KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

KUMASI GHANA

ASSESSMENT OF REHABILITATED SURFACE MINE LANDS IN ANGLOGOLD ASHANTI, OBUASI

By

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DECLARATION

I hereby declare that this submission is my own work towards the Master of Science degree in Environmental Resources Management at the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana under the supervision of the undersigned. All works consulted have been duly acknowledged in the references.

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DEDICATION

This research is dedicated to my parents, Mr Anyare Mustapha and Madam Constance Addai-Boateng for their encouragement, support and tolerance and to all my siblings- David, Favour, Adutwumwaa and Emmanuella for their love and support.

ABSTRACT

The burgeoning impact of mining on the environment has created a lot of public concern in recent years. During surface mining the vegetation and the soil are removed causing disturbances to the entire ecosystem. These ecosystems are required to be rehabilitated through a variety of treatments in accordance with the Legislative Instrument 1652 and Act 490. The main objective of this study was to investigate the processes involved in ecological rehabilitation of land affected by surface mining and how successful these schemes have been in reducing the negative impacts and ensuring the sustainable use of the land at AngloGold Ashanti, Obuasi. Persons involved with rehabilitation were interviewed to solicit information on the rehabilitation processes of the monitoring sites. The Landscape Function Analysis developed by the CSIRO was used as a monitoring tool to assess two surface mine sites T3 and Justice which were 1 and 20 year/s old respectively and compared with their natural ecotypes to determine their extent of success. On the rehabilitated sites the landscape organisation index, the infiltration, stability and nutrient cycling indices were generally lower than that of the undisturbed ecotypes. The stability, infiltration and nutrient cycling indices of T3 which were 20.6%, 16.7% and 16.2% were lower than their critical threshold values of 39.4%, 24.1%and 16.7% rendering T3 not self - sustainable. Justice was partially self - sustaining because its stability and nutrient cycling indices which were 64.6% and 26.8% exceeded their critical threshold values of 51.5% and 13.8% respectively except for its infiltration of 36.9% which was lower than that of the critical threshold of 40%. The standard errors of the various indices were calculated for statistical reliability. The results obtained suggested that within-site patchiness is more influential and it affects the stability, nutrient cycling and infiltration indices. It was recommended that more engineering features that serve as patches should be encouraged when rehabilitating surface mine sites.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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LIST OF ABBREVIATIONS

As	-	Analogue site
CSIRO	-	Commonwealth Scientific and Industrial Research Organisation
CT	-	Critical threshold
L/O	–	Landscape organisation index
LFA	–	Landscape functional analysis
BS+L	_	Bare soil + litter
GT		Grass Tussock
OP	_	Other Patches
Std	_	Standard Deviation

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background

Mining of minerals dates back to 5000 BC with most precious minerals sought for then being Copper, Bronze, Iron, Coal, Petroleum and Uranium (Otte and Jacob, 2008). Exploitation of such minerals has never ceased due to their economic value and has undoubtedly become the oldest economic activity after agriculture making tremendous and significant contributions to the world's civilization (Cao, 2006).

The Ghanaian economy depends heavily on the mining of Gold and to some extent Bauxite and other minerals for foreign exchange, internal revenue, job creation, provision of raw materials for local industries and for improvement of the socio-economic lives of the rural folks (Mireku-Gyimah and Suglo, 1993). The government of Ghana promulgated and legalized surface mining operations law in the early 1990 and this attracted small, medium and large-scale foreign mining companies to the country since surface mining is relatively less expensive to operate and has the potential of boosting the economy (Yirenkyire, 2008).

However, extensive exploitation of minerals using the surface mining method has resulted in a lot of environmental liabilities that somehow offset its benefits. 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. These result in perturbations in soil properties and processes in the soil profile that are severe for the soil's inherent resilience to respond. Soil degradation, decline in soil quality and destruction of the soil are the results of surface mining and these impacts are far beyond the range of capability for self-feedback, self purification and regeneration (Bradshaw, 1996).

In view of this the public is becoming more concerned about surface mining and its associated liabilities and this is evident in the outward expressions of concerns, questioning and societal pressure demanding that after mining has ceased the affected land should be brought back into a beneficial use by the mining companies involved as regulated by legislation of various kinds and severity (Moffat, 2004). Effective rehabilitation is to restore degraded land to almost its former state in order to curb societal unrest. The processes of effective rehabilitation require the healthy biodiversity of an ecosystem, which implies self-sustaining, interacting, and functioning in balance with a combination of physical, chemical and biological components to ensure the success of the rehabilitation (Shrestha and Lal, 2011).

Therefore the Environmental Protection Agency of Ghana (EPA) enters into agreement with mining companies committing them to adhere to the environmental management practices specified by them. Thorough mitigation of biophysical and socio - economic impacts is required by the Legislative Instrument 1652 of 1990 and Act 490 of 1994. This law also ensures that all mining companies in Ghana register and describe the impact of their activities on the environment and how it will be minimized.

The oldest gold mine in Ghana is the Obuasi mines which is currently being operated by AngloGold Ashanti. The company currently extracts gold by both surface and deep cast mining methods. Most of the surface mined out lands have been backfilled and re-vegetated as the law specifies. However, there is the need to assess the landscapes at these rehabilitated sites will assist in determining the extent of success of the rehabilitated sites.

Many researchers have studied the success of rehabilitated surface mine sites by ground base geochemical and physical studies (He et al., 1997; Shrestha and Lal 2011; Shukla et al., 2002) which is the traditional method as well as the remote sensing based approach (Sung-Min et al., 2012; Cheng et al., 2008). The collection of information via the geochemical and physical method can be a labour intensive exercise and if different observers are used the data obtained may be subjective (Randall, 2004). Although the remote sensing based approach provides objective and accurate environmental measurements in a spatially comprehensive manner it requires skilled labour and it is more expensive than the Landscape Function Analysis (LFA) which is used in this study (Ong et al, 2009). Moreover, the LFA has been verified against established scientific measurements and the LFA indices statistically correlated with other technical or scientific measurements including the remote sensing based approach (Tongway and Hindley, 2004).

1.2 Problem Statement

Habitat alteration and land degradation are expected after surface mining. The surface of the areas affected by surface mining usually become compacted such that rain water is unable to infiltrate into the soil and the result is that seed germination under these conditions is poor making natural recovery of such lands practically difficult. The rehabilitation that can revive these degraded lands is a complex and multi-faceted process that involves various disciplines in science. Hence, schemes are put in place to serve as guidelines that will enhance the biodiversity and increase the economic value of the mined out lands. The non adherence to these basic guidelines may result in the mine site being totally dysfunctional or partially functional even after rehabilitation. This is because a forest established on sites rehabilitated is usually more susceptible to erosion and agents such as drought, insect attack or infertility than that on undisturbed land. A dysfunctional land results in hunger, unemployment, poverty as well as social unrest in the communities whose lands were claimed by the mining company after mining has closed completely since the economic value of the land reduces. The hypothesis being investigated is that rehabilitation will revive the landscape and regenerate the ecosystem services. Work on the monitoring sites will show the extent of success of the rehabilitated surface mines.

1.3 Justification

A mining company's interest in the land usually terminates with the implementation of the Closure Plan. The succeeding custodian's and other stakeholder’s interest is the continued sustainable use of the land. Increased surface mine activities implies increased degraded land and reduction in fertile lands for farming resulting in food shortages and low income as the main occupation of the indigenes of Obuasi is farming. Despite countless attempts in the past, large portions of rehabilitation projects have been considered unsuccessful. They are mostly bare and devoid of vegetation. As we progress into the twenty first century there is an increasing awareness of the need to provide for sustainable ecological settings after mines are closed therefore the need to monitor and assess re-vegetated lands from time to time. Current assessment of rehabilitated mine sites generally takes place through visual inspection and this is subjective in nature and results can vary based on the assessor. Therefore, a method of assessment that depicts the productive condition and the support for long-term use of rehabilitated lands is very essential as far as increasing the economic value of mined land is concerned. This study provides information on the extent of success of two rehabilitated surface mine sites in AngloGold Ashanti, Obuasi.

1.4 Aim and Objectives

The aim of this study was to assess the effect of ecological rehabilitation of surface mined land using Landscape Functional Analysis at AngloGold Ashanti, Obuasi.

1.4.1 Specific objectives

The specific objectives were to:

- Identify schemes and procedures used in rehabilitating degraded Lands in AngloGold Ashanti, Obuasi through interviews with rehabilitation practitioners.
- Characterise and map out monitoring sites in terms of resource loss or accumulation.
- Determine the stability, infiltration and nutrient cycling indices of the landscape of the monitoring sites.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Surface mining is the method of mining that involves excavating to extract ores near the soil surface. Surface mining began in the mid-sixteenth century (Montrie-Chad 2003) and has increased substantially since the mid-seventies due to technological advancement which makes it possible to extract minerals from low grade ores (Miller et al, 1996). Surface mining involves clearing of vegetation cover, removal of top soil by earth movers, blasting, loading and hauling of ore to the processing plant with huge machines such as dragline excavators and bucket wheel elevators. Yirenkyire (2008) also indicated that, in recent years, surface mining is promoted in many mining countries due to the following reasons:

- Cost considerations compared to underground mining
- Safety considerations, compared to underground mining
- Low grade ore which requires processing huge quantities
- Location of the ore bodies and
- Competition among gold producing countries for investors

2.2 Impact of Surface Mining

Surface mining is one of the most complete forms of human caused habitat alteration and degradation (Fischer and Fischer, 2006). Areas that remain unattended to after surface mining create negative safety and environmental impacts according to Ziev (1985) and Vartzburger (2004). Mining destroys vegetation, removes soil through excavation activities and exposes bare rock surfaces thereby causing aesthetic as well as biological disorders (Goudie, 2000).

In Ghana, mining activities in most cases result in the loss of farmlands due to the large tracts of hectares mining companies acquire. (Aryee et al, 2003) indicates that surface mining infest about 13% of the total forest land of 240,000km^2 while (Tetteh, 2010) considers surface mining as the greatest agent of land degradation. In recent years there have been confrontations between mining communities and mining companies due to loss of farmlands which the communities depend on for their livelihoods (Gyimah, 2004).

It is often assumed that, small scale mining have little effect on the land resource because their operations are carried out on small pieces of land and should often be left alone (Asiedu, 2013). However, considering the number of people engaged by the industry, the combined effect of their activity on the environment cannot be overlooked.

Surface mining results in permanent changes of topography and geological structures and disrupts surface and subsurface hydrologic regime destroying the natural ecosystems, such that it requires some form of human intervention to bring it back to sustainable use (Bradshaw, 1996). The material handling operations for rehabilitation (e.g., land forming, spreading topsoil, mulching etc) also exacerbate soil compaction and alter physical and structural characteristics and restrict root development due to high bulk densities and low infiltration rates.

2.3 Terminologies Used in Mitigating Impact of Surface Mining

Several terms are used interchangeably to indicate post-mining measures to counteract the impacts of surface mining. Terms such as restoration, rehabilitation, and reclamation are commonly used in scientific and non - scientific literature to describe practices that help re-establish the structural and functional characteristics of a disturbed ecosystem to its natural or near natural state. Ecosystem reconstruction can be in the form of restoration, rehabilitation and reclamation or reallocation (Bradshaw, 1992).

