GEOSPATIAL ANALYSES OF LAND DEGRADATION SITES IN JOS SOUTH LOCAL GOVERNMENT AREA, PLATEAU STATE, NIGERIA

BY

ADAMU BALA

DEPARTMENT OF GEOMATICS, FACULTY OF ENVIRONMENTAL DESIGN, AHMADU BELLO UNIVERSITY, ZARIA
NIGERIA

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By
ADAMU BALA
(B.Eng. Geomatics Engineering, 2009)
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NIGERIA

APRIL, 2018

Declaration

I declare that the work in this dissertation entitled "**Geospatial Analyses of Land Degradation Sites in Jos South Local Government Area, Plateau State, Nigeria"** has been performed by me in the Department of Geomatics under the supervision of Dr. S.S. Garba and Dr. T.O. Adewuyi. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other Institution.

ADAMU BALA	_____	_____
Name of Student	Signature	Date

Certification

This dissertation entitled GEOSPATIAL ANALYSES OF LAND DEGRADATION SITES IN JOS SOUTH LOCAL GOVERNMENT AREA, PLATEAU STATE, NIGERIA by ADAMU BALA meets the regulations governing the award of the degree of Master of Science in Geomatics of Ahmadu Bello University and is approved for its' contribution to knowledge and literary presentation.

Dr. S. S. Garba	_____	_____
Chairman, Supervisory Committee	Signature	Date
Dr. T. O. Adewuyi	_____	_____
Member, Supervisory Committee	Signature	Date
Dr. O. A. Isioye	_____	_____
Head of Department	Signature	Date
Prof. S. Z. Abubakar	_____	_____
Dean, School of Postgraduate Studies	Signature	Date

Dedication

This research project is dedicated to my greatest human pillars, my father Alhaji Bala Mani for his untiring, infinite and collective support throughout my educations and my mother, Hajiya Hajara for her lead and counsel in all my affairs.

Acknowledgement

Praise is to Allah (SWT) the Creator of all, the Lord of all, for His infinite mercy and blessings to us. May the peace and blessing of Allah (SWT) be upon His Noble Prophet Muhammad (PBUH).

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Abstract

This research work used Geospatial techniques in the analyses of mine-induced land degraded areas of the Jos South LGA of Plateau State. Thus, the objectives were to establish the geometrical characteristics of land degraded sites; determine the attributes of the degraded sites; determine how the degraded areas relate to the neighbouring land use and analyse topography in the neighbourhood of the degraded sites. As an introduction, the concept of mining and land degradation and how the mining caused the land degradation were explanined; statement of the problem identified major issues such as accurate delineation of the degraded sites, the usefulness of the degraded sites, the nature of the terrain in relation to the degradation.

The study analysed land degraded sites using multi-sensor satellite imageries of Landsat 8 (2016), SPOT 5 (2012), Quickbird-2 (2010) and SRTM DEM data of the study area. Onscreen digitization of the land degraded areas was carried out using Quickbird-2 satellite imagery; this is followed by Maximum Likelihood Supervised classifications of land cover and land degradation features using fused Landsat 8 and SPOT 5 imageries, this was to determine the area of land that had been affected by mine-induced activities; six land cover classes related to degradation were adopted. Finally, detailed terrain analyses such as slope, aspect, flow direction, flow accumulation, of the study area were carried out using DEM data.

The results of the onscreen digitization produced 235 sites with a total area of 11.58km^2 covering 2.26 % of the study area. Getis-Ord GI* statistics was used to identify Hot or Cold Clusters of the degraded sites from the 235 sites, in which 10 major hot spot sites of 2.02km^2, at 17.43% were chosen for detailed analyses. Furthermore, all the digitized degraded sites were classified into 13 classes based on their usage. The land use classification had an overall map and Kappa coefficient accuracies of 77.82% and 73.16%

respectively. The classification results revealed a total land cover of 512.10km^2, mine ponds occupying 10.01km^2. Terrain analyses revealed that the spatial location of the degraded sites is irrespective of the terrain because most of the degraded sites occurred because of mining activities; which can be done whether at high or low land. Moreover, the terrain of the study area has continuously been altered and remodified by mining activities and unplanned mine wastes resulting to the present degraded sites. The research has adequately addressed issues of the economic value and consequences of the degraded sites and relationship between terrain and degradation. Three-way approach: onscreen digitization, automatic classification, and terrain analyses have been explained which had not been done in previous researches. Lastly, it is recommended that, certain appropriate LULC in the neighbourhood could be utilized productively; block industries, water treatment plants, fish farming, etc, should be sited around the seasonally inundated mine pond; implementation and enforcement of the existing mining laws at all levels to safeguard the environment and ecological funds being provided by the Federal Government should be utilised.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Land is one of the greatest tangible asset and foremost natural resources, but not a resource that automatically renew itself just like rainfall or sunlight, nor it is a simple commodity that can be warehoused and replaced, destroyed and redesigned, or recycled the same way as factory-made goods. Land that suffered from man`s activities may be described as spoiled or degraded, disturbed or devastated, derelict or damaged. Land is a significant natural resource that either directly or indirectly supports most of the planet's life. International Labour Organisation (ILO, 2007) reported that a major function of land to man is, agricultural activities are carried out on it; this includes the food we eat and also provide the primary basis of livelihood to 36% of the world`s total workforce.

Several definitions of land are in existence, foremost of which is the Food and Agricultural Organization (FAO) definition, which described a land as an area that can be delineated, including all features of the biosphere immediately above or below the earth surface, comprising the soil, terrain, surface hydrology, the near-surface climate, sediments and associated groundwater reserve, the biological resources, as well as the human settlements pattern and infrastructure resulting from human activity (FAO, 2015). Henssen (2014) also defined land as an area of the surface of the earth together with the water, soil, rocks, minerals and hydrocarbons beneath or upon it and the air above it. It embraces all things which are linked to a fixed area or point of the surface of the earth, including the areas covered by water, together with the sea. It is an area of the earth’s surface, containing all elements of the physical and biological environment that influence land use. It denotes not only to the soil, but also landforms, climate, hydrology, vegetation, and fauna, together with land improvements such as walkways and drainage

works (Christopher, 2015). Components of land include the soil, the vegetation, the groundwater, air, wildlife. Each of these components plays a substantial role in bestowing a quality on the land through their interaction with one another.

One of the major threats to the land is degradation because it destroys land resources (Christopher, 2015). Degradation is the consequence of physical, chemical and biological shifts determined by environmental, social and economic forces. It is also the temporary or permanent dropping of the productive capability of land (United Nation Environmental Program, UNEP, 1992). It thus covers the various forms of soil degradation, adverse human impacts on water resources, deforestation, and lowering of the productive capacity of rangelands. In general, it implies temporary or permanent regression from a higher to a lower status of productivity through the decline of physical, chemical and biological aspects (Ravishankar and Sreenivas, 2015).

Leonard *et al.,* (1989) as cited in Maiangwa *et al.,* (2007) reported that some studies show that nearly 80% of rangeland and dryland forest areas, 30% of tropical forests and around 50% of all irrigated cropland in developing countries are classified as degraded. Cleaver and Schreiber (1994) and Barbier (1997) stated that other studies show that as much as half of potentially productive agricultural land in developing countries is being lost through the processes of land degradation and abandonment (Maiangwa, *et al.,* 2007).
Ravishankar and Sreenivas (2015) testified that there are several methods in which land degradation emerge: these comprise water erosion, wind erosion, water logging; acidification, anthropogenic (mining, brick kiln, and industrial effluent-affected areas). Mining and its subsequent activities have been found to degrade the land to a momentous amount (Sahu and Dash, 2011). Nevertheless, of these processes, the most noticeable in Jos South is the degradation owing to mining activities.

Proper mining started on the Jos Plateau as far-off as 1902 through Tin and Columbite as the foremost targets (Gyang and Ashano, 2009). The Tin Mining industry on the Jos Plateau has triggered widespread manmade environmental damage, with gigantic tracks of pastoral land systematically ruined in the pursuit of Cassiterite (Tin ore) and Columbite minerals. Furthermore, on the Jos Plateau, exploration, exploitation, and processing of tin ore known to be associated with the alluvial sediments have left behind numerous ponds, lotto, and mining pits, as well as heaps of mine waste in the course of mining (Gyang and Ashano, 2009). These activities have negative consequences on the land and therefore has instigated land or environmental degradation in quite a lot of parts of the study area. Some of these dangers of mining activities affected the environment resulting in land degradation, de-vegetation, loss of aquatic animals, water, and air pollution.

Thus, bearing in mind the importance of sustainability of any land and the environment in general, and also the rate at which the land has degraded and consuming farmlands in developing countries, this research will endeavour to map and analyse the sites where this degradation typically take place, with a view to proffer solutions on how suitable any of the following: restoration, reclamation, or rehabilitation can be carried out.

1.2 Statement of the Problem

The importance of mining solid minerals to the wealth of a nation cannot be overemphasized. Minerals are very important in strengthening the economy of any nation; strategic minerals are used in defense, health, electronics and agriculture; inadequate supply of critical minerals can harm the economy of a nation. These mining activities contribute positively to the growth of Nigeria`s economy but also negatively to the physical environment, this is because such minerals mining and extraction cannot be done successfully without causing environmental effects, as such resulting in serious land degradation among other consequences.

The Jos South Local Government has experienced the consequences of mining activities for not fewer than five decades ago. Some of these mining activities commonly referred to as informal or artisanal mining activities are still being carried out extensively in the study area. Unregulated mining activities in the study area overtime lead to the mining sites and neighbouring areas experiencing enormous wastage of the land in form of tailings (minerals waste and overburdens) dumps. This harmful impact comprises land degradation, mutilation of natural landscape and vegetation, erosion of soils and degrading water quality. There are also problems of devastated, derelict lands and mine spoils depriving the inhabitants of fertile farmland in the study area. This is evident by the physical appearance of mining ponds, pollution by poisonous metals, erosions, and waterlogging in the area.

Related researches have been carried out in the past (Jonathan and Joshua, 2013; Edun and Davou, 2013; Adedeji *et al.*, 2014; Igbokwe *et al.*, 2008; Haruna and Solomon, 2011). These researchers mostly centred on the assessment of the effects of post-mining activities and gully erosion on the environment. They have either carried out inventory of abandoned mines ponds (Edun and Davou, 2013) or use satellite imageries to analyse land use changes over time (Jonathan and Joshua, 2013); some adopted gully erosion as indicators of degradation using geospatial information system (Igbokwe *et al.*, 2008), and topography analysis and statistical analysis method to make known slope and depth of gullies.

But the problems of implementation of the researches, abandonment and lack of reclamation of the degraded sites persisted probably because these researches have not adequately address major issues such as how accurate are the degraded sites being delineated; the features of the degraded sites and their economic values; the relationship between the nature of the terrain and the degradation. Moreover, most of these researches

were based on pixel-based supervised classification rather than delineation; these might have resulted in poor or mixed pixel classification, and the possibility of inaccurate delineation because of the lower resolution of satellite imageries used (Graw *et al.*,2015). Therefore, the need for this study arises to, determine economic viability and current uses of the abandoned land degraded areas, and relate how lands are being used in their neighbourhood. Also, the nature of the terrain in the study area may also expand the degraded sites. Therefore, researching on these issues will go a long way in achieving proper reclamation of the degraded sites, among other things.

1.3 Research Questions

This research is therefore aimed at answering the following research questions:

i. What are the geometrical characteristics of land degraded sites in the study area?
ii. What are the common features of the land degraded sites in the study area?
iii. Are there relationships between the degraded areas and neighbouring land use?
iv. Are there relationships between the terrain and degraded sites in the study area?

1.4 Aim and Objectives

The aim of this research is to carry out geospatial analyses of land degradation sites in Jos South Local Government Area of Plateau State, with a view to provide comprehensive information for reclamation, restoration, and remediation of the land degraded sites

In order to achieve the aim, the following objectives were pursued:

i. To establish the geometrical characteristics of land degraded sites in the study area.
ii. To determine the attributes of the degraded sites
iii. To determine how the degraded areas relate to the neighbouring land use.
iv. To analyse terrain in the neighbourhood of the degraded sites.

1.5 Justification

Jos, being a tin city and tourist centre of the north-central states, has attracted all and sundry from all parts of the country for mining and recreational activities over years. This has made it densely inhabited and congested with huge mining activities going on, which has led to high rate of urban sprawl; in so doing, the mining activities altered the land use and cover of the area, consequently making it highly susceptible to degradation in some areas, hence there is need to identify such degraded sites and tender solutions.

The results of this research can serve as decision-making support for government planners and policymakers in drafting and fulfilling development plans for viable use of land resources. Information on the extent, severity and location of degradation problems in actual fact will give utmost attention to planners and stakeholders in planning and implementing mitigation measures (Lal and Stewart, 1985; Barrow, 1994; and Sujatha *et al*., 2000 as cited by Jessica, 2002) and gain a combined effort in shaping suitable processes and land use policies.

When completed, the research could be used for operational monitoring of land degradation in Jos South Local Government Area of Plateau State using geospatial techniques. The explained methodology can also serve as a foundation for land degradation sites assessments in similar areas somewhere else.

Nowadays, with the advent of Remote Sensing and Geographic Information System technologies, mapping land degradation becomes easy, less time consuming and gives room for regular updating and projection with a view to manage land resources effectively and efficiently. Methods using GIS and remote sensing have been found to be more reliable for mapping, monitoring and modeling terrestrial resources than most ground-based studies. Apart from being low-cost means to gather information on land

degradation, it gives room for an exact delineation of boundaries at numerous levels of scales.

Knowledge on the spatial distribution of land degradation is relevant in improving land productivity, improving crop yield, increase agricultural production, boost the income of farmers, decrease in loss of biodiversity, improve the security of lives and properties, sustainable development, better standard of living, land restoration etc.

Sujatha *et al*., (2000) claimed that planning reclamation strategies and setting up preventive measures for sustainable agriculture development relies on the verifiable information on the nature, extent, severity and geographic distribution of degraded lands. Barrow (1994) also reported that a satisfactory information on degradation changes provides satisfactory strategies for the prevention and mitigation of land degradation.

1.6 Scope of the Project

The spatial extent of this research intends to cover the administrative boundary of Jos South Local Government Area of Plateau State. Although land degradation processes include anthropogenic, barren rocky or stony waste areas, water erosion, wind erosion, waterlogging, riverine sand areas. This research will mostly focus on land degradation due to the mining activities and gully erosion of the study areas. It seeks to solve the problem of incessant land degradation by thoroughly analysing the abandoned mines sites, carry out land cover mapping of degraded sites and terrain analyses to reveal the relationship between degraded sites, terrain features and spectral signatures of the land cover maps of the area.

Land degradation assessment often require several parameters; however, a two-way approach will be adopted by firstly using Quickbird 0.6m (2010) resolution imagery for onscreen digitization of degraded sites and secondly using 2.5m resolution merged

SPOT5 (2012) and Landsat 8 (2016) imageries for the pixel-based classification to analyse land cover in the neighbourhood of land degradation sites. Additionally, terrain analysis to relate land degraded sites with nature of the terrain will be conducted.

1.7 Study Area

1.7.1 Location

The study area, Jos South Local Government area covers a total area of 512 km^2. It is bounded by latitude 9°34'22.35"N and 9°54'40.19"N and longitude 8°39'54.84"E and 8°59'13.05"E. It lies at an average altitude of about 1280m above sea level. Part of the study area is located on sheet 168 Naraguta NE of the Nigeria topographic sheet (see Appendix 2). The area is bounded in the northwest by Bassa LG, in the north by Jos north LG, in the East by Jos east LG, in the Southeast by Barkin Ladi LG and Riyom LG in the Southwest (see Figure 1.1).

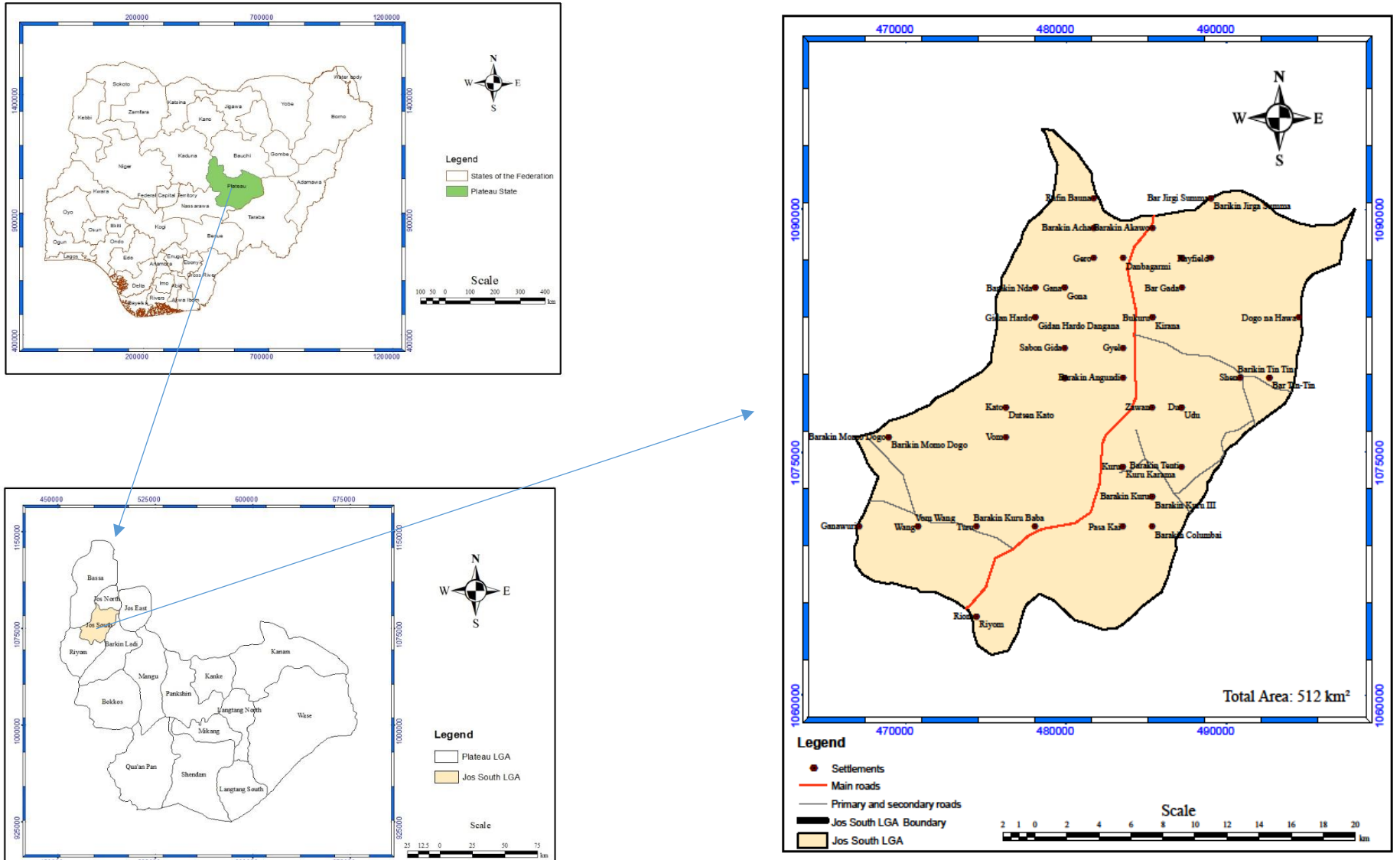


Figure 1.1: Locational Maps of the study area

1.7.2 Climate

The study area has a cool climatic condition known as mountain climate, due to its altitude. From November to February are normally the peak of cold period whereas March and April are a warm period before the onset of rain, 18°C is the average mean daily temperature, reaching up to 36ºC. The rainy season, which is between the months of May and October, has its peak in August. The mean annual rainfall ranges from 1347.5 to 1460 mm in a year. The humidity of the study area varies from places to places at different times; there is maximum mean humidity during wet (rainy) season, which approaches 100% (air saturated) but it is as low as 10% at the peak of the dry season (Dawen, 2012).

1.7.3 Geology

Three types of rocks dominate Jos Plateau: The Older Granites, the Younger Granites and also then numerous volcanoes and basalt sheets. Buchanan and Pugh (1955) reported that the granites are predominantly resistant to erosion, and generally form shallow and sandy soils, they also comprise tin which has been mined for more than a century, through and after the colonial period. There also exist basaltic rocks in some areas, which weather to form deep clay loams, these have significant agricultural potential and are cultivated for food (Buchanan and Pugh 1955). The topography of the area belongs to younger granite province with elevation ranging from 915 to 1,300 meters according to Lar (2007). The landscape is featured by flat or broadly undulating terrain with flat-topped hills.

1.7.4 Vegetation

This is the general distribution density and type of plant cover that is found in an area. Northern Guinea Savannah is found in the area, though most of the plants have been removed consequent of deforestation and earlier mining activities in the area. The vegetation of the area is commonly covered by trees such as eucalyptus, mangoes, shrubs

and other grasses. Agricultural activities are also taking places in the areas especially near some inundated mine ponds (Dawen, 2012).

1.7.5 Soil

The major soil unit in the study area belong to the broad category of tropical ferruginous soils which are much thinner, on the high plateau; there are also sizable pockets of loamy soils of volcanic origin. Soil erosion is a major environmental problem within the study area, which can be attributed to the massive mining activity (Tin) which has been taking place (Dawen, 2012).

1.7.6 Population

According to the National Population census, 2006, Jos South has the population figures at 311,392 (FRN, 2010), and this has been projected to 396,500 as of March, 2015 (Brinkhoff, 2017). The human population density of the area stands at 778 inhabitants/km². High human population densities combined with relative fertile soils in some areas have resulted in large-scale deforestation and conversion of montane grasslands to farmed areas (World Wildlife Fund, 2016). The few remaining patches of forest and woodland mosaic are depleted by the collection of firewood, as a result only a few sections of natural grassland, savannah woodland and forest remain, generally in the most inaccessible areas, with small forest areas occasionally found in narrow strips along rivers.

1.7.7 Settlement

The Berom are the largest ethnic group in Jos South LGAs in Plateau State, and claim to be the indigenous population of Jos, with Hausa Fulani, Yoruba, Igbos, and other tribes believed to have settled in the areas during the mining boom. The plateau's mineral wealth has attracted numerous Hausa, Igbo (Ibo), Yoruba, and European migrants in the 20th century; and the absence of the tsetse fly (the carrier of trypanosomiasis) at this elevation

has also lured many Fulani herdsmen to the plateau. The traditional rulers are Dagwom Rwei of Jos South and the Gbong Gwom Jos (Blench *et al*., 2006).

1.7.8 Industries and occupation

Jos South is the industrial centre of Plateau State due to the presence of industries like the NASCO group; Standard Biscuits, Grand Cereals and Oil Mills, and Zuma steel West Africa, Aluminium roofing industries, Jos International Breweries among others. Jos South also houses prestigious institutions like the National Institute of Policy and Strategic Studies (NIPSS), the National Veterinary Research Institute, College of Land Resources, the Police Staff College, the NTA television college and the Nigerian Film Corporation. The government house of the state is located at the Rayfield low-cost of the local government area. Gwom (1992) opined that the people of Jos South were predominantly farmers and hunters, but with the coming of mining activities and the location of mining camps in many areas within the local government, the early occupation of the inhabitants has been overtaken by these mining activities. Farming is still taking place, with maize, yam, cocoyam, sweet and Irish potatoes, Guinea corn and millet being the major crops cultivated. Variety of vegetables such as onions, cabbage, green pepper, carrots, cucumber peas etc. are also being cultivated (Mackey *et al.,* 1949).

1.7.9 Agricultural practice

Almost all of the Jos is now open savannah grassland because the original forested areas have long been cleared for farming or mining. Cactus hedges grow naturally, but many have been planted around villages and compounds. Fact Monster (2016) reported that Tin was mined and processed on the plateau, and farming and grazing are important. *Acha* (a grain known as “hungry rice”), sorghum, and millet are the most widely cultivated staple foods; but cash crops, especially potatoes, yams, and green vegetables, are grown for the plateau’s largest urban markets at Jos, Bukuru, Pankshin, and Vom. A large number of

cattle on the plateau supply milk to a dairy at Vom. Goats and sheep are also raised. By the early 1980s, over cultivation and overgrazing pressured some farmers to move off the plateau, but several dam and reservoir projects were constructed to foster land reclamation (Encyclopaedia Britannica, 2016).

1.7.10 Drainage

"The plateau's steep, irregular Southern slopes have many waterfalls, notably the Gurara Falls; several are harnessed for hydroelectric power" (Encyclopaedia Britannica, 2016). The plane metric arrangement of several streams of the area known as drainage pattern is influenced by the type and altitude on which the drainages develop. Many tributaries in the area run from high altitude and supply water to the main streams and mine ponds causing erosion in some part of the area (Lar, 2007).

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter focuses on the general concept of degradation, theoretical framework and different methods of land degradation assessment. Related works were also reviewed; highlighting methods employed and results achieved. Missing gaps in the previous researches were also identified, with the view to proffering solutions.

2.2 Conceptual Framework

Degradation originated from Latin which signifies a 'reduction to a lesser rank'; reductions denotes a problem emanating from the land usage, whereas rank is a gauge to quantify the problem (Piers and Harold, 2015). Land degradation leads to decline in productivity, this call for urgent steps to restore that productivity and check auxiliary harms. Among other things are being equal, the output on degraded land is lesser than that on the same land short of degradation. Degradation is a result of several forces, rather than one-way path; it is a product of an equation, where both human and natural factors bargain a place (Piers and Harold, 2015). This is illustrated by equation 2.1.

$$Net\ degradation = (natural\ degrading\ processes + human\ interference) - (natural\ reproduction + restorative\ management) \quad \ldots\ldots\ldots (2.1)$$

(Piers and Harold, 2015)

The term degradation is perceptual and denotes at least a 'rank' scale of relative measurement. As a perceptual term, however, it is open to multiple understandings. To a hunter or herder, the replacement of forest by grassland with a greater capacity to carry ruminants would not be perceived as degradation; nor would forest replacement by agricultural land be seen as degradation by a settling farmer. Degradation is a perceptual

term; hence it has diverse formations such as forest, soil, land, water, vegetation and environmental degradations (Piers and Harold, 2015).

Soil degradation is recognised as a major aspect of land degradation, just the same way land degradation is recognised as a major aspect of environmental degradation. Soil degradation is defined by Lindert (2000) as any chemical, physical or biological change in the soil`s condition that lowers its agricultural productivity. As the soil is being degraded, so is the vegetation. This is because vegetation and soil are inherently linked and therefore the degradation of one leads to the degradation of the other. Just like soil, vegetation degradation affects the variety, quantity, and quality of grassland, this often occurred as a result of overgrazing (John and Gerald, 2011). Dubovyk (2013) opined that areas with an apparent negative vegetation trend in the satellite imagery are interpreted as an indicator of land degradation. John and Gerald (2011) reported that local people in a community in Ghana considered an indication of grassland degradation as the shortage of grasses for roofing and grazing. Changes in human activities have resulted in the continuing loss of vegetation cover and soil fertility in West Africa.

Forest degradation, on the other hand, is the decline of biotic resources and lowering of the productive capacity of forests through human activities (FAO, 2016). FAO (2007) defines forest degradation as a process leading to a temporary or permanent decline in the concentration or structure of vegetation cover or its species composition. Jibrin (2009) also defined it as the reduction of the capacity of a forest to provide goods and services. Though one person's degraded forest is another person's livelihood, it is generally assumed to be indicated by the reduction of canopy cover.

Environmental degradation is a very serious problem and to pay no attention to the environment is to ignore our humanity and surrender its race that is entirely dependent on it. There is the need to manage the ecosystem responsibly so that those coming after will

not have to complain, worry or curse their ancestors (Haruna and Solomon, 2011). There is a general consensus that poverty is a major cause of environmental degradation (Sunday, *et al.,* 2013). Environmental degradation is often noticed through changes in the quality, quantity and diversity of the vegetation that is observed through a reduction in the quantity of the vegetation particularly around an immediate environ (John and Gerald, 2011).

2.2.1 The concept of land degradation

Land degradation (LD) could be defined as "the substantial decrease in either or both of an area's biological productivity or usefulness to humans due to human activities (Piers and Harold, 2015)." Biological productivity is determined by attributes of the land resources, such as soil fertility, and water properties. Land degradation incorporates the aspects of the hydrologic domain that are significant in a given area. Land usefulness is also a crucial attribute of land degradation.

The biomass productivity in an area could remain constant yet land degradation might still occur (Piers and Harold, 2015). For example, overgrazing could result in a decrease in an area's soil fertility and a diminished ability of the environment to support the growth of edible forage plants. When the vegetation cover re-establishes itself after grazing pressure is reduced, even though the grass cover (biomass) is similar in density to the initial cover, the species that replaces the original vegetation often may not nearly as pleasant.

Land degradation is one of the major aspects of environmental degradation that has been a threat to our future generation and the entire human existence (Bowender, 1987). Land degradation is a major problem facing developing countries and is projected to become an even more severe constraint into the future (Maiangwa *et al.,* 2007). Land and Soil degradation are also a problem in developed countries because they are losing fertile soil

at a very high rate. Because soils differ from place to place, the problems caused by degradation can also differ (Müller, 2013).

Land degradation causes poverty and vice versa (Sonneveld *et al.,* 2010). But both processes are highly complex, hard to forecast and to mitigate, and need insights from different perspectives (Valerie *et al.,* 2014). The Millennium Development Goals (MDGs) regarding the eradication of life-threatening poverty and hunger i.e. MDG No. 1 (Flasbarth, 2013) and environmental sustainability i.e. MDG No. 7 (Flasbarth, 2013) will not be reached unless it is assured that soils are managed sustainably. Combating Land degradation means supporting food security.

Kasperson *et al.,* (1995) defined land degradation as "a decrease in the capacity of the environment as managed to meet its user demands". This resonates with the United Nations Convention to Combat Desertification (UNCCD, 1994) definition of land degradation as the "reduction or loss in arid, semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns".

In a similar vein, Abbas and Fasona, (2012) described land degradation as land which due to natural processes or human activity is no longer able to sustain properly its economic function and or its original natural ecological function. The implications of the land use-land cover change often lead to land degradation. UNCCD (2004) and WMO (2006) as cited in Fadhil (2009) emphasized that land degradation is one of the most serious ecological problems in the world. It entails two interrelated, complex systems: the natural ecosystem and the human social system. Causes of land degradation are not only

biophysical but also socio-economic (marketing, income, human health, institutional support, poverty) undermining food production and political stability.

2.3 Nature of Land Degradation

2.3.1 Physical degradation

The physical processes which contribute to land degradation are primarily water and wind erosion, compaction, crusting and waterlogging; it also includes compaction and hard setting of soil triggered by removal or reduction of structural holes (Karkee, 2004). In farmlands, subsoil compaction may occur below the plough-layer through regular use of heavy machinery and this may be difficult and expensive to fix. Compaction decreases infiltration capacity and porosity and increases bulk density and resistance to plant root penetration (Bridges and Van Baren, 1997). In soil with a reduced infiltration capacity, saturation is reached quickly and surface flow is generated which can cause erosion.

2.3.2 Biological degradation

The biological processes are related to the reduction of organic matter content in the soil, degradation of vegetation and diminishing of activities of micro flora and fauna. These processes are generally linked with the deterioration in micro-biological biomass, decline in quantity and quality of soil organic matter (Karkee, 2004). Soils are agents for decomposition of organic matter and its conversion into a harmless, semi-stable material referred to as humus (Bridges and Van Baren, 1997).

2.3.3 Chemical degradation

This refers to a negative change in the chemical properties of soil. The chemical processes include salinization, alkalization, acidification, pollution, nutrient depletion and fertility decline and reduced organic matter content of soils in agriculturally productive areas (Vargras, *et al.,* (2009) and Ravishankar and Sreenivas (2015)). Two common problems related with chemical degradation of soils are nutrient depletion and pollution. The natural

depletion of soluble elements occurs from soils through the process of leaching by rainwater. This form of degradation may also arise whenever soils bear crops or are grazed). When chemical fertilizers are overused, the soils cannot retain the excess which is leached and this can cause pollution in the marine environment (Aminu, 2014 referring to Bridges and Van Baren, 1997). Depleting plant nutrients from soils is an obstacle to food production and therefore, a threat to food security (Bridges and Van Baren, 1997). Chemical pollution of soils is a direct result of human activity and studies have shown that it is a major cause of soil degradation. Many agricultural soils have been contaminated by the addition of sewage sludge containing toxic metals such as cadmium or zinc (Haruna, *et al.,* 2009).

2.4 Land Degradation Processes

Land degradation processes refer to phases, stages or procedures of any modification or disturbance or systematic decline in the quality of land, perceived to be harmful or undesirables; these processes affect the value of the biophysical environment by a combination of human-induced processes acting upon the land resulting in declining function (Fitzpatrick, 2002). Dejene *et al*., (1997) reported that there are misconceptions in understanding land degradation processes; this is because most studies have focussed on the physical aspects of the process. In actual sense, land degradation may be a physical process, but its fundamental bases are firmly bounded in the socio-economic, political and cultural environment in which land users operate. Although land degradation processes do occur without interference by man, these are broadly at a rate which is in balance with the rate of natural rehabilitation. So, for example, water erosion under natural forest corresponds with the subsoil formation rate. Some of the processes that lead to land degradation are:

2.4.1 Water erosion

Water erosion is the most predominant process of degradation and occurs widely in all agro-climatic zones. Water erosion or soil erosion by water is the removal of soil particles by the action of water and it is more noticeable than wind erosion in the areas of high intensity of the early rains, which occur at a time when the entire land is virtually bare. Erosion washes away the top fertile soil and organic matter, making the upland soil less fertile, terrain deformation or both. Water erosion classification comprises processes such as splash erosion, sheet erosion (a more or less uniform removal of a thin layer of topsoil), rill (small channels in the field) and gully erosion (large channels, similar to engraved rivers). The off-site and downstream effects of erosion include siltation of dams and waterways, nutrients in runoff causing eutrophication, and pesticide in runoff causing pollution of water bodies and aquatic flora and fauna (Ravishankar and Sreenivas, 2015). John and Gerald, (2011) reported that these eroded materials are deposited at the base of uplands and, in most cases, such materials are unproductive.

2.4.2 Wind erosion

This refers to the uniform dislodgment of topsoil or soil particles by wind action. It can result in loss of topsoil and the deposition of the eroded material elsewhere leads to formation of dunes. The uniform displacement of topsoil by wind action occurs in thin layers or sheets (Ravishankar and Sreenivas, 2015). The irregular displacement of soil material by wind action leads to deflation hollows and dunes. The lifted medium to coarse soil particles may reduce the productivity of adjacent fertile land when they are deposited in the form of sand castings. Wind erosion most easily occurs with fine to medium size sand particles.

Soil erosion by wind negatively impacts on soil fertility as the rich top soils are removed due to the exposure of the land for more than half of the year during the dry season. In

both water and wind erosion, as soils are carried away, the nutrients associated with them are also carried away, resulting in a reduction in soil fertility which influences negatively on crop profit. In wind erosion, the surface soil is lost and gets deposited in other fertile areas thereby altering the fertility and nutrient as well as water holding capacities (John and Gerald, 2011). The effect of the wind can carve out hollows and other features.

2.4.3 Waterlogging

Waterlogging is the lowering in land productivity through the rise in groundwater close to the soil surface or insufficient drainage of surface water, often resulting from poor irrigation management (UNU, 2010). Waterlogging is considered as physical deterioration of land and it is affected by excessive ponding or logging of water for relatively some period and affects the productivity of land or reduces the choice of captivating crops. Waterlogging occurs in some areas as a result of topography, flooding or poor drainage condition. The major consequence in these areas includes lack of proper oxygen supply to plants leading to rotting, development of soil-borne diseases, reduction in nutrient supply, non-availability of certain nutrients, etc. However, the magnitude of impact depends on the duration of waterlogging. The waterlogging could be surface (ponding of water) or sub-surface. While surface logging could be noticed, the sub-surface water logging mostly goes unnoticed (Ravishankar and Sreenivas, 2015).

Waterlogging exerts a more profound damaging impact on grassland than on farmland that is usually located on a high ground. It represents one of the most severe methods of land degradation. Also, included under this heading is the severe form, termed ponding, where the water table rises above the surface. Waterlogging is linked with salinization, both being brought about by improper irrigation management. As a result of waterlogging, water saturates the root zone leading to oxygen deficiency (UNU, 2010).

2.4.4 Salinization and alkalization

Salinization is the concentration of salts in the surface or near-surface zones of the soil and is a major process of land degradation (Thomas and Middleton, 1993). Baartman *et al.,* (2007) argued that it is a natural process resulting from high levels of salt in the soil, originating from landscape features that allow salts to become mobile (movement of the water table) and from climatic trends in favour of salt accumulation.

Salinization or Alkalization could be of natural or manmade, they are mostly associated with semiarid and arid areas (UNU, 2010). Salinization is an increase in salt in the soil water solution. The high concentration of salts results in the drying of plants due to high osmotic potential put forth on the plant. Alkalization happens mostly in inland and older alluvial plains whereas salinization is mostly associated with the coastal areas and younger alluvial plains. Alkalization is associated with waterlogging due to poor permeability of soil by the presence of sodium whereas salinization can result from improper management of canal irrigation water resulting in the rise of water table and consequent accumulation of salts in the root zone in arid, semi-arid and sub-humid (dry) conditions (Ravishankar and Sreenivas, 2015). Unsustainable practices in irrigation and production may lead to increased salinization of soil, nutrient depletion, and erosion. An estimated 950 million ha of salt-affected lands occur in arid and semiarid regions, nearly 33% of the potentially arable land area of the world, and globally, some 20% of the irrigated land (450,000km^2) is salt-affected, with 2,500–5,000 km^2 of lost production every year as a result of salinity.

2.4.5 Sedimentation

This may occur through flooding, where fertile soil is buried under less fertile sediments; or the wind blows, where sand drowns grazing lands; or catastrophic events such as volcanic eruptions (UNU, 2010). Sedimentation can harm existing crops but can

eventually lead to an increase in productivity due to increase in soil thickness and quality (Baartman *et al.*, 2007).

2.4.6 Acidification

Any soil process or management practices which lead to building up of hydrogen cations (also called protons) in the soil will result in soil acidification (Ravishankar and Sreenivas, 2015). It also takes place when base cations such as Calcium, Magnesium, Potassium, and Sodium are missing from the soil leading to high hydrogen ion concentration; this results in a reduction of soil pH below 6.5. Increasing acidity through selective removal of Calcium cations on the exchange complex affects the balance in nutrient availability, encourages P-fixation and induces free Aluminium, instigating severe toxic effects. It is also associated with iron toxicity and generally occurs in regions of very high rainfall (Ravishankar and Sreenivas, 2015).

2.4.7 Glacial

These are processes of land degradation which occur under continuous snow-covered areas in the Himalayan region. It degrades an area by two processes namely frost heaving and frost shattering. Frost heaving is defined as a process in a glacial and periglacial environment where extreme frost action and freezing of water develops uncommon forms of rock, regolith, and soil. The water crystallizes to the ice below the surface horizon leading to micro-relief variations on the surface. This process affects the germination and root growth of several crops thereby limiting the productivity of the land. Generally, these regions remain fallow during winters (Ravishankar and Sreenivas, 2015).

