KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF ENGINEERING

DEPARTMENT OF GEOMATIC ENGINEERING

MONITORING THE EXTENT OF RECLAMATION OF SMALL SCALE MINING AREAS USING ARTIFICIAL NEURAL NETWORKS

A THESIS SUBMITTED TO THE DEPARTMENT OF GEOMATIC ENGINEERING, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN GEOMATIC ENGINEERING

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OCTOBER 2016

DECLARATION

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

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DISCLAIMER

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ABSTRACT

Small scale mining is widespread mainly in developing and underdeveloped countries. It causes environmental degradation although it is a source of livelihood for several people. Reclamation is needed to restore mined areas to an acceptable condition. Artificial neural networks (ANN) are also being used recently for soil analysis, land use/land cover analysis, etc. due to the increased availability of Landsat data. There have been studies on various aspects of small scale mining, reclamation and artificial neural networks but this research focused on using artificial neural networks to monitor reclamation activities in small scale mining areas. Data used for analysis included Landsat satellite images of study area (2007, 2011 and 2016), ground truth data and shapefile of the study area. Two ANN classification methods, Unsupervised Self – Organized Mapping (SOM) and Supervised Multilayer Perceptron (MLP), were used for the classification of the satellite images. Normalized Difference Vegetation Index (NDVI) change maps and class mask maps were also generated in order to help confirm where actual change and to what extent it had occurred. Results of the study indicated disturbance and revegetation in the study area within the 9 –year period. The Barelands/mined areas class increased by 60.4% and a decrease in the vegetation class by 18.7% from 2007 to 2011. NDVI maps, NDVI change maps, class mask maps and maps showing reclaimed areas, disturbed and undisturbed areas together with statistical information obtained from the classification results, confirmed the extent to which the reclamation activities had gone. There was evidence of revegetation from 2011 to 2016 with the Barelands/Mined Area class decreasing by 51.7% and the vegetation class increasing by 3.9%. There was also an increase in the settlement class by 87.3%. The research concludes that the application of ANN be strongly encouraged for image classification and mine reclamation monitoring activities and studies in the country.

ACKNOWLEDGEMENTS

Thanks belong to God Almighty for making it possible for me to successfully complete this research. It would be impossible to acknowledge all those who contributed in various ways to the success of this research. On the other hand, it is also impossible not to notice the contributions of the following people.

I wish to first and foremost express my heartfelt gratitude to my supervisors, Dr. B. E. K. Prah and Dr. E. M. Osei Jnr. I am exceedingly grateful to them for reading through the draft copies patiently right from the beginning of this research, pointing out mistakes and providing expert guidance. Their priceless contributions, suggestions and constructive criticisms put this work in its right frame. Special thanks go to Dr. A. Arko - Adjei who provided assistance in diverse ways especially to the structure of my research. Thanks also go to Mr. Daniel Yaw Abaidoo and Mr. Jones Mantey of Goldfields Ghana Ltd (Tarkwa) who critically commented on the draft of this research.

I am particularly grateful to Mr. Jerry Ahadjie of Minerals Commission who, without hesitation, offered the relevant data for this research. Appreciation also goes to Mr. Ransford Sekyi (Executive Director) of Environmental Protection Agency for providing me with documentary information on mine reclamation for mining companies in the country.

Finally, I owe a great debt of gratitude to Mr. Kennedy Kwashie and Miss Lily Yevugah who helped with advice during the data collection stage.

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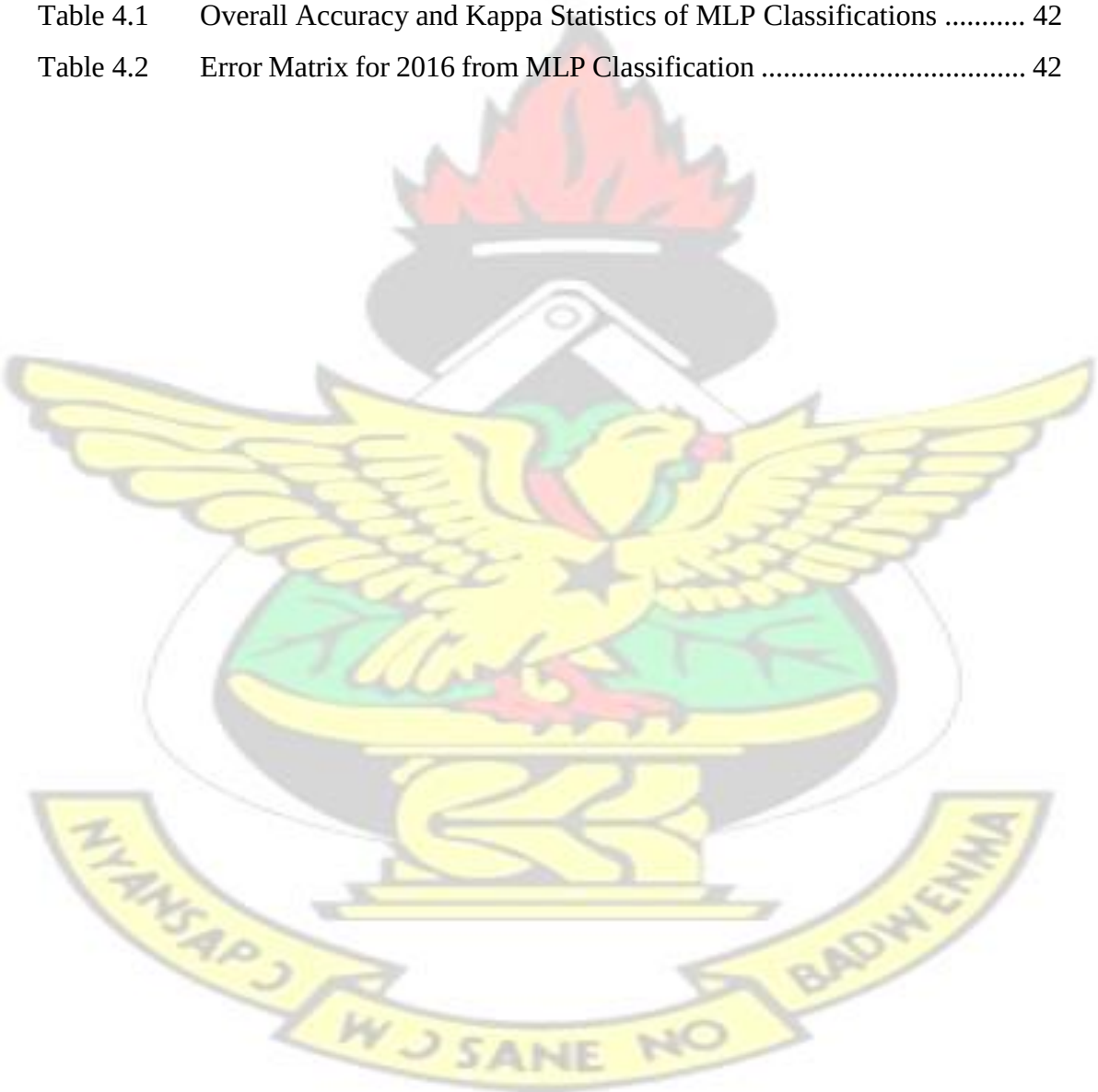

CHAPTER 1 INTRODUCTION

1.1 Background of Study

Small-scale mining is an economic activity that is found in developing and underdeveloped countries where there is a lot of poverty. Despite its positive impact on the survival of several people, it also results in environmental degradation and resource depletion in areas where mineral resources are located (Mihaye, 2013). It is also considered as equally important as large scale mining in other parts of the world due to its employment generation rate and its crucial role in poverty alleviation and rural development (Mihaye, 2013).

Areas that were conducive for several human and economical purposes such as agricultural farmlands, wildlife habitats, natural reserves for fauna, etc some years ago have been interrupted by small-scale mining and have caused these areas to lose their economic value over time.

The mining industry and its regulators have recognized that a reclamation plan has to be integrated in a mine's life cycle. Every successful reclamation supports the mine's activities, meets agreed upon goals, includes progressive certification and liability transfer, and can be reasonably assured of providing good long term landscape performances (Tetteh, 2010).

Reclamation returns the mined areas to an acceptable environmental condition regardless of the reason for which the reclamation was intended. Reclamation paves the way for landscapes that meet a variety of goals such as the restoration of bio systems and the creation of industrial resources. Reclamation activities are always in motion because, the effects of mining keeps on increasing due to its various developmental stages (McKenna, 2002).

Artificial Neural Networks are used in recent times for purposes such as soil analysis, land use/land cover analysis among many others and the general public has a lot of access to satellite imagery lately. The United States Geological Survey (USGS) declared in April 2008, the entire archive of the Landsat earth observation satellites would soon be available for public use (Anon, 2015a). New images will become available as they are acquired and processed. Therefore, the increased availability of Landsat data greatly enhances the opportunities for the implementation of artificial neural networks to monitor reclamation activities and other environmental programs (Alden, 2009).

1.2 Problem Statement

Regardless of its worldwide economic impact, mining affects the environment negatively. It results in significant degradation of the land, due to the way it is done. Drainage, air, soil and water quality, topography, vegetation, human health and habitation can be listed as important parameters that are mainly affected by mining activities. When the reserve extraction is over, the disturbed concession has to be reclaimed so as to relieve the concession and its surroundings of the damages caused (Kuter, 2014).

Policies regarding reclamation have been prepared by the Ministry of Lands and Natural Resources and the Environmental Protection Agency (EPA) to restore these areas to the way they were. However, the effectiveness and implementation of these policies for monitoring small-scale mines to reclaim the used lands are questionable.

Existing research on small-scale mining, reclamation and artificial neural networks have placed emphasis on environmental and livelihood effects of small – scale mining (Ontoyin and Agyemang, 2014), the effect of small-scale mining on soil physical properties (Mensah *et al*., 2014), using tasseled cap transformation, at-brightness

temperature and K-means algorithm to monitor coal surface mining and reclamation (Alden, 2009), artificial neural networks for soil analysis (Amato *et al*, 2015) and wildfire detection using artificial neural networks (Miller *et al*, 2003). However, not much research has been done using artificial neural networks to monitor reclamation activities in small-scale mining areas. That is what this research is focused on, using Tarkwa and its environs as a case study.

1.3 Objectives and Research Questions

The main objective of this research is:

To monitor the extent of reclamation of small-scale mining areas using artificial neural networks.

1.3.1 Specific objectives

- To assess the extent of damage caused by small – scale mining activities in the study area over time.
- To assess the extent of reclamation in the mined areas if any.

1.3.2 Research Questions

- To what extent have the small-scale mining areas been damaged?
- To what extent have these areas been reclaimed?

1.4 Justification

The study will contribute to narrowing the gap in understanding how artificial neural networks (ANN) can be used to monitor the extent of reclamation in small-scale mining areas. The lessons could help researchers and professionals in the industry to learn more

about ANN and how to use its principle for image classification in other areas besides monitoring reclamation activities.

1.5 The Structure of the Thesis

Chapter 1 presents the background of the study and problem statement of the research. It also explains the objectives, research questions and justifies the research.

Chapter 2 elaborates on the theoretical foundation of this research, by reviewing and commenting on the literature with regards to mining, types of mining, institutional and legal frameworks in relation to mining, reclamation, forms and importance of reclamation and the concept of artificial neural networks for image classification and monitoring reclamation.

Chapter 3 narrates how the research was conducted. The study area is presented and further explanation is given on methods, software and techniques including field data collection (i.e. ground truthing, Self-Organized Mapping for unsupervised classification, image segmentation and training and Multilayer Perceptron for supervised classification). It also explains the role of Normalized Difference Vegetation Index (NDVI) in the analysis and presents the flowchart of the method used in this study.

Chapter 4 presents the findings of this research in terms of the two research objectives. It begins with land use/land cover maps and statistical information showing the extent of damage caused by small – scale mining in the study area (Objective 1). It continues to show NDVI maps, NDVI change maps and land cover maps to show to which extent these areas have been reclaimed and also supported with statistical information to that effect (Objective 2).

Chapter 5 further elaborates on the land use/land cover and NDVI analysis done.

Chapter 6 explains lessons learnt from the research and analysis and are presented as conclusions and recommendations for the encouragement of the use of Artificial Neural Networks for image classification and reclamation monitoring.

CHAPTER 2

REVIEW OF RELATED LITERATURE IN MINE RECLAMATION

2.1 Introduction

This chapter reviews relevant mining and reclamation literature from both the developed and developing country contexts. This chapter also touches on how artificial neural networks can be used for image classification and be applied in this research.

2.2 Overview of Mining Activities

Mining is an operation where the earth is dug to extract natural minerals and follows after agriculture as the world's second oldest industry and one of the largest industries in the world. It is a decisive component of the world's economic development. The trade of mineral commodities is important for international trade (Amponsah - Tawiah and Dartey - Baah, 2011).

Humankind has been dependent on mining from the days of old to the present. The abundance of minerals serves as an avenue for creating wealth (Anon, 2015b). Minerals can be sold on the open market making the countries that own these minerals obtain valuable currency from countries that do not. (Anon, 2015b).

Mining begins with geological investigations that help to find the deposit and then performance of economic analyses that would provide its financial and economic feasibility or otherwise (Anon, 2015b). Following the extraction of the mineral, the material is generally cleaned or concentrated. The minerals produced are refined further to provide consumer products. The end step is converting a mineral material into a useful product for marketing (Anon, 2015b).

2.3 Mining in Ghana

The long-existing role of mining in the economic development of the country is impressive and well established. Ghana's colonial name of "Gold Coast" reflects the mining sector and particularly, the gold trade. The country has a known past of gold mining with almost 80 million ounces of gold produced when the first gold mining activity was documented (Amponsah - Tawiah and Dartey - Baah, 2011). The country can boast of 36% of the total world gold output (8,153,426 ounces between

1493 and 1600) and is the second largest gold producer in Africa, the third largest African producer of aluminum and manganese ore and produces bauxite and diamonds in significant quantities (Amponsah - Tawiah and Dartey - Baah, 2011).

Illegal mining in Ghana has been debated upon and is seen in general as highly negative, with the illegal miners irresponsibly using mercury in their gold extraction with no concern for the communities' health, wellbeing and the environment. The sentiments are often that the small-scale miners destroy the investment potential that the country can generate from the large-scale mining companies (Bach, 2014). With limited sources of income and the inability to officially register for any mining blocks due to bureaucratic delays, and no access to mining education with respect to how to mine more efficiently and with environmentally sound procedures, these miners are now seen as a highly marginalized group (Bach, 2014). Furthermore, most locals feel lazy to undergo training to become registered legal miners. This is because governmental policy processes have been done with insufficient stakeholder participation. However, in the academic sphere one is starting to discover that what is needed to deal with the galamsey sector is an integrated approach which actively involves the community (Bach, 2014).

2.3.1 Types of Mining

The Ghanaian mining sector employs two major methods in its operations: large-scale mining (legal) and small-scale mining (both legal and illegal) dependent on the differences in modes of extraction, legality of operations, quantities extracted as well as the extractive capacities.

Small-Scale Mining

Small-scale mining in Ghana normally refers to using traditional methods to extract precious minerals particularly gold and diamonds. However, other industrial minerals like salt, sand, gravel among others are also mined on small-scale basis in the country. In developing countries, it is an activity mainly driven by poverty (Owusu and Dwomoh, 2012). It is a practice that consists of undeveloped ways of extracting minerals, extreme manual processes, hazardous working conditions, and constantly affects human and environmental health negatively. About 80 - 100 million people are currently engaged in this activity all over the world and depend on it for their livelihood (Owusu and Dwomoh, 2012).

Small-scale mining requires intensive manpower with no need for a particular skill or knowledge of advanced technology. The capital investment involved in its operation is limited and leads to low productivity. The law in 1989 (PNDCL 218) reserved the small-scale mining activity for Ghanaians. Quite recently, a number of the illegal small-scale gold miners arrested in Ghana were mostly Chinese, Nigerians and Malians (Kessey and Arko, 2013). There are two types of small-scale gold miners in Ghana, namely the licensed or legal small-scale gold mining units and the unlicensed or illegal small-scale gold mining units. It appears there is a thin line either organizationally or technologically between the legal and illegal mining except that legal mining activities possess security of tenure on a demarcated concession for an agreed period of time (Kessey and Arko, 2013). Also it should be noted that, in Ghana, mining concessions are not approved for mining to be done in restricted areas such as forest and game reserves, riparian areas, sites close to residential areas and other public infrastructure. Any mining activity which takes place in these areas are illegal (Kessey and Arko, 2013).

In the case of gold, operators are given licenses by the government to mine in a designated area not more than 25 acres for 3 to 5 years (Hilson, 2001). Normally, a licensed operator employs between 5 and 20 groups of tributers consisting of 5 to 10 workers each that excavate the ore bearing rock and process gold. The agreement is that the tributers keep two-thirds of the profits, and the remaining third is given to the concessionaire (Hilson, 2001).

Large-Scale Mining

Large-scale mining generates more than 95 % of the world's total mineral production and is a source of income for approximately 2.5 million people across the world. In Ghana, there are more than 15 large scale mining companies with more than half of them operating gold mines, one bauxite mine and one manganese mine. These companies are mainly owned by private companies with a 10 % free share and an optional 20 % share for the government. The government of Ghana focuses on promoting the interest of large-scale mining companies as their operations are considered to be legal. But on the contrary, some of the operational standards and behavioural conducts have negative impacts on the environment and the rivers surrounding such mines. These companies use their legal status without caring about the environment (Fatawu and Allan, 2014). The operations of these companies are in three stages: mining, processing and mineral conveyance. Large-scale mining involves the complex use of machinery and water is used for cooling the cutting edges and also for friction induced-ignition. The water is directed from nearby watercourses to serve these purposes. Surplus mine water could either be treated for reuse or discharged back to its source. However, due to the high cost of treatment, most of these companies resort to discharging the chemical- infiltrated water back into rivers, which is inappropriate (Fatawu and Allan, 2014).