2.3.1 Ecological restoration

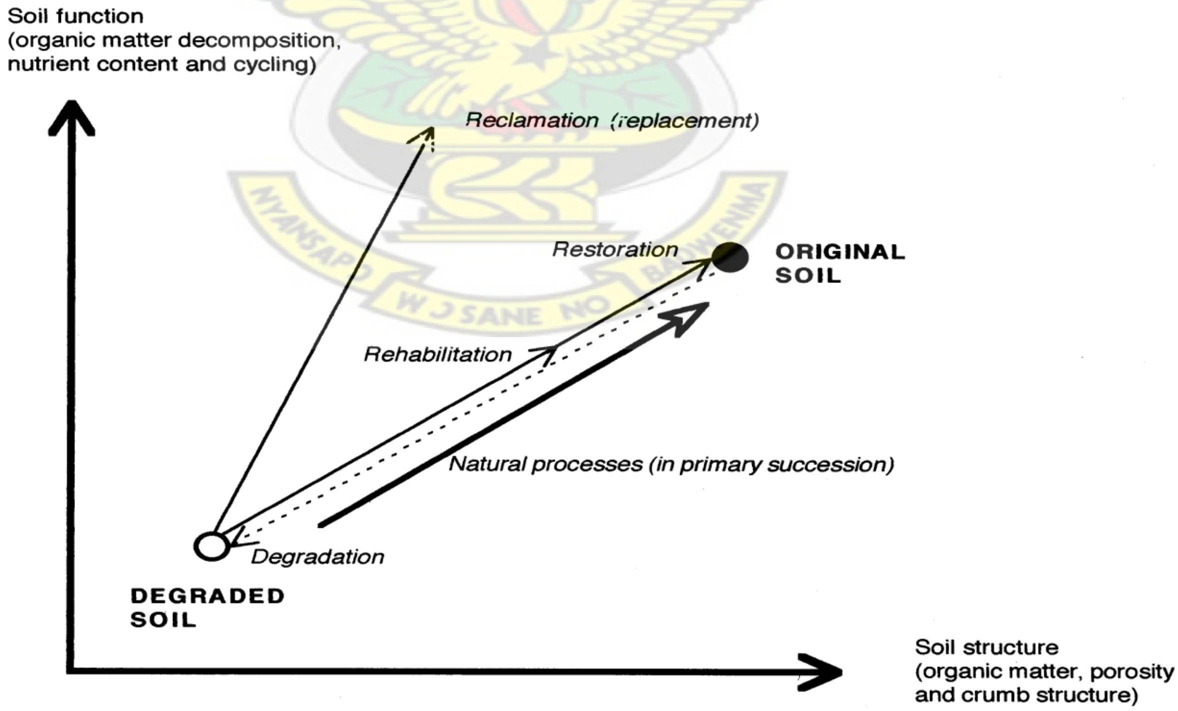
According to the Society for Ecological Restoration (1996), restoration is the intentional alteration of a site to establish a defined indigenous, historic ecosystem. Its goal is to imitate the structure, functioning, diversity and dynamics of the site in consideration (OED, 1971). The America National Academy of Sciences also described restoration as the act of reconstructing to an unimpaired or perfect state. In view of the definitions of restoration above, Cairns (1991) and Simberloff (1990) indicated that restoration efforts may be plagued with ambiguities in both their goals and criteria of success since it is rarely possible to determine what the prehistoric or historic ecosystems looked liked and how they functioned.

2.3.2 Ecological reallocation

Severely damaged ecosystem that can no longer recover even with the best of efforts and are reassigned to a different function that does not necessarily bear an intrinsic relationship with the pre-disturbance state are said to be reallocated (Blignaut *et al.*, 2010 and Aronson et al., 1993). For example, changing an emergent wetland to a pond converts the habitat from one wetland type to something quite different and this can be described as reclamation or reallocation.

2.3.3 Ecological rehabilitation

Rehabilitation, on the other hand, seeks to repair damaged or blocked ecosystem functions, with the primary goal of raising ecosystem productivity for the benefit of the local people. This is evident in the community involvement in all the processes of rehabilitation in the major mining companies in Ghana. Rehabilitation of surface mined lands aim at recreating a self sufficient or self-sustaining ecosystem, which is characterised by biotic change or succession in plant and animal communities, and the ability to repair themselves following natural or moderate human perturbations (Aronson et al, 1993). There is also the need to emphasize that rehabilitation is a 'process' driven by ecological knowledge and research not just producing a 'product'. From this perspective rehabilitation is about a broad set of activities. It should not be assumed that the objective of all rehabilitation is some form of natural ecosystem that will be almost equal to what existed prior to mining (LPSDP, 2006). Although in Ghana, a return of surface mined lands to a stable natural ecosystem is often the preferred option. If successful, this will provide a low-maintenance final land use, which seeks to control the release of potential pollution from the site. Figure 2.1 shows a schematic representation of the different approaches to land restoration by Bradshaw (1992).



Source: (Bradshaw, 1992)

Figure 2.1 Contrasting approaches to the restoration of soils of degraded land by surface mining

2.4 Rehabilitation Techniques

Rehabilitation method can be put into two methods according to Blay (1997) and these are:

a. Rehabilitation of soil properties
b. Rehabilitation of vegetation

Today rehabilitation is part of mine planning. Hitherto, it was only thought of when the degradation posed a threat to human survival even years after mining. The archaic approach meant that one was left with a post-mining environment that was typically dysfunctional, especially in the event of unplanned closure (LPSDPMI, 2006). In order to ensure a successful rehabilitation, pre-mining, mining and post mining activities must be considered.

2.4.1 Pre - Mining Rehabilitation Activities

Rehabilitation should be planned before mining commences. Each operational stage and component of the mining should be part of a plan which considers the full life cycle of a mine site. The plan needs to be flexible to accommodate changes in method and technology as indicated by LPSDPMI (2006). A detailed plan that establishes the expected end use of the site and its general characteristics at the completion of rehabilitation. The planning must take into account both government legislation and public perception (Dumker et al, 1992 and Vastag et al, 1996). Rehabilitation planning considers critical views and incorporates landscaping, screening, buffers and a site layout which minimize views of exposed faces, stockpiles and plants.

2.4.2 Rehabilitation Techniques during Mining

Use of environmentally friendly technology

Mining activities geared towards a successful rehabilitation involve the execution of the plan specified prior to mining. Depending on a number of morphological criteria associated with the ore (depth, dissemination, segregation in a formation or datum level, dip, type of substance), a mining method designed for optimal recovery in terms of quality and cost should be put into action among the many mining methods available for surface mining (BRGM, 2001).This includes the use of the technology that is more environmentally friendly. At each operational stage of the extraction, the types of chemical involved and the choice of implements should be taken into account.

Topsoil management

The top soil is viewed as the strategic rehabilitation resource that must be conserved if during mining to protect its physical and chemical properties and biological processes (Cooke and Johnson, 2001). The top soils are usually higher in organic matter, microbial activity, and nutrients than the underlying subsoil or geologic material. Top soils contain significant seed bank that can be used to great advantage in re-vegetation. Therefore as far as practicable the top soil should be stored at a suitable place with proper precautionary measures during excavation so that it could be utilized during rehabilitation process. Sahu (2011) proposed some of the best practices involved in topsoil management:

- Scraping the topsoil prior to drilling and blasting
- Stacking topsoil in a designated area
- Surrounding stacked topsoil with embankments to prevent erosion

- Protect soil from wind effects by stabilizing with grasses and bush.

2.4.3 Post Mining Rehabilitation Techniques

The post mining activities for mine site rehabilitation include;

Topographic reconstruction or landscaping / topsoil replacement

After mining the first rehabilitation process in ensuring the restoration of soil physical properties is the topographic reconstruction or landscaping. This should leave a final landform visually compatible with the surrounding natural landscapes, while ensuring that the land is stable and will not erode, and will provide an adequate substrate for re-vegetation. Erosion will result where slopes are too steep or too long. Long slopes should be broken by benches (Minerals and Petroleum Division Australia, 2004). Contour ripping is appropriate for surface mine site rehabilitation. The importance of topographic reconstruction cannot be neglected because the resulting landforms are the foundation upon which other reclamation practices are executed and eventual land uses take place (Sahu, 2011).

Re-vegetation

Re-vegetation is a principal goal of rehabilitation and results in many desirable secondary water quality and aesthetic benefits. Re-vegetation goals are from simple erosion control to the full restoration of complex native communities (Sahu, 2011). Developing a vegetation cover that is permanent should aim at establishing a plant community that will be sustainable without attention or artificial aid, and support native fauna. To extract better results, some ecological variables must be considered while selecting species for plantation. These are; their capacity to stabilize soil, soil organic matter and available soil nutrients, and under storey development. In the initial stages of re-vegetation quick growing grasses with short life cycle, legumes and forage crops are recommended. It will improve the nutrient and organic matter content in soil. Plantation of mixed species of economic importance should be done after 2-3 years of growing grasses. While selecting suitable species for plantation in mine areas, the following considerations have to be taken into account:

- Planting pollutant tolerant species.
- Fast growing plants with thick vegetation foliage
- Indigenous/exotic plants species with easy adaptability to the locality.
- Socio economic requirement of the people in the surrounding area.

Maintenance and Monitoring of Re-vegetated sites

After re-vegetation the site must be monitored and maintained. This should include adoption of preventive measures against slope failure and erosion. Replacement of dead plant species and weed control is also necessary for maintaining a proper species survival. According to WBEP (2010), the aims of monitoring are to:

- assess the environmental situation and risk to the public and the environment
- reduce/minimise risk and hazard and increase operational safety
- prove the success of mitigation and remedial actions

There are a number of parameters that are indicators of the overall productivity and habitat quality of a rehabilitated mine site. Success of re-vegetated areas can be evaluated by measuring a number of these parameters. The measurements are intended to identify which species are the most effective in establishing in disturbed areas, factors that may contribute to the enhanced or marginal growth and the kind of recovery that can be expected on the various mine disturbances over a long term (Red Dog mine, 2009). This information is necessary to take corrective actions in those areas with and thereby aiding the assessment of success of re-vegetation efforts in meeting mine closure objectives. Components that can be assessed include soil physical, chemical and biological properties, plant density and survival and plant vigor. Stability, infiltration and nutrient cycle of the landscape are very important for proper recovery of disturbed sites.

2.5 The landscape Functional Analysis (LFA) as a monitoring tool

The push for sustainable development, maintenance of biodiversity and the need for a quick but rigorous method for monitoring mined out landscapes resulted in the development of a technique to assist in the assessment of rehabilitation at disturbed sites (Randall 2004). Ecosystem Function Analysis (EFA) is a field monitoring method and a dynamic assessment system, developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), which has been adapted to suit a range of diverse environments from rangeland ecosystems through to mine site rehabilitation (Botanic Consulting, 2009). The method uses simple field indicators and allows the collection of data to determine and assess the functional status of the ecosystem components and landscape. The data provides an indication of a rehabilitated site's ecosystem development in relation to the surrounding native landscape (analogue site) and can be used to determine whether an ecosystem is evolving properly (Tongway and Hindley, 2004)

The core segment of EFA is LFA. Simple field indicators are monitored that reflect stability, water infiltration and nutrient cycling of the landscape and soil, each of which has a distinct significance for landscape function monitoring as shown in Figure 2.2. The field methodology uses visually assessed indicators at a landscape or small 'patch' scale to provide information on how landscapes function to conserve and utilise scarce resources (Randall, 2004). The nature, meaning and scope of each surface feature, together with a classification is as shown in Table 2.1

2.6 Ecological indicators

An ecological indicator is the biotic and abiotic characteristics of the environment that may provide quantitative information on the status of ecological systems (Bruce, 2001). Ghazoule and Hellier (2000) also defined ecological indicator as any variable or component of the forest ecosystem or relevant management system that is used to infer attributes of the sustainability of utilisation of the resource. An indicator may be a single environmental variable or several variables put together and expressed as an index. For proper landscape functionality, the stability, infiltration and nutrient cycling indices are instrumental. These properties affect an ecosystem's physical, chemical and biological components. The nature, meaning and scope of each surface variable, together with a classification for calculating the indices as used in the LFA methodology are as shown in Table 2.1.

