.3	Mean values of species diversity among the various studied sites	58
4.4	Species richness/dominance/relative abundance from studied sites	59
4.5	Evenness or equitable distribution of species from the studied sites	60
4.6	Liter in-situ and turn-over from various studied sites	61
4.7	Mean soil fertility potential from studied sites.	62

LIST OF FIGURES

FIGURE		PAGE
3.1	Map of Ghana showing Amansie West District	34
3.2	Map of Amansie West District showing Amansie Resolute Mining catchment area	35
3.3	Layout of studied plots	39
4.1	Mean height of trees in studied sites	55
4.2	Mean diameter of trees in the studied sites	56
4.3	Mean volume of trees in studied sites	57
4.4	Mean values of species diversity in the studied sites	59
4.5	Mean soil pH	63
4.6	Mean soil percentage organic carbon	64
4.7	Mean soil total nitrogen	65
4.8	Mean soil percentage organic matter	66
4.9	Mean soil percentage exchangeable calcium	67
4.10	Mean soil percentage exchangeable magnesium	67
4.11	Mean soil percentage exchangeable potassium	68
4.12	Mean soil cation exchange capacity in the studied sites	69
4.13	Mean soil available phosphorus in the studied sites	70
4.14	Mean soil available potassium in studied sites	71
4.15	Mean soil percentage clay in the studied sites	72

LIST OF PLATES

PLATE		PAGE
Plate I	Amansie Resolute Limited Non Reforested Waste dump stand	49
Plate II	Amansie Resolute Limited Non Reforested tailings dump stand	50
Plate III	Amansie Resolute Limited Reforested waste dump stand	51
Plate IV	Amansie Resolute Limited Reforested tailings dump stand	52
Plate V	Amansie Resolute Limited Secondary forested (Bench Mark Reserve).	53

LIST OF APPENDICES

APPENDIX		PAGE
I	Questionnaire administered to chiefs, opinion leaders and Focus groups in the mining communities	101
II	Questionnaire administered to Mines Department – Kumasi	102
III	Questionnaire administered to Environmental Protection Agency – Kumasi	103
IV	Questionnaire administered to Environmental Officer Amansie Resolute Limited	104
V	Questionnaire administered to Amansie West District Assembly Manso Nkwanta	105
VI	Regenerated/recruited species in the various studied sites	106
VII	ANOVA of species diversity for the studied sites	107
VIII	ANOVA of soil potential hydrogen concentration for the studied sites	108
IX	ANOVA of soil percentage organic carbon for the studied sites	108
X	ANOVA of soil percentage total nitrogen for the studied sites	108
XI	ANOVA of soil percentage organic matter for the studied sites	109
XII	ANOVA of soil percentage exchangeable calcium for the studied sites	109
XIII	ANOVA of soil percentage exchangeable magnesium for the studied sites	109
XIV	ANOVA of soil percentage exchangeable potassium for the studied sites	110
XV	ANOVA of soil cation exchange capacity for the studied sites	110
XVI	ANOVA of soil available phosphorus for the studied sites	111
XVII	ANOVA of soil available potassium for the studied sites	111

XVIII ANOVA of soil percentage clay for the studied sites. 112

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Mining is the process of extracting coal or other minerals like gold, bauxite and diamond from underground. Mining has a long history in Ghana, for instance Anglo Gold Ashanti Company Limited at Obuasi is on record to have mined gold for more than hundred years(New Mont, 2007). Mining has played and continues to play a very important role in the economy of Ghana in terms of export earnings. For instance in September 2000, the country realized US$400 million within six months, by 2002 mining accounted for 25% of GDP and in 2005 contributed 34% of the total national income. Most of these earning were realized form surface mining, which became pronounced in the 1990s (Gyima, 2004). Mining employs about 14,000 workers (Barning 1997). In the early 1990s, the government of Ghana promulgated the surface mining operations law as a way of boosting the economy. The legalization of surface mining, which is relatively less expensive to operate, attracted small, medium and large-scale foreign mining companies into the country. Unlike deep cast mining, surface mining is destructive and environmentally unfriendly as flora, fauna and associated top soil are removed prior to extraction of the mineral. The methods employed in the extraction and the chemicals used for processing also pollute soil, water bodies and negatively affect human health.

In view of these effects, mining companies are required by law to enter into agreement with the Environmental Protection Agency (EPA) to document and to commit them to adhere to environmental management responsibilities. Legislative Instrument 1652 of 1990 and Act 490 of 1994 commit all mining companies to register and describe the impact of their activities on the environment and how it will be mitigated. Consultations with the local communities are mandatory for them to fully appreciate the processes involved and have a say in decision on plant species to be used and how the impacts would be addressed. In addition, the company is obliged to pay a reclamation bond to the Environmental Protection Agency. This is a security or guarantee which could be used to rehabilitate a mining site in case a company fails to honour this arduous obligation. Mining licenses are granted only after a company had fully complied with these requirements.

Amansie Resolute Limited, a defunct mining company rehabilitated the degraded mine site in its concession with multipurpose tree species that are fast growing and also have the potential of improving the soil fertility to restore the ecosystem almost close to pre-mining status. Large pits created were converted into fish ponds and protected with life fencing of *Pithecellobium dulce* (Madras thorn), some of the medium and small sized pits were back-filled with soil and other coarse materials in 2000. It is therefore important to assess the potential of the rehabilitated areas in relation to the uses they could offer to the communities.

1.2 Problem Statement

Many mining companies ignore and disregard the basic community and environmental requirement prescribed by the Mining and Mineral guidelines. The non adherence to the guidelines results in soil degradation, water and air pollution, hunger, diseases, unemployment, poverty as well as social unrest in the adjacent communities.

The study was undertaken to evaluate the schemes and programmes Amansie Resolute Mining Company pursued during pre-mining, mining and post mining and its overall impacts on the communities and the immediate environment.

1.3 Justification

Amansie Resolute Limited acquired a total areas of 55.4 km^2 (554 ha) but actually operated on 348 ha. Though landowners and farmers were compensated for the land acquisition, about 5000 farm families were dispossessed of their farmlands. Consequently, this action culminated in the reduction of fertile lands for farming in the area with the resultant food shortages. The pits created in the course of mineral prospecting posed a great danger and acted as death traps to people and fauna in the vicinity. The medium and small open pits collect water when rain fell and predisposed the environment to mosquito breeding and other waterborne diseases. The degraded land lacked aesthetic beauty, was unattractive, bare and devoid of vegetation and in most cases provided a corridor that accelerated windstorm momentum. Notwithstanding the effectiveness of methods for prospecting and processing, a sizeable amount of poisonous chemicals usually gradually trickles to pollute soil and nearby water bodies. Frequent demonstration and agitation about cyanide spillage and other environmental degradation calls for an assessment of the entire process so that guidelines could be recommended for such activities in future. Since the communities had no such guidelines it was difficult to ascertain whether the right procedures were followed. This present study seeks to provide information to fill such a gap.

1.4 Aim and Objectives

The general aim of this study was to evaluate the impact of community involvement in mining and tree planting activities on restoration of degraded mine sites.

The specific objectives were:

i) To assess the extent of participation of the affected communities in the mining and reclamation of the degraded mine site.

ii) To determine species recruitment and adaptability to the reclaimed and non-rehabilitated sites.

iii) To determine soil fertility levels in terms of nutrient potential of the rehabilitated and non rehabilitated sites.

CHAPTER TWO

LITERATURE REVIEW

2.1 Historical Perspective of Mining in Ghana

Gold is the predominant mineral in Ghana and has been produced in the country since the 15th century. Portuguese navigators shipped gold to Europe by 1460 and were later followed by the English and Dutch. It mostly occurs in the Tarkwain and Birimain rock formations. The main methods employed were the underground mining and small scattered/open cast (pits) by the local people (Blowers,1990).

The major centers were Obuasi, Konongo, Dunkwa, Tarkwa, Bibiani, but it was carried out in many other communities in the country. The first European gold concession was established in 1877 in the Tarkwa area and in1897. The Ashanti Gold Fields Company Limited (AngloGold Ashanti) was founded at Obuasi. Other major mines were also started; Abosso Mine (1896), Bibiani (1901), Prestea (1903), Tarkwa (1909).

The underground mining method practiced was in harmony with the environment to some extent, though social problems could not be ruled out completely for many years. Since 1900, about 60 Mining Acts, ordinances and regulations have been enacted to regulate mining activities in the country. Until 1986, there were only few recognized mining companies in the country.

The 1986 Minerals and Mining Law PNDC L 153 which was amended by the Mineral and Mining Amendment Act of 1994, Act 475 reduced corporate tax from 45% to 35%. This attracted foreign investment into the country ($US 4 billion dollars) and also promulgated surface mining. In 1980, the small scale gold mining law also came into force. These two laws resulted in an increase in the number of mining companies in the country. Surface mining operations result in forest destruction, land degradation, air and water pollution and depletion of biodiversity. In Ghana, surface mining operations disturb about 3,000 hectares of fertile land annually (Mines Department Kumasi, 2007). Currently, about 80 percent of all the mines in Ghana use the open pit mining method (Gyima, 2004). This method usually results in the creation of huge pits and mountains of waste material as waste dumps. To forestall these adverse environmental impacts, theEnvironmental Protection Agency Legislative Instrument (LI) 1652 of 1999 obliges all mining companies to rehabilitate the lands disturbed during their operations to their original state and to fill the pits with the waste materials, to re-build soil fertility levels and restore the ecosystem resilience as close as possible to pre-mining conditions where practicable.

The procedure or guidelines are enshrined in the minerals and mining Law PNDCL 153 of 1986. Section 2 Sub section 2, Section 17 Sub sections 1 and 2, 18 Sub section 46 oblige mining companies to obtain a mining lease and enter into agreement or indenture with government and traditional authorities. Act 494 of 1994 and LI 1652 of 1999 further require mining companies to obtain an environmental permit after submitting a favorable environmental impact assessment of their activities, and also commit to pay a reclamation security bond to environmental protection agency. This acts as a guarantee and could be used to rehabilitate the degraded mined lands in case the company concerned fails to do so.

The main legislative instruments are Mineral and Mining Law 1986 PNDC L 153; Section 72, 80 (i) 82 and 83, Deed of prospecting license, clause 4; Ghana Mining and Environmental Guidelines 1994. Environmental Assessment Regulation; 1999 LI 1652; Deed of mining lease clauses 5 (a) 8a (b) AND 29 (C); Mining Regulation, 1970 LI 165; Regulations; 44 and 45. Small Scale Mining Law; 1989 PNDC L 218 Section 11.

2.2 Methods of Mining

2.2.1 Underground Mining

It is the process whereby vertical, long narrow spaces, openings or shafts are made deep into the ground, networks of opening are developed to get access to the ore body and to secure ventilation (Gyima, 2004). The operations involve the removal of rocks with little valuable metal content. The rocks are brought to the processing machine, where they are crushed, ground, milled and the precious mineral extracted. The waste material is disposed from the processing plant as mining waste (Blowers, 1990).

Though this method is laborious and expensive, it has been widely used in many parts of the world including Ghana and has fully sustained the mining industry. It is relative environmentally friendly as the area of vegetative cover and top soil removed in course of mining is usually small as compared to surface mining. Until the enactment of the surface mining law in 1986, PNDC L 153, all the commercial mining companies that operated in this country employed and relied mainly on this method. For instance, Anglo Gold Ashanti at Obusasi, Bibiani, Tarkwa, Prestea and Bogoso Mines (Gyima, 2004).

2.2.2 Solution Mining

The method involves the excavation of ores or rocks that contain the precious metals from underground or near surface. The broken rocks are gathered into heaps and extractant chemicals are added to dissolve and leach the contents. The solution is further trickled over the broken ore in the surface or underground working to fully separate the precious minerals. This method is mostly used by the small scale and illegal or "galamsey" mining operators. The quantity or amount of metal realized is usually small as compared to other methods (Blowers, 1990).

2.2.3 Surface Mining

It is the excavation to extract ores near the surface deposits. The process involves clearing of vegetation cover, removal of top soil (salvage soil) material, blasting, loading and hauling of ore to the processing plant. Surface mining operations have increased substantially over the past two decades as improvement in technology has made it possible to extract mineral from low-grade ores (Miller, 1996).

2.2.4 Placer Mining

This method involves excavation of river bed or stream sediment and the separation of valuable minerals by gravity, selective flotation or by chemical extraction. It is one of the oldest methods of mining whereby metals are separated from alluvial deposits of gravel and other materials. In Ghana, Dunkwa is noted for this type of mining from the Offin and the Ankobra Rivers. The method is less laborious than the others, but aquatic life is adversely affected (Coakley, 2002).

2.3 Mining Materials

2.3.1 Waste Rock

These are ores of low grade which are normally separated from high grade ores. Surface/open pit mining and underground mining results in the production of large amounts of rock waste and mill tailings which are usually deposited in rock waste heaps. In Canada, an estimate of 1.0 x 10^6 tons are produced daily (Government of Canada, 1991). The waste rock may be used in construction activities in the mine site. Levels of heavy metals are normally fairly low, chemically inactive with none of the necessary plant nutrients present. In recent times modern technology has made it possible for waste dumps to be reprocessed for more of the precious minerals. In Brazil, mines produce about one tonne of waste for each tone of ore (Griffith, 1970).

2.3.2 Mill tailings

Most ores are processed through concentration steps that involve costs – crushing, grinding and milling to fine grain size for beautification. At any plant, a differential flotation is used to separate the valuable sulphide minerals containing base or precious metals from others as pyrite (Fes) or pyrrhonist that have little commercial value. Mill tailings are the residual material. Including sulphide gangue minerals that are discharged to tailings impoundments (dump) typically as slurry of water and finely ground rock. The mass of tailings produced daily in Canada is estimated to be 9.5 x 10^6 tons (Government of Canada 1991). Chemically tailings are very active with high levels of heavy metals, generally acidic pH caused by the oxidation of pyrite in sulphide deposits (Holland, 2004). This further increases the level of heavy metals in solution through dissolution (a form easily taken up by plants) low levels of nutrients and toxic concentration of salts. This impedes natural regeneration and consequently the organic content of the tailings.

2.4 Mining Laws and Community Considerations

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

2.5 Mining Laws and Environmental Considerations

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

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

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

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

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

2.5.1 Effect of Mining on Biophysical Environment

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

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

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

2.5.2 Contribution of Mining to Air and Water Pollution

2.5.3 Water Pollution

Desu (1970) reported that chemicals used in the processing of ores, for instance cyanide and mercury are extremely toxic to man, animals and aquatic life. Gyimah, (2004) also stated that suspended solids from dredging and effluents from washing and treatments also pollute water bodies**.** Nemeron (1978) observed that the discharge of chemicals and other wastes makes streams unsuitablefor recreation, fish breeding, aquatic wild life and human consumption. Contamination of water resources also occurs through the leaching of heavy metals and other elements by percolating rainwater (Mitchell, 1990). This results in high concentration of dissolved metals in ground water. In 1996, cyanide spillage at Teberebe Gold Mine released 36 million liters of cyanide solution that destroyed cocoa, food crops and aquatic life. Furthermore, a tailings dam burst at Tarkwa Gold Mines contaminated river Asumin killing aquatic organisms and polluted the drinking water of thousands of people (Wassa communities affected by Mining, 2004). For instance in 1993, in the Summitville Gold Mine in United

States of America, the tailings dam was detected to contain about 6,500,000 cubic metres of toxic materials that could be washed into soil and streams that feed the Rio Grand rivers (Edward, 2001).

