MAPPING AND ANALYSIS OF SITES FOR GRAZING RESERVES IN SOME STATES OF NORTHERN NIGERIA

BY

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DECLARATION

I hereby declare that the work contained in this thesis titled "MAPPING AND ANALYSIS OF SITES FOR GRAZING RESERVES IN SOME STATES OF NORTHERN NIGERIA", has been sourced, researched, carried out, compiled and written by me in the Department of Geomatics, Ahmadu Bello University, Zaria. The information derived from the literature has been duly acknowledged in the text and a list of references provided. To the best of my knowledge, no part of this project thesis was previously presented for another degree or diploma at this or any other institution.

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CERTIFICATION

This is to certify that this dissertation titled "MAPPING AND ANALYSIS OF SITES FOR GRAZING RESERVES IN SOME STATES OF NORTHERN NIGERIA" by Ebenezer Ayobami, AKOMOLAFE meets the regulations governing the award of Masters of Science (MSc.) degree in Geomatics of the Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

I dedicate this work to the Lord God Almighty who has been my source of inspiration, knowledge and strength, my present help in the time of need and to my ever loving parents.

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ABSTRACT

The area under study has witnessed series of violent communal clashes between farmers and pastoralists as a result of encroachment into grazing reserves and farmlands by the two parties. Thus, there is a need to settle these pastoralists and their livestock on suitable land for grazing, with basic infrastructures provided on such lands. Therefore, land suitability analysis and mapping is required to find the most befitting localities for establishing, developing and maintaining grazing reserves. The aim of this research was to determine and map appropriate locations for siting grazing reserves within Kaduna and Niger states using a geospatial technique with GIS serving a platform for evaluation. The various datasets collected and processed for the suitability mapping were categorized as biophysical, environmental and socioeconomic criteria. A mosaicked Landsat 8 imagery of the study area was classified by supervised classification. Accuracy assessment was carried out on the classification with a 56.59% Kappa coefficient and overall classification accuracy of 60.88%. Ten factors and two constraints were used as criteria and weighted by Analytical Hierarchical Process (AHP) for the Multicriteria evaluation (MCE) in a GIS environment, to come up with the final suitability map which was classified according to FAO specifications. Results showed that 8% of the total area (9374.58 km^2) is highly suitable, 62% (72212.59 km^2) is moderately suitable, 1% (615.09 km^2) is marginally suitable whereas 29% (33325.92 km^2) of the total area under consideration is not suitable for siting grazing reserves. Findings indicate that unsuitability or low suitability is as a result of steep slopes, unavailability of water resources, unfavourable climatic condition, unavailability of forage and nearness to settlements. Southern parts of Kaduna and south eastern area of Niger state were found to be suitable locations for establishing grazing reserves. The study showed that GIS-based Multicriteria evaluation provides a great advantage to analyze multiple layers of data

spatially and quantitatively to technically identify suitable land and sustainable accessibility for grazing reserves development. It also provides a more realistic and achievable objectives on a non-biased basis for making decisions on site selection The Analytical Hierarchy Process (AHP) is a powerful tool for decision making in land suitability issues regarding biophysical, environmental and socio-economic factors.

Recommendations were drawn from this research which include further extending the study to develop a model to be used continually for selecting suitable sites for grazing reserves across the federation by increasing the number of criteria used for the analysis. Furthermore, it is recommended that other geospatial techniques such as Multi-objective Land Allocation (MOLA) can be used to further develop the methodology and findings from this study for solving multi-objective land allocation problems for cases with conflicting objectives.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Right from time, Fulani herdsmen (pastoralists) and farmers in northern and southern Nigeria have been living symbiotically together in communities. But over time, the mutual relationship between the pastoralists and farmers deteriorated, leading to incessant conflicts over land for livestock and agricultural crops respectively. Though, these conflicts have been an old age problem, but it has escalated in the last decade and has assumed a very deadly dimension. These clashes between the two parties has often led to loss of lives and property in affected communities. These conflicts can be said to be embedded in and aggravated by the increasing competition for land as a result of population growth, land scarcity, and a new solvency due to income earned outside agriculture (Gefu and Gilles, 1990; Fraser, 1997). Many factors have contributed in one way or the other over time to severe the peaceful coexistence that once existed between Fulani pastoralists and the farming communities.

Tenuche and Ifatimehin (2009) noted that according to other literatures, the incessant resource conflicts between farmers and herdsmen witnessed in the tropics have usually resulted in loss of lives, property and environmental degradation as also witnessed in some developed countries such as Balkans (Hellstrom, 2001; Niemella *et al*., 2005). The Fulani herdsmen have borne a large proportion of the blame for most conflict and environmental degradation in policy statements in the Guinea Savannah region of West African states (Thebaud and Batterburry, 2001). The production potential of grassland and livestock in the arid and semi-arid region of Africa is constrained by low and variable rainfall (Thebaud and Batterbury, 2001; Ifatimehin, 2008). Therefore, there is a

need for grazing lands so as to enable accessibility of pasture resources across regions by pastoralists and their livestock in order to ensure food security for the herds.

Of important note is the fact that in the past, cattle rearing was mainly prevalent in the Sudan and Sahel savanna belts where crop production by the farmers was carried out only during the short rainy season on a small scale. This gave the herdsmen access to a vast area of grass land for their livestock. But as time went on, and with the introduction of irrigated farming in the savanna belt of Nigeria, and the increased withering of pasture during the dry season, less pasture was available to the livestock. The herdsmen had to move southward from the Sahel regions to sub-humid zones like Kaduna and Niger, where the rainy season is longer, the temperature is moderate and the soil retains moisture for long, in search of pasture and water – a movement called transhumance (Ofuoku and Isife, 2009). They found more comfort in croplands and thus encroaching into the farmlands and thus, displeasing the farmers who retaliate.

Furthermore, Tonah (2006) opined that factors that account for the increasing farmer-herder conflict over time include the southward movement of pastoral herds into the humid and sub-humid zones, promoted by the successful control of animal diseases in these areas, the widespread availability of veterinary medicine and the expansion of farming activities into areas that hitherto served as pastureland. Also, the growth in population and its density has led to urbanization with an increased demand for land and pressure on land meant for farming and grazing in the past. This gave rise to an increased pressure on natural resources and a stiff competition for available resources between farmers and herders (Adebayo, 1997; Breuser *et al.* 1998).

Other factors that have contributed to the breakdown of the peaceful coexistence of farmers and pastoralists in Nigeria include: inadequacy of grazing resources, as

increasing crop cultivation (and increasing commercialization of the crop-residues) and poor management of the existing grazing reserves have resulted in a significant reduction in available livestock feed resources, in particular in the northern states. Moreover the high-yield crops introduced by agricultural research institutions (e.g. tomatoes and onions) produce almost no crop-residues for livestock feeding. Also, the regulation that twenty percent of the fadama (irrigated farmlands) would need to be set aside for grazing (National Agricultural Policy, 1988) has not been adhered to; and then, the decline in internal discipline and social cohesion, as the adherence to the traditional rules regarding grazing periods, and the authority of the traditional rulers is breaking down (Adisa, 2012).

According to Ajuwon (2004), other factors that have contributed in the long-term to this farmers-pastoralists strife include:

i. Inappropriate Land tenure and land use practices whereby traditional access rights to communal grazing and water resources are being obstructed by the individual tenureship of arable farmers.
ii. Non-observation of rules and regulations regarding dry season farming and grazing.
iii. Inadequacy and the poor state of the existing grazing reserves as they have been encroached for farming activities.
iv. Blockage and use of stock routes by farmers and individuals due to its fertility, leading to reduction in the size of these routes.
v. Poor land and soil conservation measures, limiting the areas available for operations by the farmers and pastoralists.

Whatever the causes of farmer-herdsmen conflicts are, it is evident that the conflicts have been of great negative effects. These range from economic effects such as loss of income/resources/yield, to physical effects such as home/farm destruction, bodily injury or death of family members and socio-psychological effects such as emotional exhaustion and job dissatisfaction.

In order to curb all of the aforementioned problems which have jointly been responsible for deadly clashes between the farmers and herdsmen, there is a need to settle pastoralists permanently on government-assigned and delineated lands called grazing reserves. Ismail (2013) rightly noted that grazing reserves and stock routes top the list of Fulani pastoralists' demands from the Nigerian government. It is believed that the creation, development and expansion of grazing reserves and the proper mapping of stock routes will boost livestock population, will lessen the difficulty of herding, will reduce seasonal migration, and will enhance symbiotic interaction among farmers, pastoralists, and rural dwellers. In creating and developing grazing reserves across conflict-ridden zones in Nigeria, it is important to establish them at sites with optimum comfort for the herders, their livestock and the surrounding communities. Here, suitability mapping using Multicriteria Evaluation (MCE) technique in GIS environment comes into play to ensure that the most suitable sites are set aside for these grazing reserves taking into consideration various biophysical, socioeconomic and environmental factors.

Grazing reserves are areas of land dedicated or set aside for pastoral use and they are considered as proven self-sustaining solution for pastoralists. A grazing reserve can also be said to be a piece of land that the government acquires, develops, and releases to the pastoral Fulani. It is a tract of land specially set aside by governments for use by herders

or pastoralists to hold and graze their cattle. Ingawa *et al.* (1989) defined grazing reserves in Nigeria as areas set aside for the use of pastoralists and are intended to be the foci of livestock development. Grazing reserves resemble group ranches in that both of them consist of clearly defined areas of rangeland which provides grazing for determined herds of livestock. On group ranches in Kenya, pastoralists have a right to land under national law. In Nigeria, they have not in the past had such rights and grazing reserves more closely resemble what Oxby (l982a) termed 'grazing blocks'. There are now plans for issuing 30 year leases for parcels of land within the grazing reserves in order to encourage them to invest in land improvement.

Some state and local governments in Nigeria have gazetted and obtained grazing land varying in size. The federal government shoulders seventy percent (70%) of the burden of developing the grazing reserves, the state governments shoulder twenty percent (20%) while the local governments carry 10% of the responsibilities and gives each settler on the reserve a piece of land. Depending on the herd size and the carrying capacity of the land, the settler pays an annual rent to the government (Suleiman, 1986).

Suleiman (1986) also noted that the stated purpose of Grazing Reserves is the settlement of nomadic pastoralists; they offer security of tenure as an inducement to sedenterization through the provision of land for grazing and permanent water. Large parcels of land have been demarcated, some legally sanctioned by order in the Official Gazette and basic infrastructure such as dams and boreholes have been constructed on these lands. Potential settlers are recruited through the livestock extension service.

In this research, the appropriate locations for siting grazing reserves within Kaduna and Niger states were determined using a geospatial technique. A typical technique for determining suitable locations for land use is suitability analysis using Multi-criteria

Decision Analysis (MCDA) in a GIS Environment. It is also sometimes referred to as Multi-criteria Evaluation (MCE). MCDAprovides a rich collection of techniques and procedures for structuring decision problems, designing, evaluating and prioritizing alternative decisions. However, GIS MCDAcan be thought of as a process that transforms and combines geographical data and value judgments (the decision-maker's preferences) to obtain information for decision making (Malczewski, 2006).

Suitability analysisis a GIS-based process used to determine the appropriateness of an area (land resource) for a specific use such as: agriculture, forestry, business, urban development, livelihood projects, etc. (Eastman *et al.*, 1995). The basic premise of GIS suitability analysis is that each aspect of the landscape has intrinsic characteristics that are in some degree either suitable or unsuitable for the activities being planned. Model inputs for suitability mapping include a variety of biophysical, cultural, environmental and socio-economic factors. The results are often displayed on a map that is used to highlight areas from high to low suitability. A GIS suitability model typically answers the question, "Where is the best location?" Whether it involves finding the best location for a new road or pipeline, market, a new housing development, a new school or any other social amenity of land use.

1.2 STATEMENT OF RESEARCH PROBLEM

In recent years, Nigeria has witnessed series of violent communal clashes arising from the activities of the nomads who move about on a daily basis with their cattle in search of water and green pastures.

According to Ismail (2013), these pastoralists and their livestock are on the streets in most of our cities and could also be found operating in the remotest villages in various states of the country. Roaming cows, sheep, and goats scavenging around school

playgrounds, golf courses, government residential areas, street shoulders, and railway sidings are a common sight in the cities due to pasture scarcity. These beasts obstruct traffic flow, endanger street users, amplify urban congestion and often have their excrement littering the ground. What has informed the couching of the idea of establishing grazing reserves is the incessant clashes between Fulani herdsmen and farmers in many parts of the country especially in states such as Kogi, Plateau, Benue, Niger, Nasarawa, the southern half of Kaduna and Bauchi.

There has been growing concern in various parts of the country about the increased conflicts between farmers and pastoralists. Tenuche and Ifatimehin (2009) in their research: "Resource Conflict among Farmers and Fulani Herdsmen: Implications for Resource Sustainability" describe the traditional relationship between farmers and Fulani herdsmen and the incessant resource conflict witnessed in Kogi State and how it affects livelihood and security of those involved and resource sustainability for the communities. They noted that these conflicts are most responsible for the unsustainable utilization of land and water resources as the trampling by the hooves of herds of cattle compacts the soil of farm land, destroy farm crops by the herdsmen, places restraint on effective utilization of arable farmland among other destruction of available resources. The scenario witnessed in Kogi state is a replication of what is happening in Kaduna, Niger states and other parts of the country. As grazing pasture shrinks, disputes have increased, particularly in the far north during the May to September rainy season, when herds invade farmland and eat crops. Therefore, the development of the grazing reserves and livestock routes has become imperative to avoid conflicts between pastoralists and farmers.

Two days of fighting between farmers and nomads in June, 2009 left three dead and a number of pastoralists' settlements burned in Plateau state. Local authorities expelled 700 pastoralists from Borno state in the northeast to stop clashes between settling nomads and indigenous farmers. The nomads had travelled 1,000km eastwards from Zamfara state in search of grazing land. Moreover, the livelihood of over 15 million pastoralists in northern Nigeria are threatened by decreasing access to water and pasture shortages linked to climate change.

The required change in perspective and problems described above requires new technical tools and planning strategies, grazing sites suitability mapping in GIS being one of the techniques for this change. The problem currently at hand include the resolution of conflicts between the multiple and diverse potential users of resources and the expectations to conserve resources that have been transformed and developed in the past.

Awogbade's (1987) opinion is that, there can be no solution to the intractable strife between pastoralists and farmers so long as the problems of grazing land use are not addressed. The issue of settling nomadic cattle rearers is a problem which for many years now has generated considerable discussion in Nigeria's public and government circles.

In Mediterranean regions for example, grazing activities frequently involve protected areas, either because they are permanently settled there or because they exploit pasture resources seasonally. The latter occurs owing to the presence of numerous extensive cattle and sheep farms that, following a very old and deep-rooted tradition, still today practice transhumance and migration to mountain pasture, with significant movements both in terms of the distances undertaken (at times even some hundreds of kilometers) as

well as changes in altitude. It is high time this plan is also adopted efficiently in Nigeria. Most often, the grazing of domestic animals within protected areas is not conducted in an appropriate fashion and comes into conflict with the other activities present there such as farming. Thus, usually treating with levity the aim and actions of protection pursued by the managing organization. This is manifested with the use of soils with poor or no suitability, with impractical methods of grazing and the systematic recourse to fire to clear pastureland. Improper ways of carrying out grazing and incorrect practices, besides causing irreversible environmental damage at times, it can also end up backfiring negatively on the growing of animals, bringing the possibility of their survival into jeopardy.

1.3 AIM AND OBJECTIVES

The aim of this research is to use a geospatial technique to create an appropriate model for siting grazing reserves that will ensure nomads and farmers live harmoniously in a symbiotic relationship.

Simply stated, the objectives of this research work are to:

1. Map the current distribution of land cover and land use in the study area.

2. Generate suitability models for target pastoralist grazing reserve areas in Niger and Kaduna states of Nigeria.

3. Integrate spatial information and findings on land use, socioeconomic, biophysical and environmental factors in a GIS environment using appropriate technique to achieve the objective stated above.

4. Make necessary recommendations to the government and corporate organizations on how to successfully establish and manage these grazing reserves.

1.4 RESEARCH QUESTIONS

This research seeks to answer the following questions:

1. What is the existing land use and land cover in the study area?

2. Where are the appropriate locations to site grazing reserves in Niger and Kaduna states for optimum performance and comfort for pastoralists?

3. How will geospatial techniques help in determining these suitable locations for siting grazing reserves in Niger and Kaduna States?

4. What are measures and facilities to be put in place by the government to permanently settle these pastoralists?

1.5 JUSTIFICATION OF THE STUDY

GIS and remote sensing technology play a vital role in providing accurate and reliable landscape details with lower cost and lesser time for mapping stock routes and establishing grazing reserves in Nigeria. This will go a long way in curbing the various ills experienced in the past as a result of non-existence of grazing reserves. The use of remote sensing and GIS for resource mapping, spatial analysis and decision-making has been widely reported by many researchers and it is still applicable in this case to solve the recurring problem (Jayakuma *et al.*, 2002).

Mapping suitable land for grazing reserves in Kaduna and Niger states using remote sensing technology and GIS is a critical step towards understanding the complex, interacting biological and socio-economic components of the landscape and the cessation of violent clashes between nomads and farmers. The new data and insights generated by this research will support conservation planning, conflict resolution and

contribute to sound management of critical forest, water and grazing resources. Therefore, a clear definition and classification of the suitability of land or open space for grazing is essentially needed; this will be carried out on the basis of considerations relating both to the availability of feeding resources for the livestock and the nomads, and to the limitations arising from potential conflicts with other land uses and conservation targets.

Multi criteria analysis using GIS has proven valuable both presently and in the past in the quantitative assessment and evaluation of issues associated with determining appropriate locations for infrastructure development such as grazing reserves; in this study. Suitability analysis uses a methodology which combines MCA with GIS technology to quantitatively assess and evaluate the complex physical, environmental, infrastructure and social issues that are associated with determining appropriate locations for infrastructure development.

Moreover, there is a growing expectation that geospatial techniques and information can be successfully applied to decision making on complex issues affecting both human and environment systems. This expectation is promoted by the increasing sophistication of spatial multi-criteria analysis tools and more readily accessible socioeconomic, biophysical and environmental spatial data which will be applied in this study.

This study is justified in the sense that, with the problems noted as regards to the various conflicts that have ensued between Fulani herdsmen and farmers across the country which arose from the destruction of farm lands by herds of cattle, and with the governments' willingness and strategies to curb these problems, there is a strong need for pastoralists to be given rights to land furnished with basic amenities for the settlement of their herds and their families. Suitability mapping using Multicriteria

Analysis (MCA) in GIS will solve this intractable problem of frequent farmer-herders clashes by helping to locate appropriate sites where nomads can be settled all year round; far away from agricultural lands and human settlements. This way, the security of lives and property will be ensured. Moreover, the settlement of the nomads can boost livestock production and this will go a long way in affecting positively socio-economic development as there will be market for livestock products. An added advantage academically is that this study can serve as a benchmark or a model which can be improved upon for land or site suitability analysis for grazing reserves in other states in the country.

1.6 SCOPE AND LIMITATIONS OF THE STUDY

This research covers the determination of suitable sites for grazing reserves in Niger and Kaduna states only, though it is pertinent that other states of the federation should be considered as well. This can be in subsequent studies linked to this research. The study does not go outside the context of establishing grazing reserves. Stock route mapping ought to be included to complement the grazing reserves siting but for the huge cost of the project and the long time frame required. It should be noted that while the Multi-criteria Analysis or Evaluation (MCA/MCE) is a powerful desktop tool for screening study areas and generating suitability surfaces, there are a number of specific limitations to this approach and the research itself, including:

a. Inability to represent all of the aspects that determine suitability for a site in a geographic format.

b. Lack of all data at a suitable scale relating to site specific considerations.

c. Accuracy and currency of the geospatial and attribute data.

d. Inability to carry out an extensive reconnaissance and verification of the existing grazing reserves within the study area due to the large expanse of the land mass, inadequate funding, insecurity and poor logistics.

e. In addition to the various considerations that cannot be represented through this approach, MCE could be improved via the inclusion of more site-specific data collected during field investigations.

In this study, criteria namely: distance from water, distance from roads, distance from croplands, distance from wetlands, distance from protected areas, forests, land use, grasslands, precipitation, temperature and slope were selected as factors whereas, rocks and built-up areas within the study area were chosen to serve as constraints. These factors were selected bearing in mind that the potential of these grazing reserves is based on traditional grazing practices with available forage in the sites – where no attempt is made to modify/cultivate the land for the purpose of livestock rearing and production.

This work was based on a high-level assessment and further detailed analysis for specific suitability which will be recommended based on FAO specifications. This involved the use of biophysical, socio economic and environmental datasets or variables. Subsequent field-based investigations and alternative processes are considered necessary to verify and validate the outputs of the Multi-Criteria Analysis (MCA). Furthermore, the Multicriteria analysis carried out in this research made use of data majorly from year 2013. The research was carried out within a time frame of 12 months - from data collection, processing, analysis, to the final report submission.

1.7 STUDY AREA

The area under study in this research encompasses Niger and Kaduna states of Nigeria. Niger and Kaduna states are both north-western states in Nigeria and the study area which is the joint states is geographically located between latitudes 8^0 11'N and 11^0 30'N and between longitudes 3^0 35'E and 8^0 47'E covering about 115,500 sq. km. Niger and Kaduna states are the largest and third largest states by land mass respectively in Nigeria. A map of the study area is shown in Figure 1 below. The study area has a joint population of about 10 million according to the 2006 population census. The topography consist of plains, valleys and mountains and its soils are very fertile for farming with abundance of water resources in forms of rivers, streams, lakes and dams. Popular amongst them is river Niger, river Kaduna, Kainji lake and Kainji dam.

This study area experiences distinct wet and dry seasons with annual rainfall varying from 1100mm in the northern part to 1600mm in the southern parts. The maximum temperature is recorded between March and June, rising up to about 35^oC while the minimum is usually between December and January with a value of about 24^oC. The rainy seasons last for about 150 days in the northern parts to about 120 days in the southern parts of the study area.

Generally, agricultural activities form the mainstay of the people's economy in the study area and this engages directly or indirectly more than 80 percent of the population.The even climate, rich annual rainfall and availability of wide variety of mineral and agricultural resources all attest to the economic potential of the study area. The area is a major region of animal husbandry. Major food and cash crops produced includes, cotton, groundnut, guinea corn, millet, ginger, tobacco, beans, yam, cassava, rice, sugar cane and maize. The study area is also a tourist haven with numerous tourist sites, which are used to generate internal revenue. Furthermore, the geological location of both states

endow them with abundant mineral resources. Rich commercial deposits of various types of industrial minerals of high quality are available in the study area which can be used for domestic and export purposes. The study area has huge deposits of mineral resources like gold, kaolin, columbite, aquamarine, sapphire, clay, silica, granites, marble, copper, iron, feldspar, lead, kaoline, cassiterite, columbite, tantalite and limestone to mention a few. However, most of these minerals have not been quantified and assessed for their quality and economic viability.

The drainage of the study area is characterized by rivers, streams and dams. In Kaduna state, the major rivers are River Kaduna (from where the state derives its name), Gurara, Kogon, Matsirga (River Wonderful) and Galma, in addition to several streams. Meanwhile, Niger state was named after river Niger and has other water resourcessuch as Rivers Chanchaga, Kontagora the Gurara falls, the Kainji dam, the Shiroro dam, Jebba dam, Kontagora dam and Kainji lake. All of these provide opportunities for irrigation and fish farming.

Almost all soil types, typical of the Savannah regions of West Africa can be found in this area. They vary from the shallow soils found around the rocky terrain to deep soils of the Fadama valley. Generally, the soils and vegetation are typical reddish-brown to reddish-yellow tropical ferruginous soils and savannah grassland with scattered trees and woody shrubs. The soils in the upland areas are rich in red clay and sand but poor in organic matter. However, soils within the wetland (Fadama) areas are richer in kaolinitic clay and organic matter which are very heavy and poorly drained (characteristics of vertisols). The deeper soils, which are of alluvium type although complex in nature, are amongst the best and have special potential for both rained and irrigated farming. Generally, the fertile soil and hydrology of the states permit the cultivation of most of

Nigeria's staple crops and still allows sufficient opportunities for grazing, fresh water fishing and forestry development.

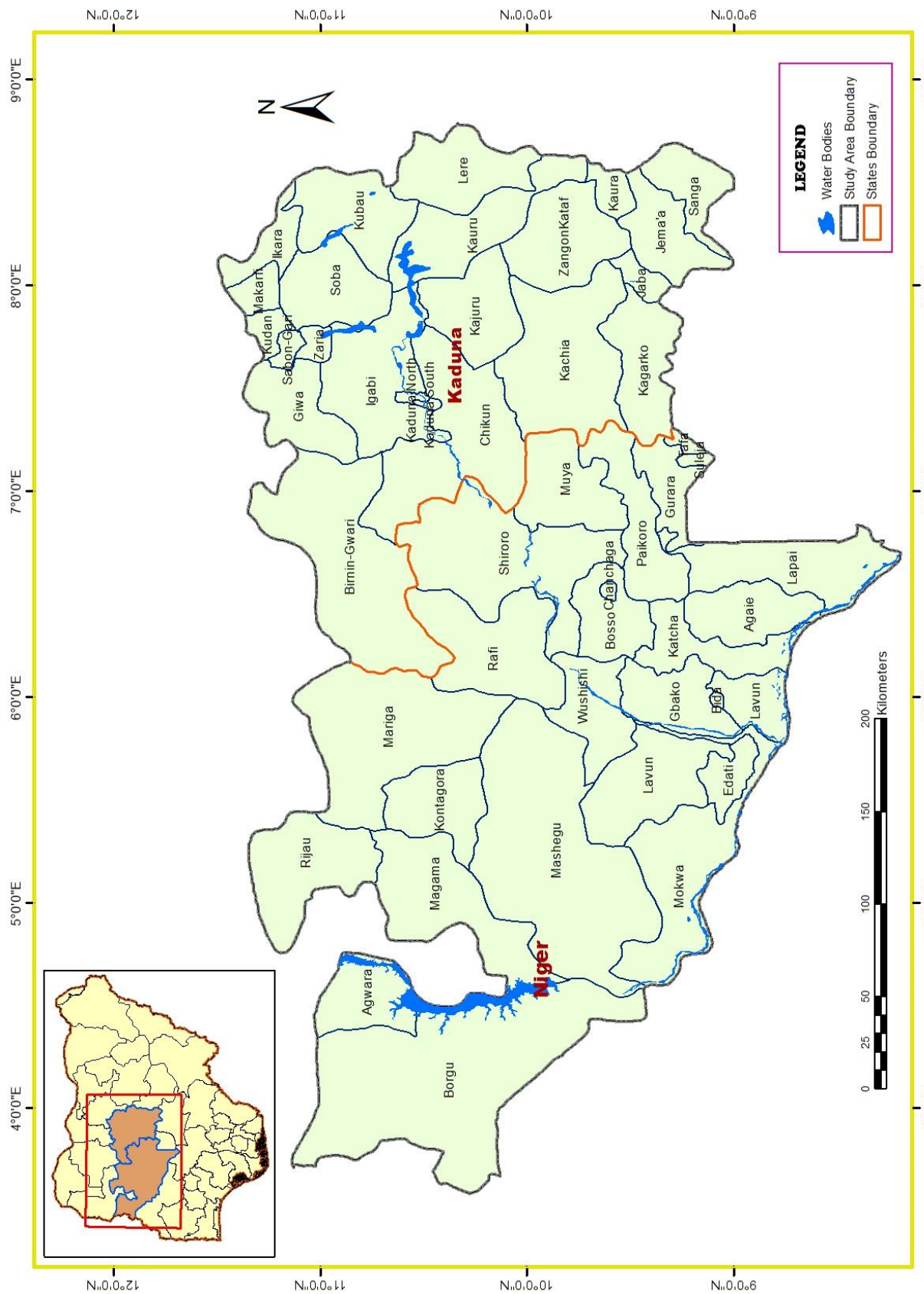


Figure 1-1: The study area

CHAPTER TWO

LITERATURE REVIEW

2.1 THEORETICAL FRAMEWORK

2.1.1 The Concept of Grazing Reserve

A grazing reserve is a piece of land that the government acquires, develops, and releases to the pastoral Fulani. It is a tract of land specially set aside by governments for use by herders or pastoralists to hold and graze their cattle. Ingawa *et al.* (1989) also defined grazing reserves in Nigeria as areas set aside for the use of pastoralists and are intended to be the foci of livestock development. Grazing reserves resemble group ranches in that both of them consist of clearly defined areas of rangeland which provides grazing for determined herds of livestock). On group ranches in Kenya, pastoralists have a right to land under national law. In Nigeria, they have not in the past had such rights and grazing reserves more closely resemble what Oxby (l982a) termed 'grazing blocks'. There are now plans for issuing 30 year leases for parcels of land within the grazing reserves in order to encourage them to invest in land improvement.

Some state and the local governments in Nigeria have gazetted and obtained grazing land varying from in size. The federal government shoulders seventy percent (70%) of the burden of developing the grazing reserves, the state governments shoulder twenty percent (20%) while the local governments carry 10% of the responsibilities and gives each settler on the reserve a piece of land. Depending on the herd size and the carrying capacity of the land, the settler pays an annual rent to the government (Suleiman, 1986).

Suleiman (1986) also noted that the stated purpose of Grazing Reserves is the settlement of nomadic pastoralists; they offer security of tenure as an inducement to sedentarization through the provision of land for grazing and permanent water. Large parcels of land

have been demarcated, some legally sanctioned by order in the Official Gazette and basic infrastructure such as dams and boreholes have been constructed on these lands. Potential settlers are recruited through the livestock extension service.

Controlled grazing which limits the number of animals entering a grazing land, leads to efficient rangeland management. Under the adopted grazing system in Nigeria, the government in the rainy-season opens the reserve to the nomads and their animals. The reserve closes in the dry-season, when animals must go on sojourn pasture (Laven, 1991). During severe shortages of feed, the government opens the communal grazing areas to the distressed herds. Livestock owners must apply to the Project Office for a grazing permit. The pastoralists must also agree to follow the government's guidelines for stocking rate. The ten hectares per herding unit is apportioned as follows: four hectares for grazing, two for settlement, two for farming of legumes, and two for fallow (Ismail, 2013).

2.1.1.1 Grazing Reserves: Their Features and Benefits

Grazing reserves provide the government and private sector an opportunity to improve the security of the nation as well as open the commercial potential of the nation’s livestock sub-sector. The key features of a grazing reserve include:

1. Gazetted land: size responsive to population and herd size.
2. Community: cooperatives established.
3. Infrastructures: earthen dams, boreholes, access roads.
4. Social services: schools and health clinics.
5. Land management: pasture development/reclamation.
6. Commercial facilities: diary, leather and meat.
7. Service centres: livestock and veterinary.