2.4.8 Others

Some of the degraded lands processes, which could not be included in the above type of land degradation processes, are included here. Ravishankar and Sreenivas, (2015) listed

these processes as mass movement or mass wastage, barren rocky or stony waste areas, riverine sand areas, sea ingression areas.

2.5 Anthropogenic Land Degradation Processes

This is a land degradation process occurring as a result of human activities. Human economic activities like mining, industrial activities, deforestation, overgrazing by livestock, mismanagement of agricultural land, overexploitation of the vegetative cover for domestic use, etc., have contributed to decreased biological productivity, diversity and resilience of the land (Gabriels and Cornelis, 2017). Mining, brick kiln activities, and industrial effluent-affected areas are contained within this type of degradation processes (Ravishankar and Sreenivas, 2015). Nutrient depletion or nutrient mining from fertile agricultural fields, without replacement through manure or fertilizer, result in nutrient deficiencies. Removing plant residues also reduces soil organic matter content. Removal of topsoil while mining for precious metals and affecting its surrounding agricultural fields is another dimension of land degradation (Ravishankar and Sreenivas, 2015). Hence, the top fertile soil is almost permanently lost, if properly not conserved. Chemical toxicity from industrial effluents and soil contamination with poisonous chemicals affects the plant growth significantly.

Anthropogenic factors leading to soil degradation are driven by desperate situations and helplessness in the case of resource-poor farmers and small landholders; and greed, short-sightedness, poor planning and cutting corners for quick returns in the case of large-scale and commercial enterprises.

2.5.1 Land degradation in abandon mining land

Mining activities can be carried out on the surface or underground, but Surface mining results in more harmful influences on the environment than underground mining. Röder and Hill (2009) described land degradation as one of the noticeable environmental

impacts of the surface coal mining. They further highlighted some of the consequences of post-mining activities as destruction of natural habitat at the mining site and at waste disposal sites, destruction of adjacent habitats as a result of emissions and discharges, destruction of adjacent habitats arising from an influx of settlers; changes in river regime and ecology due to siltation and flow modifications, changes in landform; land degradation due to inadequate rehabilitation after closure, land instability; danger from failure of structures and dams, and abandoned equipment, plants and buildings.

Kemal, (2010) reported that, in Turkey, assessment of land degradation around the mine sites and remediation of the mined-out areas is one governing condition specified to mineral industry preceding to mining extraction for sustainable development. Geospatial information technologies partake widespread series of application in monitoring the mine environment. It can be used to evaluate mining-induced land degradation through investigation of changes in topography and Land Use and Land Cover (LULC) over time (Kemal, 2010).

Researches on land degradation as a result of mining activities have been carried locally and internationally, some of these researches are reviewed below while others under review of related works in section 2.11.

Application of remote sensing in mining industry began with interpretation of aerial photographs for surface mine monitoring mainly aiming to detect temporal and spatial changes in mine sites (Anderson, 1977). Tören (2001) used Landsat TM imageries to detect mining induced environmental impacts around Soma open pit coal mine by change detection methods. Woldai and Taranik (2008) also employed InSAR data, Landsat and ASTER images and couple of others, assessed the ground surface deformation and environmental impacts for an operating open-pit mine. They were able to detect subsidence and uplift resulting from subsurface volumetric shrinkage induced by

groundwater pumping. In Ghana, Manu *et al.*, (2004) used the post-classification comparison of Landsat TM and ETM+ images to investigate the temporal and spatial extent of environmental degradation from 1986 to 2000 in the Tarkwa mining area. They concluded that over 60% of the land was degraded to the point where it could not be used for any commercial activity.

Mularz (1998) using SPOT imagery with Landsat and aerial photographs, monitored Land Use and Land Cover (LULC) changes over the lignite opencast mine and power plant area and evaluated reclamation activity on overburden dump area using post-classification comparison technique. Another application of SPOT imagery comes from Erdoğan (2002) in which SPOT satellite imagery taken 1987 and 1999, were used to monitor the changes in Göynük lignite mine in terms of the areal extent of stripping. Volumetric changes due to overburden excavation and dumping were calculated by DEM overlay method. Additionally, land use map of the research area was extracted by using maximum likelihood classification method with an 88% overall accuracy.

Choi *et al.*, (2008) demonstrated a research on flood and gully erosion at Pasir open pit coal mine in Indonesia using hydrological tools of GIS. They were able to determine the bench slopes that were most vulnerable to gully erosion.

Numerous researches on the effects of post-mining activities on the environment were also conducted in Nigeria and Jos city and environs in particular. Edun and Davou (2013) carried out an inventory of abandoned mine ponds or dams on the Jos-Bukuru area using geospatial techniques. They mapped out a total of 100 major ponds and 80 minor ponds which spread across the area of study. Edun and Davou (2013) research is related to that conducted by Adedeji *et al.*, (2014) in which they carried out an assessment of environmental impacts of inland sand mining in parts of Ogun state, Nigeria. GPS points

were collected for 27 Inland sand mining sites and integrated into Geographical Information System as attributes of sites captured for a spatial analysis.

Jonathan and Joshua (2013) opined that gully erosion in Jos metropolis is one of the physical manifestations of environmental degradation, this motivates them to identify 38 gully erosion sites and revealed that eroded lands and mining ponds occupy 4.06% and 2.92% of the land in Jos metropolis. Elsewhere, in the South-eastern part of Nigeria, Igbokwe et al., (2008) carried out similar mapping and monitoring of gully erosion impact. The method used include the development of Land Use Land Cover map, 3-D digital terrain modeling and slope, and soil analysis. The result revealed minimum and maximum soil loss in the study area.

Likewise, Haruna and Solomon (2011) mapped out the effect of tin mining on the vegetation of Bukuru area of Jos plateau for a period of 32 years i.e. between 1975 and 2007. They discovered a decline in vegetated surfaces in 1986 ranging from 0.04% to 0.58%. They attributed the decrease in vegetated surfaces to intensive mining and cultivation.

Summarily, Igbokwe *et al*., (2008); Jonathan and Joshua (2013) studied gully erosion as indicators of degradation using geospatial techniques, but Igbokwe et al., (2008) added terrain analysis in their study to reveal slope and depth of gullies. In addition, Edun and Davou (2013); Adedeji *et al.,* (2014) collected GPS points of degraded lands, attributes data and onscreen manual digitization to create spatial database of degraded sites.

2.6 Causes of Land Degradation

The causes of land degradation are diverse and reflect complex interactions. Different regions may have significantly different drivers of land degradation, comprising biophysical, socioeconomic and political factors. Natural hazards, population change,

marginalisation, poverty, land ownership problems, political instability and maladministration, economic and social issues, health problems and inappropriate land use are among some factors that determine causes of land degradation.

Land degradation and transformation in Africa is frequently triggered by agricultural activities. Macaulay, (2014) suggested that the cause of land degradation in Nigeria and Africa is land use such as tree felling for fuel-wood and timber production, crop and pastoral land expansion and agricultural growth. Accelerated land degradation is most commonly caused as a result of human interference in the environment. The most frequently recognised causes of land degradation consist of:

2.6.1 Deforestation

Deforestation is the gradual reduction of the stocking of the vegetation covers resulting from human activities. It is the removal of trees and other vegetation (for firewood, commercial or to clear land for farming and settlements). To determine the causes and potential effects of deforestation, the study of deforestation must include an integration of disparate data from both human and natural science discipline, using a Geographic Information System to provide spatial Analysis capabilities.

Forest cover loss and drought are among consequences of deforestation. Regional analyses of deforestation have revealed forest cover loss across broad land-use categories in Ghana (Baatuuwie *et al*., 2011; Stanturf *et al*., 2011; Benhin and Barbier, 2004 as cited in Prince *et al*., 2014). Drought causes deforestation since it reduces crop production and plant regeneration (Dembele, 2006). Conversely, deforestation from timber harvesting causes land degradation (e.g. Stringer and Reed, 2007; Olson, 1994; Bugri, 2008).

Akingbogun *et al*., (2012) reported that deforestation is a continuous process, and efforts have to be geared towards proper inventory and changes monitoring. Deforestation is identified as a policy issue of global importance (CIENSIN, 2005).

The degree of deforestation and forest degradation is more rapid and enormous in developing tropical countries (Forner, *et al.,* 2006 cited in Prince *et al*., 2014). The loss of biological diversity through deforestation and forest degradation threatens economic and environmental value for human sustenance (Prince *et al*., 2014).

Baartman, *et al.,* (2007) reported that deforestation seems to have caused degradation problems, but as deforestation is no longer a major issue in recent times (rather, reforestation is being done in many areas), this seems not to be a direct problem anymore.

2.6.2 Overgrazing

Overgrazing can be termed as allowing farm animals to eat all the covering vegetation until the soil is uncovered and the plants cannot redevelop themselves. It implies grazing at a higher level than desired relative to a specific management objective. According to Reeds, *et al.,* (2008) livestock can induce vegetation degradation in a dryland environment through overgrazing. “Villagers see livestock as a sign of wealth, and would like to maximize their herd size for their own social, cultural and economic reasons and this perception tends to encourage overgrazing and land degradation” (Dejene *et al.,* 1997).

Baartman, *et al.,* (2007) reported that according to the Global Assessment of Human-induced Soil Degradation (GLASOD) survey conducted in 1990, overgrazing is the peak significant cause of degradation in dryland areas of Australia, Africa, Europe and Asia.

2.6.3 Poor land management

Land management comprises the transformation of rangeland or forested land to agricultural use, therefore, poor land management is the misappropriation of such conversion (Baartman, *et al.*, 2007). This can be unsuitable farming methods for the type of land or soil; farming that is too exhaustive (compelling the land to yield food crops year after year without letting it 'rest' to build up the nutrients again; using chemical or no fertilizers rather than natural fertilizers such as animal dung or organic matter). Low fertility could indicate land degradation which has the effect of reducing crop productivity implying low income for the farmers, thus propagating poverty (John and Gerald, 2011). Hence, management of land resources is essential for both continued agricultural productivity and protection of the environment against land degradation.

2.6.4 Fires

This includes bush and savannah fires, instigated by people, which strip the soil of the plant material that prevents soil erosion. Fires, which are often used to reduce the occurrence of livestock diseases, clear land for farming and for the early growth of pasture for grazing, can destroy vegetative cover and soil organic matter; lower the diversity of soil creatures and increase erosion (e.g. Dembele, 2006; Dejene *et al.*, 1997; Bugri, 2008).

Research conducted by John and Gerald, (2011) indicated that bushfires were the number one factor that exposes the soil to erosion according to farmers in a local region in Ghana. Wildfires not only lead to land degradation through the temporary biomass damage, but also, and perhaps more importantly, by affecting the physical and chemical properties of the soil and its structure, the nutrient status, and by causing a substantial increase in runoff and soil erosion during the post-fire 'window of disturbance' (Shakesby *et al.*, 1993; Ferreira *et al.*, 2000; Shakesby and Doerr 2006 as cited in Baartman, *et al.*, 2007).

2.6.5 Pollution

This is caused by dumping scrap metal, plastics, and packaging and building rubble. It also includes environmental pollution due to refuse disposal, emission of carbon dioxide etc. Pollution can occur in a different form such as water pollution (contamination by chemicals, hard metals etc.), air pollution (especially industrial effluents, emission of poisonous gases etc.), environmental pollution (due to opencast mining, indiscriminate disposal, unregulated planning of structures in urban areas etc.). Environmental pollution and mining activities are interrelated (Ravishankar and Sreenivas, 2015).

2.6.6 Mining

Mining activities could cause prevalent environmental damages, subsequently damaging the soil and the underlying structure of the land. Chemicals used during mining pollute soil and water. They demonstrate the huge impact that manipulation of the environment by humans can have on rates of land degradation. Removal of topsoil while mining for valuable metals and disturbing its immediate agricultural fields, is another aspect of land degradation (Ravishankar and Sreenivas, 2015). Although mining activities affect small areas directly, they have significant impacts on surrounding areas. Coal mining as a surface operation can cause greater land cover changes in the surrounding areas where such mining take place (Kemal, 2010).

When the mine reaches the end of its life, the site is normally abandoned and remains a mixture of depreciated materials, mining by-products, and unproductive rubble, usually coarse, and often of extremely toxic chemical composition, which is unfavourable to colonization by plants and animals. These sites left a legacy of polluted land and groundwater, with wide impacts through the redistribution of toxic elements by wind and water flow hence causes degradation of land.

Balkau (1993) reported that most obvious environmental influences of mining are land degradation, disturbance of forest and croplands, water table change, disturbance in surface water flow, erosion, subsidence, acid mine drainage, pollution in surroundings by discharges and waste dumping.

2.6.7 Neglect or abandonment

This is the failure to take care of local plants, trees, and biodiversity. Neglect means that the soil will not be naturally fertilized and protected, so it cannot, in turn, raise other life. Abandoned land, on the other hand, are areas that are devoid of human activity or not being used productively. Degradation may decrease when cultivation methods (e.g. ploughing, leading to erosion) have ceased and natural vegetation takes over. On the other hand, there is a risk of further degradation when cultivation structures (e.g. terraces) collapse and when (over)grazing is allowed on the abandoned lands (Baartman, *et al.*, 2007).

2.7 Consequences of Land Degradation

When land is degraded, wildlife, plants, and people suffer. It can worsen the effects of poverty and bring about hunger. Degradation of land has serious consequences for food security. Many small-scale farmers in areas of degraded land can only watch in disappointment as their soil grows less each year to feed their families. This situation is made worse by droughts and erratic weather patterns caused by climate change.

John and Gerald, (2011) reported that the primary effect of land degradation in their study area, comprise scarcity of wood products for building and domestic energy supply, less pasture for animals and low crop yield which worsens poverty and hunger amongst the people. Other effects include loss in soil fertility, siltation of water bodies, low agricultural productivity, famine, malnutrition, and poverty. Lal *et al.*, (2012) observed that vegetation removal also aggravates land's vulnerability to erosion, thus depleting soil

productivity. When land is degraded, the vegetation becomes increasingly scarce, water courses dry up, thorny weeds predominate in once rich pastures, footpaths grow into gullies, and soils become thin and stony. All of these manifestations have potentially severe impacts on the environment, for land users and for people who rely for their living on the products from a healthy landscape.

Ravishankar and Sreenivas (2015) reported that development of degraded lands in India is one of the choices available to increase food production for growing population and to restore the fragile ecosystem. Land degradation has numerous environmental, economic, social and ecological consequences, such as decline in land productivity, reduced agricultural or forestry production, siltation of rivers, canals and drainage systems, decline in income of agricultural populations leading to worsening of a poverty situation, increased rural-urban migration, increased frequency of natural disasters such as floods and landslides and loss of biodiversity. They, in addition, stated that the major consequence in land degraded areas due to waterlogging include deficiency of proper oxygen supply to plants leading to rotting, development of soil-borne diseases, reduction in nutrient supply, non-availability of certain nutrients, etc.

SOW-VU (2010)'s mid-term progress report on Land Degradation Assessment (LADA) project in Senegal highlighted the impact of land degradation in percentages. The most reported items were 'Net income' (36%) and 'Productivity' (24%). The immediate effect on income and productivity also resulted in a precarious food security situation and poverty (10%). 'Reduced land availability' was mentioned in 9% of the cases, whereas effects on 'soil structure' and 'biodiversity' were indicated in, respectively 2 and 3%. 'Production and risk' and 'net income' were in all three Geographic Assessment Areas' (GAA) the dominant type of impact.

2.8 Coping Strategies or Way Forward

To improve soil fertility and crop yield, farmers spread over chemical fertilizers to their crops, but owing to financial constraints most farmers are unable to afford the required amount of fertilizers for their farms (Dejene *et al.*, 1997). Another method is through land restoration i.e. reversing land degradation processes by conversion to restorative land uses, adoption of recommended management practices and amendments (i.e. any material added to a soil to improve its processes and properties) to enhance land resilience and restoration of soil functions and ecosystem services (Lal *et al.*, 2012). Zero Net Land Degradation means the achievement of a state of land degradation neutrality. Achieving it involves a combination of reducing the rate of further degradation of land and offsetting newly occurring degradation by restoring the productivity and the provision of other ecosystem services of currently degraded lands.

2.9 Methods of Assessment of Land Degradation

Land degradation assessment is often not a simple task. It requires continuous monitoring of the environment for more than a few parameters, which are habitually difficult to collect and monitor. Several indicators are in vogue to describe soil quality like pH, organic matter content, available nutrients to plant, soil depth and texture, bulk density or porosity, water permeability, water holding capacity, nutrient retention capacity, the presence of chemicals toxic to plants or their primary consumers, and so on. Added to this, there will be several complex interactions among these properties. Thus, soil quality cannot easily be described by one variable or an index (Aminu, 2014; Ravishankar and Sreenivas, 2015).

Existing methods of degradation assessment rarely integrate different components of land degradation, focusing instead on single issues or academic disciplines. In particular, researches have focused on soil degradation, in particular on erosion rather than on

solutions (van Lynden and Kuhlmann, 2002). Furthermore, it is often difficult to detect trends in degradation status over time, due to the use of methods that are not replicable or comparable. Different methods exist for evaluating degradation, including direct observation and measurement, mathematical models and parametric equations, estimates, remote sensing and indicators (Rubio and Bochet, 1998).

The assessment of the extent of degradation encompasses monitoring and mapping on several spatial and temporal scales. FAO (2007) had used direct observations, parametric methods along with remote sensing techniques for the assessment of land degradation, on a global level at 1:5 million scales.

Ecological assessment and the measurement of soil properties (e.g. Stringer and Reed, 2007; Reed *et al.*, 2008) have been employed to study land degradation. Moreover, combinations of methods were proposed by Van Lynden and Kuhlmann (2002), these including field monitoring, remote sensing, agricultural productivity change, expert opinion and land user perspectives. Three of these techniques (field monitoring, expert opinions, and land user perspectives) are concisely reviewed and discussed below while the fourth method (remote sensing is discussed in detail in section 2.10).

2.9.1 Field monitoring

This is a method in which several indicators are assessed directly or indirectly in the field where land degradation is being observed. Aminu (2014) reported such indicators as rainfall characteristics, using rainfall gauges; vegetation status (e.g. vegetation cover, biomass etc.); soil characteristics (e.g. soil moisture, aggregate stability, organic matter content); (ground) water salinization and landscape characteristics (mainly soil erosion features).

A number of methods are required for the measurement of these parameters. These methods are highlighted by Van Lynden and Kuhlmann, (2002) to include: (geo) statistics for soil sampling, a variety of measurement techniques for the assessment of erosion ranging from the point to plot and small catchment scales, laboratory analysis for soil properties etc.

The advantage of this method is in the very many parameters and processes that can be assessed, such include biophysical characteristics of the soil, landscape and climate; human factors such as population dynamics, living standards etc. (Van Lynden and Kuhlmann, 2002). Its major disadvantages are often the high costs of monitoring (due to instrumentation and personnel) and typically small (local) scale.

2.9.2 Expert opinion

An expert in this context is a scientist who has specific knowledge and experience in a certain field of work and specific geographical area (Van Lynden and Kuhlmann, 2002). Qualitative assessment of degradation in the case of expert opinion is based on the perception by experts of the intensity of the degradation process (degree) and the impact on agricultural suitability, biotic function of the decline in productivity (Baartman *et al.,* 2007). Some degree of expert opinion, in any phase of a specific research or research project, is almost always applied. In some projects, expert opinion is explicitly named as a method of assessment (Aminu, 2014). The GLASOD estimate of the extent of degraded drylands was based on expert opinion, eliciting information about the type, extent, degree, rate and cause of soil degradation over the last 50 years from over 250 soil scientists and environmental experts in 21 regions of the world (Oldeman *et al.,* 1991; UNEP, 1997).

By its nature, it is a qualitative and potentially subjective assessment. Van Lynden and Kuhlmann, (2002) reported that this method is difficult to replicate; even if the same experts can be used, their perceptions of degradation may have changed unpredictably.

2.9.3 Land user perspectives

Land users often have the best local knowledge of land degradation and influencing factors. This perhaps is the reason for broadly recognizing the views and interests of the land user as one of the supreme significant stakeholders in the fortune of the land and hence their contribution in assessing degradation and recovery or prevention (Baartman, *et al.,* 2007).

A disadvantage of the actual assessment phase might be the bias of the land user and his or her dependency on the outcome. The major advantages include more accurate measurements of actual field level processes, the assessment uses the integrated view of the ultimate client (i.e. the farmer or landowner) and results provide a far more practical view of the types of interventions that might be accepted by land users.

2.10 The Remote Sensing Perception in the Assessment of Land Degradation

Remote sensing (RS) is the art, science, and technology of observing an object, scene, or phenomenon by instrument-based techniques; 'Remote' because observation is done at a distance without physical contact with the object of interest (ITC, 2010). Remote sensing is not only about image organisation, rather, it is about image capture and manipulation, providing the model of the earth for the study of the particular phenomenon without having to do the tedious work of examining the land surface at high resolution.

Remote sensing is used in various fields, such as meteorology, oceanography, vegetation monitoring, land use land cover mapping and change detection, cartography, disaster monitoring, hydrology, city and regional planning, mineral exploration, and environmental monitoring (Kemal, 2010).

The availability of remotely sensed data is increasing with the development of RS techniques and satellites. Lindert (2000) presents an exhaustive overview of remote

sensing tools available today, including information on resolution, spectral bands, revisit capacity, swath, price levels, catalogues access and websites. The most common and cost-effective remote sensing data used are high resolution (HR) and in particular Landsat imageries. The remotely sensed data do not correspond directly to the information needed and must be interpreted to derive soil and vegetation parameters. For example, reflection data need to be converted to properties relevant for the soil erosion process, requiring detailed fieldwork to establish relations to be used for the conversion. On the other hand, the advantages of remote sensing are that large areas can be covered at relatively low cost, with a high temporal frequency.

2.10.1 Application of remote sensing in measuring land degradation

Land degradation may be studied via several methods, such as the old traditional method of field surveying and field visits (Gao and Liu, 2008). Maps and measurements of degraded land can be derived directly from remotely sensed data by a selection of systematic techniques, including statistical methods and human interpretation (Abbas and Fasona, 2012). Scientific technique of satellite remote sensing (RS) and Geographic Information System (GIS) concerning land use and land cover change analysis have been employed to study land degradation. (e.g. Prakash and Gupta, 1998; Lillesand and Kiefer, 1994; Al-Quraishi *et al.*, 2004; Braimoh and Vlek, 2005).

Land degradation assessment using remote sensing methods has numerous advantages over other methods. FAO (2007) revealed that remote sensing methods provide a rapid, relatively inexpensive means to gather land information where no other sources are available or where the quality of available information is low. It permits an exact delineation or clear physiographic boundaries, unlike direct observation method that covers a limited area of study. Remote Sensing provides the prospect for repetitive, yearly or seasonally multi-spectral analysis; it is also easier, less time consuming unlike the old

traditional method of field surveying that is tedious and time-consuming. Furthermore, interpretation of satellite imagery can be at quite a lot of stages of intensity or scales (Ravishankar and Sreenivas, 2015). However, among its obstacles are that field checking is essential to better characterize the degradation types, and, not all land degradation features can be seen on satellite imagery, for example, sheet erosion, rills, fuelwood depletion, loss of soil fertility are not visible on RS data. Remote sensing is robust and fairly accurate but remains restricted to a physical state assessment of degradation.

Some land degradation features can be mapped directly from remote sensing images, especially using a high resolution (HR) or very high resolution (VHR) data. These features include: Wind erosion patterns, especially over large areas; salinization patterns in field crops of large irrigated schemes; overgrazing features, shown by low cover grasslands around animal paths for example; sedimentation of lakes or rivers and consequently upstream soil erosion; soil water erosion patterns, but only when of great size and over large areas (gullies); areas already burnt or areas subject to wildfire.

In India, Remote sensing data from satellites like Landsat, SPOT, and IRS, were employed subsequently to derive information on the nature, extent, spatial distribution and magnitude of various types of degraded lands like salt-affected soils, waterlogged areas, ravinous lands, eroded areas, shifting cultivation etc., and also to monitor them periodically. Besides, remote sensing data has been used as an input to derive the parameters required for spatial modeling of soil erosion (Sreenivas, 2000). Stereoscopy from IRS-1D PAN stereo can give a perspective view of the depth of ravines, which enabled improved delineation of ravines into their reclamative groups (Sreenivas and Dwivedi, 2006).

Geospatial analysis is the gathering, display, and manipulation of imagery, GPS, satellite photography and historical data, described explicitly in terms of geographic coordinates

or implicitly, in terms of a street address, postal code, or forest stand identifier as they are applied to geographic models. It was originated in Canada for cataloguing natural resources in the 1960s, using the first Geographic Information Systems (GIS). Geographic information systems are used to predict, manage and learn about all kinds of phenomena affecting the earth, its systems, and inhabitants (Rouse, 2014).

Geospatial data involving environmental parameters such as pollution and land use are very much relevant in monitoring and assessment of land degradation. In this case, geospatial information technologies, Remote Sensing (RS), Geographical Information Systems (GIS), and Global Positioning Systems (GPS) are of exceptional worth. GIS assists the professionals in the management of large amounts of spatial data and carrying out a multiplicity of spatial analysis supporting land degradation assessment (Kemal, 2010).

2.11 Review of Related Works on Land Degradation

2.11.1 Review of related works in Jos

Gully erosion is one of the physical manifestations of environmental degradation in part of the study area. Jonathan and Joshua (2013) identified 38 gully erosion sites and revealed that eroded lands and mining ponds occupy 4.06% and 2.92% of the land in Jos metropolis. They suggested, among others, that the abandoned mine ponds be used as dams for dry season farming and a comprehensive environmental planning for Jos town. Edun and Davou (2013) carried out an inventory of abandoned mine ponds or dams on the Jos-Bukuru North-Central Nigeria using geographical information system and remote sensing technique. Research materials used were Spot 5, Landsat images and GPS locations of some of the sites, ILWIS and ERDAS Imagine 8.6. The study revealed that total of 100 major ponds and 80 minor ponds were mapped out all spread across the area of study. Their recommendations centred on reclamation of abadoned mine site.

Haruna and Solomon (2011) assessed mining activities impact on vegetation in Bukuru Jos Plateau, Nigeria, using normalized difference vegetation index (NDVI). Research data and methods were Landsat TM of 1975, ETM+ of 2007, IDIRISI and Supervised maximum likelihood classification. Vegetation indices were derived from the red and near-infrared bands respectively. The findings of the differential vegetation index analysis revealed vegetated surface decrease by 0.08 between 1975 and 2007. This decrease was due to intensive mining and cultivation.

Sunday, *et al.,* (2013) analysed the poverty-environmental degradation nexus among arable crop farmers in Plateau State, Nigeria. Methods used were: well-structured questionnaires, multi-stage sampling technique with 265 farming households randomly sampled from 9 communities spread across three Local Government Areas of the three agro-ecological zones in the State. The results indicated that information on factors that lead to environmental degradation, household's income and expenditure dominated the bulk of the data. They recommended that environmental aid will to a large extent be significant in accelerating economic growth thereby subsiding environmental degradation. This should be backed by a strong environmental policy with the political will to enforce it.

2.11.2 Review of related works in Nigeria

A number of techniques have been employed to assess land degradation in Nigeria. While it is evident that such various techniques used, all have advantages and disadvantages but overall, the techniques show a clear complementarity with each other.

Adedeji *et al.,* (2014) carried out an assessment of environmental impacts of inland sand mining in parts of Ogun state, Nigeria. The materials and data used were GPS points observed on each sand mining sites, Google image and Ogun state map (collected from Bureau of Lands and survey), and ArcGIS 9.3. The mining sites were digitized, with other

spatial attributes of sites created for a spatial analysis. This formed a database of 27 Inland sand mining sites for query and other analyses.

Igbokwe *et al.*, (2008) carried out mapping and monitoring of the impact of gully erosion in South-eastern Nigeria, using satellite remote sensing geographical information systems. This entailed NigeriaSat-1 of 2005, Landsat ETM+ of 2001, SRTM Image Data of 2004, SPOT 5 of 2005 and Quick Bird Image Data of 2005, ArcGIS 9.0, ERDAS Imaging 8.6, ILWIS 3.3 and Golden SURFER 8.0. The image data were processed to obtain land cover and land use; develop 3D-digital terrain models; generate data for slope and soil analysis, and analyse soil loss using universal soil loss models. The study revealed minimum and maximum soil loss (in Tons/Ha/Yr.) of Abia, Anambra, Ebonyi, Enugu and Imo states.

In Delta state, land degradation is very prominent; hence the need to understand the various contemporary processes causing land degradation is very essential. Abbas and Fasona (2012) applied remote sensing and geographical information technique to assess land degradation in parts of Niger Delta. The study used Landsat TM image of 1986 and Nigeriasat-1 image of 2008 to assess the degraded lands for respective years. The datasets were analysed using ArcView software. The result showed that degraded lands accounted for 10.6% in 1986 and 32.16% in 2008 respectively. Additionally, Ogboi and Nmor (2013) also, administered questionnaires on land degradation forms and causes to two hundred (200) respondents in three (3) different geographical zones (North, Central and South) of Delta state with the aim of identifying the most common forms of land degradation and the cause(s) of such identified form of land degradation in the area of study. Though his research was purely based on questionnaires still he was able to identify major forms of land degradation in the three zones. The Northern Zone had: soil erosion, sedimentation, bush burning and improper waste disposal. In the Central zone, the forms

of land degradation were: bush burning, soil erosion and sedimentation and flooding. While in the Southern zone, the forms of land degradation were: crude oil pollution, flooding and improper waste disposal.

Adewuyi (2009) assessed land degradation in the Peri-Urban area of Kaduna metropolis from the perspective of land use land cover change purposely to ascertain the role of certain variables such as farming system, major crop planted, crop yield, types of trees and their numbers, vegetation types, conservation techniques etc., in the land degradation occurrence. Methods adopted were random sampling, field observation, and semi-structured interview together with descriptive statistics such as means and percentages. Numerous comparison and inferences of the variables used were carried out whereas the discussion centred on relating the analysed results with other results from previous studies and their implications for the sustainable development. His findings revealed that the existing land use land cover could not be vindicated from the ongoing land degradation in the study area due to the following reasons: about 6% of the area is already degraded; the analysed variables indicated 12.7% low average values for surface cover index; 11.4% surface index cover; 40 trees/Ha density cover; loss of vegetation biodiversity; absent of adequate conservation techniques to reduce the effect of farming and herding; and evidence of soil mining and refuse dumping problems. Adequate land use land cover planning, monitoring, and management were part of his recommendations.

Aminu (2014) assessed land degradation in Zaria. Materials and methods used include: Landsat Thematic Mapper 1990, Enhanced Thematic Mapper+, 1999 and NigeriaSat-1 2009 satellite imageries of the study area, and Maximum Likelihood Classification. Field assessment of the physicochemical status of the surface soils of the area, the use of structured questionnaires and focus group discussions for farm-level survey of farmers' perception of soil degradation problem and coping strategies through. Twenty-five

composite soil samples comprising of four sub-samples were taken from five different land uses (plantation, bad land, fadama, cultivated and scrubland land uses) and analysed for key soil physicochemical properties, including particle size distribution, bulk density, porosity, moisture content, organic matter content, CEC, and pH. The variations in the selected soil properties over the five different land uses were tested using variance (F-ratio), whereas the significant association between pairs of land uses and changes in land use land cover over the period under study were assessed using the student t-test and Chi-square analysis respectively. In addition, a Likert scale test was used to analyse respondents 'attitudes to soil degradation and perceptions of the severity of soil degradation. The result of LULC showed that land use changes and exchanges are occurring at rates not lower than 1.6% per annum.

In Niger State, Jibrin (2009) using remotely sensed data to assess the extent of forest degradation in the Kpashimi forest reserve, observed that degraded forests expanded by 48.6% while bare surfaces followed by a 40% increase. In Ibadan, Juo and Lal (1977) observed that after 3 years of forest clearance, soil organic matter declined from about 1.74% to 1.2%.

Maiangwa, *et al*., (2007) conducted a research on land degradation in the north-west zone of Nigeria, his findings revealed that existence of attenuated property rights over land, erosion, overgrazing, woodland destruction (by burning), poor agricultural practices and absence of regulations on land use were some of the major causes of land degradation in northern Nigeria.

Macaulay (2014) reviewed the human-related and climatic factors inducing land degradation in northern Nigeria. He reported that human-related activities such as agricultural or pastoral expansion, agricultural intensification, and fuel-wood extraction as well as climatic or physical factors such as rainfall variability and land-atmosphere

feedback mechanisms were suggested by various authors as agents of land degradation in Northern Nigeria. He further highlighted that the remediation strategies to reduce the impacts of anthropogenic factors include the practice of agroforestry, rainwater harvesting, local irrigation techniques, and utilization of wetter sites, contour ridging and terracing to conserve nutrient and water run-off, cautionary expansion of cultivated sites, and the maintenance of a viable seed stock well-suited to variable climatic conditions.

2.11.3 Review of related works in Africa

In Western Kenya, Graw *et al.,* (2015) carried out land tenure, poverty and land degradation using geospatial analysis. The data and methods used were ArcGIS 10.2 and R software, elevation data (SRTM), MODIS Terra (MOD13A1 of 500m spatial resolution and a bimonthly temporal resolution). The period analysed covered 2001 to 2011. Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) were used as indicators of land degradation as they measure the greenness, health, and density of vegetation cover. Also, additional biophysical data included in the study represents potential evapotranspiration (PET) and aridity index (AI). The trend was calculated by the slope of the linear regression in R. Trends calculated were further referred to as productivity trends. Based on the number of indicators used, the analysis carried out in the following categories: land tenure; population density and number of fields; poverty and land degradation; income shares and off-farm income; accessibility; fertilizer and manure input.

In Ghana, John and Gerald (2011) applied Local Knowledge of farmers in Land Degradation Assessment in the Bawku East Municipality. Questionnaires, interviews, and focus group discussions were used in the research. They deduced population growth, bush burning, overgrazing, fuelwood harvesting, expansion of farmlands and drought are the factors perceived by the farmers to be responsible for degradation in the soil and

vegetation. Moreover, lack of proper coordination among stakeholders (farmers, Non-governmental Organizations, and local authorities) in the locality has resulted in poor planning and implementation of land degradation intervention measures. To cope with the environmental challenge, strategies such as Inorganic fertilizer application, organic manure application, diversification of crops, planting of early maturing and drought-tolerant crops, dry season gardening or irrigation and mixed cropping were suggested.

In South Africa, Magaba (2012) assessed land use and land cover due to land degradation in the Alice and surrounding areas of Eastern Cape Province. Methods and materials were IDRISI software, Landsat TM data of 1984 and 2001, and maximum likelihood classification.

Pre-processed due to irregularities in sensor reading, noise, earth-sun distance, and geometry were conducted then classification. Area calculations were performed for each image. The study revealed that some of the areas which had more vegetation cover in 1984 then by 2001 they were replaced by bare surfaces which can be observed. Generally, dense forests have been degraded, transformed vegetation has been more degraded and the level of the bare surface in terms of its area increase.

2.11.4 Review of related works in Asia, Middle East, and South America

In India, Pani and Carling (2013) examined the linkages between land degradation and socio-economic development in Chambal Valley, on a spatial scale, by combining remote sensing with census data. The study adopted a multi-disciplinary approach and integrated multiple data sources and methodologies to study the implications of land degradation. These included GPS; ERDAS Imagine and ArcGIS software; Survey of India (SOI) topographic sheets; Linear Imaging Self-Scanning Sensor (LISS III); Indian Remote Sensing (IRS-1D) satellite images of 2008 were used to understand the general areal extent and characteristics of degraded land that included the ravine area. The topographic

sheet was to georeferenced the satellite imagery. Also, a regression model was used to derive Index of Socio-Economic Development (ISD); Index of Infrastructure Development (IID) and Composite Index of Development (CID) respectively. The study identified the relationship between land degradation and socio-economic development as a two-way process. The suggestion made was that negative externalities arising out of adverse geographic conditions and environmental degradation may operate at different spatial scales.

Likewise, Sahu and Dash, (2011) in their paper titled "*Land Degradation due to Mining in India and its Mitigation Measures",* discussed various practices that can be adopted to control the adverse effect of mining on land in India. They suggested constant research and development efforts, to find out newer and latest technologies and methodology to reclaim the land for better use, since economic development must have respect for environmental integrity.

In China, Gao and Liu (2008) determined land degradation causes through land cover change detection. ERDAS, Landsat TM of 1992 and ETM+ of 2002, and maximum likelihood method of classification were used to map the degraded lands. Land covers were mapped into barren, degraded land, productive (healthy) farmland, fallow (harvested) farmland, grassland, woodland, settled areas, wetland, and water; using. The results showed that areas subject to land degradation in the form of soil salinization, waterlogging and desertification increased from 2400 km^2 to 4214 km^2. Likewise, most severely degraded land decreased by 122.5 km^2. Newly degraded land stems from productive farmland (263 km^2), harvested farmland (551 km^2), and grassland (468 km^2). As a result, they attributed the worsening degradation to the excessive conversion of grassland to farming, over cultivation, overgrazing, and deforestation.

In Bhutan, Myint and Thinley (2006) mapped out potential land degradation through the integration of geographical information using field method, nine factors of land degradation (drainage density, water flow accumulation, and distance from drainage, water flow direction, slope, aspect, geology, land use and cover and distance from the road). Existing land degradation areas were mapped through field mapping owing to unavailability of high spatial resolution satellite imagery. Existing land degraded sites were documented on enlarged topographic sheet and field map sheets through field observation and visit to the sites. The polygons of existing land-degraded areas were drawn, by referencing the landscape and topographic features such as drainages, ridges, and peaks. Also, DEM was generated from spline interpolation to derive factor maps such as slope, aspect, water flow direction and water flow accumulation. The study demonstrated how to create factor maps while accessing very limited available geospatial information; integrate geospatial information through weighted factor combination mode. In Iraq, Fadhil (2009) detected land degradation using Geo-information technology for some sites in the study area. Materials and methods used were ER mapper 7.1, ERDAS Imagine 9.2, ArcView 3.3, and ArcGIS 9.1, Landsat TM of 1990 and ETM+ of 2000 and Five indices of Normalized Difference Vegetation Index (NDVI), Normalized Differential Water Index (NDWI), Tasselled Cap Transformation Wetness (TCW), Normalized Differential Sand Dune Index (NDSDI, new proposed index, to process, manage, and analyse the raster and thematic data sets. These five indices relating to land degradation were applied to the two imageries to assess the extent of land degradation. The results showed a clear deterioration in vegetative cover (2,620.4 km^2), an increase of sand dune accumulations (1,018.8 km^2), and a decrease in soil or vegetation wetness (1,720.4 km^2), accounting for 12.9, 5, and 8.5 percent, respectively, of the total study area.

In Western Baghdad, Iraq, Najeeb and Mahmood (2012) examined the effect of land degradation degree on the land cover type using Geospatial technology. The study combined several indicators: soil quality, groundwater and the nature of land use. Each indicator was weighted in relation to its influences on desertification process. Each of indicators was assigned a score ranging from 100 (best) to 200 (worst). The value zero was assigned to the areas where the measure is not appropriate and or those that are not classified (e.g. water bodies, urban areas, etc.). The function representing the variation of the indicators (scores) is liner ranging between the extreme values (100 - 200). The results showed that the risk of desertification was part of the level observed in three out of five, it was possible for it to enter the top level if there were no intervention by the authorities responsible for combating desertification and land degradation.