2.5.4 Air Pollution

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

2.5.5 Effects of Mining on Forest and Forest Resource

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

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

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

2.6 Restoration of Degraded Mine sites

Restoration of degraded mine sites is to improve the status of such sites to potential production and sustainable use through tree planting. Restoration is normally pursued in densely populated areas where land for farming is limited, firewood, and poles for building is in high demand and pressure for grazing very heavy (Orade*et al.*, 1977). The purpose of restoration is to amend soil fertility and vegetative cover and return the land to production. Soil organic matter, physical properties and chemical properties are greatly enhanced. Tuffour (1977) stated that the main objective of rehabilitation is to establish an ecosystem as close as possible to pre-mining status and in accordance with existing land use.

Ayensu (1977) recommended this general principle for establishing vegetation on local mine spoils:

1. Conduct soil test for pH and plant nutrients.
2. With low pH, acid tolerant species must be used or application of lime or organic waste
3. Species chosen must suit the climate and also be economically useful.
4. Soil samples should be taken from top 15 cm, test for lime and nitrogen
5. Top of the soil must be covered with a mulch, straw or wood chippings

Trees may be planted alone, with grasses or in combination with mechanical measures for erosion control. Products may include timber or firewood, fruit, fodder or agricultural crops. Trees are normally planted on such sites, as little else will not grow readily; there is the need to stabilize the ground surface which is normally associated with toxic substances and extreme infertility. Some afforestation of degraded mine sites in Papua New Guinea have used the planting of *Eucalyptus tereticornis* in copper tailings (Hartley, 1977) and *Pinus caribea* variety hondurensis on restored open cast iron nickel workings in the Dominican Republic. *Acacias, Eucalyptu* and other species on dolomite and bauxite mined areas in Madhya

Pradesh, India (Prasad and Chadhar, 1987) and *Eucalyptus* on wasteland from open cast tin mining in the Jos Plateau in Nigeria.

In the restoration of degraded mine sites trees act as:

i. Soil stabilizers; preventing soil surface from moving as the root system ramifies the substrate.

ii. Direct protection of bare ground from erosive forces

iii. Pioneer, colonizing species begin the process of soil development through litter fall and build up of organic matter, soil organisms and micro flora.

2.6.1 Methods of Rehabilitation

According to Blay (1997) rehabilitation methods are generally classified into two:

a) Restoration of soil properties

b) Restoration of vegetation

In practice, four general principles or ways of rehabilitating degraded mine site have been employed according to Mitchell (1990). These are:

i) Chemical stabilization of the surface

ii) Physical stabilization of the surface

iii) Biological improvement

iv) Re-vegetation

The method employed depends on the specific site, cost involved, availability of the agent or materials the period required for restoration as well as the end use of the site.

i) Chemical stabilization of the surface is usually done by the application of oil sprays and synthetic binding agents to form a double crust over the soil surface. This reduces erosion and leaching of toxic chemicals. It is usually very costly and normally precedes natural re-colonization.

ii) Physical stabilization works on the same principle as that of chemical stabilization method, except that plastic sheeting, brushwood or sawdust coverings and others are used. Again it is costly and that makes its use a temporary measure. Natural re-colonization of the site then follows:

iii) Biological improvement involves the inoculation of degraded mine sites with various types of bacteria and fungi to improve the chemical, physical and biological properties of the sites. Fungi are the most resistant to heavy metals, whilst nitrogen fixing micro organisms is the most sensitive. This makes it difficult for legumes to establish, as the bacteria involved in nitrogen fixation is not tolerant to metal contaminated areas.

iv) Revegetation is normally done through radical changes in the chemical, physical and biological properties of the degraded mine site. It involve the use of surface amendments, natural colonization of metal tolerant plants, removal and disposal of the toxic material. Surface amendments like; farmyard manure, sawdust, etc. improve the characteristics for revegetation.

Artificial tree planting then follows either in homogenous or in mixed stands. Homogenous planting leads to the depletion of some major soil nutrients hence mixed planting is usually preferred (Young, 1997).

2.6.2 Problems in Rehabilitation of Degraded Mine sites

Degraded mine sites normally lack top sub soil, but associated with only coarse weathered material with poor physical characteristics and low in organic matter. It is often erodible, easily compacted, poorly or excessively drained. The substrate surface often moves as having been dumped or re-shaped and its complete exposure renders it prone to sheet and gully erosion. The substrate is usually infertile and consists of waste development, rocks and mineral procession tailings. It is the physical and chemical properties of this mixture that must be overcome in order to successfully rehabilitate such sites (Mitchell, 1990).

2.7 Purpose of Rehabilitation of Degraded Mine sites

The purpose or objective of rehabilitating degraded mine sites is dictated by the suite of problems that must be overcome and the ultimate use of the reclaimed land. The rehabilitated mine site can be broadly put into uses such as:

i) Forestry or agricultural land

ii) Pasture

iii) Amenity/recreation

2.7.1 Rehabilitation to Forestry/Agricultural Land

The use of trees for restoring degraded sites to production has become a major branch of science and practice of agroforestry. Reclamation forestry has long been successfully used to restore fertility on degraded sites notably in India since 1989 (Young, 1997). The success of such project normally depends on the following:

i) Participation and involvement of the local people, including women and local leaders.

ii) Use of integrated land use planning to meet all needs such as: food, fuel wood, fodder, post, poles, timber and erosion control.

iii) Commitment and financial provision by funding agency to cover a long period of time

iv) Institution capable of carrying out the program for example nursery establishment and adequate facilities to meet requirements.

v) Security of land and tree tenure

vi) Choice of project objectives that meet the expected wishes and needs of the communities.

The trees must provide multiple use, that is the initial period of pure forest cover and subsequently production of other services and products (Young, 1997).

Species usedshould have specific properties, that is:

i) Capacity to grow on poor soils

ii) High rate of nitrogen fixation

iii) Deep root system and high rate of leafy biomass production

iv) A high and balanced nutrient content in foliage, litter of high nitrogen content, low in lignin and polyphenols

v) Fast growing with straight boles.

Products may include timber, fuel wood, fruit, fodder or agricultural crops, for example cashew nut (*Anacardium occidentale)*.

Tolbert and Burger (1994) outlined the forestry reclamation approach as basically:

i) Replacing 7.5-9.0 cm of surface soil and/or weathered sand stone with over burden (taken from 10 cm for the new reclaimed soil and sub soil medium)

ii) Loosely grinding non compacted top soil or top soil substitute that includes, where possible, woody debris and native seeds.

iii) Using native and non competitive domestic ground covers that quickly protect the site, encourage native forests plants and animals and enhance forest succession.

iv) Planting nursed trees for wildlife and mine soil improvement and planting valuable crop trees for their commercial value to the landowners and adjacent communities.

This approach has been used operationally and has proven successful; it cost less per acre than traditional reforestation practices. About 86% of Virginia landowners are now opting for post mining land use for forestry (Torbert and Burger, 1994). A pioneer baobab farm project for restoration of gravel workings on the Kenya coast provided nature trail for tourism, aquaculture with fish in addition to other products and services (Baumer, 1990). A mixture of reclamation for production including aquaculture and nature conservation was used for the rehabilitation of tin tailings in Malaysia (Arumugam, 1995).

Some species recommended are *Casuarina equisitifoliia*, *Tephrosia candida*, *Senna siamea, Prosopis*, *Leucaena leucocephala*, *Eucalyptus*, *Acacias.*

In the Swansen valley project South Wales U.K. a barren valley caused by toxic industrial waste was greened by planting trees able to grow in the presence of soil polluted by heavy metals (Young, 1997). One way of ensuring tree establishment in a polluted site is to plant the trees in pit filled with soil with which gypsum and farmyard manure have been added (Young, 1997).

2.7.2 Rehabilitation for Pasture

Rehabilitation of degraded mine site to pasture for grazing is one of the best options, but very difficult to create (Young, 1989). A combination of shrubs, used for animal browsing, nitrogen fixation and grasses used for land stabilization and animal grazing seems appropriate (Indo-US, 1992). Species diversity is ensured and conducive wildlife habitat provided (Evans, 1990).

There must be no or low uptake of heavy metals by plants and the risk of direct ingestion of contaminated materials by livestock must be low. The levels of metals likely to cause phyto-toxicity must be roughly equal to the upper limit advisable for direct ingestion by humans (Mitchell, 1990).

Many plants can often take up concentrations of metals and become phyto toxic above the recommended levels without showing any signs of the toxicity (Mitchell, 1990). As a result, research is currently on going to determine plant species that can absorb and reduce the toxic levels of heavy metals through laboratory test of plant specimen especially the foliage (Mitchell, 1990).

Thousands of acres of Appalachian mined lands that were originally degraded have been reclaimed as hay land, pasture or wildlife habitat. Such land is usually left unmanaged after bond release and slowly succumbs to brushy woody vegetation with little commercial value (Burger and Tolbert, 1992).

2.7.3 Rehabilitation of degraded Mine sites for Recreational Purpose

In recent times due to the difficulty in filling back large pits mining companies create in the course of their operations, aqua forestry has been introduced as an additional option for reclamation (Young, 1989). The pits are normally filled with water and limed to reduce the acidity and further stocked with fingerlings, especially herbivorous fishes (Baumer, 1990).

Tree species that have the capacity to establish on degraded lands, improve or enhance soil fertility are normally planted. For instance *Casuarina* species show remarkable ability to grow on adverse sites; sandy, saline or toxic (Diem and Dommergues, 1990). The trees could acts as windbreak, provide shade, and protect pond banks from erosion and provide desirable microclimate. Some of the trees leaves could be supplied to fishes as food (Young, 1989). Multiple use agroforestry for land reclamation with combination of timber production, game ranching and tourist amenities has been proposed (Le Houeron, 1993). Large pits filled with water could act as in-land Lake with beautiful tree surroundings and restaurant facilities attached could attract tourists both from within and outside the country. These facilities could provide a sizeable income to the Mining communities.

2.8 Tree Species for Rehabilitation of Degraded Mine Sites

In the rehabilitation of degraded mine sites, tree species used should have specific properties that can improve and maintain soil fertility, either indigenous or introduced.

Some of the recognized properties according to Young (1989) are:

i) A high rate of production of woody biomass

ii) A dense network of fine roots, with a capacity for abundant mycorrhizal association

iii) The existence of deep roots to capture nutrients from deep layers

iv) A high and balanced nutrient content in foliage, litter (high in nitrogen, low in lignin and polyphenols).

v) An appreciable nutrient content in the root system

vi) Moderate rate of litter decay to ensure adequate maintenance of soil cover

vii) Absence of toxic substances in the litter or root residue.

2.8.1 Stands Growth and Development in Rehabilitated Mine sites

A mixed stand is a collection of individual trees each with its own genetic potential for using a site, interact and compete with one another (Evans, 1990). At planting, tree growth stops temporarily till it firmly establishes in the new site, when growth accelerates. Growth of different trees is not identical. On degraded mined, sites, species which tolerate high concentration of toxic metals establish and grow faster than low tolerance species (Mitchell, 1990). Trees species compete as a result of initial spacing and individual tree growth rate. Competition could occur between roots in soil for water, nutrients or above ground when branches touch and shade one another. Evans (1979) observed tree competition in *Pinus patula* stands planted at 2.74 x 2.74 m spacing at 5 years of age when the trees were 7 m tall. In spacing trial in *Eucalyptus saligna*in Hawaii diameter began to decline at 3 years of age when tree stands were 10 m tall. In Sabah Malaysia a height growth of 13.23 m was observed in trials of 4 years *Acacia manguim* for rehabilitation of degraded mine site (Walter, 1980).

2.8.2 Litter in-situ and Turn-over Under Mixed Stands

Litter is the gradual accumulation of fallen leaves, seeds, twigs, flowers, fruits etc. under tree stands (Evans, 1990). Litter in-situ under planted trees starts from none at planting and gradually increases with plant age. Litter in-situ is the amount of litter fall and accumulations per unit area under trees stands. Whilst litter turn over is the ratio or proportion of litter hanging on the tree that could fall with slightest shaking or wind blown to the ground per unit area. Litter fall is remarkably uniform among tree species growing under similar soil and climatic conditions; however it could differ with different species growing in the same climatic area, due to differences in plant phenology (Burley and Wood, 1991). Annual returns of up to 12 tonnes/hectare have been reported for tropical rain forests. Under *Pinus caribea* with severe conditions and varied ground flora, litter accumulation is at the maximum at age 10 – 18 years with no net increase thereafter. The build up of large quantities of undecayed litter in plantations of broad leaf species is rare. Even under teak and Gmelina, which suppress other vegetation, the leaves readily decay (Evans, 1990).

In reclamation agroforestry on degraded soils, the key features are high rate of litter production complete ground cover of litter, which will probably reduce the rate of nutrient loss (Young, 1997). The light crowns of most *Eucalyptus* lead to ground cover flora species and relatively fast litter breakdown and decay. Heavy fall of litter from leguminous trees does not lead to build up since the high nitrogen content is attractive to numerous soil organisms. For example in mixed dense plantation, *Pinus patula* litter continues accumulating for many years and in extreme cases has reached over 300 tonnes/hectare (Young, 1997).

2.8.3 Natural Species Recruitment/Regeneration under Mixed Stands

Many indigenous and plantation species exhibit profuse natural regeneration. This is mostly from seeds and occasionally from suckering when shoots emerge from roots of trees (Evans, 1990). When planted species establish on degraded mine sites, canopy closure and presence of toxic levels of heavy metals limit indigenous pioneer species development. However, some develop in gaps and open spaces.

Species that develop are usually the light demanders, shade bearers and metal or toxic tolerant plants (Mitchell, 1990). The light demanders emerge first with the slightest favourable condition, whilst the shade bearers grow and survive with planted tree species, however, the growth of these species are us ally retarded. The metal or toxic tolerant species grow and develop with the planted trees.

In Ecuador, plantation species of *Cordia alliodora* encourages natural regeneration of native rain forest species. In India, natural regeneration is rare in plantations in moist teak areas, but more common in moist deciduous teak areas not subjected to ground fire (Nair, 1984). In drier tropics, natural regeneration is aided by goats and camel that eat seeds and deposit them in their dung (Ahmed, 1986). Natural species recruitment or regeneration under mixed stands of reforested degraded mine sites ensure efficient and effective restoration of the ecosystem and soil improvement (Young, 1989).

2.8.4 Natural Re-colonization of Mine sites

Natural recolonization is the gradual natural succession, establishment and development of pioneer light demander species on a degraded mine site without any human interference (Mitchell, 1990). On degraded and toxic mine sites, natural recolonization is generally limited and occurs in a patchy and sparse manner. However metal tolerant species, which develop can then be used in other degraded sites where commercial species would not survive (Mitchell, 1990).

Some plants are capable of storing the metals at the roots: whilst others are able to survive with high concentration in the shoots or leaves (adaptive plants). Most plant species tolerate only one or two metals and this limits their use, as some cannot be transferred or transplanted from one site to another. Adaptive plants are of little use in urban environments where it is more suitable to remove the toxicity than to adapt to it (Mitchell, 1990).