8. Services: livestock, agricultural extension.

The benefit of establishing a grazing reserve cannot be overemphasized as it provides security, socioeconomic and economics of scale. Emphasis on the security entails the reduced potential for conflicts between local communities and pastoralists as a result of competition for resources such as pasture land. Pastoralist have their grazing land set aside and dedicated to them.

Socioeconomic otherwise referred to as improved livelihood of pastoralists, his access to education, human and animal health care delivery, portable water etc. trading with local communities bring additional income to pastoralists. Other benefits include the practice of subsistence farming, improved market efficiencies with settled pastoralists, which should reduce prices of products and increase quality and production levels.

Economic of scales here refers to the fact that the collective cost of providing stationary resources is cheaper that providing mobile resource for nomadic lifestyle as practiced by pastoralists.

2.1.1.2 Objectives of Establishing and Developing Grazing Reserves

The primary objective of establishing and developing grazing reserves by the government is to permanently settle nomadic pastoralists so that they can be provided with modern amenities and better management practices provided under conditions favourable for livestock production.

Other objectives of establishing grazing reserves are to:

a. Protect the interest of the pastoralists who at present have no right to landed property for their occupation.

b. Improve and modernize traditional practices, integrating them into the national economic and making them more economically viable and self-sufficient.

c. Encourage sedenterization of the pastoralists in the grazing area.

d. Regulate their occupation and the use of resources in the grazing area.

e. Discourage overgrazing and degradation of the diminishing land resources.

f. Ensure grazing control, improvement and management of grazing land.

g. Minimize the conflict between nomadic pastoralists and local communities (crop farmers).

2.1.2 Evolution of Grazing Reserves in Nigeria

Grazing reserves in Nigeria started during the pre-colonial era (Bako and Ingawa, 1988). Although formally introduced by the British, grazing reserves were demarcated by the Fulani who conquered and ruled Northern Nigeria. The attempt by the British in 1940 to separate the grazing land from the farm land, however, faltered because the Europeans imposed land use controls divorced from economic and demographic dynamics in the pastoral system (Frantz, 1981).

Ismail (2013) noted that formal grazing reserves in Nigeria started accidentally in the 1950s when Hamisu Kano, working with pastoralists on livestock vaccination, foresaw the shortages of grazing land in Northern Nigeria. Supported by the government, he initiated the grazing reserve scheme from the abandoned government resettlement schemes (Fulani Settlement Scheme). The resettlement schemes collapsed because the government had neither the financial nor the managerial ability to continue with the financially burdensome scheme, and the best alternative use of the land, the government

thought, was to convert it into grazing reserves that were less financially committed. Grazing reserve hatched in 1954 after a study of the Fulani production system contained in the "Fulani Amenities Proposal." The proposal suggested the creation of grazing reserves, the improvement of Fulani welfare, and the transformation of the herd management system. By 1964, the government had gazetted about 6.4 million hectares of the forest reserve, ninety-eight percent (98%) in the savanna. Sokoto Province had twenty-one (21%) percent of the land, followed by Kabba, Bauchi, Zaria, Ilorin, and Katsina, with 11-15% percent each (Awogbade, 1980). The Wase, Zamfara, and Udubo reserves followed in succession.

In 1965, the Northern Nigerian Government incorporated the Fulani Amenities Proposal into the Grazing Reserve Law. Before the enactment of the Grazing Reserve Law of the Northern Nigeria, the pastoral Fulani relied on the goodwill of the farmers, who conferred upon themselves the lordliness of occupied and unoccupied land. Because interpersonal and kinship affiliations governed the dispensation of land, the Fulani worried about being evicted from the land when their relationship with the hosts become strained (Waters-Bayer and Taylor-Powell, 1986).

In 1976, the Federal Survey Department finished the survey for most of the land earmarked for grazing. The United States Agency for International Development gave the technical assistance. By 1980, Nigeria had established 2.3 million hectares of grazing reserves, although this figure represented only 11% of the planned size (Omaliko *et al.*, 1984; Bako and Ingawa, 1988). The government acquired less than 5% of the 10 million hectares proposed as grazing land. Of the 45 planned dams, 24 have been completed. 5 boreholes have been sunk and of the expected 722 roads, 150 have been built, showing a huge deficit (Ismail, 2013).

At the close of the year 1992, the government had identified over 300 areas with 28million hectares for grazing reserve development. About 45 of these areas, covering some 600,000 hectares, have been gazetted. Eight of these reserves, totaling 225,000 hectares, are fully established. Already, 350 of the projected 950 pastoral families and 11,600 of the planned 46,000 cattle are using these reserves (NLPD, 1992). Apart from acquiring the land, the government regulates how the pastoralists/herdsmen should use the grazing reserves.

Currently, the direction of Federal Government policy seems to indicate the desirability of settling the traditional cattle rearers, as a step forward in the essential process of establishing their land rights in the form which will provide incentives for returns to the land and in land investment. (Awogbade, 1987).

2.1.3 Grazing Reserves in Niger State and Kaduna State

In Niger state, attempts made towards large-scale production of livestock over the years include establishment of cattle ranch at Mokwa and establishment of grazing reserves at strategic locations to reduce transhumance by pastoralists. A list of designated grazing reserves in Niger state is shown in APPENDIX I.

Measures are in place to revive grazing reserves in Niger state as according to Hamagam (2014), the Niger state governor directed the ministries of land and justice to expedite action in gazetting the 21 ungazetted grazing reserves located across the state. He gave the directive in Minna saying, when the grazing reserves are gazetted, government will be able to eject farmers who encroach into areas that are not meant for them. In Niger state, out of the 23 grazing reserves in the state, only two (2) of them are gazetted. It is important that these ungazetted reserves be sited in the appropriate locations to sustain

the pastorialists and their livestock and to further prevent farmers-herders clashes. Hence, the need for this study.

The Bobi grazing reserve in Niger state, north-west Nigeria is one of gazetted reserves created by government to settle Nigeria's nomadic pastoralists. However, as part of the official grazing reserve policy, dry season transhumance movement out of the reserves is encouraged. The Reserve lies on Nigeria's North-West transhumance corridor and is located between latitudes 10^0 00'N and 10^0 10'N and longitudes 5^0 45'E and 6^0 00'E in the Northern Guinea Savanna ecological zone, where water and grazing resources are sufficient for only six (6) months of the year. It covers an area of 30,222.2 hectares, has a carrying capacity of 4632 livestock unit (lu) and a stocking rate of 3.23 hectares per livestock unit (ha/lu). (Babalobi *et al.*, 2000).

Meanwhile, the federal government established grazing reserves in Kaduna state in the 70s. Kaduna state as at 1976 had 2 gazetted, operational grazing reserves supplied with basic amenities to serve the pastorialists. The grazing reserves are: Kachia and Kukar-Jangari Grazing Reserves. The Kukar Jangari grazing reserve in Kaduna state covers an area of 121,762 hectares and had in place facilities for use by the herdsmen (Awogbade, 1987). Enhancing Nigerian Advocacy for a Better Business Environment (ENABLE, 2010) in its progress report noted that three (3) new Grazing Reserves were approved by the Kaduna State Government at the beginning of the year 2010. However, the process stalled. By lobbying the relevant officials, Miyetti Allah Cattle Breeders Association (MACBAN) succeeded in getting the process re-started in September 2010. A list of grazing reserves in Kaduna State is presented in APPENDIX II.

Commenting about the Kachia Grazing reserve in Kaduna state, Oxby (1984) wrote:

"After several years of intensified work, the Kachia Grazing Reserve in Nigeria (Kaduna State) has succeeded in settling twelve families within its 30,956 ha. This reserve is one of many that were established after the Grazing Reserves Law was passed in 1965.' Since then plans for registering land and developing and managing the reserved areas have been progressing gradually. The size of the reserves varies from 100 ha. to 122,000 ha. (Rumka, in Kaduna State). Not all of these areas have been developed, but by 1980, 149 wells, 61 boreholes, 177 dams, 68 staff houses, 25 office/clinics and 18 stores had been constructed or were underway. The development of Kachia Grazing Reserve is advanced in comparison with other reserves: the Federal Livestock Department, the Livestock Project Unit and the International Livestock Centre for Africa (ILCA), which has a research station there, are all involved in its development. There are twenty-four staff: a range management officer and his assistant, four grazing control assistants, a veterinary assistant, one typist, one driver, three plant operators, five permanent and five casual labourers, and two watchmen; all have permanent housing on the reserve for their families. Ten earth dams have been constructed but only four are in use since there are not enough animals on the reserve yet. A smallholder dairy scheme supplies supplementary cattle feed on credit to nineteen local farmers, of whom only six are members of the grazing reserve and the remainder live in nearby villages. Strips of the fodder crop, Stylosanthes, are sown in the reserve and in 1981 two herders on the reserve were helped to sow 4 ha. of Stylosanthes each as 'fodder banks' alongside their food-crop fields.

> Out of the total of twelve herding families settled in the reserve in l98l, only six of the twelve families had occupied the reserve the previous year. Two families have built small European-style houses with window frames and corrugated iron roofs. One has built mud-brick thatched huts. The rest live in tents covered in grass, stubble or reed mats. The twelve families average about 45 cattle each, the wealthiest owning 150 cattle. All of them farm food crops around their settlements in the reserve".

With regards to existing grazing reserves in Nigeria, Andrews *et al.* (2014) stated that presently, Nigeria has four hundred and fifteen (415) grazing reserves across the Federation. The Federal government has stressed the need to increase the number of grazing reserves across the nation from the current 415. Of the 415 reserves, only 141 grazing reserves have been gazetted with less than 20 equipped with resources for pastoralists.

The issue of settling nomadic cattle rearers is one which for many years now has generated considerable discussion in Nigeria's government circles. Since the grazing law of 1965 was enacted by the then Northern Nigeria Legislative Assembly and with the commencement of the First National Livestock Development (FNLD), the settlement debate has assumed a progressively wider dimension. There are several obvious reasons for this official interest in settling Nigeria's livestock owners. It is estimated that traditional livestock owners control over 90% of the total national herd but have no right to land; the movement of herds limit their access to health facilities and the government's ability to institute improved management; traditional livestock owners do not participate in the political decision making process. In addition, there is an establishment throughout the northern states of urban-based Fulani pressure group

known as “Miyetti Allah” representing the pastoralists’ socio-economic interests. This group is also involved in protecting the land rights of pastoralists (Awogbade, 1987).

This research seeks to determine the best sites for locating grazing reserves in two northern states of Nigeria using a Geospatial technique. Land suitability mapping is similar to choosing an appropriate location, except that the goal is not to isolate the best alternatives, but to map a suitability index for the entire study area. Map overlay using Weighted Linear Combination will be useful in this regard. Similarly, research conducted by Senes and Toccolini (1998) shows that they combined UET (Ultimate Environmental Threshold) method with map overlays to evaluate land suitability for development. Furthermore, Hall *et al.* (1992) and Wang (1994) also used map overlays to define homogeneous zones, but then they apply classification techniques to assess the agricultural land suitability level of each zone.

2.2 MULTI-CRITERIA DECISION ANALYSIS (MCDA)

Multi-criteria Decision Analysis sometimes also referred to as Multi Criteria Evaluation (MCE) often requires the decision maker to provide qualitative assessments for determining:

a) The performance of each alternative with respect to each criterion and
b) The relative importance of the evaluation criteria with respect to the overall objective of the problem.

As a result, uncertain, imprecise and subjective data are usually present which make the decision-making process complex and challenging (Deng and Yeh, 1998; Yeh *et. al*., 1999).

MCDA describes any structured approach used to determine overall preferences among alternative options, where the options accomplish several objectives. In MCA, desirable

objectives are specified and corresponding attributes or indicators are identified. The actual measurement of indicators need not be in monetary terms, but are often based on the quantitative analysis (through scoring, ranking and weighting) of a wide range of qualitative impact categories and criteria. Different environmental and social indicators may be developed side by side with economic costs and benefits. Explicit recognition is given to the fact that a variety of both monetary and nonmonetary objectives may influence policy decisions.

Multicriteria analysis or multi-objective decision making is a type of decision analysis tool that is particularly applicable to cases where a single-criterion approach (such as cost-benefit analysis) falls short, especially where significant environmental and social impacts cannot be assigned monetary values. MCA allows decision makers to include a full range of social, environmental, technical, economic, and financial criteria.

2.2.1 Decision

A decision is a choice between alternatives. The alternatives may represent different courses of action, different hypotheses about the character of a feature, different classifications, and so on. These set of alternatives is called the *decision frame* (Eastman, 2012).

Thus, for example, the decision frame for a zoning problem might be (commercial, residential and industrial). The decision frame, however, should be distinguished from the individuals to which the decision is being applied. This is called the *candidate set*. For example, extending the zoning example above, the set of all locations (pixels) in the image that will be zoned isthe candidate set. Finally, a *decision set* is that set of all individuals that are assigned a specific alternative from the decision frame. Thus, for example, all pixels assigned to the residential zone constitute one decision set. Similarly,

those belonging to the commercial zone constitute another. Therefore, another definition of a decision would be to consider it the act of assigning an individual to a decision set. Alternatively, it can be thought of as a choice of alternative characterizations for an individual (Eastman, 2012).

2.2.2 Decision Rule

The procedure by which criteria are selected and combined to arrive at a particular evaluation, and by which evaluations are compared and acted upon, is known as a decision rule. A decision rule might be as simple as a threshold applied to a single criterion (such as, all regions with slopes less than 35% will be zoned as suitable for development) or it may be as complex as one involving the comparison of several multi-criteria evaluations.

Decision rules typically contain procedures for combining criteria into a single composite index and a statement of how alternatives are to be compared using this index. For example, we might define a composite suitability map for agriculture based on a weighted linear combination of information on soils, slope, and distance from market. The rule might further state that the best 5000 hectares are to be selected. This could be achieved by choosing that set of raster cells, totalling 5000 hectares, in which the sum of suitability is maximized. It could equally be achieved by rank ordering the cells and taking enough of the highest ranked cells to produce a total of 5000 hectares. Having insight from Diamond and Wright (1989), the former might be called a *choice function* (known as an *objective function* or *performance index* in mathematical programming literature) while the latter might be called a *choice heuristic*.

i. Choice Function

Choice functions provide a mathematical means of comparing alternatives. Since they involve some form of optimization (such as maximizing or minimizing some measurable characteristic), they theoretically require that each alternative be evaluated in turn. However, in some instances, techniques do exist to limit the evaluation only to likely alternatives. For example, the Simplex Method in linear programming (Feiring, 1986) is specifically designed to avoid unnecessary evaluations.

ii. Choice Heuristic

Choice heuristics specify a procedure to be followed rather than a function to be evaluated. In some cases, they will produce an identical result to a choice function (such as the ranking example above), while in other cases they may simply provide a close approximation. Choice heuristics are commonly used because they are often simpler to understand and easier to implement.

2.2.3 Criterion

A criterion is some basis for a decision that can be measured and evaluated. It is the evidence upon which an individual can be assigned to a decision set. Criteria can be of two kinds: factors and constraints, and can pertain either to attributes of the individual or to an entire decision set.

i. Factors

A factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration. It is therefore most commonly measured on a continuous scale. For example, a forestry company may determine that the steeper the slope, the more costly it is to transport wood. As a result, better areas for logging would be those on gentle slopes (the gentler, the better). Factors are also known as

decision variables in the mathematical programming literature and *structural variables* in the linear goal programming literature (Ignizio, 1985).

ii. Constraints

A constraint serves to limit the alternatives under consideration. A good example of a constraint would be the exclusion from development of areas designated as wildlife reserves. Another might be the stipulation that no development may proceed on slopes exceeding 30% gradient. In many cases, constraints will be expressed in the form of a Boolean (logical) map: areas excluded from consideration being coded with a 0 and those open for consideration being coded with a 1.

However, in some instances, the constraint will be expressed as some characteristic that the decision set must possess. For example, it might be required that the total area of lands selected for development should be no less than 5000 hectares, or that the decision set should consist of a single contiguous area. Constraints such as these are often called *goals* (Ignizio, 1985) or *targets*. Regardless, both forms of constraints have the same ultimate meaning, which is: to limit the alternatives under consideration.

2.2.4 Objective

Decision rules are structured in the context of a specific objective. The nature of that objective, and how it is viewed by the decision makers (i.e., their motives) will serve as a strong guiding force in the development of a specific decision rule. An objective is thus a perspective that serves to guide the structuring of decision rules. Objectives are thus very much concerned with issues of motive and social perspective (Lemmessa, 2011).

2.3 MULTI-CRITERIA DECISION MAKING IN GIS

Decision making is a systematic procedure for analyzing complex decision problems. The strategy is to divide a decision problem into small parts, analyzing each part and aggregating them to reach a meaningful solution. Decision making is defined as a selection of alternatives and is used in many fields in both the social and natural sciences, including GIS. Geographers are often interested in connecting spatial components with decisions. For this reason GIS and Multi Criteria Decision Making (MCDM) complement each other (Elliot and Petrova, 2004).

MCDM offers a wide range of techniques and methods for decision makers to incorporate into a GIS environment. GIS offers unique capabilities for autoimmunization, managing and analyzing a variety of spatially related problems. GIS can provide techniques for analyzing geographic events where the analysis depends on spatial arrangements of the events. Many problems in environmental, economic and natural science are spatially related; therefore a combination of GIS and decision methods can benefit the decision making process.

MCDM also involves a set of alternatives that are evaluated under certain criteria. There are two major classes of MCDM. One is Multi Attribute Decision Making (MADM) and the other is Multi Objective Decision Making (MODM). MADM is based on choice from a small set of feasible attributes using decision criteria and priorities. MODM is designed to deal with feasible attributes bounded from particular constraints. Multiple objectives in MODM are considered simultaneously (Malczewski, 1999).

As indicated earlier, the primary issue in Multi Criteria Decision Making (MCDM) or Multi-Criteria Evaluation is concerned with how to combine the information from several criteria to form a single index of evaluation. In the case of Boolean criteria (constraints), the solution usually lies in the union (logical OR) or intersection (logical

AND) of conditions. However, for continuous factors, a weighted linear combination (Voogd, 1983) is most commonly used. With a weighted linear combination, factors are combined by applying a weight to each followed by a summation of the results to yield a suitability map, i.e.:

$$S = \sum w_i c_i \qquad (2.1)$$

Where:

S = Suitability
w_i = Weight of factor i
c_i = Criterion score of factor i

As Stated by Eastman (2012), this procedure is not unfamiliar in GIS and has a form very similar to the nature of a regression equation. In cases Boolean constraints also apply, the procedure can be modified by multiplying the suitability calculated from the factors by the product of the constraints, i.e.:

$$S = \sum w_i c_i \times \prod c_j \qquad (2.2)$$

Where: c_j = Criterion score of the constraint j

$\prod$ = Product.

2.3.1 Criterion Scores

All criteria are usually measured in different scales, which mean that they need to be standardized before being aggregated. There are different methods of scaling. The method that is used in IDRISI is known as linear scaling. It uses minimum and maximum values of the raw data in order to standardize criteria into range of 0 - 1 real scale or from 0 - 255 byte scale. The following formula is used:

$$x_i = \frac{(R_i - R_{\min})}{(R_{\max} - R_{\min})} * STANDARDIZ\ ED\ RANGE \qquad (2.3)$$

***Where**: R = raw value/score of the pixel*

A critical issue in the standardization of factors is the choice of the end points at which set membership reaches either 0.0 or 1.0 (or 0 and 255). Research has suggested that blindly using a linear scaling (or indeed any other scaling) between the minimum and maximum values of the image is ill advised. In setting these critical points for the set membership function, it is important to consider their inherent meaning. Thus, for example, if industrial development should be placed as far away from a nature reserve as possible, it would be dangerous to implement this without careful consideration. Taken literally, if the map were to cover a range of perhaps 100 km from the reserve, then the farthest point away from the reserve would be given a value of 1.0 (or 255 for a byte scaling). Using a linear function, then, a location 5 km from the reserve would have a standardized value of only 0.05 (13 for a byte scaling) (Eastman, 2012).

2.3.2 Criterion Weights

A wide variety of techniques exist for the development of weights. In very simple cases, assigning criteria weights may be accomplished by dividing 1.0 among the criteria. Breaking the information down into simple pairwise comparisons in which only two criteria need be considered at a time can greatly facilitate the weighting process, and will likely produce a more robust set of criteria weights. A pairwise comparison method has the added advantages of providing an organized structure for group discussions, and helping the decision making group to narrow in on areas of agreement and disagreement in setting criterion weights (Lemmessa, 2011).

The technique described and implemented in IDRISI is that of pairwise comparisons developed by Saaty (1977) in the context of a decision making process known as the Analytical Hierarchy Process (AHP). In Saaty's technique, weights can be derived by taking the principal eigenvector of a square reciprocal matrix of pairwise comparisons between the criteria. The comparisons concern the relative importance of the two criteria involved in determining suitability for the stated objective. Ratings are provided on a 9-point continuous scale (Figure 2-1). For example, if the decision maker feels that proximity to roads is very strongly more important than slope gradient in determining suitability for industrial siting, he would enter a 7 on this scale. If the inverse were the case (slope gradient was very strongly more important than proximity to roads), he would enter 1/7.

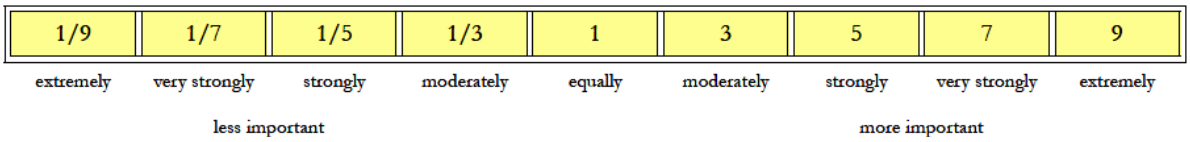


Figure 2-1: The continuous rating scale.

All GIS software systems provide the basic tools for evaluating such a model. In addition, in IDRISI, a special module named MCE has been developed to facilitate this process. However, the MCE module also offers a special procedure called an Ordered Weighted Average that greatly extends the decision strategy options available. The procedure will be discussed more fully in the section on Evaluation below. For now, however, the primary issues relate to the standardization of criterion scores and the development of the weights (Eastman, 2001).

The general objective of MCDM tools is to assist decision makers in selecting the best possible alternative from a set of feasible alternatives using user defined priorities. The

framework of the decision process is summarized by Jankowski (1995) in four distinguish steps:

1. *Problem definition:* defines a problem driven from discrepancy between the present state and the desirable state.

2. *Search for alternatives and selection criteria:* defines the alternatives that have to be taken under consideration and criteria for evaluating these alternatives.

3. *Evaluation of alternatives:* impact of each alternative on every criterion is assessed.

4. *Selection of alternatives:* deals with ordering the alternatives from most desirable to least desirable and either the top alternative is selected or a group of desirable alternatives.

According to Jankowski (1995), GIS is implemented in the second step in searching for feasible alternatives. Most decision making problems solved with GIS are related to a search for suitable sites, routes and land use. In addition, GIS is increasingly being used to assess risk-hazards.

Geographical or spatial data is defined as unorganized data that is associated with a location. When the data is organized, analyzed and interpreted, it then becomes information. In this stage the data can be useful for the decision making process. Decision making processes that include geographical data and information are related to a geographical or spatial decision method (Elliot and Petrova, 2004).

Many managers and decision makers use data that is geographically related. For example, the population density by census tract refers to a particular location.

Geographical and spatial data are interchangeable. In this case, facts, results of observation, remote-sensing images, census figures and statistics can be considered geographical data.

2.4 GIS AND MULTI-CRITERIA DECISION MAKING INTEGRATION

Spatial multi-criteria decision problems typically involve a set of geographically defined alternatives from which a choice of one or more alternatives is made with respect to a given set of evaluation criteria. Spatial multi-criteria analysis differs from conventional multi-criteria decision analysis (MCDA) in that it requires information on the criterion values and the geographical locations of alternatives. The results depend not only on the geographical distribution of attributes but also on the value judgments of decision-makers (Jankowski, 1995; Malczewski and Ogryczak, 1996). As stated by Carver (1991) and Jankowski (1995), two important components of spatial MCDA are GIS and multi-criteria decision-making.

Many spatial decision problems lead to the integration of GIS and MCDA, as these two techniques can interact with each other. GIS techniques have an important role in analyzing decision problems and are decision support systems that integrate spatially referenced data into a problem-solving environment. MCDA provides many techniques and procedures for structuring decision problems and for evaluating and prioritizing alternative decisions. The integration of GIS and multi-criteria decision-making can be thought of as a process that combines geographical data and value judgments of decision-makers to obtain information for decision-making (Malczewski, 2006).

In the context of GIS, two procedures are common for the Multi-Criteria Evaluation (MCE) the Boolean overlay and the weighted linear combination (WLC). In a Boolean approach, all criteria are assessed by thresholds of suitability to produce Boolean maps,

which are then combined by logical operators such as intersection (AND) and union (OR). With the use of WLC, continuous criteria (factors) are standardized to a common numeric range and then combined by weighted averaging. The result is a continuous mapping of the suitability (Jiang and Eastman, 2000).

Boolean analysis can only be used when there are two states (criterion satisfied and criterion not satisfied). This analysis was developed by George Boole, who devised rules and methodologies for combining two-state variables. The Boolean search is generally concerned with the 'AND' operator. The logical 'AND' operator produces a true result from the phrase 'A AND B' only if A and B are 'true'. In GIS, this methodology is used in a multiplication overlay between layers containing only zeroes (representing areas where conditions are 'false' or 'criterion is not satisfied') and ones (representing areas where conditions are 'true' or 'criterion is satisfied') (Eastman, 2003).

As opined by Joerin *et al.* (2000), combining GIS and Multicriteria Decision Analysis (MCDA) for land planning involves many tasks including data gathering and structuring, and computation of criteria using spatial analysis and simulation. While a significant amount of work would be necessary to develop these types of maps, they would be useful for several years and many decisions. Updating the maps would surely require much less work than was initially required to produce them.

Moreover, the integration of MCDA techniques with GIS has considerably advanced the conventional map overlay approaches to the land-use suitability analysis (Carver, 1991; Eastman, 1997; Malczewski, 1999). GIS-based MCDA can be thought of as a process that combines and transforms spatial and aspatial data (input) into a resultant decision (output). The MCDM procedures (or decision rules) define a relationship between the input maps and the output map. The procedures involve the utilization of geographical

data, the decision maker's preferences and the manipulation of the data and preferences according to specified decision rules. Accordingly, two considerations are of critical importance for spatial MCDA: (i) the GIS capabilities of data acquisition, storage, retrieval, manipulation and analysis, and (ii) the MCDM capabilities for combining the geographical data and the decision maker's preferences into uni-dimensional values of alternative decisions. A number of Multicriteria decision rules have been implemented in the GIS environment for tackling land-use suitability problems. The decision rules can be classified into multi-objective and multi-attribute decision making methods (Malczewski, 1999).

GIS approaches to MCDM can be summarized as spatial decision making problems involving a group of decision makers of differing interests related to the same problem (Malczewski, 1996). The weighted linear combination method and Boolean overlay techniques are used widely as MCDM in GIS.

Every decision method starts with definition of the problem and ends with recommendations. Once the problem is defined the set of evaluation criteria (objectives/attributes) needs to be specified. Each attribute needs a measurable variable. The attributes also must be measured on a scale in order to evaluate the degree to which alternatives under consideration are met. There are two types of evaluation criterion maps in GIS. Factor maps enhance the objective and are usually measured in continuous scale. For example, a company wants to build houses in the rural area, but the steeper the slope the greater the building expenses and the more expensive the houses. This could lead the company to lose profits. For these reasons the company prefers to build on a shallow slope. The slope factor map will indicate the area with shallow slope as more desirable. Constraint factor maps limit the alternatives under consideration. In the

context of this example the company will also need to limit or constrain building on conservation areas (Elliot and Petrova, 2004).

2.4.1 Criteria Weighting Methods

In the next stage, the decision maker outlines their preferences by assigning weights to the evaluation criteria. Deriving weights for each suitability criteria is a fundamental requirement for applying the Analytic Hierarchy Process (AHP) method (Malczewski, 1999; 2004). The determination of the particular criterion weight is therefore a crucial step in Multicriteria Evaluation (MCE). The AHP is considered to be an adequate mathematical method for this step (weighting of factors) when analyzing complex decisional problems (Saaty, 1980 and Malczewski, 2004). It derives the weights by comparing the relative importance of the criteria in a pairwise manner. The weights can be derived using different methods. Most commonly used methods include ranking, rating, pairwise comparisons (AHP) and trade-off analysis.

i. The Ranking Method

The ranking method is the simplest method where the importance of the weights is to arrange the criteria in a rank order. There are two ways of ranking: straight ranking (the most important first, the second important second, etc.) and inverse ranking (the least important first, the next least important second, etc.). Once the ranks have been established the weights are calculated using rank sum or rank exponent method.

ii. The Rating Method

The rating method requires weights to be determined on the basis of predetermined scale, for example from 0 to 100. There are two rating approaches, point allocation and ration estimation. Point allocation allocates 100 points across the criteria with 0 meaning that this criterion can be ignored. The weights for this approach are calculated as a

percentage of the whole. The ration estimation approach allocates 100 points to the most important criterion according to the decision maker and proportionally smaller weights are assigned to the lower ordered criteria. Dividing each weight by the total normalizes the weights.

iii. The Pairwise Comparisons Method

The pairwise comparisons create a ratio matrix and weights determined by normalizing the eigenvector with the maximum eigenvector of the ratio matrix. Thomas Saaty developed this method in 1982 and it is incorporated in Analytic Hierarchy Process (AHP).

iv. The Trade-Off Analysis Method

The trade-off analysis method makes use of direct assessment of the trade-offs that the decision maker is willing to make between two alternatives. The method compares two alternatives at one time based on two criteria in order to assess which alternative is preferable. The weights are then derived from these comparisons. According to Malczewski (1999) the critical assumptions for this method are the trade-offs the decision maker is willing to make between two criteria that are not dependent on the levels of the others criteria. A summary of methods for assigning criterion weights is shown in the table below.

Table 2.1: Summary of methods for assessing Criterion Weights.(Source: Malczewski, 1999)

	METHODS			
Features	**Ranking**	**Rating**	**Pairwise Comparison**	**Trade-off Analysis**
Number of Judgments	n	n	n(n-1)/2	<n
Response scale	Ordinal	Interval	Ratio	Interval
Hierarchical	Possible	Possible	Yes	Yes

Underlying Theory	None	None	Statistical/ heuristic	Axiomatic/ deductive
Ease of use	Low	High	High	Medium
Trustworthiness	Approximation	Not precise	Quite precise	Quite precise
Software availability	Spreadsheets	Spreadsheets	EXPERT CHOICE	LOGICAL DECISIONS (LD)
Use in a GIS environment	Weights can be imported from a spreadsheet	Weights can be imported from spreadsheet	Component of IDRISI	Weights can be imported from LD

The decision rule combines the evaluation of criterion and weights of criteria and provides an overall assessment of the alternatives. It arranges the decision space by means of one-to-one or one-to-many relationships of outcomes to decision alternatives. A decision rule can be as simple as applying a threshold to a single criterion or as complex as involving a comparison of many multi criteria evaluations.