Table 2.1: Eleven Indicators of soil surface condition for the landscape assessment

Indicator	Surface feature assessed	Score Low-high
Rain splash Protection/ Soil Cover	Assess the degree to which the surface cover and projected plant cover ameliorate the effect of raindrops impacting on the soil surface. Assess susceptibility to erosion.	1-5
Perennial Basal Cover	Estimate the basal cover of perennial grass and/or the density of canopy cover of trees and shrubs. Assess the potential biomass for nutrient	l- 4
Litter Cover	Assess the amount, origin and degree of decomposition of plant litter. Assess the soil organic matter component and degree of incorporation in the soil.	1- 10
Cryptogam Cover	Assess the cover of cryptogams (algae, fungi, lichens, mosses, liverworts and mycorrhizas) visible on the soil surface. The presence of cryptogams is a positive indicator of surface stability.	1–4
Crust Broken-ness	Assess to what extent the surface crust is broken. Assess crust stability and susceptibility to erosion.	1–4
Soil Erosion Type and Severity	Assess the type and severity of recent/current soil erosion.	1–4
Deposited Materials	Assess the nature and amount of alluvium transported to and deposited on the query zone	1–4
Soil Surface Roughness	Assess the surface roughness for its capacity to capture and retain mobile resources such as water, propagules, topsoil and organic matter.	1–5
Surface Nature	Assess the ease with which the soil can be mechanically disturbed to yield material suitable for erosion by wind or water. Assess the impact	1–5
Slake Test	Classify the texture of the surface soil and relate this to permeability. Assess the coherence of the soil when it is wet.	1–4
Soil texture	Assess the texture class of the surface soil as it affects infiltration.	1–4

Source: (Tongway & Hindley, 2004)

2.6.1 Landscape Stability

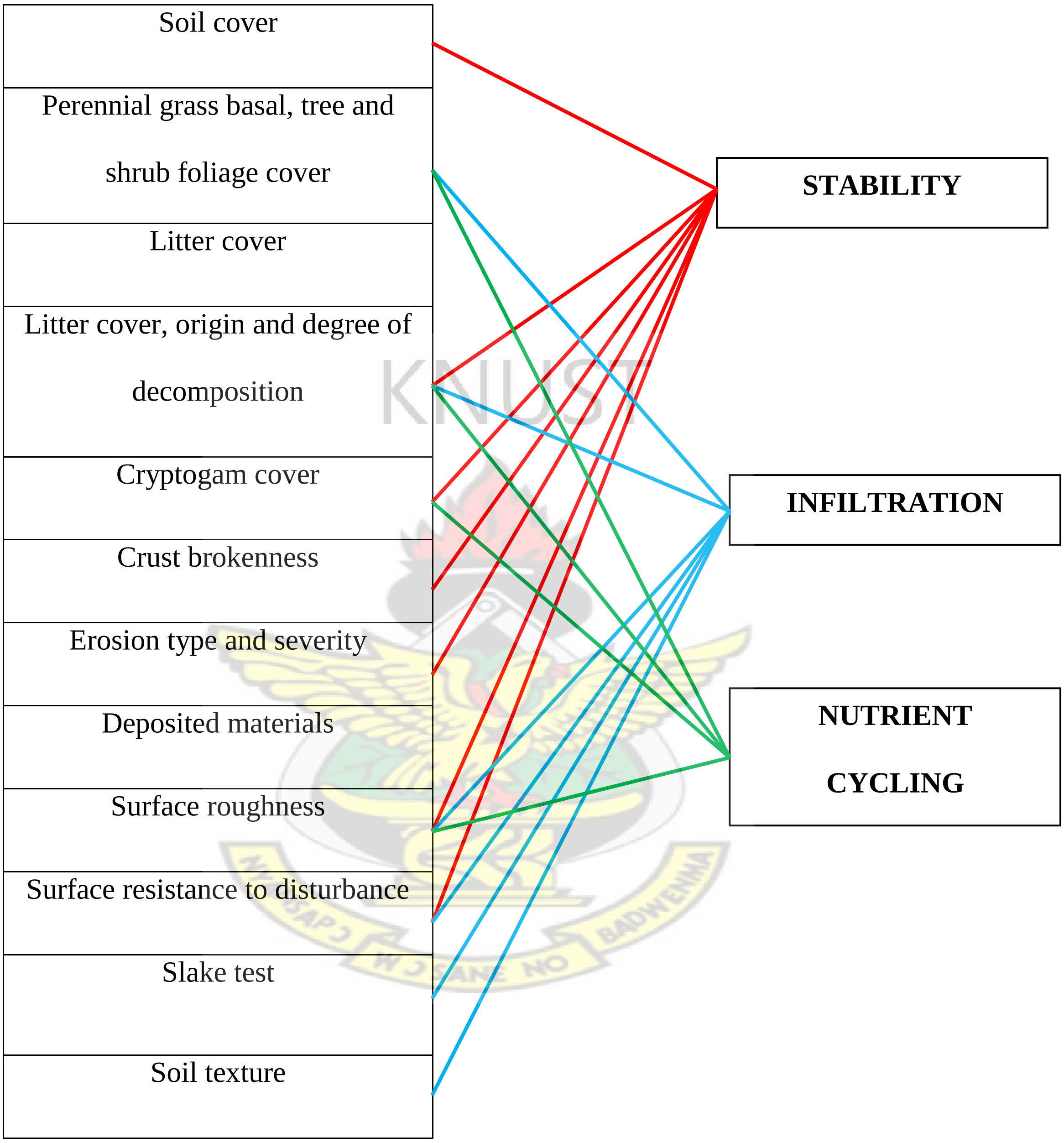
Stability refers to the ability of a soil to maintain structural integrity on wetting (soil health knowledge bank). By using the soil stability assessment, an index that shows whether soil surfaces are changing for the better or worse and how much of the bare soil is related to natural processes can be obtained. The indicators that affect the stability of a landscape include soil cover, perennial grass basal, litter cover, origin and degree of decomposition, erosion type and severity, resistance to disturbance and surface roughness as shown in Figure 2.2. The slope and type of soil on the landscape also affect its stability.

2.6.2 Soil infiltration

Infiltration is an indicator of the soil's ability to allow water movement into and through the soil profile for root uptake, plant growth and habitat for soil organisms according to the U.S Department of Agriculture. When the rate of water supply on the landscape exceeds the soil's infiltration capacity, it moves down slope as runoff and when runoff occurs on bare or poorly vegetated soil, erosion takes place. Runoff carries nutrients, chemicals, and soil with it resulting in decreased soil productivity. The indicators that affect the infiltration rate of a landscape include; perennial grass basal, litter cover, origin and degree of decomposition, surface roughness, surface resistance and disturbance, slake test and soil texture as shown in Figure 2.2.

2.6.3Nutrient cycling

The loss, retention and re-use of inorganic nutrients of an ecosystem are of great importance to that ecosystem. Biotic and abiotic processes cause nutrient to flow in and out of a landscape. The three main nutrient cycles of a landscape are the carbon, nitrogen and phosphorous cycles (Ryan, 2012). The nutrient cycling index is calculated from the aggregate of environmental variables such as; perennial grass basal, litter cover, origin and degree of decomposition, cryptogram cover and surface roughness (Tongway and Hindley, 2004



Source: (Tongway and Hindley, 2004).

Figure 2.2 Relationship between field indicators and LFA indices

2.7 Analogue sites / Reference sites

Rehabilitation of post surface mining lands aims to create self-sustaining ecosystems. It is generally assumed that rehabilitation that is similar to the local native ecosystem is more likely to be sustainable. The success of an ecosystem is currently evaluated by measures of the ecosystems required to achieve at least 65 to 75% of reference sites values (Gravina et al., 2011). The biophysical functioning of the analogue sites would yield values justifiably worthy of emulation in a rehabilitating landscape

CHAPTER THREE

MATERIALS AND METHODS

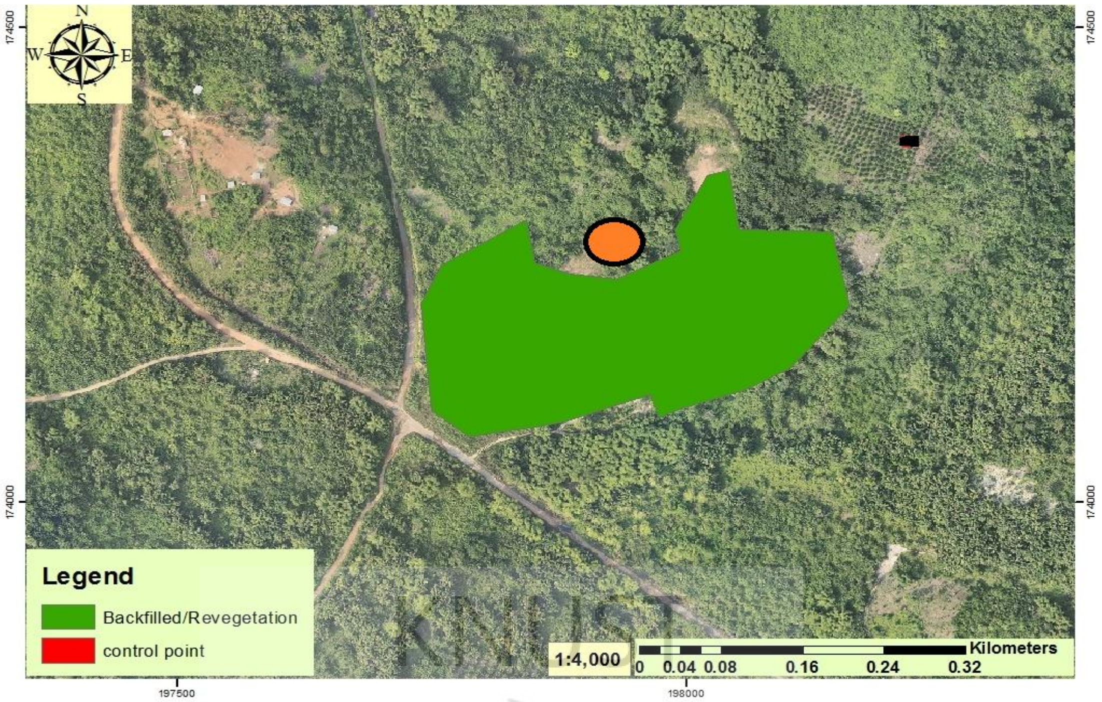
3.1 Study Area

Two sites that represent difference in years after rehabilitation (i.e. T3 and Justice (Ju) Surface mine sites) in AngloGold Ashanti Obuasi mine were selected for this study. Also less disturbed areas of both sites that is in close proximity were chosen as their respective analogue sites. Analogue sites are the reference sites that can serve as a model for rehabilitating the degraded sites and they have intact ecologies and higher functionality than the ecosystem to be rehabilitated. The areas chosen experience semi-equatorial climatic conditions with a mean annual rainfall of about 1200mm and average relative humidity of 78%. Temperature is high all year with a mean annual value of 25.5 °C which naturally supports plant growth.

3.1.1 T3 surface mine site

The T3 surface mine site as shown in Figure 3.3 is about a year old after rehabilitation. It is located along the Obuasi airport road at about 2.16 km from the Obuasi-Kumasi highway with a total re-vegetated area of 6.8 ha.