2.3.2 Institutional Framework for Regulating Small-scale Mining and Mineral Rights in Ghana

The Minerals Commission is a government agency established under Article 269 of the 1992 constitution and the Minerals Commission Act 1993 (Act 450) mining (OpokuAntwi, 2010). The Minerals Commission is the institution in charge of the regulation and management of the utilization of the mineral resources of Ghana as the ultimate promotional and regulatory sector as well as coordinating and implementing policies regarding mining (Opoku-Antwi, 2010). It also makes sure there is compliance to

Ghana's mining and Mineral laws and Regulation via effective monitoring. The commission is required by law to carry out the following functions (Anon, 2015c):

- Formulating recommendations of national policy for exploration and exploitation of mineral resources.
- Advising the Minister of Lands and Natural Resources on mineral-related matters.
- Report to the Minister on issues regarding the implementation of laid down Government policies on minerals.
- Receiving and accessing public agreements relating to minerals and report to parliament.
- Securing a firm basis of comprehensive data collection on natural mineral resources and the technologies of exploration and exploitation for national decision making.
- Perform such other functions as the Minister may assign to it.

The Minerals Commission since its establishment in 1986, which was set up as a one

– stop shop, has put Ghana's mineral resources on the world map by bringing in foreign investors (Barning, 2004).

2.3.3 Legal Framework for Regulating Small-scale Mining in Ghana

The legal framework under which mining takes place in Ghana is outlined in the following laws (Barning, 2004): The Minerals and Mining Law, amended by Act 475, the Small-scale Mining Law and Environmental Assessment Regulations Law LI 1652. The first assignment done by the Minerals Commission after its establishment, was the drafting of a new law; the Minerals and Mining Law, PNDCL 153 of 1986. This law is the prime law governing mining in Ghana. The enactment of the law has positively influenced mining industry development (Barning, 2004). The main objectives of the law are to provide:

- A framework for the granting of various mineral rights, indicating the rights and obligations of the holder.
- A fiscal regime stating the incentives available to the investor and government.
- Procedures for settlement of investment disputes.
- State ownership of all minerals in the State.

The major provisions of this law can be referred to in Appendix 1. Applicants who meet up the technical, financial and managerial criteria of engaging in mining activities are granted these mineral rights by the Minister of Lands and Natural Resources. In practice small-scale producers have to market their production to accredited buying agents which makes way for the offshore retention account to work (Barning, 2004).

2.3.4 Various Impacts of Mining Activities

The mining sector is a very instrumental segment of the extractive sector but has one of the terrible environmental consequences; and having adverse effects on the

livelihood and survival of resident communities (Boateng *et al*. 2014). Several illegal miners are dead as a result and this continuous trend is a threat to society. In recent years, the death of illegal miners has been very common (Amankwah, 2013). The environmental decay is due to the natural environment being stable and safer in the past than it is today (Yunana and Banta, 2014). Some impacts are:

Water Resources for Domestic and Irrigation Purposes

A major impact of illegal mining is the pollution of water bodies. Accessibility to safe drinking water and sanitation by 2015 is one of the requirements of the Millennium Development Goal on environmental sustainability (Amankwah, 2013). This calls for our country to strengthen its effort in water accessibility via integrated water resource management such that preventing people from having access to water should be considered a crime and an infringement on human rights (Amankwah, 2013). Sources of drinking water and for irrigation both surface and underground in many mining communities have been polluted (Kovats *et al*., 2000). The cost of water treatment for water companies that treat the water for public consumption is very expensive due to the activities of illegal mining (Amankwah, 2013). Water bodies are threatened by these poisonous chemicals. Chemicals in the soil are also washed via erosion into water bodies during rain storms as revealed by Roulet *et al*. (1998) in their studies. It was mentioned recently that there is a high percentage of mercury in the water supplied by the Ghana Water Company in Tarkwa which may affect the health of the people. This was disclosed by a UNEP report (2008).

Cocoa Production

Cocoa cultivation is the main revenue generator in the country and an occupation held in high esteem by farmers in Ghana and beyond (Boateng *et al*. 2014). Cocoa is Ghana's most important crop and forms a significant part of the agricultural sector. Cocoa

production puts a huge amount of income into the pockets of several farmers and others engaged in its transportation and processing (COCOBOD, 2001).

Galamsey (illegal mining) operators take over farmlands with force and results in loss of crop yield and income (Boateng *et al.* 2014). Also when the lands are taken from the farmer, some of the farmers look forward to compensation which is hardly done and in turn negatively affects the farmers' output. However, most of the farmers prefer cocoa farming to Galamsey because they know cocoa has a future for them and the generations yet unborn (Boateng *et al.* 2014).

Vegetation Cover

Land degradation through the loss of vegetation is due to illegal small-scale mining activities. However, Akabzaa *et al*. (2005) did mention that mining activities in an area leads to environmental degradation and an annual reduction in economic value. Some areas in Ghana are highly reduced in quality due to the loss of vegetation cover, rich top soil and wild faunal species due to the changing climate and factors affecting environmental degradation negatively (Tom-Dery *et al*. 2012).

Ghanaian Youth

According to Owusu and Dwomoh, (2012), although galamsey started long time ago, adults were mostly involved and it was believed that the job was meant for people of the northern extract in Ghana since they were known for their strength. Due to this, school children were regular and punctual at school since they did not find it beneficial to take part in that activity. Through research and study through the interviews with the illegal miners, it has been found out that illegal mining became very rampant in 1983 when Ghanaians returned home from Nigeria. The following observations were made after 1983:

- The youths' attitude towards school changed when they get involved in illegal mining as they began to make money through diamond and gold prospecting.
- The youth tend to be truants preferring diamond and gold searches to school.
- Some teachers partook in illegal mining activities and as such absent themselves often from school.
- School environments are destroyed because, the illegal miners use the chance to do what they like without taking into account whatever is on the land once they find deposits of precious minerals.

2.4 Mine Reclamation Regime in Ghana

Mine reclamation is the process of restoring land that has been mined to a natural or economically usable state. Although the process of mine reclamation occurs once mining is completed, the planning of mine reclamation activities occurs before the beginning of mining operations (Anon, 2015d). Mine reclamation creates useful and improved landscapes ranging from the restoration of productive ecosystems to the production of industrial resources. Modern mine reclamation minimizes and mitigates the environmental effects of mining." (Anon, 2015d).

Adjei (2010) also defines reclamation as the process of cleaning up a site that has been affected by environmental degradation such as those by natural causes and human activities.

Returning land to its former state after mine completion is part of every mining operation. Prior to mining, companies develop a plan to reclaim the land and before mining is complete, this plan is put into action (Adjei, 2010). Reclamation is done in many sites to make way for projects such as housing development or to restoring the area back to the wildlife habitat it was before (Adjei, 2010). In Ghana, reclamation

bonds are calculated and regularly reviewed to balance operational cost, closure and also discuss long term impacts to wildlife, soil and water quality (Tetteh, 2010).

Closure certificate as in many countries is issued only if the reclamation plan has been implemented to the satisfaction of the community and the regulatory authorities (Tetteh, 2010). In accordance with section 24 of the Environmental Impact Assessment Regulations (1999), reclamation policies in Anglogold, Iduapriem mine had been implemented together with mining in order to reclaim the land. Policies regarding reclamation of pits, waste dumps, and rompads, tailing dams, water bodies, and the final land use objective had been set up (Tetteh, 2010).

For sustainability to be achieved, the mining industry should consider merging enhanced socioeconomic growth, development and improved environmental protection (Hilson and Murck, 2000). Mine land reclamation is a necessary part of mine sustainability on the path to achieve an acceptable land use (Morrey, 1999). In terms of land use sustainability over a long period, reclamation provides the means for the ecosystem to readjust itself and for the practical reuse of mined land (Tetteh, 2010).

2.4.1 Mine Reclamation Techniques

Forestry Reclamation Approach (FRA)

The Forestry Reclamation Approach (FRA) has been promoted by mining agencies and other stakeholders as the preferred method for mine reclamation. Powell River Project, a research and education program focused on reclamation in Appalachia in United States of America, first developed and conducted the Forest Reclamation Approach. (Anon, 2015d). The FRA has laid down principles for achieving successful reclamation of mined lands which can be referred to in Appendix 2.

Holistic Approach

With this Holistic approach, rangelands can be established in order to successfully execute reclamation activities (Anon, 2015d). Using early successional species of perennial crops and other plants, along with livestock replacing the species of wildlife needed, the ecosystem can assist in producing topsoil (Anon, 2015d). The procedure can be referred to in Appendix 3.

An integrated approach that uses the holistic approach to achieve the first three steps of the FRA is also a viable option (Anon, 2015d). Once those first three steps are achieved, the livestock grazing can be reduced to compensate medium and higher successional species to gain the necessary foundation to carry on with the FRA (Anon, 2015d).

2.4.2 Institutions Involved in Mine Reclamation

The Environmental Protection Agency (EPA) of Ghana was set up under the EPA law of December 1994. The EPA ensures that all developmental activities in the country take into consideration environmental concerns through Environmental Impact Assessments (EIA's) and also to make sure that regular inspections and monitoring of environmental quality are available (Barning, 2004). The Inspectorate Division of the Minerals Commission collaborate with the EPA to implement the inspection and monitoring of mines activities. Under the 2006 Minerals and Mining Act, there are laws regarding forestry and environmental protection (Barning, 2004). In view of this, general guidelines regarding mine reclamation have also been prepared by the EPA to describe how mining activities can be carried out in an environmentally safe way (Barning, 2004). The general guidelines can be referred to in Appendix 4.

2.4.3 Benefits of Mine Reclamation

Reclamation comes along with several benefits which help to sustain the environment.

Some of them are listed below (FESS, 2007):

- Provides more land for agriculture and other uses.
- Helps people who do not normally have access to land, such as women and youths, to be able to access land for cultivation, housing, and social activities, such as providing a playing ground for youths and children.
- Increases the space for children to play and reduce the risk of children drowning and having accidents.
- Allows for effective town planning, rather than the more chaotic, ad hoc urban growth that is currently occurring.
- Prevents conflict between landowners and irresponsible mining companies Restores authority to the original landowners.
- Provides an opportunity to restore some of the original species of vegetation which were removed from the land, to restore the soil, and to increase livelihoods.
- Improve the aesthetic beauty of the land.

2.5 Reclamation Security Agreement (Generic) between EPA and Mining Companies

Several mines have different methods for site rehabilitation, and it is impossible to restore all mine sites, as restoring very large pits may be very difficult and economically unwise. But eventually, lands degraded by mining activities have some potential for economic, recreational and aesthetic use (Tetteh, 2010). So the reason for reclamation is to pinpoint the unique potential of mined land and to choose appropriate technologies and measures to transform this potential into something sustainable (Morrey, 1999). The EPA as part of its functions, monitors the reclamation activities of various mining companies which have been bonded by a Reclamation Security Agreement between the

two parties. The flowchart (Figure 2.1) summarizes the contents of the Generic Reclamation Security Agreement document between Mining Companies and the EPA. The full document is in Appendix 5.

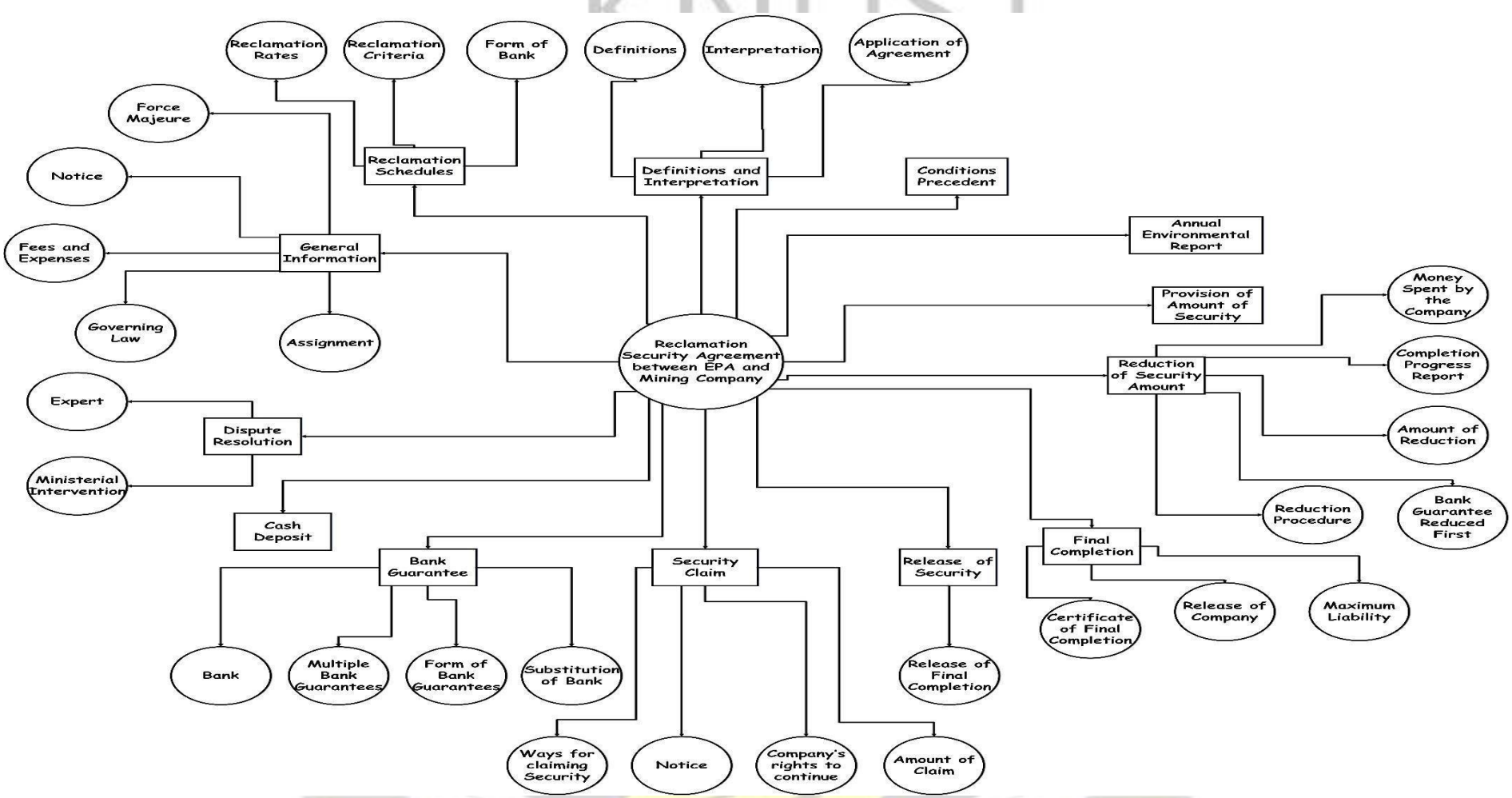

Figure 2.1 Summary of a Generic Reclamation Security Agreement

2.6 Artificial Neural Networks (ANN) for Image Classification and Monitoring Reclamation Activities

Various classifications of data obtained via remote sensing have resulted in LandUse/land-cover (LU/LC) maps for several applications such as urban planning, characterization of agricultural crops, and classification of forest ecosystems (Yuan *et al*., 2009). Artificial Neural Networks (ANN) are among the most notable classification approaches even though there are other modes of classification to accomplish such tasks. (Yuan *et al*., 2009).

The efficiency of the brain and eye regarding pattern recognition issues has caused researchers in this field to take into consideration the effectiveness of computer systems based on a simplified model of the brain than traditional classification methods (Tso *et al*., 2009). Artificial neural networks emanated from such research whose development has been extensively used in remote sensing for a while, mainly for image classification (Tso *et al*., 2009).

ANN approaches are advantageous over statistical classification methods in that they are non-parametric and need little or no knowledge of the distribution model of input data. Other advantages of ANNs include:

- Parallel computation
- Estimating non-linear relationships between the input data and desired outputs
  - Capability of fast generalization (Tso *et al*., 2009).

Previous studies on multispectral image classification have confirmed a better classification accuracy performance from ANNs than traditional classification methods (Yuan *et al*., 2009). There is difficulty providing a comprehensible explanation of the process through which a given output has been obtained from a neural network even though ANN's provide very good results in image classification. This is because, neural networks hide the relation between inputs and outputs in the weights of the neurons of

its hidden layers and hence, the characteristics of the data set cannot be understood further (Qiu *et al*. 2004).

A number of fundamental neural network architecture including counter-propagation networks and Hopfield networks can be used for image classification but this research focused on using MLP (Supervised Classification) and SOM (Unsupervised Classification) to monitor the extent of reclamation activates in small-scale mining areas within Tarkwa and its environs. These two neural network architectures are elaborated in detail in Chapter 3.

2.7 Concluding Remarks

The information provided in this chapter has laid the theoretical foundation for this research. Firstly, elaborating on mining in general and then zooming in on mining in Ghana and how it is regulated on the institutional level and on the legal level. Secondly, touching on mine reclamation activities and their benefits and finally, how ANN's are very crucial in image classification and for this research. However, in the numerous literature reviewed concerning mine reclamation, much has not been said concerning using artificial neural networks in monitoring the extent of reclamation activities in small-scale mining areas. This research therefore intends to focus on this area and in the end, serve as a contribution and an add-on to research in the area of mine reclamation.

CHAPTER 3 RESEARCH DESIGN AND METHODS

3.1 Introduction

The methods and techniques used for specific tasks in the research are explained here. This study uses a case study approach. The choice of the study area was based on the willing provision of data by the Minerals Commission and the Environmental Protection Agency (EPA), familiarity of the area and easy access to the communities. Primary data gathered included Landsat satellite images and shapefile of the boundary of the study area as well as training and ground truthing data. Secondary data gathered included small-scale mining blocks within the study area provided by the Minerals Commission and documents regarding reclamation collected from EPA.