2.8.5 Diversity of Regenerated Species

Plantation stands may have such a dense canopy that virtually no other plants may regenerate as typical of many young stands of pines, *Eucalyptus* and teak before thinning, owing to lack of sunlight reaching the forest floor. Plantations seem to be less diverse than natural forest, however, it is not uniform for several reasons:

i) Several species may be planted (mixed planting) particularly along firebreaks.

ii) A stand grows through several stages thereby providing many different kinds of habitats.

iii) In most plantation forests, there could be stands in many different stages of development

iv) As a necessity, much land within a plantation is left unplanted to produce openings which will allow other kind of vegetations to develop.

v) Wind and fire damage could also create gaps and openings (Evans, 1990).

Other practices could also be employed to encourage species diversity in plantations and enhance ecological value despite the toxicity of such sites

a) Bench mark reserve – island of natural forests that are left undisturbed. Roche (1978) suggested that for rain forest, about 200 ha should be left intact.

b) Corridors of natural vegetation – much diversity could be added if the ground is left undisturbed.

c) The use of native species – for ecological benefit, it is better to encourage the growth of the native species as it is well adapted to the particular environment.

d) Use of several species – this is usually done to ensure optimum matching of species to a site and meeting of different management objectives for the stand (Grieser, 1970).

When plantations are used to rehabilitate damaged industrial waste land, it could lead to increase in species diversity as it adds habitat complexity. Afforestation in the Nyika and Viphya plateau in Malawi led to increases in species diversity. In Venezuela afforestation with *Pinus caribea* on poor savannah soils augmented species population (Evans, 1990).

2.9 Soil Amelioration Under Planted Trees

Many studies have shown that trees improve both the physical and chemical properties of degraded mine sites. Once trees are established, litter layer develops leading progressively to the build-up of soil organic matter and nutrients (Young, 1989).

There is a general belief that plantations and natural forests in the tropics have different effects on the soil on which they grow. Most studies have therefore compared soil conditions under plantation with that of the soil under original forest vegetation.

Robinson (1970) found a drop in organic carbon and phosphorus under *Cupresus lasitanica* plantations compared with indigenous forest in Kenya. Comforth (1970) observed on coarse textured soil in Trinidad *Pinus caribea* led to the depletion of nitrogen and most mineral nutrients compared with natural forest.

Prasad and Chadhar, (1987) indicated that organic matter content, cation exchange capacity and exchangeable cations were higher in soils under natural forests and mixed plantation than in soils under monoculture. In India, Badayopadhyey and Mongia (1994) observed higher total nitrogen, available phosphorus, potassium, carbon and pH on plantation than in the natural forests. Young (1997) reported of higher nitrogen accumulation under the nitrogen fixing tree *Acacia mearnsi.*

In central Togo, a five year fallow of *Cassia siamea* and *Azadirachta indica* planted on sandy loamy soils presented an increase in top soil calcium and soil pH. Singh (1988) observed a significant increase in organic carbon, exchangeable calcium and cation exchange capacity in India with high densities of teak in three different stands; mixed forest, *Eucalyptus* and Teak, whilst available phosphorus showed a decline with plantation age.

In Nigeria, no significant difference was observed between soils under 14 years old *Pinus caribea* and adjacent natural forest by Aduayi and Kadebba (1985) however, soils under *Gmelina arborea* plantation showed increase in total exchangeable basic nutrients in topsoil than in original forest. Nye (1961) reported an increase in all the major nutrients N.P.K., Ca, Mg in a semi deciduous forest in Ghana through litter additions. *Acacia nilotica* and *Eucalyptus tereticornis* reduced top soil pH from 10.5 to 9.5 over five years in India (Singh, 1988).

The effect of trees on soil physical properties through plantation forestry practice may result in changes in soil moisture availability, bulk density and compaction. It has been observed that trees act as pumps and dry a site so that the water table is lowered, for instance *Eucalyptus* had been used for such purposes. Studies by Griffiths (1990) did not indicate significant changes in soil physical properties under mixed plantation stands and natural forest. Soil organisms play an essential role in tree nutrition through litter breakdown, nutrient and moisture uptake through mycorrhizae on the roots and any alteration could affect growth. A cover of tree litter increases organic matter which is generally associated with higher rates of soil fauna. Under five multipurpose trees in Nigeria, earth worm casts ranged from 18 t ha^{-1} to 26 t ha^{-1} under *Acioa barteri*, *Leucaena leucocephala* and *Senna siamea* (Kang *et al.*, 1994).

CHAPTER THREE

MATERIALS AND METHODS

3.0 The Study Area

The research was undertaken in the three immediate surrounding communities (Mansa NKran, Koninase, Kwankyiabo) and on a rehabilitated degraded mine site all of the Amansie resolute Limited. Amansie West District is located in the South Eastern corner of the Ashanti region and specifically lies between latitude 6^o and 6^o 30 N and longitude 2^o and 2^o 30 W. The district shares borders to the north with Atwima Kwanwoma, east with Amansie East District, south with Western and Central regions and west with Atwima District respectively (Fig. 3.1 and 3.2).

The climate of the study is a wet and dry topical climate with a mean annual rainfall of 1518 mm p. a.The mean annual temperature is around 26.5^oC (Metrological Service Station, Antoakrom).The vegetation is typical of the moist semi deciduous forest of southern Ghana (Hall and Swaine, 1991) with a mosaic of fallow farmlands consisting of secondary forest, thickets forbs regrowth and swamp vegetation.The area consists of low gentle undulating hills, which rarely exceed 680 m in elevation, The Bekwai series

Ferric Acrisol (I.S.S.S, 1994) soils are found in the summits and upper slope sites of the hills in the area. The Oda series Dystricfluvisol (I.S.S.S., 1994) soils are heavy textured soils developed on alluvial deposits along streams are also found in the area.

The main cash crops cultivated in the area are cocoa, oil palm, citrus, rice, vegetables, and recently, citronella. The main food crops are plantain, cocoyam, maize, cassava and wild yam. Acquaculture, introduced as alternative sustainable livelihood programme by Resolute Amansie Limited, has also become popular in the area.

The Amansie Resolute Concession was $55.4km^2$ (554 ha) but the company operated on 348 ha that included the Mine village, administrative infrastructure, processing plant and the control dam. A sizable secondary forest was left (intact) ecosystem stability.

Fig. 3.1 Map of Ghana showing Amansie West District

Source: Geological Survey Department Ghana (1990)

Space

Fig. 3.2: Amansie West District Map showing Amansie Resolute Mining Site.

Source: Amansie Resources Limited (1995).

3.1.1 The Original and Present Vegetation

The original vegetation of the area was typically semi-deciduous forest with a lot of economic tree species and climbers that supported a large number of fauna (Hall and Swaine, 1991). The soils in this area are more productive and therefore ideal for the cultivation of most forest and agricultural crops, for instance cocoa, oil palm, citrus, plantain, cocoyam and cassava. Excessive logging and forest clearing for farming contributed immensely to the degradation of the vegetation. Traditional gold mining by the indigenes also caused extensive havoc to the area, as innumerable number of mine pits could be located in the entire district.

At present, none of the original forests exist, except in forest reserves and sacred grooves (Adu, 1992). The current vegetation consists of pockets of fallow farmlands, secondary forests thickets, forbs regrowth and riverine vegetation. The vegetation is characterized by quick growing pioneer soft wood trees and few hard woods with less open under growth. The dominant species presently are *Trema orientalis, Alchomia cordiflora, Griffonia simplicifolia, Cedrella odorata, Combretum macronatum, Phyllanthus, Chromolaena odorata* with few and widely spaced*Terminalia ivorensis* and *Elaies guineensis; Pennisatum purperum* and *Panicum maximum* can also be seen along the main trunk roads and along some streams in the area.

3.2 Study Methodology

The studies were carried out in three sequential stages. The first study was socio economic survey of the mining communities. The second study was a botanical survey of rehabilitated and non rehabilitated sites, whilst the third study was soil sampling and analysis of the reclaimed and non rehabilitated sites.

3.2.1 Socio Economic Survey

The first study: socio economic survey was undertaken in three mining communities to collate views from the people with regards to Amansie Resolute Limited Mining Company activities. The communities were Manso Nkran, Konenase and Kwankyeabo. These communities were selected through a purposive sampling approach. The proximity and direct interaction with the mining company was also considered. The major stakeholders such as Mines Department – Kumasi, Environmental Protection Agency – Kumasi, Environmental Officer, Amansie Resolute Limited, Environmental Desk Officer, Amansie West District Assembly, Manso Nkwanta. Focus group discussion was also carried out in the communities.

A prepared semi-structured questionnaire and check list were administered to all the relevant key players from 6th – 22nd February, 2007. The interview was conducted informally on 'taboo' days in the communities. Information from opinion leaders in the communities was gathered through Rapid Rural Appraisal (Khon Kaen University, 1987) and Participatory Rural Appraisal Techniques (Mascarenhas, 1991, Chambers, 1992). This optimizes local peoples input to the research and development process and encourages decision makers to design appropriate schemes for current development processes. The key informants were interviewed in their offices during the normal working hours, through discussions, personal experience and observations. Three focus group discussions were held in the selected communities. The number of people in each group was 15, 20, and 16 representing Koninase, Manso Nkran and Kwankyeabo respectively. Focus group enables one to cross check, either confirm or refute information already obtained.Groupdiscussion normally exhibits variability within the communities, ensures honesty and is often self correcting (Fitzpatrick, 1986). The data collected was arranged, grouped and summarized. In all seventy-one people were interviewed (Table 3.1).

Table 3.1 Relevant Stakeholders Interviewed

Serial No.	Community/Agency	Number of People Interviewed
1	Environmental Protection Agency – Kumasi	2
2	Mines Department – Kumasi	1
3	Environmental Officer (Amansie resolute Limited)	1
		2
4	Amansie West District Assembly (Manso Nkwanta)	2
5	Manso Nkran (Chief and Opinion Leaders)	5
6	Koninase (Chief and Opinion Leaders)	6
7	Kwankyiabo (Chief and Opinion Leaders)	8
8	Focus group discussion in (Manso Nkran, Koninase and Kwakyiabo	46
	Total	**71**

3.2.2 Botanical Survey

The second investigation of botanical survey was conducted at all the sites between 21st and 27th of March, 2007. A botanical survey is a biodiversity inventory that examines landscape scale patterns. It uses many plots of fixed size or different dimensions across the landscape, producing a list of species at different known and precise locations. It helps in the identification of areas of high biodiversity and/or conservation priorities though without quantification of the abundance (Healey, 1988). The mining company rehabilitated three hundred hectares (300 ha) of the degraded sites; which comprises 240 ha of the waste dump and 60 ha of the tailings dump. As a way of monitoring natural revegetation/regeneration, 20 ha of the waste dump was not rehabilitated. Similarly, 5 ha of the tailings dump was not reforested.

3.2.3 Sampling Methods

An ocular estimation of 5 hectares was measured at all the study sites. To ensure fair and accurate comparism, a hectare plot was randomly picked from each of the 5 hectare study sites. The middle point of each of the hectare plots was determined, (Figure 3.3).

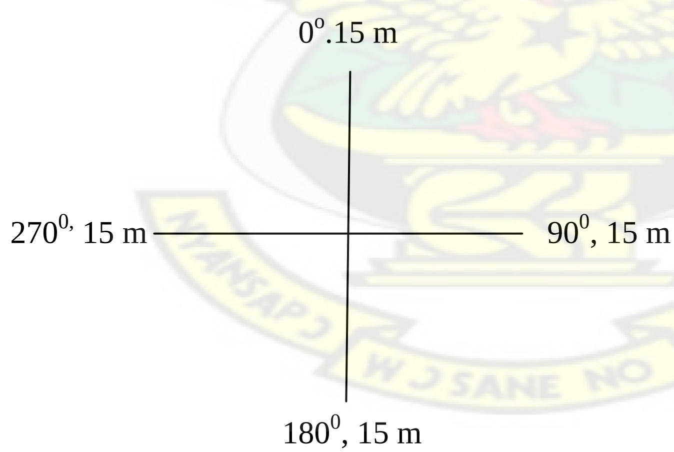

Fig. 3.3: Layout of studied plots.

From the midpoint and through an angle of 0^o, 90^o,180^o and 270^o and the distance of 15 m, the mean height, diameter and volume were measured from 12 randomly selected trees within an area of 20 m x 20 m. The tree height was measured with a Suunto clinometer and a fifty metre measuring tape to the base of the tree. The Clinometer was directed to a point where the trees topmost leaves were highly visible. The optic lens from the Clinometer which corresponds with the hairline forms an angle with the eye level. Another angle forms when the clinometer was directed to the base of the tree. The two readings were summed up and calculated with the horizontal distance to obtain the height of the trees.

A diameter or girth tape was used for the diameter measurement. A vertical length of 1.3 m was measured from the base of the tree stem with a measuring tape. The tape was stretched around the point and the accurate diameter recorded from formulae πd or $2\pi r$. The volume of the trees were also calculated with the Huber's formulae which takes into consideration the length of the stem and diameter at mid section measurement after the suunto clinometer and diameter tape have been used to obtain the diameter and height measurements.

Species recruitment or regeneration under the planted or reforested and non-reforested sites was also determined. Randomly, four 10 m x 10 m quadrats were demarcated within the already chosen sites. Species present were identified physically and counted. Specie diversity, dominance and evenness were determined by the Simpson's Shannon's Margalef's indices.

Litter in-situ and turn over were also determined at all the sites. Randomly, four

(1 m x 1 m) quadrats were measured under the trees in the selected sites. The accumulated litter was collected in all the four sites, weighed, and the average recorded. Similarly, a mat measuring 1 m x 1 m was randomly spread under the trees in four different spots in all the sites.

The amount of litter that fell on the mat were collected and weighed after the standing trees had been shaken. The averages were recorded for litter turn over.

3.2.4 Methods Employed for Tree Planting

Species used specifically for the rehabilitation of the study site were *Acacia manguim, Senna siamea* and *Leucaena leucocephala.* The species were mixed planted at a spacing of 3 m x 3 m. On the waste dump, the unweathered rock materials were crusted, slopes shaped and top covered with salvaged top soil where practicable. The tailings or control dam was allowed to fallow for six months for the semi solid materials to solidify and for the concentration of toxic chemicals to reduce. Soil amendments such as farm yard manure, wood chippings/saw dust were mixed and filled in the planting holes before seedlings were planted and that ensured early seedling establishment. Few seedlings were tried in the site to determine the tolerance before the general planting was carried out.

3.2.5 Soil Sampling and Analysis

According to Young (1997), four to ten soil samples may be adequate for soil analysis on small sites (0.5 – 1 ha) that have been subjected to the same conditions. However, large areas may need up to 25 samples. There is gain in precision when sample number exceeds 25.

Ten soil samples were collected randomly from each of the 4 selected sites. The soil sample were collected at the beginning of the rainy season (late March, 2007), when the area had recorded only two wet days. The soil samples were taken with an augur to a depth of 15 cm.

Composite soil samples collected from each site were thoroughly mixed separately in bucket and 4 samples each of 50 grams were taken to the laboratory for analysis to determine the nutrient potential from each site.