In Brazil, Lu *et al.,* (2006) developed a surface cover index (SCI) to evaluate and map potential land degradation risks associated with deforestation and accompanying soil erosion in a Western Amazon rural settlement area. The relationships between land-use and land-cover (LULC) types and land degradation risks as well as the impacts of LULC change on land degradation were examined. The findings revealed that, sites covered by mature forest and advanced successional forests have low land degradation risk potential, while some types of initial successional forests, agroforestry or perennial agriculture and pasture have higher risk potential. Moreover, deforestation and associated soil erosion were major causes leading to land degradation, while vegetation regrowth reduces such problems. Their research demonstrated the usefulness of remotely sensed data for identification and mapping of land degradation risks and monitoring of land degradation changes.

2.11.5 Review of related works globally

Globally, large areas of land are in various stages of degradation, and are expanding as land formerly vacant for agriculture and pastoralism is subjected to anthropogenic degradation processes, worsened by natural climate events, mostly droughts (Lal *et al.,* 2012).

Berry *et al*., (2003) observed that China, with 22 percent of the world`s population, has only 6.4 percent of the global land area and that 40 percent of the country was badly affected by land degradation. On a global scale, around 10 to 20% of drylands and 24% of the world's productive lands are degraded (Ravishankar and Sreenivas, 2015).

ELD, (2015) reported that annual economic losses due to deforestation and land degradation were estimated at 1.5 - 3.4 trillion Euro in 2008, equalling 3.3-7.5% of the global GDP in 2008. Competition for the scarce resources of soil and water is further intensified by the growing world population and increasing demand for alternative land management products.

A study by three United Nations agencies estimated that 43% (140 million hectares) of the South Asian region's total agricultural land suffered from one or other form of degradation. As per the GLASOD database, globally about 2 billion ha land area is prone to soil degradation, of which 562 million ha (29.7%) is agricultural land, 685 million ha (34.8%) is permanent pastures and 719 million ha (35.5%) is forest and woodland (Oldeman, Hakkeling, and Sombroek 1991 cited in Lal, 2001).

The objective of the Land Degradation Assessment in Drylands (LADA) project was to develop tools and methods to assess and quantify the nature, extent, severity and impacts of land degradation on dryland ecosystems, watersheds and river basins, carbon storage

and biological diversity at a range of spatial and temporal scales (Nachtergaele and Petri, 2013).

Owing to the need for assessing human-induced land degradation, a Global Assessment of Soil Degradation (GLASOD) map that uses soil and terrain attributes was produced at a scale of 1: 10,000,000 through a collaborative project between the United Nations Environment Program (UNEP) and ISRIC (Oldeman *et al.*, 1991). GLASOD indicates the geographic distribution of severity of water erosion, wind erosion and physical deterioration such as soil compaction. The information provided by GLASOD is crucial to policy and decision-makers for establishing priority programs (Skidmore, 2002).

Bai *et al.*, (2008) executed a proxy assessment of land degradation using normalized difference vegetation index (NDVI), Global Inventory Modelling and Mapping Studies (GIMMS), radiometer (AVHRR), CRU 2.1 data, Rain-use efficiency (RUE), Energy-use efficiency and net primary productivity (NPP). These data were corrected for calibration, variations in solar and view zenith angle, and other effects not related to vegetation change. More so, they estimated RUE from the ratio of the annual sum of NDVI to annual rainfall. Their final results from the analysis of the 23-year Global Inventory Modelling and Mapping Studies (GIMMS) and NDVI data indicated that the global sum NDVI (and NPP) increased by 3.8% ($P < 0.05$) over the period of 23 years; the increase was 3% in Africa and North America, 4.4% in Latin America, 4.5% in Australia, 5.4% in Europe and 6% in Asia. Also, 24% of the land area suffered from a declining RUE-adjusted NDVI. Two percent of the land area exhibited a negative trend at the 99% confidence level, 5% at the 95% confidence level and 7.5% at the 90% confidence level. They concluded that biomass trends depend on several factors other than land degradation and improvement; all changes measured by the RUE-adjusted NDVI/NPP index were not land degradation as usually understood, and that long-term trends of NDVI derivatives were

unsophisticated indicators of land degradation. However, as a proxy, the NDVI /NPP trend provided a globally consistent yardstick, and it highlighted places where biologically significant change was happening.

Emil (2010) carried out land degradation assessment for an abandoned coal mine with geospatial information technologies. Historical stereo aerial photos, Worldview-1, Landsat and ASTER satellite images, terrestrial laser scanning (TLS) data, global positioning system (GPS) survey data, and ancillary maps were used for this study. The volume of excavations and fillings, drainage network deviations, and slope instabilities were the investigated topographical disturbances by comparison of the digital elevation models (DEM) for pre- and post-mining stages between the years 1950 and 2009, respectively. Using aerial photos and Worldview-1 satellite image, LULC maps were prepared based on the same time period. The areal extent and spatial pattern of the LULC change were calculated and mapped by post-classification comparison method. Also, extraction of LULC map by maximum likelihood and Support Vector Machine (SVM) classification approaches were explored using ASTER data. In addition to that, image differencing algorithm was also employed using first bands of Landsat and ASTER dataset and images of Normalized Difference Vegetation Index (NDVI) to delineate spatial changes across the research area. The results of land degradation assessment show a significant topographical disturbance and LULC change in the research area. Particularly, three dump areas with a total volume of 2,334,878 m^3 were identified by DEM subtraction. It was found that stream network around the primary dump site shifted towards the South with a maximum displacement of 60m.

2.11.6 Gaps identified from reviewed studies

From the foregoing review of related studies by researchers on geospatial information system of land degradation, deductions were made that relate to data, methodology,

analysis, and results. Adewuyi (2009) used land use land cover, random sampling, field observation, and interviews to assessed land degradation; Haruna and Solomon (2011), Emil (2010), Fadhil (2009), and Bai *et al.,* (2008) used normalized difference vegetation index (NDVI) as an indicator to measure degradation based on the greenness, health, and density of vegetation cover. Besides, Fadhil (2009) employed additional indices such as normalized differential water index (NDWI) and normalized differential sand dune index (NDSDI). More so, Graw (2015), Emil (2010) and Myint and Thinley (2006) used digital elevation models (DEM) as part of the data to analyse the terrain in the analysis of land degradation. Adedeji *et al.,* (2014), Edun and Davou (2013) collected GPS points and attributes of degraded lands to create a spatial database in GIS environment. Other researchers have also centred on the assessment of effects of post-mining activities and gully erosion on the environment (Jonathan and Joshua (2013); Igbokwe *et al.,* (2008)).
In addition to software used, Graw *et al.* (2015), Adedeji *et al.,* (2014), Abbas and Fasona (2012), Najeeb and Mahmood (2012), Fadhil (2009), Igbokwe *et al.,* (2008) used ArcGIS for their analysis. Edun and Davou (2013), Igbokwe *et al.,* (2008) used both ILWIS and ERDAS Imagine for their analysis. Other authors like Pani and Carling (2013) and Fadhil (2009) used both ArcGIS and ERDAS Imagine; Magaba (2012) used IDIRISI.

These researches as good as they look have not satisfactorily address major questions such as how accurate and precise are the degraded sites being delineated? How beneficial are the degraded sites? Is the nature of the terrain related to the rate of degradation?

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter starts with a concise description of the sources of satellite datasets and ancillary data as well as the methods used to process the satellite datasets to extract land information that was later used for land degradation detection, extraction of land degraded sites and nature of the terrain and analysis. The chapter also explained the research materials and techniques as well as the standard criteria used for interpreting the data, and pre-processing, processing and analysis techniques employed in the research. For the image processing, the first part explains how the Quick bird imagery was used to digitize the land degraded areas. While the second part described how the land use land cover classification in the neighbourhood of land degradation sites was conducted using fused Landsat 8 and SPOT 5 imageries. Last part discussed terrain analysis using DEM data.

The reconnaissance surveys and field familiarisation were carried out as the first step of the research. The flowchart in Figure 3.1 is in three sections according to the stages adopted.

The first stage entails data collection (the process of acquiring data necessary for the research). Pre-processing and correction for errors of both the SPOT 5 and Landsat 8, were then carried out, trailed by layer stacking and merged resolution. Ground truthing and signature extraction were then carried out prior to the supervised maximum likelihood classification of the imagery, the accuracy of the classification was assessed and approved before the final production of the land cover land degradation maps and analyses of the land cover classes related to degradation.

The second stage in Figure 3.1 is the pre-processing and correction for errors, mosaicking, subsetting and layer creation of high-resolution Quickbird-2. This is followed by onscreen

digitisation of the degraded sites. The final products are the maps of the degraded sites together with analyses of their attributes.

The third and final stage in Figure 3.1 is the digital image processing: re-projection, subsetting of the 20m digital elevation model (DEM), creation of digital surface, aspects, slope and contour maps were done to reveal the land covers and terrain characteristics of the study area, especially, the land covers that must have resulted from land degradation. The steps adopted are shown in Figure 3.1.

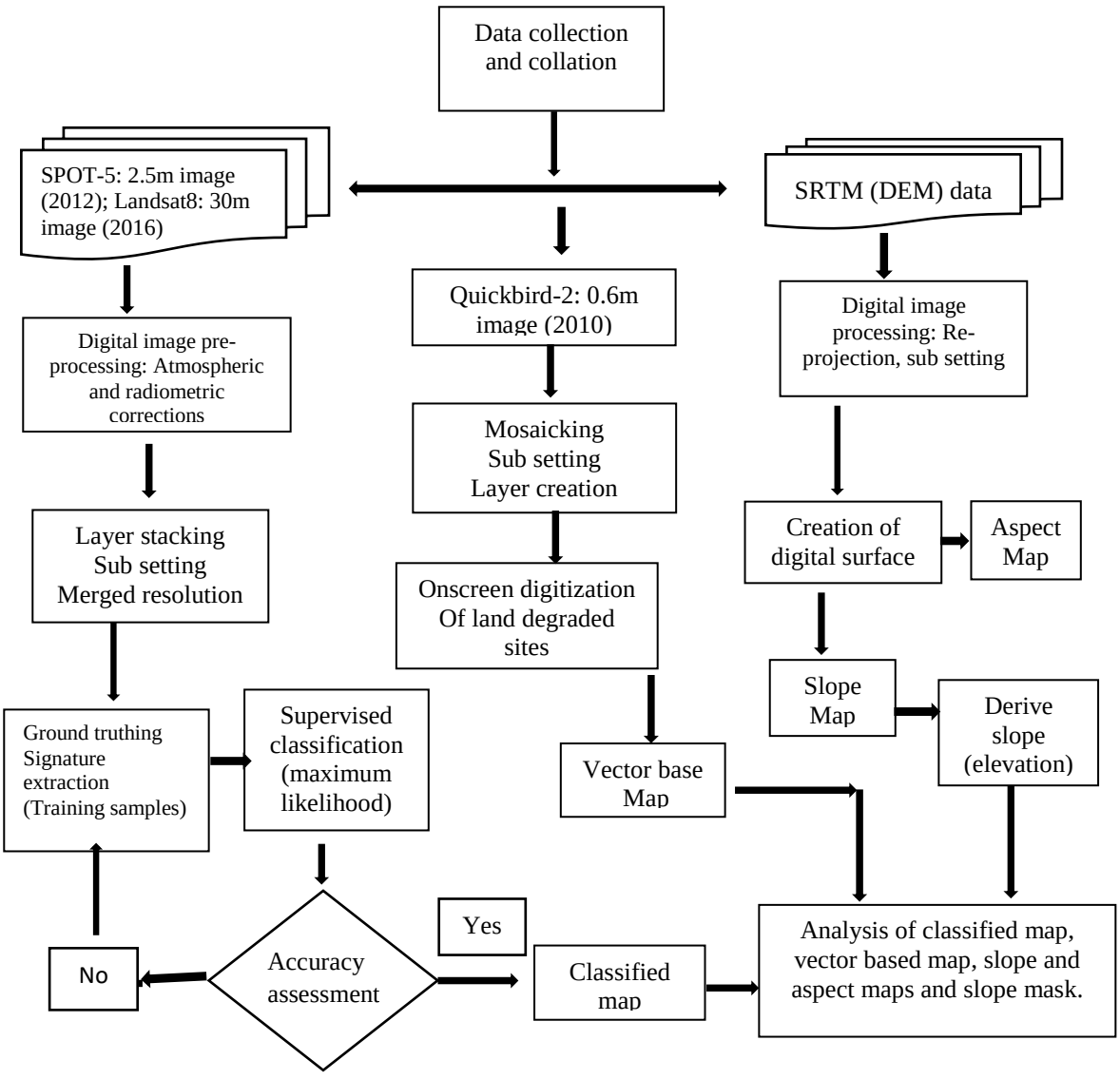


Figure 3.1: A flow diagram of the steps used in the research

3.2 Materials Used

The research employed different types of data such as remote sensing, ancillary data and numerous facilities, software, and tools. A description of each dataset utilised for this research is given below.

3.2.1 Remote sensing data

Three remote sensing images from SPOT, Landsat and Quick bird were employed for the research, to enhance accuracy and produce good results.

i. The SPOT-5 image used in this research was captured in December, 2012.

The image was obtained from the Office of the Surveyor General of the Federation (OSGOF) (copy attached in appendix 1). Four scenes of SPOT-5 satellite imagery of 2012 (details of the metadata shown in the appendix) covering the study area and beyond, was delivered to the researcher for subsequent work. The scene covering the study area is shown in Figure 3.2, and its features in Table 3.1.

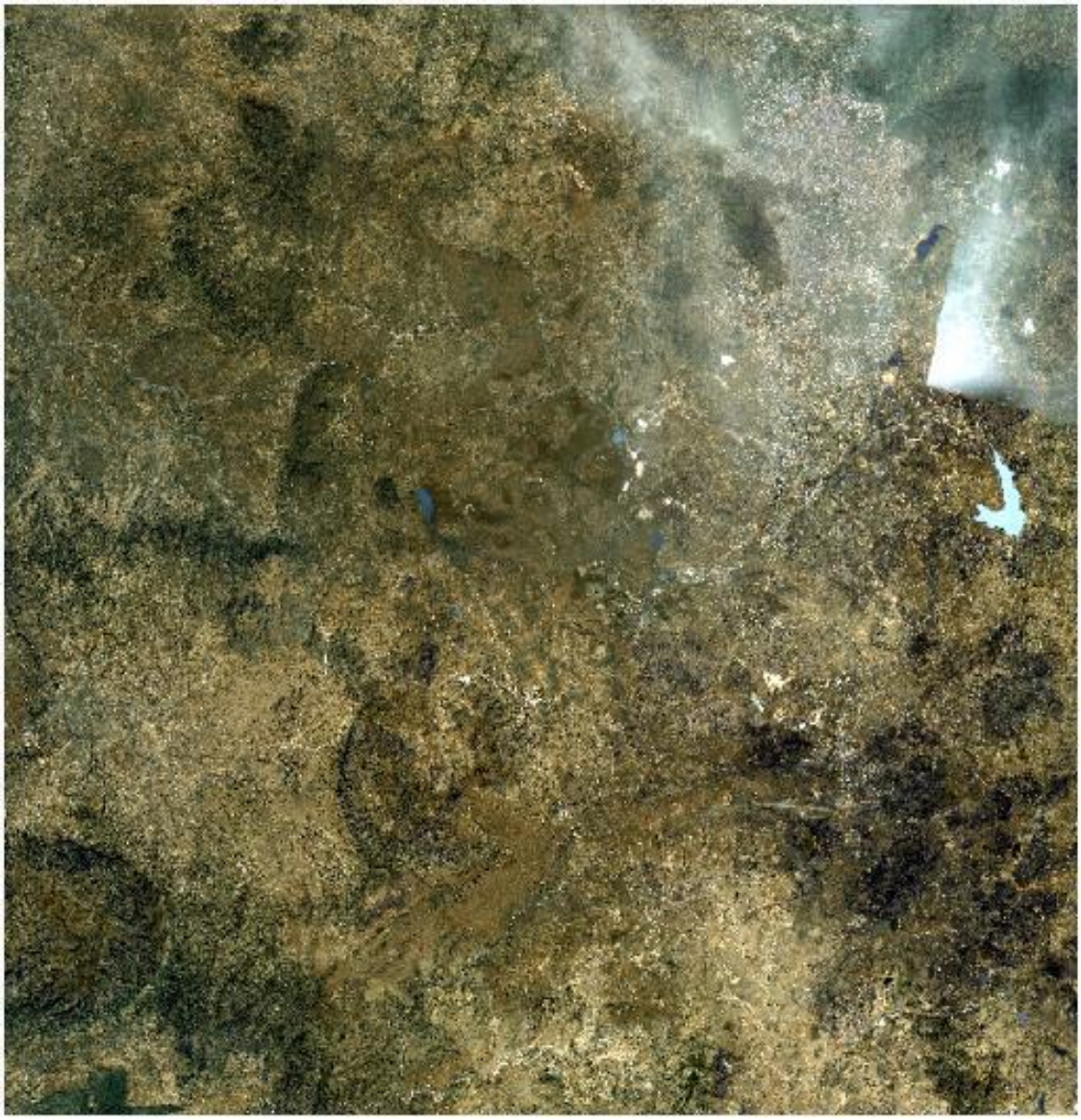


Figure 3.2: A scene of SPOT 5 multispectral image covering the study area
Source: (OSGOF, 2016)

Table 3.1: SPOT 5 Features

Products	Panchromatic: 2.5 m; 5 m; and 10 m Multispectral: 2.5 m; 5 m; 10 m and 20 m
Spectral bands	P (panchromatic); B1 (green); B2 (red); B3 (near infrared); B4 (SWIR: short-wave infrared, for SPOT 4 and 5)
Scene	60 km x 60 km
Revisit interval	2 to 3 days 1 day with the full constellation of Spot satellites
Tasking	Yes, standard or priority
Viewing angle	Cross-track: +/- 27° Forward / backward stereo viewing with SPOT 5
Location accuracy	< 30 m (1σ) with Spot 5
Pre-processing levels	1A, 1B, 2A, 2B, Ortho

Source: (ASTRIUM, 2013)

ii. Landsat 8 OLI and TIRS, 2016:

This data was downloaded from the website of United State Geological Survey (USGS) Agency. The data is an 11 bands image, which was captured during the dry season on 21st February, 2016. The researcher decided to download dry season scene so as to reduce the seasonal effects on the vegetal cover and solar illumination as well as minimize the effect of cloud cover on the image. The scene of the image is path 188, row 53, it has approximated 30m x 30m resolution for bands 1 to 7 and 9, except band 8 with 15-meter resolution and band 10 and 11 with 100 metres resolution (See Figure 3.3). The image has been pre-processed and corrected (as explained in 3.6.1). Summary details of the image are shown in Table 3.2 with further details on its properties shown in Table 3.3.

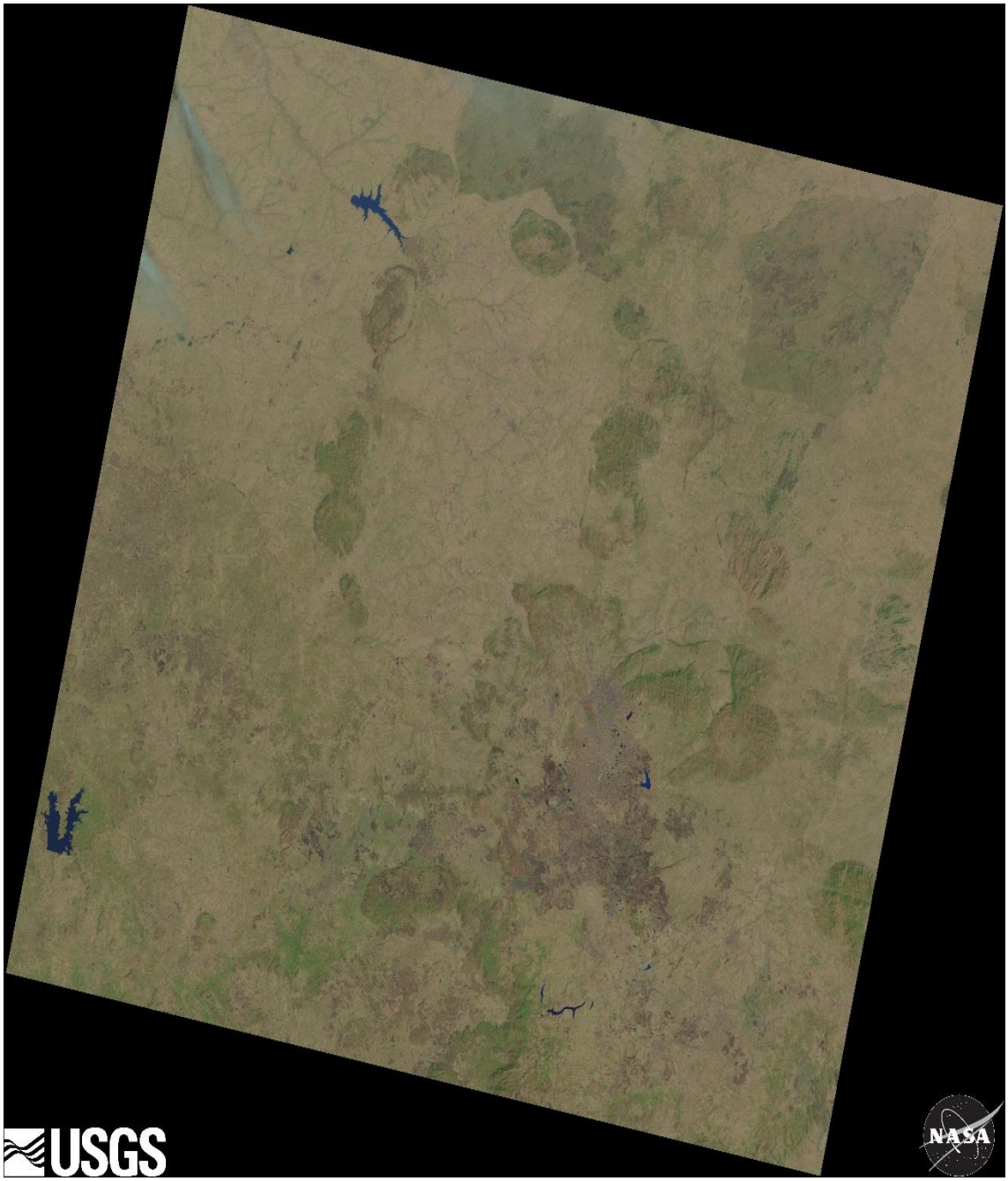


Figure 3.3: A scene of Landsat 8 p188r53 image covering the study area
Source: (USGS, 2016)

Table 3.2: Operational land imager (OLI) and Thermal Infrared Sensor (TIRS)

Band	Spectral resolution (µm)	Spatial resolution (m)	EM region
1	0.433 - 0.453	30×30	Deep blue (Visible)
2	0.450 - 0.515	30×30	Visible blue
3	0.525- 0.6	30×30	Visible green
4	0.630 - 0.680	30×30	Visible red
5	0.845 - 0.885	30×30	Near infrared
6	1.560 - 1.660	30×30	SWIR
7	2.100 - 2.300	30×30	SWIR
8	0.500 - 0.680 (Panchromatic)	15×15	Green, Red, Near Infrared
9	1.360 - 1.390	30×30	Cirrus
10	10.3 – 11.3	100×100	TIR
11	11.5 – 12.5	100×100	TIR

Source: (Aliyu, 2015)

Table 3.3: Landsat 8 properties

Spatial Resolution	Bands 1-7,9	30m
	Band 8 (panchromatic)	15m
	Bands 10 and 11	100m
Quantization level	12 bit (4096 level)	
Swath Width	170×185 Km	
Revisit (Repeat coverage)	16 days (233 orbits)	
Altitude	705 Km	
Inclination	98.2°	
Orbit type	Sun-synchronous	
Equatorial crossing	Descending Node: 10:00 am Local Time	

iii. Quick bird-2, 2010:

This data was made available by the National Centre for Remote Sensing, Jos (NCRS), under Nigeria Space Research Development Agency (NASRDA) upon presentation of an introductory letter collected from the Department of Geomatics, A.B.U. Zaria as a formal identification. The data was provided free for this research to encourage research in GIS and remote sensing in Nigeria. The data was captured in 2010. The properties of the data: resolution, bands, scene size, sensor etc. are shown in Table 3.4.

Table 3.4: QuickBird-2 properties

Satellite	**Sensor**	**Band #s**	**Spectral Range** (μm)	**Scene Size (km)**	**Pixel Res (m)**
QuickBird-2	Multi-spectral	1=Blue	450 – 520	16.5 X 16.5	2.44 - 2.88
		2=Green	520 – 600		
		3=Red	630 – 690		
		4=NIR	760 – 900		
	Panchromatic	Pan	760 – 850		0.61 – 0.72 c

Source: (Digital Globe, 2003)

3.2.2 Ancillary data

The ancillary data consist of the study area boundary (ESRI shape file), which was made available by the National Centre for Remote Sensing, Jos (NCRS), and Naraguta topographic map (168) covering part of the study area at 1: 100,000 nominal scale (as shown in appendix). The topographic sheet was used purely for familiarization of the study area and geological features within the area. SRTM Digital Elevation Model data (DEM) was made available via OSGOF, which was used for terrain visualization and analysis. Details of the bands and other sensor information are shown in Table 3.5.

Table 3.5: List of datasets used in this research and their sources:

DATA NAME	RESOLUTION	DATA DATE	DATA SOURCE	PURPOSE	DESCRIPTION
SPOT 5	2.5 m	7/12/2012	Office of the Surveyor General of the Federation	Land degradation mapping and analysis	3 bands multispectral image: NIR, red and green
Landsat 8: OLI and TIRS	15, 30& 100m	11/2/2016	http://www.glovis.usgs.gov/	Collateral data for land degradation mapping	11 bands multispectral image acquired by OLI and TIRS
Quickbird image	0.6 meters	2010	National Centre for Remote Sensing, Jos	Data for polygonising the land degraded sites	3-band multispectral image: NIR, red and green.
Digital Elevation Model (DEM)	20 m in both H and V directions	-	Office of the Surveyor General of the Federation	Terrain visualization and analysis	A raster Digital Elevation Model (DEM) covering the study area.
Nigeria administrative map (Shapefile)	-	-	National Centre for Remote Sensing, Jos	To demarcate the study area	Jos South local government boundary shapefile
Google Earth Pro 7.1.2 2041 imagery	Variable resolution	2016	http://www.google.com/earth/download/ge/agree	Ancillary data for land cover mapping	Quick look mono-spectral image displayed over red, green and blue colour gun

3.2.3 Software packages

Digital image processing and Geographic Information System (GIS) software were used to process and analyse the geospatial data used in this research. Other software relevant to the research were employed as well. These include but not limited to:

i. WinRAR version 3.7 (for unzipping Landsat 8 image raw data)
ii. MapSource (for downloading of field data from Garmin GPS)
iii. Google Earth Pro (for additional ground-truthing in inaccessible areas)
iv. ERDAS Imagine 9.2 and 2014 versions (used for pre-processing such as image correction and enhancement, post-processing such classification, accuracy assessment, change detection etc.)
v. ArcGIS 10.4.1 (for map making and analysis)
vi. Microsoft office processing tools (Excel and Word) 2016, used for project write up

3.2.4 Equipment, tools and devices

The following field equipment and tools were used for fieldwork: Garmin Handheld GPS 76CSX (for the purpose of capturing the position of the degraded sites and for navigation throughout the study area), topographic sheet of the study area in softcopy format for additional navigation, digital camera, 2 meters measuring tapes, field record book. For office work, internet modem, laptop computer, and HP LaserJet P2015 were used.

3.3 Ground Truthing and Data Collection

Site visit and data collection were done in two phases; 1) the reconnaissance survey, and 2) data collection for Ground truthing.

3.3.1 Reconnaissance field survey

Two days exploratory reconnaissance field survey was conducted on 10 to 11 November, 2015. Firstly, to assess whether the areas degraded and devastated are worth carrying out research on and secondly, to get familiarized with the general conditions in the area.

Most of the places visited are areas affected by land degradation due to mining activities over time, and erosions. Moreover, some of the mining sites were also visited, purposely to have a glance at the type of human activities that lead to the degradation, the impact, and effect on the environment and some of the degraded sites that were turned to recreational areas. At each degraded site, a GPS reading was observed at the location. Elevation and geographic position were recorded using the Garmin GPS receiver set into WGS 1984 at Geographic Coordinate System (GCS).

Photographs were taken during the field survey (this was made easier by the use of Nokia Lumia smartphone camera which captures the photos and then automatically records the coordinates of locations where each photo is captured), which formed part of the primary data collection. The photographs were intended for satellite imagery interpretation, identification of land degraded sites and photographic evidence of land degradation in the study area; some of these photographs were incorporated into the GIS database, geotagged to each degraded site as shown in results and discussion section in chapter 4. It was observed that mining activities were still going on in some sites as of the time of the visit.

3.3.2 Data collection for ground truthing

After the reconnaissance survey, ground truthing was conducted in order to reconcile between the features on the satellite imagery and the corresponding features on the ground. During ground truthing exercise, different land covers such as water bodies, farmlands, bare soils, rocky areas, and settlements were observed.

3.4 Data Attribute Handling and Encoding

The coordinates of land degraded sites (abandoned mine and gully erosion sites) observed during field visit were downloaded from the Garmin GPS receiver using MapSource and imported into Microsoft Excel in which the data were converted to a format recognised by ArcGIS software. These coordinates were used for two purposes: (i) for onscreen digitization (polygonization) of the degraded site in the neighbourhood of the points and (ii) as samples for training maximum likelihood supervised classification of various degraded sites (as discussed in 3.7.1).

3.5 Digitization of Degraded Sites

Heads-up digitizing involves displaying the digital images from satellite or aerial photos on a computer screen and drawing polygons around the land degraded site boundaries and classifying (labelling) them (Wang and Christiano, 2005). This method permits the interpreter to have a far-reaching control over how the degraded land is delineated and classified. It is likely to produce accurate results compared to per-pixel classification (Wang and Christiano, 2005) although it is very time-consuming.

Onscreen digitization of degraded sites was carried out on top of the Quickbird-2 imagery in ArcGIS workspace (this was preceded by image radiometric rectifications, image mosaicking, and image sub-setting carried out as explained in 3.6). Thereafter, the polygons were classified.

The digitation process produced 235 delineated sites in the study area. Ten major sites were chosen for detail analyses. They are: (i) The Rock & Clay Industry Limited Mines Site (ii) The Healthy Body Clinic site (iii) The Rayfield Resort Centre (iv) Dorowa Congo Site (v) Rahwol Kanang Site (vi) Zawan site (vii) Consolidated Tin Mines Pond site (viii) Yelwa site (ix) Jos International breweries site (x) Rennaj Fish and Integrated Farm Limited Pond.

The overall degradation rate was deduced using the formulae:

$$Overall\ Degradation\ Percentage\ of\ the\ ten\ sites = \frac{(Total\ Area\ Degraded\ of\ the\ ten\ sites)}{(Total\ Area\ Degraded)}\ x100$$

$$Overall\ Degradation\ Percentage = \frac{(\mathbf{2019020.2})}{(\mathbf{11581829.825439})}\ x100$$

$$\boldsymbol{=17.43\%}$$

3.5.1 Classification of degraded sites based on features

The degraded sites were classified based on their functions, the criteria of distinguishing them were based on the observed features during ground truthing, similar criteria adopted by Nigeria Erosion and Watershed Management Project (NEWMAP). This is the criteria usually employed in carrying out ecological projects by the agency; it is based on the rule of thumb, where each individual site was assessed based on its nature. The sites were code-named after the locality they belong, and where more than one site exists in a particular area, the sites were suffixed with integers to differentiate them. Furthermore, they were characterised into agricultural, irrigational, recreational, fish stocking, inundated and fenced areas. The total area of each site together with its` coordinates was shown.

The overall degradation rate was deduced using the formulae (Adewuyi, 2009):

$$Overall\ Degradation\ Percentage\ = \frac{(Total\ Area\ Degraded)}{(Total\ Area)}\ x100 \qquad (3.1)$$

3.5.2 Mapping clusters of degraded sites

Optimized Hot Spot Analysis and Getis Ord Gi* Hotspot Analysis tools in the ArcMap environment were used to analyse clustering, spatial distributions, patterns, and relationships between the degraded sites. An optimized hotspot analysis was carried out to map the geographical distribution of the degraded sites, whereas Getis Ord Gi* Hotspot Analysis tool creates a map of statistically significant hot and cold spots based on the inputted attribute values. Hot spot simply means statistically significant spatial clusters of high values (hot spot), while cold spot means statistically significant spatial clusters of low values (cold spot). The optimized hotspot analysis tool interrogates the data in order to determine settings that will produce optimal hot spot analysis results. The method allowed the researcher to summarize the salient characteristics of the spatial distribution of the degraded sites, identify statistically significant spatial clusters (hot/cold spots) or spatial outliers of the degraded sites, assess overall patterns of clustering or dispersion of the sites, group features based on attribute similarities, and explore spatial relationships amongst the sites.

The mathematical expressions for the Getis Ord General G statistical computations are stated in equations (3.2), (3.3) and (3.4) respectively.

The Getis Ord Gi star local statistic is computed as follows:

$$G_i^2 \frac{\sum_{j=1}^{n} w_{i,j}x_j - \bar{x}\sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{[n\sum_{j=1}^{n} w_{i,j}{}^2 - (\sum_{j=1}^{n} w_{i,j})^2]}{n-1}}} \quad (3.2)$$

$$X = \frac{\sum_{j=1}^{n} x_j}{n} \quad (3.3)$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2} \quad (3.4)$$

Where:

x_i = the attribute value for feature j.

w_{ij} = the spatial weight between feature i and j.

n = total number of features.

The G_i^* statistic is a z-score so no further calculations are required (ESRI, 2017c).

In the Getis Ord Gi* hotspot analysis tool, coordinates of each degraded site were used as the input features for the analyse. Fishnet polygons mesh of dimension 1km by 1km were overlaid on the incident point (coordinates of degraded sites) data and the number of incidents within each polygon cell of the study area were counted. Also, the study area boundary was provided defining where incidents are possible parameters, hence only cells with at least one incident point was used in the analysis. The output of both the optimized hotspot and Getis Ord Gi* hotspot analysis tool created discrete maps.

3.5.3 Map compilation

After the digitization of the degraded sites, map elements such as a north arrow, grid, legend, title etc., of the map were added. An appropriate scale was chosen to make the map legible. This is shown in chapter four under result and analysis.

3.6 Land Use Classification in the Neighbourhood of the Degraded Area

To achieve the third objective of relating the degraded areas to the neighbouring land use, land use classification in the neighbourhood of the degraded areas were carried out. Essentially, the goal of image processing in this research was to prepare the images for identification and classification of land degraded sites. Pre-processing of the imageries were carried out, followed by merge resolution of Landsat 8 and SPOT 5 imageries and subsequent analyses to detect and map degradation features.

3.6.1 Image pre-processing

Pre-processing refers to those operations that are preliminary to the main analysis. It forms a preparatory phase in order to increases image quality as the foundation for analyses (Mather (1999). All of the image processing, classification, map making and analyses in this research were conducted using ERDAS Imagine and ArcGIS software system.

The following were steps taken in image processing and classification:

i. Layer Stacking

Layer stacking is carried out to produce multi-band image from separate bands. Landsat 8 images are normally downloaded in a zipped file containing a total of eleven bands. Layer stack permits two or three bands to be displayed as stacked layers as a composite image. The stacked image plays a significant role in presenting image data in various colour performances.

Layer stacking was carried out for bands 1-7 and 9 of the Landsat 8, excluding bands, 8, 10 and 11. This is because band 8 is of 15-meter spatial resolution, whereas 10 and 11 are Thermal Infrared (TIR). These were considered not useful in this research. Both SPOT 5 and Quickbird came layer stacked separately.

ii. Mosaicking

Mosaicking is the process of fitting together (joining or stitching) of adjacent georeferenced imagery to form a larger image or a set of images (Aliyu, 2015). The input images must all contain the same map projection.

In this research, mosaicking was conducted only for the Quickbird imagery because it came into different scenes to cover the area of study, unlike the Landsat 8 and also for the SPOT 5 single scene covering the study area.

iii. Image sub-setting or clipping

Subsets is a processing of cutting portion of the bigger images selected to show only the area of interest otherwise called study area. Jos South LG boundary (in .shp file format) defines the area for the sub-setting.

Some of the justifications for image subset is to save processing time and effort; it minimizes computer storage space. Since the study area is only about a quarter of the scenes for the Landsat 8, SPOT 5 and Quickbird images; it was easier to use geometric correction as features were only needed in a small area, and it was easier to verify land degradation classes within the image of the study area.

3.6.2 Atmospheric correction

Atmospheric correction was needed because the images were acquired at visible and near visible wavelengths which are vulnerable to absorption and scattering by dust and water molecules in the atmosphere.

Atmospheric correction was done on the SPOT 5 image to correct for atmospheric effect (clouds or haze) presents in the image. This was executed using haze removal and cloud masking tool available in ArcGIS, which removes the darkest pixel from the image.

The cloud in the image could not be masked during the process due to the absence of SWIR band to process water mask. However, haze was removed to a minimum. This task is shown in Figure 3.4.

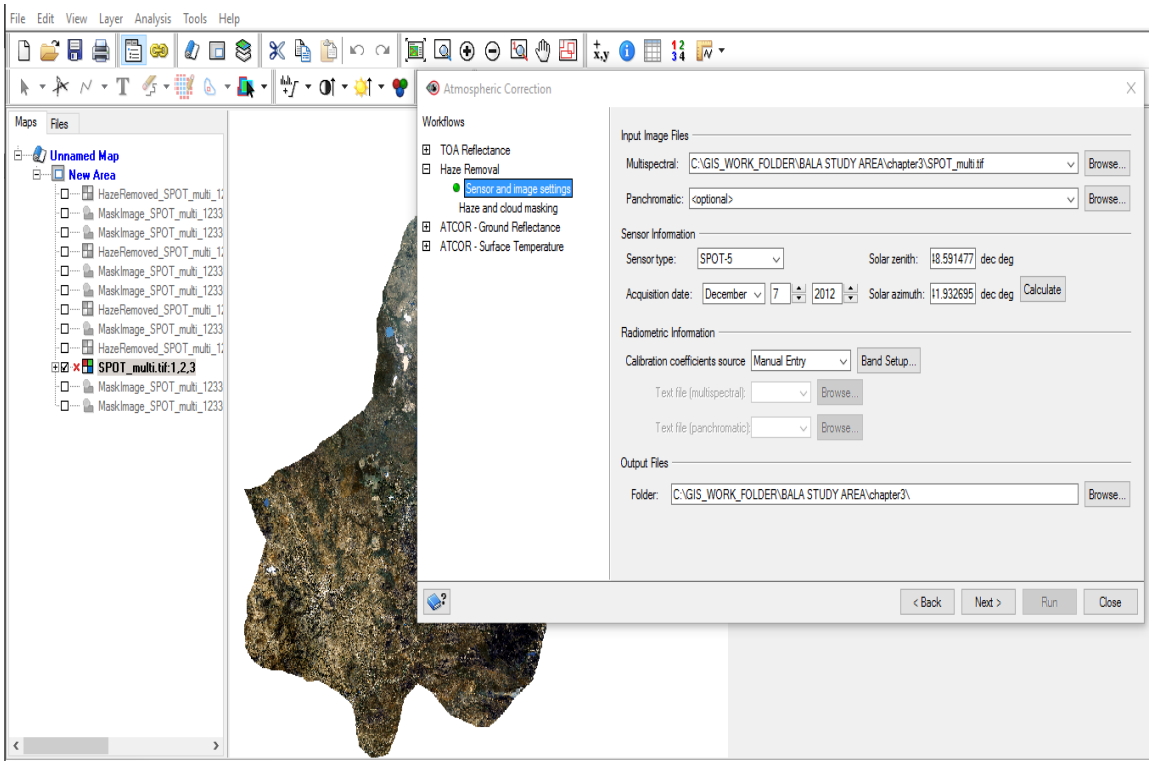


Figure 3.4: A snapshot of the process of haze and cloud making of SPOT 5

To correct for the atmospheric effect in the imageries, the DN values pixels were compared across bands in the stacked image. The difference was subtracted from the entire bands to eliminate the problem of atmospheric interference. Separation of the two types of surface brightness allowed the focus of the analysis on the actual brightness value on the Earth's surface when the image was acquired.