Sensitivity analysis determines how the recommended action is affected by the change of inputs. This analysis checks for robustness of the decision making process. It helps users to learn how decision elements interact in order to determine the most preferable alternative.

A fuzzy set indicates the measure of membership of the criterion, most commonly suitability or risk, and is a soft classifier. Hard classification or Boolean classifications provide a distinct division between what is a member and what is not, commonly referred to as a AND or a OR operator. The fuzzy set membership indicates a range of potential membership generally expressed on a scale of 0 to 1. This is particularly useful in raster based MCE applications of GIS. These fuzzy sets are commonly used with weighted linear combinations (WLC) and ordered weighted averages (OWA) (Elliot and Petrova, 2004).

The WLC combine the AND operators with OR operators (AND/OR) and is often used as an averaging operator (Jiang 2000). Therefore the aggregation process of WLC can be seen as a fuzzy measure. When using OWA the use of a AND or an OR operator is also known as MIN/MAX aggregation.

The standardization of factors can sometimes contribute to inappropriate standardization. Standardizations can over-generalize the factors and affect the overall decision making process. The disadvantages and advantages will be explained further in the AHP section.

2.4.2 Analytic Hierarchical Process (AHP)

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making approach and was introduced by Saaty (1980 and 1994). The AHP has attracted the interest of many researchers mainly due to the nice mathematical properties of the method and the fact that the required input data are rather easy to obtain. The AHP is a decision support tool which can be used to solve complex decision problems. It uses a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives. The pertinent data are derived by using a set of pairwise comparisons. These comparisons are used to obtain the weights of importance of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion. If the comparisons are not perfectly consistent, then it provides a mechanism for improving consistency (Triantaphyllou and Mann, 1995).

The Analytic Hierarchy Process(AHP), is an effective tool for dealing with complex decision making, and may aid the decision maker to set priorities and make the best decision. By reducing complex decisions to a series of pairwise comparisons, and then

synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. In addition, the AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision making process.

2.4.2.1 How the AHP works

The AHP considers a set of evaluation criteria, and a set of alternative options among which the best decision (goal) is to be made. It is important to note that, since some of the criteria could be contrasting, it is not true in general that the best option is the one which optimizes each single criterion, rather the one which achieves the most suitable trade-off among the different criteria.

The AHP generates a weight for each evaluation criterion according to the decision maker's pairwise comparisons of the criteria. The higher the weight, the more important the corresponding criterion. Next, for a fixed criterion, the AHP assigns a score to each option according to the decision maker's pairwise comparisons of the options based on that criterion. The higher the score, the better the performance of the option with respect to the considered criterion. Finally, the AHP combines the criteria weights and the options scores, thus determining a global score for each option, and a consequent ranking. The global score for a given option is a weighted sum of the scores it obtained with respect to all the criteria (Temiz and Tecim, 2009).

2.4.2.2 AHP Methodology

As put down by Saaty (1980); Vaidya and Kumar (2006), some key and basic steps involved in carrying out the AHP are as follows:

1. Stating the problem.

2. Broadening the objectives of the problem or considering all factors, objectives and their outcomes.
3. Identifying the criteria of the problem.
4. Structuring the problem in a hierarchy of different levels constituting goal, criteria, sub-criteria and alternatives.
5. Comparing each element (pair-wise comparisons) in the corresponding level and calibrating them on the numerical scale. The scale has values ranging from 1 to 9, as shown in the table below (Saaty, 1980).

Table 2.2: Table showing the scale for pair-wise comparisons

	Equal importance
	Equal to moderate importance
	Moderate importance
	Moderate to strong importance
	Strong importance
	Strong to very strong importance
	Very strong importance
	Very to extremely strong importance
	Extreme importance

6. Performing calculations to find the maximum eigenvalue (λ), consistency index (CI), consistency ratio (CR) and normalized values for each criteria/alternative. It should be noted that for preventing bias thought criteria weighting the Consistency Ratio is usually used. λ represents average value of the consistency vector, CI provides a measure of departure from consistency and CI and CR are calculated as shown in the following equations respectively.

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (2.4)$$

$$CR = \frac{CI}{RI} \quad (2.5)$$

***Where*:**

n= the number of items being compared in the matrix

λ_{max} = the largest Eigen value

RI = random consistency index

RI is the random index and depends on the number of elements being compared, as shown in the table below (Saaty, 1980).

Table 2.3: Random inconsistency indices (RI) for n=1, 2, ..., 15. Source: (Saaty, 1980)

0.00	6	1.24	11	1.51
0.00	7	1.32	12	1.48
0.58	8	1.41	13	1.56
0.90	9	1.45	14	1.57
1.12	10	1.49	15	1.59

If CR<0.10, the ratio indicates a reasonable level of consistency in the pair-wise comparison; however, if CR≥0.10, the values of the ratio indicates inconsistent judgments.

7. If the maximum eigenvalue, CI and CR are satisfactory, then decision is taken based on the normalized values; otherwise the procedure is repeated until these values lie in a desired range.

2.4.2.3 AHP and Fuzzy Standardization of Factors

In order to perform AHP in IDRISI, a fuzzy standardization must be performed for all factors. The factors are rescaled to a particular common range according to some

function by fuzzy standardization. In order to use fuzzy factors within MCE, these factors are standardized to the byte level range of 0–255. The suitability increases as the areas get closer to the value of 255 (Temiz and Tecim, 2009).

2.4.2.4 Pairwise Comparison

The pairwise comparisons create a ratio matrix and weights determined by normalizing the eigenvector with the maximum eigenvector of the ratio matrix. Thomas Saaty developed this method in 1982 and it is incorporated in AHP.

	Road Proximity	Town Proximity	Slope Gradient	Small Holder Settlement	Distance from Park
Road Proximity	1				
Town Proximity	1/3	1			
Slope Gradient	1	4	1		
Small Holder Set.	1/7	2	1/7	1	
Distance from Park	1/2	2	1/2	4	1

Figure 2-2: An example of a pairwise comparison matrix for assessing the comparative importance of five factors to suitability.
Source: (Vaidya and Kumar, 2006)

2.5 LAND SUITABILITY ANALYSIS (LSA)

Land Suitability Analysis (LSA) is a GIS-based process applied to determine the suitability of a specific area for considered use, i.e. it reveals the suitability of an area regarding its intrinsic characteristics (suitable or unsuitable). Also this analysis involved with considering wide rages of criteria including environmental, social and economic factors. Appropriate handling of such broad and heterogeneous maps requires applying a flexible tool (Jafari and Zaredar, 2010). Land suitability is also the fitness of a given type of land for a defined use (FAO, 1976). Similarly, it is as a part of land use planning methodology and defines possible options for the future land use and helps to describe

these interactions (policies, institutions and information management). Broadly defined, land-use suitability analysis aims at identifying the most appropriate spatial pattern for future land uses according to specific requirements, preferences, or predictors of some activities as cited in (Malczewski, 2003) and also, FAO (1976) defined it as the adaptability of a given area for a specific kind of land use.

Furthermore, Land Suitability Analysis (LSA) is the process of determining the fitness of a given tract of land for a defined use (Steiner and McSherry, 2000). In other words, it is the process to determine whether the land resource is suitable for some specific uses and to determine the suitability level.

In order to determine the most desirable direction for future development, the suitability for various land uses should be carefully studied with the aim of directing growth to the most appropriate sites. Establishing appropriate suitability factors is the construction of suitability analysis. Initially, suitability analysis was developed as a method for planners to connect spatially independent factors within the environment and, consequently to provide a more unitary view of their interactions. Suitability analysis techniques integrate three factors of an area: location, development activities, and environmental processes. These techniques can make planners, landscape architects and local decision-makers analyze factors interactions in various ways. Moreover, such suitability analysis enables elected officials and land managers to make decisions and establish policies in terms of the specific land uses (Al-Shalabi *et al.,* 2006).

The spatial Analytical Hierarchy Process (AHP) introduced by Saaty in the mid-1970s and developed in 1980s (Saaty, 1980 and Saaty, 1995) is among the best method which is suitable for carrying out these kinds of analysis. The combination of spatial AHP method as one of the commonly used methods of spatial multi criteria analysis with GIS

is a new trend in land suitability analysis. As regards the spatial multi criteria analysis inclusion of an explicit geographic component it is considered different from conventional multi criteria techniques. In general one of the most important uses of GIS is the land use suitability mapping and analysis (Malczewski, 2004). According to environmental, resource planning and management points of view, the Analytic Hierarchy Process is among the fastest growing decision-analytic techniques.

Land suitability classification is developed by considering different factors of land characteristics. Based on suitability of each land use, a weighted value ranging from 5 (unsuitable) to 1 (most suitable) are usually given as seen in the table below. The weighted value of each land characteristics are reclassified for each land use. Each parameter is given a value based on its suitability for each land use type. The weighted value of each land characteristics factors is added and the average value of them is taken to determine the suitability of land for each land use type. As seen in Table 2.4, the average value of them is categorized into five suitable classes to get the final suitability for each land uses (Lemmessa, 2011).

Table 2.4: FAO Standard for Suitability Classification. Source:(FAO, 1993)

Land Suitability Orders	**Land suitability Classes**	**Description**
Suitable	Highly Suitable (S1)	Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce benefits.
	Moderately Suitable (S2)	Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land.
	Marginally	Land having limitations which in aggregate are severe

	Suitable (S3)	for sustained application of a given use and will so reduce productivity or benefits or increase required inputs, that this expenditure will be only marginally justified.
Not Suitable	Currently Not Suitable (N1)	Land having limitations which cannot be overcome at currently acceptable cost.
	Permanently Not Suitable (N2)	Land with limitations to sustained use that cannot be overcome.

One of the most useful applications of GIS for planning and management is the land suitability mapping and analysis. Broadly defined, land suitability analysis aims at identifying the most appropriate spatial pattern for future land uses according to specific requirements, preferences, or predictors of some activity (Hopkins, 1977; Collins *et al.,* 2001). The GIS-based land suitability analysis has been applied in a wide variety of situations including ecological approaches for defining land suitability/habitat for animal and plant species (Store and Kangas, 2001), geological favorability, suitability of land for agricultural activities, landscape evaluation and planning, environmental impact assessment, selecting the best site for the public and private sector facilities, and regional planning (Malczewski, 2004).

The diversity of the types of land-use suitability studies can be attributed to the different ways the term land use is defined by various applications and the context of its use. For example, it is likely that the urban planners and the agricultural experts would have different perception of the term. To this end, it is important to make distinction between two notions: land use and land cover. Broadly speaking, land cover describes the physical state of the earth's surface and immediate subsurface in terms of the natural environment (such as vegetation, soils, and surfaces and groundwater) and the man-made structures (e.g. buildings). Land use itself is the human employment of a land-cover type. It 'involves both the manner in which the biophysical attributes of the land

are manipulated and the intent underlying that manipulation – the purpose for which the land is used' (Turner *et al.*, 1995).

Furthermore, the term of land use may have different connotations depending on the spatial scale. At the large scales it is typically considered as a resource and consequently land use means resource use. In contrast, at the urban scale it is characterized in terms of the potential use of the land's surface for the location of various activities. This connotation of the term land use is implicit in the context of urban and regional planning. The description of land use, at a given spatial level and for a given area, usually involves specifying the mix of land use types, the particular pattern of these land use types, the areal extent and intensity of use associated with each type (Malczewski, 2004).

In the context of land suitability analysis it is important to make distinctions between the site selection problem and the site search problem. The aim of site selection analysis is to identify the best site for some activity given the set of potential (feasible) sites. In this type of analysis all the characteristics (such as location, size, relevant attributes, etc.) of the candidate sites are known. The problem is to rank or rate the alternative sites based on their characteristics so that the best site can be identified. If there is not a pre-determined set of candidate sites, the problem is referred to as site search analysis. The characteristics of the sites (their boundaries) have to be defined by solving the problem. The aim of the site search analysis is to explicitly identify the boundary of the best site. Both the site search problem and land suitability analysis assume that there is a given study area and the area is subdivided into a set of basic unit of observations such as polygons (areal units) or rasters (Malczewski, 2004).

According to Malczewski, “The land suitability analysis problem involves classification of the units of observations according to their suitability for a particular activity. The analysis defines an area in which a good site might exist. The explicit site search analysis determines not only the site suitability but also its spatial characteristics such as its shape, contiguity, and/or compactness by aggregating the basic units of observations according to some criteria (Xiao *et al.*, 2002).”

2.5.1 Land Suitability Analysis (Mapping) and Spatial Multi-Criteria Decision Making

Land Suitability Analysis (LSA) or mapping, conceptualized as Multiple Criteria Decision Making problem, implies the assignment of values to alternatives that are evaluated along multiple decisions or criteria (Pereira *et al.*, 1993). In this regard, for Land Suitability Analysis in a raster environment, each grid cell in the database is taken as an alternative to be evaluated for its quality or appropriateness for specific purposes. Therefore, land suitability is a biological productivity of an area for a given set of uses. Livestock production suitability analysis involves integration of information from various streams of science. There are many criteria that are detrimental to land suitability analyses for livestock production. The suitability analysis evaluates many alternative land use types under various criteria from various disciplines (Lemmessa, 2011).

Criteria are both qualitative and quantitative. Decisions have to be taken at various levels starting from selecting, for instance, different livestock groups until the allocation of these groups for area that suite best. So the suitability analysis is a multiple criteria decision- making process. FAO (1985) analyzed land suitability mainly based on the land quality. Land quality is a complex attribute of land that has a direct effect on land use (FAO, 1993). These attributes are availability of water and nutrients, rooting

conditions and erosion hazards. Most land qualities are determined by interaction of several land characteristics, which are measurable attributes of the land. For example, the quality of availability of water is determined by a balance between water demand and water supply. The demand is the potential evaporation from the native vegetation, crops and soil. On the other hand, the supply is rainfall, infiltration storage of water in soil, ability of native vegetation and crops to extract the stored water. This inherent characteristic of, for example, availability of water enables the calculation of quantitative values of land quality. The value of land quality is the function of the assessment and grouping of land types into orders and classes in the framework of their fitness. Generally, land suitability is categorized as suitable (S) and not suitable (N). Whereas S features lands suitable for use with good benefits, N denotes land qualities which do not allow considered type of use, or are not enough suitable outcomes (FAO, 1985).

2.5.1.1 Multi Criteria Analysis and GIS for Land Suitability Mapping

The GIS-based approaches to land-use suitability mapping have their roots in the applications of hand-drawn overlay techniques used by American landscape architects in the late nineteenth and early 20th century (Steinitz *et al.*, 1976; Collins *et al.*, 2001). McHarg (1969) advanced the overlay techniques by proposing a procedure that involved mapping data on the natural and human-made attributes of the environment of a study area, and then presenting this information on individual, transparent maps using light to dark shading (high suitability to low suitability) and superimposing the individual transparent maps over each other to construct the overall suitability maps for each land use. Although McHarg's approach is widely recognized as a precursor to the classical overlay procedures in GIS, some researches credit Charles Eliot (Miller, 1993) and

Jacqueline Tyrwhitt (Steinitz *et al.*, 1976) as predecessors of the modern map overlay techniques.

Progress in computing sciences, including Geographical Information Systems (GIS) and Multi-Criteria Evaluation (MCE) can help planners handle this complexity of choosing a suitable site for a project. Choosing an appropriate location for an activity or a facility is obviously related to decision support and MCE. The problem can be generalized as a question of what must be done and where it should be realized. The purpose of planning (what) can involve a hospital (Malczewski and Ogryczak, 1990; Malczewski, 1991), a solid waste transfer station (Gil and Kellerman 1993), or more generally, any type of public facility. In a series of two articles, Malczewski and Ogryczak (1996) clearly defined the multiple criteria location problem. They also compared the advantages and the disadvantages of different MCE methods. Localization problems have also been treated with a more intensive use of GIS. Carver (1991) used GIS to evaluate various alternatives for nuclear waste sites. Then, he evaluates the effectiveness of three MCDA techniques used to compare scenarios in order to select the best one.

Land suitability assessment is similar to choosing an appropriate location, except that the goal is not to isolate the best alternatives, but to map a suitability index for the entire study area. Senes and Toccolini (1998) combined UET (Ultimate Environmental Threshold) method with map overlays to evaluate land suitability for development. Hall *et al.* (1992) and Wang (1994) also used map overlays to define homogeneous zones, but then they apply classification techniques to assess the agricultural land suitability level of each zone. These classification techniques can be based on Boolean and fuzzy theory (Hall *et al.*, 1992) or artificial neural networks (Wang, 1994). Combining GIS and MCE is also a powerful approach to land suitability assessments. GIS enable computation of

the criteria while a MCE can be used to group them into a suitability index. Following a similar approach, Eastman *et al.* (1993) produced a land suitability map for an industry near Kathmandu using IDRISI (a raster GIS) and AHP (Analytical Hierarchy Process) (Saaty, 1980).

2.5.2 Geographical Information Systems (GIS) and Remote Sensing

Geographic information system are a special class of information systems that keep track not only of events, activities, and things, but also of where these events, activities, and things happen or exist, almost everything that happen somewhere. Knowing where something happens can be critically important (Paul *et al.,* 2004). It is a computer-based system that provides four sets of capabilities to geo-referenced data: data input, data management (storage and retrieval), manipulation and analysis, and finally data output.

Similarly, (Burrough, 1986) defined GIS as a set of tools for collecting, storing, retrieving, at will, transforming and displaying spatial data from the real world for a particular set of purposes. Like any information system, a GIS is an organized accumulation of data and procedures that help people make decisions about what to do with things (John and Steven, 2003).

Remote sensing provides the information about the various spatial criteria/factors under consideration. According to Lillesand and Kiefer(2004), remote sensing is a technique used to derive information about physical, chemical and biological properties of objects without direct physical contact. Remote sensing techniques are more effective and useful for understanding and studying those areas in the out-of-the way mountains and remote deserts (Lo and Yeung, 2005).

Hence, it offers an efficient and effective means of collecting the information required in order to map land suitability.

2.5.2.1 Applications of GIS for Land Suitability Mapping

One of the most useful applications of GIS for planning and management is the land use suitability mapping and analysis. Broadly defined, land-use suitability analysis or mapping aims at identifying the most appropriate spatial pattern for future land uses according to specify requirements, preferences, or predictors of some activity (Malczewski, 2004). The GIS-based land-use suitability mapping has been applied in a wide variety of situations including ecological approaches for defining land suitability/habitant for animal and plant species, geological favourability, suitability of land for agricultural activities, landscape evaluation and planning, environmental impact assessment, selecting the best site for the public and private sector, and regional planning (Malczewski, 2004).

2.5.2.2 Role of Remote Sensing and GIS in Grazing Reserves Siting and Management

Satellite remote sensing was introduced as an important tool in understanding and monitoring various components of grazing land (rangeland) function and health (Palmer and Fortescue, 2003). Keeping the limits imposed by scale and image resolution, remote sensing application in grazing lands management has got wide acceptance. One of the primary applications of remote sensing in the grazing reserves is prediction of production potential of a ranch (Palmer and Fortescue, 2003). Using different imageries that have varying spatial and temporal resolution, it is possible to estimate grass biomass. Satellite imageries have been used from its earliest times for the preparation of base maps for grazing land inventory. Integrated with GIS, the system provides spatial

and temporal information, which are valuable for inventory. Furthermore, reserves conditions can be relatively easily handled with low cost and effort. Satellite image like National Oceanic and Atmospheric Administration Advanced Very High Resolution Radiometer (NOAA AVHRR) have high temporal resolution which can capture information on the condition and health of grazing lands on daily basis supported with ground trothing. Change detection using high resolution imagery is another application provided by remote sensing. Ground based change detection is expensive and requires more manpower, resources and time input. In addition, previous data should be available at the appropriate scale and level. However, for example, using Landsat imageries of the past three decades which are freely available, valuable information can be extracted using remote sensing. Livestock grazing lands change frequently and their succession favor woody plants domination.

GIS has diverse application in grazing reserves management. These include selection of suitable site for establishing new livestock water points, access road construction, disease infestation mapping, animal migration mapping, habitat suitability analysis, habitat modeling and the likes. The application of remote sensing and GIS is not limited to this level. They are also utilized in complex models used to assess reserves degradation, net primary production, below and above ground carbon sequestration (Bettinger and Wing, 2004).

2.6 REMOTELY SENSED IMAGE CLASSIFICATION

Pattern recognition is the scienceand artof finding meaningful patterns in data, which can be extracted through classification. By spatially and spectrally enhancing an image, pattern recognition can be performed with the human eye; the human brain automatically sorts certain textures and colors into categories.In a computer system, spectral pattern

recognition can be more scientific. Statistics are derived from the spectral characteristics of all pixels in an image. Then, the pixels are sorted based on mathematical criteria. The classification process breaks down into two parts: training and classifying (using a decision rule). First, the computer system must be trained to recognize patterns in the data. Training is the process of defining the criteria by which these patterns are recognized. Training can be performed with either a supervised or an unsupervised method (ERDAS, 1999).

2.6.1 Classification Algorithms

When talking about classes, we need to distinguish between information classes and spectral classes. Information classes are those categories of interest that the analyst is actually trying to identify in the imagery, such as different kinds of crops, different forest types or tree species, different geologic units or rock types, etc. Spectral classes are groups of pixels that are uniform (or near-similar) with respect to their brightness values in the different spectral channels of the data. The objective is to match the spectral classes in the data to the information classes of interest. It is the analyst's job to decide on the utility of the different spectral classes and their correspondence to useful information classes (CCRS, 2007). Common classification procedures can be broken down into two broad subdivisions based on the method used: supervised classification and unsupervised classification.

2.6.2 Classification Accuracy Assessment

Basically, the accuracy of maps from remotely sensed data is measured by two types of criteria: location accuracy and classification or thematic accuracy. Location accuracy refers to how precisely map items or elements are located on the map relatively to their true location on the ground. Thematic accuracy refers to the accuracy of the map label

describing a class or condition on the earth (Congalton, 1991) as quoted by (Onsomwang, 2007).

Accuracy assessments utilize an error matrix produced by gathering reference data to verify the actual cover type at a sample point in the field using high resolution aerial data and/or visiting the field site (Campbell and Wynne, 2011). The reference data is then compared to the thematic map classes to find the ground truth of the classification. The main requirements to assess the accuracy of thematic information derived from remotely sensed data are explained below

2.6.2.1 Error matrix

An error matrix is a table of values that compares the value assigned during the classification process to the actual value from an aerial photo or satellite image (Parece *et al.*, 2013). This is also known as confusion matrix or contingency table. The relationship between remote sensing-derived classification map and ground reference test information is commonly summarized in an error matrix. Indeed, the error matrix provides the basis on which to both describe classification accuracy and characterize errors, which may help refine the classification or estimates derived from it.

In the table below, the diagonal of the matrix summarizes those pixels that were assigned to the correct class. The column represents the ground reference test information and the rows correspond to the classification generated from analysis of the remotely sensed data. Each error is both an omission from the correct category and a commission to a wrong category. The row and column totals around the margin of the matrix (i.e. K) are both used to compute errors of inclusion (commission errors) and

errors of exclusion (omission errors). The outer row and column totals are used to compute producer's and user's accuracy [(Ongsomwang, 2007), (Map & GIS library, 2013); (Olofsson, 2013)].

Table 2.5: Characteristic of an error matrix. Source: (Ongsomwang, 2007).

Class	1	2	3	K	Row total
1	$\mathbf{X_{1,1}}$	$X_{1,2}$	$X_{1,3}$	$X_{1,k}$	X_{1+}
2	$X_{2,1}$	$\mathbf{X_{2,2}}$	$X_{2,3}$	$X_{2,k}$	X_{2+}
3	$X_{3,1}$	$X_{3,2}$	$\mathbf{X_{3,3}}$	$X_{3,k}$	X_{3+}
k	$X_{k,1}$	$X_{k,2}$	$X_{k,3}$	$\mathbf{X_{k,k}}$	X_{k+}
Column total	X_{+1}	X_{+2}	X_{+3}	X_{+k}	**N**

2.6.2.2 Sample size

This is the totality of the test reference points to be used in a classification map. The actual number of ground reference test samples to be used to assess the accuracy of individual categories in a remote sensing classification map is a very important consideration. Some analysts use an equation based on binomial distribution or the normal approximation to the binomial distribution to compute the required sample size. Others suggest that a multinomial distribution can be used to determine the sample size because we are usually investigating the accuracy of multiple classes of information on land-cover map [(Jensen, 2005) as quoted by (Ongsomwang, 2007)]. Maps & GIS library (2013) stated that the rule of thumb in creating the total sample of reference pixels is to create ten (10) times the total number of classes (i.e. N × 10 = 10N sample) for each class. However, for a class (e.g. water) that is not much in the image, the points could be less (e.g. 60) and this is compensated in a class (e.g. forest) that is widespread.

2.6.2.3 Sampling Design

There are basically five sampling designs used to collect ground reference test data for accuracy assessment. They include random sampling; systematic sampling; stratified random sampling; stratified systematic unaligned sampling; and clustering sampling [(Jensen, 2005) as quoted by (Ongsomwang, 2007)].

a. Simple random sampling

In this sampling design method, a random number generator is used to identify random x,y coordinate within the study area. This method ensures that the members of a population are drawn independently with equal probabilities of being selected and that the selection of one sample does not influence the selection of other sample. Unfortunately, this sampling may under-sample small but possibly very important classes unless the sample size is significantly large. The random samples may be located in inhospitable or cross-denied location. Finally, some clustering of the random sample points often results and, as a consequence, important spatial properties of the population may be overlooked.

b. Systematic sampling

To avoid the shortcoming of random sampling regarding the coverage of an area, a systematic sampling plan may be used. This procedure requires that it is possible to work through the study area in some consistent manner such as along a line of coordinate points. Unfortunately, if there are periodicities in the data being collected (e.g. ridge and valley topography, mountain), the regularly spaced points could hit the same on a cycle time and again, and yielding biased sample estimates of the population. It should be used with caution because it may overestimate the population parameters (Congalton, 1988). This is shown in figure in the figure below.

c. Stratified random sampling

Using this method, the study area is divided into strata, with each land-cover class corresponding to a stratum. Thus, sample locations are then randomly distributed throughout the geographic strata. Ongsomwang (2007) explained that many remote sensing analysts prefer stratified random sampling by which a minimum number of samples are selected from each strata after each thematic map has been prepared. The advantage of stratified random sampling is that all strata, no matter how small their proportion of the entire study area, will have samples located to them for error evaluation process. The drawback with stratified random sampling is that one has to wait until the thematic map has been completed in order to allocate samples to the various land-cover strata. This is shown in figure 2-3.



Figure 2-3: An example of a random, systematic and stratified random sampling design. Source: (Olofsson, 2013)

2.6.2.4 Evaluation of the error matrix

After the ground reference test information has been collected from the random located sites, the test information is compared pixel by pixel with the information in the remote sensing-derived classification map. Agreement and disagreement are summarized in the cell of the error matrix (Ongsomwang, 2007). Error matrix determines three accuracy statistics of a classified imagery, namely:

a. Overall or total accuracy

This is determined by dividing the total correct pixels (sum of the major diagonal) by the total number of pixels in the error table. However, it is usually best to look in more detail at other forms of accuracy as this type can overlook errors. For instance, a bad misclassification of one land cover can affect the total, yet this error would appear as evenly distributed between classes, meaning the accuracy percentage is misleading.

b. Producer's accuracy

This is the probability that a certain land-cover class of an area on the ground is classified as such. It reflects the view of the producer and how pixels have been included in the wrong classes. Producer's accuracy can be computed by dividing the total number of pixels in that category (column total) by the total number of pixels in the category. It is almost a counter response to the errors of omission, which is applied to illustrate how the pixels that should have been classified as a certain class based on the reference data, were omitted and placed in another class. It indicate under-estimation or under-classified. It can be computed as the incorrectly classified pixels in the column divided by the total number of pixels in the column [(Lillesand and Kiefer, 2004); (Olofsson, 2013); (Maps & GIS library, 2013)].

c. User's accuracy

This is the probability that a pixel labeled as a certain land-cover in a map is classified as the pixel. This reflects the view of the user of the thematic map. It is calculated as the number of correctly classified pixels divided by the total number of pixels in the row. This corresponds to the error of commission, which indicate over-estimation or over-classified. It is how many test pixels are incorrectly classified as a class. It can be computed as the incorrectly classified pixels in the row divided by the total number of pixels in the row [(Campbell and Wynne, 2011); (GIS & map library, 2013)].

d. Kappa coefficient

This is a discrete multivariate technique used in accuracy assessment for statistically determining if an error matrix is significantly different than another. This is the measure of agreement between the model prediction (classified image) and reality (test pixels) as oppose to being due to chance. A value of one would represent perfect agreement and a zero would represent complete randomness. It delivers an implication of the confidence in values, such as a kappa coefficient result of 0.75 would indicate that there is 75% better agreement between reference (ground) data and the image data interpreted and produced, than by chance alone. It can be computed using the formula below:

$$\hat{K} = \frac{N\sum_{i=1}^{k} x_{ii} - \sum_{i=1}^{k}(x_{i+} \times x_{+1})}{N^2 - \sum_{i=1}^{k}(x_{i+} \times x_{+1})} \qquad (2.6)$$

= (Total ×Sum of correct) – Sum of all (row total × column total)
$(\text{Total})^2$ – Sum of all (row total × column total)

K= Kappa coefficient
$_K$= the number of rows (e.g. land-cover classes) in the matrix.
X_{ii} = the number of the observation in row *i* and column *j*

X_{i+} = the marginal totals for row *i*
X_{+I} = the marginal totals for column *j*
N = the total number of observations [(Ongsomwang 2007), (GIS & map library, 2013)].

2.7 REVIEW OF RELATED RESEARCHES

Van Ranst *et al.* (1996) pointed out that physical land suitability is a prime requisite for land use planning development, since it guides decisions on land utilization for optimal use and sustainability of land resources which contributes towards better land management, mitigation of land degradation and designing land use pattern that prevents environmental constraints through isolation of rival or alternative land uses. Making effective decisions regarding land suitability are vital to achieve optimum land productivity and ensure environmental sustainability (Oluwatosin, 2005; Teshome *et al.*, 2013).

There are several approaches to land suitability evaluation for which Van Lanen (1991) identified three general types. The first one is qualitative evaluation based mainly on expert judgment, where physical suitability is obtained by qualitative procedure. The FAO (1976) framework for land suitability evaluation is a typical example. The approach is presented in discretely ranked classes (e.g. S1, S2, S3, N1 and N2). This concept of FAO is mostly applied, and, although it is qualitative, it can be complemented and enhanced by more quantitative methods (Teshome and Verheye, 1995). The second type includes a qualitative evaluation based on parametric methods that assess the suitability of land on a continuous scale. The essentials of these methods can be expressed by a mathematical model. The third method is that based on process-oriented simulation models where land performance is related to individual land characteristics with their net effect assessed using a model of land function. These quantified methods usually require high data input, which make them more expensive.