3.2.6 Laboratory Analysis

The composite soil samples were analyzed at the Soil Research Institute of Council for Scientific and Industrial Research at Kwadaso – Kumasi. At the laboratory, the soils were dried at room temperature for 20 hours, ground and sieved through a 2 mm mesh sieve. The actual nutrient contents of the samples were then determined through acceptable and recommended procedure (Young, 1997).

Organic carbon was determined by the Wackley and Blacki partial oxidation method (Ball, 1964). Available phosphorus was determined by the Bray P method (Bray and Kurtz, 1945). Total nitrogen was determined by the micro Kjedhal method (I.I.T.A., 1997). The exchangeable cations, calcium, magnesium, potassium were extracted in IN ammonium acetate (NH4OAc) at pH 7 with calcium and magnesium measured by atomic absorption spectrophotometry and potassium by emission spectrophotometry.

The soil potential hydrogen (pH) was determined on a pH meter with glass electrode. The physical properties; percentage sand, silt and clay were determined by the pipette method (I.I.T.A., 1997).

3.3 Data Analysis

The socio economic survey was analyzed descriptively based on the information obtained from the relevant stakeholders, personal observation and desk study in relation to the mining and mineral guidelines.

The botanical survey was analyzed from comparison of results from field measurements of sample parameters, height, diameter, volume increment, as well as litter in-situ ratio to litter turn over among the various sites. The diversity, dominance and evenness of recruited species were analyzed with the Simpson's Shannon's and Mackintosh's indices. Soil fertility trends among the various sites were compared graphically with the control or undisturbed secondary forest.

3.3.1 Statistical Analysis

The statistical procedure employed included one way analysis of variance (ANOVA), an F-test for equality of variance and paired T – test comparison. Duncan's multiple range test was used to compare treatment means.

3.4 Limitations of the Study

The road to the mining site was very bad, as it had developed potholes and was also very dusty, making it difficult and laborious to move through. Some of the communities were annoyed with the mining company and therefore felt reluctant initially to answer the questionnaire administered. Collecting and measuring litter turn over from the big trees were very difficult, as the trees could not be shaken from the ground very well, therefore a mat of 1 m x 1 m in size was spread under the trees for two days to capture the fallen litter.

The soil samples collected were analyzed at the Soil Research Institute at Kwadaso for a fee due to inadequate laboratory facilities at the Faculty of Renewable Natural Resources.

CHAPTER FOUR

RESULTS

4.1 Acquisition of Mining Rights

Mining companies secure mining rights after mining licenses and mining lease have been granted. The major interviewees were unanimous that the mining company pursued the laid down guideline and procedures and legally acquired the mining license and lease from the Minister of Mines after the custodian of the mining land had agreed by appending the required signatures on the site plan and indenture.

4.1.1 Communities Interaction and Acquisition of Environmental Permit

Public consultations to obtain contributions from a wide range of potentially affected and interested people were undertaken. A total of six meetings were held in all the mining communities to explain the mining processes and activities involved to the communities. The stakeholders interviewed confirmed that scoping and environmental impact assessment were given the highest consideration by the mining company. A favourable environmental impact statement from the Environmental Protection Agency therefore resulted in the issuing of environmental permit. In all, thirty forums and workshops were organized in the communities and in the District Assembly.

4.1.2 Posting of Reclamation Security Bond

Environmental management plans from Mining Companies are key requirements for mining. The mining company produced an acceptable document that described how the disturbed land would be restored or rehabilitated. In pursuance of these, the mining company deposited two thousand Ghana cedis and entered into agreement with the Environmental Protection Agency as a security that could be cashed to restore the land that would be disturbed. There was general consensus among the interviewees and this could also be seen physically from the rehabilitated site by the mining company. Three hundred hectares of land was rehabilitated with exotic species such as *Leucaena leucocephala*, *Acacia mangium*, *Senna siamea* and indigenous species such as *Triplochiton scleroxylon, Chlorophoroexcels, Entandrophragma utile, Albizzzia zygia*and*Terminalia ivorensis*. However, only a few of the indigenous species survived as most of the seedlings were from wildlings.

4.1.3 Formation of Joint Mining and Community Committee

This committee was instituted and charged with arrangements for compensation of affected farm lands, planning and implementation of development projects for the communities. The stakeholders interviewed echoed with a single voice that, the committee formed was very weak, and therefore most of the mining company's social obligations to the communities such as electricity, markets were not realized.

4.1.4 Employment Opportunity Offered

The company employed 45 casual labourers and 5 permanent office workers Table 4.1. The casual labourers were employed during the demarcation and surveying of the land, nursing of exotic species and picking of indigenous seedlings from the wild, conveying of seedlings from the nursery to planting sites and planting of the seedlings. Fence maintenance was also given to them on contract basis (piece work programme basis). Five people were engaged as office or administrative staff. In addition, 30 people were trained and employed as technicians, such as plumbers, welders, drillers, electricians, blast men, mason, and carpenters.

Table 4.1 Employment Opportunities

Employment	Number of People
Permanent office workers	5
Permanent Technician	30
Casual workers	45
Total	**80**

4.2 Mine site Rehabilitation

4.2.1 Natural Re-colonized Species on non Forested Sites (Non forested waste and Tailings Dumps)

An average of eight species were observed to have established naturally on the non forested waste dump (Plate I). The species were *Alchornia cordiflora, Phyllanthus, Elaeis guineensis, Chromolaena odorata, Combretum micronatum, Terminalia ivorensis, Milletia zancharia* and *Albizzia zygia.* On the other hand, a total of four species were recorded on the non forested tailing dump; *Cynodon dactylon, Cynodon plectothychus, Terminalia ivorensis* and *Pteris toppensis (*fern) Plate II.

4.2.2 Natural Species Recruitment Under Planted Stands (Reforested Waste and Tailing Dumps)

An average of four species were counted to have regenerated under the forested waste dumps (Plate III). The species were *Chromolaena odorata, Cynodon plectothychus, Centrosema pubescens and Phyolanthus Discordia.* Similarly, three species were observed to have emerged under reforested tailings dumps (Plate IV). These species were *Alchornia cordiflora, Musanga spp and Elaeis guinensis.*

4.2.3 The Undergrowth/Regenerated Species under Secondary Forest

An average of nine species were observed to have emerged under the big and tall trees in this particular site (Plate V). The species were *Mellitia zancharia, Alchornia cordiflora, Albizzia zygia, Rawolfia vonitolia, Terminalia ivorensis, Chloromohaena odorata, Griffonia simplicifolia, Combretum macronata* and *Elaeis guinensis.*

4.3 Mean Growth Rate of Trees Species under Studies Sites

Mean growth rate data for species is presented in Table 4.2 for height, diameter and volume. The species in the secondary forest had the highest values of (48 m, 30 m^2 and 3.391 m^3) respectively followed by the reforested waste dump with 17 m, 7.6 m^2 and 0.0771 m^3, reforested tailings dump, 16 m, 7.5 cm and 0.071 m^3, non reforested waste dump 2.5 m, 3.0 cm and 0.071 m^3 and the least values of 2,5 n, 2.5 cm and 0.00071 m^3, recorded for the non reforested tailings dump

Table 4.2 Mean growth measurement from studied sites

Site	Height (m)	Diameter (cm)	Volume (m^3)
Reforested waste dump	17	0.076	0.0771
Non reforested waste dump	2.5	0.03	0.07177
Reforested tailing dump	16	0.075	0.0710
Non reforested tailings dump	1.5	0.025	0.00074
Secondary forest	48	0.30	3.3912

Plate 1: Amansie Resolute Limited Non reforested waste dump stand (March, 2007)

Plate II: Amansie Resolute Limited non reforested tailing dump stand (March , 2007)

4.3.1 Tree Height

The mean height of trees from various sites (Table 4.2) ranged from 1.5 m – 48 m. The total average height of trees observed in the reforested waste dump was 17 m, non reforested waste dump 2.5 m, reforested tailings dump 16 m, non reforested tailings dump 1.5 m and undisturbed secondary forest 48 m.

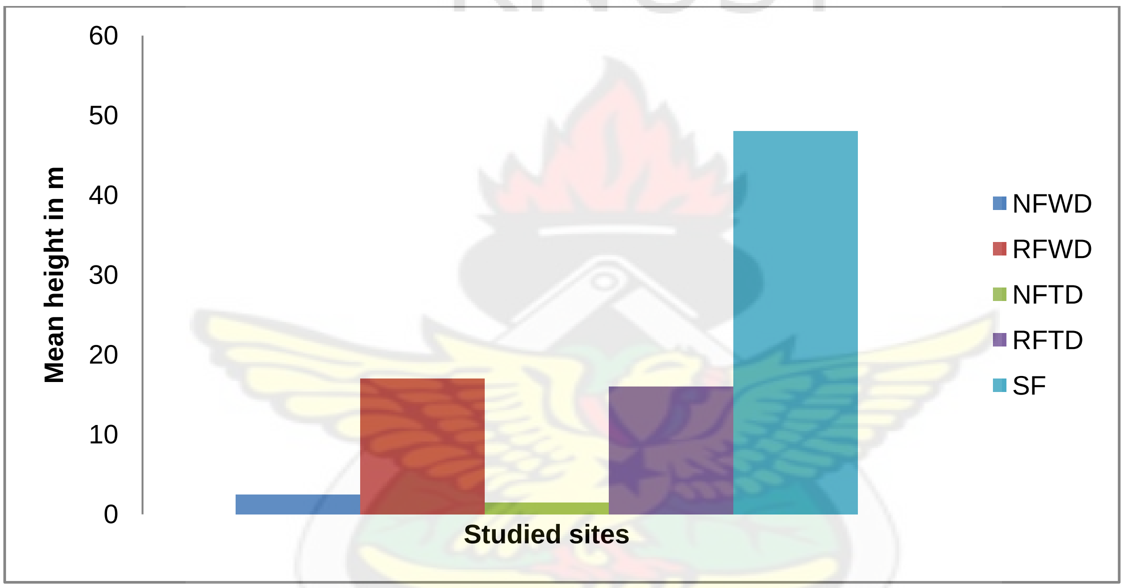

Fig 4.1: Mean height of Trees in studies site

4.3.2 Diameter Measurement

The mean diameter measurements of trees from the various sites (Table 4.2) were; reforested waste dump (0.076 m), non reforested waste dump (0.03 m), reforested tailings dump (0.075 m^2), non reforested tailings dump (0.025 m) and secondary forest (0.30 m) (Fig. 4.2).

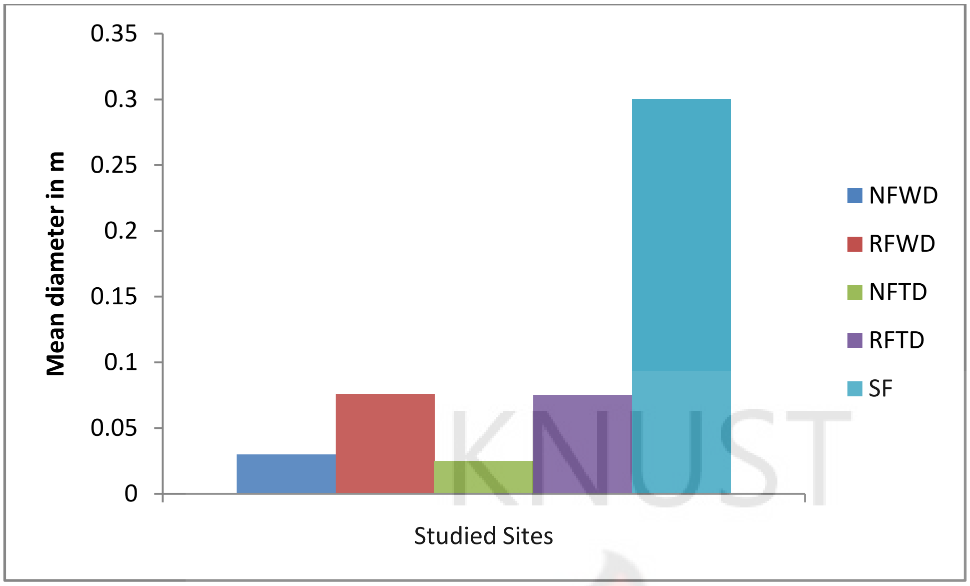

Fig 4.2: Mean Diameter of Trees in studied site

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Plate III: Amansie Resolute Limited Reforested Waste dump stand

Plate IV: Amansie Resolute Limited Reforested Tailings dump stands

Plate V: Amansie Resolute Limited Secondary forest (Bench Mark Reserve) March, 2007

4.3.3 Volume Measurement

The mean volume measurements observed from trees at various sites (Table 4.2) were, reforested waste dump 0.0771 m^3/ha, non reforested waste dump 0.00177 m^3 ha, reforested waste dump 0.0710 m^3 ha non reforested tailings dump 0.00074 m^3/ha and for undisturbed secondary forest 3.3912 m^3/ha (Fig. 4.3).

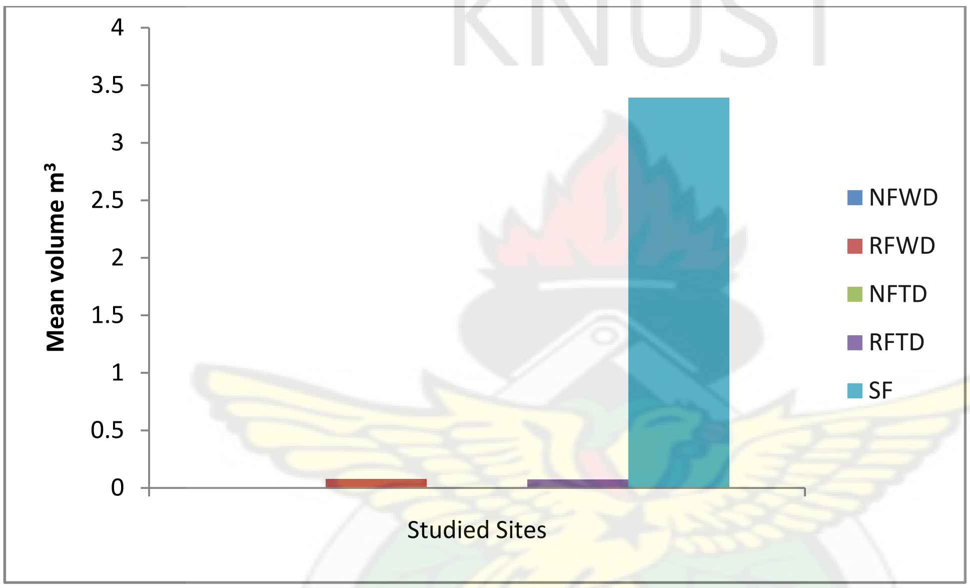

Fig. 4.3 Mean Volume of tree in Studied Sites

4.4 Diversity, Dominance and evenness of Recruited/regenerated Species on the various sites

Species diversity or different species and the total numbers of the individuals were assessed at the various sites. A total of eighteen different species were counted along the length and breadth of all the sites. The total number of species from each site were subjected to Simpson's, Shannons and Margalef diversity indices and statistically analyzed by the Duncan's Multiple Range Test. The values obtained ranged from 1.727 to 4.950. The reforested waste dump accounted for a high mean value of 4.950, followed by non reforested waste dump of 3,120, 2.011, for reforested tailings dump, and 1.857 for non reforested tailings dump. The least value of 1.727 was recorded for the secondary forest. However, there were no significant differences in species diversity among the various sites from the Duncan's test.