3.6.3 Radiometric enhancement

(i) Haze reduction: this algorithm enables the reduction of haze in an input image. The method is based on the tasselled cap transformation which yields a component that correlates with haze. (ii) Noise reduction: this dialogue enables reduction of the amount

of noise in an input raster layer. This technique preserves the subtle details in an image, such as thin lines, while removing noise along edges and in flat areas.

3.6.4 Image fusion

This involves a combination of image data for a given geographic area with different spatial resolutions in order for spatial enhancement. This technique was used for the improvement of Landsat 8 (30m) resolution with SPOT 5 (2.5 m) image (Olumide, 2007). The Landsat being the most current was enhanced by the fusion with the SPOT (spatial); this is because some of the features in Landsat are less than 30m resolution, hence cannot be seen. This yielded higher spatial resolution and better results, as derivable of degraded sites from the classified image can be visualized.

3.7 Image Classification

Image classification in this research serves a specific goal of transforming image data into land use land cover classes with a view to relate such classes to the land degraded sites neighbourhood. In order to extract important information from the SPOT 5 and Landsat 8 multispectral images, the images were classified. The merged imagery was classified instead of classifying SPOT5 alone because the Landsat 8 is dated 2016 whereas SPOT5 is dated 2012, hence it will be more current to employ both for the classification (Olumide, 2007).

3.7.1. Selection of training data

Training samples are sets of pixels that represent what is recognized as the actual class. Training data used in this classification was based on the field data from the study area carried out to observe the surface conditions (as explained in **3.3.2**) representing various land degraded areas. The training sites corresponding pixels were selected and spread throughout the study area. In addition, Google Earth imagery of 2016 was used as an ancillary data to give information and support interpretation of the latest degraded sites.

The GPS points earlier collected during reconnaissance survey were plotted and appeared on different land cover and degraded sites on the merged imagery. In addition to the use of coordinates for the development of training material, the multispectral image was also displayed onscreen in different colour renditions such as true colour composite (TCC) and false colour composite (FCC) to make different land covers available in the image to swoop. The image was analysed digitally by digitizing the various land covers, a variety of the classes were seen, however, the six were considered.

3.7.2 Selection of classification scheme

The six (6) identified classes were mine pond, settlement, bare exposed rocks, farmland, bare degraded land, and vegetation. Each land cover class was assigned a unique code and identifiable colours; the codes were later used during accuracy assessment as a reference number. The description of the adopted classes is shown in Table 3.6.

Table 3.6: A description of the six adopted land classes

Training sample	**Code**	**Color assign**	**Description**
Mine pond	1	Blue	Land surface occupied by stagnant water body without tributaries which are caused as result of excavation/mining of earth material e.g. lake, waterlogged area.
Settlement	2	Red	Places where commercial, industrial, residential and government facilities are erected.
Bare exposed Rocks	3	Gray	Land consisting of rocky and stony materials.
Farmland	4	Lemon	Land occupied or related to agriculture or farming activities.
Bare degraded land	5	Yellowish	Bare surface that consists exposed excavated earth surface material with no vegetation. Open space and cleared area with no permanent water bodies.
Vegetation	6	Light green	Land consisting of shrubs and other vegetation which is not used for farming activities.

3.7.3 Supervised classification

Classification is the process by which pixels are allocated to classes (Campbell, 2002). The goal of image classification in this research was to create cluster classes from multispectral images to understand the spectral information contained in the images.

With the signature file successfully created, a supervised classification was performed using Maximum likelihood classification algorithm. It was chosen as a parametric (probability that a pixel belongs to a particular class) decision rule. This was done using image classification tool in ArcGIS 10.4.1.

3.7.4 Accuracy assessment

The accuracy of maps from remotely sensed data is measured by two types of criteria: location accuracy (how precisely map items or elements are located) and classification or thematic accuracy (the accuracy of the map label) (Onsomwang, 2007). The assessment offers the sureness in the total land cover mapping (Richards and Jia, 1999). Accuracy assessments utilize an error matrix (Campbell and Wynne, 2011). The reference data (Ground truthing) is compared to the thematic map classes (what has been classified).

Table 3.7 commonly referred to as contingency table or confusion matrix compares a classified image against reference data (Garba, 2008, Congalton, 1991). The major diagonal entries are the training set pixels that are classified into the appropriate land cover classes. While the off-diagonal elements of the matrix are wrongly classified classes which are referred to as either omission or commission errors. Omission errors are represented by non-diagonal column elements, whereas commission errors correspond to non-diagonal row element. For example, a_{21} (Table 3.7) is a commission error in the classification of class 2 but an omission error in the correct classification of class 1. The overall accuracy (Equation 3.5) referred to as the proportion of correctly classified pixels compared to all of the pixels used, is obtained by dividing total correct pixels (sum of

major diagonal) by the total number of (reference) pixels in the error table. The producer accuracy (Equation 3.6) is gotten by dividing the total incorrectly classified pixels in the column by a total number of pixels in the column. The user's accuracy (Equation 3.7) is computed by dividing total incorrectly classified pixels in the row divided by the total number of pixels in the row. Both user`s and producer accuracies measures provide an indication of how well a class was classified (Garba, 2008, Congalton, 1991).

The Kappa statistic is the measure of agreement between the model prediction (classified image) and reality. It is more sophisticated than the overall accuracy because it measures how well the classified data settles with the reference data and takes the misclassifications into account in addition to the correctly classified pixels in the ideal classification; this is stated in Equation 3.10 and can be expressed as Equation 3.11 when applied to the confusion matrix. Garba (2008) reported that kappa statistic is considered as a tool to compare results of several classification procedures using the standardised normal distribution (Equation 3.12), because of its capability to measure the level of agreement.

Table 3.7: Illustration of a confusion matrix

	Reference:					
	Class1	Class 2	…	Class N	Row Total	User Accuracy%
Classified						
Class 1	a_{11}	a_{12}	…	a_{1N}	a_{1+}	a_{11}/a_{1+}
Class 2	a_{21}	a_{22}	…	a_{2N}	a_{2+}	a_{22}/a_{2+}
⋮	⋮	⋮	⋯	⋮	⋮	⋮
Class N	a_{N1}	a_{N2}	…	a_{NN}	a_{N+}	a_{NN}/a_{N+}
Column Total	A_{+1}	a_{+2}	…	a_{+N}	a_{++}	
Producer accuracy%	A_{11}/a_{+1}	a_{22}/a_{+2}	…	a_{NN}/a_{+N}		

Source: Garba (2008)

$$\text{Overall accuracy} = \frac{\sum_{i=1}^{k} n_{ii}}{n} \quad (3.5)$$

$$\text{Producer accuracy} = \frac{n_{jj}}{n_{+j}} \quad (3.6)$$

$$\text{User accuracy} = \frac{n_{ii}}{n_{i+}} \quad (3.7)$$

Error of omission = 100 – producer's accuracy (3.8)

Error of commission = 100 – user's accuracy (3.9)

$$Kappa = \frac{Observed_accuracy - chance_agreement}{1 - chance_agreement} \quad (3.10)$$

$$K = \frac{\sum_{i=1}^{k} n_{ii} - \sum n_{i+} n_{+i}}{n^2 - \sum_{i=1}^{k} n_{i+1} n_{+i}} \quad (3.11)$$

$$Z = \frac{|K_1 - K_2|}{\sqrt{\sigma_{K_1}{}^2 + \sigma_{K_2}{}^2}} \quad (3.12)$$

$$Z = \frac{|K_1 - K_2|}{\sqrt{\sigma_{K_1}{}^2 + \sigma_{K_2}{}^2 - 2\sigma_{K_1 K_2}}} \quad (3.13)$$

Where

K= Kappa coefficient

k= the number of rows (e.g. land-cover classes) in the matrix.

n_{ii} = the number of the observation in row i and column j.

n_{i+} = the marginal totals for row i

n_{+I} = the marginal totals for column j

n = the total number of observations

z = standardised normal distribution

3.8 Analyses of Terrain in the Neighbourhood of the Degraded Sites

To achieve the forth objective, terrain analyses were carried out. The study area DEM data has 20m resolution and it comes georeferenced and projected World Geodetic System (WGS) 1984 datum in longitude and latitude. Since the DEM was meant for terrain analysis, there was a need to re-project it to UTM WGS 84 so that both horizontal and vertical axis can have linear and uniform units. After this, the DEM scene was then clipped to match the study area. These tasks were executed in ArcMap 10.4.1 and it is shown in Figure 3.5.

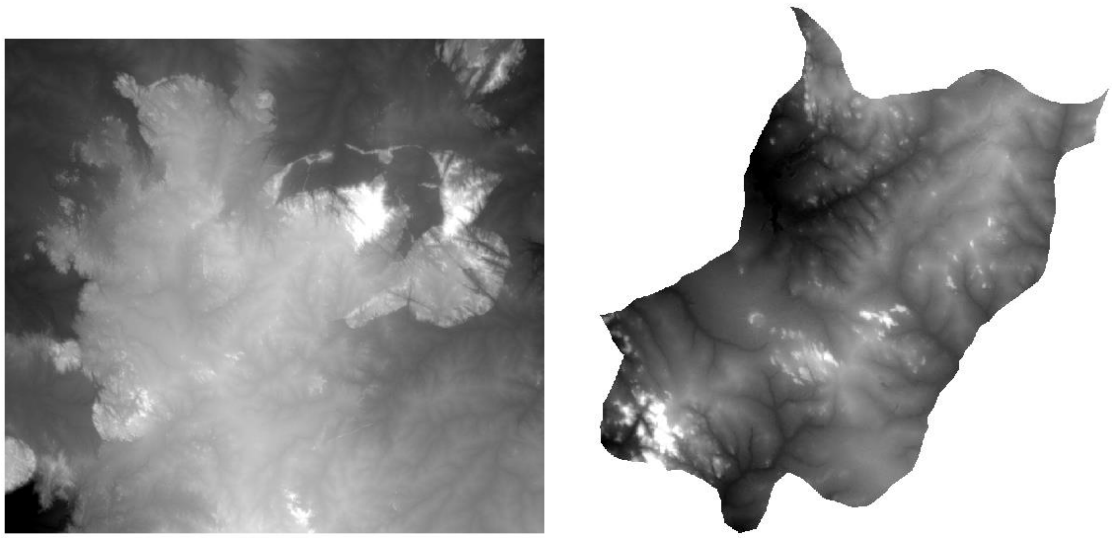


Figure 3.5: (a) A DEM scene; Jos South (b) A subset DEM of the study area

3.8.1 Creation of surface models

The DEM was used to generate slope and aspect maps. Slope is the amount of rise of a surface (change in elevation) divided by the distance over which this rise is computed (the run), along a straight line transect in a specified direction. Slope identifies the steepest downhill slope for a location on a surface. Slope is calculated for each cell in raster images. For raster images, it is the maximum rate of change in elevation over each cell

and in relation to its eight neighbours. It can be calculated in percentage and degree (ESRI, 2017a).

$$Percent\ of\ slope = (Rise \div Run) \times 100 \quad (3.14)$$

$$Degree\ of\ slope, \theta = \tan^{-1}(Rise \div Run) \quad (3.15)$$

Aspect is a direction in which a slope at a given point on a surface has a maximum value. It identifies the downslope direction of the maximum rate of change in value from each cell to its neighbours. It can be thought of as the slope direction. The values of each cell in the output raster indicate the compass direction that the surface faces at that location. It is measured clockwise in degrees from 0 (due north) to 360 (again due north), coming full circle. Flat areas having no downslope direction are given a value of -1 (< 0) (ESRI, 2017b).

3.8.2 Derivation of slope (elevation) mask

Image mask is a way to mask out pixels from an image. It is a binary raster that has two values, namely, active pixels (1) and masked pixels (0). It is used for analysing attributes of a terrain i.e. its flatness, heights, and depths. The goal is to visualize or analyse a terrain by setting pixels to certain values or thresholds. The advantage of applying a mask in terrain analysis is to "screen out", "lay emphasis" or "focus on" certain pixels in a particular land cover; and crisper display of the image (Aliyu, 2015).

In this study, depth is of concern and is associated with derelict mine ponds, gully, eroded surfaces and excavated surfaces, due to the configuration of the study area (being a mine site and also rocky in nature). The following steps were used in creating the image mask as outlined below:

Step 1: Examine the pixel values of the land covers in the derived slope map. In the case of land degradation, depths are of concern since it involves excavation of the earth

surface, example: derelict mine pond, gully, eroded surface etc. The slope values for areas with depths and flatness are less than zero (< 0), while other land covers have slope pixel values above 0.5.

Step 2: Set a threshold pixel values for areas with depths and areas with heights. Zero (0) is assign to depths (values < 0.1) and one (1) is assigned to areas with heights (values > 0.1). Using build mask tool in raster management toolset, a binary image is formed having pixel values of zero (0) and one (1). The zero corresponds to areas with depths which are to be highlighted, while one corresponds to areas that are to be suppressed.

Step 3: Resample the derived slope mask with the merged SPOT 5 and Landsat 8 images so that they will have the same dimension (row and column values). The image mask will have the same size and shape with the parent image (SPOT 5). The computation is a pixel by pixel multiplication. Apply the slope (elevation) mask to the SPOT 5 image. This is shown in Figure 3.6.

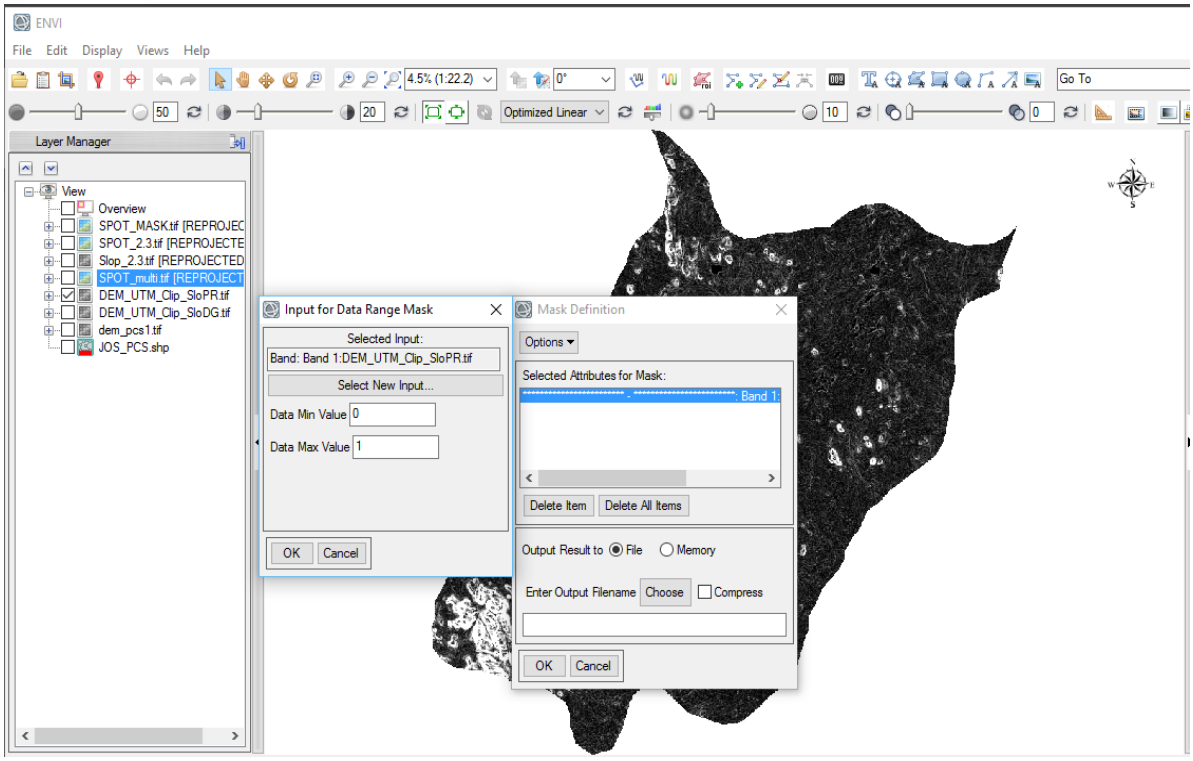


Figure 3.6: A snapshot of the creation of slope mask.

3.8.3 Derivation of flow direction, flow accumulation and stream network

Primary attributes such as flow direction, flow accumulation and stream networks were derived directly from the DEM. To hydrologically correct the digital elevation model, and derive some hydrological datasets called primary attributes, the Fill function was used to modify the elevation value to eliminate some imperfections in the DEM data, and to accurately depict surface water in relation to the degraded areas. It also, fills the sinks in a grid. This is because, if cells with higher elevation surround a cell, the water is trapped in that cell and cannot flow. Flow Direction tool was then used to compute the flow direction for a given grid. The values in the cells of the flow direction grid indicate the direction of the steepest descent from that cell. ArcMap's Flow Direction tool uses a calculation method called the 'D8' algorithm. This method is well suited to the identification of individual channels, channel networks and basin boundaries making it suitable for relating the terrain to the degraded sites. However, it is based on two simplifying assumptions that is, the use of 8 discrete flow angles, and each pixel has a single flow direction. Computing flow direction was achieved using flow direction command under Spatial Analyst Tools.

Moreover, Flow Accumulation was executed using the same procedure as that of flow direction. The flow accumulation grid contains the accumulated number of cells upstream of a cell, for each cell in the input grid. This was achieve using flow accumulation command under Spatial Analyst Tools. Raster calculator was then used to obtain the stream networks from the flow accumulation result.

CHAPTER FOUR

RESULTS AND ANALYSES

4.1 Introduction

This chapter presents the results and analyses of land degraded sites in the study area. The results are presented in the form of maps, photos, graphs, charts and statistical tables. The analyses generally involved detecting and demarcating degraded areas, as well as evaluating the amount and dimension of land degradation. The first section discusses the results of the different types digitized degraded sites with their attributes and their characteristics which were executed using the Quickbird imagery. The second section talks on the result of the classified land cover map from merged Landsat and SPOT imageries depicting degraded areas, its spatial distribution, and accuracy assessment of the classified maps. The last section discusses the terrain mapping and analyses with Digital Elevation Model, Slope, Aspect, and Contour analysed. Numerous overlays of maps depicting one or more themes were also discussed. Statistical analyses and summary of findings were reported as well.

4.2. Land Degradation as Observed in the Field

In this study, the detection of land degradation features is directly linked to the surface features affected by mining activities. The study focused however on the detectability and mapping of land degraded sites by remote sensing.

The characterization of land degradation in the study area was straightforward (based on field observation). One of the observable indicators of land degradation in the study area is the sign of extreme ponding and gullying, which is very prominent, exposing sub-surface areas. This could be due to excavation for mining activities and the topography of the area.

There are deposits of huge mining waste near some of the abandoned mine ponds, and logging of water for relatively some period which affects the value and usefulness of the land, especially for the economic purpose. It was almost impossible to assess the depth of gully areas because of seasonal inundation in most of the sites. It was also observed that removal of topsoil while mining for precious metals affected most of the surrounding agricultural fields, which resulted in land degradation. Inadequate rehabilitation after the closure of mining sites also lead to the degradation of some sites while in other abandoned mined areas, thick eucalyptus trees were planted as a means of rehabilitation. The high altitude of the area and steep slopes make water erosion common, especially in the rainy season.

4.3 Demarcation and Delineation of Degraded Sites

Figure 4.1 is the result of digitized degraded sites; the red polygons indicate the sparsely distributed degraded sites. They were carefully digitized and assigned names and other attributes.

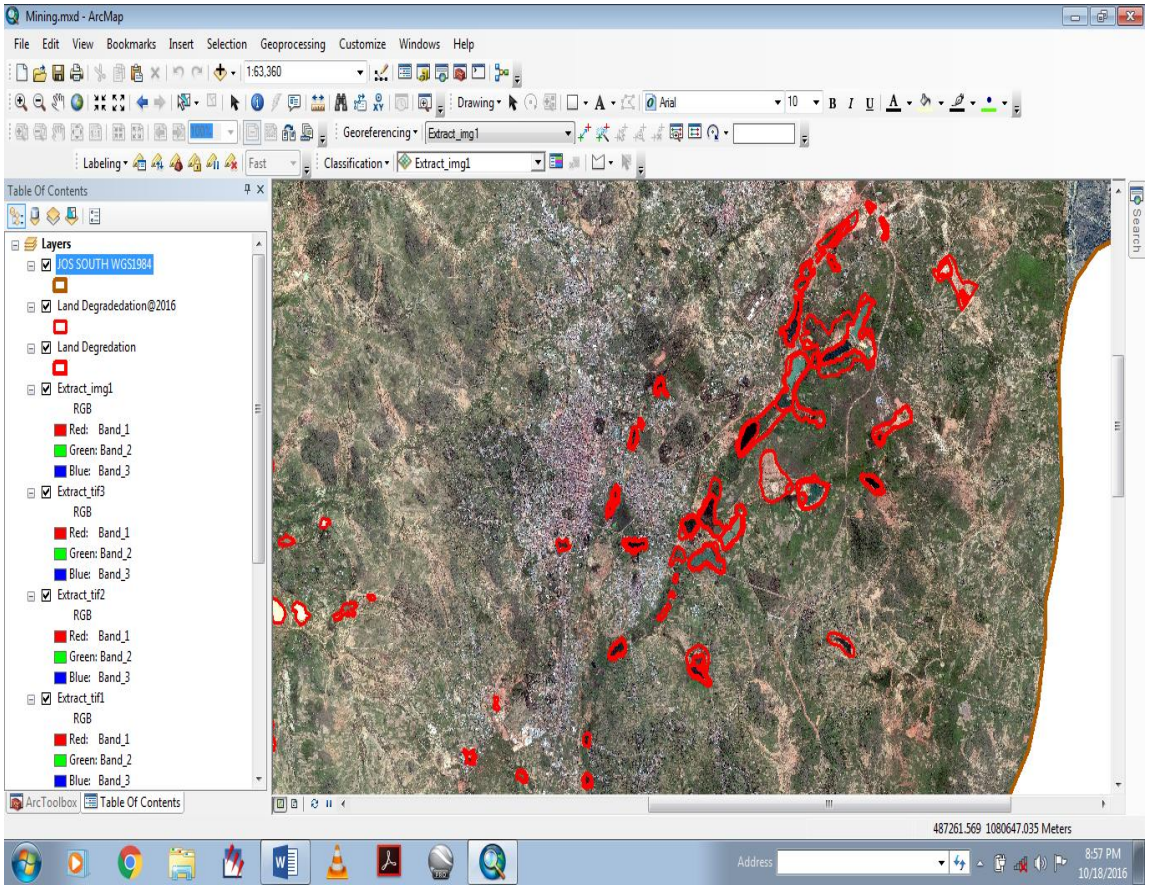


Figure 4.1: On-screen digitization of degraded sites on the Quick bird-2 imagery

The results of the ten selected sites are as follow:

(i) The Rock and Clay Industry Limited Mines

This is the largest degraded site in the study area with a surface area of 660,638.7m^2. This site is located at the back of Rock & Clay Industry Limited, Kuru Janta 25km from Jos city centre, along Jos Heipang Road.

It is roughly estimated as 50m depth, with a steep slope and undulating topography and surface soil colour is brownish to reddish; mining activities have been going on as of the time of site visit. The local miners dug large holes in search of Cassiterite, which resulted in larger loto mining pits and gullies encroaching the nearby farmlands. The gullies are less inundated with very few grasses and shrubs at the surface of the gullies. Figure 4.2 depicts the site location in the study area and its properties.

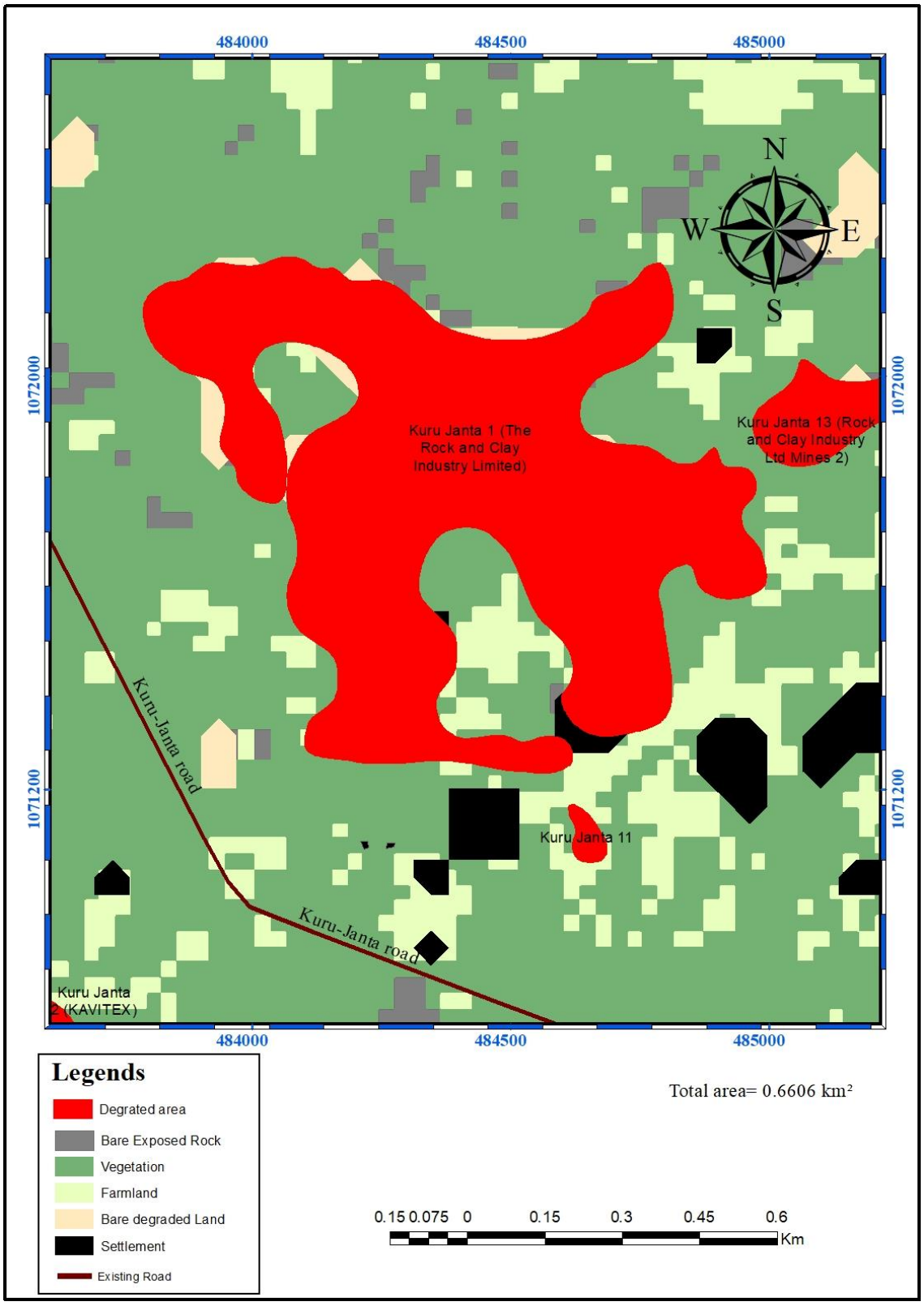


Figure 4.2: Map of the Rock and Clay Industry Limited digitized degraded site

The picture in the Plate I shows the photographic nature of the site in Figure 4.2, it shows hill valleys, gullies, loto mining, mounts with small patches of water and the local miners carrying out mining activities which they say they inherited from their grandparents.



Plate I: Active Mining Site at the Kuru Janta, behind Rock and Clay Industry Limited Mines

(ii) The Healthy Body Clinic site

This is a mining pond located in Kwata, surrounded by residential leased block industry; threatening the adjacent developed facilities; it is referred to as a death trap because children could easily drown into the water and die, but with time, it was partly reclaimed and converted to recreational and economic centre through construction of a resort centre adjacent to the site named 'Healthy Body Clinic resort' as shown in Figure 4.3. The site

has been partially abandoned perhaps due to the seasonal inundation of the site. It has a total degraded area of 11175.7m^2.

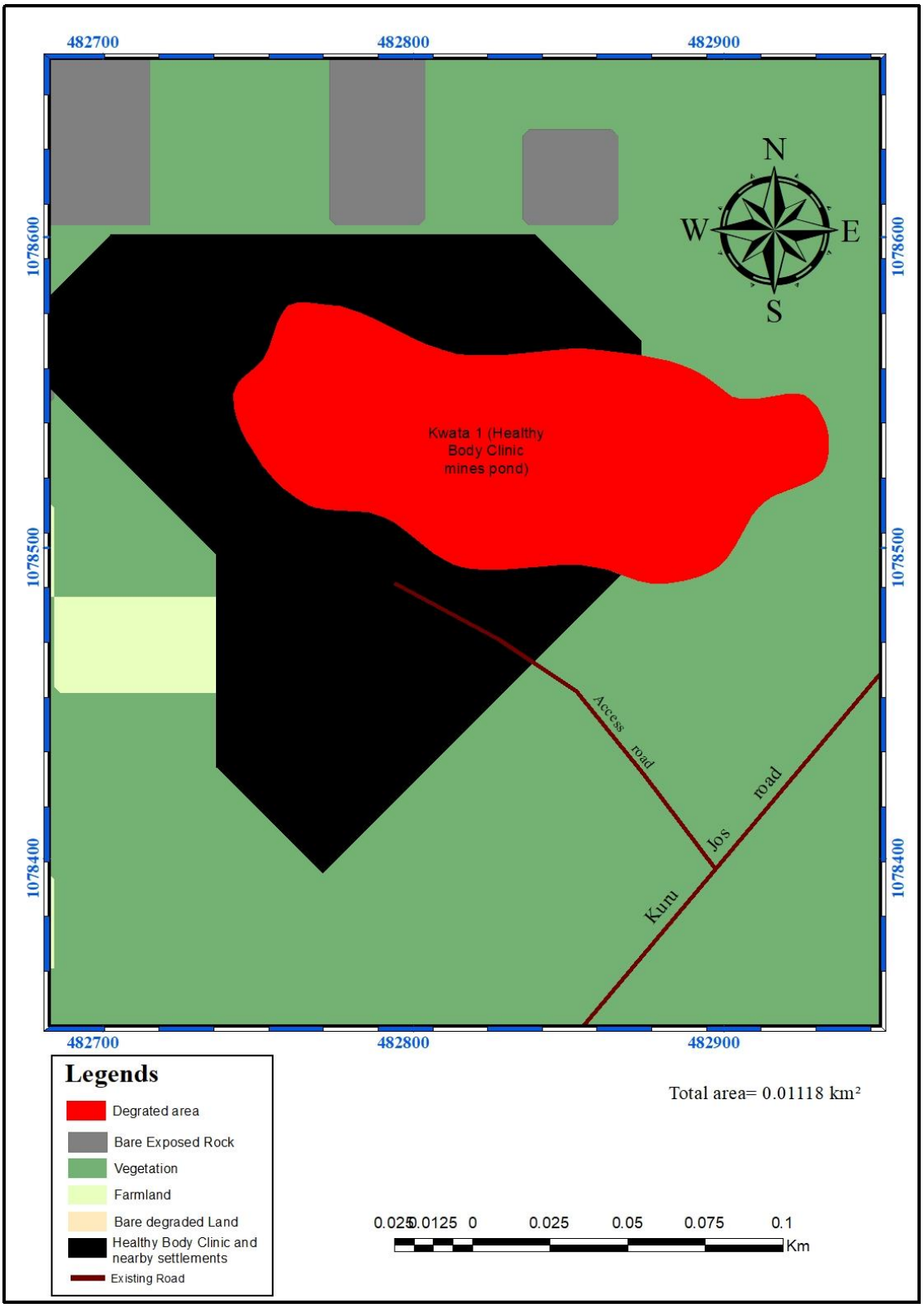


Figure 4.3: Map of the Kwata 1 Site popularly called Healthy Body Clinic.

Plate II shown is the degraded site in Figure 4.3, block industry known as Merit Moulding Industry was constructed near the inundated site so that the water could be used for making blocks.



Plate II: The Healthy Body Clinic Pond

(iii) The Rayfield Resort centre

This is a site consisting of two ponds and also covered a part of the watercourse area where mining activities are still taking place. At this spot, two major mine pits were observed and separated by a minor road as shown in Figure 4.4.

One of the ponds is completely filled with water of an approximate depth of 12 meters, and the other having very little water with inclusions of smaller ponds at the floor of the pit. The site has been turned into the recreational centre because of the seasonal inundation of the ponds. The total area is 524482.6m^2. The inhabitants narrated that the

seasonal inundation was as a result of underground water coming from aquifers which were hit by miners in those days. The site has been turned into an amusement park with clubs, recreational outfits and speed boats for fun and relaxation. The water is also being used by the mineral and construction companies and inhabitants for consumption.

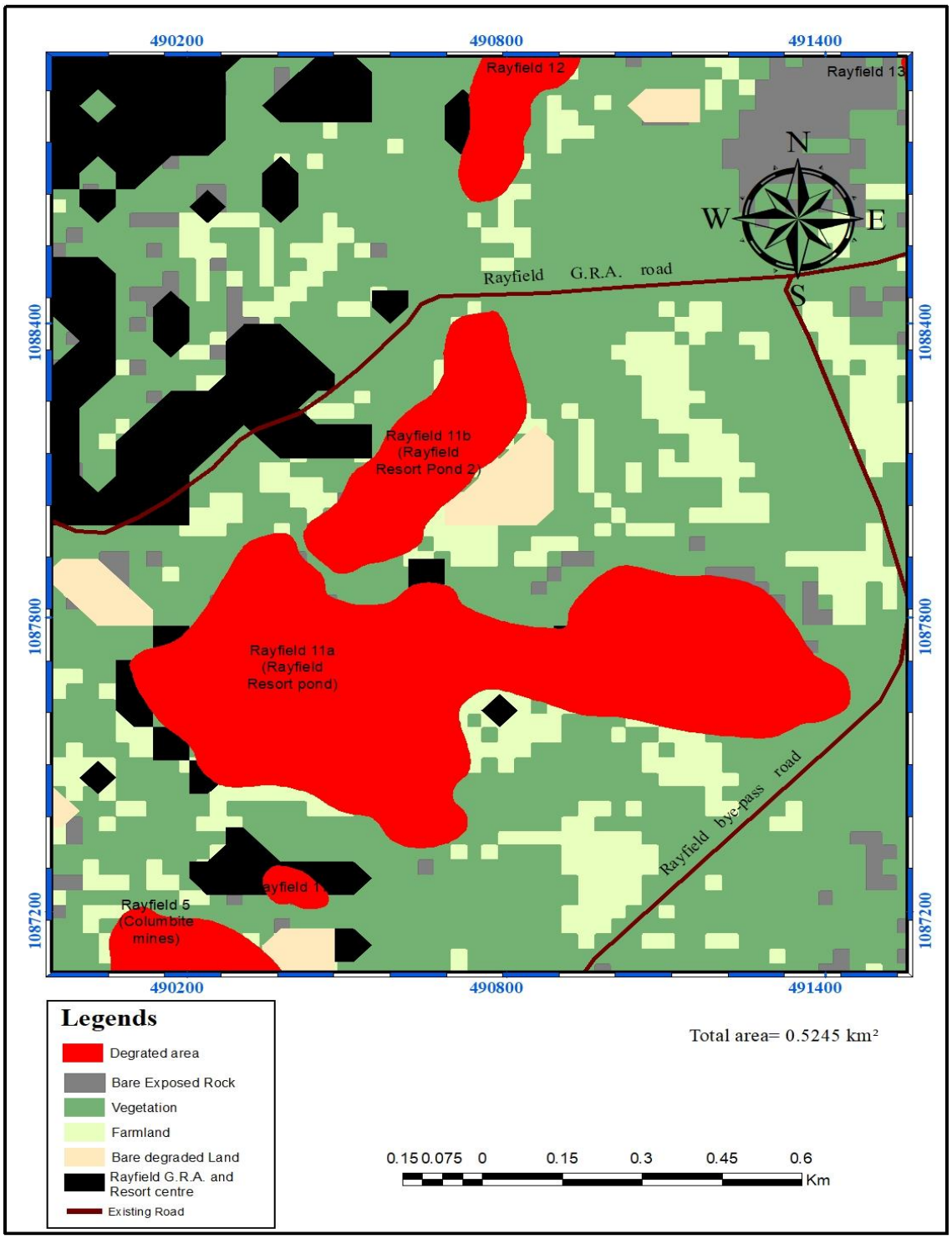


Figure 4.4: The Rayfield Resort centre digitized degraded site

Plate III depicts the artisanal miners searching for Tin and Columbite around Rayfield site i.e. Figure 4.4, this leads to gully erosion and land degradation in the site. The site is gradually eroding and degrading the neighbouring as a result of continuous excavation by artisanal miners.



Plate III: Artisanal miners searching for Tin and Columbite at the Rayfield Resort centre site

(iv) Dorowa Congo Site

This is an abandoned mine site with seasonal inundation and big gullies around the area. It has a total area of 22282.7m^2 as shown in Figure 4.5. In this site, the settlements are built at the edge of the gullies. Large seasonal inundation makes the inhabitants prone to danger due to the risk of building collapse and drowning of children into the water. There is also the danger of environmental pollution because the inundated gullies are being used

as landfills with all sort of waste and garbage thrown inside, this results in continuous bad odor, causing air pollution to the around the vicinity.