However, of all the different approaches to land suitability evaluation, each has different data needs and different qualities of prediction (Nahusenay and Kibebew, 2015). The data requirement for any of the selected approaches for land evaluation depends on the criteria needed for the Multicriteria Evaluation (MCE) in a GIS environment.

To this end, a broadrange of criteria is required for performing effective landsuitability evaluation and an appropriate method is required to handle such wideheterogeneous criteria. Spatial Analytical Hierarchy Process (AHP) as a commonly used method of compensatory model is asuitable tool for this purpose. In general, one of the most important uses of GIS is the land use suitability mapping and analysis (Jafari and Zaredar, 2010).

In most of the cases seen in literatures and previous studies, the various criteria for grazing reserves or grazing land suitability assumed for livestock grazing range from models of forage production to water (accessibility, quantity and quality) and to soil erosion vulnerability (Arzani *et al.*, 2006; Amiri, 2008, 2009). Ayoubi and Alizadeh (2006) evaluated range suitability for livestock grazing qualitatively (plant access to moisture, saltiness and the amount of sodium, physical hampers against root expansion, range accessibility and water accessibility) and found that slope, moisture accessibility, outcrops and water accessibility were the limiting factors. Dvaran *et al.* (2009) analyzed goat production suitability in Turkey and explain that erosion, destruction of shoots and branches and forest degradation are the most important limiting factors. Amiri *et al.* (2008) assessed rangeland suitability for camel grazing and found that water accessibility, severe erosion and low forage production as the most effective factors on suitability. Arzani *et al.* (2006) studied sheep grazing suitability in four regions and found that slope, water accessibility and erosion mostly affected range suitability within

these regions. Oberlie and Bishop (2009) presented a model for cattle grazing suitability, including slope and water remoteness as the important factors. The Bureau of Land Management (BLM) Land Use Planning Handbook (BLM, 2005) identifies the following factors for consideration when determining availability of land for livestock grazing:

a. Other uses for the land;
b. Terrain characteristics;
c. Soil, vegetation, and watershed characteristics;
d. Presence of undesirable vegetation, including significant invasive weed infestations and
e. Presence of other resources that may require special management or protection, such as special status species, special recreation management areas or areas of critical environmental concern.

The geospatial analysis carried out on these criteria for land suitability mapping/analysis is usually done using MCE technique in a GIS environment or platform.

Studies have also shown that land suitability analysis is an important tool in making locational and siting decisions in planning studies. Broadly defined, land-use suitability analysis aims at identifying the most appropriate spatial pattern of future land use according to specified requirements, preferences, and predictors of specific activities. (Collins *et al.,* 2001 and Amiri *et al.,* 2012). A number of technological developments have facilitated the implementation of land evaluation principles and models. In order to incorporate the different land attributes that differ spatially and to identify the best suitable land use (grazing lands inclusive), GIS has proved to be the best tool. The

powerful query, analysis and integration mechanism of GIS makes it an ideal scientific tool to analyze data for land use planning (Terfa and Suryabhagavan, 2015).

Of the truth, Geographic Information Systems (GIS) has experienced rapid growth in recent years. GIS is a technology using a computer programme which aids in managerial, policy and development decisions, primarily by modelling suitability of land and forage resources for planning livestock grazing, taking system complexity into account (Amiri *et al.*, 2012). GIS technology is being increasingly employed by different users to create resource database and to arrive at appropriate solutions/strategies for sustainable development of rangelands (Venkataratnam, 2002). Today, GIS is a tool that can assist a community to plan and to support the information management during the grazing reserves establishment and development process, while at the same time ensures the proper balance between competing resource values. It can enhance the accessibility and flexibility of information and can improve the linkages and understanding of relationship between different types of information (Baniya, 2008).

Relevant literature has revealed that MCE can be used successfully as a technique to map out suitable sites for grazing. Terfa and Suryabhagavan (2015) carried out rangeland suitability evaluation for livestock production using remote sensing and GIS. The study analyzed and mapped suitable areas for livestock production in using remote sensing and GIS techniques. These researchers considered rainfall, land-use/land-cover, soil, slope, access to water, veterinary service and livestock market centre as criteria and made use of Landsat TM remote sensing satellite image for landuse/land-cover analysis, and Multi Criteria Evaluation (MCE) in IDRISI GIS environment to come up with the final suitability map. The map overlay procedure followed the conventional scheme for GIS based MCDA.

Similarly, Amiri *et al.* (2012) monitored land suitability for mixed livestock grazing using GIS. In the research, a suitability model for livestock grazing was derived from the combination of three suitability sub-models involving soil sensitivity to erosion, forage production suitability, and the suitability of the water resources. Arzani *et al.* (2006), Amiri (2009b) and Alizadeh *et al.* (2011) determined rangeland suitability for sheep and goats grazing using a livestock grazing model with the three components of forage production, water resources, and the soil sensitivity to erosion. Amiri *et al.* (2012) employed the same three measures, while also applying the FAO (1991) land suitability evaluation technique to determine the final livestock grazing suitability model for the rangelands.

There have been a lot of studies and researches carried out by scientist around the world on land suitability analysis to make decisions and proffer solutions. Pereira and Duckstein (1993) have used MCDA and raster GIS to evaluate a habitat for endangered species. Some other papers have focused on the technical aspects of combining GIS and MCDA (Jankowski, 1995). In 2000, Nisar Ahamed *et al.* conducted cropland suitability analysis using GIS-based fuzzy membership model. Results presented that maximum area is potentially suitable for groundnut growing. Sicat *et al.* (2005) modeled farmers' knowledge for land suitability classification. Malczewski (2006) conducted a research to incorporate the concept of fuzzy (linguistic) quantifiers into the GIS-based land suitability analysis. Shearer and Xiang (2009) conducted a land suitability assessment for a parkland banking program in North Carolina. They incorporated the synchronized voices into an assessment model to estimate which level of suitability best characterizes each parcel of land for a particular use. Msanya *et al.* (2001) also carried out land suitability evaluation for the production of food crops and extensive grazing in Wami plains of Tanzania. They concluded that the land suitability classification carried out in

their study can be used as a basis for the preparation and implementation of a land use plan in Wami plains. Lemessa (2011) in his thesis analyzed suitability of Yabello rangeland in Ethiopia for livestock production integrating GIS and Remote Sensing techniques with MCE.

In their research, Jafari and Zaredar (2010) noted that land suitability analysis is very important in that, nowadays there are formidable challenges facing decision makers in order to embark on rangeland management. In their work, they aimed to examine a relatively new method of multi criteria evaluation by using spatial analytical hierarchy method for determining the most suitable areas for rangelands in Taleghan basin of Iran. Results indicated that the spatial analytical hierarchy process is a powerful support system resolving different uses of land suitability issues in the region (Jafari and Zaredar, 2010).

2.7.1 Gaps Identified

a. In the review of some related works (Amiri et al., 2012; Amiri, 2008, 2009; Arzani et al., 2006;Ayoubi and Alizadeh, 2006; Dvaran et al., 2009; Oberlie and Bishop, 2009), it was discovered in some of the researches that fewer factors were utilized in the overall suitability analysis for siting grazing reserves/rangeland. In adapting the suitability of a land for establishing grazing reserves, due consideration should be given to the climatic conditions, vegetation, soil, the status of the current utilization, and topography. Therefore, recognizing the factors effective in grazing suitability model and determining the amount of limitations they impose is important for analyzing and assessing the grazing land/rangeland (a term used interchangeably in some literature) or grazing reserves.

b. The researches reviewed were mostly done covering a relatively small study area unlike this study which covers an extensive area of about 150,000 sq.km. Choosing and applying factors for the suitability analysis becomes easier with smaller areas than a large study areas as utilized in this study.

c. Suitability analysis using Boolean logic and relational database linkages as carried out by Boateng (2005) have been found to be inaccurate and fairly cumbersome process. To curb this excesses, the Multicriteria evaluation using fuzzy logic ad Analytic Hierarchy Process (AHP) with weighted linear combination was used in this research. This yield a more accurate result than the Boolean logic means of selecting criteria for suitability analysis.

CHAPTER THREE

METHODOLOGY

3.0 OVERVIEW

The various procedures used in this research to arrive at the final suitability mapping result include: the collection of various datasets relevant to the analysis to be carried out,

these datasets were then prepared for better interpretation. These steps include: rasterization, vectorization, interpolation of specific point data, radiometric correction of satellite imagery, mosaicking, subsetting etc. Geospatial analysis was then carried out, a procedure in which criteria were selected and standardized. MCE was afterwards carried out to produce the final suitability map. The steps are summarily depicted in the organogram below.

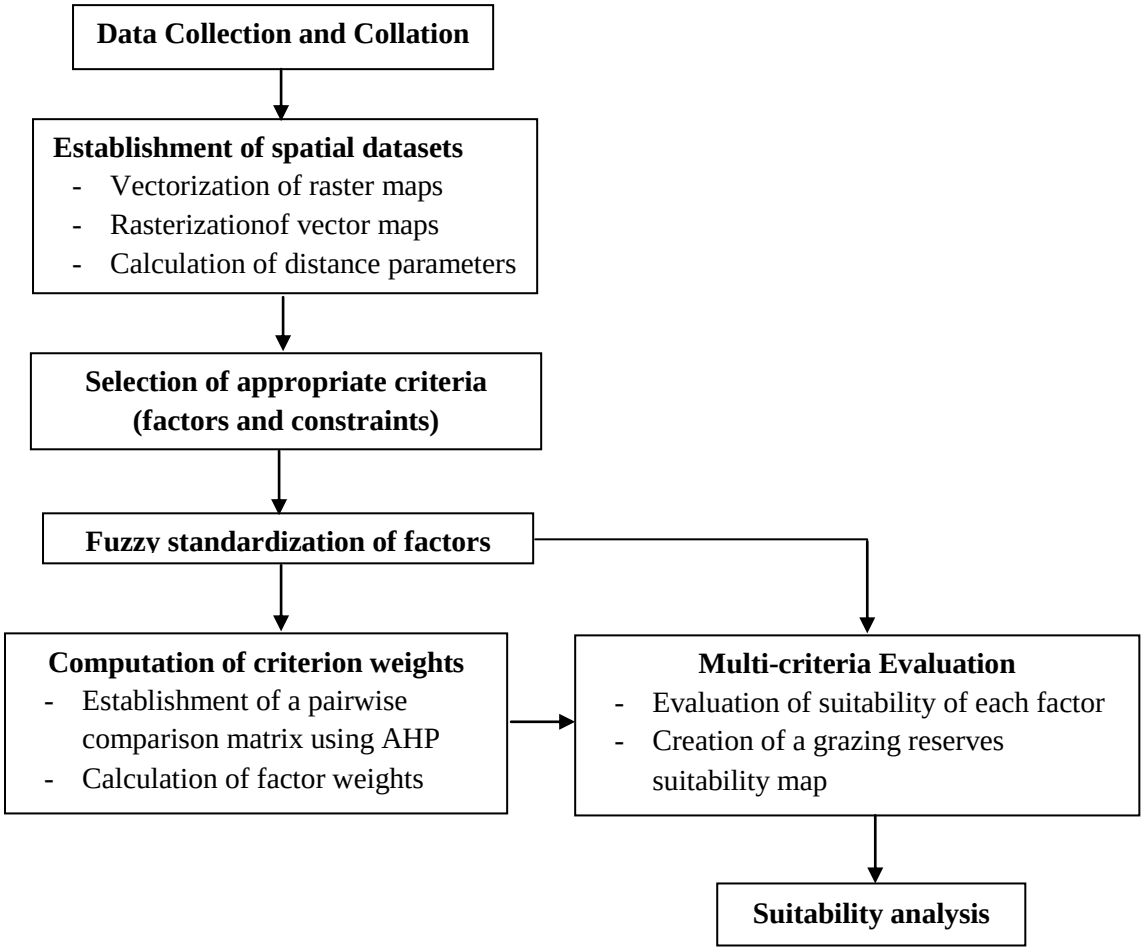


Figure 3-1: A chart for the GIS-based Multi-criteria analysis for grazing reserves

3.1 DATA COLLECTION

The data used in this thesis can be broadly divided into two categories: Remotely sensed (satellite) imagery and GIS datasets (which consists of data derived from remote sensing

and/or other secondary sources). These data were collected from various sources as tabulated summarily in Table 3.1.

Table 3.1: Detailed description of datasets used in this study

Data	Source	Scale/Resolution	Acquisition date	Description	Purpose/Usage
Landsat 8 Satellite Imagery	http://earthexplorer.usgs.gov	30 meters spatial resolution except band 8 (panchromatic) with 15 meters resolution.	June – November 2013	11 bands multispectral image data acquired by both the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) onboard the Landsat 8 satellite.	Land cover mapping.
SRTM	http://earthexplorer.usgs.gov/, http://dds.cr.usgs.gov/ltaauth//hsm/lta1/srtm_v2/tif/3arcsec/e007/n09_e007_3arc_v2.tif?id=q98ca00gs2o9okh1npr0132bc0&iid=SRTM3N09E007V2&did=119497227&ver=production	3 arc-seconds (approximately 90 meters) spatial resolution.	October 2012	A raster Digital Elevation Model (DEM) with global coverage.	Terrain modelling.
Administrative Map	http://www.gadm.org/		January 2012	A map showing political boundaries of Nigeria, its states and local government	Boundary demarcation.

				areas.	
Protected/Conserved areas	http://www.protectedplanet.net/download.shp?q=nigeria&type=all, http://wcmc.io/wdpa_current_release		January 2015	Terrestrial, freshwater or marine areas that are recognized dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values. This includes, for example, national parks and nature reserves.	Locating existing conserved areas and subsequent usage a criteria.
Road Network	http://www.diva-gis.org/datadown	1:1,000,000 (approx.)	2010	A global data of road networks.	Suitability mapping criteria.
Inland Waters	http://data.biogeo.ucdavis.edu/data/diva/wat/NGA_wat.zip	-	-	Vector dataset containing rivers, streams, lakes, dams etc.	Suitability mapping criteria.
Temperature	http://apps.ecmwf.int/datasets/data/interim-full-daily/	0.125 decimal degrees spacing in longitude and	2013	Gridded point data containing	Suitability mapping criteria.

		latitude.		interpolated mean daily temperature in Kelvin.	
Precipitation	http://apps.ecmwf.int/datasets/data/interim-full-daily/	0.125 decimal degrees spacing in longitude and latitude.	2013	Gridded point data containing interpolated mean daily precipitation in millimeters (mm).	Suitability mapping criteria.

The Landsat 8 satellite imageries were used for the classification of land cover types in the study area from which some factors were extracted for the suitability mapping. The STRM DEM was used to calculate the slope map of the study area which was subsequently used as a criteria for the MCE. The temperature and precipitation data served as biophysical (climatic) factors used in subsequent analysis in the course of the work. The boundary of the study area was digitized from the administrative map of the study area and the digitized boundary was used to subset for the Local Government Areas (LGAs) within the study area. The digitized boundary vector was subsequently used to subset all other datasets to fit within the study area. The administrative map was used to extract the boundary of the study area and the Local Government Areas (LGAs) within them while the roads network dataset served the purpose of the socioeconomic factor for the Multicriteria Evaluation. Euclidean distances were calculated from the water (rivers, streams, lakes and dams) data and the protected areas, thus serving as biophysical and environmental factors for the suitability analysis.

3.2 SOFTWARE AND HARDWARE

Avariety ofRemoteSensing and GIS softwarewereusedincombinationfortheprocessing andanalysisofthedata for this study. ERDAS Imagine (versions 9.2 and 2014), ENVI 5.1, IDRISI Selva (v17), ArcGIS 10.1 and Microsoft Office 2013 Suite were the software used in this study. ERDAS Imagine (v9.2 and 2014) and ENVI 5.1 were used for the remote sensing image pre-processing, enhancement, image classification and accuracy assessment. GIS analysis was executed using IDRISI Selva and ArcGIS 10.1. Microsoft Office Word 2013 was used for word processing and typesetting while Microsoft Excel 2013 was used for data analysis and presentation in the form of graphs and charts.

In addition to the software, hardware was also utilized in the course of this research. A laptop computer with the following specification, served as the platform on which all the software mentioned above were run: A HP 15 notebook PC with Intel(R), Pentium(R), CPU N3520 2.16GHz processor. A HP LaserJet 1320 printer was also utilized as an output device for hardcopy printouts.

3.3 DATA PREPARATION

The various datasets collected in their raw format were processed for better interpretation of the data and to meet the specification for further usage and subsequent analysis.

3.3.1 The Landsat 8 Imagery

The Landsat 8 satellite images the entire Earth every 16 days in an 8-day offset from Landsat 7. Data collected by the instruments onboard the satellite are available to download at no charge from GloVis, EarthExplorer, or via the LandsatLook Viewer platforms of USGS within 24 hours of reception. Landsat 8 carries two instruments: The Operational Land Imager (OLI) sensor includes refined heritage bands, along with three new bands: a deep blue band for coastal/aerosol studies, a shortwave infrared band for cirrus detection, and a Quality Assessment band while the Thermal Infrared Sensor (TIRS) provides two thermal bands (bands 10 and 11). Landsat 8 images/products are delivered as 16-bit images (scaled to 55,000 grey levels). The figure below illustrates some of the striking differences between Landsat 7 and Landsat 8 products.

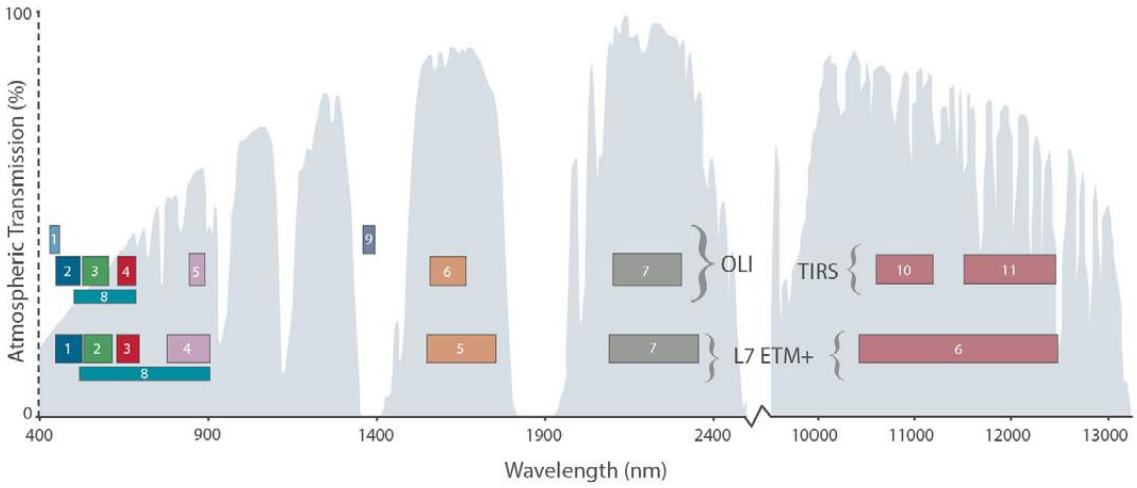


Figure 3-2: Differences in wavelengths of bands in Landsat 8 and Landsat 7 data. Source: (USGS, 2013).

Landsat 8 images have a large file size, at approximately 1 GB compressed. Landsat 8 data products are consistent with the all standard Level-1 (orthorectified) data products created using Landsat 1 to Landsat 7 data to the following specifications:

Processing:	**Level 1 T- Terrain Corrected**
Pixel Size:	OLI multispectral bands 1-7,9: 30-meters OLI panchromatic band 8: 15-meters TIRS bands 10-11: collected at 100 meters but resampled to 30 meters to match OLI multispectral bands
Data Characteristics:	• GeoTIFF data format • Cubic Convolution (CC) resampling • North Up (MAP) orientation • Universal Transverse Mercator (UTM) map projection (Polar Stereographic projection for scenes with a center latitude greater than or equal to -63.0 degrees) • World Geodetic System (WGS) 84 datum • 12 meter circular error, 90% confidence global accuracy for OLI • 41 meter circular error, 90% confidence global accuracy for TIRS

	• 16-bit pixel values
Data Delivery:	.tar.gz compressed file via HTTP Download
File size:	Approximately 1 GB (compressed), approximately 2 GB (uncompressed)

3.3.2 Landsat 8 Satellite Image Processing

Cloud free Landsat 8 OLI/TIRSimageries (path: 188-191, row: 52-54)that were acquired for dates between June 2013 to November 2013 were prepared and analyzedtoclassifythelanduse/landcoverofthestudyarea.Themosaicsofthe11scenes coveringthe whole extent of the studyarea was prepared in ERDAS Imagine. Landsat 8data has 11 bands. Bands 1 – 7 were utilized in this study while band 8 (panchromatic), band 9 and TIRS bands 10 and 11were not utilized inthe analysis.

3.3.2.1 Satellite Image pre-processing

Pre-processing operations are sometimes referred to as image restoration and rectification, are intendedtocorrectforsensorandplatform-specificradiometricandgeometricdistortionsofdata (Lillesand and Kiefer, 2004).Hence,theimagesusedforthepresentstudyweresubjecttoprocedures to correct for radiometric distortions.

3.3.2.2 Radiometric Corrections

Dealing with multi-date image dataset requires that images obtained at different times of the year are comparable in terms of radiometric characteristics. Radiometriccorrections thus becomesnecessarydueto variationsinscene illuminationandviewing geometry,atmosphericconditions,andsensornoiseandresponse(Lillesand and Kiefer,

2004).Each ofthesewillvarydependingonthespecificsensorandplatform usedtoacquirethedataandthe conditionsduringthedataacquisition.

In this study, image enhancement techniques such as radiometric correction and calibration were applied to the multi-dated satellite images using ENVI 5.1 software "Radiometric Calibration" tool in order to increase visual discriminations between features and increase the amount of information to improve interpretability. This involved the conversion of pixel Digital numbers (DN) to Reflectance values in all the satellite imageries. ENVI 5.1 automatically layer stacks the imported satellite imagery bands for each scene before the radiometric correction is executed.

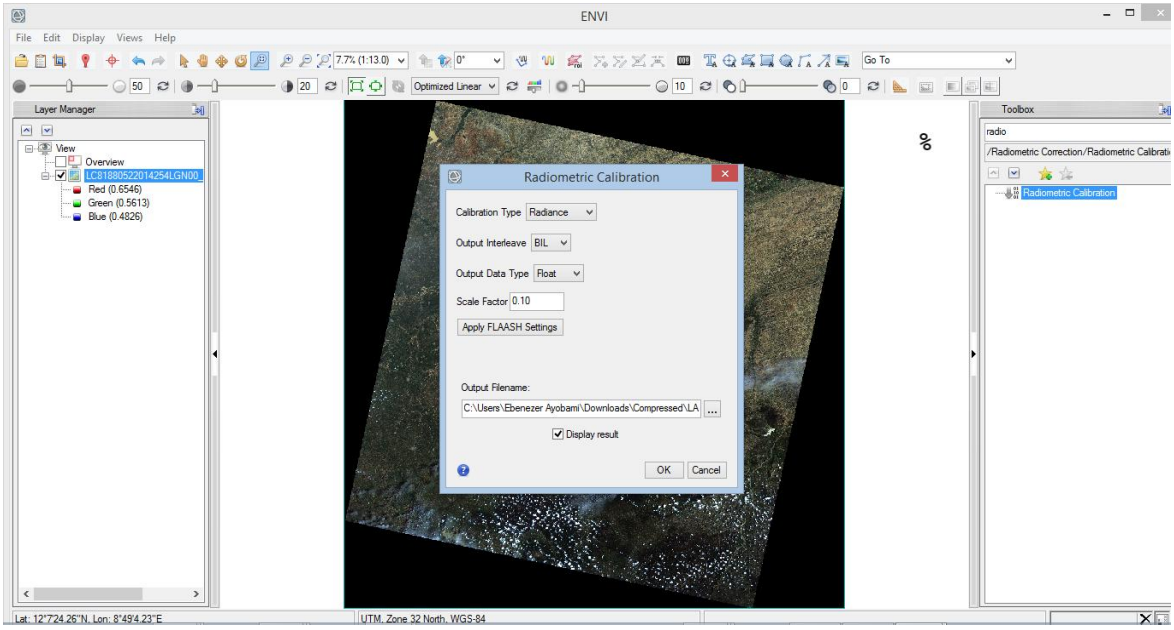


Figure 3-3: Radiometric calibration of imagery in ENVI software

3.3.2.3 Algorithm for Radiometric Calibration of Landsat 8 Imagery

Landsat 8 product data can be converted to Top of atmosphere (ToA) Radiance or Reflectance using rescaling factors and parameters found in the metadata file (MTL.txt) provided with the data.

This is a two-step process. First, Digital Numbers (DNs) are converted to radiance values, then the radiance values are converted to reflectance values. For each scene it is important to know the distance between the sun and earth in astronomical units, the day of the year (Julian date), and solar zenith angle.

1. DN to Radiance

There are two formulas that can be used to convert DNs to radiance; the method used depends on the scene calibration data available in the header file(s). One method uses the **Gain** and **Bias** (or Offset) values from the header file. The other method uses the $\mathbf{L_{min}}$and $\mathbf{L_{max}}$spectral radiance scaling factors

Gain and Bias Method

The formula to convert DN to radiance using gain and bias values is:

$$L_\lambda = M_L Q_{cal} + A_L \quad (3.1)$$

where:

L_λ = ToA spectral radiance (Watts/(m^2 × srad × μm))

M_L = Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number)

A_L = Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number)

Q_{cal} = Quantized and calibrated standard product pixel values (DN). (USGS, 2013)

2. Radiance to ToA Reflectance

Operational Land Imager (OLI) band data can also be converted to ToA planetary reflectance using reflectance rescaling coefficients provided in the product metadata file

(MTL file). The following equation is used to convert DN values to ToA reflectance for Operational Land Imager (OLI) data as follows:

$$\rho\lambda' = M_\rho Q_{cal} + A_\rho \quad (3.2)$$

Where:

$\rho\lambda'$ = ToA planetary reflectance, without correction for solar angle. Note that $\rho\lambda'$ does not contain a correction for the sun angle.

M_ρ = Band-specific multiplicative rescaling factor from the metadata

(REFLECTANCE_MULT_BAND_x, where x is the band number)

A_ρ = Band-specific additive rescaling factor from the metadata

(REFLECTANCE_ADD_BAND_x, where x is the band number)

Q_{cal} = Quantized and calibrated standard product pixel values (DN). (USGS, 2013)

3.3.3 Mosaicking

Mosaicking is the seamless joining or stitching of adjacent imagery. Joining Landsat imagery that was collected along the same satellite path (one image taken after the other) is straightforward: with very little time elapsing between imagery collection, the atmosphere and sensor properties do not change (that much). However, when collecting adjacent imagery from differentsatellite paths, several days may have passed, resulting in radiometric differences in the sensed imageries. As such, there is a need to adjust the radiometric differences between the images in an effort to make the joining appear seamless. It is important to note that mosaicking is not a perfectly clean process: it often requires additional image processing to remove some of the 'noise' near the stitch.

The images were mosaicked using the MosaicPro tool in ERDAS Imagine and reprojected from the default UTM Coordinate System to Geographic Coordinates

System (GCS_WGS 84). This was to eliminate the error associated with zones crossing in some of the satellite imageries. Some lie within UTM zone 31 while others were within UTM zone 32. The mosaicking process interface is shown in Figure 3-4.

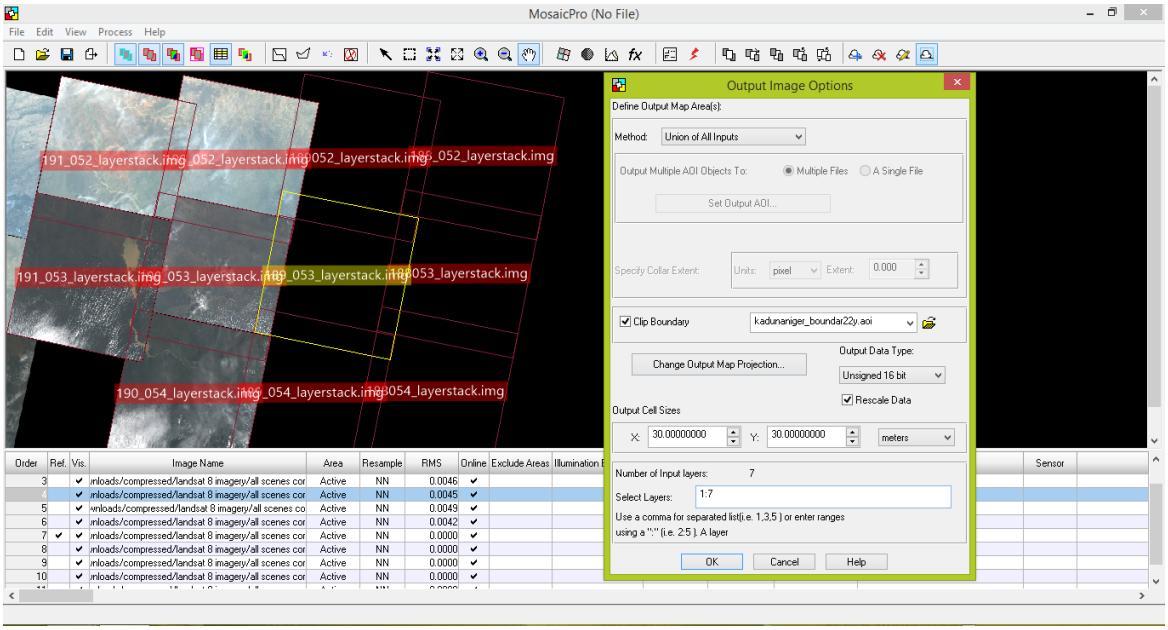


Figure 3-4: Mosaicking of satellite imagery scenes using Erdas Imagine MosaicPro

Having been mosaicked, the imagery was further subjected to sub-setting to fit the study area using ERDAS IMAGINE 2014. The subsetting was carried out using the Area of Interest (AOI) tool. An AOI file was created using the digitized boundary vector of the study area. This AOI file was then used to subset the mosaicked scenes of the Landsat 8 satellite imagery.

3.3.4 Image Classification

Image classification serves a specific goal, that is: converting image data into thematic data. The resultingclassifiedimageiscomposedofamosaicofpixels,eachofwhichbelongto aparticular theme or class,andisessentially athematicmapoftheoriginalimage.Thematiccharacteristicssuchas land use/land cover can be used for further analysis and input into GIS based models. Furthermore,

imageclassificationcanalsobeconsideredasdatareduction:the*n*multi-spectralbandsresultin asinglebandrasterfile.

3.3.4.1 Supervised Classification

A false colour composite using bands 7, 5 and 3 was used for the supervised classification of the area under study. This combination provides a "natural-like" rendition, while also penetrating atmospheric particles and smoke. Healthy vegetation appeared as bright green and can saturate in seasons of heavy growth, grasslands appeared as green, pink areas represent barren soil, oranges and browns represent sparsely vegetated areas. Dry vegetation was orange and water showed as blue. Sands, soils and minerals are highlighted in a multitude of colours. Built-up areas appeared in varying shades of magenta while grasslands appeared as light green. With this band combination, olive-green to bright-green hues normally indicate forested areas with coniferous forest being darker green than deciduous.

