University of Nairobi

School of Engineering

APPLICATION OF GIS AND REMOTE SENSING IN LAND USE ZONING:

Case study: Turkana County.

BY

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A Project report submitted in partial fulfillment of the requirements for the Degree of Master of Science in Geographic Information Systems.

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DECLARATION

I, **Maureen Wangari Munyagia**, hereby declare that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other University.

Maureen Wangari Munyagia

………………………………… ……………………… …………………

Name of student Signature Date

This project has been submitted for examination with my approval as University supervisor.

Prof. Galcano Mulaku

………………………………………… ……………………… …………………

Name of supervisor Signature Date

DEDICATION

I dedicate this project to the people of Turkana.

ACKNOWLEDGEMENTS

First, I would like to thank my supervisor Prof. Galcano Mulaku for his help during my project and for his great way of teaching and guidance which greatly helped during the project period. Secondly, I would like to thank my classmates, for their help during the course of carrying out this project Last but not least, I would like to thank my parents and friends that have been of great support to me during my studies.

ABSTRACT

Turkana County is a County in Kenya which spans 71,597.8 km² making it the largest County in Kenya and has a population of approximately 855,399 (Government of Kenya, 2010).

It is bordered by the countries of Uganda to the west, South Sudan to the North, Ethiopia to the Northeast, and Lake Turkana to the East. Neighbouring counties in Kenya are West Pokot to the South West, Baringo to the South and Samburu to South East. It is bound between latitudes 0.90 N and 5.5^0 N and longitudes 34^0E and 37^0E.

The project aimed at the development of land use zones for Turkana County with the use of remote sensing and Geographical Information Systems (GIS) technologies.

Spatial Multi-criteria Decision Analysis (MCDA) is a proven method for land-use planning purposes. However, most land-use planning applications focus on a specific theme, such as urban development and are often limited to a relatively small area.

As the project area was really large in size, 71,597.8 km², the approach used was with reference to the Land-Use Conflict Identification Strategy (LUCIS) model, which was developed at the University of Florida in The United States of America.

Criteria to be used for the suitability analysis were designed to suit the Turkana area and this resulted in the identification of data to be used, that is, land cover, rainfall, slope and lithological formation.

Four main land-use zones, that can support urban and settlement areas, rain fed agriculture, irrigated agriculture and livestock were then identified.

Stakeholder's involvement was realized by assigning weights to the goals and resulting preference maps. The Analytical Hierarchy Process (AHP) was used as the weighting method to assign weights to the objectives identified for the zones of interest. Suitability maps for the four zones were then created. Finally, the suitability maps of the three land-use categories were combined, in order to visualize conflict areas.

In conclusion, Turkana County has the potential to support urban and settlement areas, rain fed agriculture, irrigated agriculture and livestock and this could be implemented on the ground.

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ABBREVIATIONS AND ACRONYMS

GIS- Geographical Information Systems

MCDA- Multi-criteria Decision Analysis

LUCIS- Land Use Conflict Identification Strategy

AHP- Analytical Hierarchy Process

CI- Consistency Index

CR- Consistency Ratio

RI- Random Consistency

DSS- Decision Support System

Landsat-TM- Landsat Thematic Mapper

MOLA- Multiple-Objective Land Allocation

TRMM- Tropical Rain Measuring Mission

ASTER- Advanced Spaceborne Thermal Emission and Reflection Radiometer

DEM- Digital Elevation Model

ESRI- Environmental Systems Research Institute

USGS- United States Geological Survey

CHAPTER 1
INTRODUCTION

1.1 Background

In Kenya, 83% of the land area of 5,826,460 ha is arid and semi-arid, receiving rainfall of less than 700 mm per year. This rainfall is erratic and poorly distributed, which cannot reliably support food production. Agriculture in Kenya contributes 55% of the Gross Domestic Product (GDP), provides 80% of employment, accounts for 60% of export and generates about 45% of Government revenue (Blank et al, 2002).

A high population lives in rural areas, but with dwindling land holdings in high to medium potential areas, opening of new lands for agriculture in arid and semi-arid areas needs to be explored and intensified through the use of the remote sensing and GIS technology (Ndegwa and Kiiru, 2011).

Turkana County spans 71,597.8 km^2 and is the largest County in Kenya with a population of approximately 855,399 (Government of Kenya, 2010). It is bordered by the countries of Uganda to the west, South Sudan to the North, Ethiopia to the Northeast, and Lake Turkana to the East. Neighbouring counties in Kenya are West Pokot to the South West, Baringo to the South and Samburu to South East. It is bound between latitudes 0.90 N and 5.5^0 N and longitudes 34^0E and 37^0E. Figure 1 shows the map of the County in relation to its neighbouring counties and countries.