3.2 Case Study Area

Tarkwa is the capital of the Tarkwa-Nsuaem Municipal Assembly. It falls within latitudes 5˚9'0"N and 5˚25'0"N and longitudes 1˚50'0"W and 2˚10'0"W (Figure 3.1). Tarkwa has a history of almost a century of gold mining and has the highest concentration of mines in a single district in Ghana, with all the new mines operating open-pit. Multinational mining companies in Tarkwa also have mining concessions in other West African countries with similar rock units. These geological rock formations called Birimian rocks occupy about three-fifths of Ghana and nearly the whole study area. Tarkwa and its environs constitute undulating terrains with drainage systems. It experiences the most frequent rainfall pattern in the country (Average rainfall per year of 187.83 cm between March and September). Resettlement, relocation, negotiation and compensation for the loss of crops in the area as well as health risks on inhabitants have become a serious issue due to the significant impact of mining activities.

3.2.1 Topography

The study lies within mountain ranges covered by thick forests. In some cases, the ranges are mixed up with undulating valleys. Tarkwa township and its surrounding settlements can be found between two long ranges of hills. The mountain ranges rise to an average of 300 metres with the highest being 335 metres above mean sea level. These mountain ranges are rich in biodiversity and with the several settlements in-between them presenting a very nice distribution of plant species. Quite unfortunately, these ridges are the main areas where gold is found, and are therefore the target for open pit mining.

3.2.2 Vegetation

The vegetation of the study area is within the tropical rain forest belt and is generally made up of climbers and shrubs of different heights. The trees, which generally reach heights of between 15 and 45 metres are found mostly at the top of hills where mining has not yet begun. The density of trees has been reduced in areas disturbed by mining activities over the years. Lack of protection from mining activities is primarily responsible for the degradation of the vegetation in the area. In areas where mining has taken place, the vegetation is now made up of ferns and other shrubs which grow a lot on the hills.

3.2.3 Land Tenure System

The Abunu and Abusa tenancy system dominates the Tarkwa township and its environs. These two main practices of land tenure system are still in force. The land is in the custody of the various chiefs within the area. Land holding rights within these areas include grazing rights, residential and agricultural rights, state ownership of forests reserves, public estates, and exploration and mining rights. Issues associated with land holdings in the area include: indeterminate boundaries of stool and family lands, compulsory acquisition of large tracts of lands by government and for mining companies

without compensation, leaving landowners almost landless and becoming tenants on their own lands.

3.2.4 Economic Activities

Tarkwa and its environs contain about 44% of Ghana's forests, accounts for 50% of Ghana's gold production, 39% of cocoa, half of timber production and produces all of the country's manganese (Akabzaa and Darimani, 2001). Economic activities rely on the availability of natural resources in the area. The inhabitants of the area had subsistence and commercial farming as their main economic activities until recently when mining took over as the main economic activity.

3.2.5 Mining Activities

Tarkwa has the most mining companies in the country including the only manganese mine. Half of the large-scale mines in Ghana are located in the Tarkwa area, producing a significant proportion of the country's gold output. Also, over 70 registered, smallscale mining companies together with over 200 galamsey operators are in the area. About 30 local and foreign companies are involved in mineral prospecting in the area. Eight major companies operating in the area use the open-pit method of mining. Cyanide heap leach operations are used for gold ore extraction. These techniques have bad influence on the safety of humans and the environment. Using heavy machinery to exploit small amounts of mineral ore destroys the vegetation of the area and leads to dust and noise pollution.

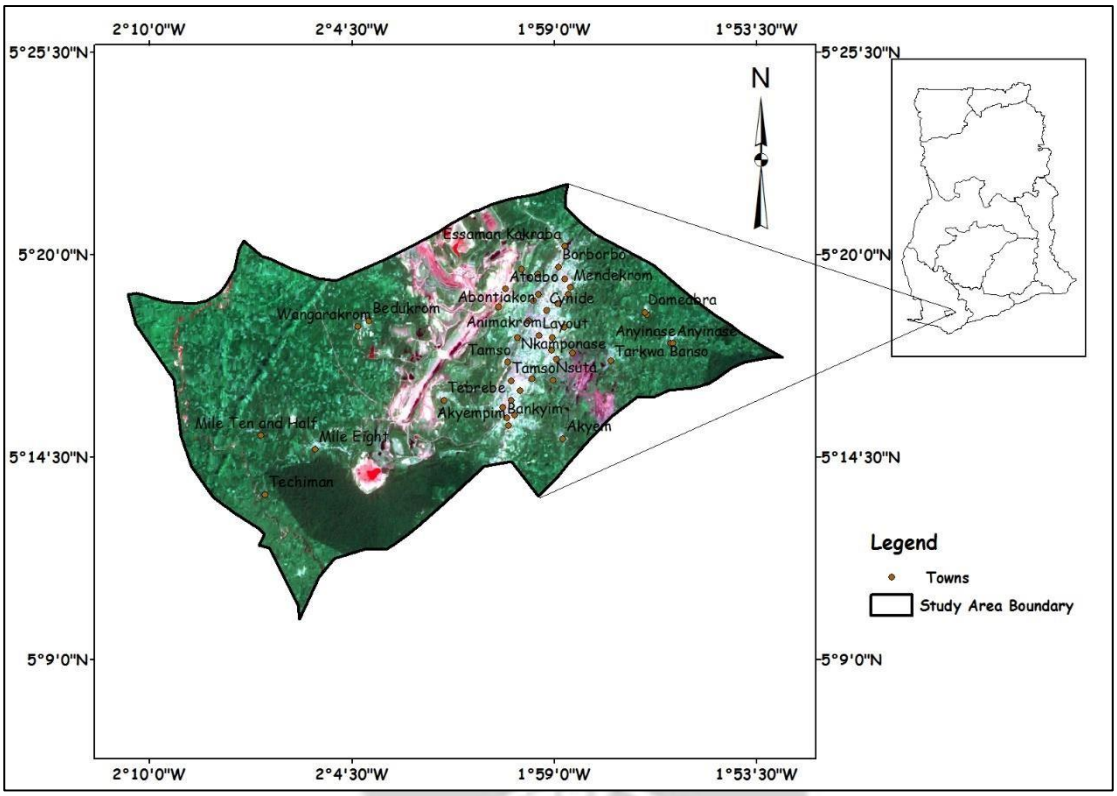

Figure 3.1 Landsat Image of Study Area

3.3 Data Acquisition and Preparation

Landsat satellite images for this research were downloaded from the United States Geological Survey (USGS) website (Table 3.1). Shapefiles of Tarkwa and its environs were obtained from the Minerals Commission. Ground training data was gathered from various communities within Tarkwa and its environs.

Table 3.1 Research Data

	Acquisition Date	Satellite	Spatial Resolution	Sensors	Number of Bands
2007	13th January, 2007	Landsat 7	30 m	ETM +	8
2011	29th March, 2011	Landsat 7	30 m	ETM +	8
2016	6th January, 2016	Landsat 7	30 m	ETM +	8

3.4 Image Classification

The workflow design for the research is shown in Figure 3.2

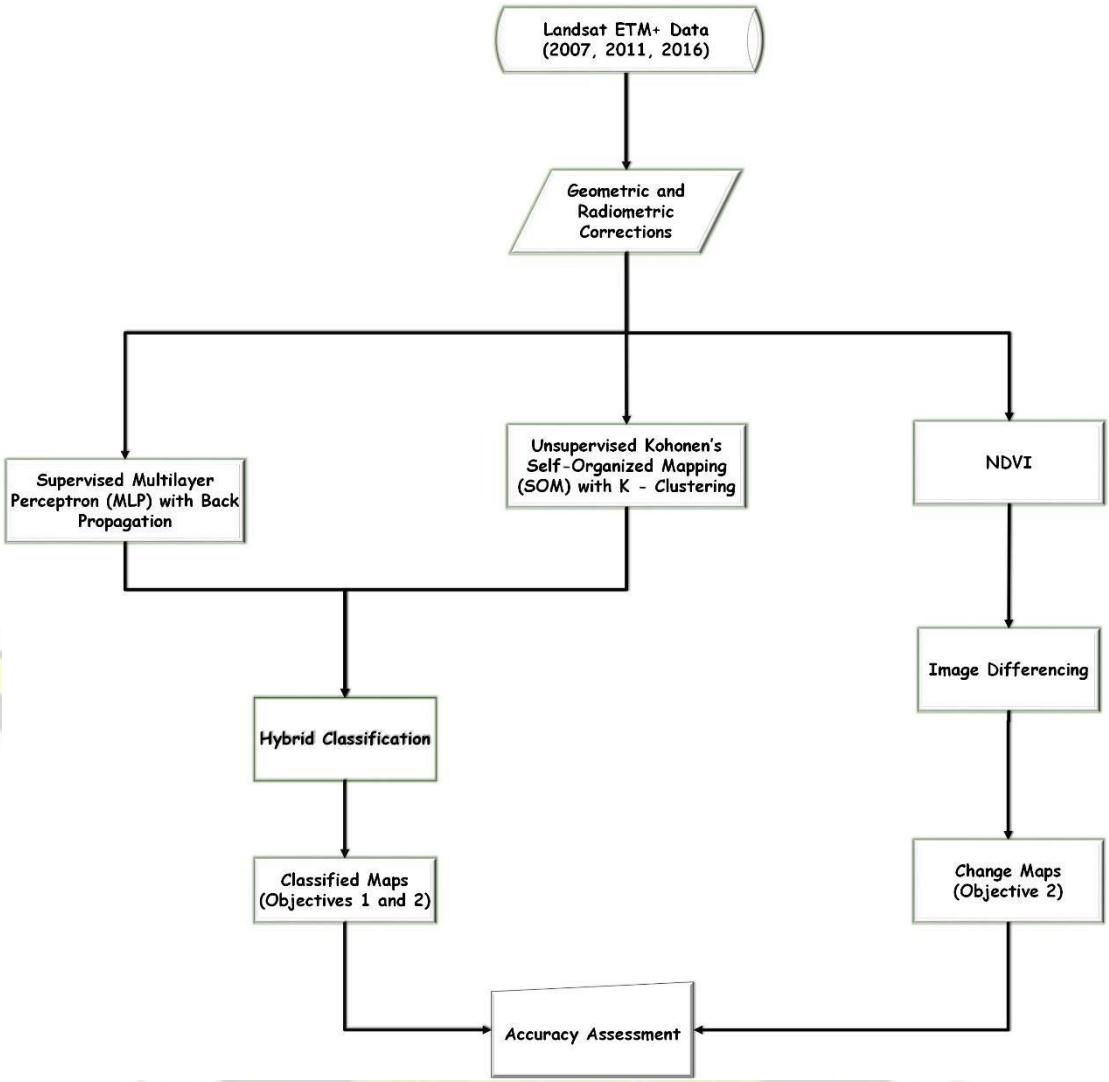

Figure 3.2 Design of the Workflow

3.4.1 Land Use/Land Cover Analysis

Two Artificial Neural Network (ANN) classification methods, Unsupervised SelfOrganized Mapping (SOM) and Supervised Multilayer Perceptron (MLP), were used in this research to classify the Landsat satellite images. When the Landsat satellite images were obtained, corrections were made on them (scan line removal) after which the area of interest was extracted from it. Composite bands were then generated from

the images (2007, 2011 and 2016). The unsupervised SOM classification was then performed on the images for all three years. The ground training data with the help of the unsupervised SOM classification maps served as a guide to segment and train the generated composite bands to generate the supervised MLP classification maps for the three years (Hybrid Classification). Four categories resulted from the classification (Table 3.2)

Table 3.2 Class Names and Definitions

Class Name	Class Definition
Vegetation	Vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes, sparse vegetation
Water Bodies	All areas of open water
Settlement/Built-up Areas	Residential/Commercial/Industrial/Transportation
Barelands/Mined Areas	Mine Areas, bare construction sites, rock, sand, or fallow agricultural land

Statistical analysis was then performed on the classified images to gain quantitative information on changes which had occurred over the time series. The accuracy of the analysis was then determined to ensure the results were within the acceptable error margin. ArcMap was used for the mask extraction and in the creation of the resultant maps. The IDRISI Taiga Software (Clark Labs) was used to perform the Artificial Neural Network classifications including the image segmentation and training. The Quantum GIS Software was used for the scan line removal.

3.4.2 NDVI and Class Mask Analysis

Following the creation of the land use/land cover maps, NDVI maps and NDVI difference maps were also generated and a comparison of the two maps were conducted.

The small-scale mining blocks were then overlaid on the NDVI images. Overlaying these areas on the NDVI change images and comparing these areas to the composite bands of the various years helped confirm where the actual change and to what extent it had occurred. This analysis led to the identification of a number of changes. The small-scale mining blocks were also overlaid on the classified images to help assess the extent of reclamation in the mining areas. The IDRISI Taiga Software was used again for the NDVI calculation and the image differencing was done using ArcMap. A class mask of the Barelands/Mined Areas class was also generated to show what land use/ land cover types were present in the 2007 image that were being mined in the 2011 image.

3.5 Unsupervised Self – Organized Mapping (SOM)

The SOM network automatically detects the relationships within the set of input patterns. This property can be used to convert images from higher dimensions to a twodimensional feature space using learning vector quantization to train and classify the image (Kangas *et al*., 1990).

The input and output neurones in a SOM are respectively known as the sensory cortex and the mapping cortex, which are parallel to the functions in the brain (Figure 3.3). The number of neurones in the input and output layers define a SOM network. The number of input neurones is the same as the number of input features. But then, there are no specified rules about the number of output neurones (Tso *et al.*, 2009). One of the benefits of the SOM is that it is able to handle categorical data. The SOM model in IDRISI Taiga uses the principle of Kohonen's Self-Organizing Map.

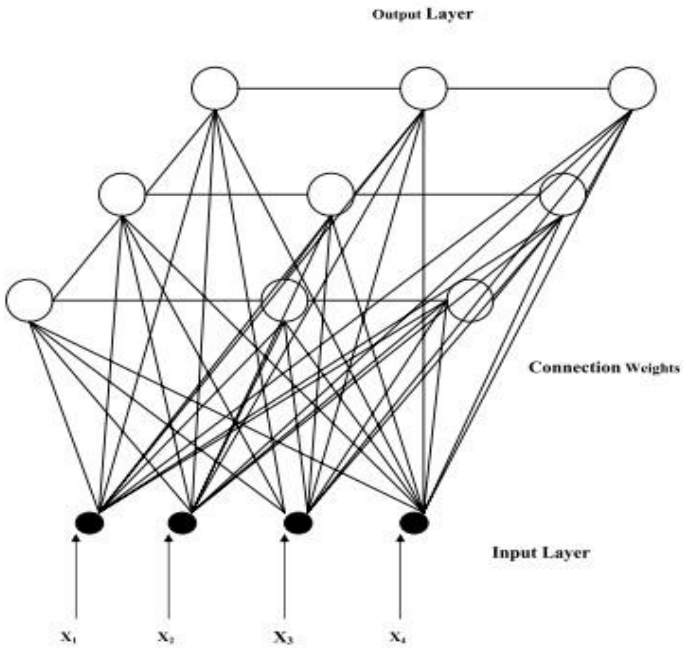

Figure 3.3 The structure of a Self-Organized Mapping Neural Network (Source: Yuan *et al*, 2009).

Basically, the architecture is made up of a layer of input neurons linked with synaptic weights to neurons in a two-dimensionally arranged array output layer which are usually square-shaped.

The corrected satellite images were taken through a coarse tuning phase that was in effect the unsupervised classification. The parameters of SOM used in the classification are presented in Table 3.3.

Table 3.3 Parameters used for Unsupervised Classification (SOM)

Group	Parameter	Value Used

Sampling in band images	Interval in Column	7
	Interval in Row	7
Network Parameters	Output layer neuron	4 x 4 = 16
	Initial neighborhood radius	6.66
	Min Learning rate	0.5
	Max Learning rate	1
Classification Specification	Output hard classification map	Yes
	Display feature map	No
	Algorithm for unknown pixels	Minimum Mean Distance

3.6 Supervised Multilayer Perceptron (MLP)

MLP is a supervised method based on the back-propagation learning algorithm. This network is composed of an input layer, an output layer, and an intermediary hidden layer at least (there can be more than one intermediary layer). Other variables are nodes in the input layer, while final classes result as neurons in the output layer (Freire *et al*., 2009). The topmost layer of neurones in Figure 3.4 is the input layer, which contains the set of neurones that receive external inputs (These external inputs are pixel values in the various bands of a multispectral image). The central layer is the hidden layer (It is possible to have more than one hidden layer in complex networks). The output layer produces classification results (Tso *et al*.,2009). The MLP training set in this analysis used customized specifications.

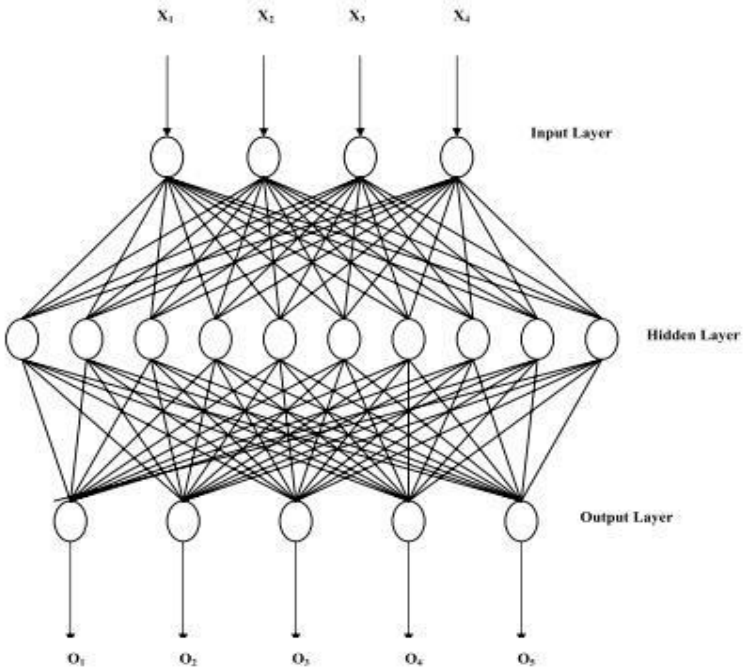

Figure 3.4 The structure of a three-layer MLP Neural Network (Source: Yuan *et al*, 2009).