The mosaicked Landsat 8 imagery was classified in ArcGIS 10.1 to extract land cover classes using the Maximum Likelihood Classifier supervised classification technique. Supervised classification uses the spectral signatures obtained from training samples to classify an image. With the assistance of the Image Classification toolbar in ArcGIS, training samples were created to represent the classes to be extracted from the imagery. After which a signature file was created from the training samples which was then used by the multivariate classification tools to classify the image.

The Imagery was classified into 10 classes. Some of these classes were extracted to create factors which were subsequently used for the suitability analysis in IDRISI.

3.3.4.2 Accuracy Assessment

For the purpose of accuracy assessment in this study, reference pixels were generated using stratified random distribution process in the classified image. As discussed in the preceding chapter, it has been found that the stratified random sampling method offers a huge advantage over simple random and systematic sampling methods, especially when assessing a change map as it allows us to target small map categories. (Maps & GIS library, 2013) stated that the rule of thumb in creating the total sample of reference pixels is to create ten (10) times the total number of classes in the classified image. In this case, the image was classified in to 10 classes. Therefore, the number of sample reference pixels per class will be $(10 \times 10) = 100$ reference pixels for each class.

Google earth satellite image of the study area and the mosaicked Landsat imagery were used as reference for ground truthing. The Landsat imagery of the study area was sampled by the stratified random sampling method, with each class represented by a stratum. This was executed in ArcGIS. A point shapefile was created and one hundred (100) reference points were generated for each class, resulting in a total of 1000 sample points. It should be noted that when placing the points on the base image, temptation of viewing the classified image should be avoided as it could bring bias into the reference points and this in turn can affect the accuracy assessment at large.

In ArcGIS, two fields were created in the attribute table of the reference points, namely: land-cover (text) and class (short integer). The base image was used to find the land-cover types of the reference points and number codes were entered for each class corresponding to the class code of the classified imagery. The points were then converted to raster and the converted raster and the classified image were further combined to form a table. The error matrix was finally generated by using the pivot table

tool in spatial analyst toolbox. An error matrix is a table of values that compares the value assigned during the classification process to the actual value from the image. The computations for descriptive evaluation of the error matrix (error of omission, commission etc.) and discrete multivariate analytical technique (Kappa coefficient) were achieved in Microsoft Excel environment.

From the error matrix, the overall classification accuracy was computed by dividing the total number of the correctly classified pixels of each class (values along the matrix diagonal) by the total number of classified pixels of all the classes. Kappa statistic considers a measure of overall accuracy of image classification and individual category accuracy as a means of actual agreement between classification and observation.

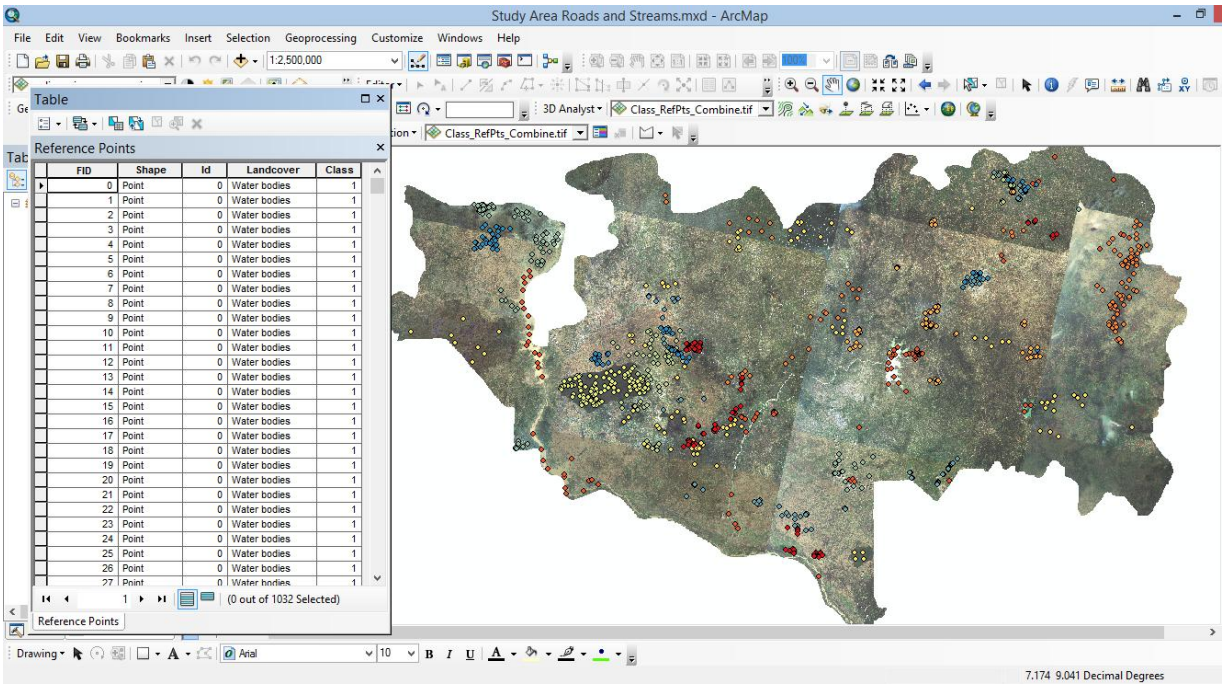


Figure 3-5: A stratified random sampling distribution of reference points for accuracy assessment in ArcMap. Source: (Author's lab work).

3.3.5 Preparation and Selection of Criteria

The other datasets were also subjected to processing to suit the need or requirement of the suitability mapping. The prerequisite of land suitability mapping is the selection of the influencing factors since there are too many factors affecting the land suitability. The selection of influencing factors should also consider the objective of suitability assessment. The number of influencing factors is flexible based on the environment of the study area and the aim of the assessment.

Land suitability assessment is a multiple criteria evaluation process. The attributes of land suitability criteria are to be derived from spatial and non-spatial, qualitative and quantitative information under diverse conditions (Chen *et al*., 2010). In land suitability analysis, each evaluation criterion is represented by a separate map in which a 'degree of suitability' with respect to that particular criterion is ascribed to each unit of area. These 'degrees of suitability' then need to be rated according to the relative importance of the contribution made by that particular criterion, towards achieving the ultimate objective.

In this study, criteria namely: distance from water, distance from roads, distance from croplands, distance from wetlands, distance from protected areas, forests, land use, grasslands, precipitation, temperature and slope were selected as factors whereas, rocks and built-up areas within the study area were chosen to serve as constraints. These criteria were chosen based on the consideration of literature inputs and data availability.

The effective criteria prepared from raw datasets and selected in this study for land suitability for grazing reserves are explained below with their importance also mentioned briefly.

3.3.5.1 Temperature

Daily temperature data for the year 2013 was downloaded for 1305 grid points covering the area of study area at 0.125 decimal degrees spacing in longitude and latitude, from the European Centre for Medium-Range Weather Forecasts (ECMWF) database.

The monthly means of the temperature for these grid points was computed in Microsoft Excel and these readings were interpolated to 65000 randomly selected points within the study area by Kriging interpolation method using a modified Surfer™ interpolation script (as shown in APPENDIX III) in Golden Software's Scripter™, thus giving approximate temperature readings for the 65,000 points including their latitude-longitude (LATLON) coordinate values. The interpolation interface in Scripter™ is shown below.

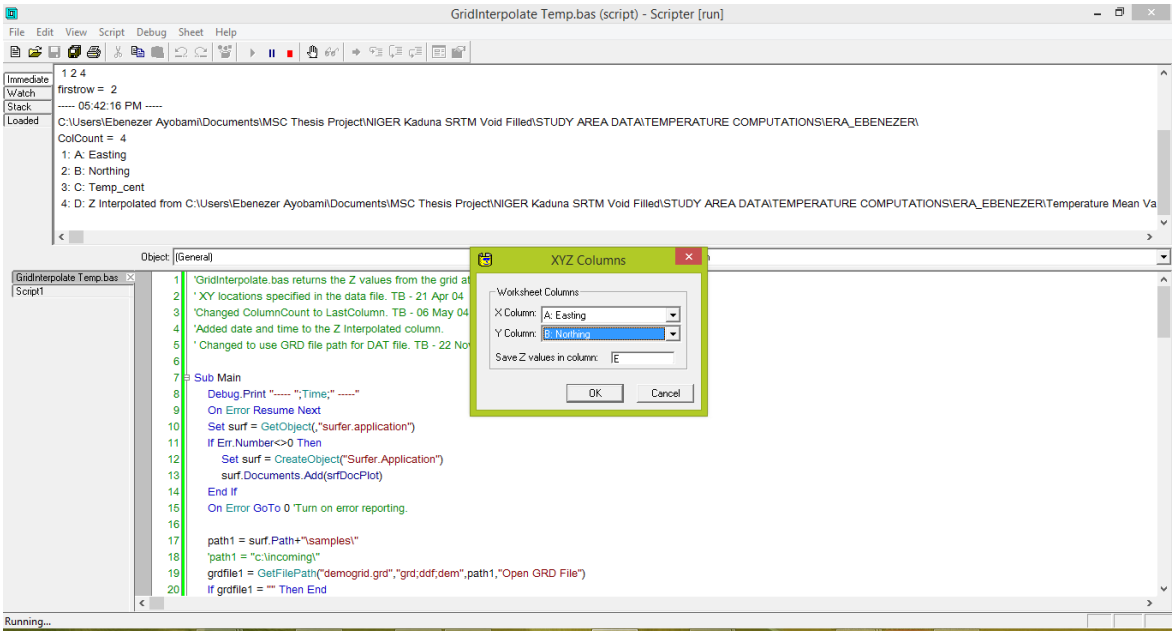


Figure 3-6: The interpolation of mean temperature using Scripter

The resulting table was imported into ArcGIS and was used to create a point map in ArcGIS and further interpolated by Kriging to produce a temperature raster surface for the study area. This procedure was used to produce the temperature map of the study area. The original temperature data was in GCS_WGS 84 coordinate system.

Temperature is another important climatic factor selected for this land suitability mapping. Temperature causes stress to animals in hot, warm and very cool climates. Heat to the body comes mainly from outside and from the metabolism within the body metabolic heat. It costs energy to get rid of excess heat and to maintain the body temperature. When body temperature is high appetite is lost, resulting in a negative energy balance and sometimes resulting in heart collapses. High surrounding temperature decreases feed intake more in some cattle (Abule, 2009). A term often found in literature is "the comfort zone ", that means the environment in which livestock thrive best. A high day temperature can be compensated by a cool night. Temperature creates real problem when the mean monthly temperature exceeds 24^{o}C for 5 months or more. All these were taken into consideration in this study.

3.3.5.2 Rainfall

Daily precipitation data for the year 2013 was downloaded for 1485 grid points covering the entire area of study area at 0.125 decimal degrees spacing in longitude and latitude. The total annual rainfall for each grid point was computed and interpolated to 65000 random points selected from the study area just as it was done for the temperature data. Kriging interpolation was used to create a raster surface in ArcGIS which served as the rainfall map. The values for annual rainfall of the area under study ranges from 277.95mm – 1114.30mm.

Rainfall is very important in grazing reserves site selection, as it controls the plant growing seasons and affects the availability of drinking water. Rainfall is also among factors affecting the growth of forage plants on grazing lands. It is important that there is enough rainfall for grasses or forage on grazing land to grow properly and in abundance.

Usually, an annual rainfall of a range of 300 - 800mm is considered suitable for growing forage on grazing reserves (FAO, 1991).

3.3.5.3 Slope

The downloaded SRTM DEM tiles were mosaicked in ArcGIS using 'Mosaic to new raster' data management tool. The resulting raster was further subset using the study area boundary vector with the aid of the 'clip' tool. Having clipped the SRTM, a percentage slope map was generated using the 'Slope' spatial analyst tool in ArcGIS.

Slope is a very important factor for land suitability analysis of rangeland. Places with high slope (more than 30%), is not very suitable for livestock grazing due to being impassable. Rugged topography is one of the most important causes of poor livestock distribution on rangelands. The reluctance of livestock to use steep slopes is not entirely undesirable, since these areas are often fragile and valley bottoms can better withstand grazing (Lemmessa, 2011). However, in many cases slopes serve as barriers to the use of benches and ridge tops above valley bottoms. According to Abule (2009), the different slope categories are 0-2% (flat), 2-5% (gentle undulating), 5-8% (undulating), 8-15% (rolling), 15-30% (moderately suitable), 30-60% (steep) and greater than 60% (very steep). Livestock vary considerable in their willingness to use steep terrain. Large, heavy animals such as mature cattle or camels have difficulty in traversing steep, rocky slopes. Therefore, these animals make little use of slopes with more than a 10% gradient. Sheep and goats use these areas more readily because of their small size, greater agility, and surefootedness. (Lemmessa, 2011).

3.3.5.4 Road Network Map

The road network data collected is a global dataset therefore, the road data was re-processed in ArcGIS and clipped to extract roads within the study area.

Road is also an important criterion in this site suitability mapping because of the need to transport animals and their products from the reserves to markets around or within the settlements. Construction of new road is expensive especially in hilly regions. Therefore, this criterion was selected as a socioeconomic factor, as effort is being made to locate the grazing reserves closer to existing roads.

3.3.5.5 Water Resources Map

Just like the road network map, the same procedures were adopted as the inland waters dataset was imported into ArcGIS as a data layer and was re-edited and clipped to create the water resources map of the study area.

All animals require drinking water to be available at some time. Places are suitable for grazing land where in addition of having biophysical factors should not be far away from water sources such as streams, rivers, lakes, dams etc. Animals should have easy access to water for their survival and also for growth of forage. Water is very essential for plants and livestock.

Animals obtain water directly from their food, and indirectly by metabolic processes. The need to drink additional water depends particularly on the air temperature, with high temperatures increasing the need to replace water lost from the body, and on the class of animal, with lactating and young animals requiring more water more frequently (FAO, 1991).

3.3.5.6 Protected Areas

The January 2015 version of the World Database on Protected Areas (WDPA) data was used in this study. This data included all the shape and attribute files for designated nationally protected areas and areas defined under international conventions and agreements. The protected areas shapefile was also edited and clipped in ArcGIS as was done to the roads and water resources maps, to create a final output map.

It is expedient that grazing reserves be established in areas not too far away from these protected areas as set aside by the United Nations Environmental Programme (UNEP). Moreover, some of these protected areas have been set aside as reserves and parks. For this study, it was assumed that these grazing reserves should be located within 6km of a protected area.

3.3.5.7 Proximity to Grasslands, Forests and Wetlands

The maps of Grasslands, forests and wetlands were extracted in IDRISI from the classified Landsat 8 imagery using the BREAKOUT module. These maps are shown in APPENDIX IV. A very important requirement for the survival of livestock especially cattle, sheep and goat, is the availability of grass or forage for consumption. The grazing reserves must be sited on grasslands or not far away from grasslands and forests as well. It is very possible to have grasses or short shrubs growing around forest boundaries which will be beneficial to the herdsmen and their herds.

Wetlands are areas where sumptuous grass can be found all year round for cattle. Areas close to wetlands will be suitable for siting grazing reserves due to the availability of feeding resources.

3.3.5.8 Land Uses

The classified Landsat 8 imagery served as the land use criteria used for the suitability mapping. Grazing reserves sites are usually in conflict with urban development and agricultural lands but compatible with forestry and grasslands. Land cover map of Kaduna and Niger state in this study was categorized as follows: wetlands, croplands, forests, built-up areas, water bodies, grasslands, bare surface, rocks and scanty vegetation. In this study, built up areas and croplands are not suitable for siting grazing lands while grasslands and forests are considered as suitable. The land cover map was reclassed in IDRISI (as shown in Figure 3-7) to the byte scale with suitability of classes decreasing from 255 to 0.

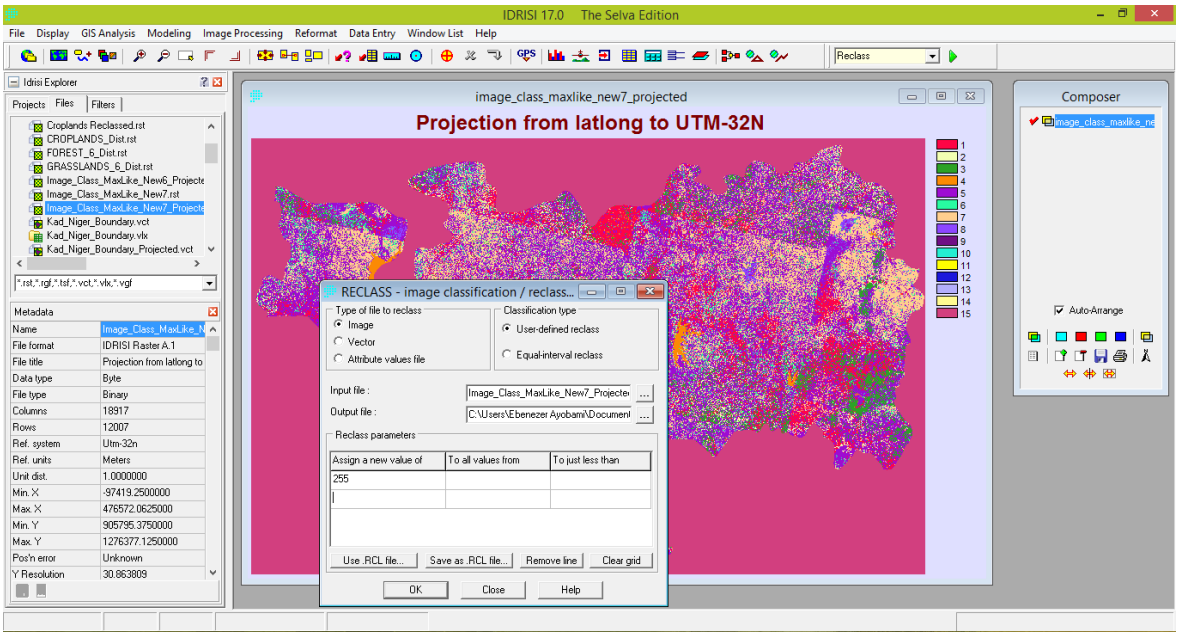


Figure 3-7: IDRISI interface during the reclassification of land cover image.

Grassland has the highest suitability of 255 with built-up areas with the lowest suitability of 0. The evaluation criteria (factors and constraints) are listed in Table 3.2.

Table 3.2: The full set of criteria for potential grazing reserves land suitability mapping in this study(Source: author's research)

Criteria		Description
Biophysical Factors	Slope	Slope is one of the basic parameter for land suitability assessment. The slope map is derived from DEM.
	Temperature	High temperatures affect livestock negatively while medium to low temperature is suitable for them.
	Rainfall	Moisture availability is important for plant growth and it contributes to availability of water in rivers, streams and dams.
	Land Cover	Various land uses have varying level of suitability for siting grazing reserves. Grasslands with highest suitability while rocks and developed land has lowest suitability.
	Distance from water sources (streams, rivers, lakes, dams)	The proximity to the water area is an indispensable parameter for the siting of grazing reserves. Animals essentially need water to survive.
	Distance from grasslands	Food for livestock is usually in abundance on grasslands. Thus, the need to establish grazing

		reserves closeby.
	Distance from forests	These are protected areas as well but can be useful for siting reserves as moisture is available and hence, growth of forage around forested areas.
	Distance from wetlands	Here, ever green forage can be found for livestock. It is wisdom to site grazing reserves close to these lands.
Socioeconomic factor	Proximity to roads	This part includes both the primary and secondary transportation network. It can aid transportation of livestock and products to and from markets.
Environmental factor	Proximity from Protected areas	These are areas set aside for special purposes by the United Nations. Grazing lands can be sited on or close to these areas.
Constraints	Rocks	These are hard, stony surfaces on which developing a grazing land and growing of forage is almost impossible.
	Built-up areas	These are populated areas or settlements. Grazing reserves should not be located within such areas but at the same time, not too far away.

3.3.6 Creation of Distance/Proximity Maps

Each of the datasets prepared (as discussed in the preceding sections) were imported into IDRISI in raster or vector formats for further analysis. This includes the road map, the rivers, classified imagery, protected areas, administrative map and the SRTM DEM. When importing the datasets, IDIRISI converts datasets with other formats into IDRISI format with .rst extension for rasters and .vct for vector files.

To separate the various classes in the classified imagery into single independent imagery, the BREAKOUT module was run. BREAKOUT creates Boolean images for all

categories or classes in an image or vector file in IDRISI. Each class image was then renamed as a separate image for further processing in the software environment. Upon successful importing of all variables into IDRISI, the vector files had to be converted into raster files before the distance maps could be created. The RASTERVECTOR module was used to achieve this. Figure 3-8 shows this operation as executed in IDRISI.

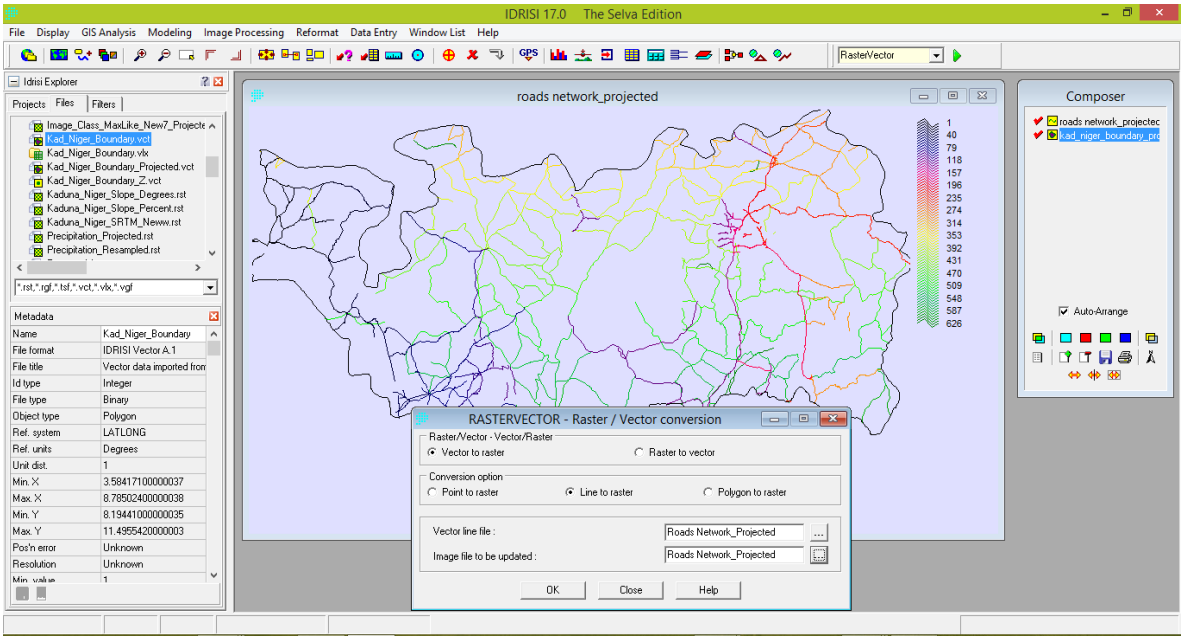


Figure 3-8: Vector to raster conversion interface in IDRISI.

It is of note that all the datasets were projected to UTM coordinate system for the possibility of measurements. This aided the creation of the distance maps whose units were in meters.

The DISTANCE module in IDRISI Selva software package creates a raster image which measures the Euclidean distance (as the crow flies) between each cell and the nearest, of a set of target features. These procedures were followed to create distance maps for the roads, rivers, streams, other water bodies, settlements, croplands, wetlands, protected areas etc.

3.4 GEOSPATIAL ANALYSIS

3.4.1 Standardization of Criteria (Factors and Constraints)

The process of setting the relative importance of each criterion is known as the standardization of criteria. Since the various factors chosen are in different units of measurements, for example: slope (in percent), distance maps (in meters) and constraints (no units), there is need to standardize all of these criteria. In this process scales of 0 to 1 or 0 to 255 are normally used for criteria standardization. A pairwise comparison technique is typically used for rating and standardizing the ordinal values. This technique is an extension of the classic binary logic, with the possibility of defining sets without sharp boundaries and allowing for partial assignation of elements to a particular set. A fuzzy set is essentially a set whose members may have degrees of membership between 0 and 1, as opposed to a classic binary or Boolean set in which each element must have either the value 0 or 1 as their membership degree (Malczewski, 2004).

In this particular land suitability analysis for potential sites for grazing reserves, the various criteria were represented by GIS dataset raster layers. Each criteria was subsequently standardized using the fuzzy factor standardization. This was executed using IDRISI GIS application. Each factor was standardized to a byte scale of 0 to 255 using the FUZZY module in the software, before weighting and subsequent overlay operations were carried out. In fuzzy standardization, the suitability of each factor increases as the areas get closer to the value of 255 and 0 represents unsuitability of a factor. APPENDIX IV displays the standardized criteria maps of the study area.

Each factor was standardized based on a range of values for suitability or unsuitability for the siting of grazing reserves. Most of these range of values were based on FAO standard and as obtained from other relevant literatures, though some were slightly

modified based on the knowledge of the terrain and the area under study. These factors are shown in Table 3.3.

Table 3.3: Suitability rating of each evaluation criteria used. Source: (Adapted and modified from FAO, 1991; Abule, 2009; Lemmessa, 2011)

Factors	**Suitability Classes**			
	S1	**S2**	**S3**	**N**
Slope (in percent %)	0-10	10-30	30-40	≥ 40
Temperature (^{o}C)	15 – 20	20 – 30	30 – 35	≥ 35
Rainfall (mm)	≥ 800	500 – 800	300 – 500	0 – 300
Distance from water sources (streams, rivers, lakes, dams) (km)	0 – 3	3 – 4.8	4.8 – 6	≥ 6
Distance from grasslands (km)	0 – 0.5	0.5 – 1	1 – 2	≥ 2
Distance from forests (km)	0 – 0.5	0.5 – 1	1 – 2	≥ 2
Distance from wetlands (km)	0 – 1	1 – 2	2 – 3	≥ 3
Proximity to roads (km)	1 – 2	2 – 4	4 – 6	≥ 6
Proximity from Protected areas (km)	0 – 2	2 – 4	4 – 6	≥ 6

3.4.2 Assessing the Criteria weights through AHP

Through a pairwise comparison matrix, the AHP calculates the weighting for each criterion. The purpose of weighting in this land suitability analysis is to express the importance or preference of each factor relative to other factors' effects on a land's suitability for grazing. In the procedure for Multi-criteria evaluation (MCE), it is necessary that the weights sum to 1. The WEIGHT module in IDRISI was used employing the pairwise comparison technique to help develop a set of factor weights that will sum to 1.0. In a pairwise comparison matrix, factors are compared two at a time in terms of their importance relative to the stated objective. In the application of the AHP method it is important that the weights derived from a pairwise comparison matrix are consistent. Therefore, one of the strengths of AHP is that it allows for inconsistent relationships while, at the same time, providing a Consistency Ratio (CR) as an indicator of the degree of consistency or inconsistency

In developing the weights in this study, each factor's importance was considered comparing it to another factor one at a time and the rating was entered into the pairwise comparison matrix according to the AHP 9-point continuous rating scale as shown below. Since the matrix is symmetrical, only the lower triangle actually needs to be filled in. The remaining cells are then simply the reciprocals of the lower triangle.

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very strongly	Extremely

Less important **More important**

NB: 2, 4, 6, 8 are Intermediate values

Figure 3-9: Nine-point weighting scale for pair-wise comparison (Saaty, 1980)

The figure above is explained thus:

Intensity of importance	***Definition***
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

After all possible combinations of two factors are compared, the WEIGHT module calculates a set of weights and, importantly, a Consistency Ratio (CR). This ratio indicates any inconsistencies that may have been arisen during the pairwise comparison process. The determination of the CR value is critical. The CR has been widely used as a measure of the consistency in a set of judgments of AHP applications. If the CR ≤ 0.10, it deems that the pairwise comparison matrix has an acceptable consistency and that the weight values calculated are valid and can be utilized. Otherwise, if the CR ≥ 0.10 it means that the pairwise comparisons are lacking consistency, in other words the matrix

needs to be adjusted and the element values should be modified. The module allows repeated adjustments to the pairwise comparisons and reports the new weights and consistency ratio for each iteration until it reaches consistency and acceptability. Figure 3-10 reveals the Analytical Hierarchy Process (AHP) weight derivation interface in IDRISI to derive the weights for the standardized factors.

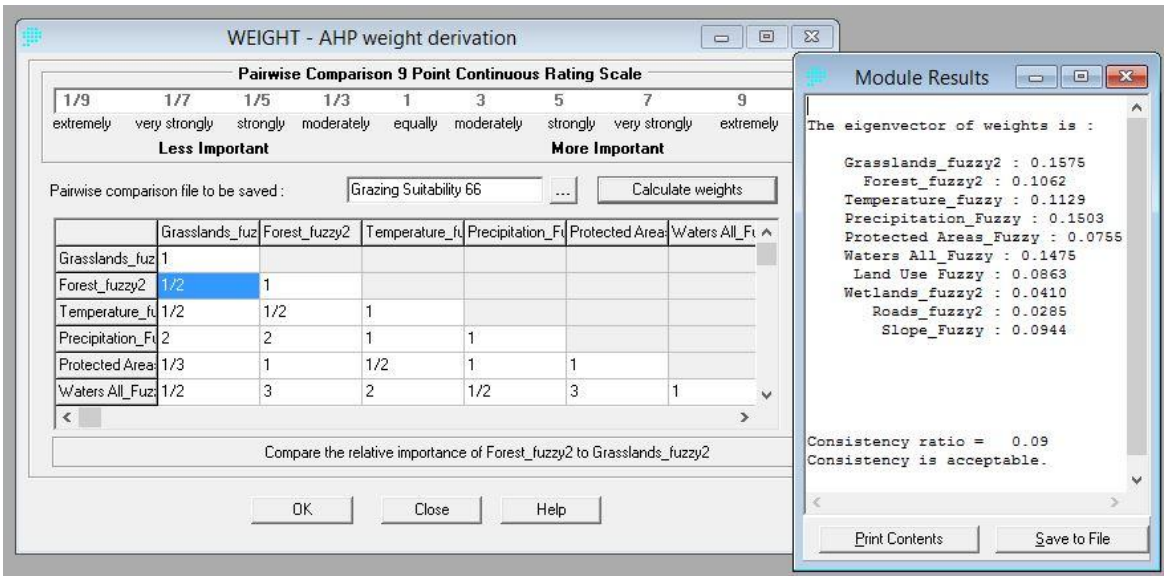


Figure 3-10: Weight derivation using Analytic Hierarchy Process (AHP) in IDRISI

3.4.3 Criteria Weighting

Having used the pairwise comparison matrix using Analytic Hierarchy Process (AHP)to compare all the criteria used in this study to check for their relative importance (executed in IDRISI Selva software), the weights for each factor was computed as well as the consistency ratio (CR). The full pairwise comparison matrix for all the criteria is correctly depicted in APPENDIX V.