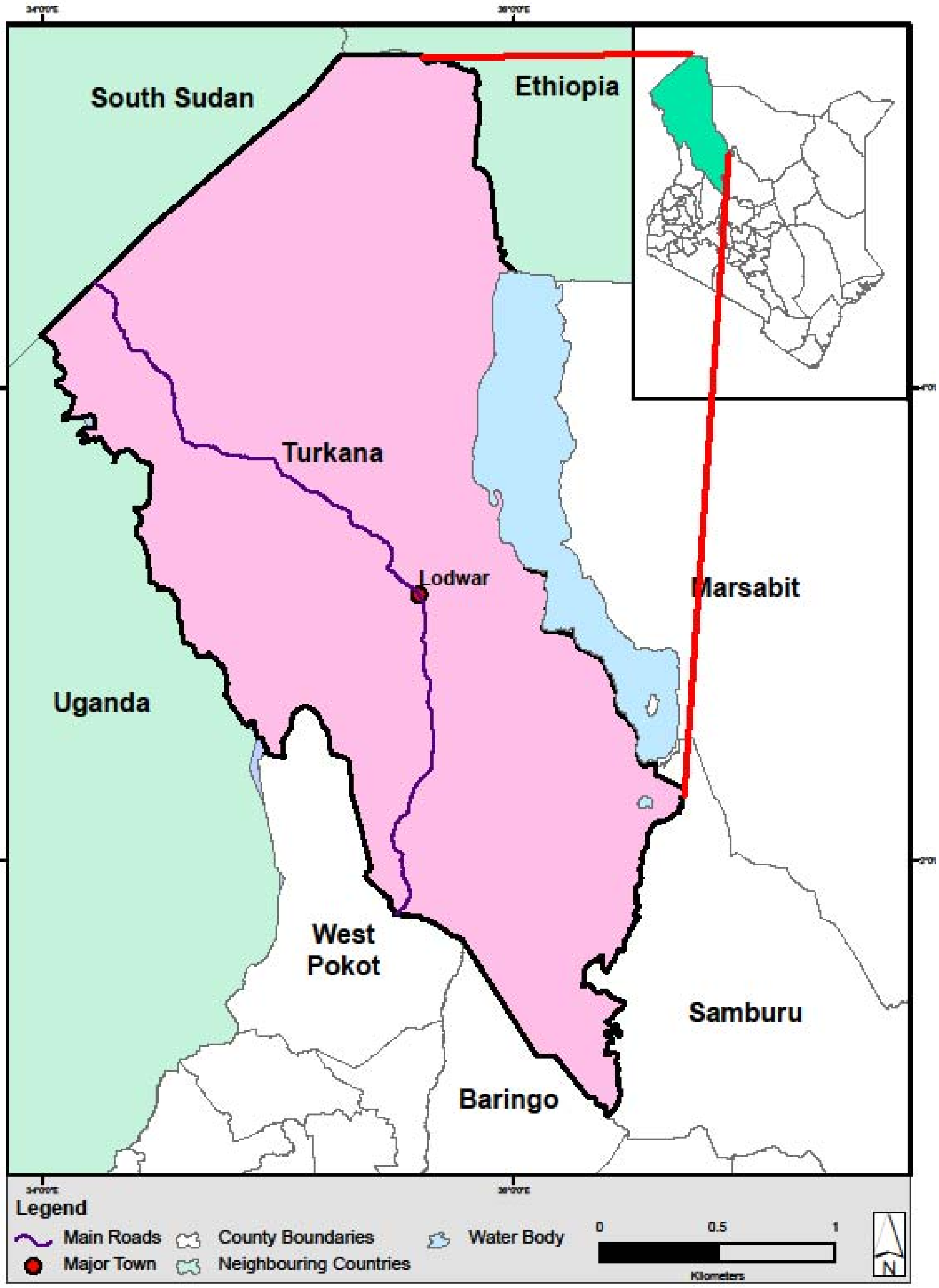

Figure 1: Map showing Turkana County

With the recent discovery of large reserves of groundwater in 2012 and oil resources in 2013 in the area, it is necessary to plan on the possible land uses that can be undertaken in the area to ensure that the available resources are put to optimal use and make the area more productive and this will in turn benefit the residents of the area.

The discoveries have also elicited a lot of interest from within and without the Kenyan borders and this will see a lot of development in the area in the future.

This needs to be preceded by strategic plans and important among them is land use zoning to ensure that all potential areas can be exploited to the fullest as well as avert conflict in land use in the future.

1.2 Problem Statement

The people of Turkana over rely on pastoralism and this has led to food insecurity in the area. As a result of climate change, the traditional livestock management systems being maintained have suffered a great deal and so have the people. A solution to this problem is proper land use zoning and implementation.

The Kenyan government has not been able to address the food security issue compared to many other parts of the world which are more arid. Attempts by Non-Governmental Organisations to meet food security have been there for a long time but the projects undertaken always have a short life cycle and have most of the time ended in failure.

There are no land use zones in place currently and thus land is not being used optimally to ensure that the people of Turkana benefit. The identification of land use categories will then ensure that land is put to optimal use for the most appropriate specific land use.

1.3 Objectives

The overall objective of this project is to apply GIS and remote sensing technologies to identify efficient and environmentally sound land use zones for different land uses for the Turkana area as well as identify possible conflict areas of these land uses.

The specific objectives were to carry out:

i. Image classification to identify current land cover.
ii. Identification of potential land use categories and their zones.
iii. Future land-use conflict identification of the identified land uses.

1.4 Justification for the Study

The goal of sustainable land use is to meet the needs of all current and prospective land users while at the same time ensuring that the natural resource base is protected for future users. The need for comprehensive land use data has been recognised for a long time and has provided an incentive for the development of land inventory and classification systems the world over. These systems have been implemented using both manual and digital systems. With manual systems, analogue data sources i.e. maps; aerial photographs and statistical data are systematically analysed using techniques such as overlay (McHarg, 1969) to produce land capability/suitability maps on the basis of which decisions on land allocation are made.

While such processes produce objective decisions, manual analysis methods have several limitations including, inflexibility, cumbersome to use and difficult to update. Most of these deficiencies can be overcome by computerising data sources and analysis using Geographic Information Systems. Besides enhancing data analysis, computerised data systems provide a medium for data integration, where spatial and non-spatial data from disparate sources are captured and stored together in a digital database. If properly organised, such databases allow easy data access for both utilisation and update. Finally, the flexibility with which output can be displayed ensures that information gets to the various users in formats and details most suitable to them.

1.5 Scope of work

For this study, digital land cover information was derived using image processing and analysis. The digital processing involved:

i) Generation of an enhanced colour composite of the area from LandSat 8 images.
ii) Supervised classification using maximum likelihood classifier.
iii) Current land cover identification

Determination of land use zones using the land cover for the area, slope data, rainfall data and lithological formation. Future land use conflict was also identified with the use of weighting using AHP as the weighting method.

1.6 Organisation of the report

This report is organised into five chapters. Chapter one presents a background into the subject and the study area, states the problem, highlights the objectives of carrying out the project, justification for carrying out the project as well as the scope of work carried out. Chapter two describes a literature review of suitability analysis and land use zoning. First, a history of suitability analysis is discussed; second, the use of GIS and remote sensing in land use zoning is discussed; third, the LUCIS model is discussed. Finally, stakeholder involvement using the AHP weighting method is discussed. Chapter three describes the materials and methods used. First, the criteria and datasets used are highlighted, second; suitability analysis for the land zones is discussed and finally land use conflict identification is discussed. Chapter four presents the results obtained and discusses these results. Chapter five draws conclusions and recommendations for possible future work. This is followed by references and appendices.

CHAPTER 2
LITERATURE REVIEW

2.1 History of suitability analysis

The use overlay maps for land-use suitability analysis started in the late nineteenth and early twentieth century, (Miller and Elliot (1993); McHarg (1996)). Sun prints and the overlay of transparent sheets on a window, we used to view site characteristics. At a later stage, halfway through the twentieth century, new methods were developed.

Tyrwhitt (1950) published an article about town and country planning, giving an example of a new overlay technique. Four maps were drawn on transparent paper about soil, relief, hydrology and rock types, all at the same scale and referenced to common control features. Sieve mapping was used, where areas with constraints were eliminated and the remaining areas were defined as suitable (Steinitz *et al*., 1976). This method was widely accepted and used for planning purposes in both North America and Great Britain (Lyle and Stutz, 1983).

The publication of McHarg's Design of nature in 1969 was an important step in suitability analysis. He was the first to use transparent maps with light and dark values for different factors, and then superimposed them over each other to create suitability maps (Belknap and Furtado, 1967; McHarg, 1969; Gordon, 1985).

2.2 GIS and remote sensing in land use zoning.

Proper land-use planning involves making knowledgeable decisions about land use and the environment. Holistic planning involves input from multiple, interrelated data sources and types. In order to accomplish this feat, a great deal of information must be considered simultaneously. Intensification of land use is thus crucial for the purpose of increasing and stabilizing agricultural production for an ever expanding population that is being experienced in Kenya and the world over. The needs of the expanding population are most acute in the arid and semi-arid regions where food and water requirements are greatest while the supplies are minimal.

Remote sensing and GIS are fundamental tools for the inventory and analyses of natural resources for planning, management and development.
The integrated use of GIS and image processing technologies provide specific examples involving water, soil and vegetation resources management applications.
The technologies of remote sensing and GIS are very important for the study of semi-arid and arid regions of the world and are adequate for the classification of soils, land survey and for land use classification.

Van Ittersum *et al.* (1998) describe three main stages in the process of land-use planning:

i. an evaluation of land suitability for each land-use type,
ii. the optimization of the different land-use areas,
iii. the spatial allocation of land-uses.

Anderson et al (1976), defined land use and land cover classification categories which have been in use with modifications depending on the areas and context under consideration. These are shown in Table 1.