3.6.1 Image Segmentation and Training

The image segmentation procedure generated a representation of the border where each pixel belonged to a cluster, which was displayed using different colors. The images for all the three years were then trained into four classes each. The training was done with the help of the ground training data and the unsupervised SOM map. An average of 200 pixels per class were used as training data for the year 2007, an average of 175 pixels per class for the year 2011 and 200 pixels per class for the year 2016 (Table 3.4). The trained pixels were then used to generate the supervised MLP maps.

Table 3.4 Parameters used for Supervised Classification (MLP)

Group	Parameter	Value Used

Input Specifications	Average training and testing pixels per class		2007	2011	2016
		Training	200	175	200
		Testing	200	175	200
Network Topology	Hidden Layers	Varied			
Training Parameters	Automatic Training	No			
	Dynamic Learning rate	Yes			
	End Learning rate	0.001			
	Momentum factor	0.5			
	Sigmoid constant "a"	1			
Stopping criteria	RMS	0.01			
	Iterations	100000			
	Accuracy	100%			

3.7 Normalized Difference Vegetation Index (NDVI)

This numerical indicator uses band 3 (visible red) and band 4 (near -infrared) of the electromagnetic spectrum to check whether there are traces of vegetation in the feature being observed. NDVI has assisted in vegetative studies because it has and is being used to analyze crop yields and performance of pasture among others (Anon, 2008). With values ranging from -1 to 1, negative values indicate clouds, snow, water and other non – vegetated areas, while positive values show vegetated areas or reflective surfaces (Winter, 2003).

Using the study area masks, NDVI maps were generated for each year using the red (band 3) and near infrared bands (band 4). Change maps were deduced by finding the difference between the initial year image and the final year image. The 2007 NDVI

image was deducted from the 2011 NDVI image, and the 2011 NDVI image from the 2016 NDVI image. Areas that had improved in terms of vegetative cover contained values greater than zero, while areas that had been disturbed or had decreased vegetative cover consisted of values less than zero.

3.8 Limitations of Research

Access to some of the small scale mining sites to gather ground truth data was a challenge. This was due to the concession lessees being uncomfortable with my presence. On some occasions, they threatened with physical assault although there were attempts to convince them that the purpose of the visit was for research purposes only.

CHAPTER 4 RESULTS

4.1 Introduction

This chapter presents the results of the research. Firstly, maps showing the extent of damage caused by small scale activities in the study area are shown. This is followed by maps showing the extent to which reclamation has been done in these areas.

4.2 Assessing the Extent of Damage Caused by Small – Scale Mining Activities in the Study Area Over Time

The maps for the years 2007, 2011 and 2016 (Figures 4.1, 4.2, 4.3) as well as statistical information displayed in the bar chart (Figure 4.4) indicate evidence of damage as a result of mining activities in the area.

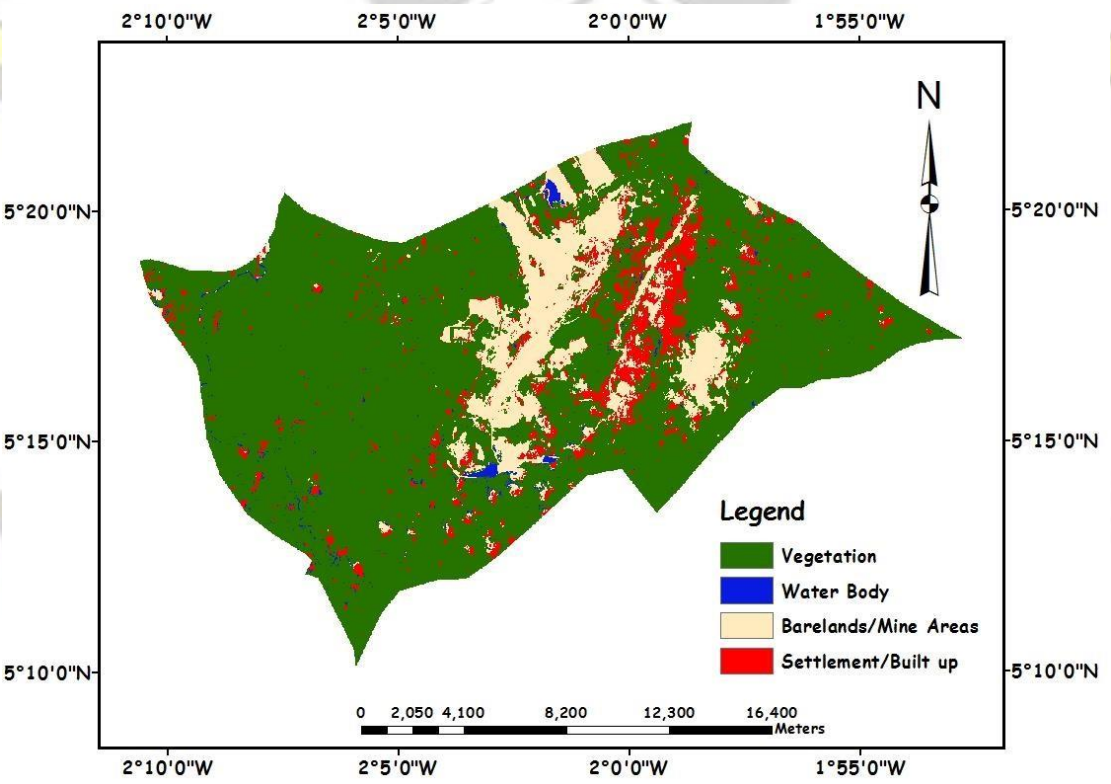

Figure 4.1 2007 MLP Image Map

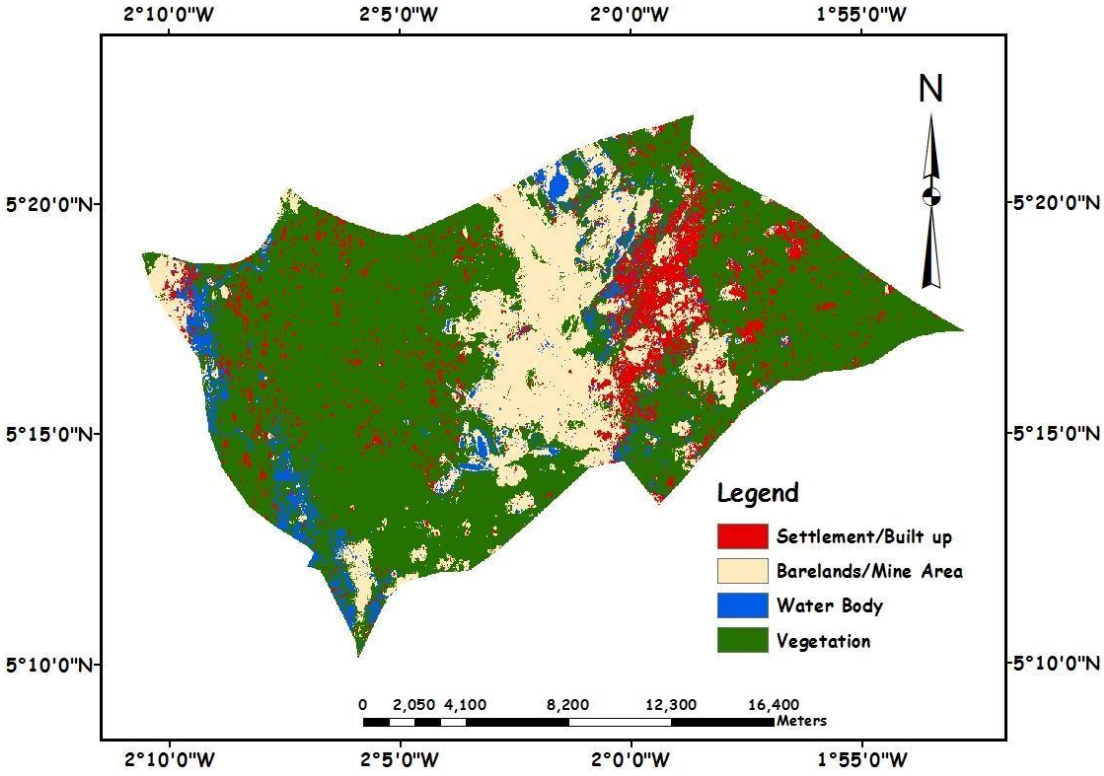

Figure 4.2 2011 MLP Image Map

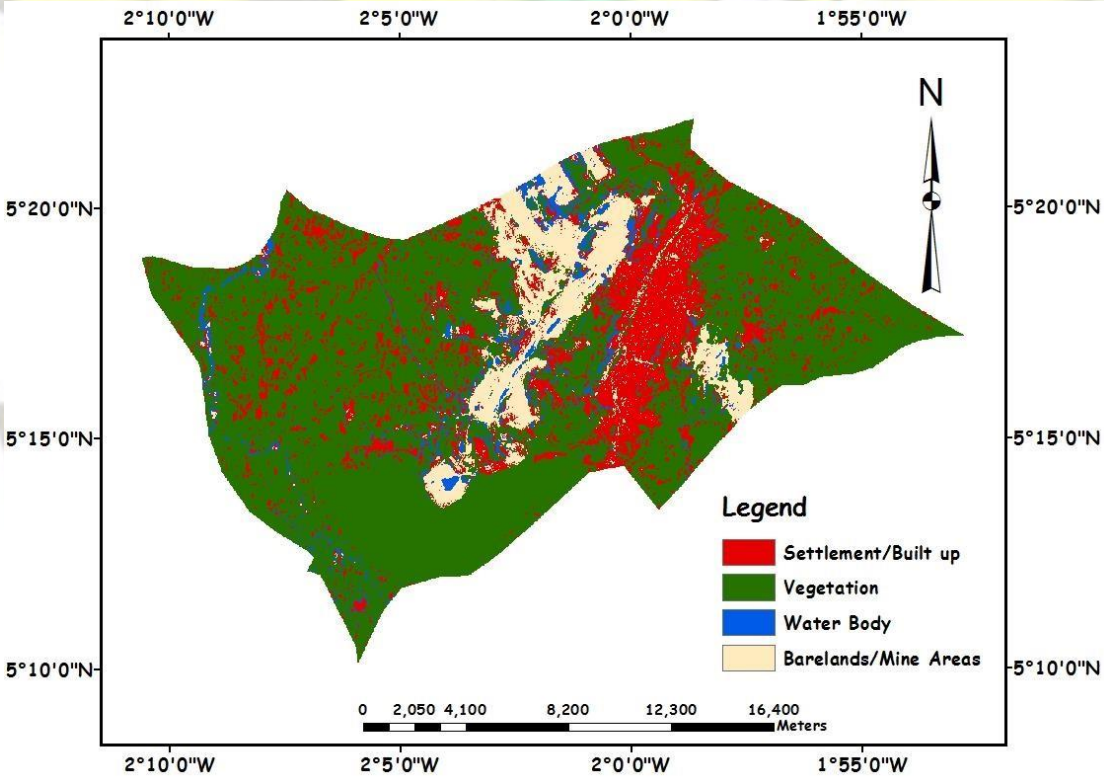

Figure 4.3 2016 MLP Image Map

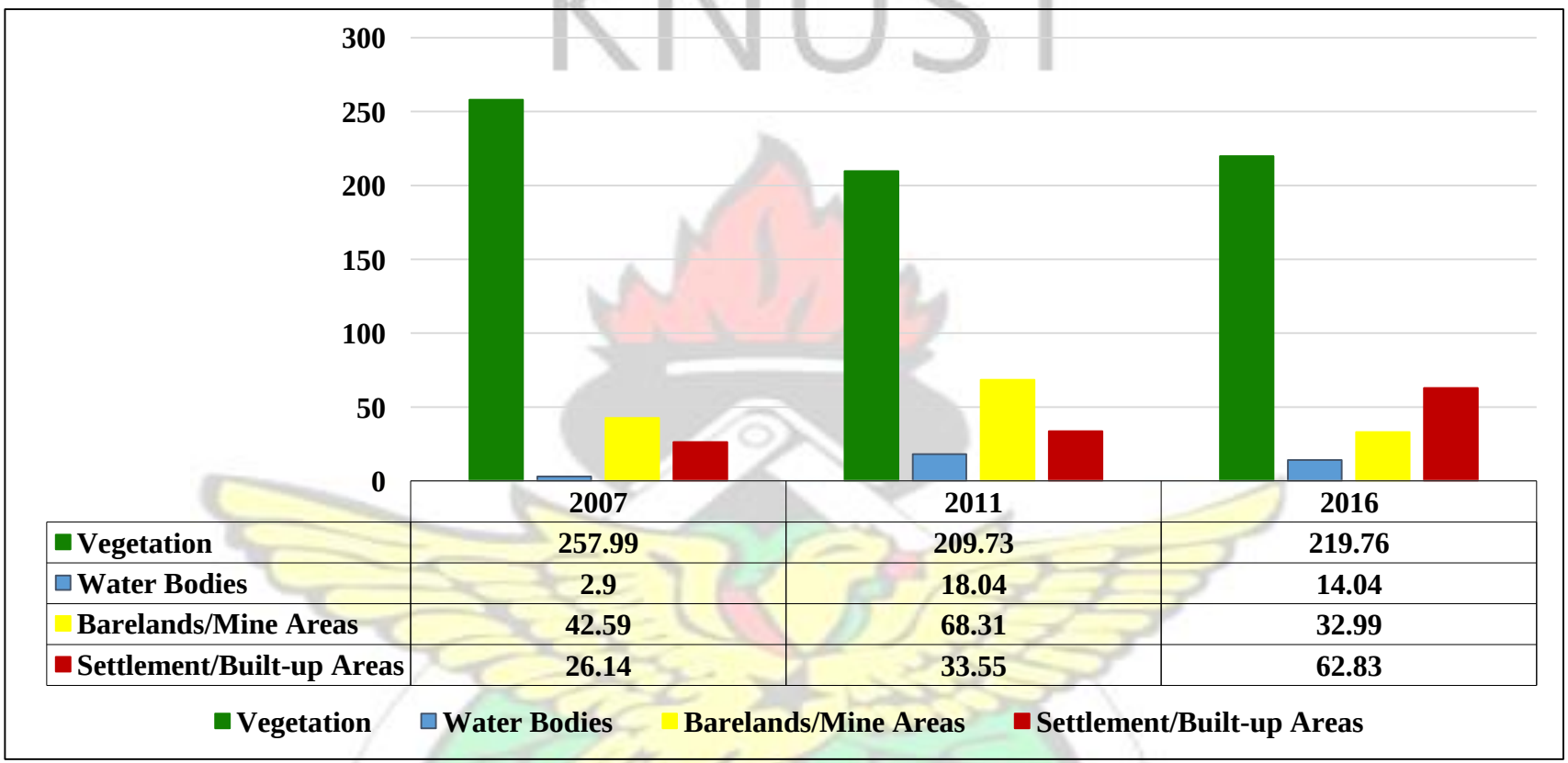

Figure 4.4 Bar Chart Showing Areas (Sq. Km) of LULC Classes for 2007, 2011 and 2016

Land Use/Land cover classification produced straight forward results. A visual comparison of the three images shows a sharp increase in mining activity from 2007 to 2011 and the evidence of reclamation from 2011 to 2016.

4.3 Assessing the Extent of Reclamation Activities in Small-scale Mining Areas

This analysis led to the identification of a number of changes. These included areas that had been disturbed by mining, areas previously disturbed by mining that were now revegetated, areas previously disturbed where vegetation had not recovered, and areas of no change (undisturbed areas). Maps showing the changes mentioned (Figures 4.5, 4.6), NDVI maps (Figures 4.7, 4.8, 4.9), NDVI change maps (Figures 4.10, 4.11) as well as statistical information displayed in the bar chart (Figure 4.12) show the extent to which the reclamation activities have gone. These changes are discussed further in Chapter 5.