The judgment of consistency of each criterion can be checked by calculating the consistency ratio (CR). This was done automatically in IDRISI. The formula used has been discussed in preceding chapters. In this study, the CR of the matrix of paired comparisons in the suitability analysis was computed to be 0.09.

3.5 SUITABILITY MAP CREATION

After weighting of all the criteria, as regards the relative importance of each criterion, the final grazing reserves suitability map was created using Weighted Linear Combination (WLC) overlay technique using the Image Calculator in IDRISI. With a weighted linear combination, the factors were overlaid by multiplying the computed weight to each corresponding factor followed by a summation of the results to yield a suitability map. The operation is depicted by this formula.

$$S = \sum w_i c_i \tag{3.3}$$

Where:

S = Suitability;
w_i = Weight of factor *i*;
c_i = Criterion score of factor *i* (i.e. the fuzzy standardized factor raster)

In this case of suitability analysis, two Boolean constraints were also applied. So, the procedure was modified by multiplying the suitability calculated from the factors by the product of the constraints, i.e.:

$$S = \sum w_i c_i \times \prod c_j \tag{3.4}$$

Where: c_j = Criterion score of the constraint j

$\prod$ = Product.

The suitability mapping results are shown and analyzed in the proceeding chapter.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 RESULTS OF DATA PREPARATION

The output of the datasets prepared as discussed in chapter 3 are shown below. Figure 4-1 is the mosaicked Landsat 8 imagery of the study area after radiometric corrections had been applied to the different scenes.

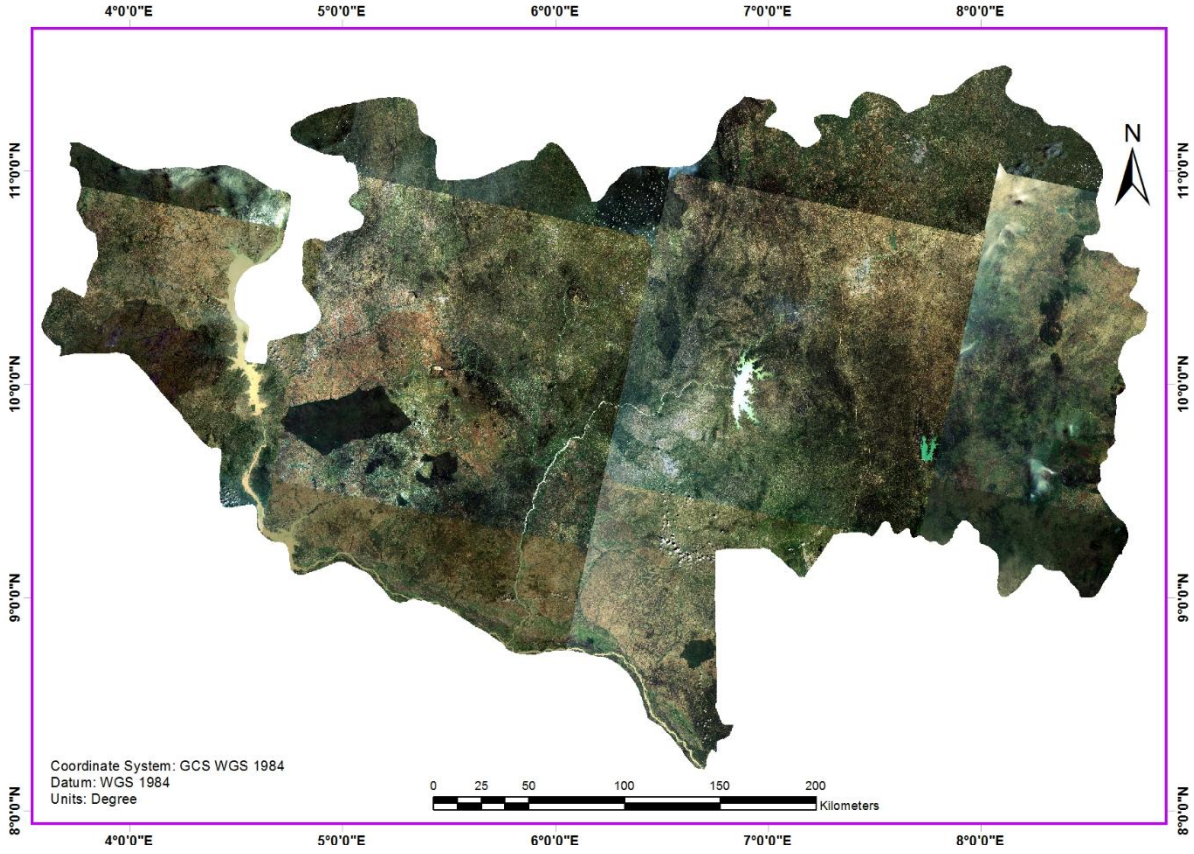


Figure 4-1: Mosaicked radiometrically calibrated Landsat 8 true colour composite imagery of the study area

The mosaicked imagery displayed above was classified by supervised classification for landuse and land cover analysis. The figure below shows the classified imagery with 10 feature classes. Some of these classes were extracted to create factors which were subsequently used for the suitability analysis in IDRISI.

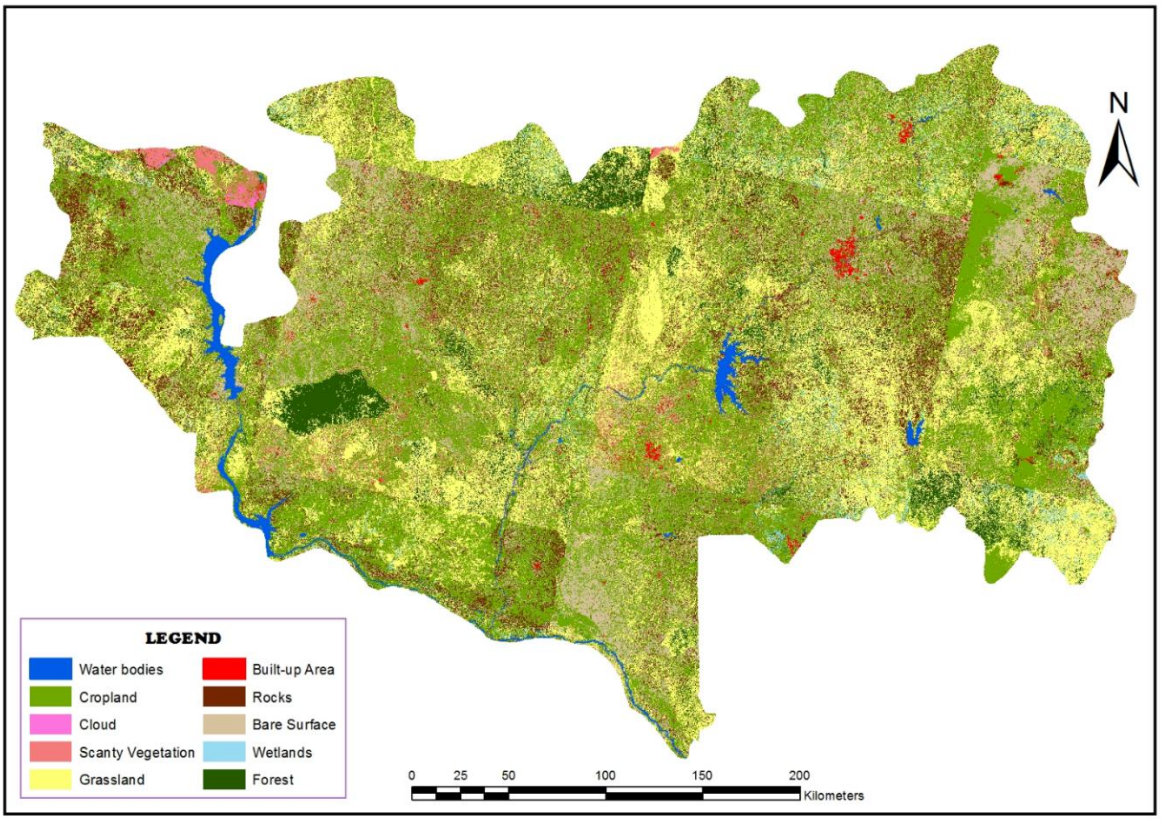


Figure 4-2: Classified Landsat 8 imagery of the study area

Figure 4-3 and Figure 4-4 are the temperature and precipitation climatic datasets respectively, prepared for the suitability analysis.The range of total annual temperature for the study area is between 24^{o}C to 29^{o}C (approximately) while the values for annual rainfall of the area under study ranges from 277.95mm – 1114.30mm.

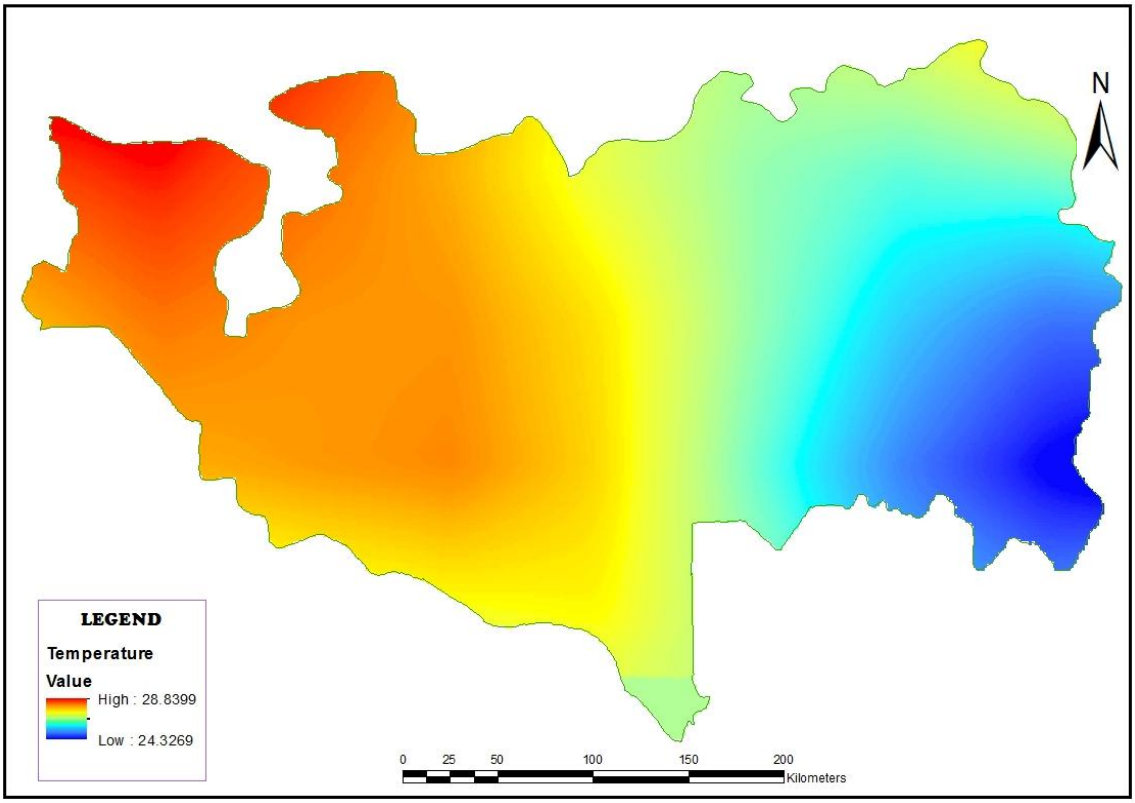


Figure 4-3: Interpolated temperature map of the study area

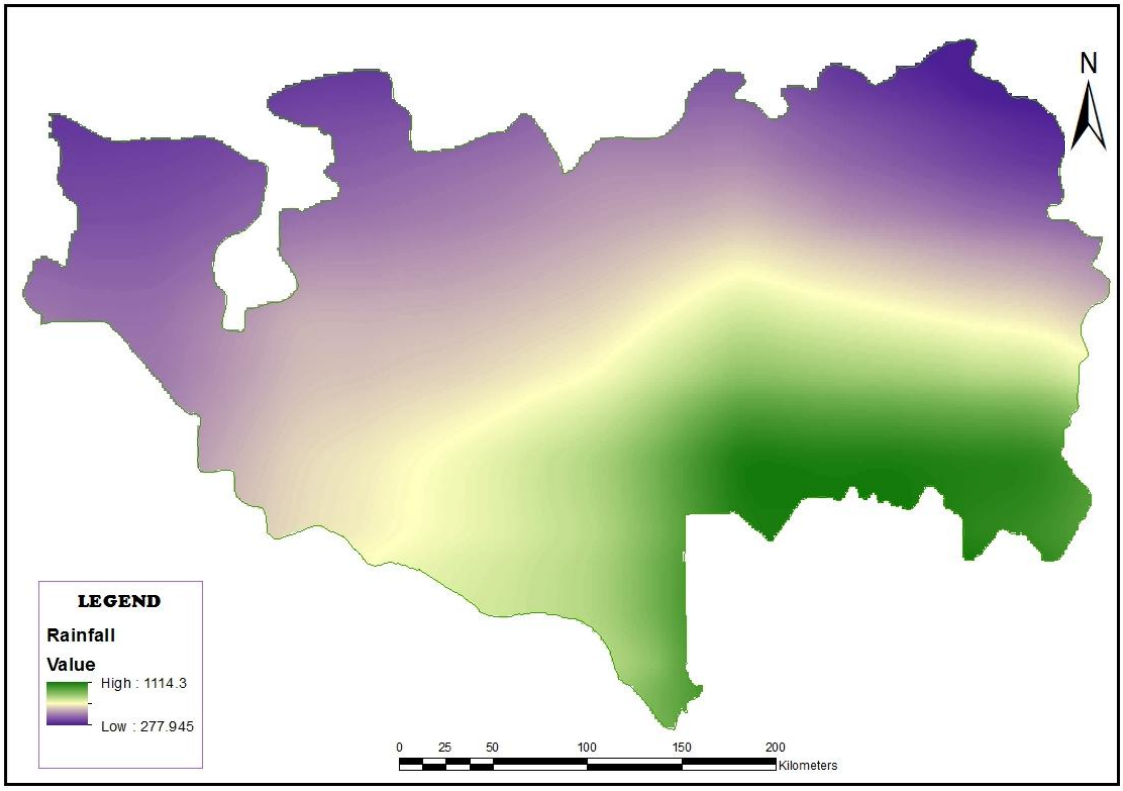


Figure 4-4: Interpolated rainfall map of the study area

The SRTM DEM of the study area is shown in Figure 4-5, with highest elevation of 1364 meters and lowest elevation of 34 meters above mean sea level. The slope map generated from the DEM is shown in Figure 4-6. The values of the slope map are in percent.

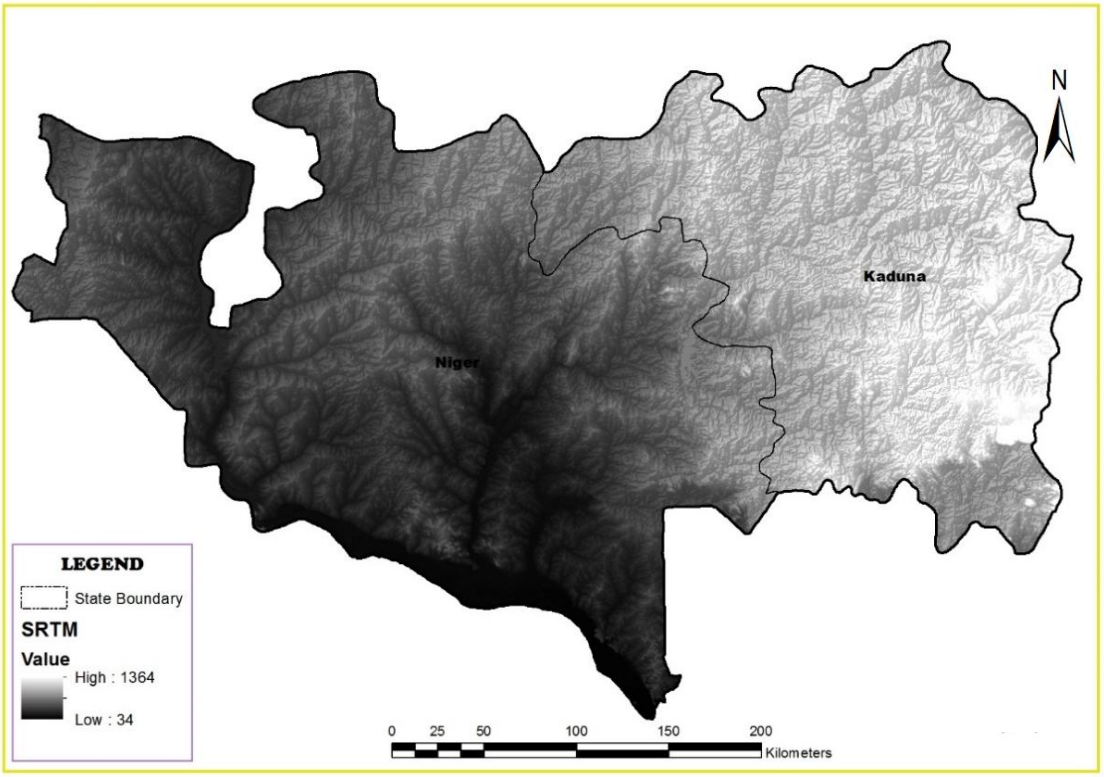


Figure 4-5: SRTM Digital Elevation Model (DEM) of the study site



Figure 4-6: Percent slope map of the study area

Protected areas in Kaduna and Niger states are shown in Figure 4-7. This includes nature reserves, national parks and forest reserves.

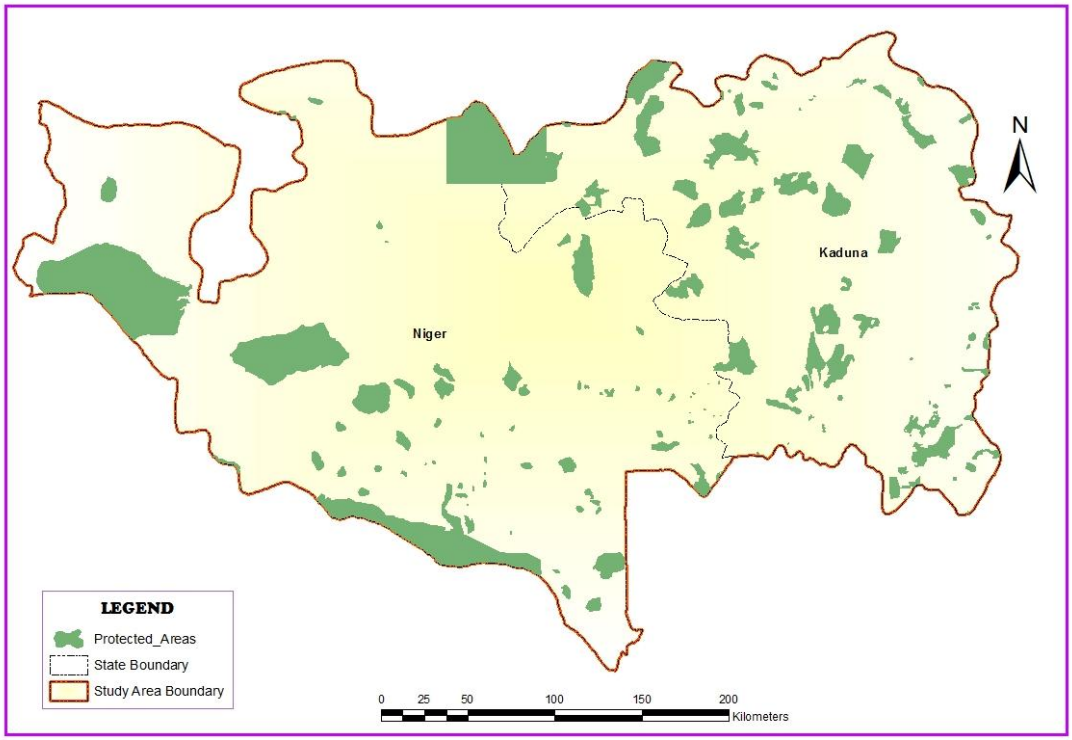


Figure 4-7: Map of protected areas in the study site

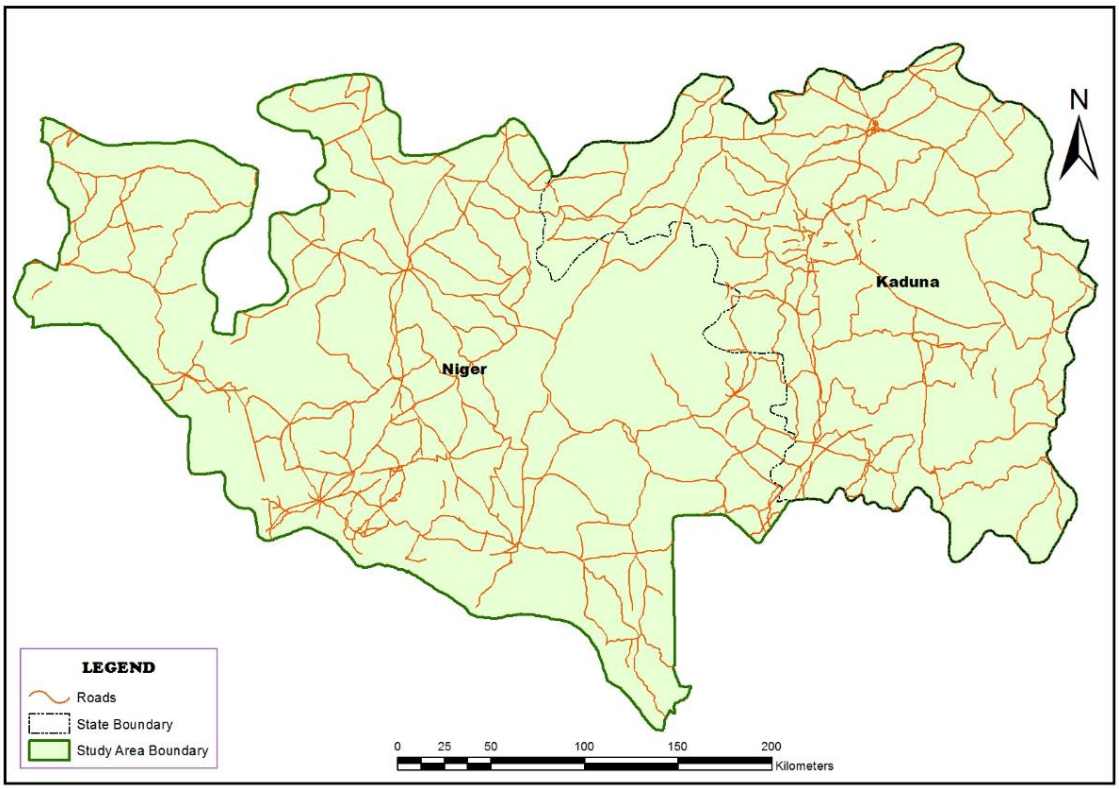


Figure 4-8: Map of road network in the study area

Figure 4-9 is the output of the processing of the water resources dataset. This includes rivers, streams, lakes and dams within the study area. A typically visible water body is the Kainji dam in the north west of Niger state and River Kaduna which cuts across the study area.

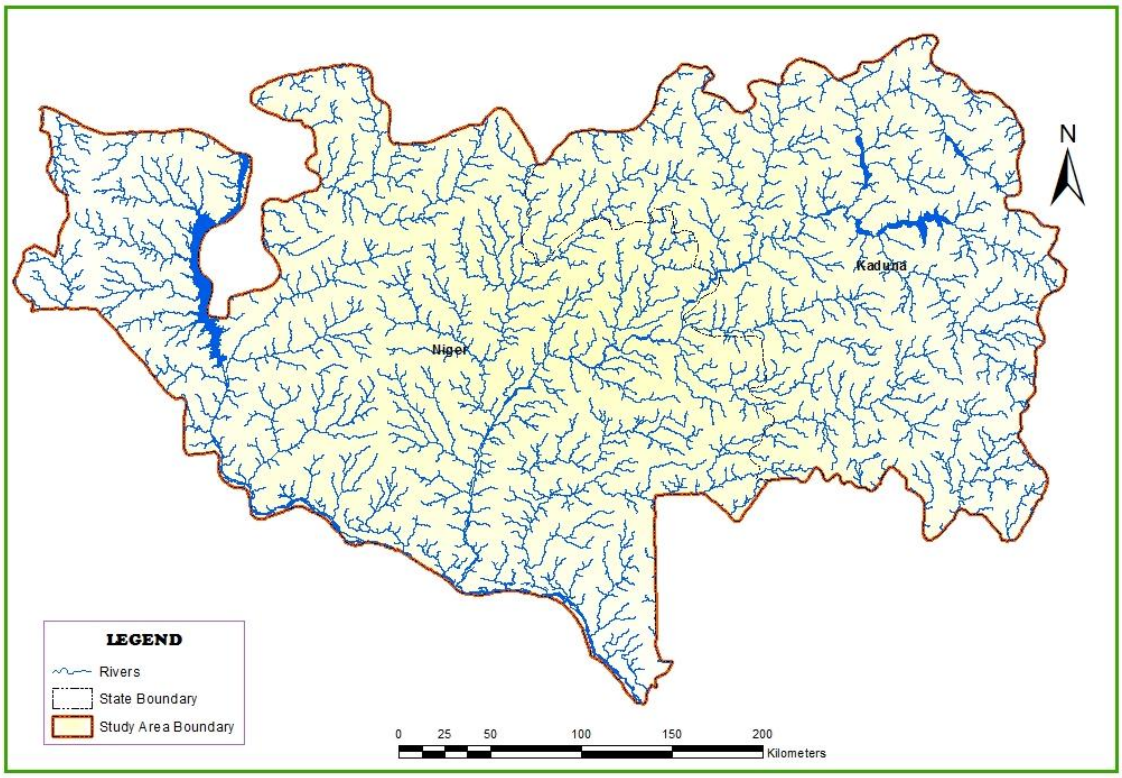


Figure 4-9: Water resources map of the study area

4.2 ACCURACY ASSESSMENT

The results of the accuracy assessment of the supervised classification carried out on the satellite imagery of the study area was obtained by applying some statistical formulae on the derived error matrix to obtain errors of commission and omission, user's and

producer's accuracies, Kappa coefficient and the overall accuracy shown in the tables below. The error matrix is shown in APPENDIX VI with the correctly classified pixels along the matrix diagonal.

Table 4.1: Descriptive statistics of the error matrix of image classification carried out. Source: (Author's lab work)

	0.00	1.01	98.99	100.00
	74.19	28.00	72.00	25.81
	7.69	75.26	24.74	92.31
	89.47	93.94	6.06	10.53
	45.83	35.00	65.00	54.17
	3.92	10.91	89.09	96.08
	14.29	15.15	84.85	85.71
	22.94	15.15	84.85	77.06
	58.82	94.07	5.93	41.18
	27.19	16.16	83.84	72.81

The table above shows the accuracies and errors associated with each class. Water bodies shows the highest producer's accuracy of 98.99% with a 0% error of commission while wetland shows the least producer's accuracy of 5.93% with a 58.82% error of commission and a 94.04% omission error.

Table 4.2: Overall accuracy and Kappa coefficient of the classification. Source: (Author's lab work)

Classified image	Overall accuracy (%)	Kappa coefficient (%)
OLI & TIRS	60.88	56.59

The most important issue in mapping land use land cover changes using remote sensing is the measure of map quality, which is accuracy. The land use land cover maps have errors and the importance of the errors depend on the purpose of the map. From Table 4.2, the Kappa coefficient and overall accuracy obtained for the image classification

was56.59% and 60.88% respectively. It means that there was 56.59% (Kappa coefficient) statistical agreement between reference pixels or points and the classified image. It can also be deduced from the error matrix that there was 60.88% (overall accuracy)which is a measure of how correctly, the reference pixels were classified on the map.

Onsomgwong (2003) making reference to Jensen (2005) noted that deductions that can be made from the values of Kappa coefficients are as follows:

i. Kappa values > 80% represent strong agreement or accuracy between the classified map and the reference information.
ii. Kappa values between 40% and 80% represent moderate agreement or accuracy between the classified map and the reference information.
iii. Kappa values < 40% represent poor agreement or accuracy between the classified map and the reference information.

4.3 RESULTS OF CRITERIA WEIGHTING

Weighting of all criteria used in this study was executed in IDRISI as discussed earlier. The result of the weighting is shown in the table below.

Table 4.3: Criterion weights derived by AHP

Criteria	Weights
Grassland proximity	0.1575
Forest proximity	0.1062
Temperature	0.1129
Precipitation	0.1503
Protected Areas distance	0.0755
Water proximity	0.1475
Land Use	0.0863
Wetlands	0.041
Road proximity	0.0285
Slope	0.0944
Total	**1.0000**
Consistency Ratio (CR) = 0.09	

The table above indicates that grasslands having the highest weight of 0.1575 is rated as the most important factor for grazing reserves land suitability, followed by precipitation/rainfall with a weight of 0.1503. Road proximity has the smallest weight of 0.0285 indicating that is the least important of all the factors as considered in the suitability analysis in this study.

4.4 GRAZING RESERVES SUITABILITY MAPPING

Multi-criteria land suitability analysis in this study used biophysical, socioeconomic and environmental indicators as necessary factors for best possible outcome. Spatial information like maps and land related attributive characteristics were incorporated into GIS for land suitability evaluation as a system. Use of social and economic parameters through AHP analysis provides reflection of real situation of the study area. Meanwhile, GIS technique along with AHP used for the land suitability evaluation improves efficacy of the outputs of the evaluation.

Having carried out MCE in IDRISI using all the appropriate factors and constraints, the final output was the grazing reserves suitability map as shown in Figure 4-10, showing the unclassified suitability map in byte format ranging from 0 – 255 with suitability increasing from 0. Values of 225 showing the most suitable areas for sighting grazing reserves.