Geographical Information System (GIS) technology is an important part of the land-use zoning process. The various factors to be taken into account need to be analysed, visualised and presented to support decision-making. One of the most commonly used methods for land-use decision making is spatial Multi Criteria Decision Analysis (MCDA). This method combines all the spatial factors that are important, and results in a map with the best locations for a certain type of land-use. Recent literature surveys show that MCDA has attracted significant interest over the past 15 years (Malczewski 2004, 2006; Mendoza and Martins, 2006).
Most often with spatial MCDA, the goal is to find the most suitable location for a certain object. Existing Spatial Decision Support Systems (SDSS), which are decision making tools that make use of spatial MCDA, often concentrate on a specific stage of land-use planning.

Table 1: Land use and land cover classification categories (Anderson 1976)

Level I	Level II
1 Urban or Built-up Land	11 Residential
	12 Commercial and Services
	13 Industrial
	14 Transportation, Communications, and Utilities
	15 Industrial and Commercial Complexes
	16 Mixed Urban or Built-up Land
	17 Other Urban or Built-up Land
2 Agricultural Land	21 Cropland and Pasture
	22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
	23 Confined Feeding Operations
	24 Other Agricultural Land
3 Rangeland	31 Herbaceous Rangeland
	32 Shrub
	33 Mixed Rangeland and Brush Rangeland
4 Forest Land	41 Deciduous Forest Land
	42 Evergreen Forest Land
	43 Mixed Forest Land
5 Water	51 Streams and Canals
	52 Lakes
	53 Reservoirs
	54 Bays and Estuaries
6 Wetland	61 Forested Wetland
	62 Nonforested Wetland
7 Barren Land	71 Dry Salt Flats
	72 Beaches
	73 Sandy Areas other than Beaches
	74 Bare Exposed Rock
	75 Strip Mines Quarries, and Gravel Pits
	76 Transitional Areas
	77 Mixed Barren Land
8 Tundra	81 Shrub and Brush Tundra
	82 Herbaceous Tundra
	83 Bare Ground Tundra
	84 Wet Tundra
	85 Mixed Tundra
9 Perennial Snow or Ice	91 Perennial Snowfields
	92 Glaciers

Source: Anderson (1976)

A few systems, consider all the three stages afore mentioned and these include, What-If? (Klosterman, 1999), SIRTPLAN (FAO 2000), the Rural Land-use Exploration System (RULES) (Santé-Riveira et al., 2008) and the Land-Use Conflict Identification Strategy (LUCIS) model Carr and Zwick, 2007). What-if? has a focus on urban planning (Klosterman *et al*., 2003; Kim, 2004). The SIRTPLAN system, is a group of independent programmes, and uses a strictly defined methodology which makes it difficult to apply (Santé-Riveira et al., 2008).
RULES is a planning support system for rural land-use allocation, and is demonstrated with a case study in northwest Spain. It is innovative because all three land-use planning stages are incorporated in one tool (Santé-Riveira et al., 2008).

The LUCIS model does not have a specific focus on a certain type of land-use planning, and is therefore particularly suitable for regional and countrywide planning. It consists of three general models, describing the suitability of urban, agriculture, and conservation land-use. Finally, these three land-uses are combined to identify conflicts. Its broad focus makes it particularly suitable, and will therefore be used as reference point for this project.

2.3 The LUCIS model

Land-Use Conflict Identification Strategy (LUCIS) was developed at the University of Florida (Department of landscape architecture and department of urban and regional planning).
Ten years of development resulted in a comprehensive GIS model, and was tested with the help of a case study of an area composed of nine counties in North Central Florida (Carr and Zwick, 2007).

The GIS model is goal driven, and produces a spatial representation of probable patterns of future land-use. There are three major land-use categories: urban, agriculture and conservation. The concept of this design was firstly used by Odum (1969), and later redesigned by Carr and Zwick (2007). Each of these categories consisted of goals, objectives and sub-objectives. Weights were used to assign importance to each of them. Carr and Zwick (2007) subdivided the model in five general steps, which are shown in the Figure 2.

Step 1: Goals and Objectives

Define goals and objectives that become the criteria for determining suitability.

↓

Step 2: Data Inventory

Identify data resources potentially relevant to each goal and objective

↓

Step 3: Suitability

Analyse data to determine relative suitability for each goal

↓

Step 4: Preference

Combine relative suitability of each goal to determine preference for the three major land use categories

↓

Step 5: Conflict

Compare the three land use preferences to determine likely areas of future land-use conflict

Figure 2: Five main stages of the LUCIS model.

Goals and objectives are a hierarchy set of statements, which are used as the criteria for determining suitability. Data inventory involves the selection of suitable data for the suitability analysis. Suitability analysis involves the creation of land-use suitability maps for each goal earlier defined. For preference, the suitability from step 3 is transformed into preference. The outputs of the goals within one land-use category are combined with the use of weights, which then result in a single preference output for each land-use category. Future land-use conflict identification involves the use of preference maps of the individual land-use categories from step four as input.

2.4 Analytical Hierarchy Process

In any project, stakeholder's involvement is of paramount importance and their demands need to be taken into consideration. Their demands should be analysed and visualised to support discussions and the decision-making process. In cases where stakeholder participation cannot be accomplished, weighting can be applied to the various criteria under consideration.

The Analytical Hierarchy Process (AHP), a weight assigning technique, was developed by Saaty (1980). It has been widely applied on various complex decision making problems, not only in the field of GIS but also in many other fields (Contreras *et al*., 2008) for example in the selection of a vendor for the entertainment system on board of the entire British Airways fleet, to allocate resources to their activities by the Department of Defence in the US, to allocate money on research projects, and for student admissions, personnel promotions and hiring decisions (Saaty, 2008).

The AHP can be summarized as follows:

i. First, the unstructured problem must be decomposed in a hierarchical structure, usually consisting of goals, objectives and sub-objectives.
ii. Secondly, relative ratings are obtained using pair-wise comparisons between the different criteria or alternatives. The ratings of the criterion range in values between 1 and 9, describing the intensity of importance over one another. See Appendix A for a detailed description of the suggested values.)
iii. Thirdly, pair-wise comparisons are used as input in the pair-wise comparison matrix.
iv. The fourth step of the process is the calculation of the weights, and can be further subdivided in three sub-steps:
    - Firstly, the columns of the pair-wise comparison matrix are summed,
    - Secondly, all individual matrix elements are divided by their column total, which results in a normalized pair-wise comparison matrix.
    - By computing the average of the elements in each row of the normalized matrix, the final weight can be obtained.
v. Finally, estimation of the consistency ratio (CR) is done to determine the consistency of the comparisons (Malczewski, 2004). This can be subdivided in two sub-steps:

- Firstly, the weighted sum vector is calculated.
- Second, is the calculation of Lambda (average of previously calculated values), the consistency index (CI) and Consistency ratio (CR).

If CR < 0.10, it indicates that there is a reasonable level of consistency in the pair-wise comparisons. If the value is ≥ 0.10, it means that comparisons are inconsistent and have to be reconsidered.

In the case of group decision making, individual weights of the participants need to be aggregated into a single weight for the specific criterion. According to Saaty (2008), only the geometric mean can be used here, not the widely used arithmetic mean.