Table 4.3 Mean Values of Species diversity among the studied sites

Site	RWD	NRWD	RTD	NRTD	SF
Mean species diversity	4.950[a]	3.120[a]	2.011	1.857[a]	1.727[a]

Mean values followed by the same letters are not significantly different by Duncan's Multiple Range Test (α = 0.05).

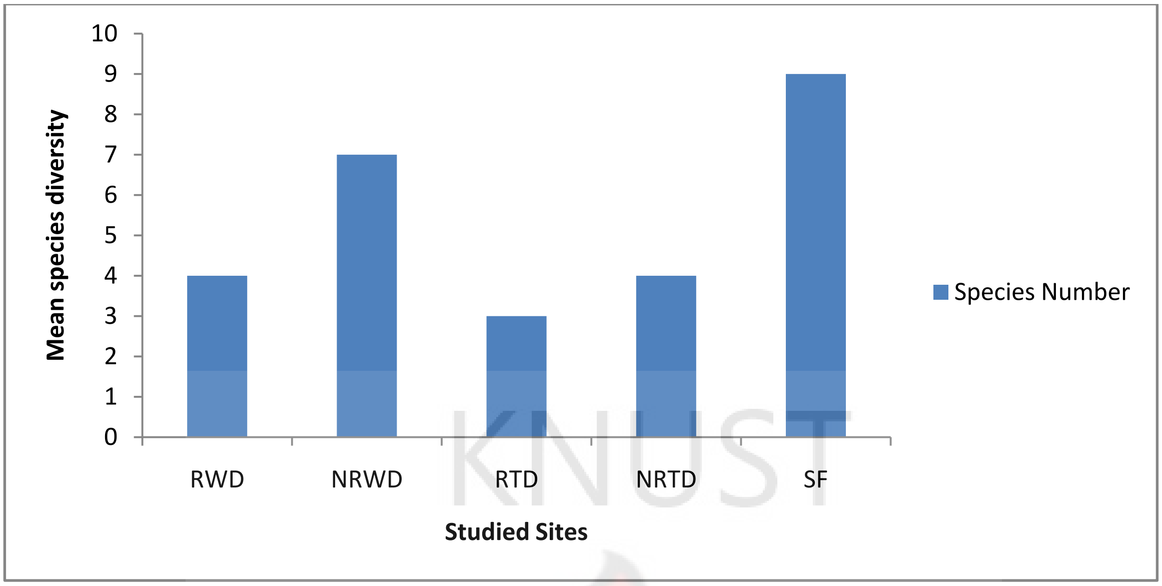

Fig. 4.4: Mean Value of Species diversity among the various studied sites

Table 4.4: Species richness dominance/relative abundance from studied sites

Sample	Species Number	Shannon H
RWD	4	0.02844
NRWD	7	0.03673
RTD	3	0.02033
NRTD	4	0.02521
SF	9	0.04062

Species dominance was determined with Shannon's index, which relates to the maximum possible diversity for a given number of species occurring and or present in almost equal numbers. The species dominance ranged between 0.02033 – 0.04062. The highest value of 0.04062 was observed in the secondary forest, followed by 0.03673 for the non forested waste dump, a value of 0.02844 for reforested waste dump, non forested waste dump registered a mean value of 0.02521 and the least mean value of 0.02933 for reforested tailings dump (Table 4.4).

Table 4.5 Evenness or equitable distribution of species from studied sites

Sample	Species Number	Shannon H
RWD	4	0.4318
NRWD	7	0.6482
RTD	3	0.3826
NRTD	4	0.4195
SF	9	0.7798

Evenness or equitable distribution was assessed with Mackintosh Evenness index. The value ranged from 0.3826 – 0.7798 and exhibited a similar trend to that of diversity and dominance. Evenness or equitable distribution relates to how the individuals are divided among the species present, the closeness of total number of individual species in the particular site. The secondary forest recorded the highest value of 0.7798 followed by non reforested waste dump with 0.6482, reforested waste dump had a value of 0.4318, non reforest tailings dump had a value of 0.4195 while reforested tailing dump had the least value of 0.3826 (Table 4.5).

4.5 Litter in-situ and turn-over on the studied sites

The mean in-situ litter value recorded was 1000 g and that of litter turn over was 200 g, a ratio of 5:1 or 20% for reforested waste dump. Similarly, the accumulated litter in-situ observed for non reforested waste dump was 170 g and that of turn over was 70 g, a ratio of 2.4:1 or 41.176%. The mean litter in-situ recorded for non reforested tailings dump of turn over was 10 g representing a ratio of 2:1 with a litter efficiency of 50%. The undisturbed secondary forest recorded a mean litter in-situ of 960 g and 212.14 g for litter turn over, a ratio of 4.5:1 or 23% as represented by (Table 4.6).

Table 4.6 Mean value of litter in-situ and turn over on the studied sites (kg m^{-2})

Site	Litter in-situ (g)	Litter turn over	Ratio of in-situ to turn over	Percentage
Reforested waste dump	1000	200	5:1	20
Non reforested waste dump	170	70	2.4:1	41.176
Reforest tailings dump	160	70	2.3:1	43.75
Non reforested tailings dump	20	10	2:1	50
Secondary forest	960	212.14	4.5:1	23

TABLE 4.7:Mean Top Soil Facility levels in Non Forested waste and tailing dumps reforested Waste and tailings dumps and secondary forest

TOTALExchangeable cationAvailable											
P.H.Org. cNOrg. M				MC/100gC.E.C AvailablePK Clay Clay							
Treatment	H_20	%	g^kg^{-1}	%	Ca	mg	K	100 Mg/100g	ppmp	ppmK	%
NFWD	7.27a	2.15a	0.185a	3.705a	10.01a	6.675a	4.84a	23.77a	42.37a	265.78a	33.285a
RFWD	6.76b	0.935b	0.11ba	1.615b	6.875b	3.205b	1.01a	12.825b	16.98b	153.05b	33.125a
NFTD	6.66b	0.555b c	0.8ba	O.96cb	5.61b	2.735b	0.61a	10.935cb	20.710c	100.39c	10.345b
RFTD	5.2854 c	0.250c	0.045ba	0.43^{c}	4.135b	1.2^{c}	0.415a	9.47cb	1.965c	98.74c	5.04a
SF	5.065c	0.045c	0.01b	0.08c	1.67c	6.865c	0.38a	6.09c	0.83c	98.74c	4.005a

Mean values followed by the same letters in the same column are not significantly ($p<0.05$) different by Duncan's Multiple Range Test (a = 0.05).

4.6 Soil Nutrient Levels

4.6.1 Potential Hydrogen (pH) Concentration

The pH (H_20) of the soils in the sites are shown in Fig. 4.5. ranged between 5.0650 – 7.2700, slightly acidic to alkaline. The soils under secondary forest were very acidic, followed by reforested tailings dump, non forested tailings dump and reforested waste dump. The soils under non forested waste dump were alkaline. The mean values were significantly different at 5% level (Appendix VIII, $P<0.0001$).

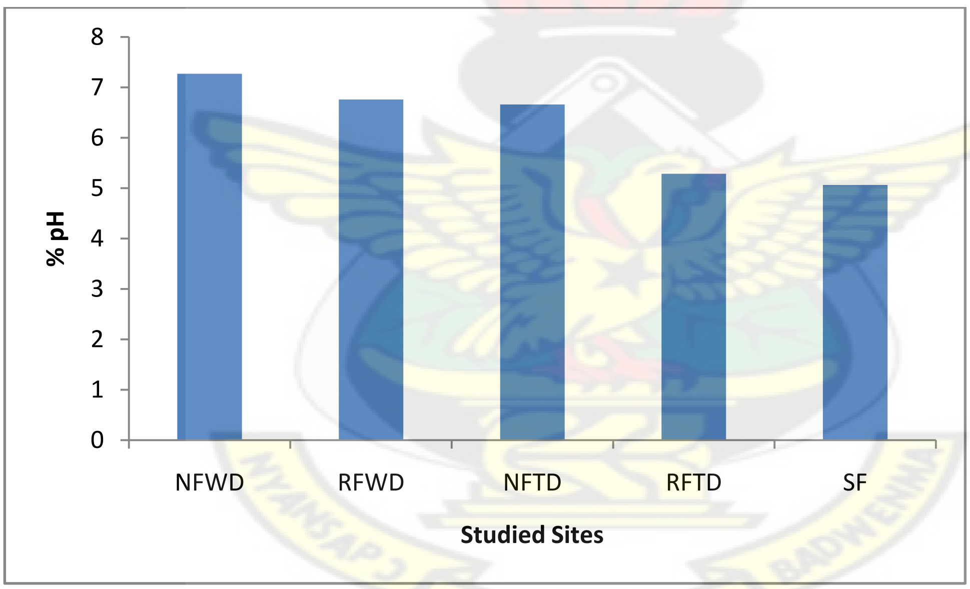

Fig. 4.5: Mean pH for Reforested Waste and Tailings Dumps, Non-Reforested Waste and Tailings Dumps and Secondary Forest

4.6.2 Percentage Organic Carbon

The mean value for percentage organic carbon 2.150 (Fig. 4.6) was markedly higher under non forest waste dump; this was more than 50% and least in secondary forest; 0.045. Similarly, the mean value observed for reforested waste dump was 0.9350 with the non forested tailings dump and reforested tailings dumps recording 0.5550 and 0.250 respectively. The values were significantly different at 5% level (appendix IV, P<0.0017).

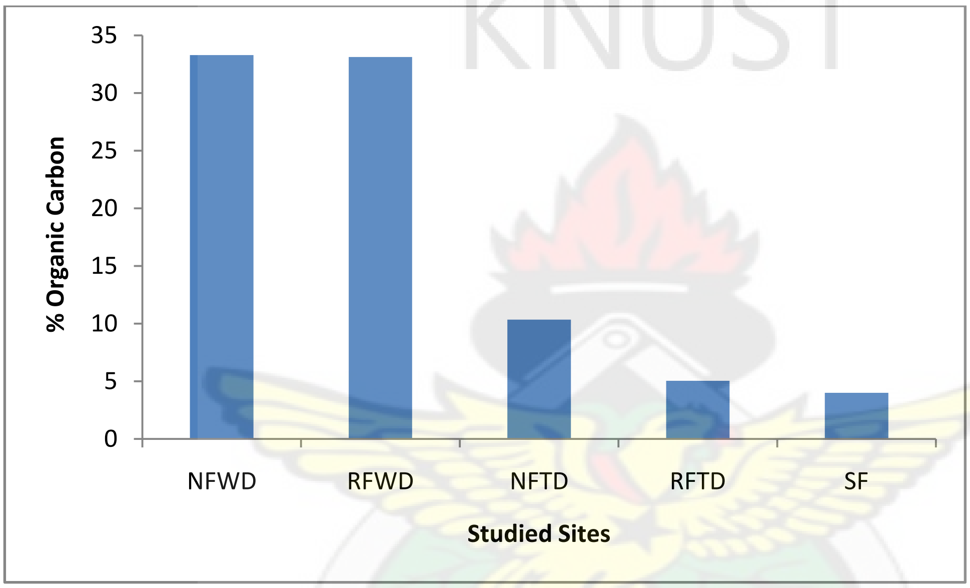

Fig. 4.6: Mean soil percentage organic carbon for Reforested Waste and Tailing Dumps, Non-Reforested Waste and Tailing Dumps and Secondary Forest.

4.6.3 Percentage Total Nitrogen

The percentage mean total nitrogen ranged from 0.10 – 0.800 (Fig. 4.7). The non forested tailings dump had the highest percentage of 0.8000, followed by non forested waste dump with 0.185. The reforested waste dump and tailings dumps recorded 0.110 and 0.045 respectively. The secondary forest had the least value of 0.010. These values are also reflected in the organic matter percentages in the various sites (Table 4.7). The values were not significantly different at the 5% level (Appendix X, P < 0.183).

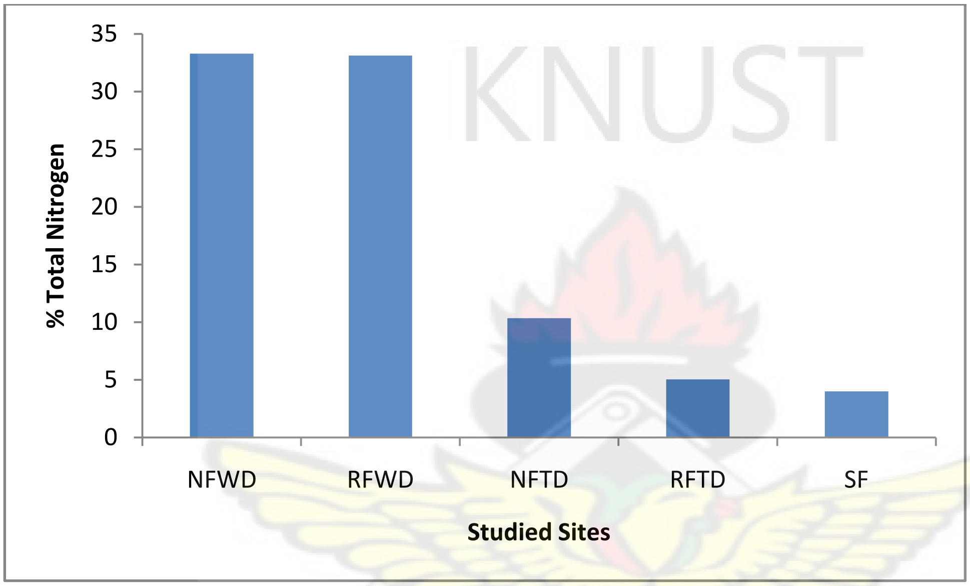

Fig. 4.7: Mean soil percentage Total Nitrogen in Reforested Waste and Tailings Dumps, Non-Reforested Waste and Tailings Dumps and Secondary Forest

4.6.4 Percentage Organic Matter

Non forest waste dump recorded the highest percentage organic matter content of 3.705 and the least of 0.080 by the secondary forest (Fig. 4.8). The percentage organic matter in ascending order was similar to percentage organic carbon as the former is a major contributor to the latter (Table 4.7). The reforested waste dump recorded a value of 1.615 as the second highest; whilst 0.960 and 0.430 were recorded for non reforested tailings and reforested tailings dump respectively. There was a clear relationship between the organic matter percentages, and significant differences among the values at 5% level (Appendix VI, $P < 0.002$).