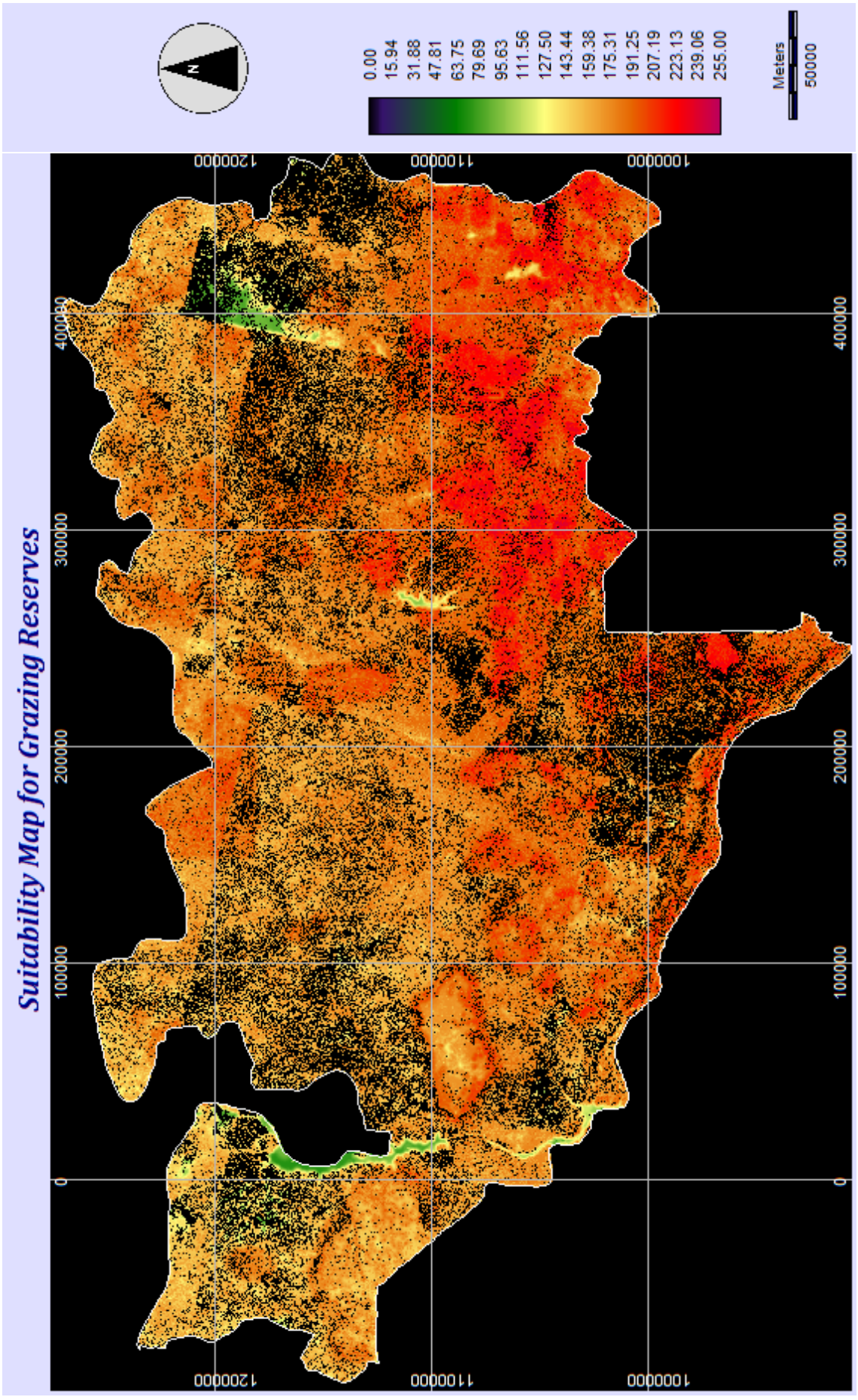


Figure 4-10: Grazing reserves land suitability image

4.4.1 Reclassified Suitability Map

The FAO classification model for suitability is widely used in the studies of land suitability assessment. This model is based on two general suitability orders (suitable and not suitable) which area subdivided into a total of 5 suitability classes.

Table 4.4: The description of land suitability classes Source: (FAO, 1991 and 1993)

Land Suitability Orders	Land suitability Classes	Definitions of Classes
Suitable	Highly Suitable (S1)	Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce benefits.
	Moderately Suitable (S2)	Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land.
	Marginally Suitable (S3)	Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits or increase required inputs, that this expenditure will be only marginally justified.
Not Suitable	Currently Not Suitable (N1)	Land having limitations which cannot be overcome at currently acceptable cost.
	Permanently Not Suitable (N2)	Land in which there are limitations so severe so as to make its use permanently impracticable or uneconomic or land with limitations to sustained use that cannot be overcome.

The suitability map was stretched linearly in IDRISI using the STRETCH module, from the byte range to the real data range i.e. from 0 - 255 to 0.0 - 1.0. The output was then reclassified according to FAO (1991) standard thus.

Table 4.5: Range used for land suitability map classification

Land Suitability Class	Notation	Range
Highly suitable	S1	0.8 – 1.0
Moderately suitable	S2	0.4 – 0.8
Marginally suitable	S3	0.2 – 0.4
Currently not suitable	N1	0.1 – 0.2
Permanently not suitable	N2	0.0 – 0.1

The reclassified land suitability map is shown in Figure 4-11. It shows five classes of land suitability according to FAO classification as discussed in the section above. These are: highly suitable, moderately suitable, marginally suitable, currently not suitable and permanently not suitable.

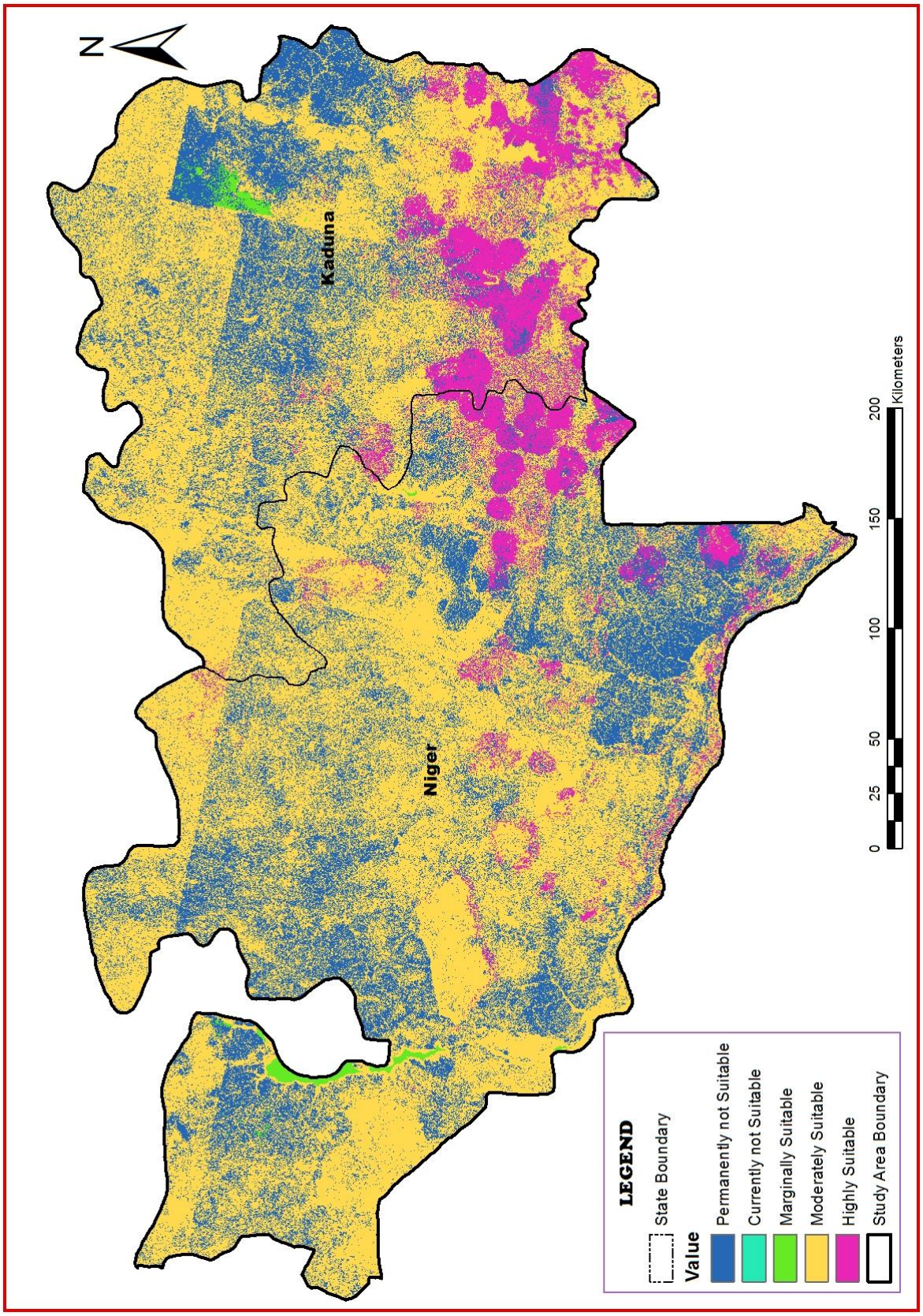


Figure 4-11: The classified grazing reserves land suitability map

The area coverage of each suitability class is shown in Table 4.6. The area coverage of each suitability class was calculated after exporting the raster output of the weighted overlay to ArcGIS. The field calculator function was used to compute the area covered by each suitability class.

Table 4.6: Area coverage of suitability classes. Source: (Author's lab work)

Suitability Class	Area	
	Square Kilometers (km^2)	Percentage (%)
Highly Suitable	9374.58	8
Moderately Suitable	72212.59	62
Marginally Suitable	615.09	1
Currently not Suitable	0.02	0
Permanently not Suitable	33325.90	29
Total	**115528.18**	**100**

This classified suitability map shows that the total area under study is 115528.18 km^2. 8% of this total area which amounts to 9374.58 km^2 is highly suitable for siting grazing reserves while 62% of the total area is moderately suitable. This suitability class covers a land area of 72212.59 km^2. 1% (615.09 km^2) of the area is marginally suitable for grazing reserves, 0% of the investigated area is currently not suitable whereas 29% of the total area of the study site is permanently not suitable for siting grazing reserves. Together, the suitability classes; 'currently not suitable' and 'permanently not suitable' make up 29% of the total area which is 33325.92 km^2. Areas of land currently not suitable for grazing reserves is partially negligible. The results indicate that a large chunk of the study area (about 71%) of the total area of land jointly account for being

suitable (this is about 82202.26 km^2). Only 29% (33325.92 km^2) of the total land mass is unsuitable for siting a grazing reserve.

Findings indicate that the unsuitable areas are places with high slopes (> 40%), places with non-availability of water sources close by, areas with low annual rainfall (less than 300mm), with high temperatures (above 35^0C) and rocky terrain. To buttress this, Mfitumukiza (2004) also believed that remoteness of water resource is one of the main suitability limiting factor for extensive grazing.

Meanwhile, results indicate that areas with abundant availability of grasslands, water, rainfall, minimal temperature, flat or gentle slopes, are suitable for establishing grazing reserves. As far as feeding of the animals is concerned, land having high quality and good amount of grass biomass is preferred by cattle, sheep and goat which constitute a large number of the animals reared by herdsmen. Flat or gentle slope is another factor which makes portion of land suitable for grazing. Animals can easily graze on flat and gentle slope and they can feed on most of the available forage without much losing much energy in climbing. Considering slope as a criteria, Holechek *et al*. (2001) stated that slope more than 60% is unsuitable for grazing animals. Hence, high slope is a limiting factor in this suitability analysis. Mountainous areas come into focus as livestock tend to graze less as slope increases (Gillen *et al.*, 1984), so they use up more energy to graze in such areas. The negative effect of steepness of slope is that less livestock tend to graze on such slopes and availability of water on steep slopes is minimal. Similarly, Arzani *et al*. (2005), Amiri (2009) and Sour *et al.* (2012) showed in their researches that in their study area, there was no water resources limitations and pointed out that steep slopes was a main suitability limiting factor in mountainous areas.

Investigation of water resources in the study area suggested that Kaduna and Niger states have many natural and artificial sources of water in the forms of streams, rivers, lakes and dams. This is due to sufficient annual rainfall in the study area and hence, there was no limitation in the form of water resources in the study area except in few places which, combined with other factors eventually resulted in unsuitability for grazing reserves.

Overlaying the administrative boundary map of the study area over the suitability map as depicted in Figure 4-12, shows that the highly suitable areas lie in the southern part of Kaduna state, especially Kachia, Kagarko, Zangon Kataf, Kaura and Jema'a. The south-eastern part of Niger state also show high level of suitability. These areas include: Paikoro, Suleja, Tafa, Gurara, Muya, Bosso and Lapai.

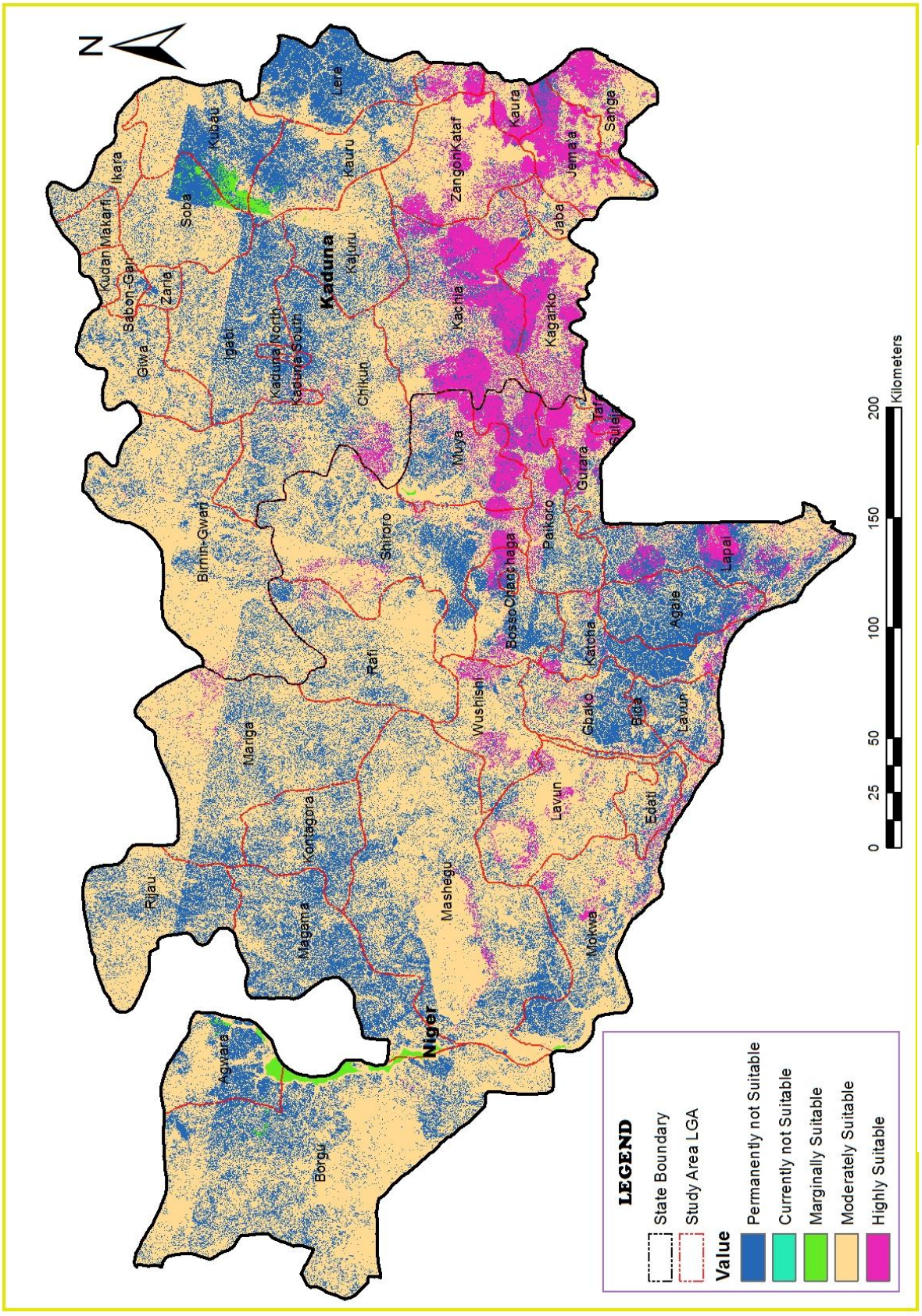


Figure 4-12: Administrative boundaries of the study area overlaid on the suitability map

The reason for the high suitability of these areas is not far-fetched as the climatic condition in these areas is conducive for the specified land use. The temperature is mild

and there is abundance of rainfall. These areas are seen as hotspots for establishing extensive grazing land for pastoralists and their livestock.

In general, the results obtained from this study indicate that the Analytical Hierarchy Process (AHP) is a powerful tool for decision making in land suitability issues regarding environmental and economic factors. By using this method, whole areas can be classified in detail about the suitability degrees for considered land use. Specified land suitability helps decision makers to define effective management plan for each objective, considering its criteria's suitability index. It is the responsibility of decision makers, especially the government to make clear selection of the area to be used for establishing grazing reserves, which can further be evaluated through multi-criteria analysis using AHP as done in this study. With GIS being one of the powerful tools, efficacy of the evaluation process will be maintained.

4.5 RESEARCH CONTRIBUTIONS

Suitability analysis and mapping has been carried out and reported for various objectives and decision making process, using varying criteria for analysis. These have been reportedly carried out in Asia (Arzani *et al.*, 2006; Amiri, 2008; Amiri *et al.*, 2012), Europe (Dvaran *et al.,* 2009), America (Oberlie and Bishop, 2009; Shearer and Xiang, 2009), East Africa (Lemmessa, 2011; Msanya *et al.,* 2001). But from the various literatures studied, no research has been carried out or reported on suitability analysis in West Africa, which happens to be greatly affected by the farmer-pastoralists relationship. Furthermore, no research has been executed on suitability mapping for grazing reserves in any part of Nigeria, equally affected by incessant clashes between farmers and herdsmen. This research succeeded in generating a suitability model for target pastoralist grazing reserve areas in Niger and Kaduna states of Nigeria.Therefore, the objectives of this study, while recognizing important factors affecting suitability of land for siting grazing reserves, was also designed to serve as a model for further studies and determination of suitable sites for grazing reserves in other parts of Nigeria.This study furthermore shows and determines the kind and rate of the limitations and factors reducing the suitability of a particular area for extensive grazing.

While some studies concentrated on the use of fewer criteria such as quality of water, quantity of water, water accessibility and slope (Arzani *et al.*, 2006; Amiri, 2008, 2009; Oberlie and Bishop, 2009), this study utilized several other criteria ranging from biophysical, socioeconomic and environmental factors for better suitability analysis and mapping output. Moreover, the fuzzy standardization of individual factors and eventual Weighted Linear Combination (WLC) for Multicriteria Evaluation (MCE) as done in this study supercedes the Boolean combination of criteria, as used in previous studies, which equally produces suitability maps but not of same accuracy as suitability mapping conducted using WLC.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Land suitability in this research was extracted by weighted linear combination overlay technique based on Multi-criteria Evaluation (MCE) using GIS, a process that has resulted in suitability being portrayed in five classes namely: highly suitable, moderately suitable, marginally suitable, currently not suitable and permanently not suitable. The results clearly indicate which areas in Kaduna and Niger States are suitable or unsuitable for grazing reserves. Finding indicated that the following location are suitable for siting grazing reserves. These are:Kachia, Kagarko, Zangon Kataf, Kaura, Jema'a, Paikoro, Suleja, Tafa, Gurara, Muya, Bosso and Lapai.

This study has shown that GIS provides a great advantage to analyze multiple layers of data spatially and quantitatively. Depending on the available spatial data, the accuracy and reliability of the result using GIS application could be high. The GIS-based Multicriteria Evaluation (MCE) approach in land suitability mapping is advocated technically to identify suitable land and sustainable accessibility for grazing reserves development. As seen from this research and other studies, GIS-based Multicriteria Evaluation (MCE) method provides a more realistic and achievable objectives on a non-biased basis for making decisions on site selection. In the course of this study, pair-wise comparison matrix was constructed using AHP method and priority weights were calculated in IDRISI Selva; a decision analysis software. This research can assist the government, researchers, experts and development organizations in incorporating their policy as a grazing reserves development model.

This aim of this study was to analyze suitability of land within Kaduna and Niger states of Nigeria for siting grazing reserves, integrating GIS and Remote Sensing with MCE. Among several factors governing land suitability for extensive grazing, ten factors

namely: distance from water, distance from roads, distance from wetlands, distance from protected areas, proximity to forests, land use, grasslands, precipitation, temperature and slope were selected whereas, rocks and built-up areas within the study area were chosen to serve as constraints. The weighting analysis showed that the influence of these factors is not equal as varying weight was computed from the pairwise comparison in AHP. The suitability of the study area for grazing reserves ranged from highly suitable to permanently not suitable. This research revealed that majority of the area is moderately suitable for grazing reserves while a smallest portion of the area is currently not suitable for establishing grazing reserves based on the criteria considered.

The objectives of this study included amongst other things: mapping the current land cover of the area under study, generating a suitability model for grazing reserves, using socioeconomic, biophysical and environmental factors to create the model stated above and making recommendations to stakeholders on the establishment and maintenance of these grazing reserves. These objectives were all achieved in this research as the land cover map of the study area was successfully created from Landsat 8 imagery of the study area and using various factors in their spatial form, the suitability map of the study area was generated in a GIS environment while appropriate recommendations were made to the government and corporate organizations on how and where to cite grazing reverses for optimum performance within the study area, so as to enhance cordial relationship between farmers and herdsmen within the study area.

Moreover, it has been deduced from the results obtained from this study that the Analytical Hierarchy Process (AHP) is a powerful tool for decision making in land suitability issues regarding biophysical, environmental and socio-economic factors. By using this technique, a whole area can be classified in detail about the suitability degrees

for considered land use. Specified land suitability helps decision makers to effectively formulate a management plan for the specified land use (in this case, grazing reserves) considering the suitability index from each criteria.

5.2 RECOMMENDATIONS

It has to be stressed that more land suitable for livestock grazing and settlement of pastoralists is needed in the country. At least, some percentage of the current total agricultural land should be available for this purpose. The land can be in the form of federal farmland or grazing reserves which can be developed or utilized in its natural or existing state for livestock grazing. It follows that the Government should therefore continue with its policy to develop existing grazing reserve land in order that more areas be opened for improved livestock production and then, the lingering crises between farmers and pastoralists can be curtailed or eliminated. Besides, grazing reserves development to a large extent will bring about positive changes in the socio-economic well-being of farmers in rural areas and for this reason too, this objective should be further pursued. In this context, it is equally important to ensure that all existing grazing reserves should only be utilized for livestock purposes, including those that may be privatized. Other important recommendations emanating from this study are enumerated below.

1. The results obtained from this study can be critically looked into by the government and adopted for the siting of grazing reserves for optimum livestock productivity and conducive environment for settling the nomadic pastoralists. Particular attention should be paid to areas mapped as highly suitable and moderately suitable, especially in southern parts of Kaduna state and the south-western parts of Niger state. Therefore, it is recommended that government at all

levels should give attention to funding projects for the proper establishment and maintenance of these grazing reserves so as to settle these herdsmen permanently and make all necessary facilities available to them. This way, the inherent conflicts between the nomadic pastoralists and the local community (farmers) will be curtailed if the reserves are properly gazetted, developed and maintained for sustainability. This will attract or catch the attention of more pastoralists to settle permanently in the grazing reserves.

2. The established grazing reserves should strictly be utilized for:

    i. Providing pastoralists with grazing areas to which they could withdraw their

    livestock when farmers' crops are at vulnerable growth stages. This will reduce farmers-herders clashes which usually leads to loss of lives and property.

    ii. Supporting the exploitation of the resources and infrastructure available for the mutual benefit of crop farmers and pastoralists by not treating the grazing reserves as enclosures permanently separating the pastoralists and their livestock from farmers.

3. Findings from literature indicate that some of the existing grazing reserves are in very poor conditions. With a conducive climate for investment, a lot can be achieved by rehabilitating and reactivating most of the grazing reserves by ensuring that the staff quarters, veterinary clinics, milk collection centres, dams and boreholes, electricity, schools and clinics as well as efficient transportation

facilities are put in place in these reserves so as to enable the staff and settlers to have and live a comfortable life in the grazing reserves.

4. If grazing reserves are to succeed, they should not be conceptualized as creating the opportunity to create small ranches or mixed farms. They must be a part of district-wide land use plans, intended to encourage integration of livestock enterprises into the overall economy. Clearly demarcated areas within the reserves should be allocated to specific households with a certificate of occupancy to guarantee their right for cropping and strategic fodder development. There should be a focus of low input technology directed towards improving the productivity of the resources available to small and medium-sized herd owners settled in the reserves.

5. This study can be further extended to develop a model to be used continually for selecting suitable sites for grazing reserves across the federation by increasing the number of criteria used for the analysis. A setback in this research was that with the limited time frame, there was a problem in acquiring all required datasets as most of them are not readily available. An important point that must be taken into account is the availability of these additional criteria. The next step of this study should be to enlarge the criteria set used in this research for greater efficiency of the geospatial method adopted for suitability mapping of grazing reserves.

6. Other geospatial techniques such as Multi-objective Land Allocation (MOLA) can be used to further develop the methodology and findings from this study for suitability mapping as it can provide a procedure for solving multi-objective land allocation problems for cases with conflicting objectives. This is recommended because findings from this research indicates that decisions bordering on site selection can easily be taken with GIS-assisted Multicriteria Evaluation (MCE).

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APPENDICES

APPENDIX I: Grazing Reserves in Niger State. Source: (Niger State Bureau of Statistics, 2012).

S/N	NAME OF GRAZING RESERVE	LOCATION /LGAs	SIZE (HA)	REMARKS
1	Audu Kenchi Grazing Reserve	Lavun LGA, Edati	4,000	Not gazetted
2	Adunu/Bare Grazing Reserve	Paikoro/Munya	3,650	Not gazetted
3	Jita Grazing Reserve	Paikoro	2,500	Not gazetted
4	Ugu Grazing Reserve	Rafi	4,250	Not gazetted
5	Tunga Bako Grazing Reserve	Rafi	4,000	Not gazetted
6	Yakila Grazing Reserve	Rafi, Wushishi	3,000	Not gazetted
7	Allawa Grazing Reserve	Shiroro	3,650	Not gazetted
8	Bobi Grazing Reserve	Mariga, K/Gora, Wushishi,Mushegu	30,222	Gazetted
9	Funa Funa Grazing Reserve	Kontagora, Mariga	12,700	Not gazetted
10	Mazuga Grazing Reserve	Kontagora	3,650	Not gazetted
11	Kataeregi Grazing Reserve	Katcha, Bida	4,906	Not gazetted
12	Edotsu Grazing Reserve	Katcha, Bida	3,000	Not gazetted
13	Ekogi Grazing Reserve	Agaie	3,000	Not gazetted
14	Nankiokan Grazing Reserve	Agaie	2,560	Not gazetted
15	Ndadakun Grazing Reserve	Agaie	1,650	Not gazetted
16	Iri Grazing Reserve	Rijau, Magama	12,460	Gazetted
17	Libelle Grazing Reserve	Magama, Rijau	3,200	Not gazetted
18	Kampanin Abba Grazing Reserve	Bosso LGA	3,840	Not gazetted
19	Sheyi Grazing Reserve	Bosso/Shiroro	6,500	Not gazetted
20	Tsohon Lapai (B/Maza) Grazing Reserve	Lapai	3,500	Not gazetted
21	Tsohon Lapai (D/Kpetsuye) G. R.	Lapai	3,500	Not gazetted
22	Utula Grazing Reserve	Lapai	6,650	Not gazetted

23	Kokoli Grazing Reserve	Borgu	-	Not gazetted

APPENDIX II: Details of grazing reserves in Kaduna state. Source: (NLPD, 2013)

S/N	Name of Grazing Reserve	Location /LGAS	Size (Ha)	Facilities	Condition	Remarks
1	Kachia Grazing Reserve	Parts of Kachia, Zangon Kataf and Kajuru	74,000	- Staff quarters - 13 earth dams - Junior secondary school - Primary school - 12,500 cattle - Clinic - Milk collection point - 2 boreholes	Fairly good	• 35221.213 Hectares gazetted out of the 74,000 Hectares and divided into six blocks. • Problem of encroachment by local inhabitants. • The reserve requires more facilities.
2	Gayan Grazing Reserve	Birnin Gwari	13222.38	- 3 earth dams - 204 settlers - Primary school - Milk collection point - 2 boreholes	Fairly good	• The reserves requires more facilities for the purpose for which it was established. • There's need to tackle the menace of encroachment by local inhabitants. • The reserve is gazetted.
3	Kagarko Grazing Reserve	Kagarko	4969.779	NIL	Fairly good	• Only about 45% of the total land area was accessible due to resistance by some settlers or holders. • It is not gazetted. • The reserve needs expansion into forest reserve to make up for area already taken up for settlement of the increasing population of the

						community.
4	Damau Grazing Reserve	Kubau	3574.05	- 5 boreholes at strategic locations - An earth dam - A 12km access road - 2 milk collection centres - 30 hectares of established pasture (fenced) - Veterinary clinic and equipment - Staff quarters - An office block - Cattle market - Crush and dip	Fairly good	• The reserve is presently undergoing some development by the National Livestock Project Division (NLPD). • The processes of legislation and gazetting are still in progress.
5	Gamagira Grazing Reserve	Soba	64000	NIL	Bad	a. It is heavily encroached. b. It is not gazetted. c. The reserve needs resurvey, demarcation and monumentation. d. All facilities need to be provided for proper take-off.
6	Gwantu Grazing Reserve	Sanga	20200	- Office block - Cattle holding centre - Hay shed	Bad	a. It is heavily encroached. b. The reserve needs resurvey, demarcation and monumentation. c. All facilities area heavily dilapidated.

7	Dogon Dawa Grazing Reserve	Birnin Gwari	9900	- Office Block	Bad	a. It is heavily encroached b. It is not gazetted c. The reserve needs resurvey, demarcation and monumentation. d. The office is highly dilapidated. e. It requires all standard facilities for grazing reserves.
8	Abet Grazing Reserve	Zangon Kataf	1900	- Office Block	Bad	a. It is heavily encroached b. It is not gazetted c. The reserve needs resurvey, demarcation and monumentation. d. The office is highly dilapidated. e. It requires all standard facilities for grazing reserves.
9	Kwaba Grazing Reserve	Zaria	5100	NIL	Bad	a. Heavily encroached and overtaken by farmers. b. Needs to be retrieved, resurveyed and demarcated. c. It requires all standard facilities for a grazing reserve. d. The reserve is not gazetted.
10	Randagi Grazing Reserve	Birnin Gwari	6800	NIL	Bad	a. Heavily encroached and overtaken by farmers. b. Needs to be retrieved, resurveyed and demarcated. c. It requires all standard facilities for a grazing reserve.

						d. The reserve is not gazetted.
11	Sabon Birni Grazing Reserve	Igabi	3300	NIL	Bad	a. Heavily encroached and overtaken by farmers. b. Needs to be retrieved, resurveyed and demarcated. c. It requires all standard facilities for a grazing reserve. d. The reserve is not gazetted.
12	Fadan Kagoma Grazing Reserve	Jema'a	4800	NIL	Bad	a. Heavily encroached and overtaken by farmers. b. Needs to be retrieved, resurveyed and demarcated. c. It requires all standard facilities for a grazing reserve. d. The reserve is not gazetted.
13	Saminaka Grazing Reserve	Lere	8500	NIL	Bad	a. Heavily encroached and overtaken by farmers. b. Needs to be retrieved, resurveyed and demarcated. c. It requires all standard facilities for a grazing reserve. d. The reserve is not gazetted.
14	Tashan Daji Grazing Reserve	Zangon Kataf	6000	NIL	Bad	a. Heavily encroached and overtaken by farmers. b. Needs to be retrieved, resurveyed and demarcated. c. It requires all standard facilities for a

						grazing reserve. d. The reserve is not gazetted.
15	Guga Pasture	Giwa	250	NIL: requires standard facilities for pasture production.	Bad	a. Heavily encroached and overtaken by farmers. b. The reserve is not gazetted.
16	Kudan Pasture	Kudan	250	NIL: requires standard facilities for pasture production.	Bad	a. Heavily encroached and overtaken by farmers. b. The reserve is not gazetted.
17	Aba Pasture	Zaria	800	NIL: requires standard facilities for pasture production.	Bad	a. Heavily encroached and overtaken by farmers. b. The reserve is not gazetted.