One of the main advantages of AHP is its simplicity in use, and the corresponding potential to support participation by a wide range of groups, like stakeholders, community leaders, experts and the general public (Saaty, 1980; Malczewski, 1999). Due to its simplicity, people with different backgrounds can work together effectively. Furthermore, personal preferences are suppressed by using pairwise comparisons where alternatives are weighted against each other. It is therefore harder to get the predetermined preference on top of the list from the final weight of the alternatives. The method, in spite of its broad use, has also received some criticism (Goodwin and Wright, 1998). It is argued that the questions of the pairwise comparison are meaningless.
To illustrate this critique, if criterion x is compared with criterion y, the decision maker should know how much of criterion x (cost) is compared with how much of criterion y (quality of environment) (Malczewski, 1999). The answer to this criticism is to think of average quantities and qualities in order to be able to give a reasonable judgement (Malczewski, 1999). In addition, another point of criticism is the so called rank reversal problem (Belton and Gear, 1983). In short, the rank of a criterion might change when a criterion is removed or added from the initial set of criteria. To overcome or minimise this problem, it is important to develop a complete set of criteria.

Various remote sensing data have been used for earth resources management and development of semi-arid regions by different stakeholders the world over. In India, a research was conducted on soil and land use distribution over a part of the northern plains, Indus- Gangetic plains, based on the optical interpretation of LandSat-2 multispectral satellite imagery. In Brazil, studies for land use and land capability mapping for resource management were carried out in the Semi-arid region of Paraiba, Brazil (Teotia and Santos, 2010).

Mwasi (2001) carried out a study on a land use conflict resolution process that uses a GIS based decision support system to optimise land use allocation in a semi-arid area within the Baringo district of Kenya. The system considers multiple land use objectives, determines the amount of land required by each together with their ecological requirements. An appropriate digital database was then created from which the twin processes of multi-criteria evaluation and multi-objective decision making are applied so as to allocate the available land such that all the objectives are satisfied with minimal environmental and socio-economic conflicts. The decision-making tools incorporated within the Decision Support System (DSS) module of the IDRISI for Windows were used. He however noted that the participatory decision making approach, where stakeholders strive to reach a consensus on land use prioritisation, needs to be adopted.

Present land use patterns were obtained from a classified 1995 Landsat-TM image and carry out optimised land use allocation from MOLA. Optimal lands for rain fed agriculture (maize, millet and groundnuts cultivation) seemed to agree with the present land use patterns. Land currently occupied by sisal plantations was allocated to millet and grazing. This is because sisal and millet compete for the same lands and millet and grazing were given higher priorities relative to sisal in order to enhance food security. The Loboi plains, which were currently occupied by irrigation schemes, were allocated to conservation. This was caused by their high ratings in rockiness and erosion extent. The sites identified as ideal for urban development were strongly influenced by population density than by any other factor. Although vegetation characteristics were not put into consideration, there seemed to be a general trend towards protecting sparsely vegetated areas (Mwasi, 2001).

CHAPTER 3
MATERIALS AND METHODS

3.1 Criteria and datasets

For the suitability analysis to be performed successfully, suitable criteria had to be defined. The criteria chosen were the use of land cover, rainfall, slope and lithological formation data to identify different land use zones. These were then used to decide on four major land use categories to be explored. These categories were urban and settlement areas, rain fed agriculture, irrigated agriculture and livestock areas.

Different types of data required for the selected criteria to be met were then identified.
These were administrative boundaries, land cover, rainfall, slope, lithological formation and protected areas. Administrative boundaries and protected areas were obtained from Survey of Kenya. Identification of the land cover was made by image classification of LandSat 8 imagery pan-sharpened using the panchromatic band 8. Rainfall data was sourced from TRMM. Slope was derived from the ASTER DEM. Lithological formation was obtained from the International Livestock Research Institute (ILRI) website. ESRIs' ArcGIS 10.0 Model Builder was used extensively to create models for the individual criterion identified and for the suitability analysis.

There was need to set a common measurement scale for all the datasets and as there resulted in six land covers from image classification, rainfall and slope data were reclassified into six discreet integer values with 6 representing the most suitable and 1 representing the least suitable. Lithological formation only had four different classes and thus the reclassification was done into four discreet integer values with 4 representing the most suitable and 1 representing the least suitable.

LandSat 8 imagery was sourced from the United States Geological Survey (USGS) website.
The panchromatic band, band 8, was use to pan sharpen the imagery to improve the image quality and to achieve better classification accuracy. This was done using the ERDAS IMAGINE software. A model for the creation of a mosaic of the images and clipping the data to be within the area of interest was then created; see Appendix B for the model. Image classification was

then carried out on the resulting image mosaic and six land covers were extracted: shrubs, urban and settlement areas, bare areas, vegetation, lake water and other water.

As the area is arid, it does not receive a lot of rainfall and thus there was need to use data spanning a long time period in order to get a good average of the rainfall in the area. Annual average data from 2000 to 2010 was downloaded from the TRMM project website. A model for extracting the data covering the area of interest and reclassifying it into six classes was then created; see Appendix C for the model.
#

For the derivation of slope for the area of interest, ASTER DEM data was downloaded from the USGS website. A model for extracting the data that covers the area of interest, deriving the slope and reclassifying it into six classes was then created; see Appendix D for the model. As the resulting classes had the highest class with the highest slope and the lowest class with the least slope, reversing of the slope values was applied in order to assign high class values to the values representing less steep slope and the lower class values to represent the highest steep areas.

The lithological data was in vector format and required to be converted to raster format. It also required clipping to the area of interest. A model to do the conversion, clipping to the area of interest and reclassifying into four classes was created; see Appendix E for the model.

The protected areas data was in vector format and required to be converted to raster format. It also required clipping to the area of interest. A model to do the conversion and clipping was created; see Appendix F for the model

3.2 Suitability analysis

Models for the three land use categories were developed in ESRIs' ArcGIS 10.0 Model Builder for use in determining the most suitable areas Weights assigned to the objectives were calculated using the AHP method and were used in the model.

The four land use categories identified were treated as goals and their objectives were defined. For the rain-fed agriculture, objectives identified were: existing agriculture, rainfall sufficient to sustain agriculture, slope suitable for agriculture and lithological formation suitable for agriculture. For land suitable for livestock, objectives identified were: bare areas, slope suitable for livestock, closeness to settlement areas and rainfall suitable for livestock. For irrigated agriculture, objectives identified were: existing agriculture, slope suitable for irrigation, lithological formation suitable for agriculture and closeness to water body for irrigation.

For each goal, weights for the different objectives were calculated using AHP as described below.

1. Pair-wise comparisons of the objectives were used as input in the pair-wise comparison matrix. The ratings of the criterion range were decided using the values suggested by Saaty (1980). For example, if existing agriculture is of equal importance as compared to lithological formation, the value of 1 is assigned to the corresponding matrix position and the reciprocal value, in this case 1/1, will be assigned to the transpose position
2. Individual matrix elements of the pair-wise comparison matrix were divided by their column total, resulting in a normalized pair-wise comparison matrix.
3. Final weights were computed by getting the average of the elements in each row of the normalized matrix.
4. Finally estimation of the consistency ratio to determine the consistency of the comparisons was carried out. First, the weighted sum vector was calculated. This is done by multiplying the weight of the first criterion (residential) times the first column of the original pair-wise comparison matrix, and then the second weight times the second column, and so on. Finally the values from the rows are summed and divided by the earlier obtained weights.
5. Lambda λ, was calculated as the average of previously calculated values.
6. The consistency index (CI) was calculated using the formula
   $(\lambda - n) / (n - 1)$ where n is number of objectives
7. Consistency Ratio (CR) was calculated as CI / RI (where RI is Random Consistency Index obtained from the Random Consistency Index table)

If CR < 0.10, it indicates that there is a reasonable level of consistency in the pair-wise comparison but if the value is ≥ 0.10, it means that comparisons are inconsistent and have to be reconsidered.