The previous vegetation of T3 consisted of pockets of fallow farmlands, secondary forest thickets and forbs re-growth. The vegetation was characterized by quick growing pioneer soft wood, trees and few hard woods with less open under growth. Palm trees, bamboo, *Terminelia superba* (Ofram), *Mansonia altissima* (Oprono) were some of the species present prior to the surface mining. The analogue site chosen was the undisturbed land upslope of T3 as indicated in Figure 3.1. It is characterised by a vegetation type that is similar to T3 prior to the surface mining but bamboo and pockets of farmlands dominate this site.



Source: Environmental Department A.G.A.L, Obuasi

Figure 3.1 Map showing T3 and its analogue site

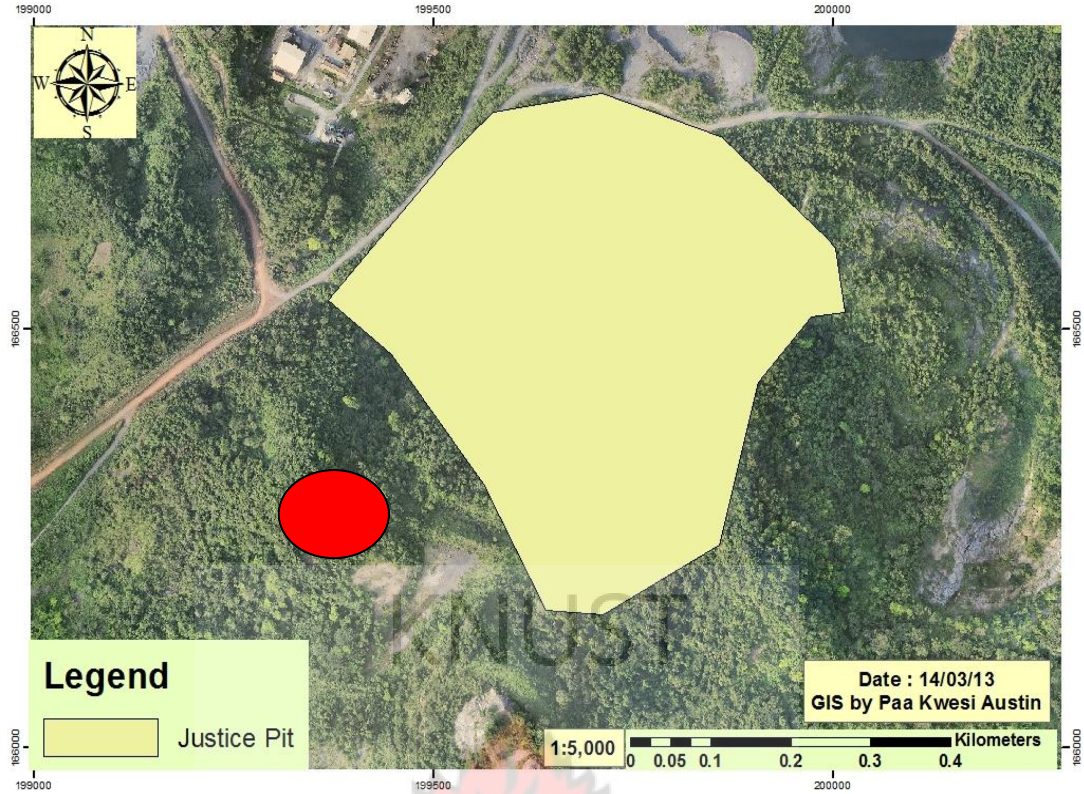
Source: Environmental Department A.G.A.L Obuasi

Figure 3.2 Backfilling of T3

Figure 3.3 One year old re-vegetated T3

3.1.2 Justice surface mine site

Justice as shown in figures 3.4 and 3.5 is a surface mine site located behind the Kwesi Mensah shaft one of the currently operational underground shafts about 1km from Anyinam Lodge with a total re-vegetated area of 23.94 ha as shown in Figure 3.5. The rehabilitation of Justice was done about 20yrs ago. Prior to surface mining the vegetation was similar to that of T3.



Source: Environmental Department A.G.A.L., Obuasi

Figure 3.4 Map showing Justice and its analogue site

Figure 3.5 Twenty year old rehabilitated Justice Site

3.2 Procedure used for the study

The studies were carried out in three stages. The first stage was on the review of rehabilitation processes of the surface mine monitoring sites based on available literature and interview with a checklist. The second stage was on the characterisation of the landscape of the monitoring sites according to resource loss and accumulation whilst the third stage was on the determination of the nutrient cycling, infiltration and stability indices of the monitoring sites.

3.2.1 Review of rehabilitation processes on the two surface mine sites

A prepared check list (See Appendix A) was used to interview three key staff of the company involved in rehabilitation at the Environmental Department of AngloGold Obuasi. Information on the landscape reconstruction of the two sites through to the planting of seedlings and maintenance of the sites were solicited. Information on guidelines for rehabilitation in AngloGold Ashanti Obuasi was sought. Documented processes of rehabilitation were also reviewed.

3.2.2 Landscape functioning of the monitoring sites.

The landscape function Analysis (LFA) procedure was followed to characterise the landscape and determine the infiltration, nutrient cycling and stability indices of the landscapes of the monitoring sites.

The procedure used for assessing was as follows:

- Characterisation and mapping of the monitoring sites in terms of resource loss or accumulation.
- Determination of the stability, infiltration and nutrient cycling indices of the landscape of the monitoring sites.

3.3 Characterisation of Landscape according to resource flow

Characterizing the landscape of the monitoring sites provided information on how the landscape functions and utilizes scarce resources. Patches are the features on the landscape that accumulate resources by restricting the flow of water, topsoil and organic matter which will then be used by biota. It comprised of biological features and physical features that trap these resources. Inter-patches are the areas between patches where resources are freely transported down slope. The organization of the patches and inter-patches was classified along a transect. A visual inspection of the sites was made and the number and location of transects were carefully analyzed in order to avoid data that may show the site as doing well yet on a large landform it may not be so or vice versa.

3.3.1 Marking out of transects on the monitoring sites

T3 was divided into three parts with an approximate area of 2.3 hectares for each part. A transect was marked out from the upslope edge with a tape pulled straight and tightly to a 50m distance down slope for the first part, the second transect was marked out in the mid-area parallel to the first transect with the starting point almost coinciding with the end of the first transect. The third transect was also marked out at the other end parallel to the second transect as shown in Figure 3.7. Two transect were marked out at Justice because it has a landform and character that do not differ so much as compared to T3 which had three transects.The transect was in the middle of each of the two parts it was divided into using the 50m transect tape as shown in Figure 3.8 and for the analogue sites, two transects were marked out on each using the same procedure as used in Justice. In all nine transect were constructed on the monitoring site.

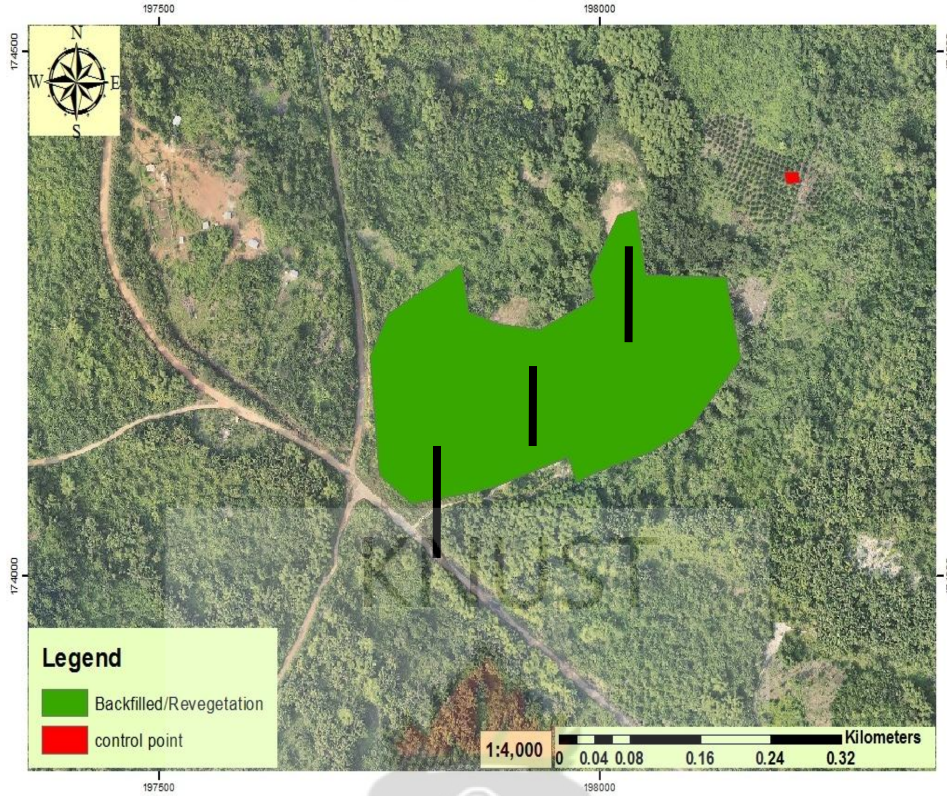


Figure 3.6 Transect Layout on T3

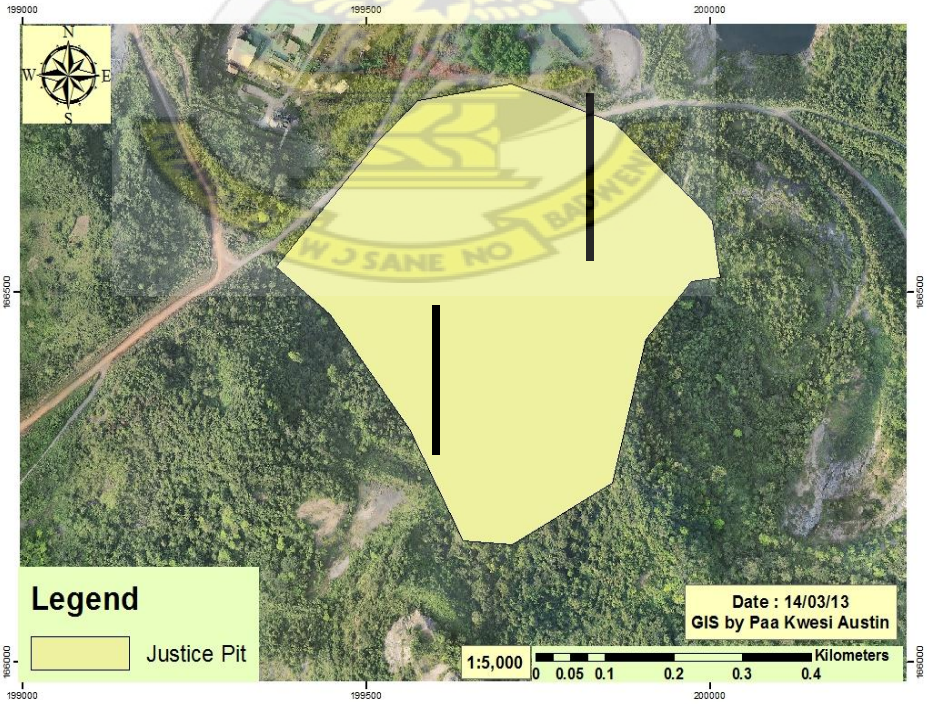


Figure 3.7 Transect Layout on Justice

Figure 3.8: Sample Transect Laid on T3

Patch and inter-patch identification and measurement

Each patch and inter-patch was given a descriptive name to distinguish the different types present along a transect. The distance between successive patches was measured at a precision of ±2cm. The width of the patches was also measured. The landscape organization index was then calculated from the measurements made as the sum of patch length to the total length of the transect.

$$\boldsymbol{landscape\ organisation\ index} = \frac{total\ patch\ length}{total\ length\ of\ transect}$$

The higher the landscape organisation index the more functional the landscape is in terms of retaining resources for biota use. The mean length of patch or inter-patch type was also calculated by dividing the total length of patch or inter-patch type along the transect by the number of times it occurred along the transect.