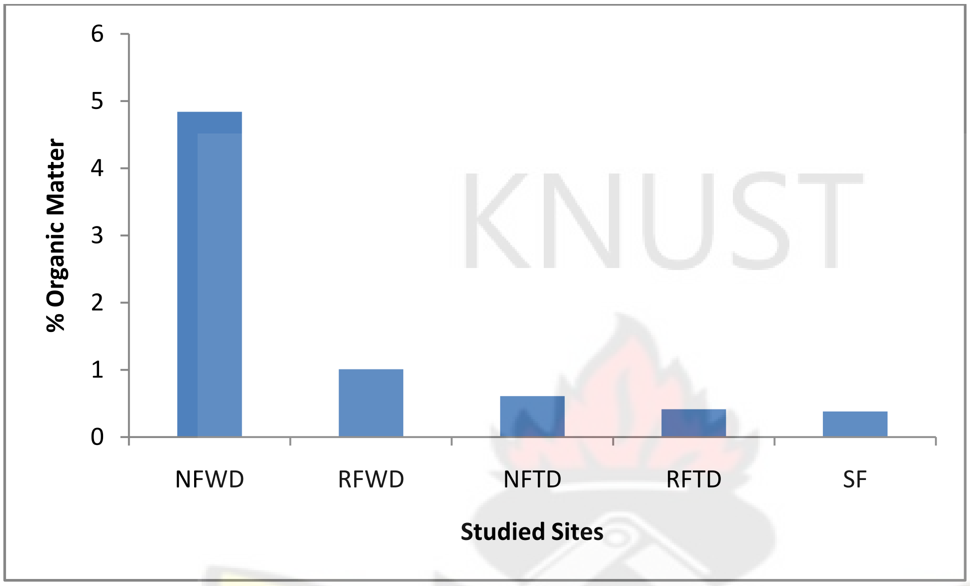

Fig. 4.8 Mean soil Percentage Organic Matter in The Reforested, Non-Reforested Waste and Secondary Forest

4.6.5 Exchangeable Cations (calcium, magnesium and potassium) concentration

The percentages of exchangeable cations at all the sites exhibited one common trend (Figs. 4.9 – 4.11) The highest percentages were recorded for calcium, magnesium and potassium in non forested waste dump; 10,010, 6.680 and 4.840 respectively. Reforested waste dump had the second highest values of 6.8760, 3.2050 and 1.0100. Non forested tailings dump recorded 5.610, 2.2550 and 0.6000 respectively. Similarly 4.13501, 1.2000 and 0.4150 were recorded for reforested tailings dump. The secondary forest had the least values of 1.6700, 0.8650, and 0.3800 (Table 4.7). Generally there were significantly differences among the values at 5% level (Appendices XII, XIII, and XIV).

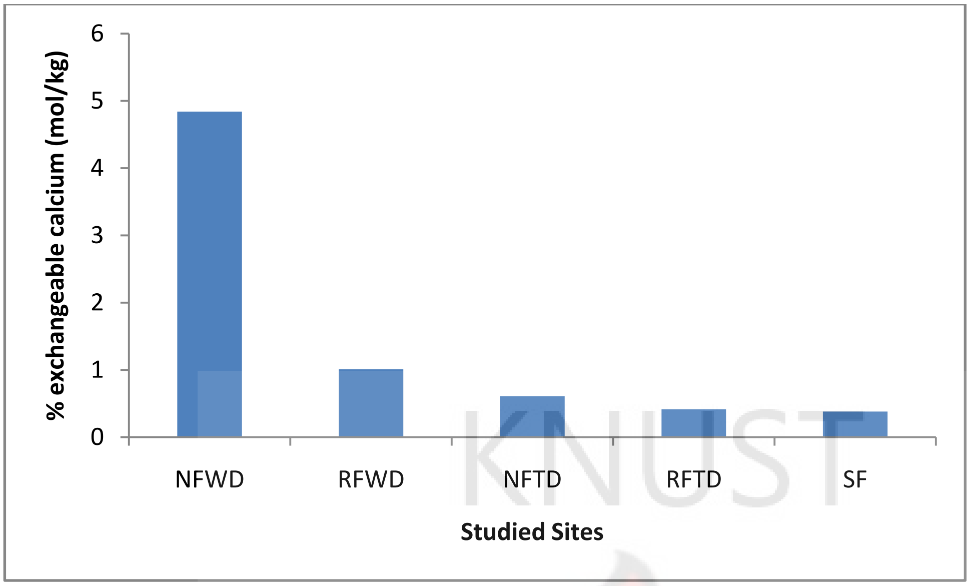

Fig. 4.9 **Mean soil Percentage Exchangeable Calcium in Reforested, Non Reforested and Secondary Forest Sites**

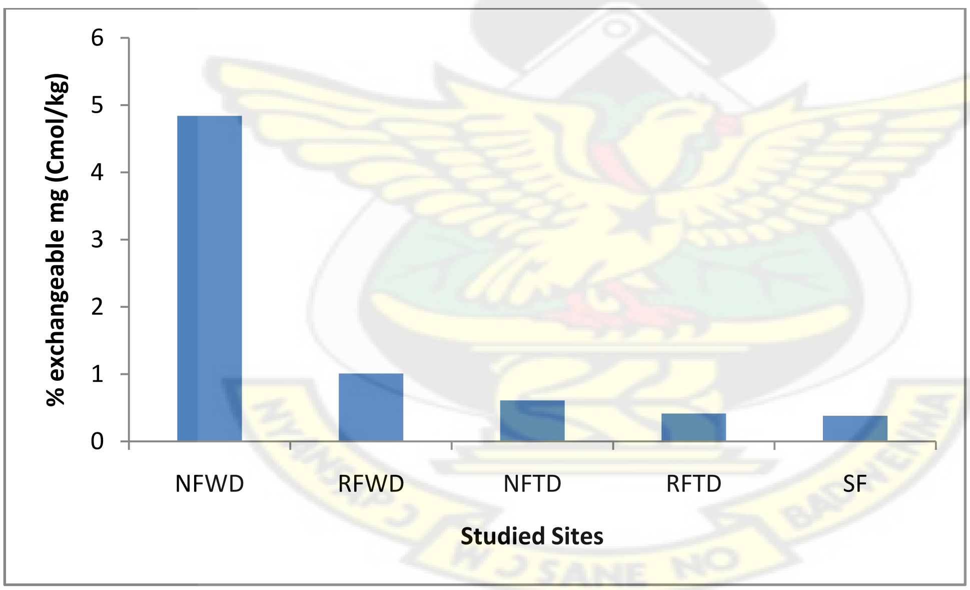

Fig. 4.10: **Mean soil Percentage Exchangeable Magnesium in Reforested, Non-Reforested Waste and Secondary Forest Sites.**

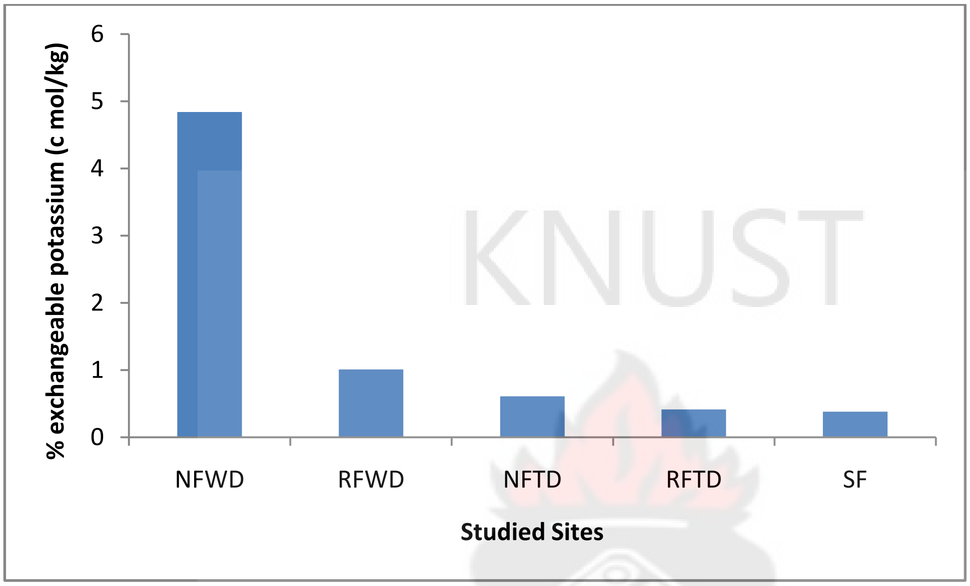

Fig. 4.11: Mean soil Percentage Exchangeable Potassium in Reforested, Non-Reforested and Secondary Forest Sites

4.6.6 Cation exchange capacity

The cation exchange capacity within the sites followed a similar trend to the exchangeable cations (Fig. 4.12). The values ranged from 6.090 – 23.770. The highest value of 23.770 was recorded for the non forested waste dump, followed by the reforested waste dump: 12.825. The non forested tailing and reforested tailing dumps registered 10.935 and 9.470 respectively, whilst the secondary forest had the least value of 6.090 (Table 4.7). There were significant differences at 5% level (Appendix XV, $P < 0.0026$).

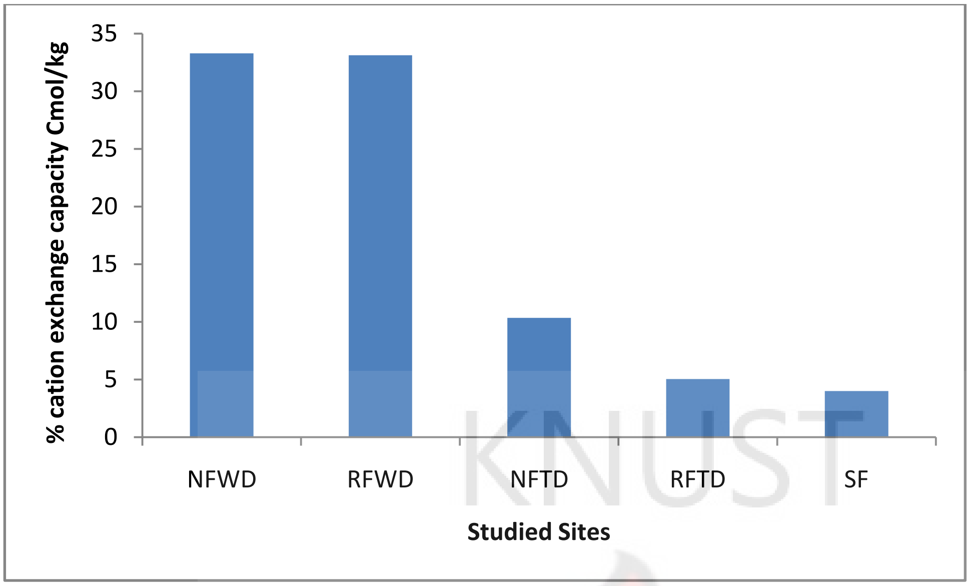

Fig. 4.12: Mean soil cation exchange capacity in Reforested, Non Reforested and Secondary Forest sites.

4.6.7 Available Phosphorus

The mean values of available phosphorus (Fig. 4.13) recorded for the various sites followed the same trend as noted earlier for cation exchange capacity. The non forested waste dump recorded 42.375 which were far higher than that of reforested waste dump: 16.980.The non forested waste dump had a mean value of 2.700 and reforested tailings registered 1.965. The secondary forest had the least value of 0.830 (Table 4.5). Significant differences among the values were observed at 5% level (Appendix XVI, $P < 0.0001$).

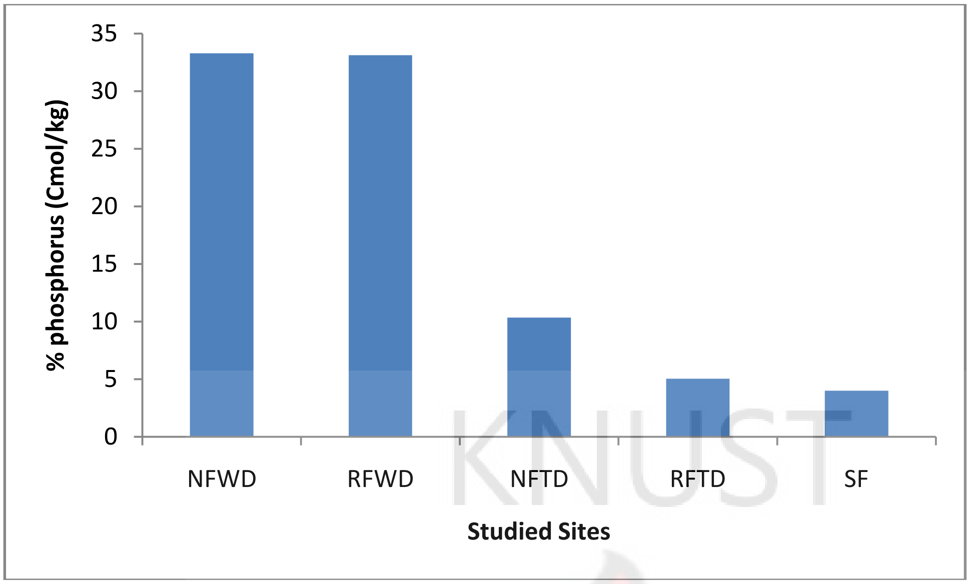

FIG. 4.13: Mean soil available phosphorus in Reforested, Non-Reforested and Secondary Forest sites.

4.6.8 Available Potassium (K)

The mean values for available potassium ranged between 98.70 – 265.78 (Fig. 4.14). The highest value of 265.78 was observed in the non forest waste dump. The reforested waste dump followed with 153.05. The non forested tailings and reforested tailings recorded 100.39 and 98.74respectively. Surprisingly the secondary forest also registered a mean of 98.74 which was equal to that of the reforested tailings (Table 4.7). Significant differences were observed between reforested tailings dump and non forest waste dump at 5% level (Appendix XVII).

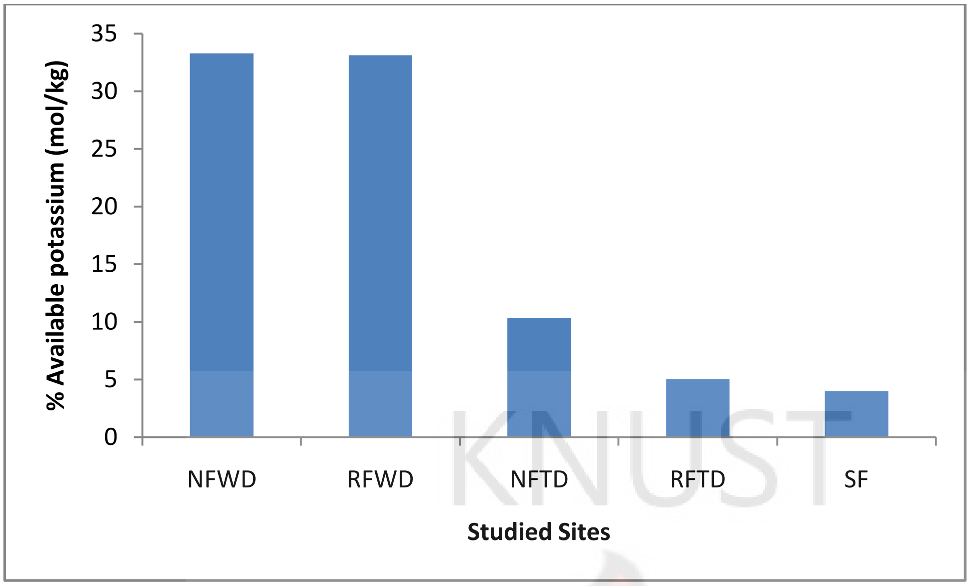

Fig. 4.14: Mean available Potassium in Reforested, Non-Forested and Secondary Forest Sites

4.6.9 Percentage Clay

The percentage clay content ranged from 4.03% - 33.29% (Fig. 4.15). The non forested waste dump had the highest percentage of 33.29%. The non forest tailings and reforested tailings recorded 10.25% and 5.04% respectively. The leased value of 4.00% was observed in the secondary forest (Table 4.7). There were significant differences among the value at 5% level. (Appendix XVIII).