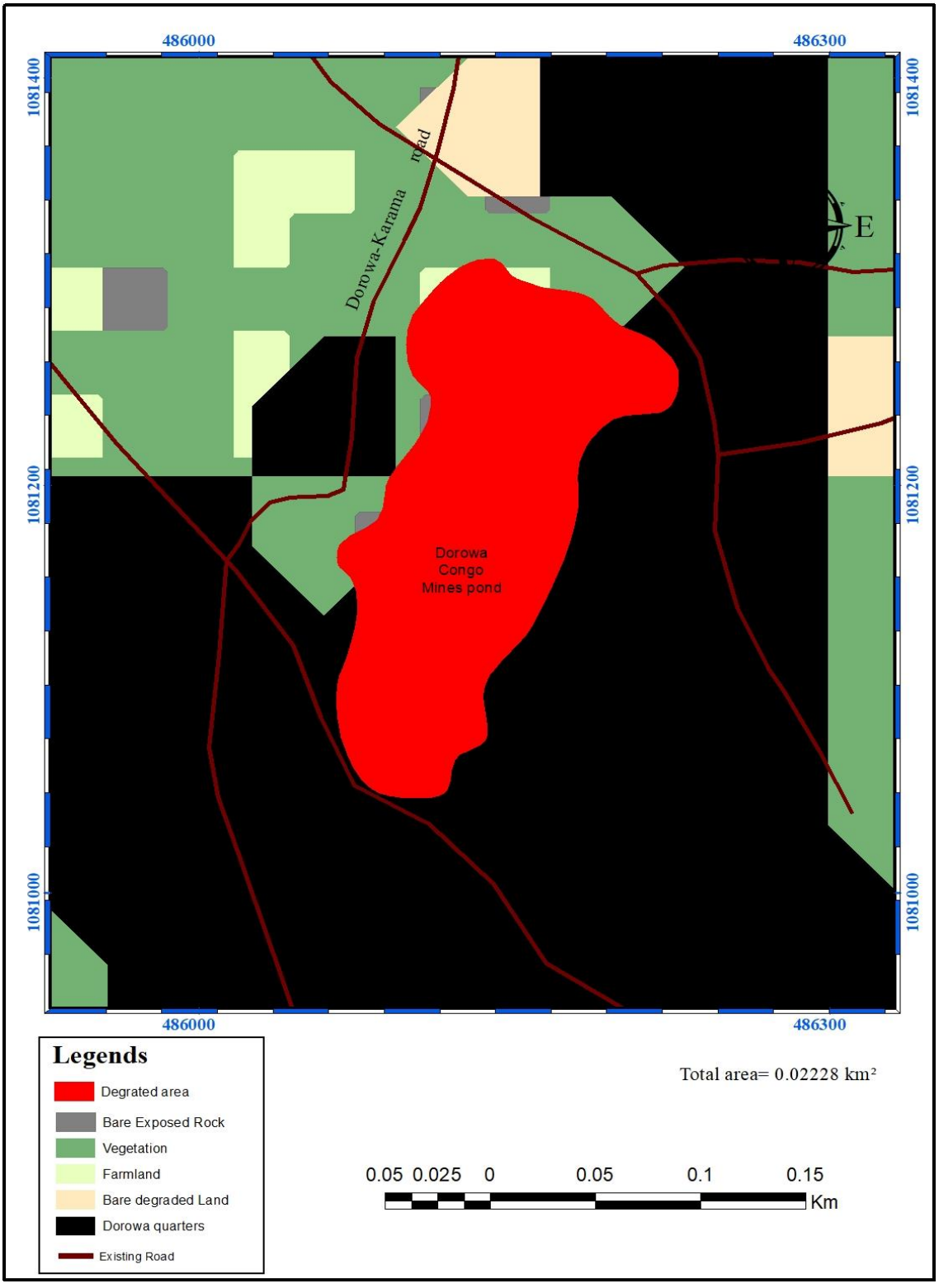


Figure 4.5: The Dorowa Congo digitized degraded site

Plate IV shows the Dorowa Congo area with settlements, waste, and gullies, it can be seen that the buildings at the edge of the site are at higher risk of collapse which could result in loss of lives.



Plate IV: Settlements built at the extreme edge of pond full of contaminated water

(v) Zawan Site

This site is also seasonally inundated; it is located in Zawan area of angle D as shown in Figure 4.6. It has a total area of 25855.4 $m^{2.}$ The site poses a great danger to the inhabitants because children can easily drown in the water.

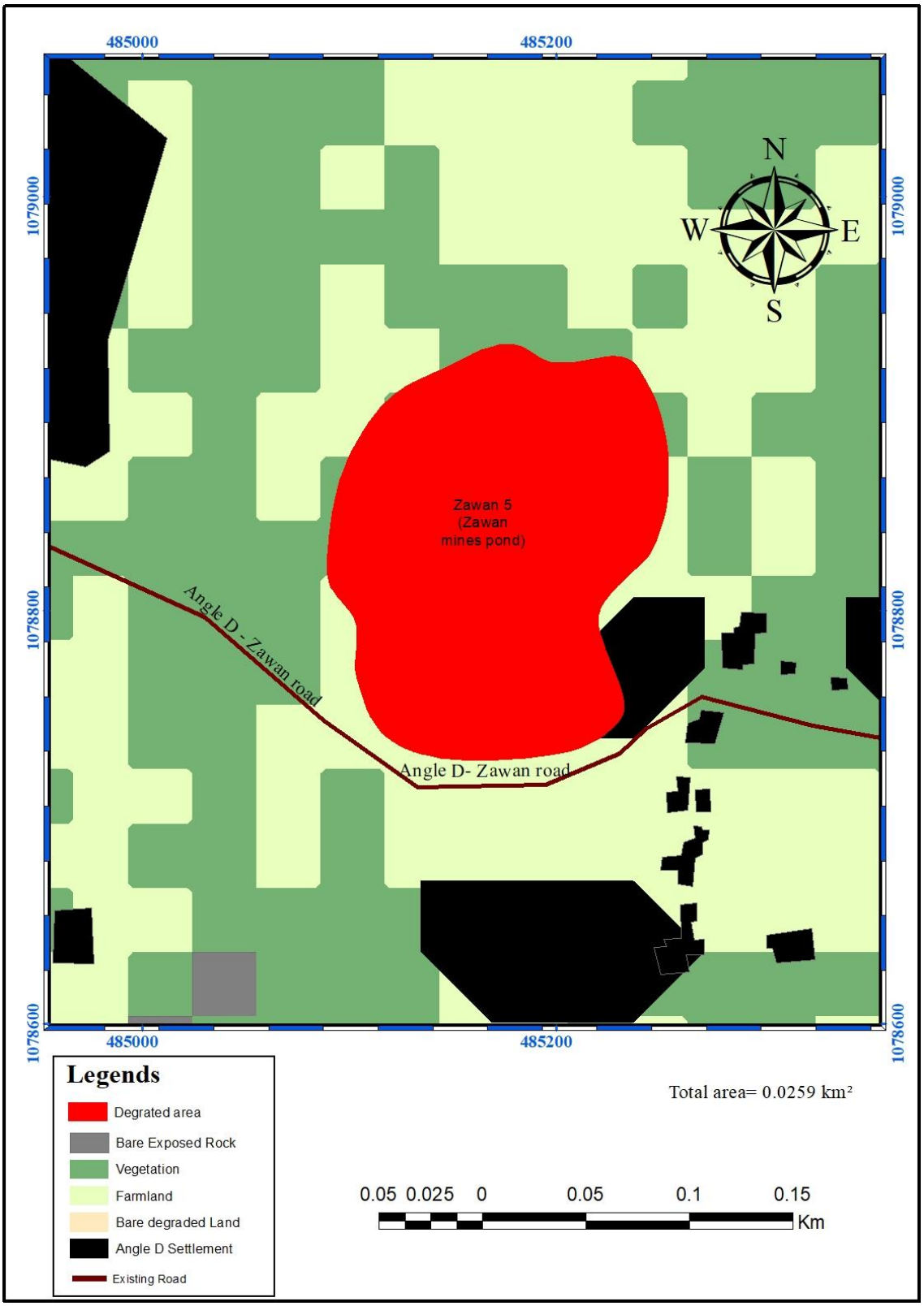


Figure 4.6: The Zawan digitized degraded site

The inhabitants reported a frequent loss of lives especially among the children as a result of drowning, because it is left unsecured. This prompted Federal Ministry of Mines and Steel Development (MMSD) to carry out some reclamation by demarcating the site using free cast monuments as shown in Plate V.



Plate V: Partially Reclaimed Degraded Site at Zawan

(vi) Consolidated Tin Mines Ponds

Figure 4.7 shows Consolidated Tin Mines degraded site, located at Bukuru area of Jos South; it is an abandoned mined site with seasonal inundation and a total area of 26184.9m^2, that has been converted into a source of water for construction and consumption. There has been remediation and reclamation through partial stone pitching at the boundaries.



Figure 4.7: The Consolidated Tin Mines digitized degraded site located at Bukuru

Plate VI is the photograph of Figure 4.7 showing the abandoned sites with settlements built at the extreme edge of the site.



Plate VI: Settlements built at the extreme edge of pond

(vii) Jos International Breweries Mines Site

This site contains two ponds located near Kwang road, Rayfield, with a total area of 171612.0 m^2 as shown in Figure 4.8. Because of seasonal inundation, the sites have been turned into a source of water for a block industry near the ponds.

Plate VII is huge tailings and waste excavated from the site in Figure 4.8 and dumped nearby, the tailings contain traceable minerals, the inhabitants also use the dumps for constructions.

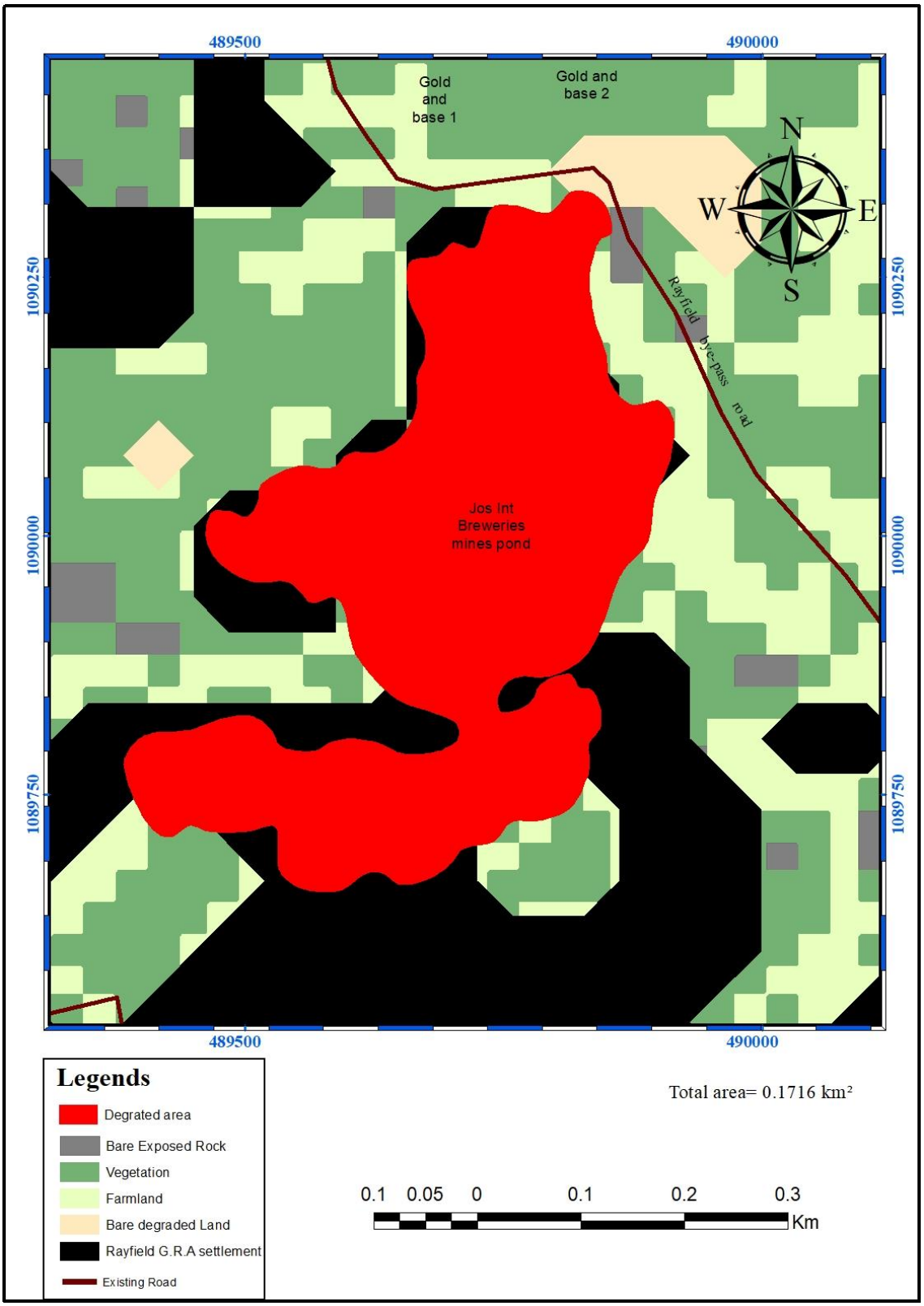


Figure 4.8: The Jos International Breweries Mines digitized degraded site



Plate VII: Huge Tailings around Jos International Breweries Mines Site

(viii) Yelwa Ponds Sites

There are two old mine pits collectively called Yelwa treatment plant and Yelwa Block industry ponds; both have been filled with water as shown in Figure 4.9. They are roughly 100 metres apart. They are located about 1km east of Bukuru town. The Yelwa Treatment plant pond is used by the Plateau State Water Board to pump, treat and distribute water to the nearby communities for both domestic and industrial uses. The Yelwa Block Industry pond is used in block making by Jacob block industry. There is no more possibility for reclamation around the Yelwa Treatment plant pond, hence, there is a need for barricading the perimeter of the pond to prevent the risk of drowning and pollution by run-off water. While for the Yelwa block industry pond needs to be demarcated for proper management. The latter site could be used for industrialization purpose. The excavated spoils or dumps during the mining of these pits were not seen around the perimeter of the

pond at the time of field study. It must have been washed away by run-off water or probably used for building construction by the inhabitant of the area.

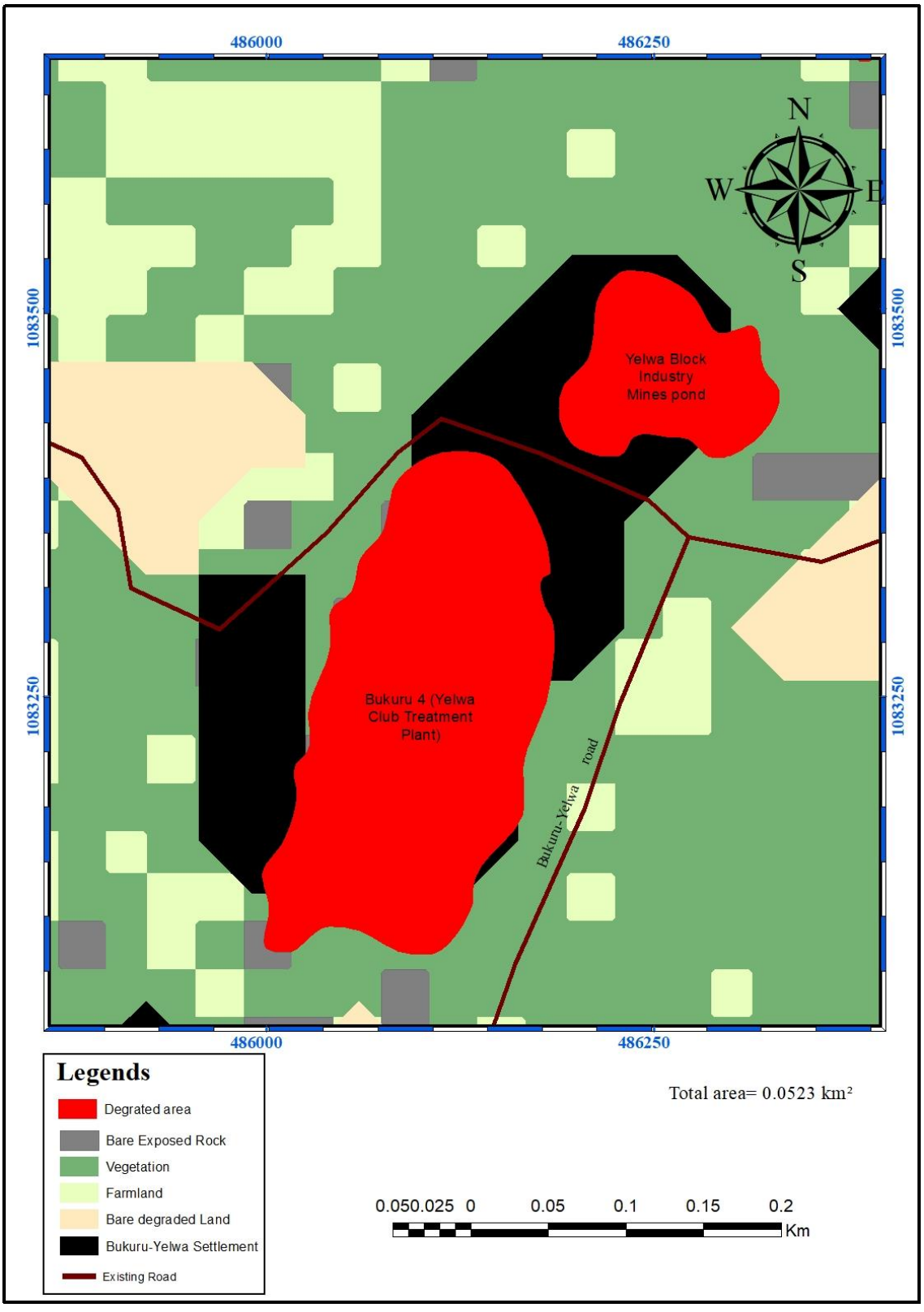


Figure 4.9: The Twin Yelwa degraded sites

(ix) Rahwol Kanang sites

This is a big site containing about six mines ponds clustered together which are seasonally inundated as shown in Figure 4.10. The ponds have been partially reclaimed and turned into economic activities. The inhabitants use the ponds as a source of water for irrigation and fish farming. The ponds are relatively shallow with few settlements around the vicinity and a total area of 489943.4m^2 for all the five ponds.

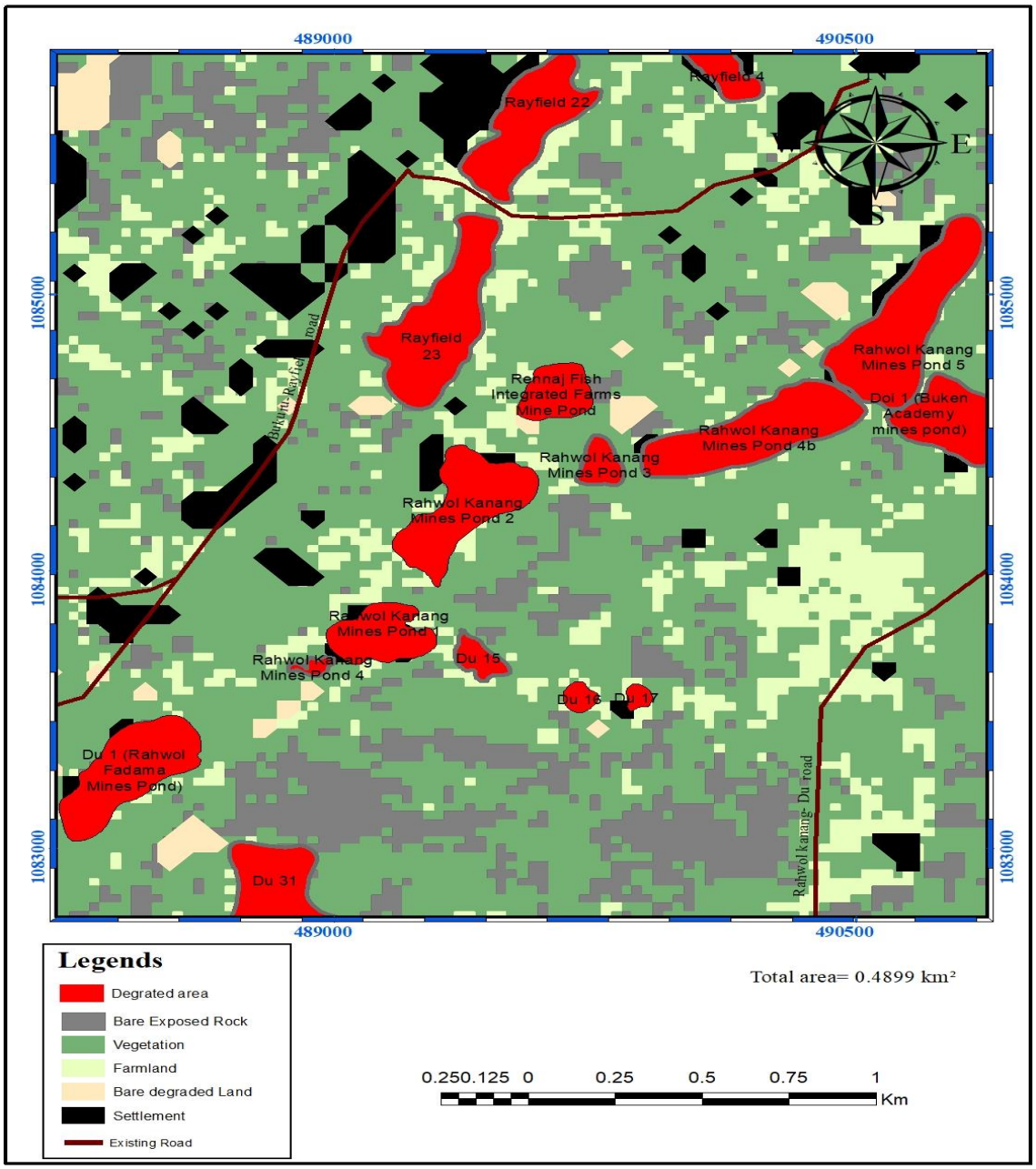


Figure 4.10: Clustered Rahwol Kanang degraded sites

Some parts of the ponds were fenced with blocks to reduce the rate of inflow of water into nearby residents during the rainy season. These barricaded blocks are actually not good for embankment or as embankment material.

There are also large tailings around the site which is the excavated soil from the site during mining activities as shown in Plate VIII. For Rahwol Kanang sites reclamation operation, backfilling method is suggested due to the abundant spoils seen around the perimeter of the pond.



Plate VIII: Rahwol Kanang Pond

(x) Rennaj Fish and Integrated Farm Limited Pond

At this stop, a fish pond has been observed as shown in Figure 4.11. It contains water and is used for fish farming. Water from the Rahwol top ponds is pumped using generating pumps to this Rennaj Fish and integrated farm limited ponds, where it is used for the fishery.

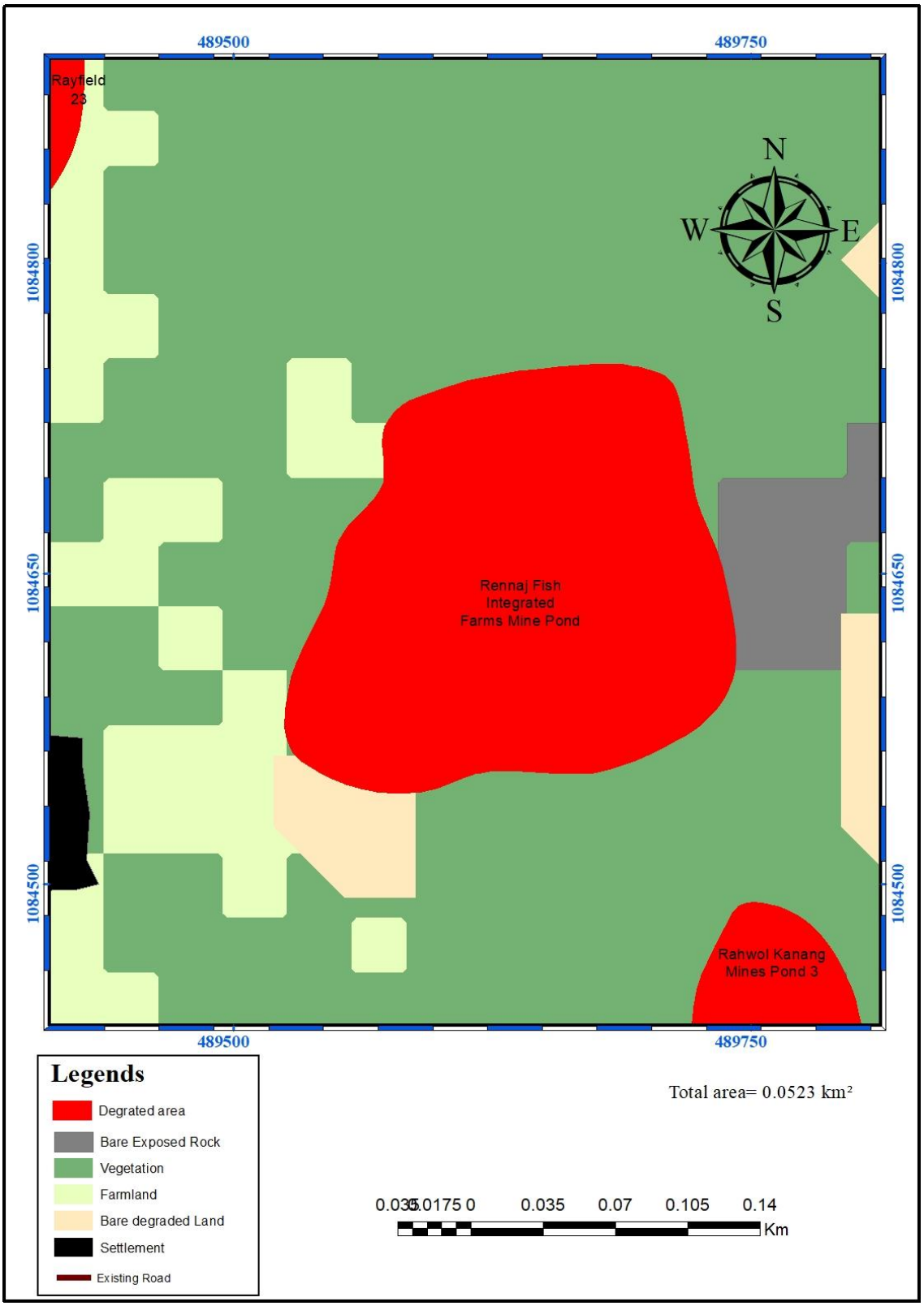


Figure 4.11: The Rennaj Fish and Integrated Farm Limited Pond

The ten major degraded sites analysed in section 4.3 were summarized in tabular form, these are presented in Table 4.1. The ten sites summarized in Table 4.1 constitute a total area of 2.0190 km², likewise, the total area of the 235 digitised degraded area is 11.5818 km², hence the total percentage of the ten degraded areas is 17.43%.

Table 4.1: Summary of Ten (10) Selected Major Degraded Sites

S/No	Name	Total Area (km^2)	Coordinates	Remarks
1	The Rock and Clay Industry Limited Mines	0.6606	9°41'49.12"N; 8°51'30.45"E	Active Illegal mine site
2	The Healthy Body Clinic site	0.0112	9°45'24.10"N; 8°50'38.36"E	Resort centre; Block Industry; seasonal inundation
3	Rayfield Resort centre	0.5245	9°50'24.91"N; 8°55'0.62"E	Resort centre; Illegal Mining
4	Dorowa Congo site	0.0222	9°46'51.12"N; 8°52'25.53"E	Seasonal inundation; used as landfills; settlements built nearby
5	Zawan site	0.0259	9°45'34.33"N; 8°51'51.87"E	Seasonal inundation, threat to life; partially reclaimed
6	Consolidated Tin Mines Ponds	0.0262	9°47'7.47"N; 8°51'38.05"E	Seasonal inundation; partially reclaimed through stone pitching
7	Jos International Breweries Mines Site	0.1716	9°51'37.91"N; 8°54'26.95"E	Water used for block industry;
8	Yelwa Ponds Sites	0.0523	9°48'5.40"N; 8°52'30.25"E	Water treatment plant; block industry
9	Rahwol Kanang sites	0.4899	9°48'14.70"N; 8°54'3.77"E	Irrigation; Fish stocking; farming
10	Rennaj Fish and Integrated Farm Limited Pond	0.0345	9°48'44.22"N; 8°54'20.07"E	Fish stocking; Farming; Source of water
	Total Area	**2.0190**		

In Figure 4.12, the size of the graduated symbols is equivalent to the sizes of individual sites in area percentage. The trend of the degradation is towards the north-east and south-east of the study. From the Figure 4.12, the sites with largest sizes cover area percent 2.5 to 5.3%, likewise, the smallest sizes covered 0.01 to 0.07%.

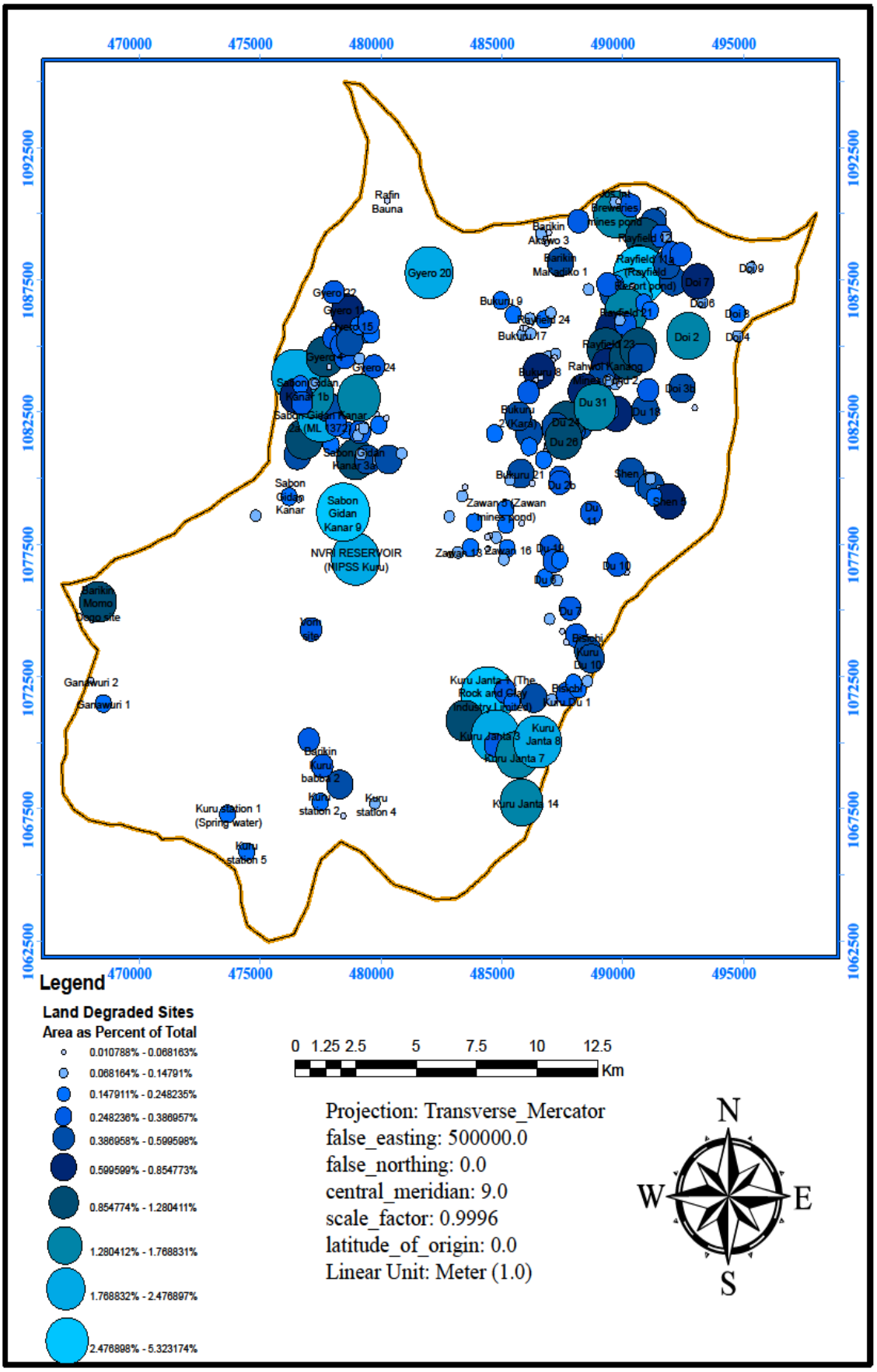


Figure 4.12: Graduated symbol land degraded areas as percent of total area

4.3.1 Field photographs and geotagging

The photographs integrated into the GIS database and geotagged to each degraded site can easily be queried as shown in Plate IX and Plate X, these would aid in describing the true nature and photographic evidence of land degradation of the sites.

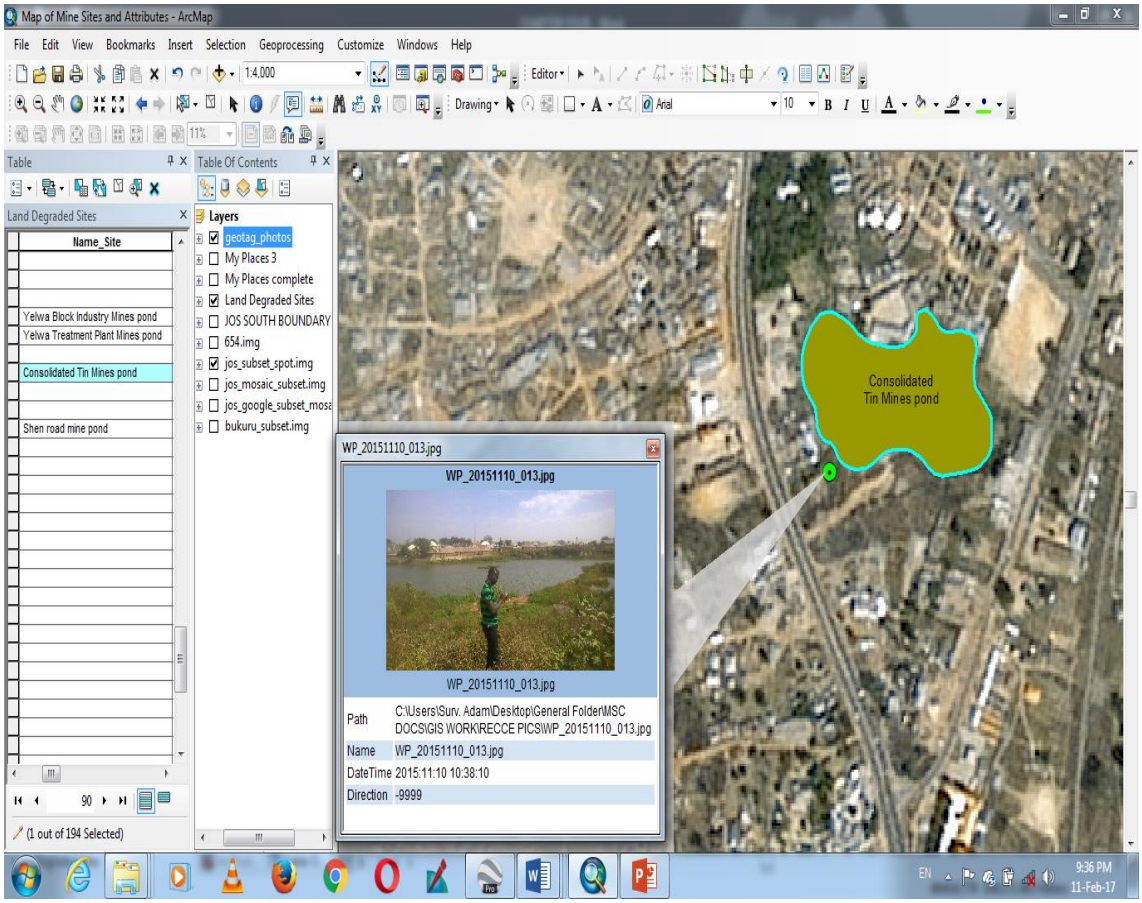


Plate IX: The Consolidated Tin Mines digitized degraded site with geotagged photo

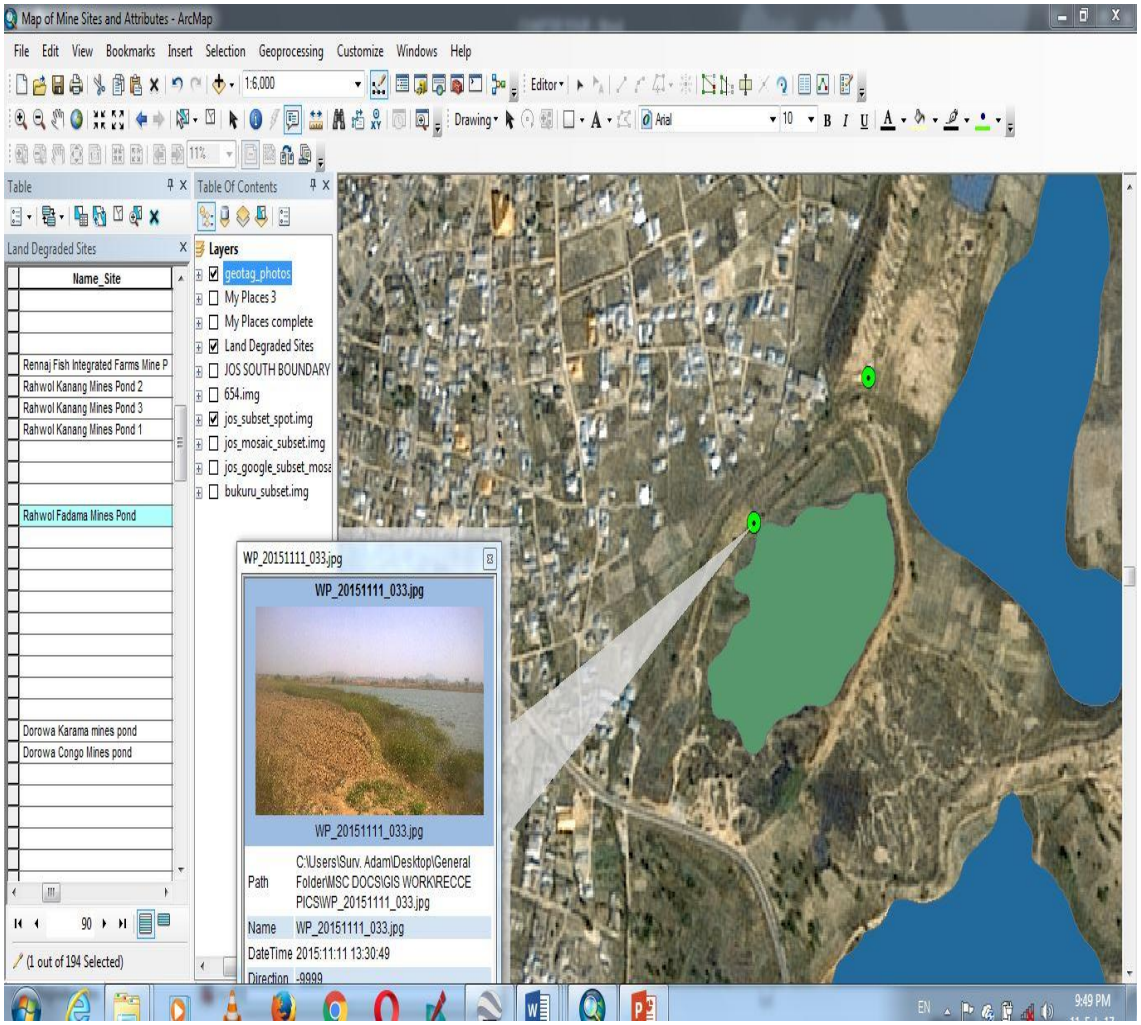


Plate X: One of Clustered Rahwol Kanang digitized degraded site

4.3.2 Results of classification of degraded sites based on features

Table 4.2 is the summary of attributes and features of the degraded sites. The degraded sites were classified based on their functions, the criteria of distinguishing them were based on the observed features during ground truthing.