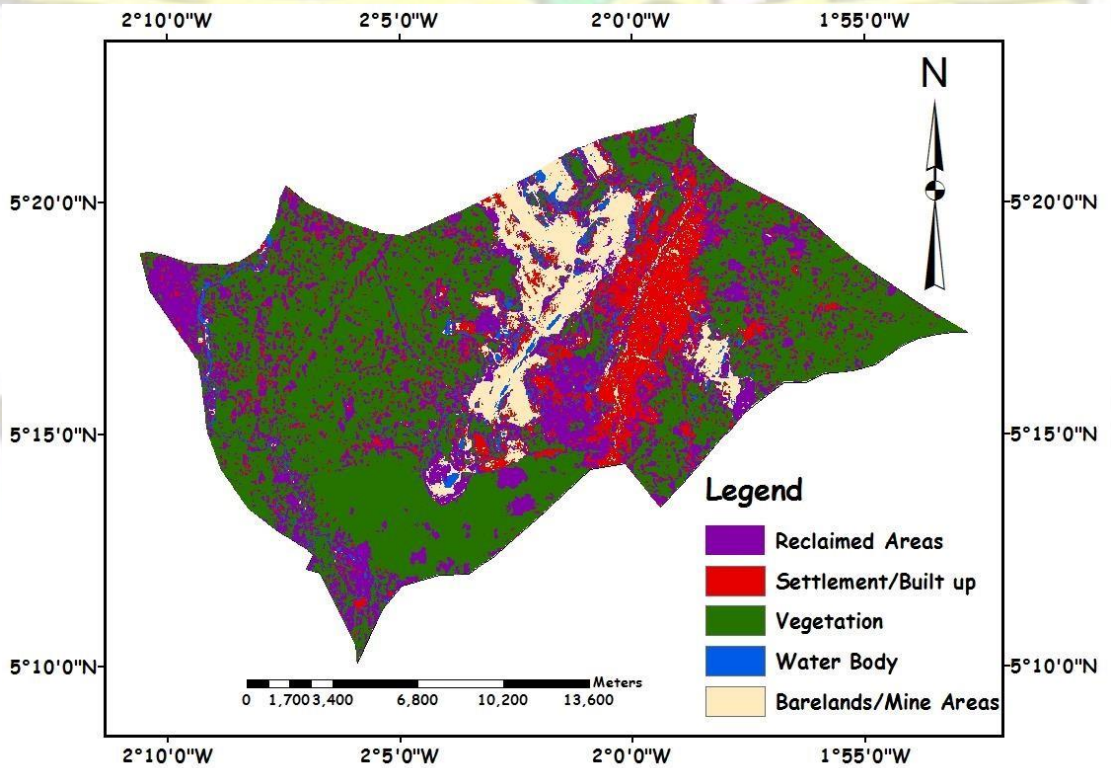

Figure 4.5 Map Showing Reclaimed Areas as of 2016

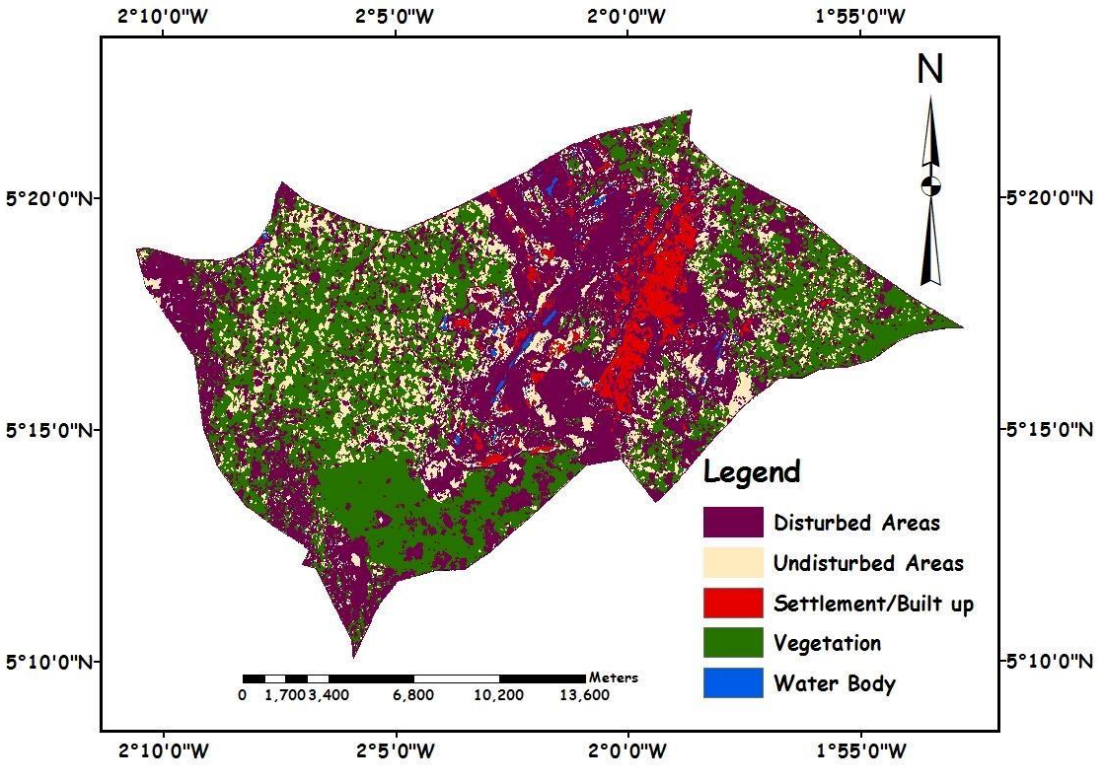

Figure 4.6 Disturbed and Undisturbed Areas as at 2016

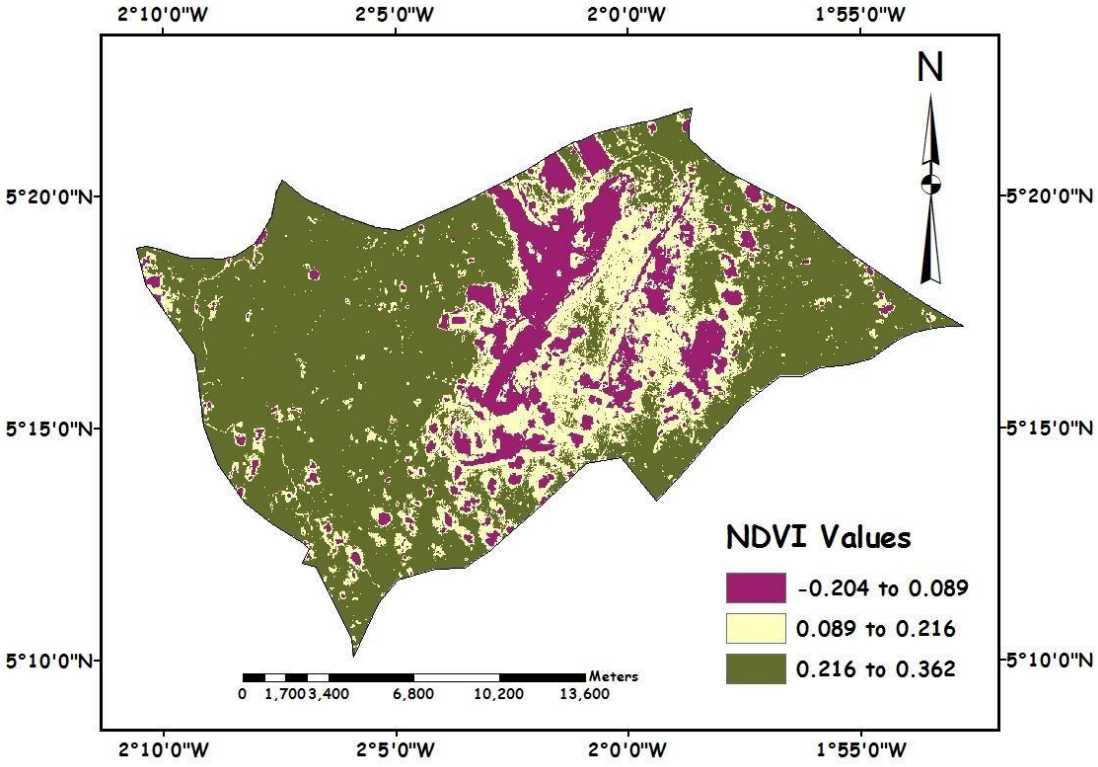

Figure 4.7 NDVI 2007

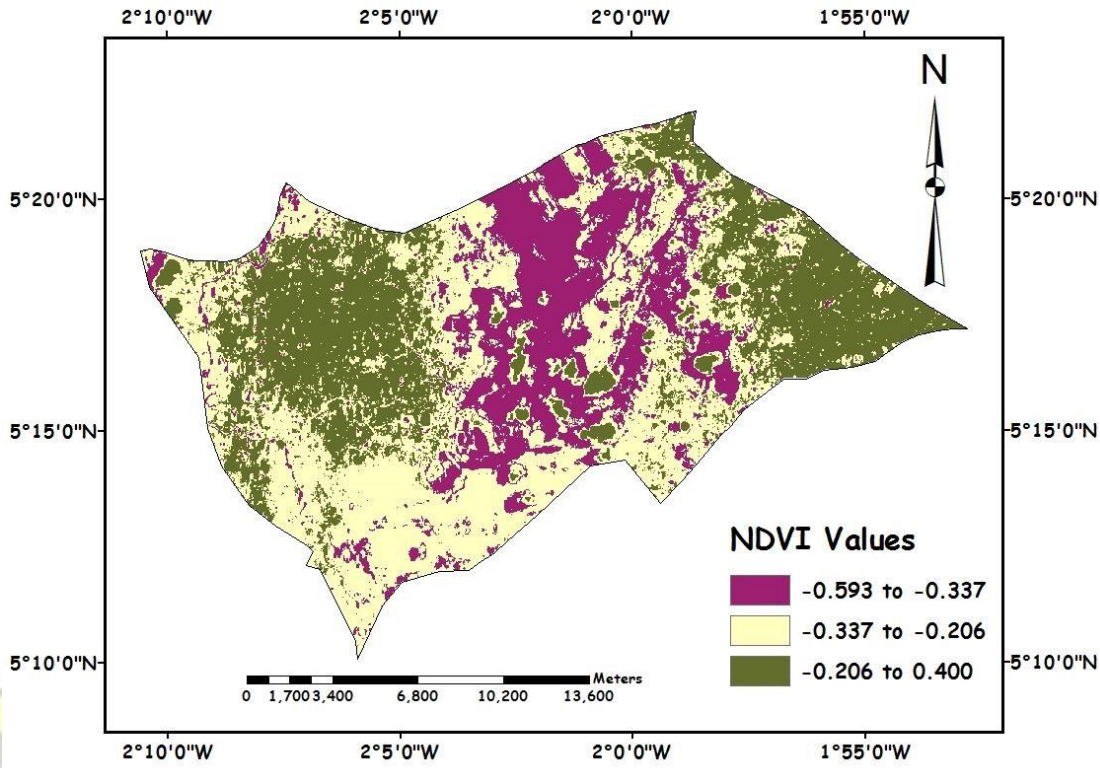

Figure 4.8 NDVI 2011

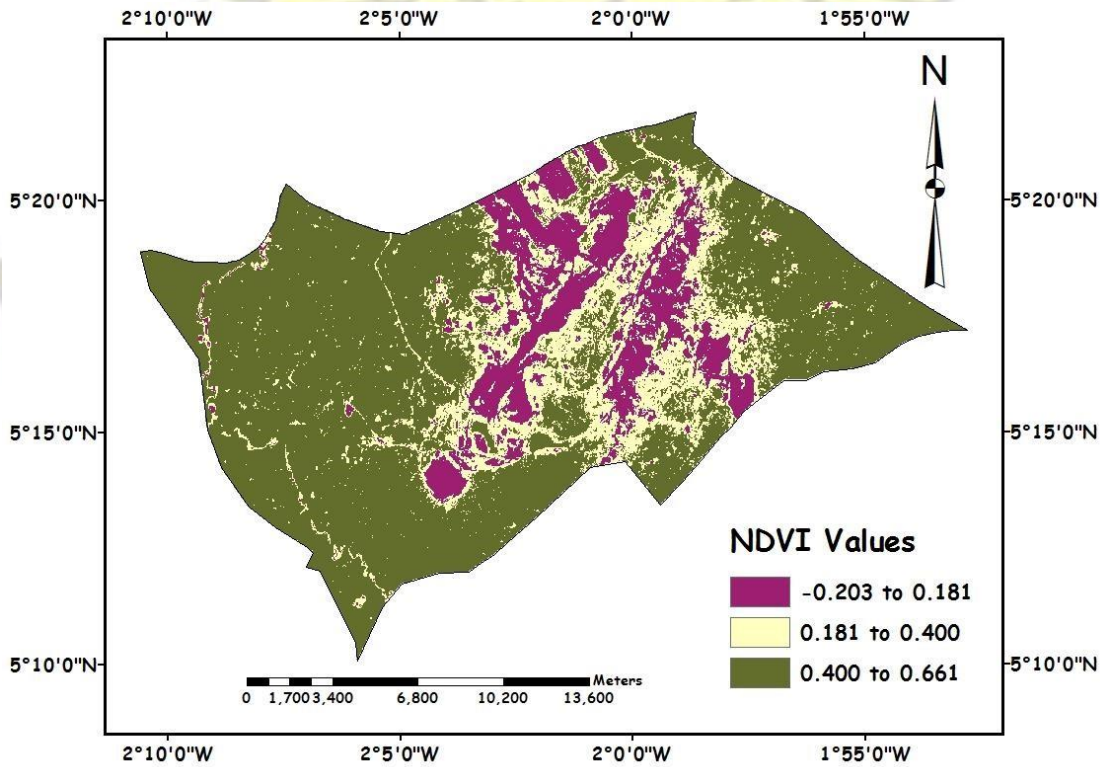

Figure 4.9 NDVI 2016

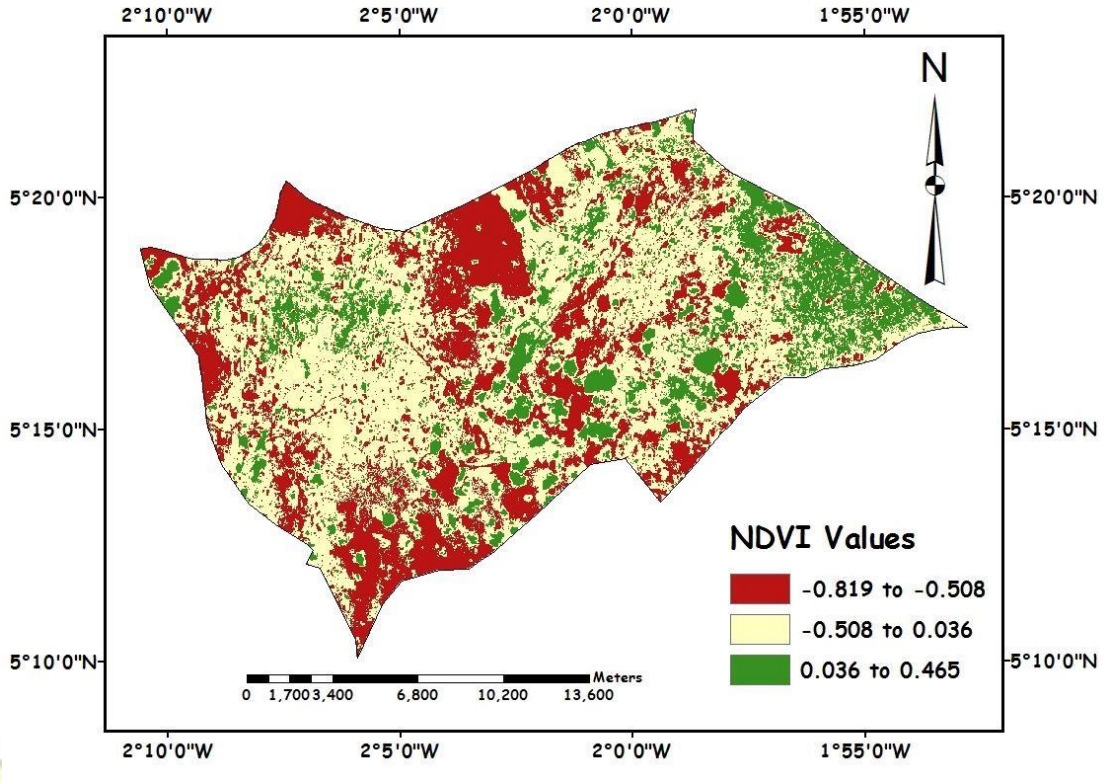

Figure 4.10 2007 – 2011 NDVI Change Map

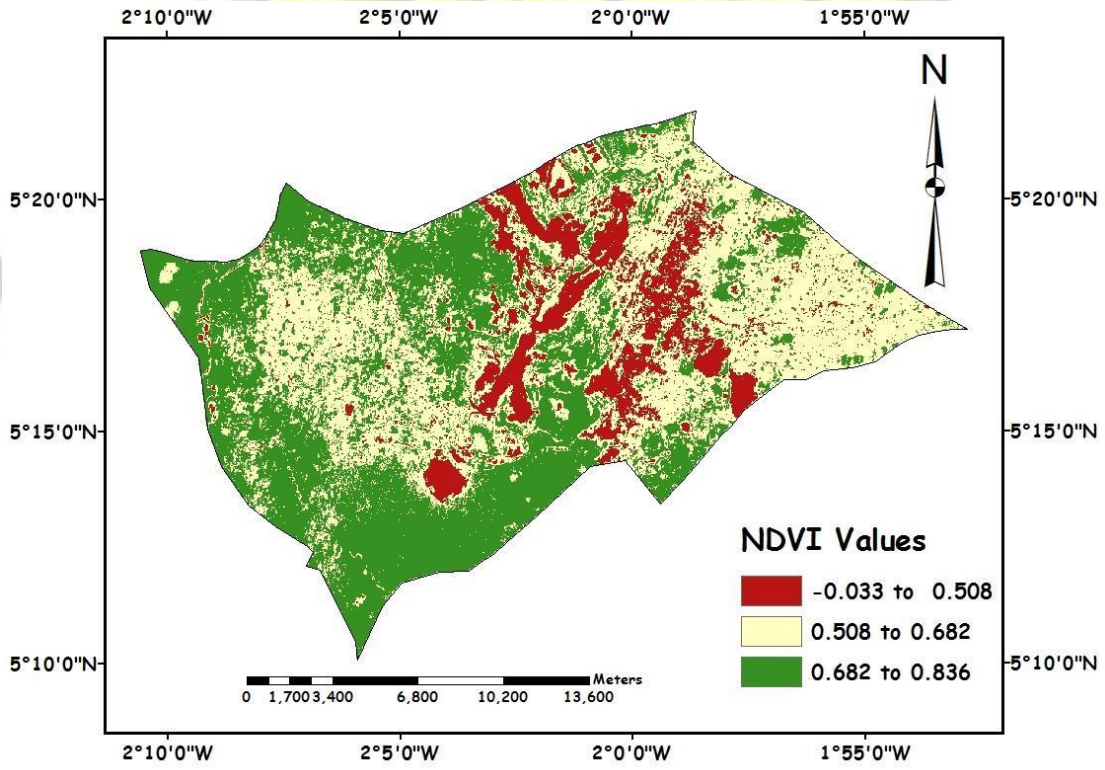

Figure 4.11 2011 – 2016 NDVI Change Map

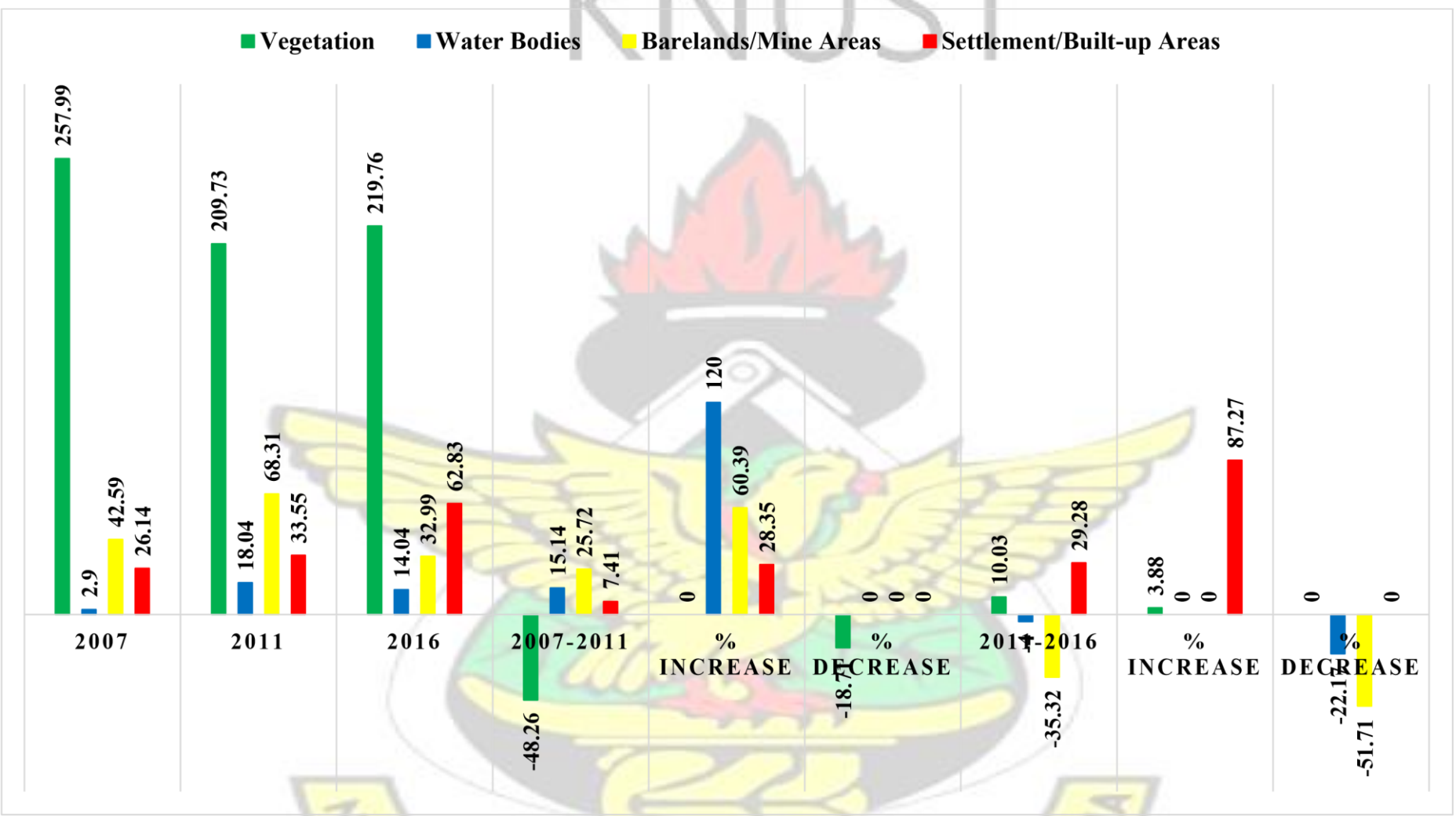

Figure 4.12 Land Use/Land Cover Change from 2007 to 2016

4.4 Accuracy Assessment

Table 4.1 shows the kappa and the overall accuracies for the years 2007, 2011 and 2016 and their error matrices respectively. Table 4.2 shows the error matrix for 2016. The error matrices for the years 2007 and 2011 can be found in Appendix 6.

Table 4.1 Overall Accuracy and Kappa Statistics of MLP Classifications

Year	Overall Accuracy	Kappa
2007	84.2 %	0.7070
2011	82.4 %	0.7004
2016	87.9 %	0.7898

Table 4.2 Error Matrix for 2016 from MLP Classification

		Reference Data					
		1	**2**	**3**	**4**	**Classified Totals**	**Users Accuracy**
MLP 2016	**1**	**11310**	644	359	2289	14602	**77.5 %**
	2	691	**47170**	3323	856	52040	**90.6 %**
	3	40	262	**3094**	484	3880	**79.7 %**
	4	605	41	483	**11287**	12416	**90.9 %**
	Reference Totals	12646	48117	7259	14916	**82938**	
	Producers Accuracy	**89.4 %**	**98.0 %**	**41.1 %**	**75.7 %**		
		Overall Accuracy: 72861/82938 = 87.9 %					

CHAPTER 5 DISCUSSIONS

5.1 Introduction

This research focused on the small-scale mining areas in Tarkwa and its environs. This region provides 50% of the gold mined in Ghana and will likely see an increase in mining activities over the next 15 years. Utilizing Landsat satellite images through the archives of the U.S.G.S. makes it possible to monitor small-scale mining and reclamation operations, and to characterize land use/land cover changes as a result of mining activities.

One of the reasons for this study was to monitor the extent of reclamation in small-scale mining areas using artificial neural networks. Landsat images for 2007, 2011 and 2016 were used for the analysis. These images were analyzed to detect disturbances caused by mining, identify reclaimed areas, and to detect land use/land cover change over the 9-year time period.

Results from the study indicate that artificial neural networks with the help of NDVI and class mask analysis are useful for monitoring disturbances from small-scale mining activities, and for monitoring the progression of reclamation activities in small-scale mining areas, as well as land use/land cover changes.

5.2 Land Use/Land Cover Analysis

The land use/land cover mapping was conducted in order to assess the damage caused and extent of reclamation activities in the small-scale mines within the study area (Figure 5.1).

The land use/land cover mapping was accomplished by applying the unsupervised Self organized mapping and supervised multilayer perceptron classification algorithms to composite bands of images of the three years. The classification scheme used for the land use/land cover mapping in this research can be referred to in Table 3.2.