Table 2: Random Consistency Index (Saaty 1980)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

3.2.1. Rain-fed agriculture land use

The goal was decomposed into four objectives: existing agriculture, rainfall sufficient to sustain agriculture, slope suitable for agriculture and lithological formation suitable for agriculture.

The pair-wise comparison matrix of the objective ratings is as below:

Criterion	Rainfall	Land cover	Slope	Lithology
Rainfall	1	1	3	2
Land cover	1.000	1	2	2
Slope	0.333	0.500	1	2
Lithology	0.500	0.500	0.500	1

The AHP Normalized pair-wise comparison matrix is as below:

Criterion	Rainfall	Land cover	Slope	Lithology
Rainfall	0.353	0.333	0.462	0.286
Land cover	0.353	0.333	0.308	0.286
Slope	0.118	0.167	0.154	0.286
Lithology	0.176	0.167	0.077	0.143

Final weights calculated were:

Criterion	Weight
Rainfall	0.358
Land cover	0.320
Slope	0.181
Lithology	0.141

For the calculation of consistency ratio, the sum vector was calculated as:

Criterion	Rainfall	Land cover	Slope	Lithology	
Rainfall	0.358	0.320	0.543	0.281	**4.193**
Land cover	0.358	0.320	0.362	0.281	**4.131**
Slope	0.119	0.160	0.181	0.281	**4.099**
Lithology	0.179	0.160	0.090	0.141	**4.053**

$$\lambda = (4.193 + 4.131 + 4.099 + 4.053) / 4$$

$$= 4.119$$

$$CI = 0.040$$

$$CR = 0.044$$

A model for the objectives was then created in Model Builder and the weights obtained above used to establish potential areas for rain fed agriculture. The protected areas were used as mask as the areas they cover cannot be assigned to any other land use. See Appendix G for the model created.

3.2.2 Irrigated agriculture land use

The goal was decomposed into four objectives: bare areas, slope suitable for livestock, closeness to settlement areas and rainfall suitable for livestock.

The pair-wise comparison matrix of the objective ratings is as below:

Criterion	Slope	Land cover	Lithology	Rainfall
Slope	1	1	2	3
Land cover	1	1	3	2
Lithology	0.500	0.333	1	2
Rainfall	0.333	0.500	0.500	1

The AHP Normalized pair-wise comparison matrix is as below:

Criterion	Slope	Land cover	Lithology	Rainfall
Slope	0.353	0.353	0.308	0.375
Land cover	0.353	0.353	0.462	0.250
Lithology	0.176	0.118	0.154	0.250
Rainfall	0.118	0.176	0.077	0.125

Final weights calculated were:

Criterion	Weights
Slope	0.347
Land cover	0.354
Lithology	0.174
Rainfall	0.124

For the calculation of consistency ratio, the sum vector was calculated as:

Criterion	Slope	Land cover	Lithology	Rainfall	
Slope	0.347	0.354	0.349	0.372	**4.098**
Land cover	0.347	0.354	0.523	0.248	**4.157**
Lithology	0.174	0.118	0.174	0.248	**4.093**
Rainfall	0.116	0.177	0.087	0.124	**4.065**

$\lambda = (4.098 + 4.157 + 4.093 + 4.065) / 4$

$= 4.103$

$CI = 0.034$

$CR = 0.038$

A model for the objectives was then created in Model Builder and the weights obtained above used to establish potential areas for irrigated agriculture land use. The protected areas were used as mask as the areas they cover cannot be assigned to any other land use. See Appendix H for the model created.

3.2.3 Livestock land use

The goal was decomposed into four objectives: bare areas, slope suitable for livestock, closeness to settlement areas and rainfall suitable for livestock.

The pair-wise comparison matrix of the objective ratings is as below:

Criterion	Land cover	Rainfall	Slope	Lithology
Land cover	1	3	2	2
Rainfall	0.333	1	1	2
Slope	0.500	1.000	1	2
Lithology	0.500	0.500	0.500	1

The AHP Normalized pair-wise comparison matrix is as below:

Criterion	Land cover	Rainfall	Slope	Lithology
Land cover	0.429	0.545	0.444	0.286
Rainfall	0.143	0.182	0.222	0.286
Slope	0.214	0.182	0.222	0.286
Lithology	0.214	0.091	0.111	0.143

Final weights calculated were:

Criterion	Weights
Land cover	0.426
Rainfall	0.208
Slope	0.226
Lithology	0.140

For the calculation of consistency ratio, the sum vector was calculated as:

Criterion	Land cover	Rainfall	Slope	Lithology	
Land cover	0.426	0.624	0.452	0.280	**4.183**
Rainfall	0.142	0.208	0.226	0.280	**4.111**
Slope	0.213	0.208	0.226	0.280	**4.101**
Lithology	0.213	0.104	0.113	0.140	**4.077**

$\lambda = (4.183 + 4.111 + 4.101 + 4.077) / 4$

$= 4.118$

$CI = 0.039$

$CR = 0.044$

A model for the objectives was then created in Model Builder and the weights obtained above used to establish potential areas for livestock land use. The protected areas were used as mask as the areas they cover cannot be assigned to any other land use. See Appendix I for the model created.

3.2.4 Urban and settlements land use

The goal identified was to find the most suitable land for urban and settlement areas. This goal was decomposed into four objectives: existing urban area, rainfall suitable for urban areas, slope suitable for urban development and lithological formation suitable for urban development. 0

The pair-wise comparison matrix of the objective ratings is as below:

Criterion	Land cover	Slope	Lithology	Rainfall
Land cover	1	3	3	3
Slope	0.333	1	1	2
Lithology	0.333	1.000	1	3
Rainfall	0.333	0.500	0.333	1

The AHP Normalized pair-wise comparison matrix is as below:

Criterion	Land cover	Slope	Lithology	Rainfall
Land cover	0.500	0.545	0.563	0.333
Slope	0.167	0.182	0.188	0.222
Lithology	0.167	0.182	0.188	0.333
Rainfall	0.167	0.091	0.063	0.111

Final weights calculated were:

Criterion	Weights
Land cover	0.485
Slope	0.190
Lithology	0.217
Rainfall	0.108

For the calculation of consistency ratio, the sum vector was calculated as:

Criterion	Land cover	Slope	Lithology	Rainfall	
Land cover	0.485	0.569	0.652	0.323	**4.181**
Slope	0.162	0.190	0.217	0.216	**4.137**
Lithology	0.162	0.190	0.217	0.323	**4.105**
Rainfall	0.162	0.095	0.072	0.108	**4.052**

$\lambda = (4.181 + 4.137 + 4.105 + 4.052) / 4$

$= 4.119$

CI $= 0.040$

CR $= 0.044$

A model for the objectives was then created in Model Builder and the weights obtained above used to establish potential areas for urban use. The protected areas were used as mask as the areas they cover cannot be assigned to any other land use. See Appendix J for the model created.