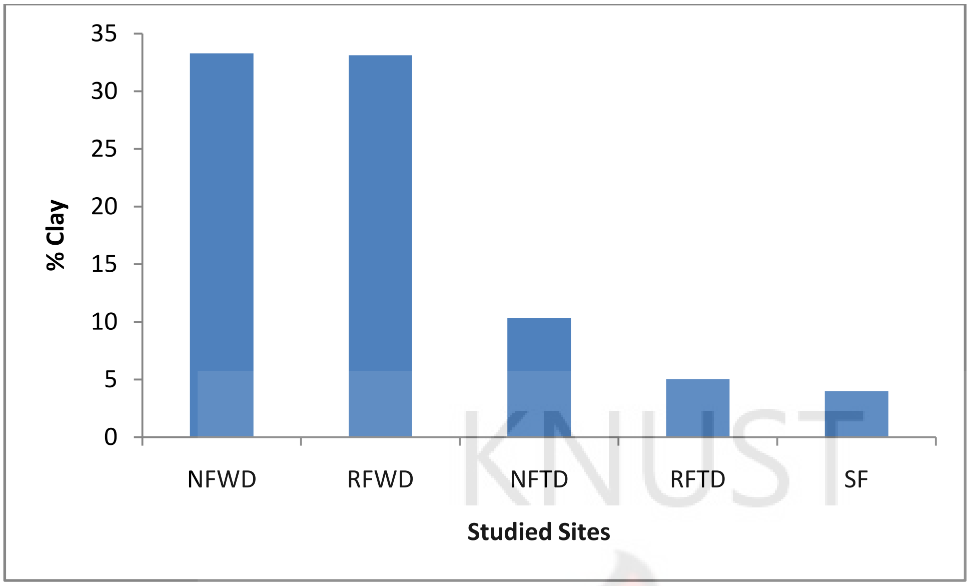

Fig. 15: Mean percentage Clay in Reforested, Non-Forested and Secondary Forest Sites

CHAPTER FIVE

DISCUSSION

5.1 Pre-Mining Commitments

5.1.1 Acquisition of Mining Rights

Mining generally destabilizes ecosystems and adversely affects adjacent communities. Therefore guidelines have been developed by Minerals Commission and Mines Department for companies with exclusive interest in mining to reduce their impacts to tolerable and acceptable levels to minimize conflicts and misunderstandings which often occur between mining companies and communities where actual mining is carried out.

The companies are enjoined to access mining rights by first obtaining mining licenses and mining leases. Amansie Resolute Limited registered as a company in line with Act 179 of the 1963 company's code. This facilitated the acquisition of a mining license in conformity with the Mining and Minerals Act PNDC L 153 of 1986, Section 36 (1) (2) and (3) and Act 703 of 2006, Section 34. The mining lease was also secured from the allodia owner of the land through negotiation to satisfy PNDC L 153 of 1986 Section 53, Sub-section (1) b,c,d Section 17 Sub-section 13 and Act 703 of 2006 Section 39 Sub-section 2 (a) and 2 (b). Scoping was conducted in all the communities in the Mining area where people's views and concerns were collected and factored into the environmental management plan consistent with L 1652 of 1999; environmental assessment regulation.

To ensure harmony and peaceful co-existence between mining companies and the mining communities, a joint committee was formed, as enshrined in the mining and minerals law

PNDC L 153 Section 71 Sub-section 1 and 2 Section 73 Sub-section 4 and Act 703 of 2006 Section 72 Subsection 4 and 5 and Section 73 Subsection 1, 2, and 3. The committee worked creditably and that helped to minimize conflicts and misunderstanding between the communities, however some of the communities' prime needs like electricity could not be provided by the Mining Company.

5.1.2 Reclamation Security Bond and Environmental Management

Reclamation security bond, a financial commitment for the rehabilitation of the would be degraded site was arranged with the Environmental Protection Agency. Amansie Resolute fulfilled the obligation as required by the Mining and Minerals Act PNDC L 153 of 1986, Section 17 Sub section 2 (a) and (b), Act 703 of 2006 Section II Sub section a, b and c and L1 1652 Environmental Assessment Regulation of 1999. The company deposited two hundred thousand Ghana cedis to the Environmental Protection Agency and the Mines Department for this purpose.

The company rehabilitated the degraded waste and tailings dumps with exotic and indigenous species. The exotic species achieved 95% success, whilst the indigenous recorded only 50% success as most of the seedlings were collected from the wild. The rehabilitation in general recorded about 72% success and that could be due to effective monitoring and supervision by the Environmental Protection Agency and the Mines Department and the involvement of the communities. It is likely that the mining company integrated environmental management through the continuum operations from exploration through design and construction to mining, mineral processing, rehabilitation and decommissioning (Ghana Chamber of Mines, 2006).

The financial commitment exhibited by the mining company was also a major contributory factor for the success of the programme. Young (1997) observed that a participatory approach with a village or communal body as well as individual land owners, coupled with good planning and implementation ensures successes of reclamation programmes. The joint mining and community committees have been given further impetus recently by the World Bank through the introduction of the Extractive Industry Transparency Initiative (EITI). This initiative requires a mining company to liaise with the mining communities, disclose their profit margin to the Minerals Commission and apportion a certain percentage towards the development of the communities. This has been adopted by Newmont Ghana

Gold Limited at the Ahafo Concession (Newmont, 2007).

5.1.3 Employment Consideration

Employment was offered to people in the adjacent mining communities for services which could be handled without any difficulty. In all, 80 people were employed especially as surveying and nursery assistants, fence maintenance and in the transplanting and maintenance of seedlings. Some of the people from the communities were trained and employed as plumbers, welders, drillers, masons, carpenters, electricians, blasters etc. (Anglo Gold Ashanti, 2000. The number of people employed was below the communities' expectation as surface mining operations are very capital intensive than deep mining which is more labour intensive (Bergman, 2004). The number of employed however, satisfied the localization policy as enshrined in the Mining and Minerals Act PNDC L 153 Section 36 (b) (d), Section 54 (1) and Act 703 of 2006 Section 11 (d) Section 50 (1) (2) and (3). Mining contributes only 2% of employment in Ghana because most of the minerals are exported and processed elsewhere and therefore does not provide any linkages to the other sectors to provide additional employment for the benefit of the economy (CEPIL, 2000).

5.2 Performance of Planted Trees

The mean height, diameter and volume measurement from the rehabilitated sites compare favourably with similar trials in India and Australia (Evans, 1990). The mean values for the reforested waste and tailing dumps were almost equal and this could be attributed to the adoption of recommended methods before and during planting. Species were tried at the sites, soil tests were conducted, applicationof soil amendments was done and the fallowing of the tailings control dam was also done. These methods ensured early seedling establishment and subsequent growth (Ayensu, 1977). Though most of the species were exotic, the few indigenous species that survived were also observed to have achieved a sizeable height, diameter and volume. Evans (1990) observed a relationship between diameter and height as stochastic and governed by the probability theory. Hush (1982) noted that if two variables are correlated with a common variable, they appear to correlate to each other. Therefore trees height, diameter and volume correlated greatly among the species from the studies sites. Though the age of the secondary forest was not considered, the growth of the planted trees was in the ratio of 1:3 which was very appreciable. The height growth of trees is a measure of mine soil quality ‘site index’ for forest which relates to wood volume and wood value (Burger and Tolbert, 1992).

5.3 Natural Species Recolonization/recruitment, Diversity, Dominance and Evenness under the various sites.

Natural re-colonization and recruitment usually occur from buried seeds in the disturbed sites (Simpson, 1989). Seed bank data can yield information on three features of the new vegetation.

i) Species composition diversity

ii) Relative abundance, dominance

iii) Potential distribution evenness

The re-colonized species in all the planted sites consisted of about 98% pioneer and non pioneer light demanding species. The secondary forest had the highest diversity of species. This could probably be due to the fact that it had not been disturbed frequently by human activities, such as fire, over grazing and gap opening (Sousa, 1984). This was followed by the non forested waste dump. This could also be due to mixed planting or the buried seeds from the salvaged soil which became exposed, received the required favourable conditions and advantageously regenerated. Seed banks often play a significant role in natural regeneration (Secondary succession) after vegetation disturbance (Roberts, 1981). The reforested tailings dump and reforested waste dump followed in that order. The species of the reforested tailings dump, could be due to seeds that might have been carried in the runoff, as the site was on the lower slope.

The reforested waste dump recruitment could also be attributed to the planting distance employed which afforded the seeds the necessary exposure (Sunlight, Moisture) which ensured germination and establishment (Evans, 1990). The non forested tailing dump recorded the least diversity of species probably due to the non tolerance of most species to polluted, acidic, high levels of heavy metals and toxic concentration of salts (Mitchell, 1990). Nair (1984) observed better regeneration in moist deciduous teak plantation in India. This may probably be due to the presence of more species as well as their distribution resulting in greater diversity (De Benedicts`, 1973). Higher species diversity allows for greater array of species interaction and results in high degree of niche specialization. This usually gives rise to species dominance and distribution as species establishes in favourable part of the habitat with environmental homogeneity and minimum competition for food and space (Jayaraman, 2000). Species diversity therefore results in species interaction and high ecosystem stability. Whitemore (1989) observed more species of large woody climbers in forest regeneration on previously disturbed land than in secondary forest.

5.4 Litter in-situ and Turn-over

The litter in-situ and turn over under the various sites correlated positively with tree growth. Unexpectedly the ratio for the reforested waste dump was higher than the secondary forest. This could be due to the fact that soil micro organism activities were very slow in terms of litter breakdown by soil microbes. The non reforested waste dump followed the secondary forest, the litter recorded, might have been carried by runoff water to that site. The reforested tailing dump followed and that could partly be explained by soil micro organisms activities being vigorous, as the site was on the lower ground. The non forested tailing dump recorded the lowest and that could be due to the phenology of the different species that regenerated at the site. Burley and Wood(1991) observed that species growing in the same climatic area may exhibit different litter fall due to plant phenology. It therefore appears reasonable and logical to suggest that litter in-situ to litter turn-over is greatly influenced by plant growth, phenology,environmental conditions as well as the activities of soil micro organisms. Munlongoy and Vander Meersch(1993a) reported that nutrients released through litter in land reclamation are not fully recycled due to immobilization, leaching and run off wash away.

5.5 The Chemical and Physical Properties of Soil

5.5.1 The difference in Natural Levels between Non Forested, Reforested Waste Tailing dump and Secondary Forest

The pH value of 7.27 for the non forested waste dump may be due to high base content of the waste material. The value for the non forested tailing dump was also higher than the reforested tailings dump. It could be deduced that the values for the reforested waste and tailings dump may have come from trees through litter fall, decomposition or calcium accumulation in slowly mineralizable litter or might have come from nitrogen fixation from species planted that could cause soil acidification (Dreschel, 1991).The pH value for the secondary forest agrees with studies by Nye (1961), where soil under natural tropical forests was strongly acidic due to leaching of most plant nutrients. Gill (1986) made similar observation on *Acacia nilotica* and *Eucalyptus tereticornis*which reduced pH from 10.5 to 9.5 within a five year period in India.

Organic carbon percentage for non forested waste dump was significantly higher than reforested waste dump and could be linked to the soil amendments applied or nutrients that are recycled in the upper slope and carried down the topo sequence through erosion and leaching to the low lands (Hirose and Watkatsuki, 1997). The percentage organic carbon was conversely higher on the reforested tailing dump than on the non forested tailings and that perhaps be due to accumulation in the above ground biomass of the big trees.

Percentage total nitrogen was higher in the non reforested waste and tailings dump. This may be attributed to the soil amendment of farm yard manure applied that exhibited gradual mineralization. A similar trend was observed by Comforth (1970) in Trinidad where *Pinus caribeae* planted on coarse textured soil led to the depletion of nitrogen than the natural forest.

The low percentage total nitrogen recorded for the secondary forest could be due to high soil microbial activity andhigher mineralization as a result of organic matter accumulation and breakdown at the beginning of the rains (Young, 1997). It could also be attributed to leaching which is a characteristic of most humid tropical forests.

Percentage organic matter was also higher in the non forested waste and tailings dumps. This could again be attributed to nutrient recycled in the upper slopes that are carried to the lower slopes through run off as indicated by Hirose and Watkatsuki (1997), Owusu Sekyere*et al.*, (2004). The removed sediments are richer in organic matter and nutrients than the top soil from which it was derived. The low percentages in the reforested sites might have been due to increased soil microbe activity and organic matter breakdown (Young, 1997). The secondary forest recorded lower percentage of organic matter due to high temperature and ample moisture that accelerated decomposition at the beginning of the rains. Soil organic matter percentages are a function of addition and decomposition of litter. The percentage exchangeable calcium in the non forested sites were higher than that of the reforested sites and that could be due to high base content of the two sites Owusu Sekyere, *et al.*, (2006).

Lower percentages of exchangeable calcium were observed in the reforested waste and tailings dumps which could perhaps be attributed to the effect of trees in reducing soil acidity through complexion of Aluminum ions and thus reducing the amount found as free ions in the soil solution (Young, 1997). A lower percentage observed in the secondary forest might have been caused by accelerated organic matter decomposition by increased soil micro organism activity with high temperature and sufficient moisture.

The exchangeable magnesium content in the non forested sites was significantly higher than that of the reforested sites. This could be reflected in the higher magnesium content of slowly mineralizable litter that might have been washed down the slope to enrich such sites. Conversely, the lower exchangeable magnesium values in the reforested sites could be attributed to lower content of magnesium in litter as compared to foliage. Plant translocation magnesium to the new foliage before leaf senesces and thus only a fraction remains in the litter that falls (Dreschsel, 1991). Significant higher magnesium content for secondary forest may be due to the ability of trees to pump nutrients from deeper layers to enrich the top soil through litter fall (Manu*et al.*, 1997).

Significantly higher exchangeable potassium observed in the non forested waste and tailings dump reflects the higher base content of the waste dump. Reforested waste and tailings dumps recorded low levels of exchangeable potassium and that might have been caused by the uptake of potassium by planted trees. Lundgren (1978) observed a mean value of 23 kg/ha of potassium from a managed *Pinus patula* plantation in Tanzania due to logs that were taken from the site. The secondary forest registered the least value of exchangeable potassium and that may have been due to leaching which is a common feature with soils in the humid tropics.

Non forested waste and tailings dump recorded significantly higher percentage of cation exchange capacity and this could be linked to greater organic matter content which enhances cation exchange capacity (Young, 1989). The reforested waste and tailing dump also achieved higher percentages of cation exchange capacity than the secondary. This could again be attributed to high levels of organic matter. The secondary forest recorded low levels of cation exchange capacity and that could be explained that most agroforestry multipurpose species store more nutrients and organic matter in the leaf litter and soil during different times of the year (Adesina, 1988).