Using these images, several land use/land cover changes are identified. The year 2011 was identified as that in which mining activities were most intense. Some of the areas changed from active small-scale mining sites to reclaimed areas, or to some form of vegetation. Other areas classified as reclaimed have reverted to vegetation since mining activities in the area have become less intensive.

In 2007, mining activities were less intense than in 2011. Between the two dates, the Barelands/Mine area class increased in size by 26 km^2 of land which indicates damage by mining activities. Between 2011 and 2016, the area covered by the Barelands/Mined Area category decreased. This was due to decreased mining in the area and increase in vegetation regeneration which proves that, reclamation activities were in progress.

Land use/Land cover maps which were produced from three different image dates were directly compared and were useful for visually assessing the change. A class mask of the 2011 Barelands/Mined Areas class compared to the 2007 land use/land cover classification (Figure 5.2) showed what land cover types were present in 2007 in areas that were being mined in 2011. This mask showed that most of the land that were converted to mines were previously classified under vegetation and settlements.

It can be deduced then, that the small-scale mining activities occurred mainly at the expense of vegetation and settlements. It can also be concluded that, inhabitants of the areas which were being mined moved out and settled at other places due to an increase in the settlement class by 87.3% from 2011 to 2016.

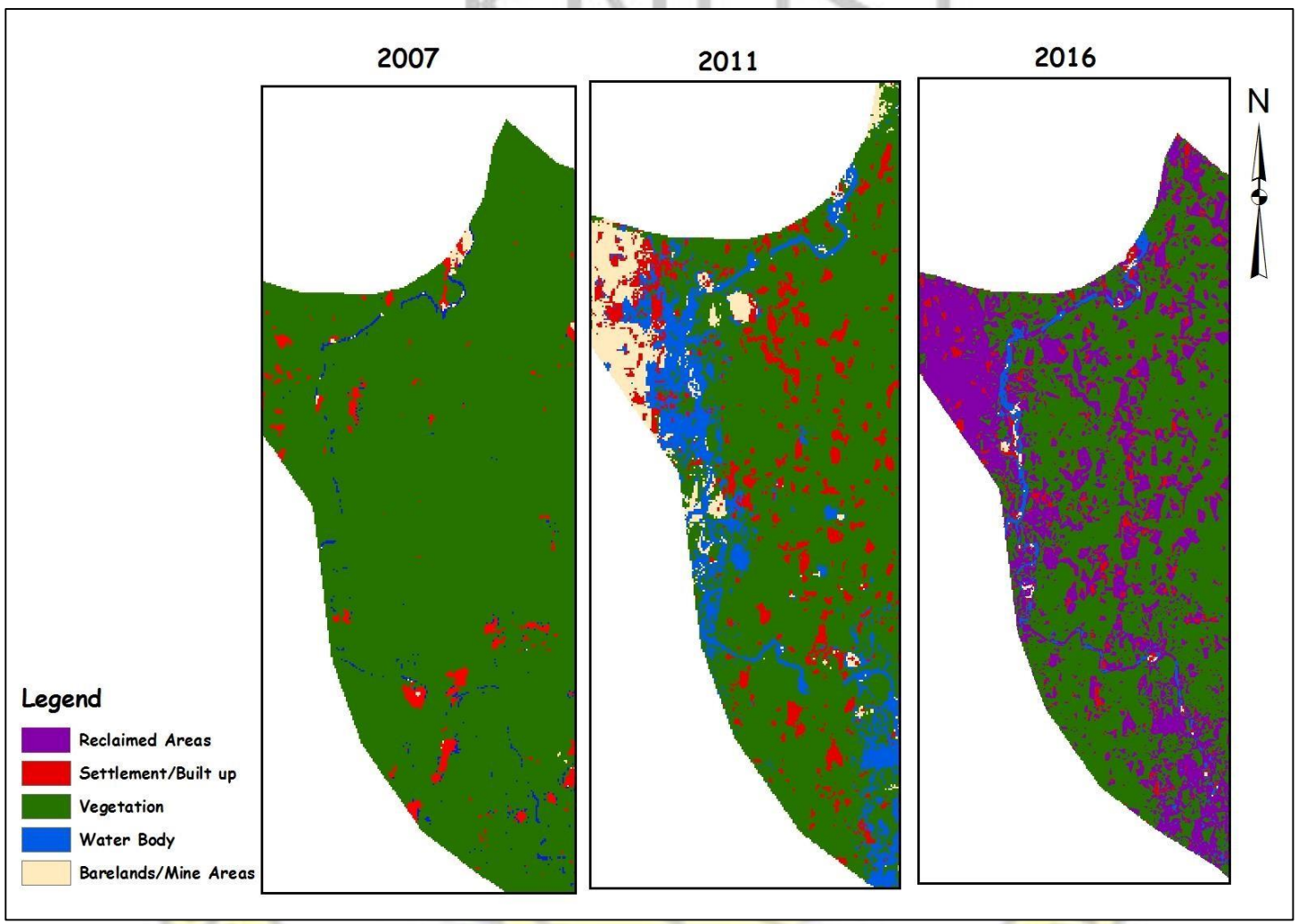

Figure 5.1 Land Use/Land Cover Characterization

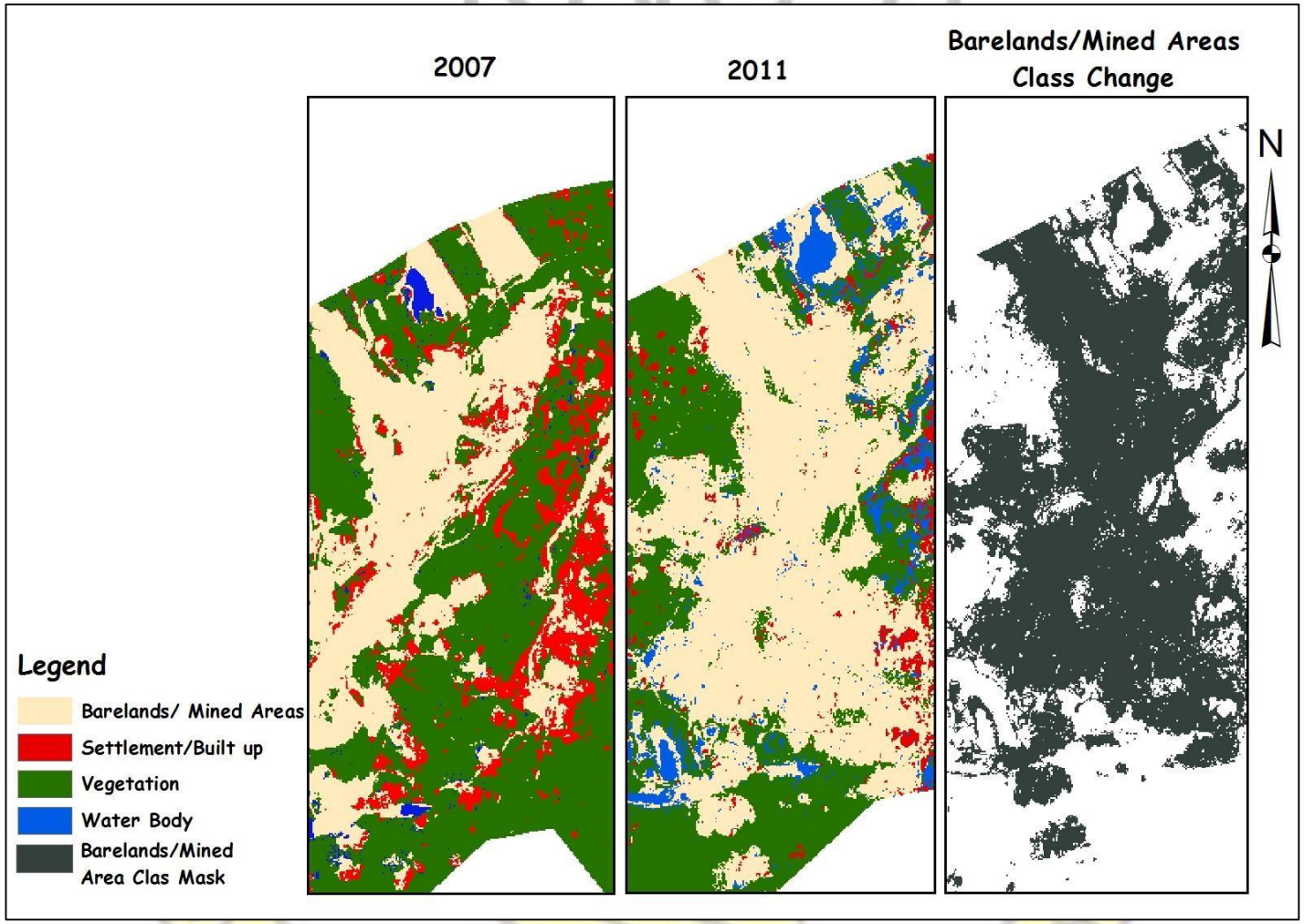

Figure 5.2 2007 _ 2011 Barelands/Mined Areas Change

5.3 NDVI Analysis

Mining areas were strongly associated with low NDVI values compared to the rest of the landscape i.e. -0.204 to 0.089 (2007), -0.593 to 0.337 (2011) and -0.203 to 0.181 (2016). A striking pattern of change can be seen across the area from 2007 through to 2016. Low NDVI values correspond to the purple colour and indicate areas where vegetation has been disturbed or removed.

Reclaimed or revegetated areas, and areas near the rivers and streams had the highest NDVI values. Areas undergoing active reclamation had higher values because more plants are grown in these places to compensate for plant species that have potentially low survival rate (Alden, 2009). Areas near water bodies had high NDVI values (0.400 to 0.661 in 2016) because trees grew more densely in these areas.

Change maps obtained by subtracting the NDVI image of one year from that of another year were very useful in the identification of disturbed, undisturbed and reclaimed areas. In the change map created by subtracting the 2011 image from the 2016 image, disturbed areas had the lowest values (-0.033 to 0.508) while reclaimed areas had the highest (0.682 to 0.836) (Figure 4.11). Vegetation that had not been altered between image dates comprised of the values that fall between those of disturbed and reclaimed areas (Figure 5.3).

NDVI analysis was used to monitor the progress of reclamation activities in small-scale mining areas. NDVI values on a regular basis relative to the surrounding area gave an idea of the success of reclamation activities. NDVI image differencing was used to track the success of reclamation on a long term basis and was important for delineating areas where reclamation may be failing or where vegetation may be disturbed (Figures 4.10 and 4.11).