3.3 Land use conflict identification.

The final stage aimed at identifying future land-use conflicts. The land use zone maps of the individual land-use categories were used as input. Water bodies and protected areas had to be left out of consideration for this analysis, because they already had a permanently designated land-use and thus a mask was applied that covered all these areas. The land use zones were then normalized as they did not contain the same values and it was necessary to use the same scale when doing the conflict identification.

The divide tool in ArcGIS was used with the cell values being divided by the highest value present in the concerned land use map. The output for the individual land uses contained values between 0 and 1. The normalized land uses were then collapsed into three classes, low, medium and high preference. Standard deviation is usually the best method for collapsing preferences, because it results in the most even distribution (Carr and Zwick (2007) and was thus used to collapse the normalized land uses.

To be able to identify preference differences and possible conflicts between the land-use categories, the collapsed land uses were reclassified in different ways. Rain fed agriculture was reclassified into: low preference 1, medium preference 2 and high preference 3. Irrigated agriculture was reclassified into: low preference 10, medium preference 20 and high preference 30. Livestock was reclassified into: low preference 100, medium preference 200 and high preference 300. Urban was reclassified into: low preference 1000, medium preference 2000 and high preference 3000.

The three were then combined to produce a single raster that represented potential land-use conflicts. The resulting raster values showed areas of low, medium and high preference. For example, a cell with a value of 1111 shows that all the four land uses have low preference, and a cell with value 3321 shows that urban/settlements and livestock have high preference, irrigated agriculture has medium preference and rain fed agriculture has low preference. See Appendix K for the model used for this analysis.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1. Results

4.1.1 Current land cover

Image classification resulted in a land cover map with 6 land cover classes as shown in Figure 3.

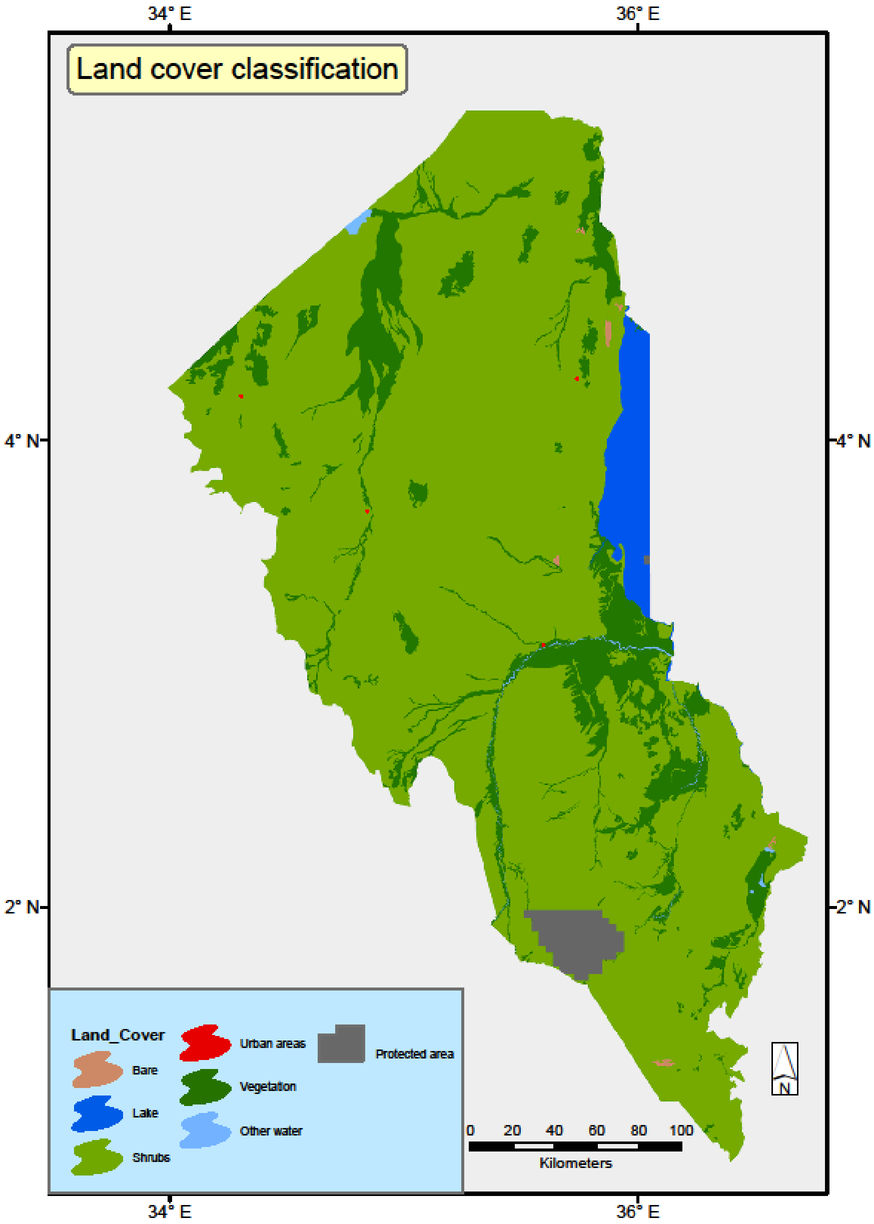

Figure 3: Map showing the current land cover

4.1.2 Land suitable for rain fed agriculture

Land suitable for rain fed agriculture was obtained once the model was run and the output is as shown in the Figure 4.