The percentage available phosphorus was significantly higher in the non forested waste and tailings dumps than in the reforested waste and tailings dumps. This was observed by Schroch *et al.*(1995) in La Cote d'Ivoire as due to a decrease in available phosphorus under trees as a result of tree roots taking it up for their growth. It may also be due to or attributed to different pH, values. Around the sites, Singh (1988) also observed a decline in available phosphorus with plantation age. The percentage available phosphorus in the secondary forest was the lowest and that correlates strongly as phosphorus availability in acid tropical soils are generally low. This was also in consonance with observation made in India by Monja and Huxley (1979), as available phosphorus measured was higher in plantations than in the natural forest.

Significantly higher percentages of available potassium were observed in the non forested waste and tailing dumps probably due to a greater percentage of the rocks in the site being unweathered. The reforested waste and tailing dumps also registered appreciable percentages than or almost equal to that of the secondary forest probably due to leaching which usually occurs in established tree stands and in the secondary forest (Young, 1997). This was also demonstrated by Badayopadhey and Mongia (1994) in India.

The percentage clay recorded for the non forested and reforested sites were not significantly different. Studies by Jung (1969) revealed an increase in clay content beneath trees and this could be due to trees acting as a physical barrier and trapping clay particles. A slight difference was observed between the reforested tailing dump and that of the secondary forest. This was also observed by Jose (1972); clay content in soils correlated with organic matter content. Fleming (1981) showed that leguminous trees generally retain greater amount of nutrients taken up from the soil in the normal nutrients cycling process. This together with a greater biomass may be responsible for the lower amount of nutrients in rehabilitated sites.

The study agrees with trials at Ibadan where after twelve years, almost all soil properties showed no significant differences between reforested site and control Mulongoy and Vander Meereth(1993). Aweto and Jordan (1985) observed no significant differences between most secondary tropical humid forests and mixed plantation forests soils compared to what is held in the biomass. This may be due to the fact that the biomass takes a large quantity of nutrients from the soil and returns only a fraction through nutrient cycling process.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Mining guidelines are meant to streamline the activities of mining companies in the country. First and foremost to enter into proper agreement with the Government and the custodians of the mining communities, provision of social services and interventions in the mining activities, managing the environment to safeguard the health of the people and improving the standard of living, in the course of mining, restoration of the degraded mine sites; protecting and managing of the rehabilitated sites up to the period of decommissioning.

Amansie Resolute Limited followed the laid down procedures as enshrined in the mining and mineral amendments and laws. This facilitated their operations and minimized conflicts which most often erupt between mining companies and the mine communities (PNDC L 153, 1996, LI 1652 of 1999 and Mining and Minerals Amendment Act of 2006).

Rehabilitation is said to be successful when a minimum of 650 trees is observed to have established on a hectare of land. The rehabilitation could therefore be said to be successful in view of the tree stands and nutrient levels of the soil samples analyzed.

6.2 Recommendations

- The company could not honour all the corporate social responsibilities such as provision of electricity to the communities.Mining companies should therefore work hand in hand with the mining communities; needs assessment should be conducted in the communities and prioritized in the course of scoping. Communities should first be provided with the most pressing social amenity to satisfy them and win their confidence. A sizable number of people from the communities should be offered employment.
- There were no significant differences in the results from both the growth and species diversity studies. The litter in situ and turn over ratios did not reflect the soil fertility status of the studied sites.Natural regeneration could be allowed for restoration of the degraded sites but it takes a longer time. Tree planting is therefore encouraged to speed up the reclamation process and also provide wood products.
- Species diversity should be assessed in addition to planted species by EPA/Mines Department as diversity ensures ecosystem stability and integrity. Species that have been identified to tolerate degraded/polluted mine sites should be used for the reclamation of such areas where commercial species would not survive.
- The soil fertility levels from parameters studied did not exhibit significant differences from the secondary forest.

- The soil sampling and analysis should therefore be studied at different periods to determine whether the results would conform to this study.
- Heavy metals should also be studied to determine whether their levels would be tolerable for crop production.
- Degraded mine sites could be restored almost close to pre-mining status to provide forest resources and improve the ecosystem; if mining communities are involved and reclamation programmes are well planned and executed according to PNDCL 153, 1986 LI 1652 of 1999 and mining and minerals amendment Act 703, 2006.
- Finally, the legitimate owners/managers of the rehabilitated sites should be spelt out and well defined as most District Assemblies do not have the capability to manage and protect such sites after decommissioning from illegal miners, bush fires etc.

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APPENDICES

Appendix I: Questionnaire administered to Chiefs, Opinion Leaders and Focus Groups in the Mining Communities

1) Were you and your elders consulted before the mining land was released? Yes/No
2) Were the farmers compensated for the lands occupied? Yes/ No
3) How many farmers were compensated?
4) Was the compensation paid adequate?
5) What crops were being cultivate on the land before mining
6) How many farm families were dispossessed of their farm lands?
7) Were the indigenes of the communities employed during the mining operations? Yes/ No
8) How many people were employed directly and indirectly?
9) What problem did the communities experience during the mining operations?
10) Did you have a committee in place that worked hand in hand with the mining company Yes/ No
11) Were you consulted and involved during the post mining operations/activities of the mining company? Yes/ No
12) Were your views or inputs considered?
13) What is your perception about the planted trees
14) Would you have preferred other species rather than those planted? Yes/ No
15) Were the communities provided with alternative sources of livelihood? Yes/ No
16) What do you think about the sustainable livelihood activities undertaken e.g. Fish pond, citronella cultivation etc.
17) How are they helping the communities?
18) What is your general perception about the reclamation?
19) What alternative sustainable/livelihood programme would you have preferred?

Appendix II: Questionnaire administered toMineDepartment – Kumasi

1) How is mining licensed acquired?
2) What social services are mining companies obliged to render to communities in their catchment area?
3) How many hectares of land on the average do the registered mining companies disturb annually in this country?
4) When was the surface mining operation law promulgated in this country?
5) What laws commit mining companies to rehabilitate degraded lands in course of their operations?
6) What laws commit mining companies to consult and involve the communities in their operational areas in all their activities i.e. pre – mining to decommissioning?
7) Do you have an oversight role in the mining activities/operations? Yes/No.
8) What activities did you monitor closely that could have affected human health adversely?
9) Why mining companies should rehabilitate mining sites?
10) What are the available methods for reclamation of degraded mined sites?
11) What other departments did you collaborate in monitoring the mining activities?
12) What do you expect mining companies to do in the post mining operations?
13) What functions do you expect the established trees to perform that would be to the mining communities and the entire nation?
14) What steps should a mining company take in rehabilitating a degraded mine site?
15) What is your perception about the rehabilitated mine site?
16) What measures have you put in place to avert what happened at Bonte Mines?

Appendix III: Questionnaire administered to Environmental Protection Agency – Kumasi

1) Were the chiefs and the people in the mining catchment are well briefed of the mining operations and impacts before commencement?
2) Did you receive environmental impact assessment before mining operations started? Yes/No? If yes, what resources received the highest consideration?
3) Did the mining company experience conflicts with the communities in the course of the mining operations? Yes/No? If yes, what were the controversial issues and how were they solved?
4) Did the company pay the reclamation bond? Yes/No? if yes, was it adequate to cater for the cost of rehabilitation?
5) What guide/steps should mining companies pursue in the rehabilitation of the degraded mine site?
6) Was the E.P.A. consulted/involved in the selection of appropriate method for rehabilitation?
7) Were the communities consulted? Yes/No?
8) What methods are available for rehabilitation of mined site?
9) Were the E.P.A. and communities involved in the selection of trees species for the rehabilitation? Yes/No? What was the main aim of the rehabilitation?
10) Are there any indicators for measuring the success of the rehabilitation programme?
11) What do you expect at the end of the rehabilitation of the site?
12) What benefits would the communities derive from the planted trees?
13) Will the rehabilitated lands be released back to the original occupants after decommissioning of the mining operations? Yes/No? If no why?
14) On the average how many hectares of land do the registered mining companies disturbs in a year in this country?
15) What are your general comments/views on the rehabilitation?
16) Were the trees in the tailings dump planted the same year Yes/No?
17) Have you done any soil test on the planted sites to determine the nutrient potential? Yes/No?

Appendix IV: Questionnaire administered to Environmental Officer – Amansie Resolute

1) When was the Obotan Gold Mines commissioned?
2) What was the original vegetation of the mining site?
3) Did the mining company conduct environmental impact assessment before operation started? Yes/No?
4) Did the mining company experience any conflict with the immediate surrounding communities during operations? Yes/No? If yes how ere the conflicts addressed?
5) What steps did you pursue in the rehabilitation of the degraded mine site?
6) Were the chiefs and elders in the surrounding communities consulted or involved in the rehabilitation? Yes/No? if yes, were their view considered or respected?
7) What tree species did you use for the rehabilitation? How were this species selected?
8) What is the stand composition?
9) What did you consider in planting the species?
10) When did the rehabilitation programme started?
11) What are your indicators for measuring the success of the rehabilitation programme?
12) What functions do you expect the planted trees to perform?
13) What benefits will the community derive from the established trees?
14) What was the main aim of the rehabilitation programme?
15) What methods did you use in the planting of trees in the waste and tailings dumps?
16) Were the people from the mining companies employed in the mining operations?

Appendix V: Questionnaire administered to Amansie West District Assembly

1) What role did the district assembly play in the pre-mining, mining and post mining operations of the Amansie Resolute Limited?
2) What adverse environmental impacts did the immediate surrounding communities experienced during the mining operations?
3) How were these impacts addressed?
4) What are your perceptions about the rehabilitated degraded mine site?
5) In general, what advice would you give to the surrounding communities after the decommissioning of the mining operation?

Appendix VI: Recruitment/Regenerated Species on the various sites

SITE	SPECIES PRESENT	TOTAL NUMBER OF EACH SPECIES	TOTAL SPECIES POPULATION
Reforested waste dump	*Chromolaena odorata*	6	
	Chnodon plectohtychus	5	
	Centrosema pubescens	2	14
	Phyllanthus discordea	1	
Non reforested waste dump	*Milletia aancharia*	8	
	Albizzia zygia	3	
	Alchormia cordiflora	6	
	Spondias mombim	2	
	Chrololaena odorata	10	47
	Trama orientalis	13	
	Cynodon plectothychus	5	
Reforested tailings dump	*Alchormia cordiflora*	3	
	Musanga spp.	2	
	Elaeis guinensis	4	9
Non reforested tailings dumps	*Albizzia zygia*	2	19
	Terminalia ivorensis	2	
	Cynodon plectothychus	5	
	Ferm	10	
Secondary forest	*Milletia zancharia*	4	
	Alchormia cordiflora	6	
	Albizzia zygia	3	
	Rawolfia vomitolia	3	
	Terminalia ivorensis	4	38
	Chromolaena odorata	6	
	Griffonia simplicifolia	5	
	Combretum macronata	3	
	Elaeis guinesis	4	

APPENDIX VII: Anova of species diversity for the studied sites

Sources of Variation	Sum of Species	Degree of freedom	Mean sum of squares	F-ratio	Probability
Treatment	22.09806377	4	5.52451594	0.79	0.5569
Error	69.82888989	10	6.983988899		
Total	**91.93695366**	**14**			

n.s not significant since F cal < F tab

APPENDIX VIII: Anova for soil pH concentrated from the studied sites

Sources of Variation	Sum of Squares	Degree of freedom	Mean sum of squares	F-ratio	Probability
Treatment	7.59954000	4	1.89988500	138.98	<0.0001
Error	0.06835000	5	0.01367000		
Total	**5.82261000**	**9**			

Significant at 5% level since F cal > F tab

APPENDIX IX: Anova for soil percentage organic carbon from the studied sites

Sources of Variation	Sum of Squares	Degree of freedom	Mean sum of squares	F-ratio	Probability
Treatment	5.54486000	4	1.38621500	24.95	<0.0017
Error	0.27775000	5	0.05555000		
Total	**5.82261000**	**9**			

Significant at 5% level since F cal > F tab

APPENDIX X: Anova for soil percentage total nitrogen from the studied sites

Sources of Variation	Sum of Squares	Degree of freedom	Mean sum of squares	F-ratio	Probability
Treatment	0.03574000	4	0.00893500	2.39	0.1826
Error	0.0187000	5	0.00374000		
Total	**0.5444000**	**9**			

N.S: Not significant at 5% level since F cal < F tab

APPENDIX XI: Anova for soil percentage organic matter from the studied sites

Sources of Variation	**Sum of Squares**	**Degree of freedom**	**Mean sum of squares**	**F-ratio**	**Probability**
Treatment	16.45466000	4	4.11366500	25.12	0.0017
Error	0.81870000	5	0.1637400		
Total	**17.27336000**	**9**			

N.S: Not significant at 5% level since F cal > F tab

APPENDIX XII: Anova for soil exchangeable calcium in the studied sites

Sources of Variation	Sum of Squares	Degree of freedom	Mean sum of squares	F-ratio	Probability
Treatment	77.29390000	4	19.32347500	14.38	0.0060
Error	6.72050000	5	1.34410000		
Total	**0.5444000**	**9**			

Significant at 5% level since F cal > F tab

APPENDIX XIII: Anova for soil exchangeable magnesium in the studied sites

Sources of Variation	Sum of Squares	Degree of freedom	Mean sum of squares	F-ratio	Probability
Treatment	42.79124000	4	10.69781000	56.55	0.0002
Error	0.94580000	5	0.18916000		
Total	**43.73704000**	**9**			

Significant at 5% level since F cal > F tab

APPENDIX XIV: Anova for soil exchangeable potassium from the studied sites

Sources of Variation	Sum of Squares	Degree of freedom	Mean sum of squares	F-ratio	Probability
Treatment	29.21484000	4	7.30371000		0.3933
Error	28.88345000	5	5.77669000		
Total	**58.0982000**	**9**			

Significant at 5% level since F cal > F tab

APPENDIX XV: Anova for soil exchange capacity for the studied sites

Sources of Variation	Sum of Squares	Degree of freedom	Mean sum of squares	F-ratio	Probability
Treatment	359.5342600	4	86.8835650	20.65	0.0026
Error	21.7667000	5	4.3533400		
Total	**381.3009600**	**9**			

Significant at 5% level since F cal > F tab

APPENDIX XVI: Anova for soil availablephosphorus from the studied sites

Sources of Variation	Sum of Squares	Degree of freedom	Mean sum of squares	F-ratio	Probability
Treatment	2508.982660	4	627.245665	182.15	<0.0001
Error	17.217500	5	3.443500		
Total	**2526.200160**	**9**			

Significant at 5% level since F cal > F tab

APPENDIX XVII: Anova for soil available potassium from the studied sites

Sources of Variation	Sum of Squares	Degree of freedom	Mean sum of squares	F-ratio	Probability
Treatment	41818.57944	4	10454.64486	32.36	0.00009
Error	1615.35325	5	32307065		
Total	**43433.93269**	**9**			

Significant at 5% level since F cal > F tab

APPENDIX XVIII: Anova for soil availablepercentage clay in the studied sites

Sources of Variation	Sum of Squares	Degree of freedom	Mean sum of squares	F-ratio	Probability
Treatment	1757.333000	4	439.333250	386.86	<0.00001
Error	5.678200	5	1.135640		
Total	**1763.011200**	**9**			

Significant at 5% level since F cal > F tab