3.4 The Stability, Infiltration and Nutrient Cycling Indices of the Landscape of the Monitoring Sites

Soil surface features were observed within query zones marked out a long each transect. The query zones were distributed along the entire length of each transect and five replicates of each inter-patch and patch type were assessed for statistical reliability. Where it was insufficient to find five query zones the available query zones were used. The distances in meters along the transects for each patch and inter-patch type where the actual query zones were sited for the surface assessment were recorded. The critical thresholds for the various indices were calculated.

From the LFA methodology developed by the CSIRO, the critical threshold is

Calculated as;

$$CT = \frac{(Top\ value - lowest\ value)}{2} + \ lowest\ value$$

CT = critical threshold

Top Value = Upper Biogeochemical Boundary.

Lowest Value = Lowest Biogeochemical Boundary

Soil surface features assessment method

A total of 134 query zones were used for the assessment. The eleven indicators as mentioned in Chapter Two were assessed at each query zone to determine the stability, infiltration and nutrient cycling indices of that particular zone. Decision making was visual and assisted with guidelines and photographic images in the LFA manual to assign indicator to a class or score. The indicators were as follows;

- Rain splash protection

Objects that intercept and break up rain drops making them less erosive were looked out for in the various query zones. These objects included rocks greater than 2cm in diameter and other immovable objects. The percentage of the physical surface cover and projected plant cover on the query zone was determined. A score of 1-5 was used with one indicating that the soil is bare and has no protection from rain splash and 5 indicating that it has 50% and above rain splash protection.

- Perennial Basal Cover

Perennial grass cover was assessed by summing the diameter in contact with the soil inside the query zone. Perennial trees were also assessed by the cover over hanging the query zone. A rule was used in measuring the width and length of cover overhanging the query zone and the % it covers on the query zone. A scoring of 1-5 that represents low root biomass to high root biomass respectively was done for all the query zones

- Litter cover

The amount of litter, origin and degree of composition were assessed. The amount was in 10 classes as per the Table 3.1. Where the litter was above 100% it was compressed with the palm to remove air gaps and its thickness was measured with a rule.

Table 3.1 Percentages of litter and its class

% Cover of plant litter	Class
<10	1
10-25	2
25-50	3
50-75	4
75-100	5
100 up to 20 mm thick	6
100, 21-70 mm thick	7
100, 70-120 mm thick	8
100, 120-170 mm thick	9
100, > 170 mm thick	10

The type of litter present was assessed to know whether it was derived from plants growing nearer to the query zone.

- Cryptogam cover

Water was put on the soil surface to observe greening. Where greening was observed it meant cryptogams were present. No habitats for cryptogams exist in loose soils and extensive litter covered soil so those types were scored zero. Depending on the greening a score of 1-3 was given.

- Crust brokenness

Area and severity of a broken crust were assessed. Where the soil is loose and has a lot of litter cover or perennial plant cover it was given a zero score because crust brokenness was irrelevant.

- Soil erosion type and severity

Rill, sheet and gully erosions and their severity were looked out for in the query zone and recorded.

➢ Deposited Materials

The amount of silt, sand and gravels that has been recently transported to the query zone was assessed by the percentage of space it covers on the query zone. Scores of 1, 2, 3 and 4 were given for 50 and over, 50 - 20, 20- 50, 5-0 percents respectively.

➢ Surface roughness

Depressions in the soil surface were observed. Soil surface relief that did not facilitate resource retention attracted low scores as indicated in the Table 3.2.

Table 3.2: Soil surface roughness scoring

Surface roughness	scores
<3 mm relief in soil surface. Smooth: little or no retained materials	1
Shallow depressions 3-8 mm relief. Low visible retention	2
Deeper depressions 8-25 mm or grass plants growing close together. Moderate visible retention	3
Deep depressions that have a visible base of large visible retention	4
Very deep depressions or cracks >100mm.	5

➢ Surface nature

A pen cob, the finger and a metallic rod were used to determine the soil’s resistance to disturbance. Surfaces that had no physical crust and are under a dense grass sward was scored 5. Surfaces that required a metallic rod or pen cob to break through were scored 4 and 3 respectively where as surfaces that allowed the penetration of the finger was scored 2 and 1 respectively depending on the length of penetration of finger. Where water was used to check the cryptogam cover, a lump of the soil was taken and dried in an oven before measurements were taken.

- Slake test

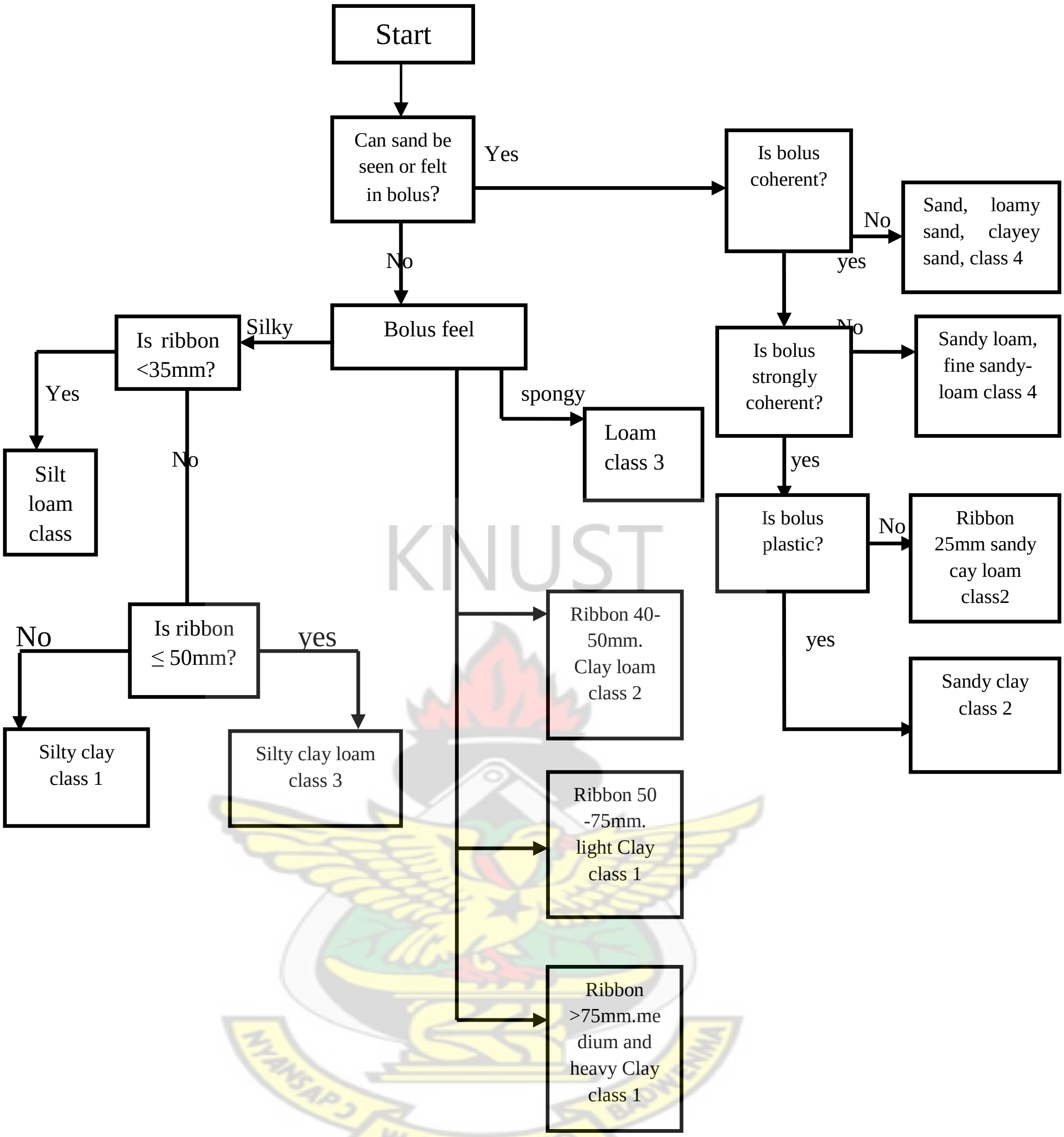
Air - dry soil fragments of about 1/cm³ in size was taken with a knife and placed in a bowl containing clear water over a period of 1minute. Depending on the time the soil fragments slump a score is given to the fragment. If no coherent fragment is available for test it is classified as 0. If fragment slumps in less than 5 s it is classified as 1 and 5 to 10 s is classified as 2. Surfaces that remained intact with less than 50% slumping by volume over 10 s were scored 3.When whole fragment remains intact with bubbles of air it was scored 4.

- Soil texture

A sample of soil from a depth of 0 – 5 cm was taken. A little water was added at a time to the sample in the palm and kneaded until the ball of soil just failed to stick to the fingers. More water and soil were added to attain the sticky point. Kneading was continued until there was no apparent change in the soil ball. The flow chart in Figure 3.10 enabled soil texture indicator to be quickly determined and classified.

Table 3.3 Soil Texture Scoring

Texture	Class
Silty clay to heavy clay	1
Sandy clay loam to sandy clay	2
Sandy loam to silt loam	3
Sandy to clayey sand	4



Source: LFA methodology manual by CSIRO

Figure 3.9 Soil texture flow chart

Data obtained from the soil surface assessment in these query zones were entered into an Excel workbook developed by CSIRO to give the stability, infiltration and nutrient cycling indices for each zone from the scores noted during the soil surface condition assessment. Average infiltration, nutrient cycling and stability indices over the proportion of the landscape were determined for the analogue and rehabilitated areas.

3.5 Data analysis

Data was analysed using descriptive statistics. The EFA excel work book calculated the standard error for the various indices. The statistical package for social sciences was used in calculating the standard deviation for the measurements made.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Rehabilitation of T3 and Justice

From the interview conducted, the following were the processes used for the rehabilitation of T3 and Justice.

4.1.1 Landscape reconstruction.

The backfilling and topsoil spreading on T3 was undertaken by Dorijones Company on contract. Prior to back filling, 60,000/m^3 of water was pumped out of the pit at a rate of 2.3m^3/min as shown in Figure 4.1. Waste rock was not used for the backfilling. Soil was pushed from the adjacent undisturbed sites for this purpose. The soil was compacted with a roller to prevent water from infiltrating to the bottom of the pit. A total volume of 800m^3 of top soil was transported to the site. The spreading of the soil was localised i.e. limited to where seedlings were planted.

The landscape reconstruction of Justice was also carried out on contract. Trucks, excavators and a compactor were used during the back filling. Waste rock was used for the backfilling followed by the spreading of subsoil which was also pushed from the adjacent sites into the pit. The soil was compacted with a roller to make the landscape more stable. Top soil was transported to the site and spread on the entire landscape of Justice.

Source: Environmental Department A.G.A.L., Obuasi

Figure 4.1 T3 after surface mining

4.1.2 Re-vegetation of T3 and Justice.

As per the consultations with the local people some local species that will benefit the indigenes were planted on both Justice and T3. The species included *Anegreila Robusta (Asanfena), Daniella Ogea (Shedua), Terminelia superba (Ofram), Mansonia altissima (Oprono), Khaya ivorensis (Mahogany), Triplochiton scleroxylon (Wawa), Entandrophragma utile (Edinam).*

The exotic species planted also included *Cedrella odorata, Gmalina sp*., *Cassia mangium*, *Cassia siamea*. These chosen exotic species are fast growing and adaptable to the local environment. Unlike T3, the number of exotic species on Justice exceeds the number of local species. The seedlings were planted at a 3m interval to allow space for root extension and the penetration of sunlight.