APPENDIX III: Script used for climatic factors interpolation

```
'GridInterpolate.bas returns the Z values from the grid at the
' XY locations specified in the data file. TB - 21 Apr 04
'Changed ColumnCount to LastColumn. TB - 06 May 04
'Added date and time to the Z Interpolated column.
' Changed to use GRD file path for DAT file. TB - 22 Nov 04.

SubMain
Debug.Print"----- ";Time;" -----"
OnErrorResumeNext
Set surf = GetObject(,"surfer.application")
IfErr.Number<>0 Then
Set surf = CreateObject("Surfer.Application")
        surf.Documents.Add(srfDocPlot)
EndIf
OnErrorGoTo 0 'Turn on error reporting.

    path1 = surf.Path+"\samples\"
'path1 = "c:\incoming\"
    grdfile1 = GetFilePath("demogrid.grd","grd;ddf;dem",path1,"Open GRD
File")
If grdfile1 = ""ThenEnd
    path1 = Left(grdfile1,InStrRev(grdfile1,"\"))
Debug.Print path1

    datfile1 = GetFilePath("demogrid.dat","dat;xls",path1,"Open Data
File")
If datfile1 = ""ThenEnd
    surf.Visible = True

Set wksdoc1 = surf.Documents.Open (datfile1)

'Specify XYZ columns.
Dim wkscols()
ReDim wkscols(1 To wksdoc1.UsedRange.LastColumn)
Debug.Print"ColCount = ";wksdoc1.UsedRange.LastColumn

For i = 1 To wksdoc1.UsedRange.LastColumn
        wkscols(i)=Chr(i+64)+": "+Trim(Str(wksdoc1.Cells(1,i)))
Debug.Print i;": ";wkscols(i)
Next i
AppActivate surf.Caption

BeginDialog UserDialog 350,147,"XYZ Columns"' %GRID:10,7,1,1
GroupBox 20,14,310,91,"Worksheet Columns",.GroupBox1
Text 30,36,70,14,"X Column:",.xCol
Text 30,58,70,14,"Y Column:",.yCol
DropListBox 100,35,220,70,wkscols(),.DropListBox1
DropListBox 100,56,220,77,wkscols(),.DropListBox2
Text 30,84,170,14,"Save Z values in column:  ",.zCol
OKButton 140,119,90,21
CancelButton 250,119,90,21
TextBox 210,84,100,14,.TextBox1
EndDialog

Dim dlg As UserDialog
    dlg.droplistbox1 = 0 'default value = wkscols(index) = col A
    dlg.droplistbox2 = 1 ' col B
    dlg.textbox1 = Chr(Asc(wkscols(wksdoc1.UsedRange.LastColumn))  +1)
```

```
'Debug.Print wksdoc1.UsedRange.LastColumn

'dlg.textbox1 = Chr(Asc(wksdoc1.UsedRange.LastColumn) + 1)

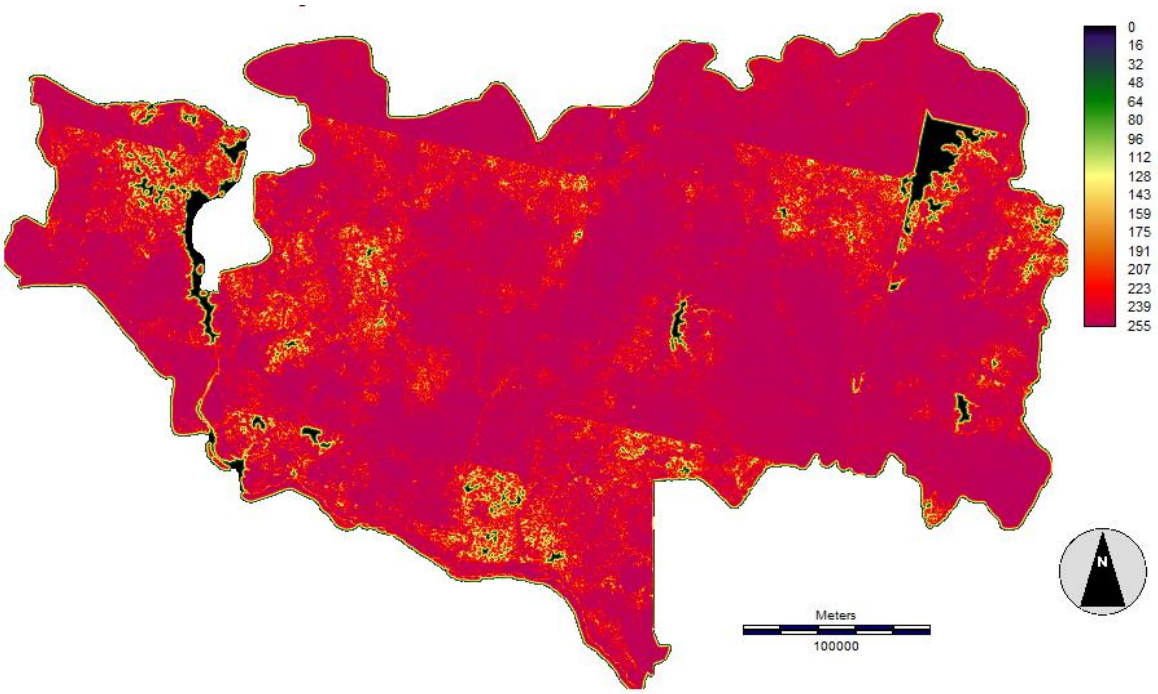
IfDialog (dlg) = 0 ThenEnd
    xcolumn = dlg.droplistbox1
    ycolumn = dlg.droplistbox2
    zcolumn = Asc(UCase(dlg.textbox1)) - 64
Debug.Print xcolumn;ycolumn;zcolumn

With wksdoc1
'find first numeric row.
For rownum = 1 To.UsedRange.LastRow
IfIsNumeric(.Cells(rownum,xcolumn)) And _
.Cells(rownum,xcolumn) <>""And _
IsNumeric(.Cells(rownum,ycolumn)) And _
.Cells(rownum,ycolumn) <>""ThenExitFor
Next rownum
        firstrow = rownum
Debug.Print"firstrow = ";firstrow
IfNotIsNumeric(.Cells(firstrow,xcolumn)) Or _
.Cells(firstrow,xcolumn) = ""Or _
NotIsNumeric(.Cells(firstrow,ycolumn)) Or _
.Cells(firstrow,ycolumn) = ""Then
MsgBox("No numeric data found in specified columns.", _
vbOkOnly,"Data Not Found")
End
EndIf

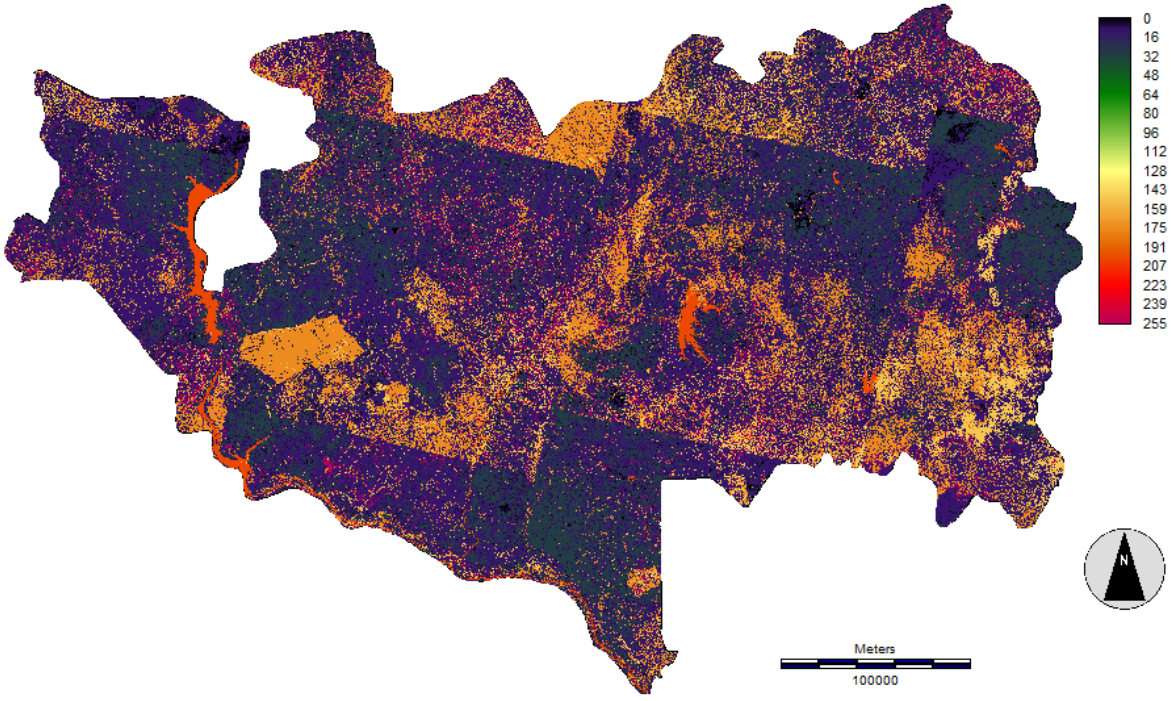
If firstrow = 1 Then
.Cells(1,1).Insert(wksInsertRows)
.Cells(1,xcolumn) = "X"
.Cells(1,ycolumn) = "Y"
EndIf
.Cells(1,zcolumn) = "Z Interpolated from "& grdfile1 & _
" on "&Date&" "&Time


Set grid1 = surf.NewGrid
        grid1.LoadFile(grdfile1,headeronly:=False)
For j = 2 To.UsedRange.LastRow
            zinterp = grid1.Interpolate( _
.Cells(row:=j,col:=xcolumn) , _
.Cells(row:=j,col:=ycolumn) )
'Debug.Print "Z val:";zinterp
.Cells(row:=j,col:=zcolumn).Value = zinterp
Next j
EndWith
MsgBox("View and save Z values in the Surfer worksheet.",vbOkOnly, _
"Interpolation Complete")
AppActivate surf.Caption
EndSub
```

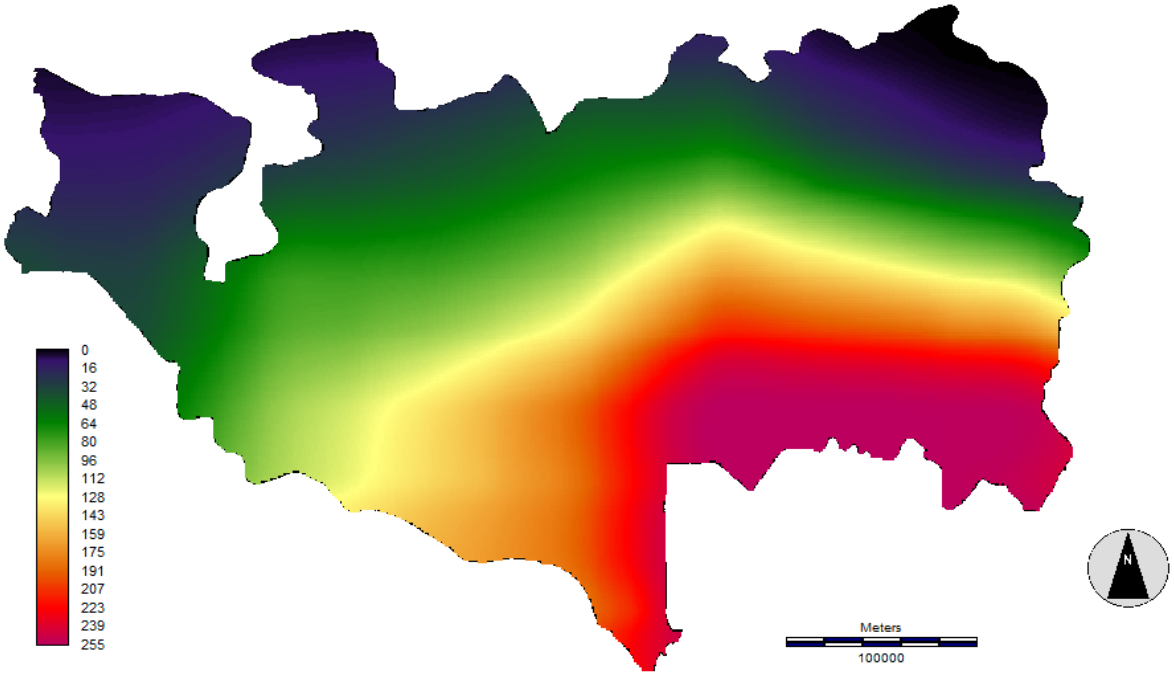
APPENDIX IV: Fuzzy standardized criteriamaps



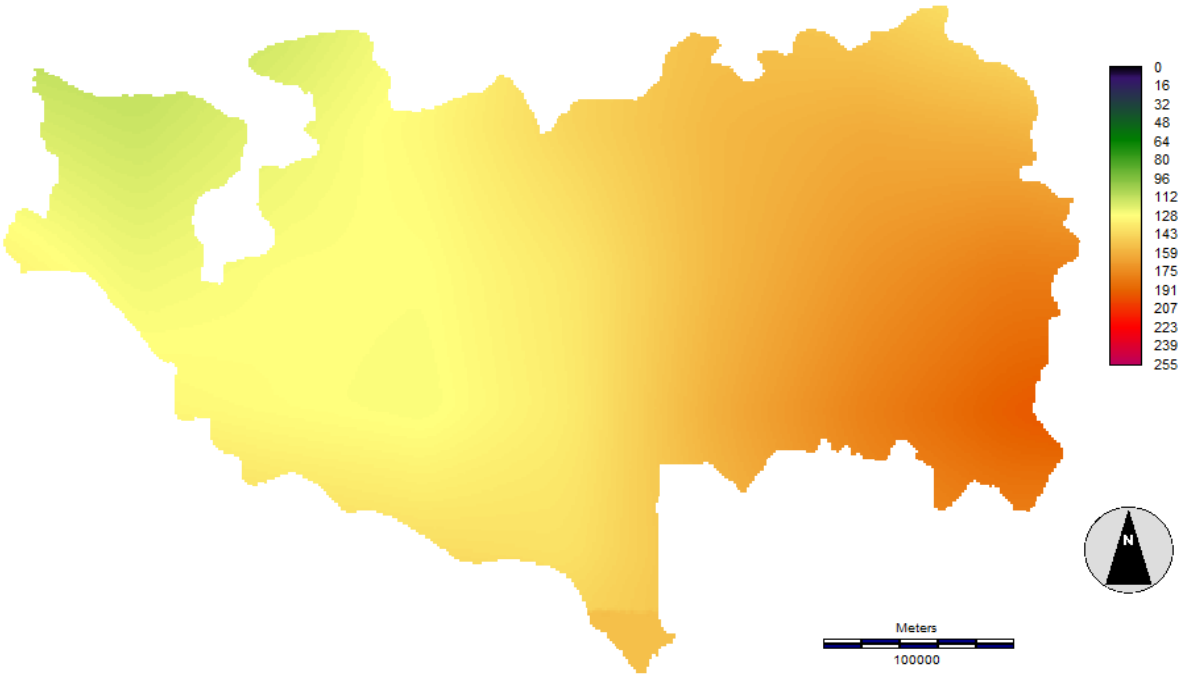
Grasslands proximity map



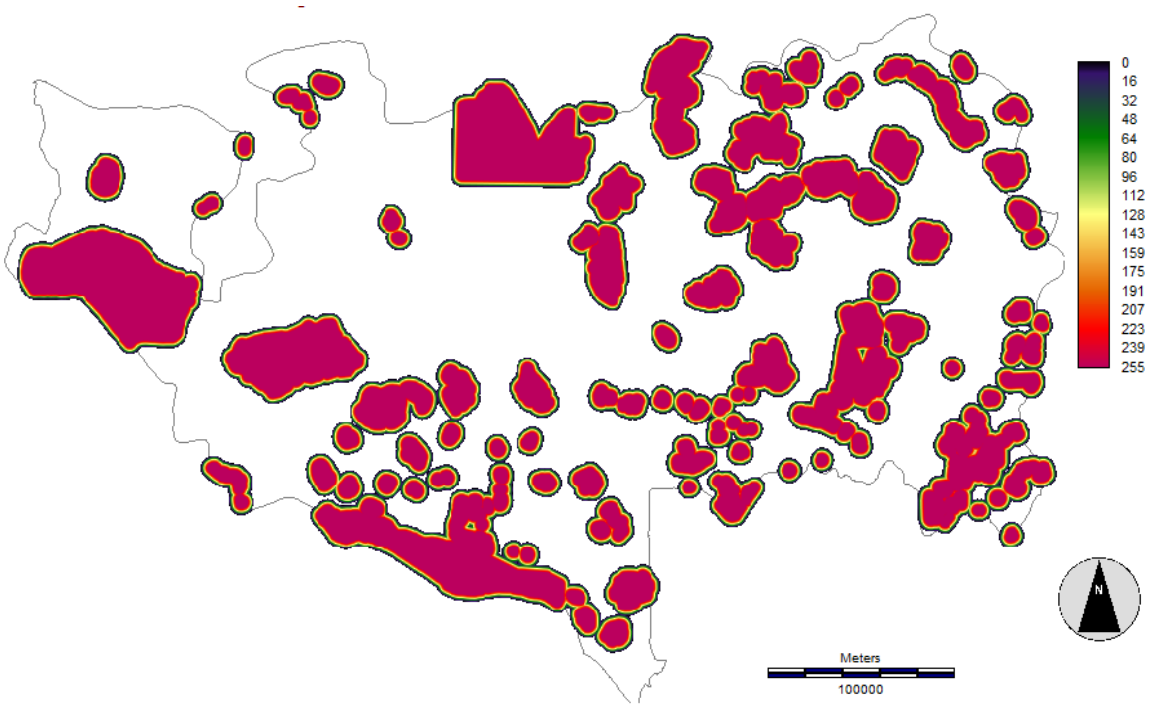
Landuse map



Rainfall



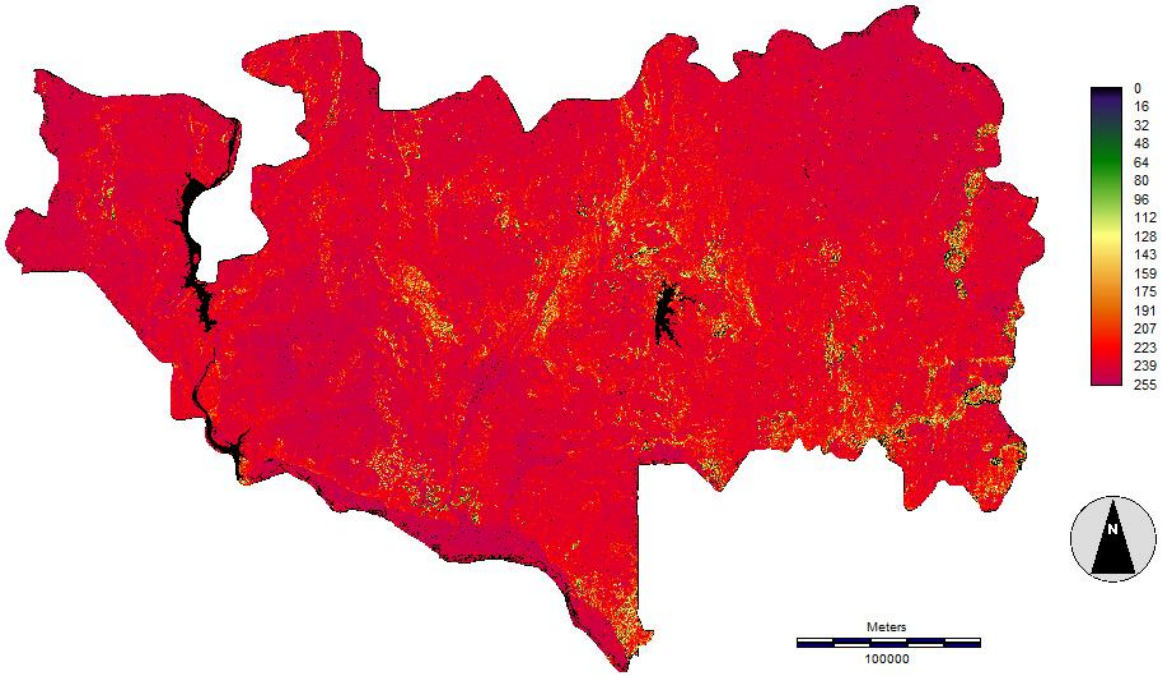
Temperature



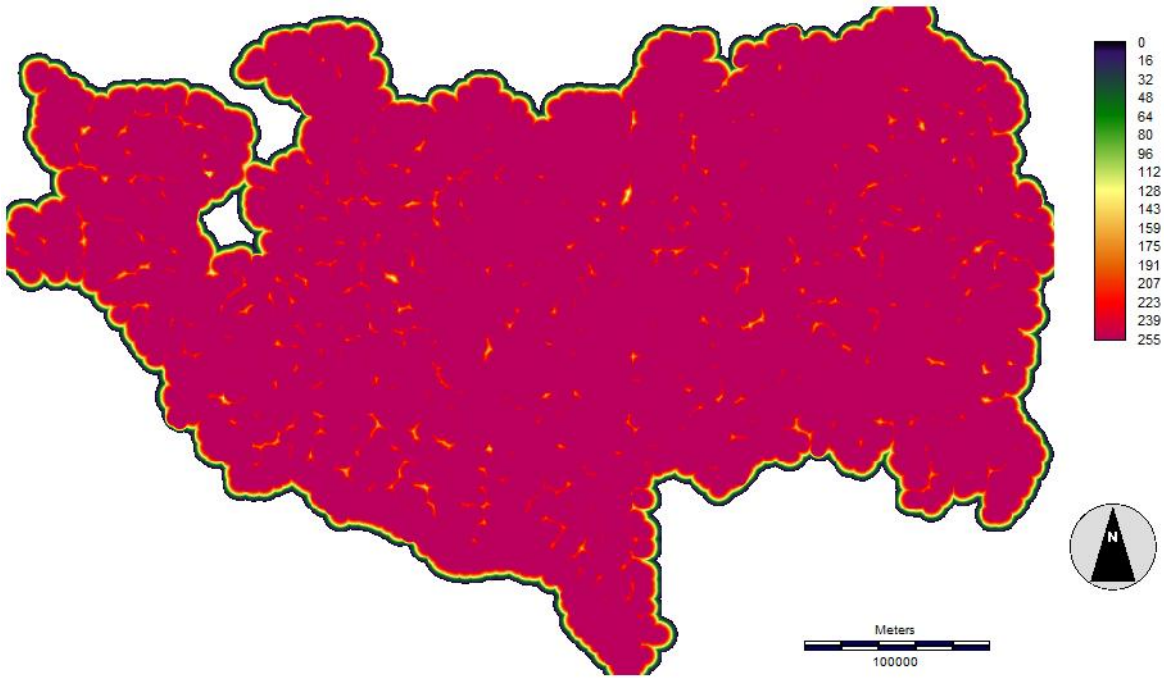
Protected areas proximity map



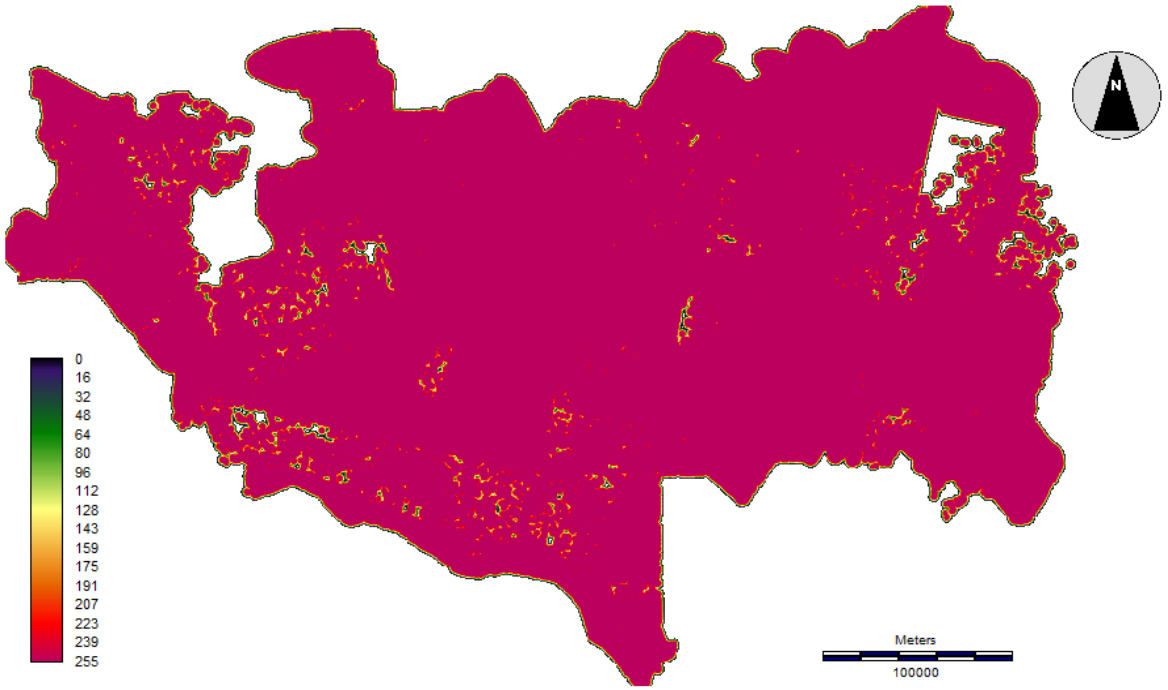
Roads proximity map



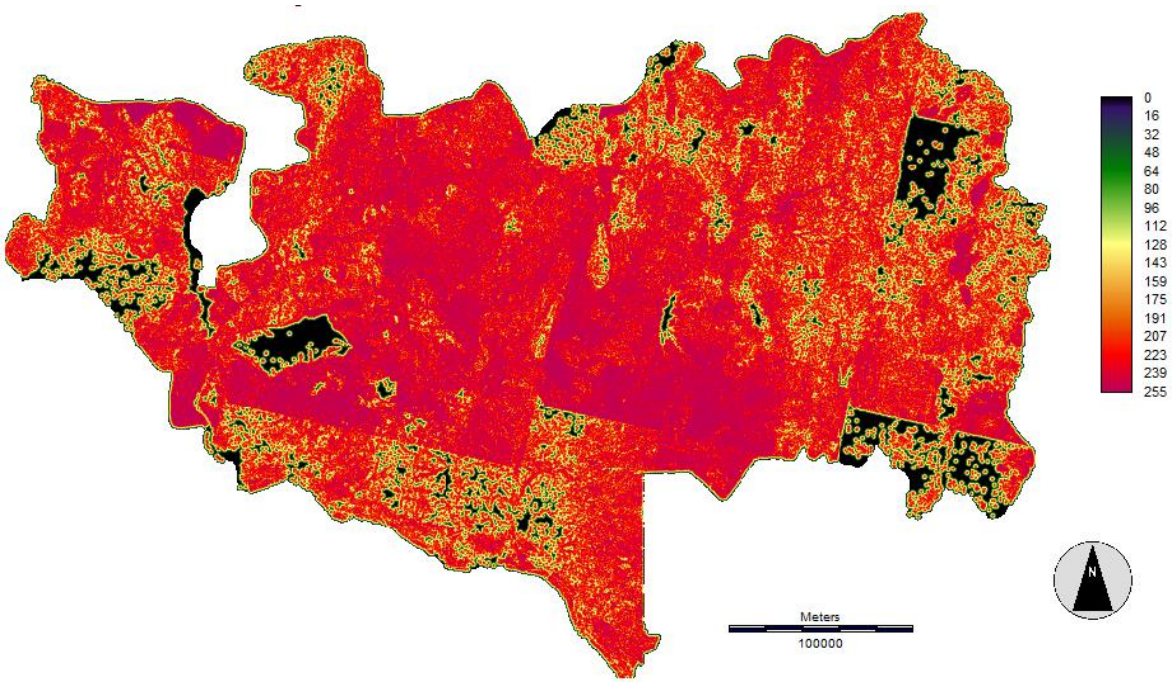
Slope map



Water resources proximity map



Wetlands proximity map



Forests distance map

APPENDIX V: Pairwise comparison matrix of all factors used for suitability mapping

	Grassland proximity	Forest proximity	Temperature	Precipitation	Protected Areas distance	Water proximity	Land Use	Wetlands	Road proximity	Slope
Grassland proximity	**1**									
Forest proximity	1/2	**1**								
Temperature	1/2	1/2	**1**							
Precipitation	2	2	1	**1**						
Protected Areas distance	1/3	1	1/2	1	**1**					
Water proximity	1/2	3	2	1/2	3	**1**				
Land Use	1/2	1	1/3	1/3	1	1/3	**1**			
Wetlands	1/3	1/3	1/5	1/2	1/3	1/2	1/3	**1**		
Road proximity	1/3	1/3	1/3	1/3	1/4	1/5	1/6	1/2	**1**	
Slope	1/2	1/3	1	1	3	1	1/2	2	3	**1**

APPENDIX VI: Error matrix computed from the image classification

Water bodies	**98**	0	0	0	0	0	0	0	0	0	**98**
Cropland	0	**72**	29	63	8	1	2	4	97	3	**279**
Cloud	0	1	**24**	0	0	0	0	1	0	0	**26**
Scanty Vegetation	0	5	43	**6**	0	0	0	1	2	0	**57**
Grassland	0	8	0	25	**65**	0	0	0	10	12	**120**
Built-up Areas	0	0	1	0	0	**98**	1	1	1	0	**102**
Rocks	1	1	0	0	1	2	**84**	8	0	1	**98**
Bare Surface	0	3	0	0	0	9	12	**84**	1	0	**109**
Wetland	0	9	0	0	1	0	0	0	**7**	0	**17**
Forest	0	1	0	5	25	0	0	0	0	**83**	**114**
TOTAL	**99**	**100**	**97**	**99**	**100**	**110**	**99**	**99**	**118**	**99**	**1020**