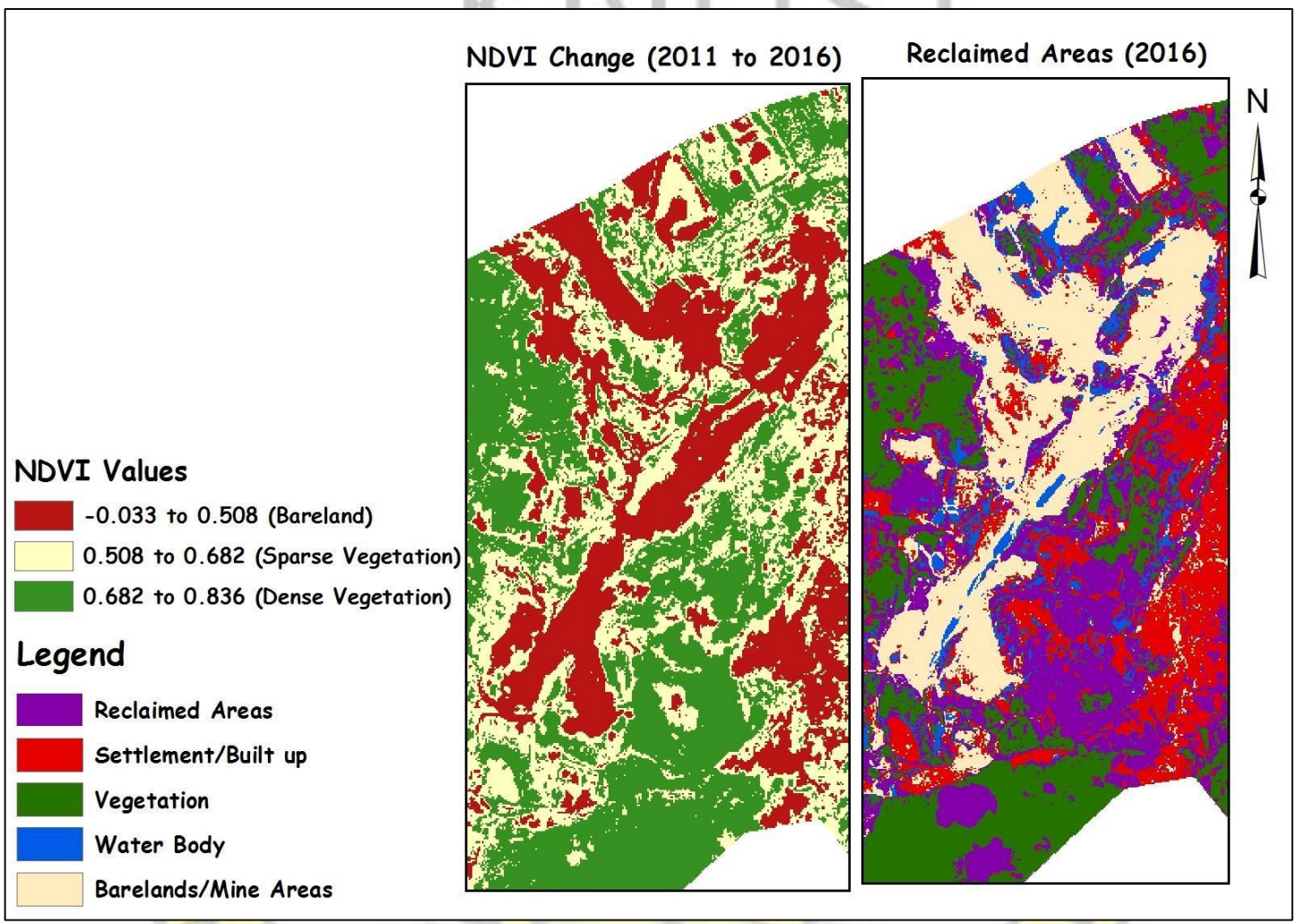

Figure 5.3 NDVI Change (2011 - 2016) and Reclamation as of 2016

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

This chapter concludes this research with respect to the research objectives and recommends the use of ANN for image classification and reclamation monitoring.

6.1 Conclusions

Objective 1: To assess the extent of damage caused by mining activities in the small-scale mining areas over time

The research was able to assess the extent of damage caused in the study area over time by analyzing maps obtained from the use of ANN, backed with statistical information. Visual observation of the three images indicated a sharp increase in mining activities from 2007 to 2011. The Barelands/mined areas class increased by 60.4% while the vegetation decreased by 18.7% during the same time period.

The overall kappa and other accuracies obtained from the ANN classifications in this research have proven it to be a more accurate classification method compared to other traditional classification methods due to factors such as the size and quality of training data, network architecture, and training parameters.

Objective 2: To assess the extent of reclamation in these areas if any

The extent of reclamation in the study area was confirmed by identifying a number of changes in the study area such as areas disturbed by mining, reclaimed areas, areas disturbed by mining which had not yet been reclaimed and undisturbed areas. These changes were depicted by maps obtained through ANN classification with the help of statistical information, NDVI and class mask analysis. Low NDVI values corresponded to areas where vegetation had been disturbed or removed whereas high NDVI values corresponded to areas where there was vegetation or reclamation. The NDVI analysis also showed that areas undergoing reclamation had higher values because they are often heavily seeded to make up for plant species that have low survival rate. A class mask

analysis run on 2011 Barelands/Mined Areas class compared to the 2007 land use/land cover classification showed that most of the land that were converted to mines were previously classified under vegetation and settlements. There was evidence of revegetation from 2011 to 2016 with the Barelands/Mined Area class decreasing by 51.7%, the vegetation class increasing by 3.9% and an increase in the settlement class by 87.3% hence concluding that:

- Small-scale mining activities were done mainly at the expense of land under vegetation cover and settlements.
- Inhabitants of the areas which were being mined left and resettled at other places.

6.2 Recommendations

The analysis, results and conclusions made from this research led to the following recommendations:

1. Artificial Neural Networks should be encouraged and be used more for image classification in general and reclamation monitoring in particular due to the size and quality of training data, network architecture, and training parameters as well as the ability to improve the accuracy and fine tune information obtained from individual classes as compared to other classification methods.
2. Even though high resolution remote sensing datasets are expensive, they should be incorporated more in image classification for the monitoring of mined areas. This is because it is easy to generate land use/land cover and change maps from them for a better appreciation of the environmental condition at any given time.

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APPENDIX

Appendix 1 MAJOR PROVISIONS OF MINERAL AND MINING LAW PNDCL 153

A. ACQUISTION OF MINERAL RIGHTS

1. A reconnaissance license, which is for a year and renewable for an another year.
2. A prospecting license may be granted for an area of 150 kilometers not more than 3 years, with possibility of further renewals of up to 2 years, though there are relinquishment of obligations at each renewal. The holder of a prospecting license is entitled to a mining lease upon the presentation of an acceptable feasibility study which incorporates environmental impact studies.
3. A mining lease may be granted for a period of 30 years and may be renewed for a further 30-year period, for an area not exceeding 50 square kilometers.

B. SMALL SCALE MINING LAW

The main provisions include:

1. The prohibition of small-scale gold mining unless a license has been granted by the Minister.
2. The size of the concession.
3. Criteria applicable to license holders
4. The establishment of District Small-scale Centres to provide advice and training facilities to make sure of effective and efficient mining operations, including health, safety and environmental aspects.
5. Prohibition of the use of explosives.
6. Exemption from payment of income tax and royalties for a 3-year period, the encouragement of the use of mercury retort, the limiting of sale of gold only to authorized buyers.

Appendix 2 FORESTRY RECLAMATION APPROACH

1. Create a suitable rooting medium for good tree growth that is no less than four feet deep and made of topsoil, weathered sandstone, and/or the best available material.
2. Loosely grade the topsoil or topsoil substitute established in step one to create a non-compacted growth medium.
3. Use groundcovers that are compatible with growing trees.
4. Plant two types (or more) of trees: early successional species for wildlife and soil stability, then commercially valuable crop trees.
5. Use proper tree planting techniques.

Appendix 3

HOLISTIC APPROACH

1. Grade the best available material to the required topography, establishing key lines.
2. Sow the native species of early successional species of plants and grasses.
3. Cover the area with a loose layer of hay mulch to provide the initial "jump start" of forage required for the livestock.
4. Using your key lines as a guide, establish paddocks and implement Holistic planned grazing techniques to heal the land.
5. If the goal is to establish a wildlife area or natural park, as the keystone species begin returning (a process called ecological succession) or are introduced in large enough numbers, livestock can be reduced or eliminated.

Appendix 4 GENERAL MINE RECLAMATION GUIDELINES PREPARED BY THE EPA DESCRIBING HOW MINING ACTIVITIES CAN BE CARRIED OUT IN AN ENVIRONMENTALLY RESPONSIBLE MANNER

- The company shall prepare an initial Reclamation Plan as part of the EIA and Environmental Action Plan (EAP) and execute the plan to achieve the following minimum standards:
    - The reclamation objective for restorable land will be to chemically and physically stabilize the land and leave it in a safe condition and return it to the same land capability as prior to mining.
    - The reclamation objective for non-restorable land will be to chemically and physically stabilize the land and leave it in a safe condition and encourage revegetation.
- The Reclamation Plan shall encompass all land on the concession to be disturbed by the company and any of its tributers.
- The Reclamation Plan shall:
    - Identify land which is restorable (such as the tops of waste dumps and land used for stockpiles) and land which is non-restorable (such as deep open pits and the steep outer faces of waste dumps). o Identify the quantities of reclamation media required.
    - Identify the sources of reclamation media to meet the required quantities.
    - Identify applicable reclamation techniques.
    - Develop a planned approach to progressive reclamation as an integral part of the mine plan.
    - Commence reclamation as soon as possible after the commencement of operations.
    - Where practicable, undertake reclamation trials to refine techniques.
- A final (formalized) reclamation plan shall be developed within the first two years of operation and submitted to the Environmental Protection Council (EPC), Inspectorate Division of Minerals Commission. In the case of a mine located in a forest/wildlife reserve(s) a copy of the reclamation plan shall be submitted to the Forestry Commission.

- A final reclamation plan shall be developed within the last five years of mining operations planned ceasure.
- The company shall honour all commitments made in the reclamation plan except where written permission is given by EPC in the light of new field evidence.
- Government reserves the right to request companies to post reclamation bonds.

Appendix 5

RECLAMATION SECURITY AGREEMENT

(*GENERIC*)

BETWEEN

THE ENVIRONMENTAL PROTECTION AGENCY OF THE REPUBLIC OF GHANA

AND

……..

(NAME OF COMPANY)

THIS RECLAMATION SECURITY AGREEMENT

Is made on ……. 2000 between the following parties:

1. Name and Address of the company

   …….

   …….

   …….

2. **The Environmental Protection Agency Of P. O. Box M326, Ministries Post Office, Accra Ghana Acting by its Executive Director (EPA)**

Recitals

A. The Government of the Republic of Ghana (Government) has granted the Company the Mining Lease. The Company operates the Mine on the land subject to the Mining Lease (Mining Lease Land).
B. The Company is obliged to provide the security to the EPA, as security for the performance by the Company of its obligations in relation to the reclamation of the Mining Lease Land, which has been disturbed by the Company.
C. The parties have agreed that the Security will be provided to the EPA on, and subject to, the terms of this agreement.

The parties agree

In consideration of, among other things, the mutual promises contained in this agreement:

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1. Definitions and Interpretation

1.1 Definitions

In this agreement:

Acid Rock Drainage (ARD) is defined as the generation of sulphuric acid from the weathering of sulphidic rock material with the subsequent percolation of leachate which enhances solubility of metals.

Amended Foreign Exchange Retention Account Agreement means the agreement entitled: "Amended Foreign Exchange Retention Account Agreement" dated

…… between the Company, the Bank of Ghana, the Government……. (Company's Bankers).

Annual Environmental Report means the annual environmental report to be provided by the company to the EPA under regulation 25 of the Environmental Assessment Regulations;

Bank Guarantee means a bank guarantee described in clause 9; (can also be irrevocable letter of credit, performance bond, insurance)

Merchant Bank means Merchant Bank of Ghana Ltd., Address;

Cash Deposit means cash deposit described in clause 10;

Cost Estimate means the estimate of costs (set out in schedule 1) involved in performing the work described in the Reclamation Plan;

Days means Working Days;

Disturbed Land means Mining Lease Land which has been directly disturbed by the company since the commencement of the Mining Lease as described in the Reclamation Plan;

Environmental Assessment Regulations means the Environmental Assessment Regulations 1999, LI 1652 made under the Environmental Protection Agency Act 1994 (Act 490);

Environmental Certificate means the Environmental Certificate form EPA under regulation 22 of the Environmental Assessment Regulations;

Environmental Permit means the environmental permit date ……. Provided by the EPA to the Company in respect to the Mine;
Final Completion means the satisfaction of the criteria set out in part 2 schedule 2 over a period of three years commencing on the date on which Land Use Completion is first achieved;

Force Majeure has the meaning given to that term in clause 12.1(b);

Land Use Completion means the satisfaction of the criteria set out in part 2 of schedule 2 as applied in relation to the relevant Tract of the Disturbed Land;

Mine means the …… operated by the Company on the Mining Lease Land;

Mining Lease means Mining Lease dated ……. granted by the Government to the Company;

Primary Completion means the satisfaction of the criteria set out in part 1 schedule 2 as applied in relation to the relevant Tract of the Disturbed Land;

Reclamation Plan means the reclamation plan dated ……delivered by the Company to the EPA under the **Environmental Permit** and which will be subject to annual review.

Security means:

(a) The Bank Guarantee
(b) The Cash Deposit

Tract of the Disturbed Land means each tract described in the Reclamation Plan including: (Ref Schedule 1)

1.2 Interpretation

In this agreement, headings and boldings are for convenience only and do not affect the interpretation of this agreement and, unless the context otherwise requires:

(a) Words importing the singular include the plural and vice versa
(b) Words importing a gender include any gender
(c) An expression importing a natural person includes any company, partnership, joint venture, association, corporation or other corporate bodies and any governmental agency;
(d) The word "including" when introducing an example or list of examples of a general proposition, does not limit the meaning or ambit of the general proposition to the example or the list of examples or at all;
(e) A reference to a clause, party, annexure, exhibit or a schedule is a reference to a clause of, and a party, annexure, exhibit and schedule;
(f) A reference to a statute, regulation, proclamation, ordinance or by-law includes all statutes, regulations, proclamations, ordinances or by-laws amending,

consolidating or replacing it, and a reference to a statute includes all regulations, proclamations, ordinances and by-laws issued under that statute;

(g) A reference to a document includes all amendments or supplements to, or replacements or innovations of, that document

(h) A reference to a party or any document includes that party's successors and permitted assigns;

(i) Provisions of this agreement will be construed adversely to a party solely on the ground that the party was responsible for the preparation of this agreement or that provision; and

(j) A reference to a body, other than a party to this agreement (including, without limitation, an institute, association or authority), whether statutory or not:

a. Which ceases to exist; or

b. Whose powers or functions are transformed to another body

It is a reference to the body which replaces it or which substantially succeeds to its powers or functions.

1.3 Application of Agreement

This agreement applies to only Disturbed Land

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2. Conditions Precedent

Prior to the Company Providing the initial security to the government all of the following steps will be completed:

(a) Written approval from the EPA of the Reclamation Plan and the Cost Estimate dated …… Including, in the case of the Reclamation Plan, confirmation that the Reclamation Plan constitutes an "approved work plan" for the purposes of regulation 23 of the Environmental Assessment Regulations;

(b) Execution of this agreement and any stamping and registration required which must be borne by the Company.

3. Annual Environmental Report

(a) Regulation 25(1) of the Environmental Assessment Regulations requires the Company to submit an annual Environmental Report to the EPA.

(b) The Annual Environmental Report will contain a completion progress report (**Completion Progress Report**), which specifies any work performed in relation to a Tract of the Disturbed Land and the level of reclamation the Company believes has been achieved (primary Completion, Land Use Completion or Final Completion) in relation to the Tract of the Disturbed Land. **4. Provision and Amount of Security**

(a) The amount of the Security is to be equal to the total Cost Estimate, as reduced under clause 5

(b) The Company will provide the Cash Deposit to the Government on or before execution of this agreement and will establish the Bank Guarantee within 60 days after the date on which the conditions precedent set out in clause 2 have been satisfied by the Government or waived by the Company.

(c) The initial Security will be, in aggregate, an amount of US$..... which will be made up as follows:

a. A bank Guarantee in aggregate amount of US$ ……. and
b. A cash Deposit in aggregate amount of US$.....

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5 Reduction of Security

5.1 Money spent by the Company

The amount of the Security will be reduced in accordance with this clause 5.

5.2 Completion Progress Report

(a) The EPA will be review the Completion Progress Report (which forms part of the Annual Environmental Report) during the 45-days period (**Completion Review Period**) following receipt of the Annual Environmental Report.

(b) For the purposes of reviewing the Completion Progress Report, the EPA may inspect the Mine site during the Completion Review Period.

(c) If by 45 days after the end of the Completion Review Period, the Company has not received an approval or rejection of the Completion Progress Report (in the form described in clause 5.2(d)), the EPA will be deemed to have approved the Completion Progress Report.

(d) Any rejection of the Completion Progress Report must:

a. Be received by the Company within 45 days after the Completion Review Period;

b. Be in writing; and

c. Provide detailed reasons why the Completion Progress Report was not approved, including identifying which, and the reasons why, Tracts of the Disturbed Land did not satisfy the relevant completion criteria.

(e) If the Company receives a rejection of the Final Completion Report, it may agree to EPA's assessment and undertake necessary remedial measures or commence the dispute resolution procedures set out in clause 11 by giving notice to the EPA that it wishes to resolve the matter under clause 11 of this agreement.