4.1.3 Monitoring and maintenance of T3 and Justice

For T3, planted seedlings that are not doing well are replaced with new seedlings to ensure that the number of plants planted still remains the same. Grass (Vetivae) was planted in rows across slope to control erosion. Where the soil is bare, Palm fronds are used to cover it as a form of litter to control wind and water erosion. Monitoring is done by taking soil samples of the surface mine sites and analyzing for nitrogen, carbon and other elements to know the nutrient status of the mined site as compared to the undisturbed or control site.

Not much monitoring and maintenance currently go into Justice anymore probably because of its age although gullies are evident.

4.2. Landscape characterisation of sites patch

4.2.1 Length and Width of T3 and its Analogue Site

Table 4.1 Proportions of patch and inter- patch types on T3.

Patch / inter-patch type		Transect 1		Transect 2		Transect 3	
	n	Total ength(m)	%	Total Length (m)	%	Total Length (m)	%
Bare Soil + Litter	3	22.62	45.24	3.1	62.1	3.0	35.4
Crusted Bare Soil	3	1.68	13.4	3.5	7.0	4.1	40.7
Grass Tussock	3	4.73	28.4	1.3	20.6	2.3	22.7
Vetivae	2	0.93	11.20	-	-	-	-
Depression	1	-	-	-	-	-	1.2
Other Patches	1	0.23	1.80	1.0	10.4	-	-

n = the number of transect the patch or inter – patch type occurred on

Table 4.1 shows the proportion of patch and inter-patch length on T3. Bare soil + litter has the greatest proportion in all the transects except for Transect 3 which has crusted bare soil taking a greater portion with a percentage of 40.7 indicating how prone that part of the landscape is in terms of leaking resources. Transect 1 had the highest number of patches as compared to the other transects on the same landscape. Apart from the Grass tussock and a depression found along the Transect 3 there were no other patch on that Transect compared to Transect 1 and 2 of the same landscape.

Table 4.2 Width of Patches on T3

Patch type	Transect 1			Transect 2			Transect 3		
	n	Mean width (cm)	Std	n	Mean width (cm)	Std	Mean width (cm)	n	Std
Grass tussock	3	86.7	30.6	8	133.6	380.9	63.2	5	26.8
Vetivae	6	44.5	20.5	-	-	-	-	-	
Other patches	4	15.7	30.9	5	143.0	45.8	-	-	
Depression	-	-	-	-	-		80	1	-
Total patch width	-	146.9		-	276.6		143.2	-	

n= the number of times a particular patch occurred along a transect

The widths of patches along a Transect are equally important as the lengths of patches along the Transect. The length and width of patches gives an area of patch that retains resources. The higher the width of patch the higher the area. Transect 2 had the highest mean width on the T3 landscape 276.6 as indicated in Table 4.2 with Transect 3 having the lowest.

Table 4.3 Proportions of patch and inter- patch types on T3 analogue site

Patch type	Mean Length			
	Transect 1		Transect 2	
	Total Length (m)	%	Total Length (m)	%
Bare Soil + Litters	1.768	49.2	1.8	47.0
Grass Tussock	4.92	78.7	4.8	69.0
Trees	0.3	2.2	0.33	5.0

Along all the two transects marked out on T3 analogue site grass tussock was the major patch found. It constituted 78.7% and 69.0% on Transect 1 and Transect 2 respectively indicating how well the landscape is doing in terms of retaining resources for biota use than the disturbed site. Crusted bare soil was not found on any of the transects marked out on the analogue site indicating that every part of the landscape is able to retain some amount of resource as shown in Table 4.3.

Table 4.4 Width of patches on T3 analogue site

Patch type	Transect 1			Transect 2		
	n	Mean	Std	n	Mean	Std
Grass Tussock	7	714.7	1832.8	8	646.5	1763.3
Trees	4	31.8	19.2	2	30	8.5
Total	-	837.8	-	-	676.5	

n = the number of times a particular patch occurred along a transect

The T3 analogue sites had higher widths of patches as shown in Table 4.4 implying higher patch area which is the result of plant litter build up between adjacent grass plants.

4.2.2 The landscape organisation index (L/O)

Table 4.5 Landscape organisation index for T3 and its analogue site

Site	**T3**			**Analogue**	
Transect	**1**	**2**	**3**	**1**	**2**
Total Length (m)	20.7	15.5	12.0	34.30	39.90
L/O	0.41	0.32	0.24	0.68	0.79
Mean L/O		**0.32**		**0.74**	

The landform of T3 has an uneven slope and the bank and trough method (contour ripping) which is the required method for surface mine land reconstruction was not used and that accounted for the presence of sheet erosion on the landscape. Unmanaged grazing by native animals such as sheep and goats on the landscape accounted to some extent for the low total mean patch width of T3 Transect 3 as indicated in Table 4.6 as the livestock enters the landscape through that part and also an access route through T3 to an adjacent orange farm is a threatening process on this landscape as vehicular movement has resulted in compaction thereby limiting the growth of biota. Topsoil placement was limited to where seedlings were planted therefore the entire landscape did not get the advantage of the significant seed bank contained in the top soil.

T3 comprised of a multi patch which was due to both biological and physical or engineering features. Some of the physical features found on T3 included bamboo sticks, sacks filled with sand and waste rocks which are all erosion control measures.. The width and length of patches of the reference site of T3 far exceeds that of T3 as expected when L/O of T3 and its reference site are compared. The (L/O) for each of the three transects marked out on T3 indicates that there is an uneven patch distribution on the landscape with Transect 1 with the highest L/O due to the presence of Vetivae and the L/O for Transect 3 also shows that that part of the landscape is not functioning properly as compared to the other two transects due to low width and length of patches. The average L/O for T3 was lower than that of the analogue site as expected in a newly rehabilitated site. it has a value of 43% of its analogue site and hence does not meet the criteria of a successful rehabilitation according to Gravina (2011) that it must be at least 65% of its analogue site value.

4.2.3 Patch Length and Width of Justice and its Analogue Site

Table 4.6 Patch and inter- patch types on Justice

Patch /inter-patch	Transect 1		Transect 2	
	Total Length (m)	%	Total Length (m)	%
Bare Soil + Litter	1.8	25.7	1.8	26.0
Grass Tussock + Trees	4.9	70.0	4.8	69.3
Trees	0.3	4.3	0.33	4.7

The percentage of Grass tussock was 69.3 along the Transect 2 with bare soil + litter and trees being 26.0% and 4.7% respectively as indicated on Table 4.6. Meaning almost 30% of the length along the transect allows the leakage of resources down slope along Transect 2. However, the litter found on the bare soil is able to retain some resources as it flows down slope. Transect 1 also had grass tussock as its major patch type.

Table 4.7 Width of patches on Justice

Patch type	Transect 1			Transect2		
	Mean	n	Std	Mean	n	Std
Grass Tussock + Trees	222.3	10	169.5	181.8	5	111.7
Trees	26.5	4	3.4	28.8	6	**3.7**

n= the number of times the patch type appeared along the transect

The major patch on both transects 1 and 2 of the Justice analogue site is the grass tussock + trees with a mean width of 222.3 and 181.8 respectively. The grass tussock + trees on Transect 1 appeared 10 times along the transect while it appeared 5 times along Transect 2.

Table 4.8 Proportions of patch and inter- patch types on Justice analogue site.

Patch /inter-patch	Transect 1		Transect 2	
	Length (m)	%	Length (m)	%
Bare Soil + Litter	1.5	36	1.4	25.4
Grass Tussock + Trees	2.67	64	4.1	74.6

Table 4.8 summarizes the proportions of each patch and inter-patch type along the 2 transects marked on the landscape. Grass tussock + trees had the greatest proportion which is 64% and 74%.

Table 4.9 Width of grass tussock + trees on Justice analogue site

Transects	1	2
Total width (cm)	5582	5503
n	11	9
Mean width	507.5	611.4

n = the number of times grass tussock occurred along transect 1 and 2 on Justice

The only patch present on the justice analogue site is grass tussock+ tree occurring 11 times along the Transect 1 and 9 times along Transect 2 with a mean of 507.5cm and 611.4cm respectively.

Landscape characterisation of Justice and its analogue site

Table 4.10 landscape organisation index for Justice and its analogue site

Site	**Justice**		**Analogue**	
transect	1		2	
Total Length (m)	25.4	26.5	32.0	37.3
L/O	0.51	0.53	0.64	0.7
mean	**0.52**		**0.75**	

Similar to T3 contour ripping was also not used during the landscape reconstruction of Justice as indicated in the literature review to be the appropriate method for surface mined landscape reconstruction and that may have contributed to the presence of gullies on Justice which is a threat to the landscape. The topsoil that was not used also deprived Justice of the seeds the soil contained. The patches on Justice were biological features and it consisted mainly of trees and undergrowths. The width of patches on the analogue site far exceeds that of Justice as shown in the patch obstruction Tables Justice analogue site has a bigger obstruction area as compared to the disturbed site along the transects which means the analogue site is able to retain more resources. The L/O of 0.52 for Justice was 69% of its analogue L/O which is 0.75 (Table 4.10) showing that it meets the success criteria as indicated by Gravina (2011). The landscape organisation index for each of the two transects constructed on Justice show that there is an even patch distribution on the landscape.

4.3 Surface Feature Assessment

Table 4. 11: Mean stability, infiltration and nutrient cycling indices for T3 (%)

Patch /inter-patch	n	Stability	Std err	Infiltration	Std err	Nutrient	Std err
BS+L	3	19.3	0.9	13.0	1.1	11.0	0.9
CBS	3	15.1	1.2	10.4	1.03	8.1	0.7
GT	3	20.7	1.3	16.4	1.3	16.9	1.3
Other patches	2	24.3	0.7	17.8	1.3	20.9	1.12
Vetivae	1	28.7	0.6	29.5	2.0	26.5	1.3
Depression	1	15.6	1.2	13.0	0.9	14.0	1.6
Mean		**20.6**		**16.7**		**16.2**	

$n =$ the number of transect the patch or inter-patch type occurred on.

T3 had 6 patch and inter-patch type on its landscape with 3 of the types bare soil + litter (BS+L), crusted bare soil (CBS) and grass tussock (GT) occurring along all the transects. The grass vetivae found on Transect 1 recorded the highest stability, infiltration and nutrient cycling index due to its ability to retain resources. The lowest stability, infiltration and nutrient cycling index was recorded on the crusted bare soil as indicated in Table 4.11. T3 had an overall stability, infiltration and nutrient cycling indices of 20.6, 16.7 and 16.2 respectively as indicated in Table 4.12.

The crusted bare soil had the lowest indices because it surface contains no patch or litter to retain resources and it is less porous disallowing water to infiltrate through.

Table 4.12: Mean stability, infiltration and nutrient cycling indices for T3 analogue site (%).

Patch/inter-patch	n	Stability	Std Err	Infiltration	Std Err	Nutrient	Std Err
BS+L	2	60.55	1.8	26.65	0.85	24.7	0.55
GT	2	69.0	2.2	36.6	1.15	30.85	1.95
Trees	2	64.8	1.95	41.2	1.0	25.9	1.3
Mean		**64.8**		**34.8**		**27.2**	

n is the number of transect the patch or inter-patch occurred on.

The analogue site was characterised by three major patch and inter-patch types occurring on the two transect which are the bare soil + litter, grass tussock and trees. The highest stability and nutrient cycling indices were recorded at the grass tussock area where as the highest infiltration index occurred at the Trees area as shown in table 4.12. The grass tussock gives the the landscape a cover that distracts the flow of water from upslope hence allowing for a better infiltration, stability and nutrient cycling indices as indicated in chapter 2.5.