Table 4.2: Summary of Attributes and Features of the Degraded Sites

S/No	Classes	Total Area (km^2)	Area Degraded (%)	Total number of sites
1	Active Mine sites	1.3180	11.38	9
2	Agricultural Usage	0.7354	6.35	18
3	Dormant	0.7832	6.76	25
4	Fencing	0.3833	3.31	8
5	Fish Stocking	1.1738	10.14	22
6	Inundated seasonally	1.7946	15.50	29
7	Irrigation	1.5478	13.36	50
8	Ownership	0.9036	7.80	11
9	Partial inundation	0.4553	3.93	13
10	Resort Centre	0.6682	5.77	6
11	Tree planting	0.3991	3.45	13
12	Waste dumps/Tailings	0.9340	8.06	21
13	Water treatment	0.4854	4.19	10
	TOTAL	11.5818	100	235

From the Table, 2.26% is the total percentage of the entire degraded sites in the study area, this might look small but it is actually devastating when compared with the percent total of the settlement cover of 6.99%. this implies that the degraded area almost covered one-third of the entire settlement in the study area. Figure 4.13 shows a map of degraded sites with their attributes, the result revealed different degraded sites. However, several queries can be conducted such as searching by name of sites, total area, classes, etc. The complete table of the database is in Appendix 3.

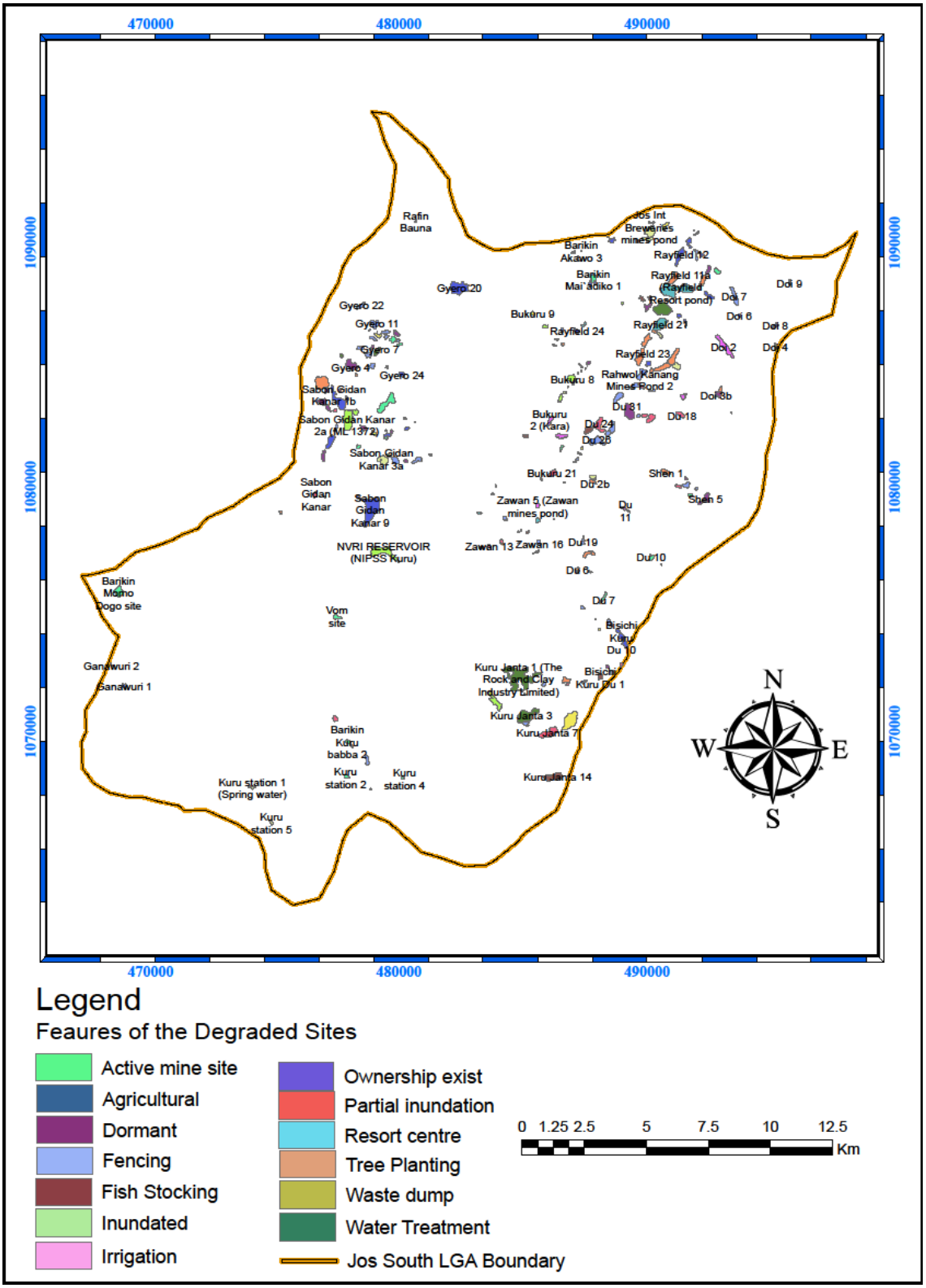


Figure 4.13: Map of degraded sites with their features

4.3.3 Results of mapping clustered degraded sites

Figure 4.14 is the result of the Optimised Hot Spot Analyses of the degraded sites. The map shows hot and cold spot regions at different confidence levels of 90%, 95% and 99%. The fishnet polygons represent a dimension of 1km, therefore each degraded site fall within one or more fishnet polygon. From the map, there is hot spot clustered sites around Rayfield, Bukuru, Du, Sabon Gidan Kanar and Gyero areas. In contrast, Kuru Janta, Ganawuri, Vom and Barikin Kuru Babba were the Cold spot areas experiencing very few degraded areas, this is because the areas were mostly rocky hence there are less mining activities. There were also areas with no significant clustering as shown on the map.

The z-scores and p-values returned by the pattern analysis as shown in Appendix 7 indicated that the null hypothesis can be rejected. The reason being that the degraded sites (or the values associated with the sites) exhibited statistically significant clustering or dispersion instead of random pattern. The p-value in the appendix 7 which is 0, is the probability that the observed spatial pattern was created by some random process. When the p-value is very small as in this case 0, it means it is very unlikely (small probability) that the observed spatial pattern of the degraded sites is the result of random processes, so the null hypothesis can be rejected. Likewise, Z-scores of -10.04 is standard deviations. Very low (negative) z-scores, associated with very small p-values, are found in the tails of the normal distribution. When p-values is very small and either a very high or a very low z-score, this indicates it is unlikely that the observed spatial pattern reflects the theoretical random pattern.

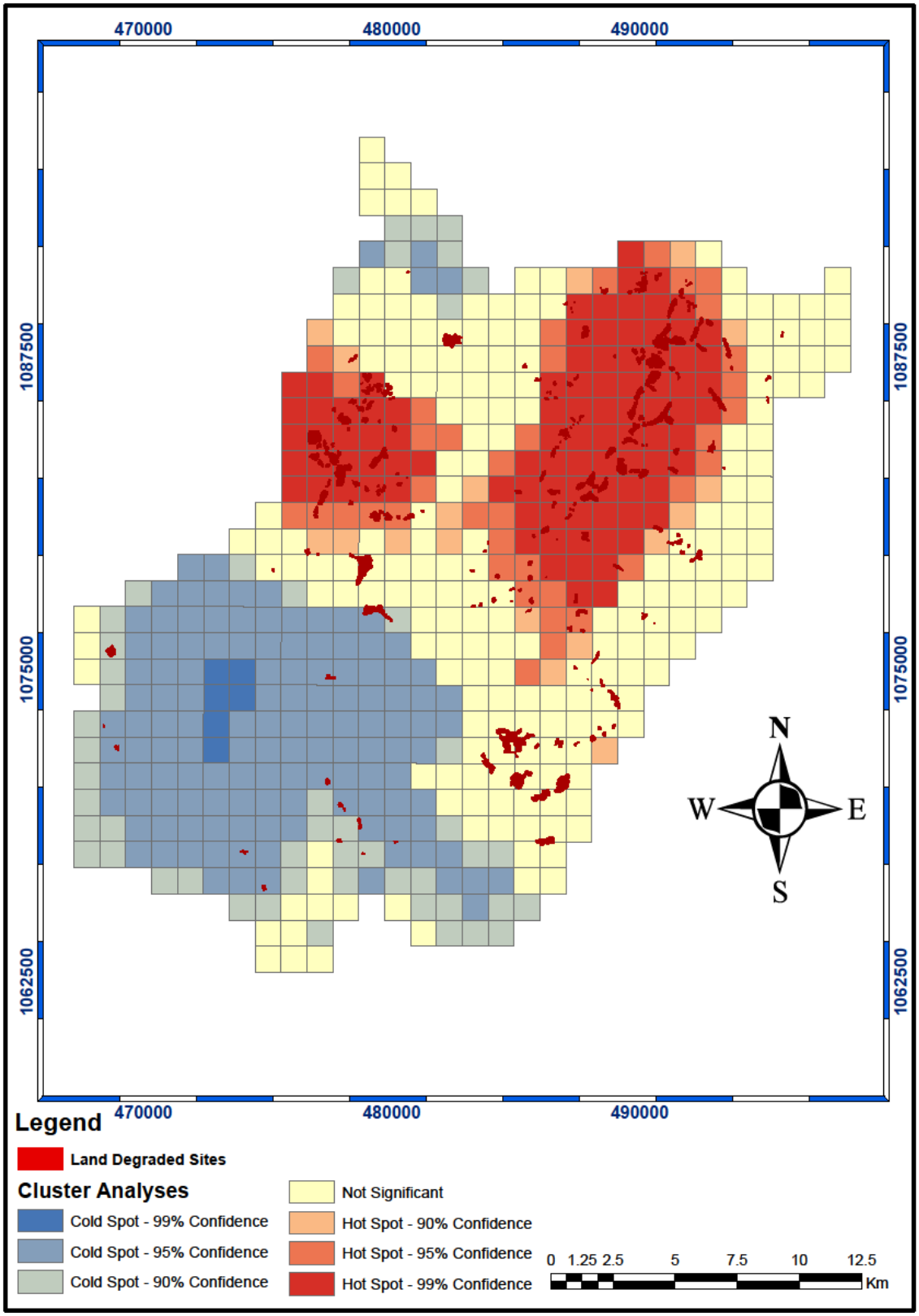


Figure 4.14: Map of Hot and Cold degraded sites

4.4 Analyses of Land Use Classification in the Neighbourhood of Degraded Area

4.4.1 Results of image processing

Figure 4.15 shows the result of subset carried out to clip the entire scene to the area required, this helped to reduce data redundancy and increased the efficiency of the result.

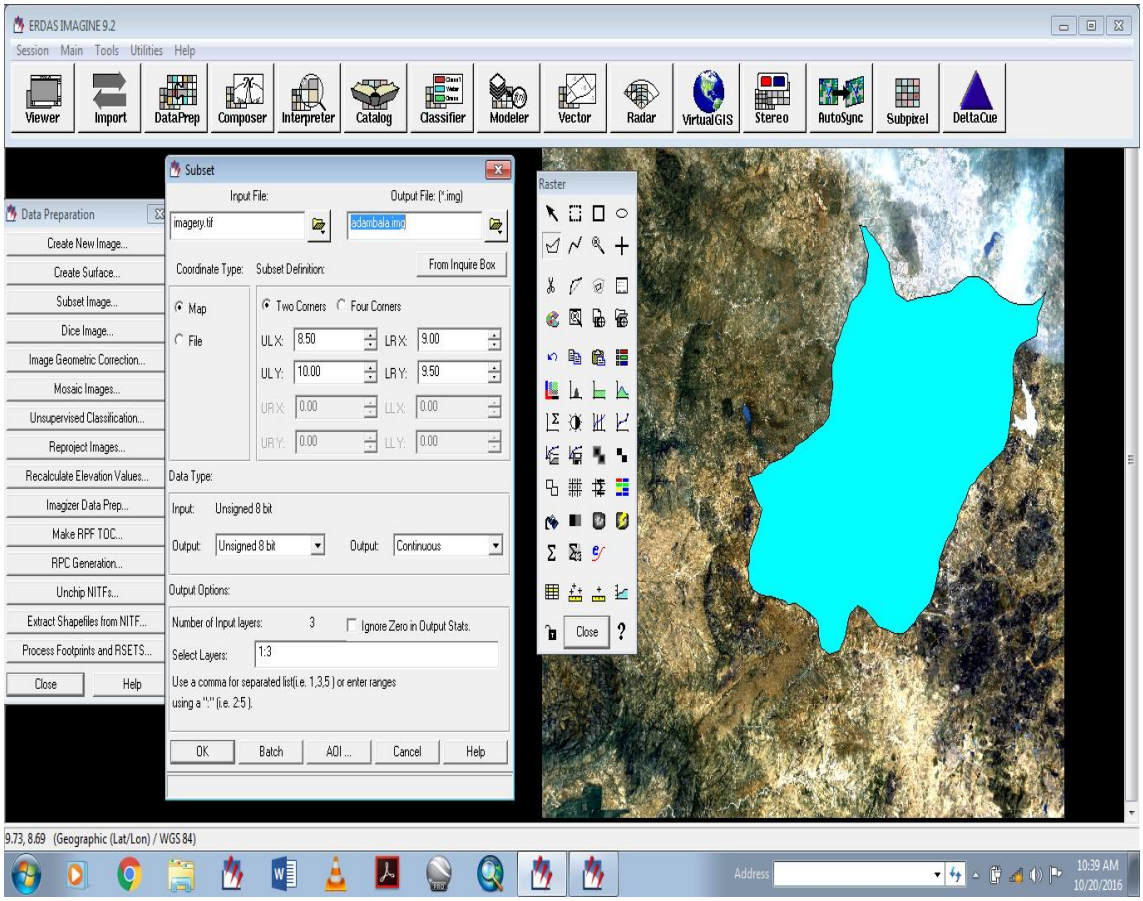


Figure 4.15: A subset image of SPOT 5 scene.

4.4.2 Classification accuracy assessment

Using the reference data and the classified maps, confusion matrices were constructed for the merged imagery as shown in Table 4.3.

Table 4.3: Simple descriptive statistics of the error matrix of the merged Landsat 8 and SPOT 5

		Reference									
		Rocky Areas	Vegetation	Farmland	Bare degraded land	Settlement	Mine ponds	Row Total	Number of Correct	Producers Accuracy	Users Accuracy
Classified Data	Rocky Areas	101	49	5	21	0	0	176	101	75.37%	57.39%
	Vegetation	5	184	8	4	3	1	205	184	59.55%	89.76%
	Farmland	0	37	107	0	2	2	148	107	81.06%	72.30%
	Bare degraded land	5	6	3	135	0	0	149	135	74.59%	90.60%
	Settlement	20	10	2	2	117	0	151	117	93.60%	77.48%
	Mine ponds	3	23	7	19	3	198	253	198	98.51%	78.26%
	Column Total	134	309	132	181	125	201	1082	842		

Accuracy commonly referred to as a measure of map quality is essential in mapping land cover of degraded areas using remote sensing technique. The classified maps inevitably contained errors and the errors should be minimum, also, the importance of the errors depend on the purpose of the classified map. In Table 4.4, the resulting classification of the imagery had an overall map accuracy and the Kappa coefficient accuracy of 77.82% and 73.16% respectively. This was very good overall accuracy and accepted for the subsequent analysis**.** Kappa coefficient signified that there is 73.16% statistical agreement between the reference pixels or points and the classified maps. The Kappa coefficient expresses the proportionate reduction in error generated by a classification process compared with the error of a completely random classification. Kappa accounts for all elements of the confusion matrix and excludes the agreement that occurs by chance.

Also, it means that there is 77.82% (overall accuracy) probability that the reference pixels are correctly classified on the map.

Table 4.4: Overall accuracy and Kappa coefficient of merged Landsat 8 &SPOT 5.

Classified image	Overall accuracy (%)	Kappa coefficient (%)
Merged Imagery	77.82	73.16

In Table 4.3, the producer's accuracy of mine pond is 98.51% i.e. there is 1.49% omission error (error of exclusion) for the reference points. In the same vein, the user's accuracy for mine pond is 78.26% and 21.74% commission error (error of inclusion) for the points. Thus, the producer's accuracy implied that the reference points for mine pond were correctly placed and the user's accuracy implied that they were correctly classified as mine pond. The producer's and user's accuracies for rocky outcrops and vegetation land were recorded as the lowest accuracy achieved even though it is still very accurate. This is due to pixel similarities (mixed pixels) with each other, especially vegetation does exist in some rocky areas.

The higher accuracy was achieved due to the utilization of more ancillary data in collecting training samples for classification and the season of the image during the process of classification. In general, there was some evidence for both systematic commission and omission errors resulting from the classifier side as incorrectly commits pixel of the class being sought to other classes as well when some class on the ground were misidentified as another class by the classifier, but these systematic commission and omission errors are minimal and within the acceptable range.

4.4.3 Land cover

This section presents analyses of the relationship between land cover types and land degradation. According to the land cover classes adopted in the study: rock outcrops, vegetation, and farmlands cover are the major part of the land area, while the remaining classes occupy only about 16.44% of the land area. The degradation that affected different land cover types were determined by overlying the land cover data with the digitized degraded sites.

Special attention was paid to land cover classes that coincided with degraded areas such as inundation and bare degraded land because such areas represent land cover types that were likely to have been affected by degradation. Table 4.5 shows the percentage of degraded areas classes to the total area of the land cover types, computed to quantify the degradation.

Deriving the proportion of degraded land to total land cover area enabled an identification of land cover types that suffered the greatest degradation. Since only single date land cover data were available for analysis, the relationship was determined to provide an indication of land cover classes that suffered degradation and not to assess conversion between land cover types.

The land use and land cover classified map derived from the fused imagery is shown in Figure 4.16.

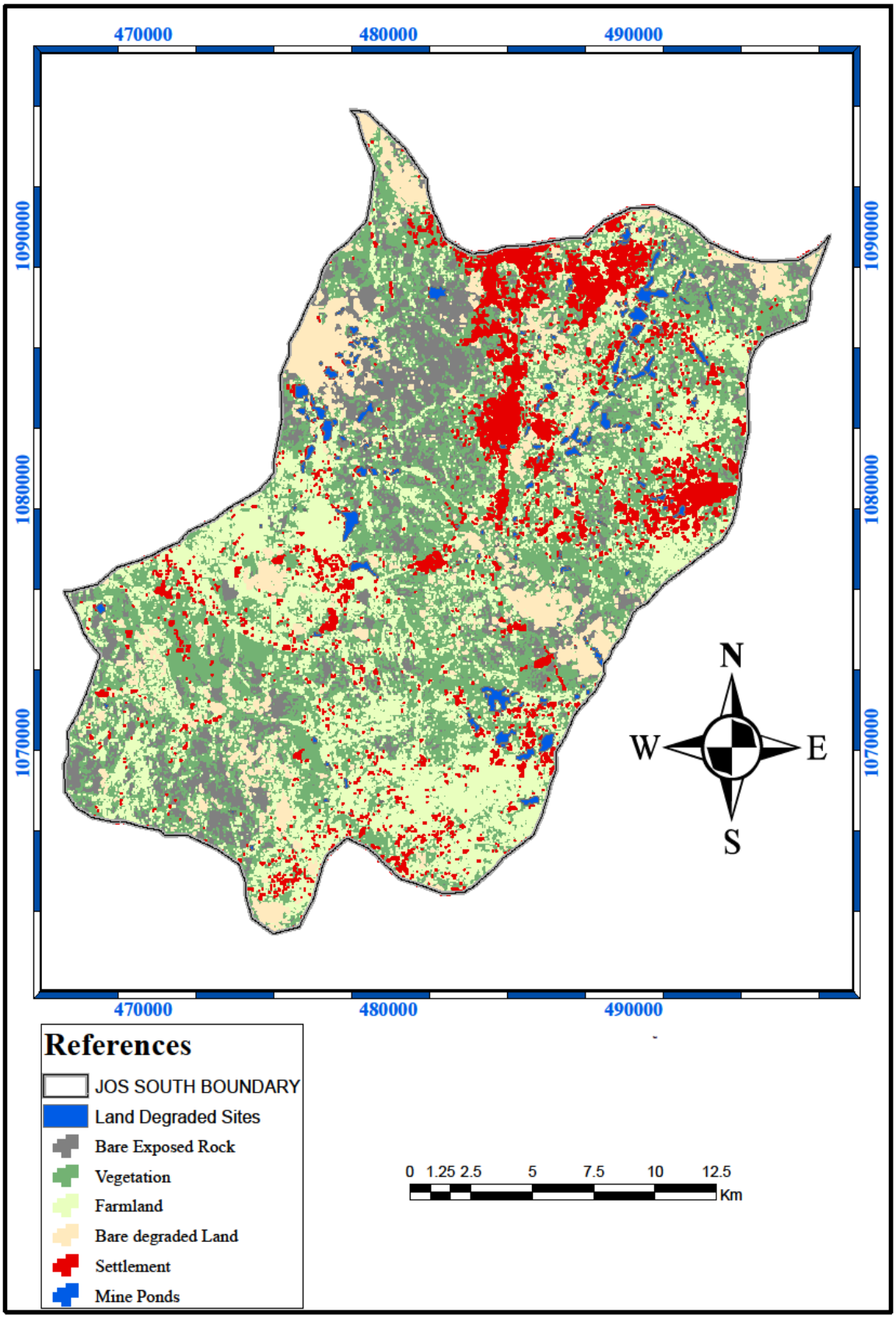


Figure 4.16: Land cover map of Jos South

In Figure 4.16, the classified map showed the land covers in the study area. It can be seen that settlement areas are concentrated in the central upper part of the area and are shown in red colour. Similarly, the mine ponds (degraded) are dispersed all over the area characterizing where mining activities are taking place and are shown in blue. Again, the presence of rocky covers indicated that the study is characterized by steep terrain and are shown in grey colour. Farmlands and vegetation covers are found all over the area and are displayed in light green and green.

4.4.4 Land cover distribution

The area and percentage of each class of the classified map of merged SPOT 5 and Landsat 8 of the study area are shown in Table 4.5. This was computed from the classified map in square kilometres. Much of the area mapped as degraded (9.45%) is the abandoned mine ponds and bare degraded land which primarily occurred as a result of illegal mining activities. It is comprised mainly of inundated ponds, bare lands, and grassland to a lesser extent.

Table 4.5: Extent of land use and land cover distribution of the fused imagery

LULC CLASS	**AREA (Km^2)**	**AREA (%)**
Mine pond	10.0052	1.95
Settlement	35.7792	6.99
Exposed Rock Outcrop	212.809	41.56
Farmland	92.9401	18.15
Bare degraded land	38.4006	7.50
Vegetation	122.163	23.85
TOTAL	**512.0971**	**100**

Source: (Author's lab work)

The extent and the different percentages of the area mapped as degraded lands are shown in Table 4.5, and Figure 4.16. From Table 4.5, it is observed that mine ponds and bare degraded lands account for a total of 9.45%, these are the most obvious land degraded

covers with less economic activities going on, vegetation cover occupied a large area of 122.163 km² that accounted for 32.27% of the classified map; farmland occupies an area of 165.05 km² that constituted 23.85% of the area. Exposed Rock Outcrop covers nearly half of the whole land cover due to the presence of plateaus and mountains in the area accounting for 212.809 km², and settlements occupied areas of 35.7792 km². Table 4.5 indicates that bare degraded areas together with mine ponds are more than settlements by 2.46%, also rocky outcrops occupied more areas than combined Mine pond, Settlement, Farmland, and Bare degraded land by 6.97%.

4.4.5 Land cover characteristics of mapped degraded areas

In order to begin to understand how land-cover and land-use may have affected degradation in the study area, a descriptive analysis of the distribution of mapped degradation classes in relation to other different land cover and land use classes was undertaken.

i. Inundated mine ponds

Inundated mine ponds are areas representing both seasonal and temporary inundated lands usually in form of abandoned mine ponds and severe logging actions. The degraded class might have resulted from the activities of mine and excavation of laterites for building and road construction. It could also be as a result of increased gully erosion leaving behind big gullies occupied by water. From site visited, the inundated lands were mainly found around the abandoned mine areas, with effects of this seasonal inundation including loss of lives by inhabitants as a result of accidental drowning into the water, transfer of settlements, unpleasant and unproductive especially for agriculture and living. From the land cover classification, it was evident that the mine ponds were actually the major land degradation class, considering the fact that inundation makes land less valuable in this case.

ii. Bare degraded areas

Bare degraded areas are areas that have been exposed, mostly appear as borrow pits due to an offshoot of mining activities as described in Plate I and III. They include sandy areas and areas that had experienced mining activities but no inundation, active mining areas as well as eroded or wash out areas. In some of the areas, people have illegally excavated laterites and sands for commercial purposes. Figure 4.17 shows the relationship between Bare Degraded land and Degraded sites; the bare surfaces are spots excavated in anticipation of mining activities but lack vegetation and hence barren.

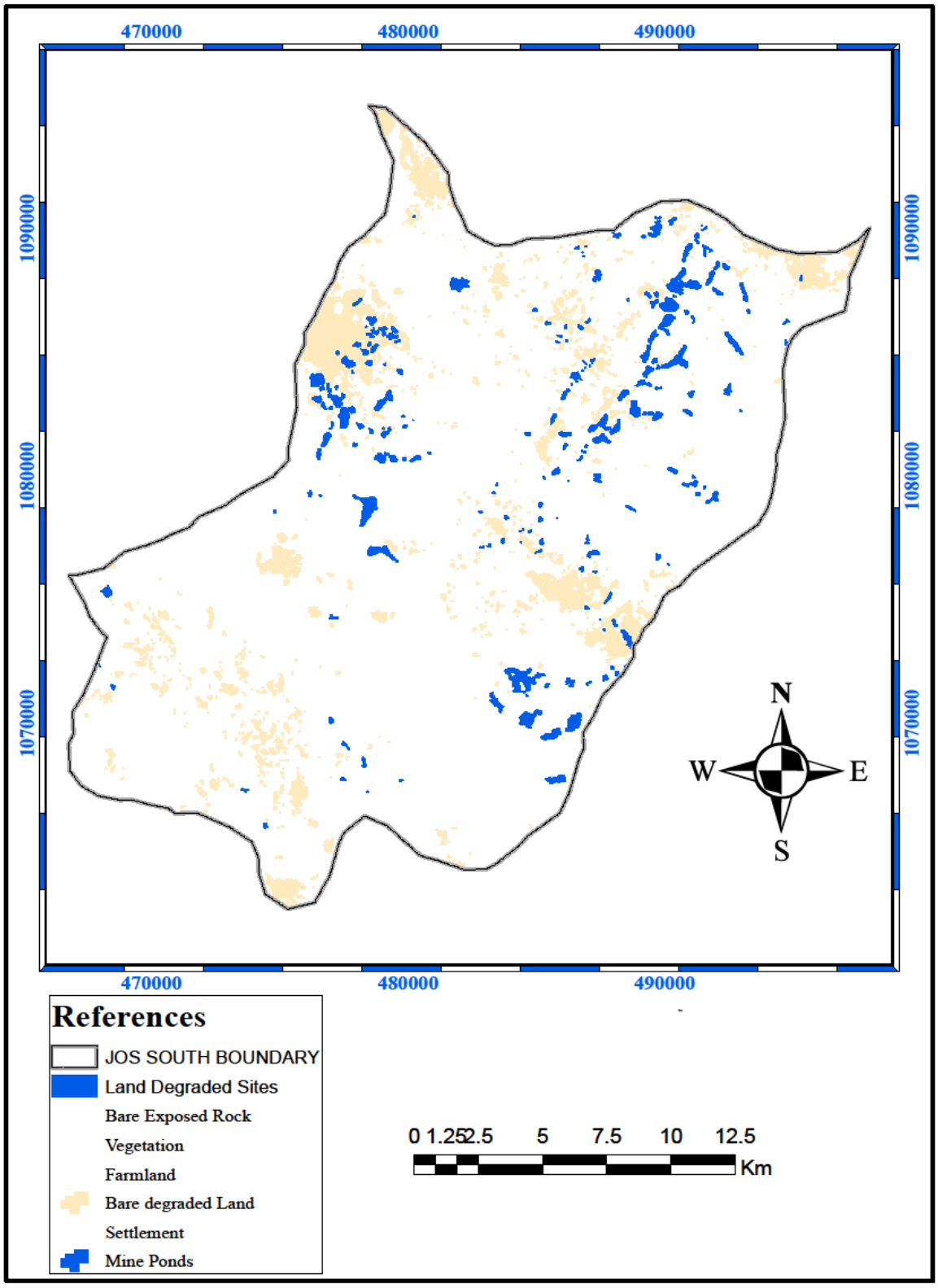


Figure 4.17: Relationship between Bare Degraded land and Degraded sites

iii. Bare Exposed Rock Outcrop

Jos is famously known to be associated with plateau containing both younger and older granite igneous rock. This rock is largely spread across the area and covered a total of 41.56% of the total land cover in the study area. This land cover could be referred to as degraded areas because it is barren and agricultural activities are seldom carried out. Some areas are turned to quarry areas where rocks are blasted and crushed for economic purposes. Figure 4.18 shows the relationship between Bare rock outcrop and Land degraded sites, the relationship between this cover and degradation is that this land cover is not much influenced by degradation because rock outcrops do not get easily eroded or excavated, except where quarry activities (blasting and crushing) are carried out turning this land cover to big gullies and inundated due to rainfall.

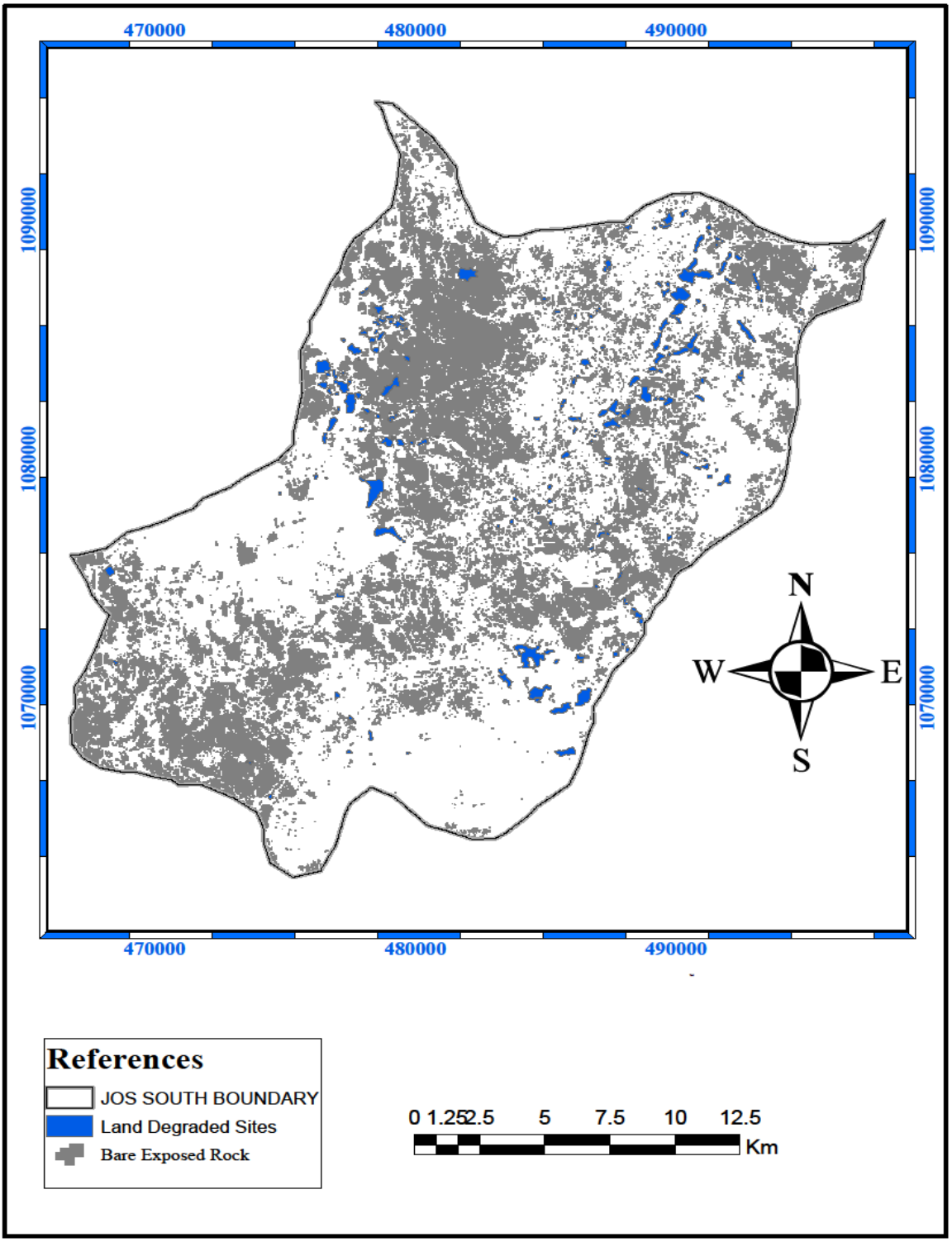


Figure 4.18: Relationship between Bare rock outcrop and Land degraded sites

iv. Farmlands

The total farmland cover is 18.15% covering a total area of 92.94 km² which include forested areas that are freshly cleared for farming. The relationship here is that farming activities expose the topsoil to erosion, and the steep slope of the areas make it more severe. With the soil exposed, it becomes susceptible to the erosion, especially during rainy season. The continuing action of the rain favours high rate of permeation in the area, enough to loosen the underlying layers. This results in gulling as witnessed in many of the areas. Also, some farmlands have been disturbed due to tin mining activity.

v. Vegetation

Figure 4.19 shows the relationship between Vegetation, Farmland, and Land degraded sites. The relationship between vegetation and degradation is that large portions of the vegetation cover are cleared annually for farming purposes and searching for minerals, resulting in vegetation degradation, deforestation, and severe damage. In some sites, Eucalyptus trees were planted as a form of reclamation. Vegetation covers a total area of 122.163km² which amount to 23.85%.

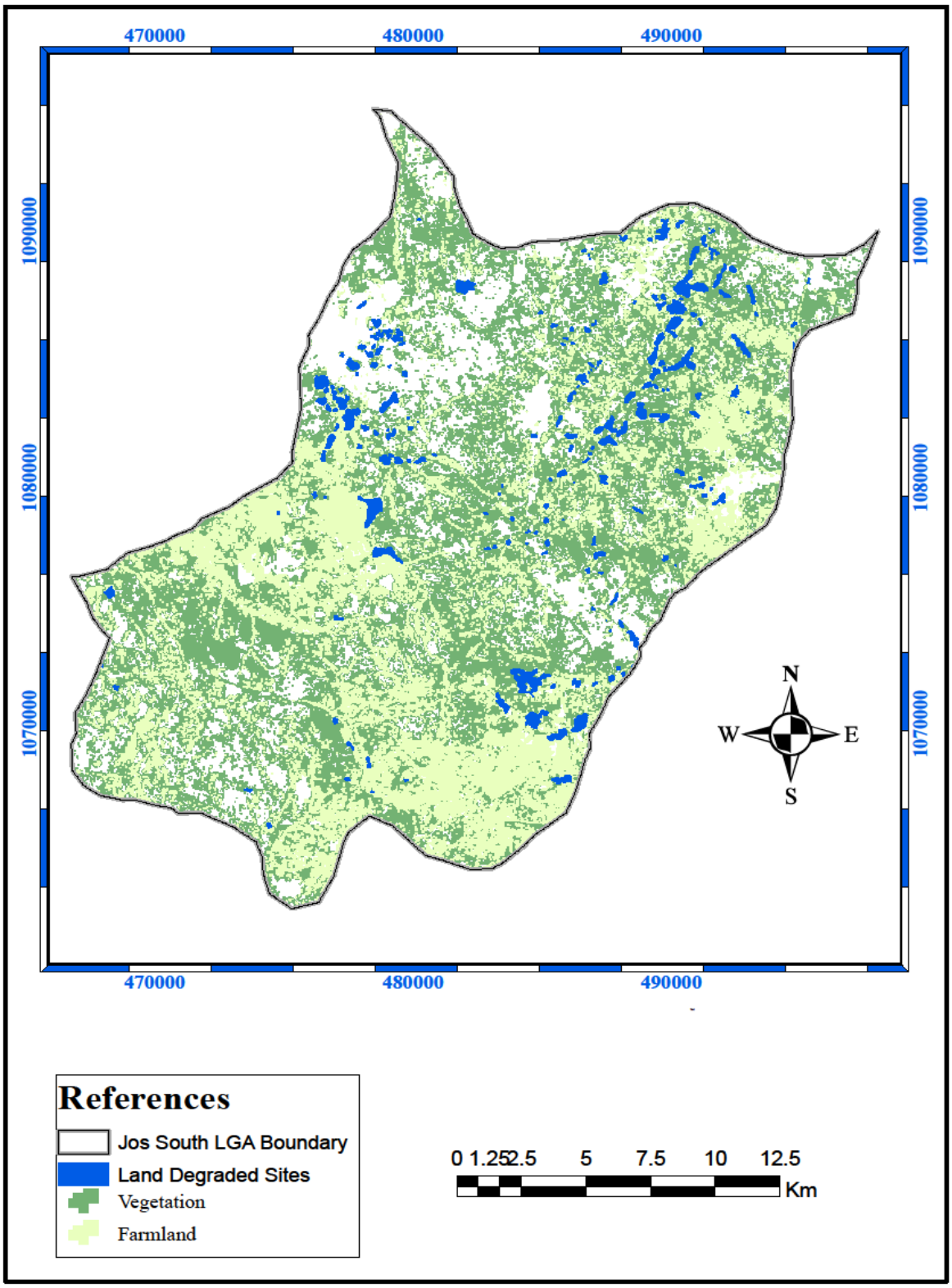


Figure 4.19: Relationship between Vegetation, Farmland, and Land degraded sites

vi. Settlement Patterns

Settlement patterns, the nature of housing and infrastructural expansion contribute to the land degradation in the region. Figure 4.20 shows the relationship between Settlements and Land degraded sites. Settlements are not properly planned; some houses are built indiscriminately near the abandoned mine pits without due consideration to dangers such may posit. This is because most of the area is rocky hence houses cannot be constructed easily. With rock outcrop largely occupying the area at 41.56%, there will be high population pressure in housing, in areas without such rock outcrops. The total area covered by the settlement is 35.78km² at 6.99%.