5.3 Amount of Reduction

If either Primary Completion, Land Use Completion or Final Completion has been achieved in respect of Tract of the Disturbed Land, the amount of the Security reduction will be calculated as follows:

(a) If Primary Completion has been achieved in respect of any Tract of the Disturbed Land, the Security will be reduced to an amount which is 30% of the Cost Estimate in relation to that Tract of the Disturbed Land;

(b) If Land Use Completion has been achieved in respect of any Tract of the Disturbed Land, the security will be reduced to an amount which is 20% of the Cost Estimate in relation to that Tract of the Disturbed Land; and

(c) If Final Completion has been achieved in respect of any Tract of the Disturbed Land, the security will be reduced to zero in relation to that Tract of the Disturbed Land.

5.4 Bank Guarantee reduced first

As part of any reduction of the Security under this clause 5, the amount of the Cash Deposit will not be reduced until the amount of the Bank Guarantee has been reduced to zero.

5.5 Reduction Procedure

If the Security is to be reduced, the EPA will, within 60 days of the approval of the Completion Progress Report, do all things necessary to effect the reduction, including:

(a) In the case of a reduction to the Bank Guarantee, exchanging the existing Bank Guarantee for a new Bank Guarantee for the revised amount or otherwise authorizing the Bank to reduce the Bank Guarantee; and

(b) In the case of a reduction to the Cash Deposit; authorizing a payment by Merchant Bank from the Cash Deposit account to the Company

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6 Final Completion

6.1 Certificate of Final Completion

(a) On completion of the work to reclaim the whole of the Disturbed Land, the Company will apply to the EPA for a certificate of Final Completion.

(b) The EPA will review the application the application to it under clause 6.1(a) during the 90-day period (**Final Review Period**) following receipt of the application.

(c) For the purposes of reviewing the application, the EPA shall inspect the Mine Site during the final review Period.

(d) If by the end of 45 days after the Final Review Period, the Company has not received a certificate of Final Completion or a rejection of the application (in the form described in clause 6.1 (e)), Final Completion will be deemed to have occurred.

(e) Any rejection of an application for a certificate of Final Completion must:

1. Be received by the Company within 45 days after the Final Review Period;
2. Be in writing:
3. Provide detailed reasons why the certificate of Final Completion was not approved, including identifying which, and the reasons why, Tracts of the Disturbed Land did not achieve Final Completion.

(f) If the Company receives a rejection in accordance with clause 6.1(e), it may agree to EPA assessment and undertake necessary remedial measures to commence dispute resolution procedures set out in clause 11 by giving notice to the EPA that it wishes to resolve the matter under clause 11 of this agreement.

6.2 Release of Company

(a) On and from the date Final Completion is achieved, the Company will be released from all environmental responsibilities, obligations and liability in relation to the Mining Lease Land or the relevant Tract of the Disturbed Land with the exception that the Company will leave the Cash Deposit in place for an additional three years after the Final Completion is achieved; provided that there is no Acid Rock Drainage occurrence.

(b) In the event of Acid Rock Drainage, the Company shall be required to provide the necessary remedial measures.

6.3 Maximum Liability

(a) In the case of default on the terms of clause 8.1, the amount of the Company's total liability for the reclamation of the Disturbed Land to the level of Final Completion shall not exceed the total of the security held at the time.

(b) If the total cost of achieving Final Completion of a particular area of Disturbed Land exceeds the estimate in the reclamation plan, then the Company shall bear all costs incurred in excess of the estimate stated in the Reclamation Plan for completing the said tract of land.

7 Release of Security

7.1 Release of Final Completion

(a) Except as noted in clause 6.2, EPA shall release the security within 45 days from the date Final Completion is achieved under clause 6.

(b) EPA will do all things necessary to effect the release of Security under clause 7.1(a).

1. In the case of Bank Guarantee, providing the Bank Guarantee to the Company or otherwise authorizing the Bank to cancel the Bank Guarantee; and
2. In the case of the Cash Deposit, 45 days following the third anniversary of the date of achieving Final Completion, authorizing a payment by Merchant Bank of the balance of the Cash Deposit to the Company.

8 Security Claim

8.1 Circumstance in which Security may be claimed

EPA may not make a claim under the Security unless:

(a) The company becomes insolvent or enters into any agreement or composition with its creditors or takes advantage of any law for the benefit of debtors or takes advantage of any law for the benefit of debtors or goes in to liquidation, whether compulsory or voluntary, except for the purpose of reconstruction or amalgamation;

(b) Final Completion for the whole of the Disturbed Land is not achieved by the latest projected date in the current Reclamation Plan and the Company is not continuing in good faith towards achieving Final Completion, except where the failure either to achieve Final Completion by the latest projected date or to continue reclamation work is caused by any delay, interruption, loss or damage occasioned by Force Majeure.

8.2 Notice

If EPA intends to make a claim under the Security, it must give written notice to the Company not less than 90 days before it intends making the claim. If the company disputes EPA's claim, it may commence dispute resolution procedures set out in clause 11 by giving notice to EPA that it wishes to resolve the matter under clause 11 of this agreement.

8.3 Amount of Claim

EPA may only claim, in relation to any Tract of the Disturbed Land, an amount which equals the Cost Estimate allocation to that Tract of the Disturbed Land which is necessary to reclaim that Tract of the Disturbed Land to the level of Final Completion.

8.4 Company's rights to continue

A claim by EPA of the whole or part of the Security will not:

(a) Preclude the Company from continuing its operations at the Mine; or
(b) Revoke the Environmental Permit or other permits issued by the EPA

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9 Bank Guarantee

9.1 Bank

Any Bank Guarantee forming part of the Security will be provided by (company's bankers) ……. Which has a Standard & Poor's credit rating of at least AA (Bank) subject to approval by EPA.

9.2 Multiple Bank Guarantees

The Bank Guarantee may be made up of multiple individual Bank Guarantees with an aggregate amount of not less than the amount of the Security to be satisfied by Bank Guarantee.

9.3 Form of Bank Guarantee

Subject to any requirements of the Bank, the Bank Guarantee will be in a form substantially similar to the form set out in schedule 3.

9.4 Substitution of Bank

(a) The Company may subject to approval by EPA substitute a Bank Guarantee provided by one bank with a Bank Guarantee provided by another Bank if the terms of the Substitute Bank Guarantee are (substantially) the same as those of the first bank Guarantee

(b) If the Company elects to substitute a Bank Guarantee provided by one Bank with a Bank Guarantee provided by another Bank, it will give EPA 45 days written notice of the proposed substitution.

(c) On the date of proposed substitution, EPA shall provide the Company with the first Bank Guarantee in exchange for the substitute Bank Guarantee. The first Bank Guarantee will then be cancelled.

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10 Cash Deposit

(a) The Cash Deposit which forms part of the security:

1. Will be in an amount of US$.....;
2. Will be deposited by the Company with the Bank and held in an interest bearing account denominated in US$ in the joint names of the company and EPA;
3. May be claimed by EPA on the terms of clause 8.1;

(b) Any interest accruing on the Cash Deposit may be paid to the Company annually to any Bank specified by the Company.

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11 Dispute Resolution

11.1 Dispute Resolution

The parties will make reasonable efforts to resolve any dispute arising under this agreement or any matter contemplated by this agreement including consulting each and cooperating with each other in good faith for a period of not less than 45 days.

11.2 Expert

Any disputes which cannot be resolved under clause 11.1 will be dealt with as follows:
(a) Either party may refer the dispute for resolution to an agreed third party who must be a partner in a firm of independent Ghana based environmental engineers who must not be or previously have been an agent or consultant of either party;

(b) The third party will act as an expert and not as an arbitrator and will decide on the matter according to the best interest of both parties within 60 days of the referral;

(c) The parties will co-operate with the third party and may make written submissions to the third party;

(d) The third party may on request have access to the records and personnel of the parties; and

(e) The company will pay all professional fees and costs of the third party for disputes initiated by the company;

(f) The Agency will pay all professional fees and costs of the third party for disputes initiated by the Agency.

11.3 Ministerial Intervention

A party not satisfied after the process listed in 11.2 (a-f) shall submit a written complaint to the Minister responsible for the Environment.

(a) The complaint shall be submitted to the Minister within 45 days of the complainant becoming aware of the decision of the expert; (b) The complainant shall:

- State the issues objected to
- Have attached a copy of the decision objected to and
- Have attached all documents relevant for considering and determining the complaint

(d) The Minister shall within 14 days of receipt of a complaint appoint a panel composed of a representative each of the following:

- The Ministry responsible for the Environment and not below the rank of a Director
- The Attorney-General's Department not below the rank of a Senior State Attorney
- The Ministry responsible for Mines and not below the rank of a Director
- Two persons with specialization in the relevant field (Mine and the Environment)

(e) Minister shall refer the complainant to the panel which shall give a fair hearing to all parties and determine the issue as it considers appropriate.

- The panel after hearing all parties may after or confirm the decision of the expert
- The proceedings of the panel shall be fully documented together with the reasons for the panel's decision and presented to the Minister
- The decision of the Minister (on the advice of the panel) shall be final and the parties shall be bound by it.

12 General

12.1 Force Majeure

1. The company is not liable for any failure in the fulfilment of its obligations under this agreement to the extent that the failure is due to any delay, interruption, loss or damage occasioned by Force Majeure
2. For the purposes of this agreement, Force Majeure means events beyond the control of the company:
    a. Any act of God, fire, flood, storm, lightning, epidemic;
    b. Any war, revolution, civil strife
3. Force majeure shall not include:
    a. Any event which is caused by the negligence of the Company or the company's agents, employees, hairs and assigns nor
    b. Any event which a diligent company could reasonably have been expected to both take into account at the time of the conclusion of this Bond and avoid or overcome in the carrying out its obligations.

12.2 Notice

If the Company claims the benefit or protection of clause 12.1, it must promptly give notice of the claim to the Government of the EPA, as appropriate. Performance of any obligation affected by Force Majeure must be resumed as soon as possible after termination or abatement of the Force Majeure event.

12.3 Fees and Expenses

(a) Each party must pall all costs and expenses incurred by that party and any employee, officer, agent or contractor of that party in relation to the negotiation,

preparation and execution of this agreement or any document described or contemplated by this agreement.

(b) No fees or charges will be payable by the company to the Government or the EPA or nay of their employees, officers, agents or contractors in relation to anything this agreement requires or contemplates will be done by the Government or the EPA or any of their employees, officers, agents or contractors.

(c) The security shall not be used by Government or the EPA to fund any costs and expenses of the normal operation or functions of the government or EPA, but rather only for completion of the reclamation work described in the reclamation plan

(d) In the event that the bank providing the Bank Guarantee is not at least an "a" rate bank by Standard and Poors, then the cost of any confirmation relating to the Bank Guarantee, the cost involved shall be borne by the company.

12.4 Notices

(a) Any notice or other communication including, but not limited to, any request, demand, consent or approval, to or by a party to any Transaction document:

1. Must be legible in writing and in English addresses as shown below: A. If to the Company:

   B. If to the EPA:

   Address: P. O. Box M326, Ministries Post Office, Accra, Ghana

   Attention: Executive Director Facsimile: 233-21-662690

   Or as specified to the sender by any party by notice;

2. Where the sender is a company, must be signed by an officer or under the common seal of the sender;
3. Is regarded as being given by the sender and received by the addressee: A. If by delivery in person, when delivered to the addressee;

   B. If by post, 3 business days from and including the date of postage; or

C. If by facsimile transmission, whether or not a business day or is after 4:00 pm (addressee's time) it is regarded as received at 9:00 am on the following business day; and 4. Can be relied upon by the addressee and the addressee is not liable to any other person for any consequences of that reliance if the addressee believes it to be genuine, correct and authorized by the sender.

(b) A facsimile transmission is regarded as legible unless the addressee telephones the sender within 24 hours after the transmission is received or regarded as received under clause 12.4(a) (3) and informs the sender that is not legible.

(c) In this clause 12.4, a reference to an addressee includes a reference to an addressee's officers, agents or employees.

12.5 Assignment

The Company must not transfer or assign any of its rights or obligations under this agreement without prior written consent of EPA, provided however that if the Company assigns its rights under the Mining Lease, it may assign its rights under this agreement.

12.6 Governing Law

This agreement is governed by the laws of the Republic of Ghana.

Schedule 1 - **Reclamation Rates**

Operational Area	Reclamation Area (Ha)	Cost/hectare Total (US$)
Total		

Schedule 2 - **Reclamation Criteria**

Part 1 – Primary Completion

Pit

- Stable slopes free from rock fall and soil movement (bench height between 3 – 6 meters, berm width not less than 10 meters and slope angles of not more than 65 degrees)
- Water discharge meets with Ghana's environmentally effluent quality guidelines
- Protected access to rock faces and all steep slopes with inert waste rock as perimeter bund at minimum distance of 50 meters from the pit face.
- Establishment of protective zones around the pit to protect community members from water hazards.

Waste Dumps

- Stable slopes and surfaces free from rock and soil movement and erosion
- Slopes battered between 20 – 30 degrees
- Water run – off managed effectively
- Gentle rolling landforms of similar aesthetics to existing area

Rom Pad and Ore Stockpiles

- Stable slopes and surfaces free from rocks and soil movement and erosion
- Slopes battered between 20 – 30 degrees
- Water run-off managed effectively
- Gentle rolling landforms of similar aesthetics to existing area

Plant site and contractor facilities

- Soils free from erosion
- Water run-off managed effectively
- Facilities not required by local community/government removed
- Any contaminated soils (hydrocarbons) encapsulated and free from leachate
- Free of all hazardous materials and waste

Leach Pad and Ponds

- Stable slopes and surfaces free from rocks and soil movement and erosion
- Slopes battered between 20 – 30 degrees
- Water run – off managed effectively

- Gentle rolling landforms of similar aesthetics to existing area
- Water discharge meets with Ghana's environmental effluent quality guidelines

Tailings storage facilities

- Embankments stable and free from erosion
- No steep slopes or faces leading into storage facility
- Protected access to unconsolidated tailings
- Provision of 1m embankment freeboard
- Overflow spillway constructed

Water Bodies

- Retaining structures stable and free from erosion
- Mine related slopes or faces leading into storage facility
- Water levels reduced to minimum practical elevations
- Quality conform to EPA guidelines

Backfill and borrow pit (Recreation Area)

- Soils stable and free from erosion
- Water run-off managed effectively
- All facilities related to construction removed
- Prevent contamination of soils but any contaminated soils (hydrocarbons) shall be encapsulated and free from leachate

Townsite

- Soils stable and free from erosion
- Water run-off managed effectively
- All facilities related to construction removed
- Prevent contamination of soils but any contaminated soils (hydrocarbons) shall be encapsulated and free from leachate

Part 2 – Land Use Completion

Reforested Areas

- Tree density equivalent to adjoining secondary forest
- Understorey species providing leaf area index of 1
- Use of indigenous species not less than 40%
- Creation of conditions favorable for the return of fauna

Plantation timber/forest resource

- Planted species stocking rate of 1000 trees/ha

Recreation

- Soils stable and free from erosion through provision of vegetative cover/ grass
- Area functioning for its designate purpose

Water Resource/Aquaculture

- Dead, inundated and fringing vegetation removed
- Fresh water inflow assured
- Littoral zone of 10% of the lake area (pit) must be ensured to sustain biological productivity

Agriculture

- Appropriate topsoil cover
- On waste dumps topsoil cover of 0.5mm thickness is recommended
- Soils stable and free from erosion
- Completion of three food crop cycles
- Qualitative and quantitative analysis of vegetative cover
- Creation of conditions favorable for the return of fauna
- Planted cash crop species sustainable

Townsite

- Soils stable and free from erosion
- Area functioning for its designed purpose

Part 3 – Final Completion

An area will be deemed to have a final completion if it continues to retain the criteria for land use as indicated in Schedule 2, part 2 when no additional monitoring and maintenance are required after reclamation works have been achieved after 3 seasonal cycles, excluding sites experiencing Acid Rock Drainage (ARD) phenomenon. Where ARD phenomenon occurs, an area will be deemed to have a final completion if it continues to retain the criteria for land use as indicated in Schedule 2, Part 2, when no additional monitoring and maintenance are required after reclamation works have been achieved after a period of not less than 7 years.

Schedule 3 - Form of Bank Guarantee

(to be inserted)

Executed as an agreement

Signed for an on behalf of

(Name of Company) it's

General manager/CEO/

Managing Director

……

Signed for an on behalf of the

Environmental Protection Agency

by its Executive Director

……

EXECUTIVE DIRECTOR

In the Presence of

NAME ……

DESIGNATION…….....

SIGNATURE ……

DATE ……

In the Presence of

NAME ……

DESIGNATION…….....

SIGNATURE ……

DATE ……

Appendix 6

ERROR MATRIX FOR 2007 FROM MLP CLASSIFICATION

		Reference Data					
		1	**2**	**3**	**4**	**Classified Totals**	**Users Accuracy**
MLP 2007	**1**	**54780**	7267	963	1736	64746	**84.6 %**
	2	60	**1263**	40	48	1411	**89.5 %**
	3	113	746	**14382**	1585	16826	**85.5 %**
	4	367	140	1731	**8141**	10379	**78.4%**

	Reference Totals	55320	9416	17116	11510	**93362**	
	Producers Accuracy	**99.0 %**	**13.4 %**	**84.0%**	**70.7 %**		
		Overall Accuracy: 78566/93362 = 84.2 %					

ERROR MATRIX FOR 2011 FROM MLP CLASSIFICATION

		Reference Data					
		1	**2**	**3**	**4**	**Classified Totals**	**Users Accuracy**
MLP 2011	**1**	**9928**	922	281	1179	12310	**80.6 %**
	2	2600	**19411**	1647	1475	24133	**80.4 %**
	3	433	1067	**4493**	1512	7505	**59.9 %**
	4	3818	2211	3186	**61004**	70219	**86.9 %**
	Reference Totals	16779	23611	9607	65170	**115117**	
	Producers Accuracy	**59.2 %**	**82.2 %**	**46.8 %**	**93.6 %**		
		Overall Accuracy: 94936/115167 = 82.4 %					