Stability, Infiltration and nutrient cycling levels varied with the highest level of each of these indices recorded at Transect 1. This accounted for the fact that T3 Transect 1 contained more of the Vetivae a type of grass for preventing erosion and hence accumulating a lot of resources. All the indices were lower than that of the analogue site. The analogue site had more litter on its surface than the surface mine site contributing to a higher nutrient cycling index of the analogue site. The analogue site had more undergrowth than T3 allowing for a better infiltration and stability.

Table 4.13: Critical threshold for T3 indices

	Top value		Lower value	
Feature	**value**	**location**	**value**	**location**
Stability	69.1	T3Ast2	9.6	T3t3
Infiltration	43.4	T3Ast2	4.8	T3t3
Nutrient Cycling	30.2	T3Ast2	3.2	T3t3

Sample calculation for the Critical Threshold for T3 Stability**:**

$$\boldsymbol{CT}\ (stability) = \frac{\mathbf{(69.1 - 9.6)}}{\mathbf{2}} + \mathbf{9.6}$$

$$= \mathbf{39.4}$$

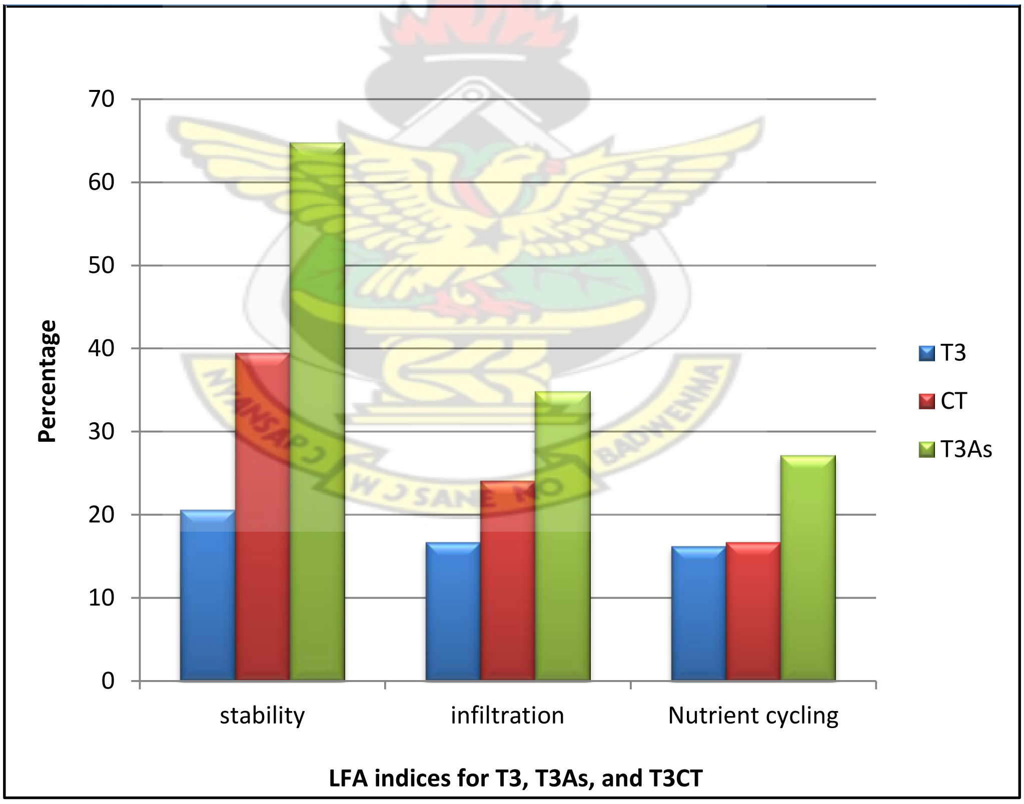


Figure 4.2: Critical threshold indices for T3

T3 can be said not to be self sustaining because all its indices are lower than that of the critical threshold values as shown in Figure 4.1. With time if the right maintenance and monitoring is done the value of T3 can be raised above the critical threshold. The nutrient cycling index of T3 is almost coinciding with the critical threshold indicating how well the landscape is doing in terms of nutrient cycling.

Table 4.14: Mean stability, infiltration and nutrient cycling indices of Justice (%)

Patch /inter-patch	n	Stability	Std Err	Infiltration	Std Err	Nutrient	Std Err
BS+L	2	60.0	2.1	41.7	2.05	24.9	1.85
GT	2	69.2	2.0	33.8	1.70	31.0	1.75
T	2	64.8	2.4	35.3	2.20	24.6	2.3
Mean		**64.6**		**36.9**		**26.8**	

On the Justice landscape the highest stability was recorded at the grass tussock area where as the highest infiltration and nutrient cycling indices were recorded at the bare soil + litter area due to litter accumulation and decomposition. The lowest infiltration was recorded in the area of trees as indicated on table 4.16.the mean stability infiltration and nutrient cycling indices were 64.6, 36.9 and 26.8.

Table 4.15: Stability, infiltration and nutrient cycling indices of Justice analogue site

Patch /inter-patch	n	Stability	Std Err	Infiltration	Std Err	Nutrient	Std Err
BS+L	2	75.25	2.6	49.9	2.4	28.4	1.3
GT+T	2	70.3	2.25	41.9	2.2	34.7	1.45
Mean		**72.8**		**45.9**		**31.6**	

Justice analogue site had one patch and inter-patch type occurring on two transects. The area of the bare soil + litter had a greater stability and infiltration index than the grass tussock area due to extensive litter accumulation.

Stability and nutrient cycling levels were relatively consistent between all transects, with Transect 1 recording the highest stability level. Infiltration levels varied with the highest level recorded at Transect 1. Transect 2 recorded the highest nutrient cycling index. Transect 2 of Justice recorded a stability index that is slightly higher than the analogue site thus rehabilitated sites when properly managed can with time do comparatively well as the analogue site. Comparing the differences between the indices of the disturbed sites and analogue sites it can be deduced that the indices of Justice are closer to its analogue site indices than T3 is to its analogue site.

Table 4.16: Values for calculating critical thresholds

	Top value		**Lower value**	
Indices	**value**	**location**	**value**	**location**
stability	80.5	JAst2	22.4	Jt2
infiltration	50.2	JAst2	29.8	Jt1
Nutrient cycling	36.2	JAst2	22.4	Jt2

Sample calculation of the critical threshold for Justice

Sample calculation for the Critical Threshold for T3 Stability**:**

$$\boldsymbol{CT}\ (stability) \quad = \frac{\mathbf{(80.5 - 22.4)}}{\mathbf{2}} + \mathbf{22.4}$$

$$= \mathbf{51.5}$$

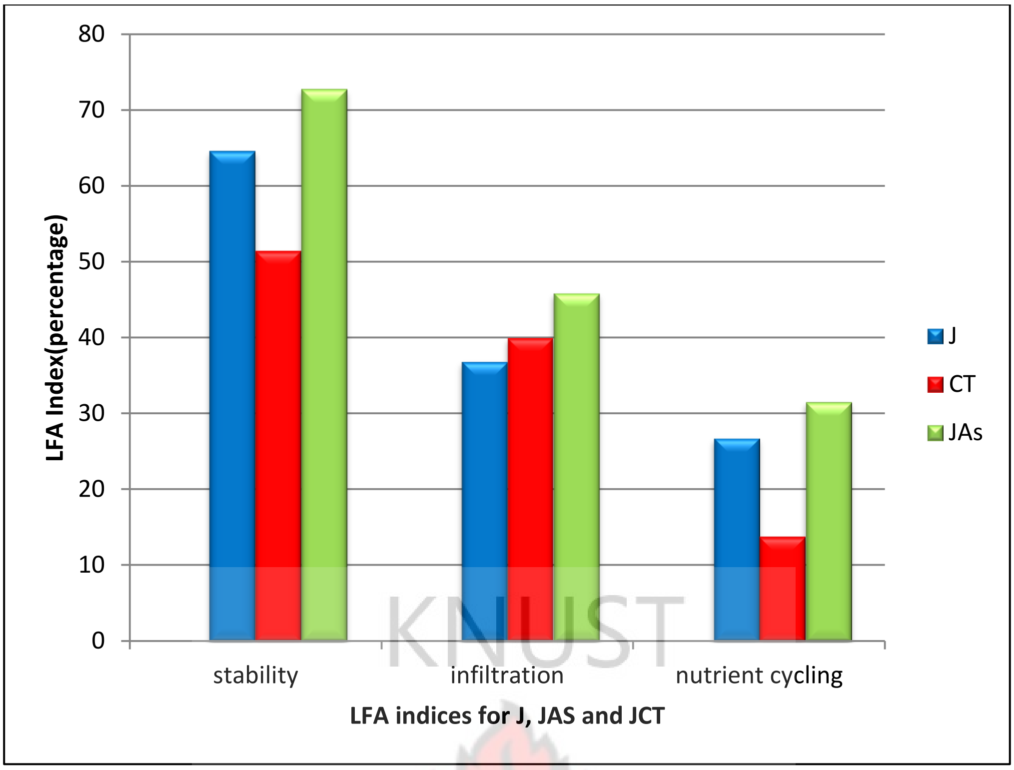


Figure 4.3: Critical threshold, Justice and Justice Analogue site values

Justice surface mine site can be said to be partially successfully or self sustaining to some extent because the stability and nutrient cycling indices exceeds that of the critical threshold values and are close to the analogue site values except that the infiltration index is lower than that of the critical thresh old as indicated in Figure 4.4 serving as a threat to the landscape.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

It was deduced that although the majority of the processes of rehabilitation were followed accordingly on both T3 and Justice some key processes like contour terracing (on both sites) and spreading topsoil on the whole of T3 were left out and this may have contributed to some extent the presence of gullies on the sites.

The landscape organisation index of T3 was 0.32 about 43% of its analogue site which was 0.74 which does not meet the success criteria as indicated by Gravina (2011) as expected in a newly rehabilitated site. the L/O of T3 also implies that about 70% of the length along the transect of T3 leaks resources. Justice had an L/O of 0.52 about 69% its analogue site value of 0.75 making it successful. Less than 50% of the length along the Transect of Justice leaks resources down slope of the landscape.

The stability, infiltration and nutrient cycling indices of T3 were 20.6, 16.7 and 16.2 respectively. These indices were lower than its analogue site indices which were 64.78, 34.82 and 27.15% respectively. The stability, infiltration and nutrient cycling indices of T3 were lower than its critical threshold values of 39.4%, 24.1% and 16.7% indicating it to be not self-sustainable. The stability, infiltration and nutrient cycling indices of Justice which were 64.6%, 36.9%, and 26.8% were closer to its analogue site which was 72.8%, 45.9% and 31.6%. Justice was partially self-sustaining because its stability and nutrient cycling indices which were 64.6% and 26.8% exceeds its critical threshold values of 51.5% and 13.8% respectively except for its infiltration of 36.9% which was lower than that of the critical threshold value of 40%.

5.2 Recommendations.

Monitoring should be continued using LFA every other year on rehabilitated sites so that the rate of change of the indices with time on the monitoring site can also be assessed for a more reliable critical threshold. During monitoring assessment of erosion conditions should not be restricted along the Transect alone.

Measurements of on-site rainfall should be inculcated in the monitoring to study the trend of the amount of rainfall and its impact on the site to aid in irrigation.