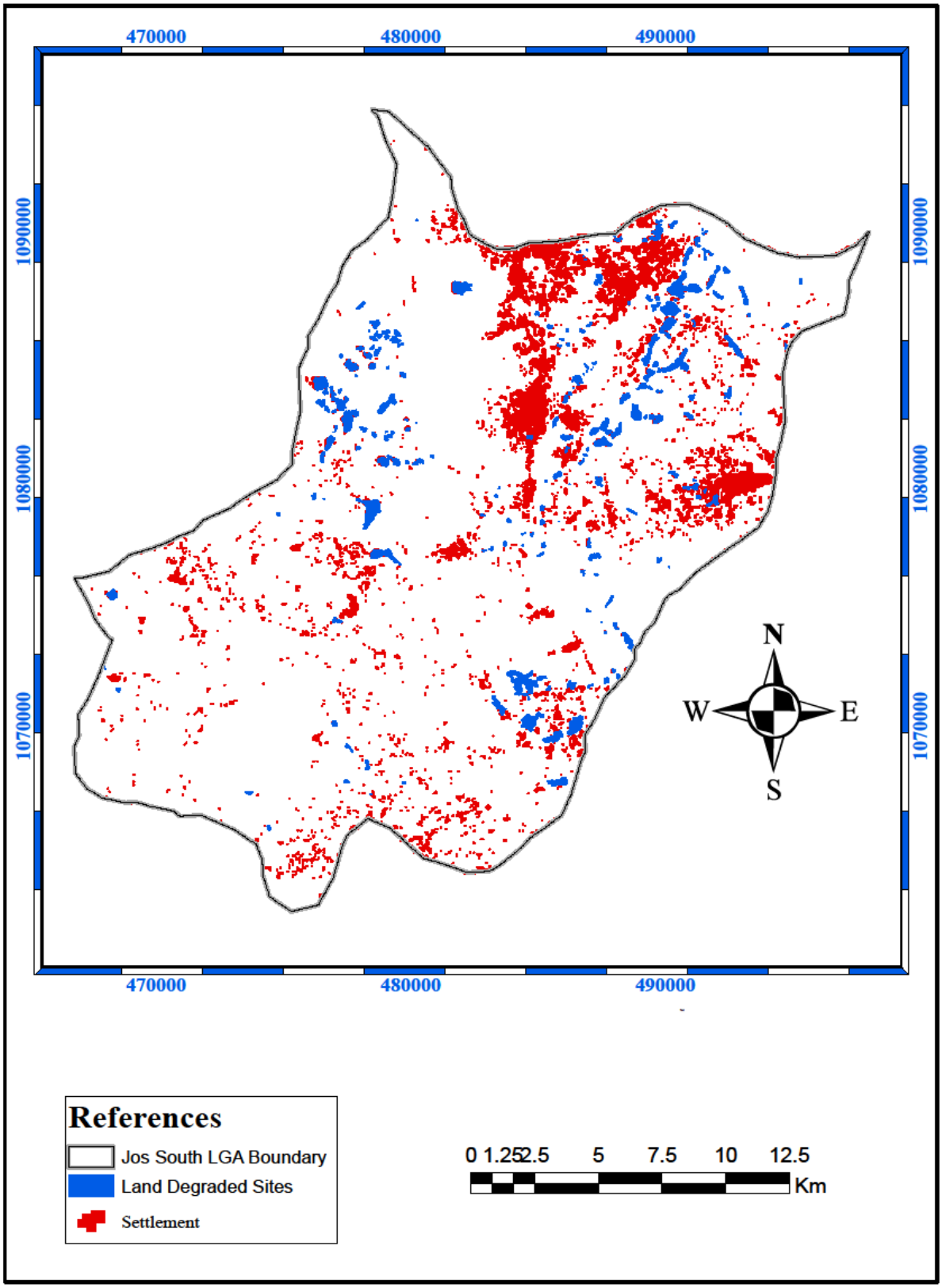


Figure 4.20: Relationship between Settlements and Land degraded sites

4.5 Analyses of the Terrain in the Neighbourhood of the Degraded Sites

The high elevation of the area contributes to land degradation because when heavy rain falls, water moves from the upstream carrying sediments down the lowland. The resultant high overflow on the steep slopes aggravates soil erosion and ultimately causes the land cover to depreciate resulting in degradation of the area. In addition to elevation, slopes which were affected by degradation were identified because mountain surfaces inherently have steep slopes. The steepness of slope is significant in the study of land degradation mainly because of the impacts of soil erosion caused by water on the slopes. It was also significant to study in what way the direction of slopes influences land degradation. Aspect is the compass direction related to each slope.

Figure 4.21 is the overlay of the digitized degraded sites on the elevation model, this was done to relate the change in elevation and degraded sites. The result shows the digitized mining ponds spread randomly in the study area, it can be observed that the spatial location of the sites is irrespective of the elevation, this is because most of the degraded sites occurred as a result of mining activities; the major condition or criteria for mining minerals is its availability hence mining activities can be done whether at high or low land.

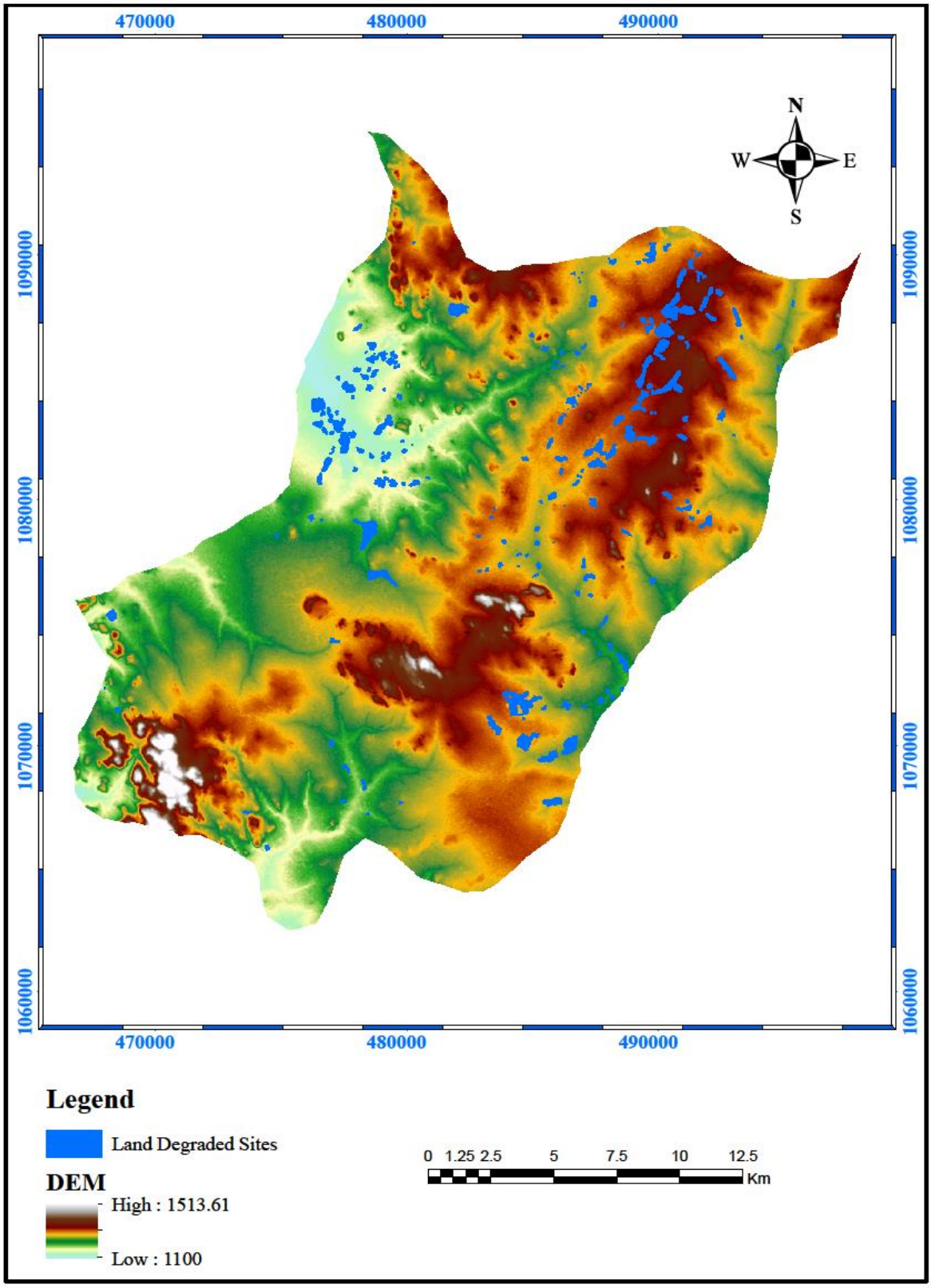


Figure 4.21: Overlay Maps (Degraded Sites and DEM) of the Study Area

Figure 4.22, the slope map showed the configuration of the terrain in terms of depths and heights. The depths were overlaid by land degraded areas shown in a blue colour representing values less than one. This implied that land covers with depths (e.g. derelict ponds) have slope values of 0 to 0.99, this further describes that the study area is characterized by excavated surfaces, gully and abandoned mines that have become derelict ponds (filled with water and stagnant). Similarly, land covers with high elevation are shown in green to red colours. This implied land covers corresponding to rocky surface, and that the study area is characterized by rocks. The slope map showed that high elevation cover (rock surface) are predominant in the south-west part of the study area. Other land use and land covers such as settlements, farmland, vegetation, and bare degraded land are shown in light green to dark green colour.

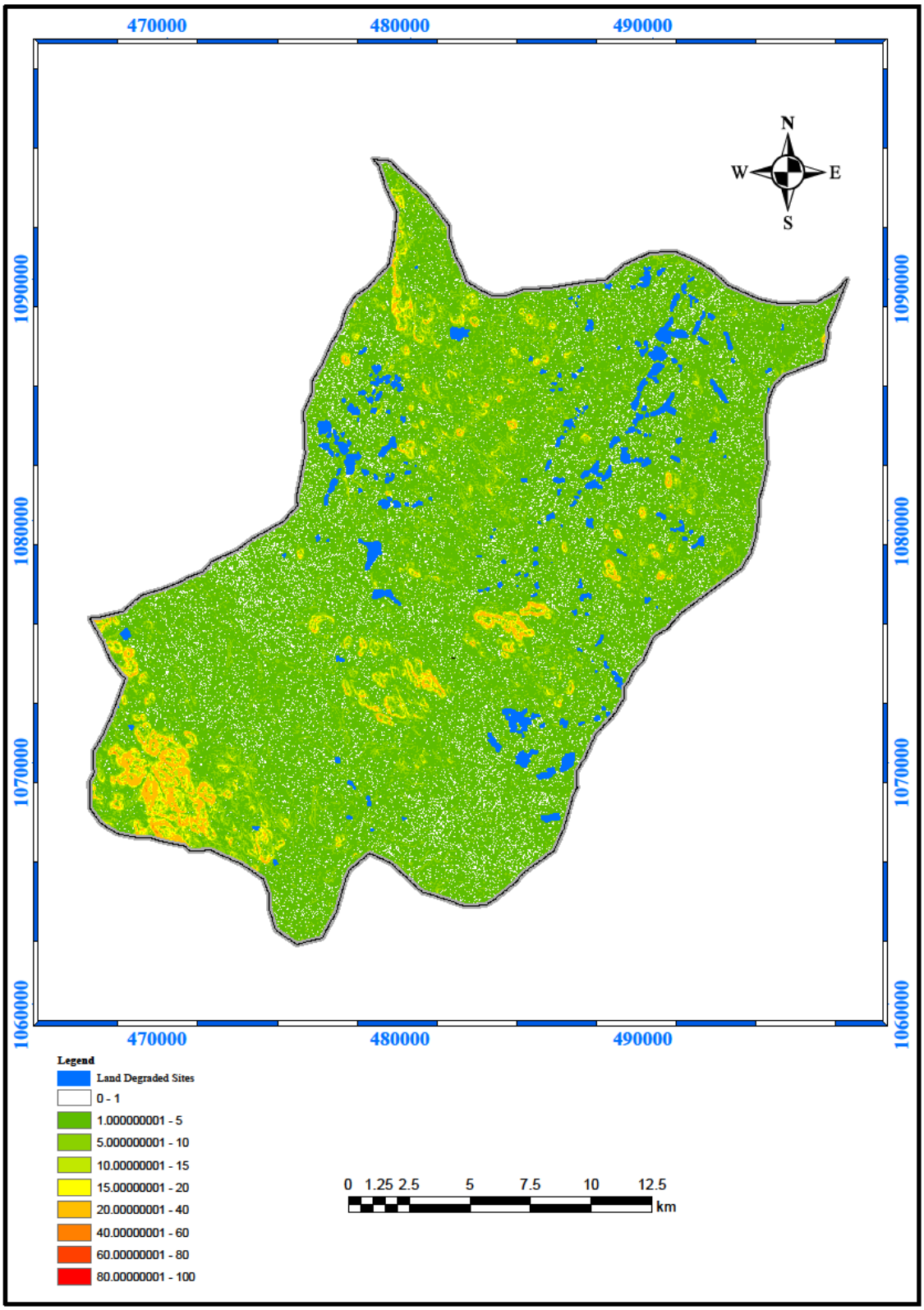


Figure 4.22: Slopes of Jos South derived from DEM of the study area

In addition to slope, the direction of slope (aspect), was also derived from the elevation data and classified as indicated in Figure 4.23. Aspect map describes the direction of slope in the four fundamental directions between 0˚ to 360˚. In Figure 4.23, land covers with black colour indicate flatness of the area and this corresponds to land covers with depths. This implied land covers that are derelict mine ponds. The slope directions of other land covers are shown in different colour ramps depending on the cardinal direction.

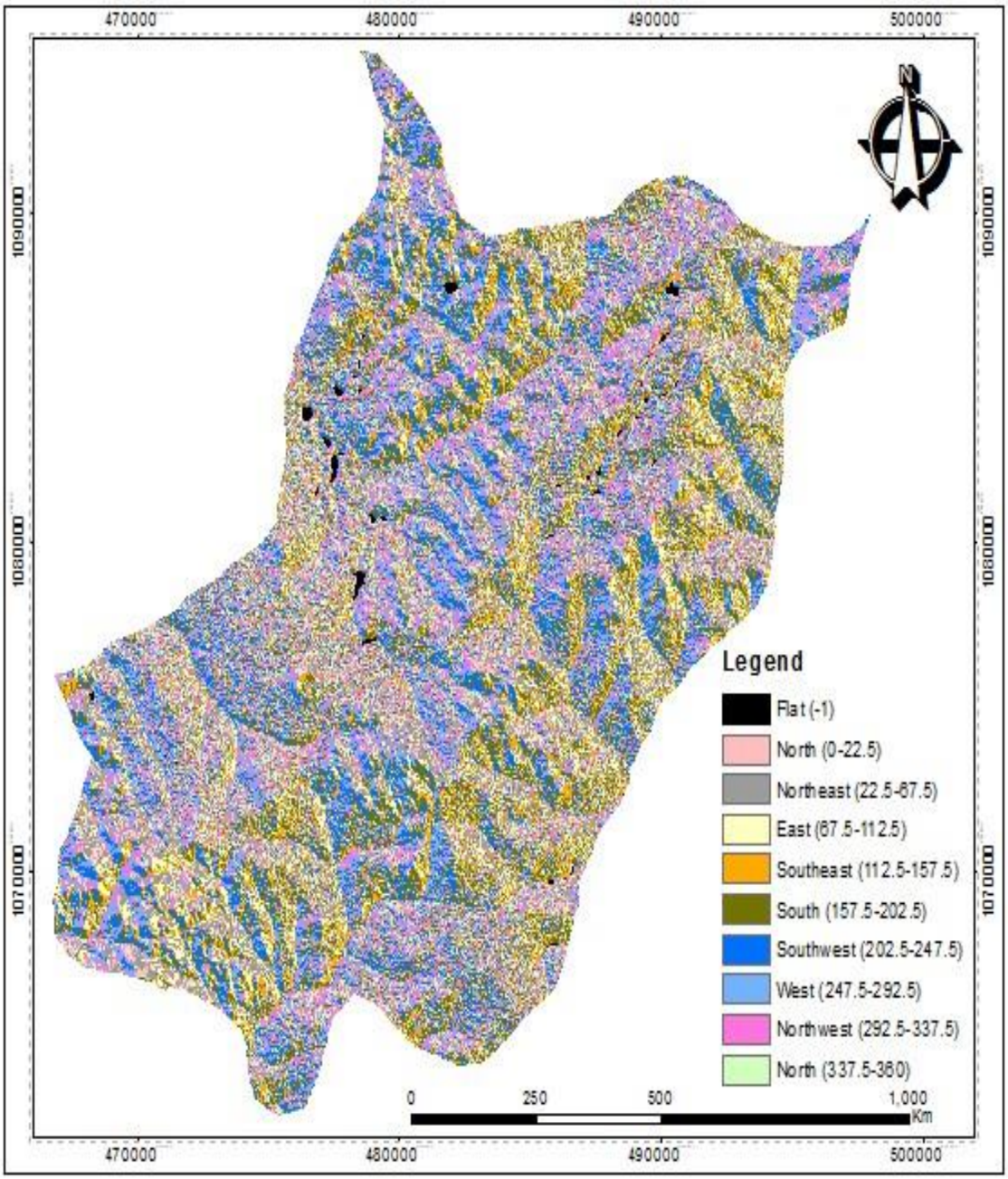


Figure 4.23: Aspect map derived from DEM of Jos South

In order to describe the study area focusing on the land covers with depths, a slope mask was created from the slope mask. In Figure 4.24, land cover with depths that correspond to derelict ponds are shown in blue colour, while other land covers are represented in grey colour. The slope mask indicated that mining activities are more concentrated in the north-east and north-west parts of the study area. Though, few derelict ponds can be found in the southern part of the study area.

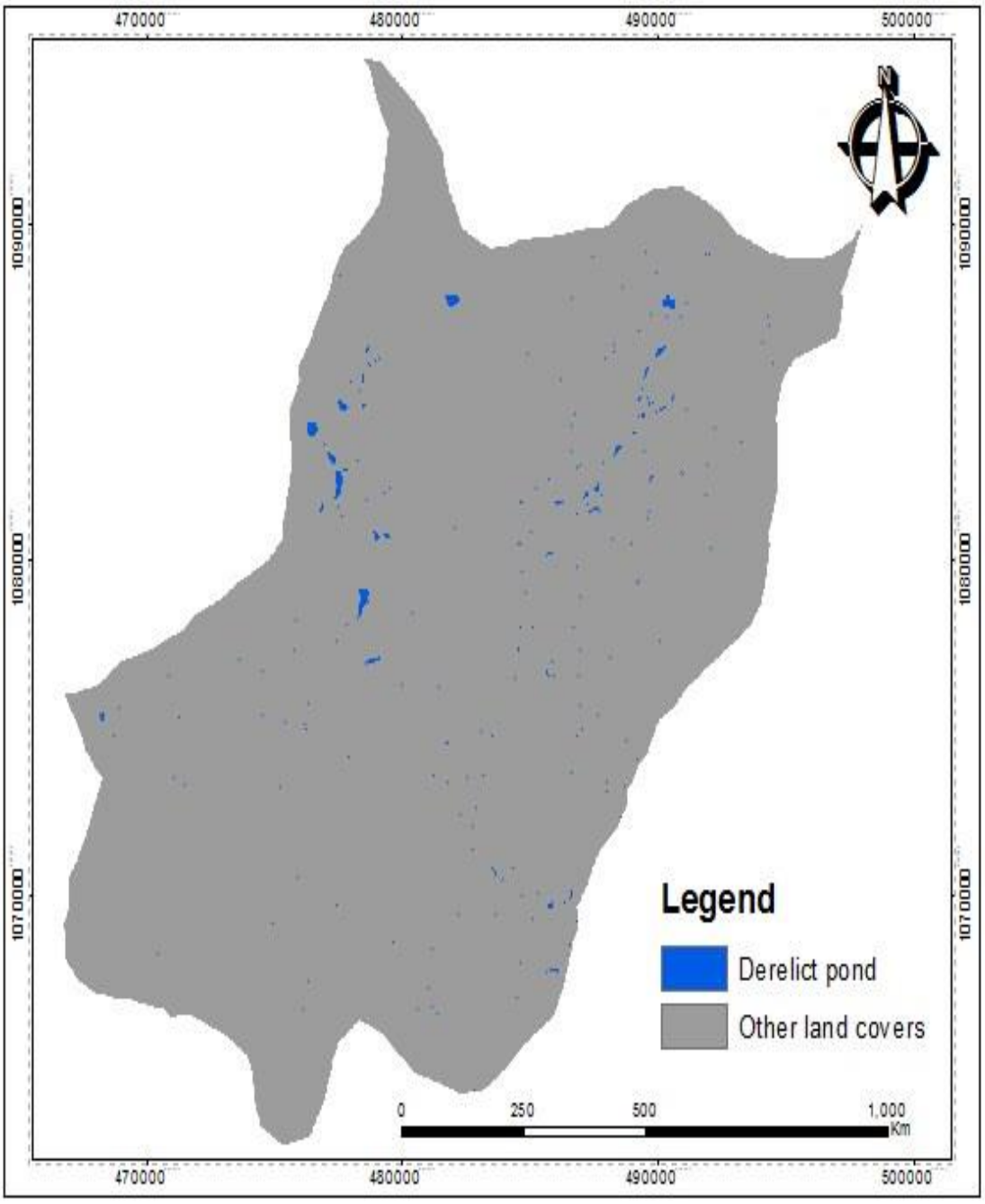


Figure 4.24: Slope mask derived from slope map of Jos South

In Figure 4.25, the result shows the digitized mining ponds spread randomly in the study area and overlaid on the contour map, it can be observed that the spatial location of the sites is irrespective of the contour values, some sites are located on steep slope while others are at gentle slope, this is because most of the degraded sites occurred as a result of mining activities; the major criteria for mining minerals is its availability hence mining activities can be done whether at high or low land.

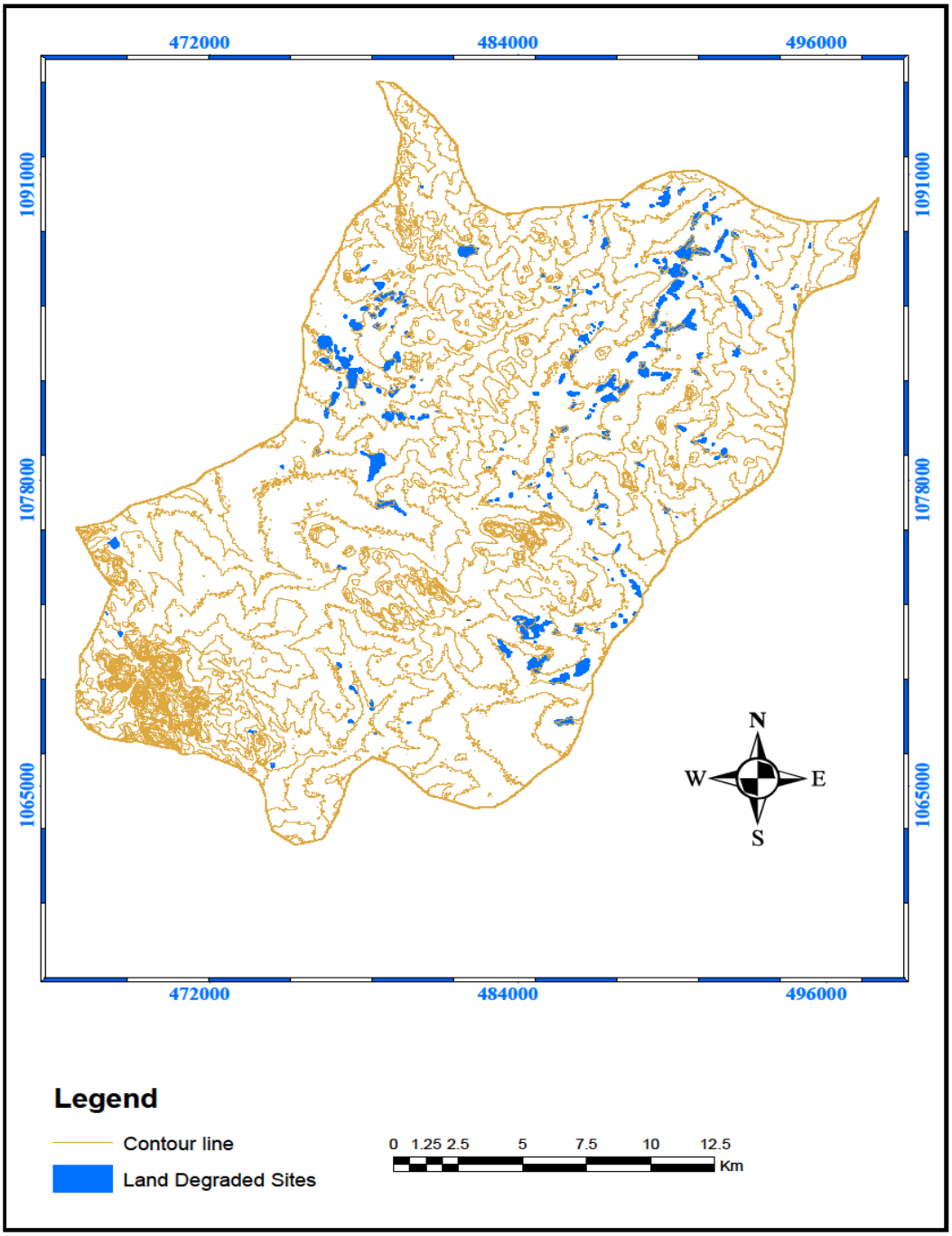


Figure 4.25: Study area maps showing land degraded sites overlaid on contours

4.5.1 Analyses of flow direction and flow accumulation

Flow Direction indicated for every cell the direction that water would flow through it. The value of the cell is a number representing a cardinal direction as shown in Figure 4.26. The output of the Flow Direction tool is an integer raster whose values range from 1 to 255. The values for each direction from the center is indicated using integer values. For example, if the direction of steepest drop was to the left of the current processing cell, its flow direction would be coded as 16. In Figure 4.26, integer 1,4, 16 and 64 represent East, South, West and North flow directions respectively, whereas integers 2, 8, 32 and 128 represents South-East, South-West, North-West and North-East flow directions respectively.

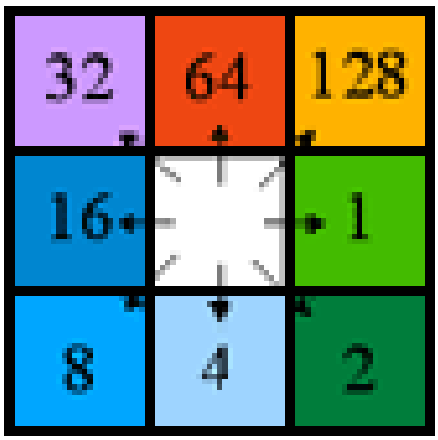


Figure 4.26: Flow direction coding

In Figure 4.26, if a cell is lower than its eight neighbors, that cell is given the value of its lowest neighbour, and flow is defined toward this cell. If multiple neighbors have the lowest value, the cell is still given this value, but flow is defined with one of the two methods explained below. This is used to filter out one-cell sinks, which are considered noise. Results in Figure 4.27 indicated that integer 1 has 13.21%, integer 2 has 7.92, integer 4 has 15.37, integer 8 has 10.39%, integer 16 has 17.91%, integer 32 has 9.65%, integer 64 has 16.02% and integer has 9.53. Results in Figure 4.27 indicated that flow direction for most of the degraded sites are 16 and 64 meaning North and West directions.

Figure 4.28 also shows the stream networks derived from flow accumulations, it is observed that most of the stream networks were connected with the degraded sites which is an evidence why most of the degraded sites are seasonally inundated.

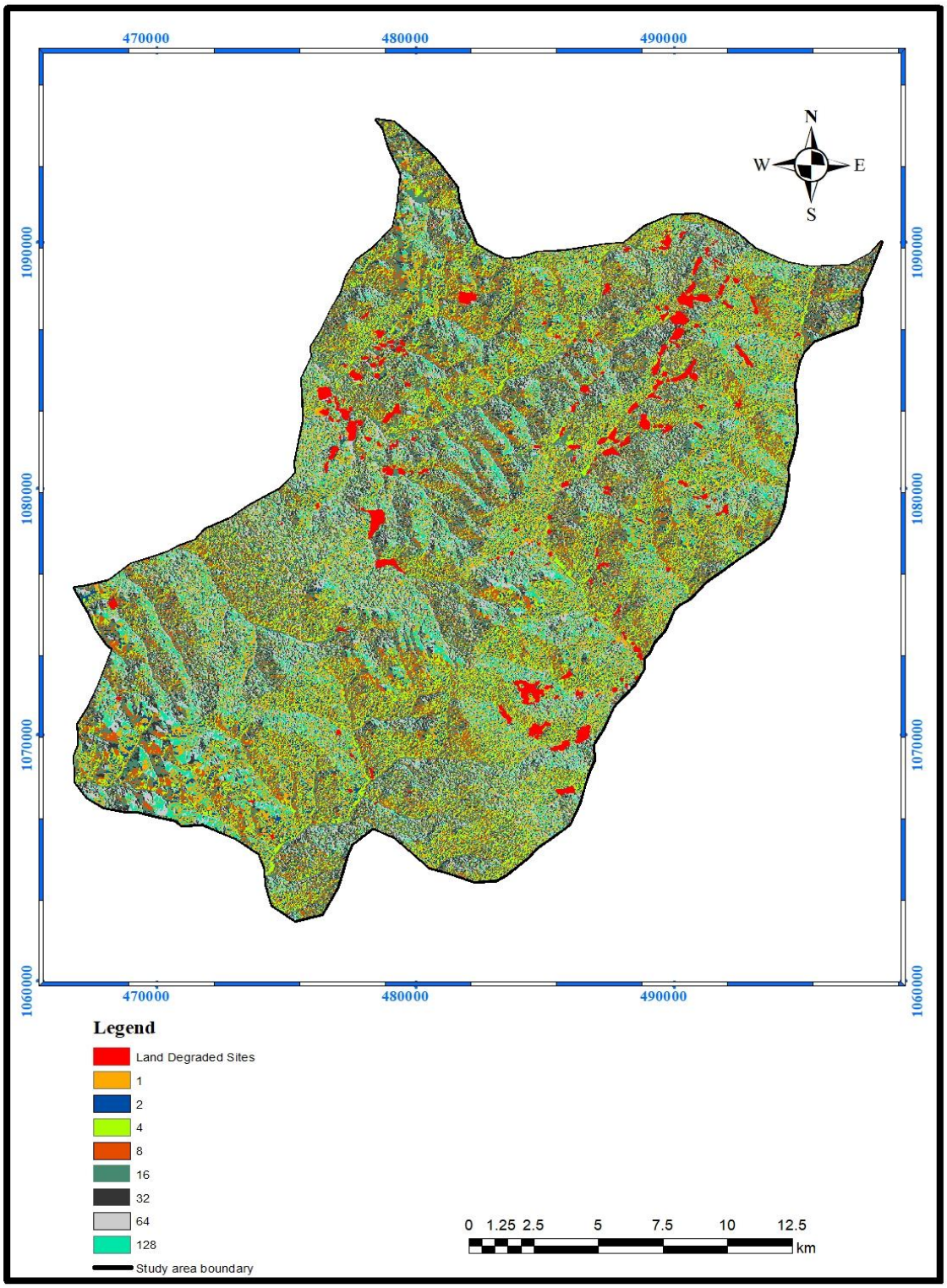


Figure 4.27: Land degraded sites overlaid on the flow direction map

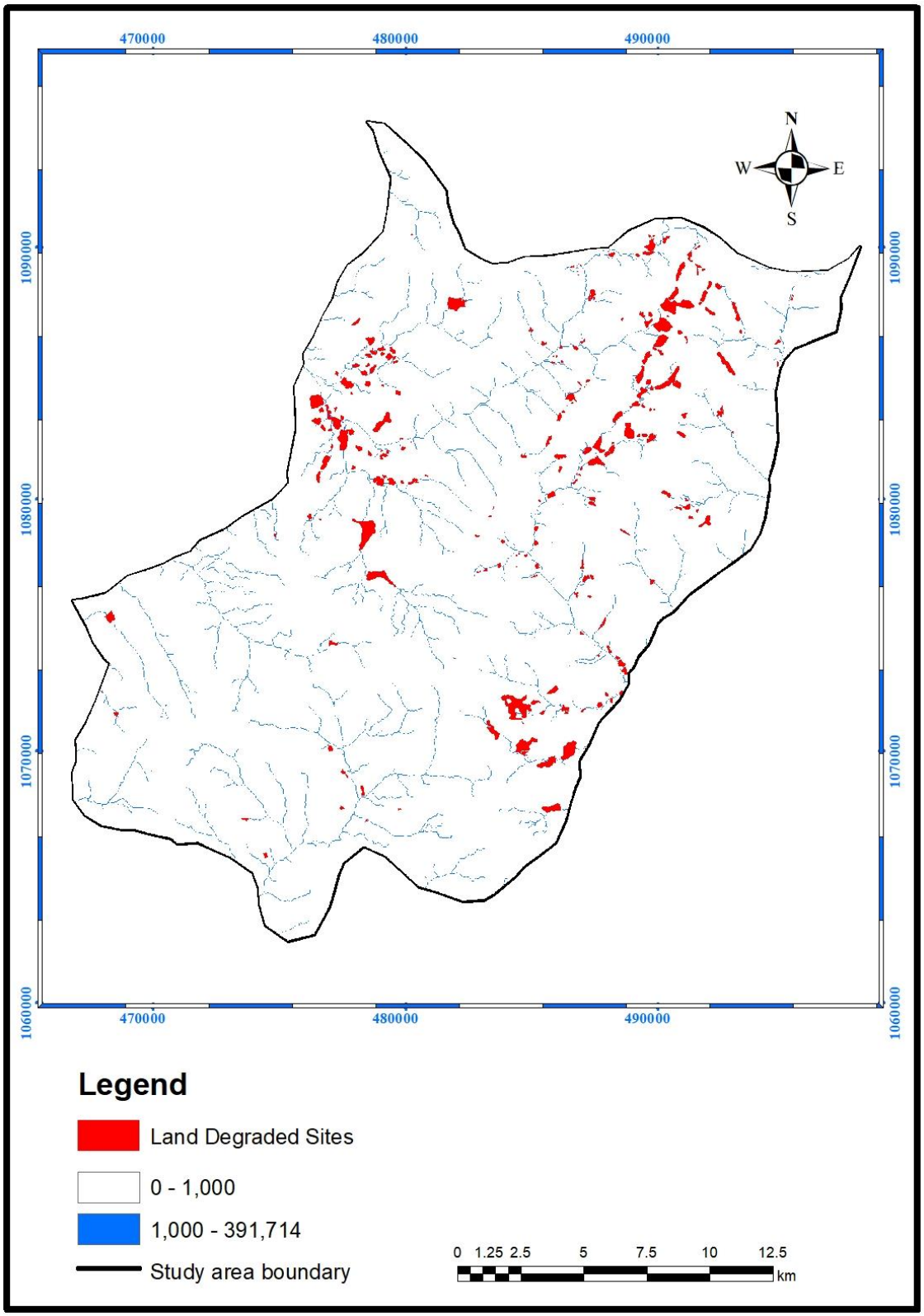


Figure 4.28: Land degraded sites overlaid on the flow accumulation map indicating the stream networks

CHAPTER FIVE

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

5.1 Introduction

This chapter entails the summary of findings, conclusions and recommendations arrived at based on the satellite and ancillary datasets, methodology, results, and analyses. Recommendations suggested were also based on the findings from the research.

5.2 Summary of Findings

This research has demonstrated that satellite imageries with other ancillary data and proper methodologies can be used effectively for geospatial analyses of land degraded sites. Hence, with all the objectives of the research being accomplished, the innovations in this research rest on the main findings summarized below:

i. The objective one was accomplished by delineation and analyses of land degraded sites using onscreen digitization. There were 235 digitized degraded sites delineated in the study area, out of which 10 major sites were chosen for detail analyses.

ii. The objective two was accomplished by the classification of degraded sites based on their usages, functions, features and economic potentials, the results produced indicated that most of the sites are seasonally inundated with various uses such as irrigation, fish stocking, agricultural and recreational.

iii. The objective three was achieved through accurate classification of the six land cover classes related to land degradation. The six classes were distinctly classified. The maps showed the spread of mine ponds, bare degraded land, settlements, rocky areas, farmlands, and vegetation. The classification results also revealed a total land cover of 512.10km^2,

iv. The objective four was accomplished through terrain analyses showing the digitized mining ponds spread randomly in the study area, which implied that the spatial location of the degraded sites is irrespective of the elevation, the reason being that most of the degraded sites occurred as a result of mining activities; this further proved that the major condition or criteria for mining minerals are its availability hence mining activities can be done whether at high or low land.

v. In the slope analyses, land covers with depths (e.g. derelict ponds) have slope values of 0 to 0.99, this revealed that the study area is characterized by excavated surfaces, gully and abandoned mines. Furthermore, flow direction, flow accumulation and stream networks were derived to show additional relationship between the degraded sites and the terrain.

5.3 Conclusions

The study has effectively analysed land degraded sites using onscreen digitization, maximum likelihood supervised classification and digital elevation model data.

This research has effectively answered all the research questions raised.

Where are the geometrical characteristics of land degraded sites in the study area? The precise locations were determined with a total land degraded sites of 235 being delineated, at 11.5818km², covering a 2.26 % of the entire degraded sites in the study area. Ten major degraded sites were also analysed totaling 17.43% of the total degraded areas.

What are the common features of the land degraded sites in the study area? The common classification of degraded sites was based on their usage, which include active mines sites, Dormant sites, Fish farming sites, Irrigation sites, water treatment plants, etc. The complete Table of the database is shown in Appendix 3.

Are there relationships between the degraded areas and neighbouring land use? Yes, in some areas and no in other areas as discussed in 4.4.

Are there relationships between the terrain and degraded sites in the study area? The study revealed that the spatial location of the degraded sites is irrespective of the terrain because most of the degraded sites occurred as a result of mining activities; which can be done whether at high or low land.

It is evident from the findings that mining not only alters the land cover and vegetation but also lead to erosion and degradation of land and deposition of the mining wastes in the nearby lands. The satellite multi-sensor, multi-spectral data enabled deriving information on land cover and degradation of the area. The information on demarcated mine-induced degraded areas as derived from the digitized sites and the land cover map was integrated with DEM data to analyse areas affected by mining and overburden dumps. The slope, aspect, and contour information have been derived from DEM generated.

The study has shown that information from satellite remote sensing and integrated with GIS can play a useful role in understanding the nature and extent of changes in land use/ land cover, where they are occurring and monitoring these changes at local scale. The research has also adequately talked about consequences of the degraded sites and relationship between terrain and land degradation.

However, some problems were encountered in the course of this project which were surmounted.

Firstly, there were some obstacles in getting the satellite imagery required for the research from the Office of the Surveyor General of the Federation. The people in charge argued the existence of the data at first, and then later, complaint that most people come to request for the data claiming it is for research while in a real sense, they intend to use it for

commercial/contract works. The SPOT 5 data acquired also had cloud cover in some part of the study area. The Quickbird-2 imagery also does not cover the study area completely. Secondly, some part of the study area is not secured for ground truthing, due to criminal activities meted especially to the strangers, this made it difficult for the researcher to cover all the areas during the field visit.