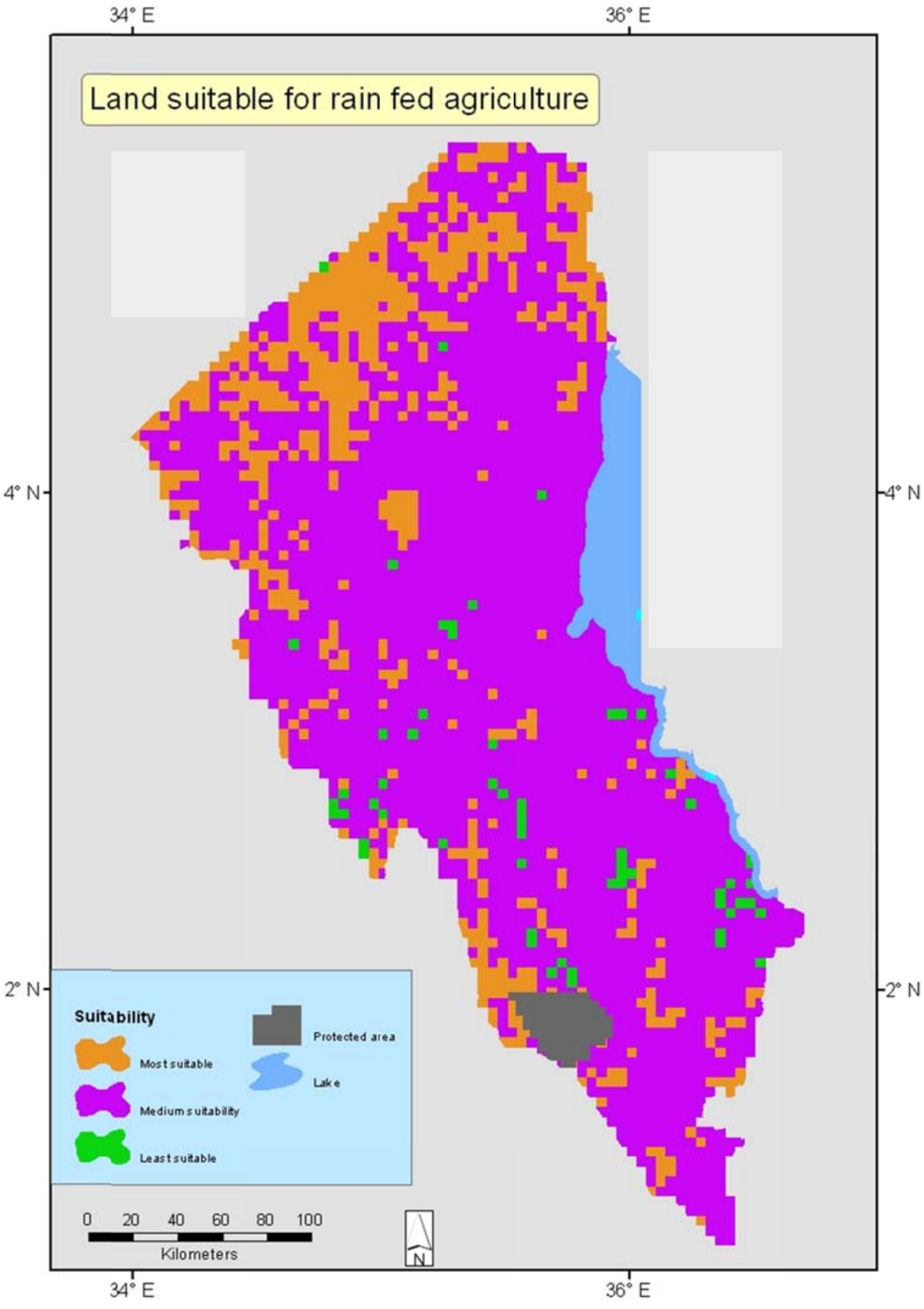

Figure 4: Map showing suitability areas for rain fed agriculture use

4.1.3 Land suitable for irrigated agriculture

Land suitable for irrigated agriculture was obtained once the model was run and the output is as shown in the Figure 5.

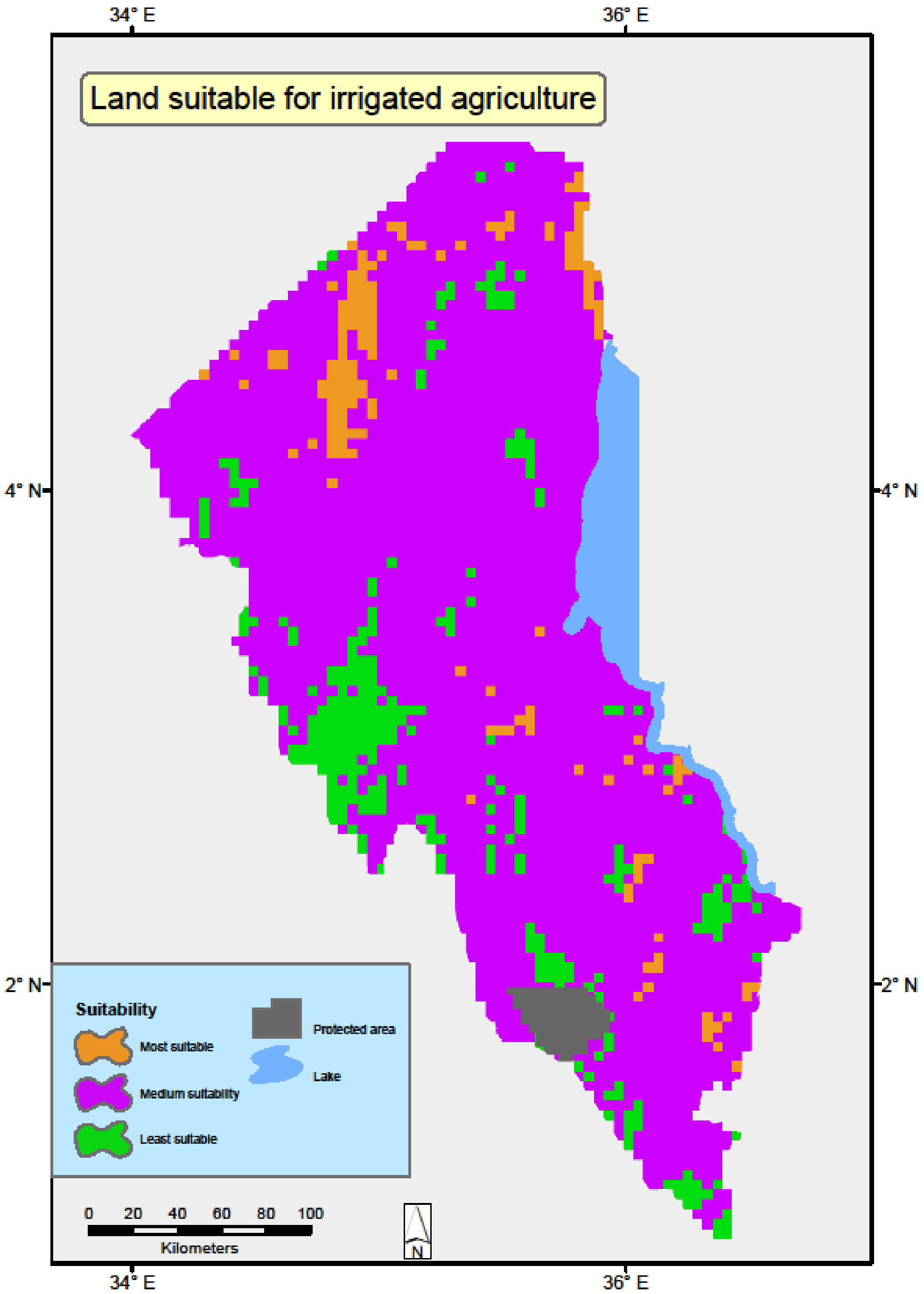

Figure 5: Map showing suitability areas for irrigated agriculture use

4.1.4 Land suitable for livestock

Land suitable for livestock use was obtained once the model was run and the output is as shown in the Figure 6.