Remedial works on large gullies formed on both T3 and Justice should be done to prevent further erosion. For successful rehabilitation, new land construction is the fundamental framework, this should, however, involve contour terrace building and the control of soil erosion. During back filling the waste rock removed should be used to fill the pits first before subsoil and topsoil to allow for a more stable landscape. Erosion control measures such as the growing of more Vetivae on T3 should be encouraged.

Effective rehabilitation and monitoring should be encouraged on small scale surface mined lands in Ghana in order to retrieve loss farmlands. Although they are carried out on small pieces of land is combined effect can be detrimental.

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APPENDICES

APPENDIX A

CHECK LIST.

1. What was the type of vegetation that existed prior to surface mining of the monitoring sites?
2. What were the methods used in the rehabilitation Justice and T3 sites?
3. How was land reconstruction and spreading of topsoil carried out on the monitoring sites?
4. What were the species of trees used in re-vegetation?
5. What informed the choice of species for the re-vegetation?
6. What are the erosion control measures on the landscape?
7. What type of monitoring is done on the rehabilitated sites
8. What type of maintenance is carried out on both sites?

Appendix B

Appendix B1:The landscape organisation data for T3 transect 1(T3t1)

Distance (m)	Patch width (cm)	Patch/ interpatch identity	Notes
0			
0.65		BS+L	Baresoil+ litter
5.00	60	GT	
5.30		BS+L	
5.60	10	V	Vetivae
8.70		CBS	Crusted baresoil
8.90	60	V	
9.92		BS+L	
9.93	0.05	S	Seedling(termnalia supava)
10.57		BS+L	
17	120	GT	
17.3		CBS	
17.8	42	V	
18.0		BS+L	
18.80	62	WR	Waste rock
20.20		CBS	
23.60	80	GT	
23.64		BS+L	
23.68	0.3	Mansonia	
34.70		BS+L	
34.75	0.5	Palm tree	
39.00		BS+L	
41.00	70	V	
44.10		BS+L	
46.50	40	V	
48.40		CBS	
48.60	45	V	
50.00		BS+L	

Appendix B2: The lanscape organisation data for T3 transect 2(T3t2)

Distance (m)	Patch width (cm)	Patch/ interpatch identity	Notes
0			
2.4	82	GT	Grass tussock
7		BS+L	Bare soil +litter
9	120	GT	
9.7		BS+L	
10.8	420	GT	
11.53		BS+L	
11.90	50	GT	
20.2		BS+L	Litter mainly palm fronds
21	90	Sack filled with sand	For erosion control
21.88	190	B	Bamboo stick +litter
23.6	25	GT	
24.1		BS+L	
24.6	280	GT	
25.3		BS+L	
26.7	50	GT	
30.4		BS+L	
33.6	110	V	Grass (vetivae)
39. 8		BS+L	
40.6	42	GT	
41.8		BS+L	
45.3		CBS	Crusted bare soil
45.5	135	HG	Heaped gravel
49.9		BS+L	
50	190	V	Vetivae

Appendix B3:The landscape organisation data for T3 transect 3(T3t3).

Distance (m)	Patch width (cm)	Patch/ interpatch identity	Notes
0			
2.2		CBS	Crusted bare soil
3.82		BS+L	Baresoil + litter
4.28		CBS	
4.4		BS+L	
4.6		CBS	
8.15	40	GT	Grass tussock
14.20		BS+L	
18.4		CBS	
19.3	30	GT	
24.40		BS+L	
25.0	80	D	depression
28.8		BS+L	
30.0	90	GT	
31.0		BS+L	
32.0	72	GT	
45.30		CBS	
50	84	GT	

Appendix B4:The landscape organisation data for T3 Analogue site transect 1(T3Ast1).

Distance (m)	Patch width (cm)	Patch/ interpatch identity	Notes
0			
2.20		BS+L	Bare soil + litter
2.80	71	GT	
3.50		BS+L	
4.00	122	GT	
5.60		BS+L	
5.90	35	T	Mango tree
6.20		BS+L	
15.70	960	GT	
15.90		BS+L	
20.50	880	GT	
20.90		BS+L	
21.20	36	T	Palm tree
30.25		BS+L	
30.40	320	GT	
30.45		BS+L	
42.00	1250	GT	
42.25		BS+L	
42.40	25	T	Specie unidentified
43.25		BS+L	
43.50	31	T	Specie unidentified
43.62		BS+L	
50.00	1400	GT	

Appendix B5: The lanscape organisation data for T3 Analogue site transect 2(T3Ast2)

Distance (m)	Patch width (cm)	Patch/ interpatch identity	Notes
0			
5.2	675	GT	Grass tussock
5.6		BS+L	Baresoil + litter
10.40	1480	GT	
10.98		BS+L	
11. 20	720	GT	
11.50		BS+L	
11.82	36	T	tree
11.85		BS+L	
15.90	950	GT	
21.62		BS+L	
26.35	210	GT	
28.25		BS+L	
39.25	151	GT	
40.15		BS+L	
40. 38	24	T	
40.51		BS+L	
48.20	430	GT	
48.35		BS+L	
50.00	556	GT	

Appendix B6:The lanscape organisation data for Justice Transect 1(Jt1)

Distance (m)	Patch width (cm)	Patch/ interpatch identity	Notes
0			
3.4		BS+L	
5	135	GT+T	
7.8		BS+L	Bare soil + Litter
8.3	78	GT+T	
9.6		BS+L	
10.4	342	GT+T	
13.2		BS+L	
15.4	210	GT+T	
16.1		BS+L	
18.5	115	GT+T	Grass Tussock +Tree
19		BS+L	
24.2	230	GT+T	
24.8		BS+L	
25	30	T	
25.3		BS+L	
26.7	72	GT+T	
28.1		BS+L	
28.3	28	T	
29		BS+L	

29.3	26	T	
31.4		BS+L	
36	60	GT+T	
39.2		BS+L	
39.6	22	T	
41.2		BS+L	
44	561	GT+T	
47.2		BS+L	
50	420	GT+T	

Appendix B7: The lanscape organisation data for Justice Transect 2 (Jt2)

Distance (m)	Patch width (cm)	Patch/ interpatch identity	Notes
0			
1.2		BS+L	
1.7	32	T	
2.3		BS+L	
2.6	28	T	
3.8		BS+L	
7.5	216	GT+T	
9.4		BS+L	
9.7	25	T	
11.8		BS+L	
18.4	137	GT+T	
20.6		BS+L	
21	34	T	
23.5		BS+L	
24	29	T	
27.3		BS+L	
30.5	76	GT+T	
33.4		BS+L	
33.7	25	T	
35.3		BS+L	
41.2	360	GT+T	
44.4		BS+L	
49.1	120	GT+T	
50		BS+L	

Appendix B8:The lanscape organisation data for Justice Analogue site Transect 1(JAsT1)

Distance (m)	Patch width (cm)	Patch/ interpatch identity	Notes
0			
2.5	240	GT+T	
2.7		BS+L	
4.5	650	GT +T	
5.6		BS+L	
9.8	143	GT+T	
10.4		BS+L	
15.6	1100	GT+T	
16.2		BS+L	
20.2	920	GT+T	
20.6		BS+L	
22.3	625	GT+T	
24.5		BS+L	
30.7	540	GT+T	
36.8		BS+L	
37.2	98	GT+T	
39.4		BS+L	
40.2	140	GT+T	
43.6		BS+L	
47.5	970	GT+T	
48		BS+L	
49.3	156	GT+T	
50		BS+L	

Appendix B9:The landscape organisation data for Justice Analogue site Transect 1(JAsT1)

11	Patch width (cm)	Patch/ interpatch identity	Notes
0			
4.8	940	GT+T	Grass tussock + tree
5.2		BS+L	
9.6	1120	GT+T	
10.2		BS+L	Bare soil + litter
17.3	67	GT+T	
18.6		BS+L	
22	420	GT+T	
23.5		BS+L	
27.1	159	GT+T	
28.4		BS+L	
30	687	GT+T	
32.6		BS+L	
34.3	520	GT+T	
36.7		BS+L	
43.2	860	GT+T	
44.5		BS+L	
48.7	730	GT+T	
50		BS+L	

APPENDIX C

Appendix C1: Query zones for T3t1

Type of query zone	R1	R2	R3	R4	R5
BS + L	0-0.65	8.90– 9.92	17.80 -18.00	23.60-23.64	48.60-50.00
CBS	5.60-8.70	17.0-17.30	18.80-20.20	18.80-20.20	46.50-48.40
GT	0.65-5.00	0.65-5.00	10.57-17.00	10.57-17.00	20.20-23.64
V	5.3-5.60	8.70-8.90	17.30-17.80	39.00-41.00	48.60-50.00
Other patches	9.92-9.93	18.0-18.80	23.64-23.68	23.64-23.68	34.70-34.75

Appendix C2: Query zones for T3t2

Type of query zone	R1	R2	R3	R4	R5
BS + L	6.2-7.0	10.8-11.53	24.6-25.3	33.6-39.8	45.5-49.9
CBS	41.8-45.3	41.8-45.3			
GT	0-6.2	7.0-9.0	9.7-10.8	11.53-11.90	25.3-27.70
Other patches	11.9-20.2	21.88-23.6	30.4-33.6	45.3-45.0	49.9-50

Appendix C3: Query zones for T3t3

Type of query zone	R1	R2	R3	R4	R5
BS+L	2.2-3.82	8.15-14.20	19.3-24.40	25.0-28.8	30.0-31.0
CBS	0-2.2	3.82-4.28	4.4-4-6	14.20-18.4	32.0-45-30
GT	4.6-8.15	18.4-19.3	28.8-30.0	31.0-32.0	45.00-50.0
depression	24.4-25.0	24.4-25.0			

Appendix C4: Query zones for T3Ast1

Type of query zone	R1	R2	R3	R4	R5
BS+L	0-2.20	4.0-5.6	21.20-30.5	42.0-42.25	43.5-43.62
GT	2.2-2.80	6.20-15.70	30.25-30.4	30.45-42.0	43.62-50
T	5.60-5.90	20.0-21.20	42.25-42.4	43.25-43.5	

Appendix C5: Query zones for T3Ast2

Type of query zone	R1	R2	R3	R4	R5
BS+L	5.2-8.6	11.2-11.5	15.9-21.62	9.25-40.15	48.20-48.35
GT	0-5.2	10.88-11.20	11.85-15.9	28.25-39.25	48.35-50
T	11.5-11.82	40.15-40.38			

Appendix C6: Query zones for JT1

Type of query zone	R1	R2	R3	R4	R5
BS+L	0-3.4	10.4-13.2	24.2-24.8	29.3- 31.4	44 -47.2
GT+T	3.4-5	16.1-18.5	25.3-26.7	31.4-36	47.2-50
T		24.8-25	28.1-28.3	29-29.3	39.2-39.6

Appendix C7: Query zones for JT2

Type of query zone	R1	R2	R3	R4	R5
BS+L	0-1.2	7.5-9.4	22-23.5	30.5-33.4	49.1-50
GT+T	3.8-7.5	11.8-18.4	27.3-30.5	35.3-41.2	44.4-49.1
T	1.2-1.7	9.4-9.7	20.6-21	23.5-24	33.4-33.7

Appendix C8: Query zones for JAsT1

Type of query zone	R1	R2	R3	R4	R5
BS+L	2.5-2.7	15.6-1.2	22.3-24.5	37.2-39.4	49.3-50
GT+T	0-2.5	10.4-15.6	20.6-22.3	36.8-37.2	48-49.3

Appendix C9: Query zones for JAsT2

Type of query zone	R1	R2	R3	R4	R5
BS+L	4.8-5.2	17.3-18.6	22-23.5	30-32.6	48.7-50
GT+T	0-4.8	10.2-17.3	23.5-27.1	32.6-34.3	44.5-48.7