The first problem was surmounted by writing official letter endorsed by the department, together with a copy of the research proposal and submitted to the Surveyor General of the Federation, this made it easier for the researcher to acquire relevant data for the research. Landsat 8 2016 was used to enhance the SPOT 5 imagery, this is to reduce the effect of cloud cover and reveal more degraded sites. The second problem was solved by going to the study area together with a staff of Plateau State ministry of Solid minerals, who is also familiar with the study area. Google earth imagery was used as a supplement of ground-truthing in some of the areas the researcher could not access.

5.4 Recommendations

In the light of all that has been stated above, the following suggestions here hereby proposed:

i. There are certain appropriate LULC in the neighbourhood that could be utilized productively, for example, block industries, water treatment plants, fish farming, and other economic activities should be sited around the seasonally inundated mine pond, so that they can be more useful, if not the mine ponds ought to be demarcated or reclaimed to curtail prevalent accidents.

ii. Future research works should focus on land degradation monitoring by integrating GIS and satellite remote sensing with soil properties such as soil pH, texture, water capacity contents etc. to analyse accurate degradation of soil

especially farmlands. Likewise, Object-Based Image classification should be tested in future research to develop urban environmental monitoring.

iii. Because of the illegal mining going on in some degraded sites aggravating the degradation rate, the researcher recommends urgent priority in the implementation and enforcement of the existing mining and other environmental protection laws at all levels to safeguard the environment.

iv. Ecological funds being provided by the Federal Government should be utilised for rehabilitation, reclamation and remediation of the existing dormant land degraded sites in the study area.

5.5 Contribution to Knowledge

i. The methodology in this research has demonstrated how land degraded sites can be analysed using geospatial technology. The concise literature and related works reviews have contributed to literary knowledge.

ii. The research has also contributed to knowledge by bridging the existing gap in the previous researches of not adequately addressing the issue of the economic value and consequences of the degraded sites and relationship between terrain and the neighbourhood of the degradation sites.

iii. Three-way approach: onscreen digitization, automatic classification, and terrain analyses have been explained which has not been done in the reviewed researches.

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APPENDICES

Appendix 1: Application letter for image request

Department of Geomatics,
Faculty of Environmental Design,
Ahmadu Bello University,
Zaria,
Kaduna State.
15th. January, 2016.

The Surveyor General of the Federation,
Office of the Surveyor General of the Federation,
Yawuri Street,
Garki II, Abuja.
Through:
The Head,
Department of Geomatics,
Faculty of Environmental Design,
Ahmadu Bello University,
Zaria, Kaduna State.

OFFICE OF THE SURVEYOR GENERAL OF THE FEDERATION
RECEIVED
01 FEB 2016
SIGN

Recommended for your approval, Sir
15-01-2016

DEPARTMENT OF GEOMATICS
AHMADU BELLO UNIVERSITY
ZARIA-NIGERIA

Dear Sir,

APPLICATION FOR HIGH RESOLUTION SATELLITE IMAGERY

I wish to kindly request for the above mentioned subject matter. I am Bala Adamu, with registration number P13EVGM8007, a full time MSc. student of the Department mentioned above.

The Department has approved a research topic titled "Geospatial analyses of Land Degradation Sites in Jos South Local Government Area of Plateau State" for me, to conduct a research, as part of the requirement for the award of Master of Science in Geomatics.

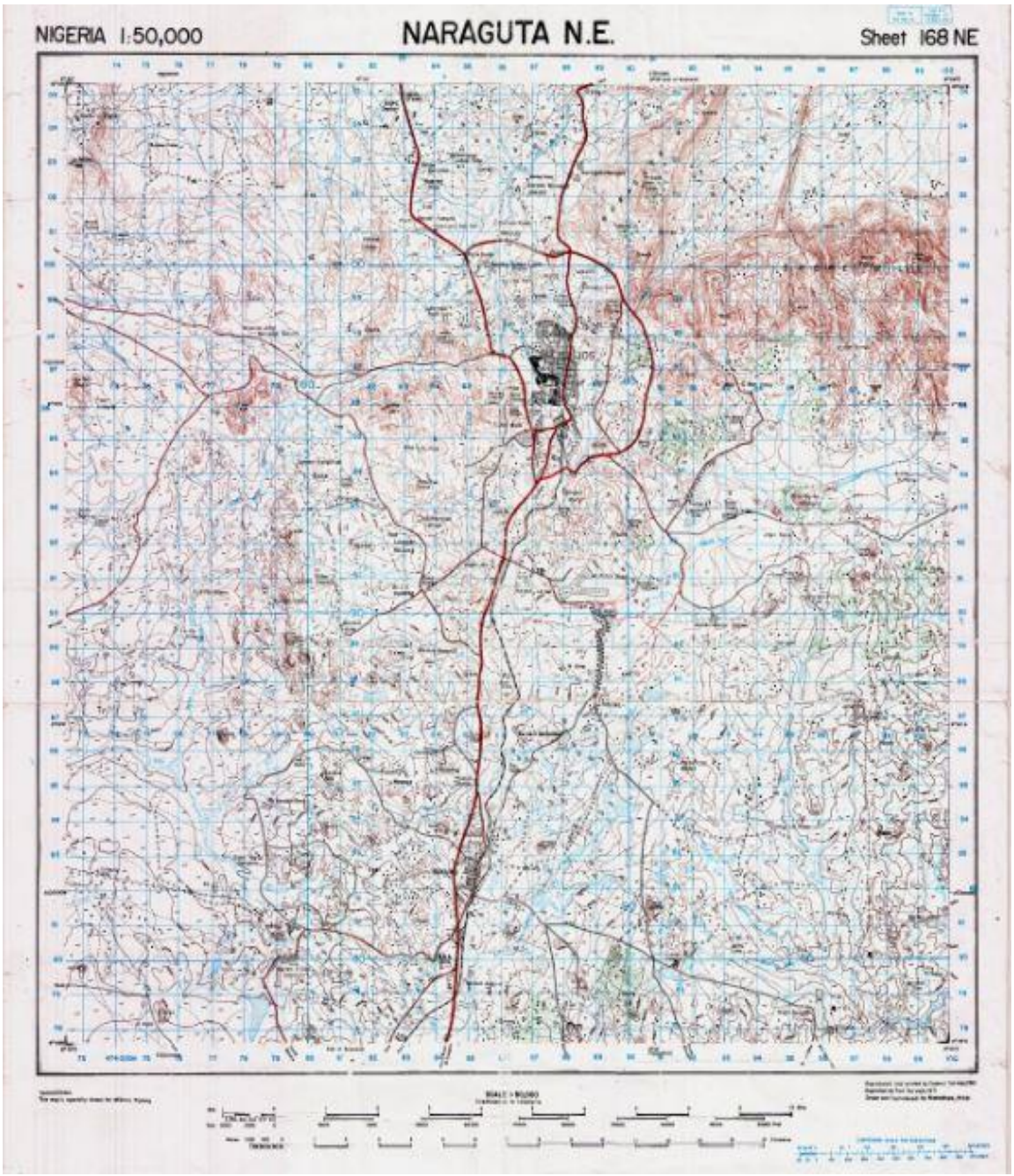
However, high resolution satellite imagery such as SPOT 5, QuickBird or Ikonos covering the study area is required as part of the materials to execute the research, this is to have a good view and analyses of the study area.

Attached is a copy of research proposal for your perusal, please. I would be grateful if my application is approved. Thank you.

Yours faithfully,

Adamu Bala

Appendix 2: Naraguta topographic sheet 168 NE covering part of the study area



Appendix 3: Records of the Land Degraded Sites

S/NO	NAME OF DEGRADED SITES	CLASSES OF DEGRADED SITES	AREA(m^2)	LONGITUDE	LATITUDE	REMARKS
1	Rayfield 5 (Columbite mines)	Active mine site	282496.00	8°54'36.683"	9°49'56.621"	Active Coulumbite mining; ownership exist
2	Kuru Janta 1 (The Rock and Clay Industry Limited)	Active mine site	616521.00	8°51'30.449"	9°41'49.122"	Hill valley; loto mining taking place; ownership exist; mounts with small patches of water
3	Kuru Janta 13 (Rock and Clay Industry Ltd Mines 2)	Active mine site	44117.70	8°51'54.458"	9°41'50.952"	Loto mining in progress
4	Kuru Janta 3	Active mine site	268796.00	8°51'40.523"	9°40'57.466"	Deep elongated paddock with artisanal mining taking place
5	Gyero 3	Active mine site	16307.20	8°47'32.076"	9°48'54.492"	Mining activities evident; dumps; within GONA valley; existing mining lease belonging to CTM
6	Kuru Janta 9	Active mine site	13643.80	8°52'55.613"	9°41'40.061"	
7	Gyero 7	Active mine site	50498.70	8°48'20.15"	9°49'1.176"	Illegal mining going on with huge tailing dumps and sands being quarried
8	Gyero 10	Active mine site	8839.00	8°48'35.123"	9°48'39.831"	Illegal mining going on with large paddocks and and massive mines dumps
9	Sabon Gidan Kanar 3b	Active mine site	16786.40	8°48'36.332"	9°46'40.585"	Sand quarrying; north east of 3A
10	Du 15	Agricultural	15359.00	8°54'12.645"	9°48'12.096"	Farmlands nearby; ponds adjacent
11	Du 14	Agricultural	80428.30	8°54'26.91"	9°47'29.856"	
12	Du 13	Agricultural	28750.20	8°54'13.531"	9°47'35.515"	
13	Du 24	Agricultural	140125.00	8°53'18.267"	9°47'25.906"	
14	Bukuru 21	Agricultural	60327.00	8°52'14.137"	9°46'15.841"	
15	Zawan 12	Agricultural	23309.60	8°51'5.586"	9°44'48.544"	
16	Zawan 15	Agricultural	6030.80	8°50'35.837"	9°44'38.013"	
17	Zawan 14	Agricultural	3255.99	8°50'41.123"	9°44'39.039"	

S/NO	NAME OF DEGRADED SITES	CLASSES OF DEGRADED SITES	AREA(m^2)	LONGITUDE	LATITUDE	REMARKS
18	Zawan 13	Agricultural	13492.50	8°50'47.472"	9°44'41.345"	
19	Kuru Janta 7	Agricultural	181901.00	8°52'11.831"	9°40'31.463"	Extension for Agricultural purposes
20	Barikin Kuru babba 1	Agricultural	34482.20	8°47'25.462"	9°40'51.075"	
21	Sabon Gidan Kanar	Agricultural	28355.10	8°46'58.453"	9°45'49.363"	
22	Sabon Gidan Kanar 1f (NG 6)	Agricultural	15740.10	8°47'26.423"	9°47'41.121"	Silted; grass growing
23	Gyero 23	Agricultural	2962.03	8°48'10.322"	9°49'27.952"	
24	Shen 3	Agricultural	22387.90	8°54'59.701"	9°46'1.383"	
25	Du 18	Agricultural	50654.80	8°55'5.285"	9°47'32.779"	
26	Bisichi Kuru Du 4	Agricultural	16729.20	8°53'43.523"	9°42'1.181"	
27	Kuru Janta 4	Agricultural	11144.60	8°52'32.651"	9°41'35.202"	Dam built across Gada biyu-Bisichi stream
28	Barikin Mai`adiko 1	Dormant	55985.40	8°53'7.199"	9°50'40.116"	Dried up; abandoned
29	Rayfield 16	Dormant	2303.22	8°55'20.204"	9°51'41.729"	Small; abandoned; less threat
30	Dura mines pond	Dormant	10622.80	8°55'26.266"	9°50'25.824"	Opposite Dogo mines; no settlement around; seasonally inundated
31	Doi 10	Dormant	4326.19	8°57'27.664"	9°50'35.441"	Shallow; no settlement nearby; farmlands around; Tree Planting
32	Doi 9	Dormant	8624.52	8°57'25.581"	9°50'30.813"	No settlements nearby; located near a water coarse
33	Dorowa Congo Mines pond	Dormant	22282.70	8°52'25.532"	9°46'51.117"	Abandoned; settlements nearby
34	Barikin Kuru babba 2	Dormant	31902.90	8°47'25.462"	9°40'51.075"	
35	Barikin Momo Dogo site	Dormant	109296.00	8°42'40.012"	9°43'38.904"	Abandoned; inundation
36	Sabon Gidan Kanar 1m	Dormant	20887.40	8°47'55.136"	9°46'52.951"	

S/NO	NAME OF DEGRADED SITES	CLASSES OF DEGRADED SITES	AREA(m^2)	LONGITUDE	LATITUDE	REMARKS
37	Gyero 17	Dormant	51553.70	8°48'43.908"	9°49'17.276"	Small pond with low mining dumps and no activities taking place
38	Rafin Bauna	Dormant	5250.04	8°49'12.62"	9°51'53.713"	
39	Sabon Gidan Kanar 7c	Dormant	1461.99	8°49'10.428"	9°47'25.829"	
40	Bisichi Kuru Du 6	Dormant	1312.40	8°53'10.113"	9°43'3.444"	
41	Vom site	Dormant	42680.70	8°47'28.72"	9°43'6.452"	
42	Du 7	Dormant	40060.10	8°53'22.189"	9°43'31.525"	Broken old mining embankment
43	Du 10	Dormant	32164.40	8°54'24.897"	9°44'26.403"	Old embankment stored water for mining purposes
44	Rayfield 10	Dormant	43738.20	8°55'50.205"	9°50'48.016"	Old broken earth dam; development has taken over the site
45	Gold and base 1	Dormant	9675.49	8°54'21.205"	9°51'51.414"	
46	Gold and base 2	Dormant	5624.32	8°54'26.921"	9°51'52.566"	
47	Kuru station 2	Dormant	20245.10	8°47'41.149"	9°39'33.07"	No dumps or mining activities going on
48	Kuru station 4	Dormant	9114.53	8°48'54.987"	9°39'30.899"	Too remote for human settlements; no dumps or activities in the sites
49	Gyero 2	Dormant	204863.00	8°48'36.665"	9°47'53.97"	Broken embankment with no settlement around
50	Gyero 12	Dormant	18941.10	8°48'50.016"	9°49'8.805"	Broken embankment with dry reservoir close to settlement
51	Sabon Gidan Kanar 4 (Mills)	Dormant	9930.29	8°48'31.459"	9°47'4.425"	Devastated
52	Shen 6	Dormant	20384.00	8°55'15.549"	9°45'48.443"	
53	Zawan 10 (Dorowa Karama pond)	Fencing	68151.90	8°52'21.496"	9°47'9.813"	Agricultural usage
54	Zawan 5 (Zawan mines pond)	Fencing	25855.40	8°51'51.867"	9°45'34.33"	Partially reclaimed; Domestic usage; threat to lives; protected

S/NO	NAME OF DEGRADED SITES	CLASSES OF DEGRADED SITES	AREA(m^2)	LONGITUDE	LATITUDE	REMARKS
55	Bukuru 2 (Kara)	Fencing	45720.00	8°52'9.368"	9°47'28.476"	Used for fishing by state ministry of Agriculture even though highly silted
56	Du 3	Fencing	33220.60	8°55'3.731"	9°48'0.794"	Behind WAYE foundation; used for Agricultural activities
57	Doi 2	Fencing	175487.00	8°55'59.591"	9°49'8.593"	Huge dumps of overburden nearby; Tree Planting
58	Du 11	Fencing	29619.80	8°53'48.518"	9°45'30.312"	Embankment
59	Zawan 1	Fencing	3594.48	8°51'27.705"	9°44'44.715"	Fencing; Tree Planting; Agricultural
60	Bukuru 5	Fencing	1668.89	8°52'28.407"	9°46'5.469"	Has heaps of mines dump
61	Rayfield 11b (Rayfield Resort Pond 2)	Fish Stocking	97513.60	8°54'57.726"	9°50'40.416"	Owned by Government; Fencing
62	Rayfield 8 (Dogo mines pond)	Fish Stocking	69444.40	8°55'32.169"	9°50'33.959"	Ownership exist; expansive and elongated; heaps
63	Rayfield 22	Fish Stocking	91964.70	8°54'16.3"	9°49'16.545"	
64	Rayfield 23	Fish Stocking	122790.00	8°54'8.425"	9°48'54.387"	
65	Rahwol Kanang Mines Pond 3	Fish Stocking	17130.70	8°54'24.134"	9°48'35.071"	
66	Rahwol Kanang Mines Pond 4	Fish Stocking	5379.79	8°53'56.767"	9°48'11.571"	
67	Du 29	Fish Stocking	2525.17	8°52'46.193"	9°46'45.487"	
68	Du 2b	Fish Stocking	32430.20	8°53'7.946"	9°46'14.964"	Pond with annual inundation; Fencing; used for irrigation and water supply
69	Du 6	Fish Stocking	20980.20	8°52'44.447"	9°44'9.228"	Large pool; dries up in dry season
70	Sabon Gidan Kanar 1a	Fish Stocking	236312.00	8°46'59.452"	9°48'21.635"	
71	Bukuru 16	Fish Stocking	10005.10	8°52'27.085"	9°49'9.565"	
72	Bukuru 6	Fish Stocking	2416.77	8°52'33.192"	9°48'12.839"	Partial wall fence; Resort centre
73	Shen 1	Fish Stocking	50504.40	8°54'41.8"	9°46'19.114"	

S/NO	NAME OF DEGRADED SITES	CLASSES OF DEGRADED SITES	AREA(m^2)	LONGITUDE	LATITUDE	REMARKS
74	Doi 3	Fish Stocking	18167.80	8°55'54.482"	9°48'9.969"	Fishes noticed swimming in the ponds
75	Rahwol Kanang Mines Pond 4	Fish Stocking	111218.00	8°54'37.726"	9°48'38.375"	
76	Rahwol Kanang Mines Pond 5	Fish Stocking	130279.00	8°54'54.361"	9°48'53.385"	
77	Chaha 1	Fish Stocking	11918.70	8°46'12.588"	9°45'26.392"	Large reservoir for mining purposes; siltation; irrigation on the downstream; situated in a large open farmland
78	Du 4a	Fish Stocking	44816.70	8°52'56.225"	9°44'26.406"	Twin ponds which dry up in dry season; Tree Planting; used for fishing in rainy season; heaps dump
79	Du 4b	Fish Stocking	20052.20	8°53'7.558"	9°44'32.506"	Twin ponds which dry up in dry season; Fencing; used for fishing in rainy season; heaps dump
80	Rayfield 3	Fish Stocking	15819.50	8°54'28.296"	9°49'26.728"	Fencing; Highly silted; heaps of dumps; Resort centre
81	Kuru Janta 10	Fish Stocking	54255.40	8°52'33.113"	9°41'41.778"	
82	Gyero 1	Fish Stocking	7894.50	8°47'53.677"	9°48'29.093"	It is deep with heaps and irrigation taking place
83	Gyero 20	Inundated	278206.00	8°50'13.16"	9°50'25.92"	Seasonal inundation; few trees with no settlement around
84	Barikin Mai`adiko 2	Inundated	19725.90	8°53'2.139"	9°50'30.49"	Shallow; inundated
85	Barikin Mai`adiko 3	Inundated	10093.80	8°53'9.135"	9°50'30.793"	Twin to Barikin mai`adiko 3; shallow; near settlement
86	Barikin Akawo 1	Inundated	10703.40	8°52'40.269"	9°51'12.436"	Inundated; source of water to nearby settlement
87	Rayfield 26	Inundated	1725.46	8°53'26.295"	9°51'32.386"	Part of bigger Rayfield 27 site

S/NO	NAME OF DEGRADED SITES	CLASSES OF DEGRADED SITES	AREA(m^2)	LONGITUDE	LATITUDE	REMARKS
88	Rayfield 27	Inundated	35767.50	8°53'33.696"	9°51'27.885"	Seasonal inundation; source of water for constructions
89	Rayfield 14	Inundated	50102.30	8°55'12.154"	9°51'24.48"	Shallow; clustered to Rayfield 12 and 13
90	Rayfield 12	Inundated	116784.00	8°54'59.085"	9°51'9.31"	Shallow; Mine dumps quarried due to advancing community development
91	Ran Kuangdu mines	Inundated	10603.80	8°55'31.4"	9°51'8.818"	Seasonal inundation; small; near farmlands
92	Rayfield 18	Inundated	24214.00	8°54'20.569"	9°50'10.305"	Seasonal inundation; no much trees around; little bit far from settlements
93	Rayfield 7	Inundated	54240.90	8°55'9.849"	9°49'38.744"	Threat to residents; expansive and elongated
94	Doi 8	Inundated	24551.30	8°57'6.619"	9°49'33.105"	Twin shallow ponds; seasonally inundated
95	Doi 6	Inundated	13488.60	8°56'20.448"	9°49'48.471"	Abandoned; farmlands near
96	Rayfield 6a	Inundated	24724.00	8°54'59.158"	9°49'47.832"	Small pond; source to Yakubu Gowon dam
97	Rayfield 6b	Inundated	19290.40	8°55'9.849"	9°49'38.744"	Small pond; source to Yakubu Gowon dam
98	Rennaj Fish Integrated Farms Mine Pond	Inundated	34505.60	8°54'20.074"	9°48'44.223"	Inundated water used for block industry and recreation
99	Du 16	Inundated	8139.07	8°54'20.694"	9°48'7.679"	
100	Sabon Gidan Kanar 9	Inundated	479802.00	8°48'12.755"	9°45'30.772"	
101	Sabon Gidan Kanar 1i	Inundated	114327.00	8°47'16.846"	9°46'59.406"	
102	Sabon Gidan Kanar 1k	Inundated	20840.90	8°47'42.136"	9°47'56.96"	Tiny ponds; east of 01B
103	Sabon Gidan Kanar 1b	Inundated	203107.00	8°47'25.736"	9°47'56.757"	Large and deep
104	Gyero 24	Inundated	33868.10	8°48'54.731"	9°48'30.514"	
105	Rayfield 24	Inundated	25886.50	8°52'44.783"	9°49'28.837"	

S/NO	NAME OF DEGRADED SITES	CLASSES OF DEGRADED SITES	AREA(m^2)	LONGITUDE	LATITUDE	REMARKS
106	Sabon Gidan Kanar 5a	Inundated	31356.60	8°48'35.31"	9°47'8.973"	Near residence; Small; North East of 4
107	Sabon Gidan Kanar 7b	Inundated	20157.40	8°49'0.361"	9°47'17.571"	Tiny pond, water for ML 9910
108	Kwata 3	Inundated	4396.47	8°50'58.23"	9°46'0.748"	Reclaimed; reserve water
109	Bisichi Kuru Du 8	Inundated	18897.50	8°53'39.868"	9°42'46.959"	
110	Bisichi Kuru Du 10	Inundated	59300.80	8°53'44.05"	9°42'40.325"	
111	Bisichi Kuru Du 11	Inundated	45814.40	8°53'50.029"	9°42'27.867"	
112	Rayfield 15	Irrigation	15308.50	8°55'22.922"	9°51'37.835"	Irrigation; medium in size
113	Rayfield 13	Irrigation	40738.40	8°55'23.839"	9°51'9.583"	Entails three mining ponds; irrigation evident; heaps
114	Doi 7	Irrigation	98998.30	8°56'14.134"	9°50'15.854"	
115	Rahwol Kanang Mines Pond 2	Irrigation	90370.50	8°54'12.153"	9°48'31.139"	
116	Rahwol Kanang Mines Pond 1	Irrigation	48757.60	8°54'3.767"	9°48'14.699"	
117	Du 1 (Rahwol Fadama Mines Pond)	Irrigation	92187.60	8°53'36.282"	9°47'59.055"	Used for fishing and irrigation
118	Du 17	Irrigation	5434.12	8°54'26.971"	9°48'6.82"	
119	Du 12	Irrigation	16164.90	8°54'4.953"	9°47'33.882"	
120	Du 21	Irrigation	9061.32	8°53'34.269"	9°47'25.852"	
121	Du 22	Irrigation	53637.40	8°53'29.994"	9°47'19.101"	
122	Du 23	Irrigation	37855.90	8°53'23.291"	9°47'8.353"	
123	Du 28	Irrigation	6562.47	8°52'50.752"	9°46'44.316"	
124	Du 26	Irrigation	148295.00	8°53'11.654"	9°46'58.798"	
125	Du 30	Irrigation	20817.80	8°52'43.098"	9°46'32.185"	
126	Bukuru 22	Irrigation	8195.58	8°51'57.577"	9°46'9.061"	
127	Zawan 3	Irrigation	19931.00	8°51'11.163"	9°45'18.765"	
128	Zawan 11	Irrigation	3900.51	8°51'31.937"	9°45'1.663"	
129	Zawan 16	Irrigation	26482.50	8°51'53.346"	9°44'46.399"	
130	Du 20	Irrigation	1902.33	8°54'38.002"	9°44'15.104"	
131	Du 19	Irrigation	31838.50	8°52'52.78"	9°44'49.215"	

S/NO	NAME OF DEGRADED SITES	CLASSES OF DEGRADED SITES	AREA(m^2)	LONGITUDE	LATITUDE	REMARKS
132	Kuru Janta 12	Irrigation	20084.20	8°52'2.983"	9°41'38.304"	
133	Kuru Janta 6	Irrigation	33070.30	8°51'39.632"	9°40'44.285"	Confluence of KURU JANTA 2&3 with large irrigation
134	Barikin Kuru babba 3	Irrigation	46219.00	8°48'8.094"	9°39'56.554"	
135	Ganawuri 1	Irrigation	24501.50	8°42'43.995"	9°41'35.22"	
136	Ganawuri 2	Irrigation	3736.45	8°42'29.553"	9°42'3.547"	
137	Sabon Gidan Kanar 1j	Irrigation	18287.20	8°47'27.126"	9°47'18.841"	
138	Gyero 5	Irrigation	41531.60	8°48'16.247"	9°48'41.627"	Expansive and close to human settlements; irrigation taking place linking GYERO 6 via a channel
139	Gyero 13	Irrigation	35448.40	8°47'58.698"	9°49'4.225"	Small and deep mine site with irrigation taking place
140	Gyero 6	Irrigation	41860.90	8°48'9.884"	9°48'55.291"	Mining pond with irrigational land nearby
141	Gyero 14	Irrigation	32192.40	8°48'17.665"	9°49'16.508"	Large mine pond with irrigation taking place
142	Gyero 16	Irrigation	37091.20	8°48'31.603"	9°49'25.593"	Large with more farmland for irrigation
143	Gyero 18	Irrigation	11530.50	8°48'49.52"	9°49'15.174"	
144	Gyero 11	Irrigation	77856.40	8°48'18.308"	9°49'37.898"	Large reservoir with tailings and irrigation nearby
145	Gyero 22	Irrigation	38686.30	8°47'59.73"	9°50'0.569"	
146	Sabon Gidan Kanar 3c	Irrigation	65036.80	8°48'46.184"	9°46'35.008"	Massive irrigation going on; twin to 3A
147	Sabon Gidan Kanar 6	Irrigation	55175.60	8°49'15.702"	9°46'35.846"	Irrigation; deep; close to settlement
148	Sabon Gidan Kanar 8	Irrigation	8743.87	8°49'31.332"	9°46'42.368"	Irrigation nearby; tiny; near primary school
149	Bukuru 20	Irrigation	13660.30	8°52'26.213"	9°49'29.196"	
150	Bukuru 18	Irrigation	2740.79	8°52'16.538"	9°49'17.114"	
151	Bukuru 19	Irrigation	5913.56	8°52'19.623"	9°49'16.505"	
152	Bukuru 12	Irrigation	1868.27	8°52'56.998"	9°48'37.047"	

S/NO	NAME OF DEGRADED SITES	CLASSES OF DEGRADED SITES	AREA(m^2)	LONGITUDE	LATITUDE	REMARKS
153	Shen 2	Irrigation	47349.50	8°55'10.746"	9°46'4.144"	
154	Shen 4	Irrigation	11530.10	8°55'24.038"	9°45'56.528"	
155	Doi 5	Irrigation	4643.28	8°56'10.242"	9°47'38.451"	
156	Sabon Gidan Kanar 5c	Irrigation	4086.70	8°48'31.82"	9°47'14.26"	
157	Bisichi Kuru Du 3	Irrigation	19860.10	8°53'31.272"	9°41'52.395"	
158	Bisichi Kuru Du 7	Irrigation	29563.80	8°53'28.951"	9°42'58.08"	
159	Bisichi Kuru Du 5	Irrigation	12809.90	8°52'52.796"	9°43'18.289"	
160	Kuru station 3	Irrigation	6291.33	8°48'13.359"	9°39'16.187"	Small mine pond with irrigation activities taking place
161	Gyero 9	Irrigation	19989.20	8°48'31.855"	9°49'17.847"	Part of GONA river; Irrigation; Mining paddocks
162	Zawan 2	Ownership exist	5054.20	8°51'28.681"	9°44'59.084"	Ownership exist
163	Kuru Janta 2 (KAVITEX)	Ownership exist	146623.00	8°50'57.041"	9°41'16.209"	Owned by KAVITEX with access road and power supply
164	NVRI RESERVOIR (NIPSS Kuru)	Ownership exist	266743.00	8°48'31.469"	9°44'33.944"	Domestic water supply; seasonally inundated
165	Sabon Gidan Kanar 2a (ML 1372)	Ownership exist	258334.00	8°47'41.767"	9°47'29.482"	Large pond; no activities; massive dumps
166	Sabon Gidan Kanar 2b (ML1373)	Ownership exist	48137.90	8°47'52.849"	9°47'39.201"	Small pond that is part of 2A
167	Bukuru 8	Ownership exist	87120.50	8°52'40.855"	9°48'25.957"	Located behind late Da Victor Pam`s residence; Fenced
168	Bukuru 4 (Yelwa Club Treatment Plant)	Ownership exist	40670.00	8°52'24.762"	9°47'57.993"	Used as treatment plant for water supply; Fencing; Tree Planting
169	Rayfield 2	Ownership exist	8221.88	8°53'44.891"	9°50'4.581"	Mine pond fenced; ownership exists
170	Sabon Gidan Kanar 7a	Ownership exist	7432.15	8°48'58.016"	9°47'30.583"	Lease exist; belongs to Consolidated Tin Mines but no activities

S/NO	NAME OF DEGRADED SITES	CLASSES OF DEGRADED SITES	AREA(m^2)	LONGITUDE	LATITUDE	REMARKS
171	Zawan 7	Ownership exist	9311.72	8°51'51.209"	9°44'33.995"	Fencing; Eastern part of Blind school, Zawan; Owned and used for fishing by state ministry of Agriculture
172	Bukuru 3 (Near UMA bread)	Ownership exist	25950.50	8°52'4.289"	9°49'34.093"	Located near Uma bread; it has been partially reclaimed but continous erosion evident
173	Barikin Akawo 2	Partial inundation	2308.79	8°52'47.068"	9°51'6.458"	No residence nearby; medium in size
174	Barikin Akawo 3	Partial inundation	2932.25	8°52'51.404"	9°51'14.469"	Small in size; no much threat to life
175	Barikin Akawo 4	Partial inundation	2519.48	8°52'48.707"	9°51'1.952"	Near dense vegetation
176	Rayfield 25	Partial inundation	40834.40	8°54'41.576"	9°51'48.975"	Partial inundation; shallow
177	Doi 4	Partial inundation	13645.10	8°57'8.472"	9°49'7.932"	Shallow; no settlement around
178	Du 27	Partial inundation	9834.81	8°52'53.291"	9°46'52.949"	
179	Kuru Janta 11	Partial inundation	5630.41	8°51'36.053"	9°41'23.58"	
180	Kuru Janta 8	Partial inundation	286870.00	8°52'38.856"	9°40'48.347"	Large site with rocky terrain towards the north; storage for land downstream
181	Sabon Gidan Kanar 2c	Partial inundation	23921.90	8°48'17.264"	9°47'10.627"	Remnant of a larger pond 2D
182	Gyero 15	Partial inundation	38960.00	8°48'22.156"	9°49'21.636"	Meandering stream
183	Bukuru 11	Partial inundation	2766.44	8°52'50.674"	9°48'34.894"	
184	Bukuru 9	Partial inundation	18768.20	8°51'46.405"	9°49'50.343"	
185	Bisichi Kuru Du 12	Partial inundation	6269.09	8°53'14.485"	9°42'50.161"	
186	Rayfield 11a (Rayfield Resort pond)	Resort centre	426969.00	8°55'0.622"	9°50'24.914"	Owned by Government; Fencing
187	Rayfield 17	Resort centre	7827.95	8°54'45.272"	9°50'8.724"	Shallow water; adjacent Rayfield resort centre
188	Rayfield 21	Resort centre	180274.00	8°54'33.429"	9°49'39.134"	
189	Zawan 6	Resort centre	26159.20	8°51'51.627"	9°45'14.369"	Fencing; Recreation

S/NO	NAME OF DEGRADED SITES	CLASSES OF DEGRADED SITES	AREA(m^2)	LONGITUDE	LATITUDE	REMARKS
190	Kwata 1 (Healthy Body Clinic mines pond)	Resort centre	11004.80	8°50'38.36"	9°45'24.104"	Mining pond surrounded by residential leased block industry; threatening the adjacent developed facilities; death trap
191	Rayfield 1	Resort centre	15995.90	8°52'54.72"	9°49'35.775"	Located at Mazarin junction; Fencing; Tree Planting
192	Rayfield 28	Tree Planting	16405.30	8°54'5.721"	9°51'27.529"	Dense vegetation; near settlements
193	Du 25	Tree Planting	66510.30	8°52'56.817"	9°47'16.665"	
194	Zawan 4	Tree Planting	10526.00	8°51'41.922"	9°44'59.701"	Agricultural usage; tree planting
195	Du 5	Tree Planting	11378.40	8°53'3.791"	9°44'5.03"	Normally dries up around April due to excessive irrigation; nomadic herds
196	Kuru Janta 14	Tree Planting	168165.00	8°52'18.696"	9°39'36.732"	
197	Bukuru 15	Tree Planting	12464.60	8°52'50.497"	9°48'41.076"	
198	Bukuru 13	Tree Planting	1721.15	8°52'59.218"	9°48'40.339"	
199	Bukuru 1 (Consolidated Tin Mines pond)	Tree Planting	26184.90	8°51'38.052"	9°47'7.47"	Located near old Consolidated Tin Mines, Bukuru; it is partially stone pitched
200	Kwata 2	Tree Planting	8837.19	8°50'53.643"	9°45'49.553"	Reclaimed; trees planted
201	Bisichi Kuru Du 1	Tree Planting	36862.10	8°53'15.489"	9°41'46.115"	
202	Rayfield 20	Tree Planting	31055.10	8°54'12.185"	9°50'11.131"	
203	Zawan 9 (Dawhol Dangang)	Tree Planting	5093.92	8°51'54.529"	9°44'34.291"	
204	Bukuru 7	Tree Planting	3885.57	8°52'40.58"	9°48'16.993"	Located South of new Plateau State Government house
205	Rayfield 9	Waste dump	38133.30	8°55'39.166"	9°50'49.054"	Heaps of overburden dumps; shallow and elongated
206	Rayfield 19	Waste dump	55862.40	8°54'17.695"	9°49'59.768"	
207	Sabon Gidan Kanar 1h	Waste dump	55737.40	8°47'8.451"	9°46'41.667"	Dumps and illegal mining around the site
208	Gyero 4	Waste dump	135753.00	8°47'49.715"	9°48'42.395"	Large tailings with Artisans working on the dumps

S/NO	NAME OF DEGRADED SITES	CLASSES OF DEGRADED SITES	AREA(m^2)	LONGITUDE	LATITUDE	REMARKS
209	Gyero 8	Waste dump	15594.60	8°48'15.03"	9°49'5.857"	Irrigation; dumps and paddocks
210	Sabon Gidan Kanar 3d	Waste dump	15226.40	8°49'0.342"	9°46'34.421"	Mine tailings dumps; quarried for sand
211	Bukuru 14	Waste dump	14227.00	8°53'0.245"	9°48'44.836"	
212	Bukuru 10	Waste dump	3057.86	8°52'47.186"	9°48'31.127"	
213	Shen 7	Waste dump	12352.70	8°55'9.537"	9°46'11.629"	
214	Shen 5	Waste dump	94515.00	8°55'33.654"	9°45'41.386"	
215	Doi 3b	Waste dump	49518.40	8°55'53.117"	9°48'1.269"	
216	Bisichi Kuru Du 2	Waste dump	17333.90	8°53'25.791"	9°42'0.332"	
217	Gyero 19	Waste dump	39920.90	8°48'48.736"	9°49'23.87"	Mine dumps
218	Sabon Gidan Kanar 1c (Embankment)	Waste dump	72505.00	8°47'9.869"	9°47'52.646"	Embankment with Agricultural land; mine dumps noticeable
219	Sabon Gidan Kanar 1d (Mine tailing dumps)	Waste dump	27479.60	8°47'14.244"	9°48'7.051"	Mine tailing dumps
220	Sabon Gidan Kanar 1e (NG 6 mine dumps)	Waste dump	31332.80	8°47'16.074"	9°47'43.072"	Mine dumps
221	Sabon Gidan Kanar 1g	Waste dump	4886.64	8°47'12.358"	9°45'45.791"	
222	Sabon Gidan Kanar 1l	Waste dump	13110.70	8°47'32.676"	9°48'8.198"	Tiny ponds; heaps
223	Sabon Gidan Kanar 2d	Waste dump	38593.00	8°48'3.282"	9°47'16.396"	Tailing dumps with artisanal mining going on
224	Sabon Gidan Kanar 5b	Waste dump	13295.00	8°48'39.904"	9°47'12.006"	Mine dumps; East of 5A
225	Du 31	Waste dump	185548.00	8°53'55.809"	9°47'33.631"	
226	Jos Int Breweries mines pond	Water Treatment	171612.00	8°54'26.953"	9°51'37.905"	Seasonal inundation; block industry; huge tailings nearby
227	Rayfield 4	Water Treatment	29871.20	8°54'34.179"	9°49'21.261"	Located west of Lafiya village; Fencing; used for irrigation

S/NO	NAME OF DEGRADED SITES	CLASSES OF DEGRADED SITES	AREA(m^2)	LONGITUDE	LATITUDE	REMARKS
228	Du 2a	Water Treatment	34181.00	8°53'7.946"	9°46'14.964"	Pond with annual inundation; Fencing; Fish Stocking; used for irrigation and water supply
229	Kuru station 5	Water Treatment	23865.10	8°46'1.154"	9°38'33.535"	
230	Sabon Gidan Kanar 3a	Water Treatment	112243.00	8°48'28.818"	9°46'35.908"	Medium; Irrigation; dumps
231	Bukuru 17	Water Treatment	10626.80	8°52'14.525"	9°49'7.662"	
232	Yelwa Block Industry Mines pond	Water Treatment	11669.20	8°52'30.251"	9°48'5.401"	
233	Doi 1 (Buken Academy mines pond)	Water Treatment	67966.00	8°54'58.99"	9°48'41.38"	Located opposite Buken Academy and used as it`s source of water; has heaps and tailing dumps; partially silted;
234	Zawan 8	Water Treatment	1249.46	8°52'14.602"	9°45'16.634"	Southern part of Health College, Zawan
235	Kuru station 1 (Spring water)	Water Treatment	22153.50	8°45'36.823"	9°39'17.933"	Irrigation going on; mining shaft with quality water gushing out

Appendix 4: Metadata of Landsat-8 Image used in this Research

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Appendix 5: Metadata of SPOT-5 Image used in this Research

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Appendix 6: A snapshot of the accuracy assessment results in ERDAS 2014