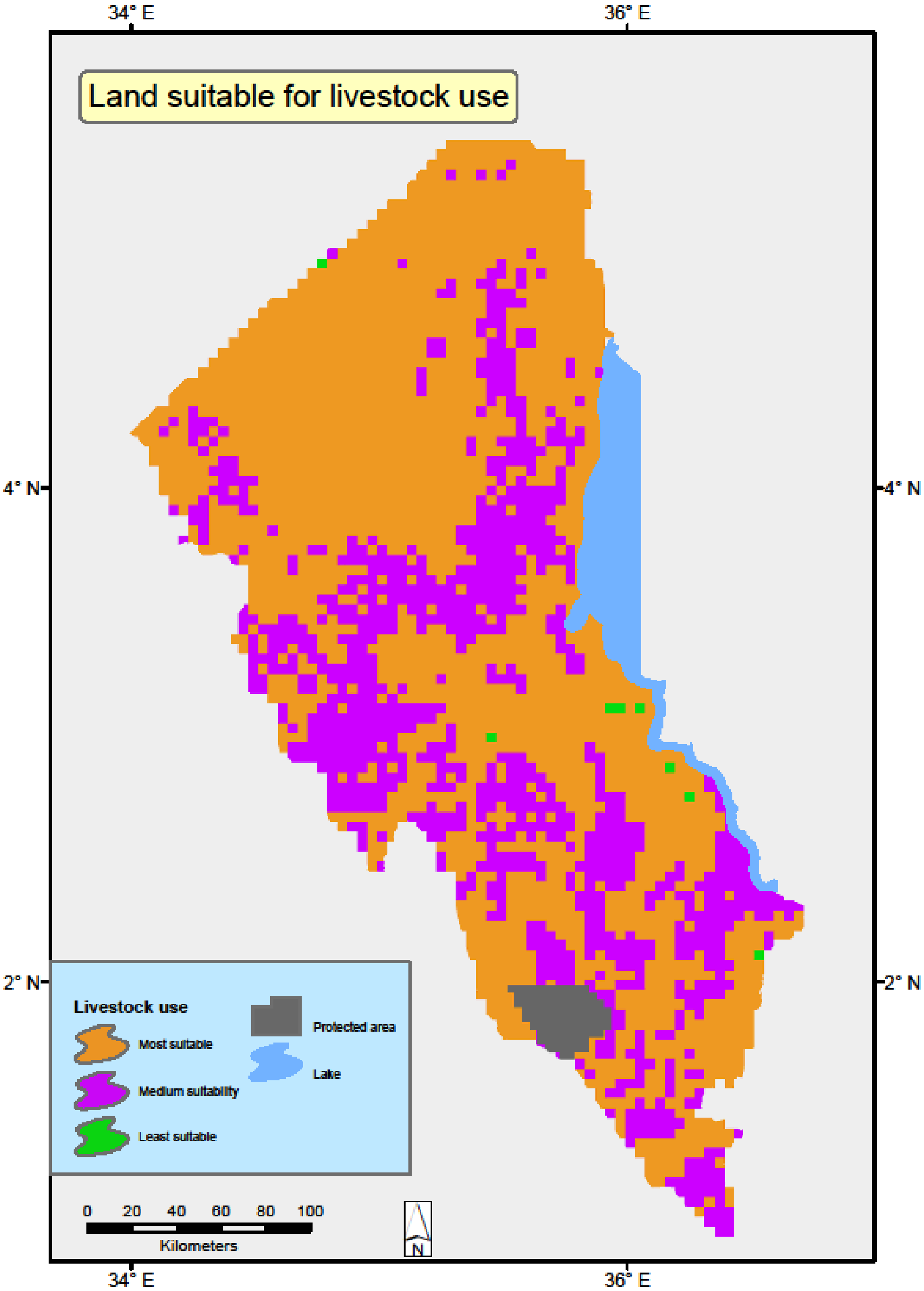

Figure 6: Map showing suitability areas for livestock use

4.1.5 Land suitable for urban and settlement areas

Land suitable for urban and settlements use was obtained once the model was run and the output is as shown in the Figure 7.

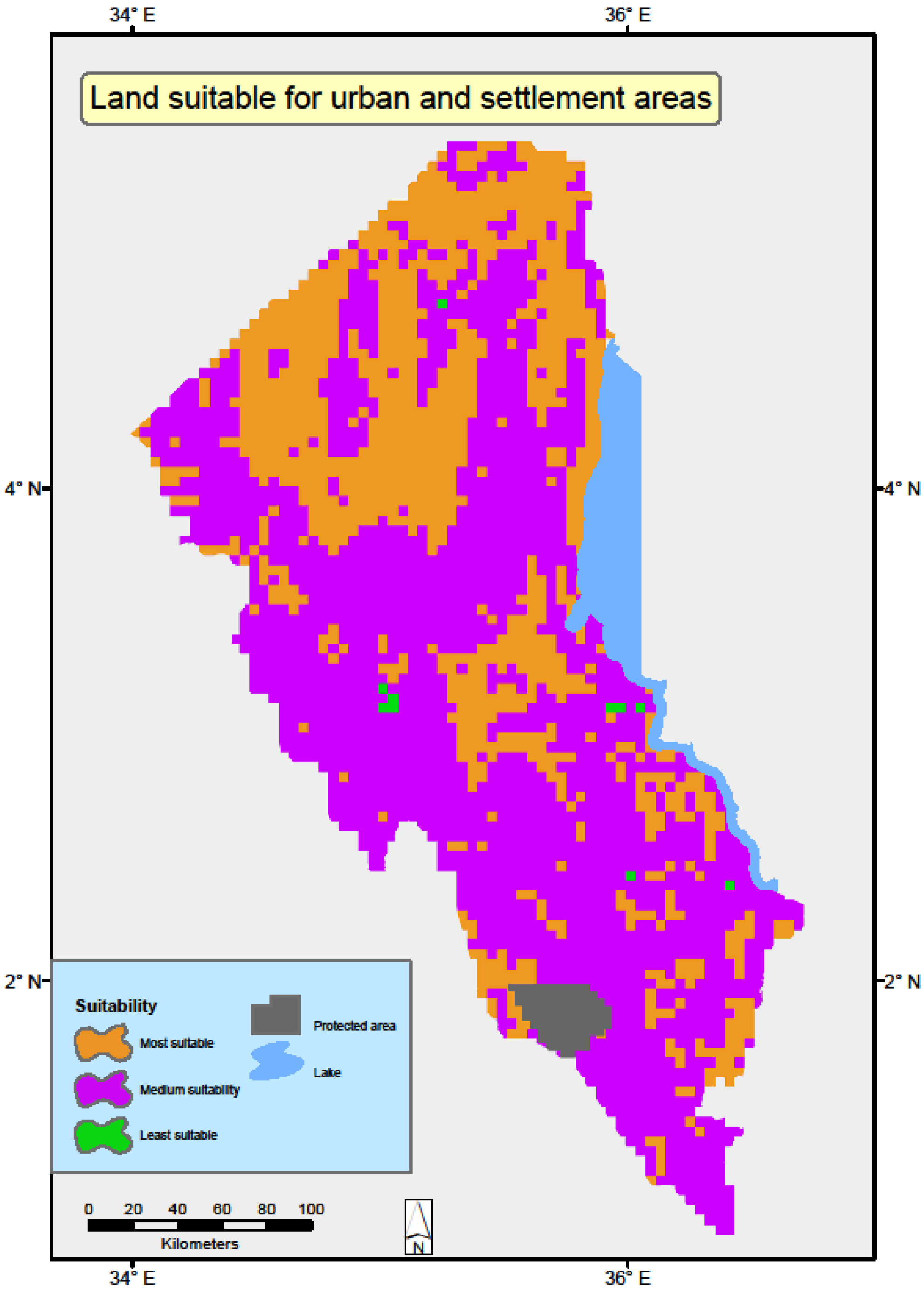

Figure 7: Map showing suitability areas for urban and settlement use

4.1.6 Future land use conflict areas

Areas of future land use conflict were obtained from running the model that had earlier been developed and the output is as shown in the Figure 8.

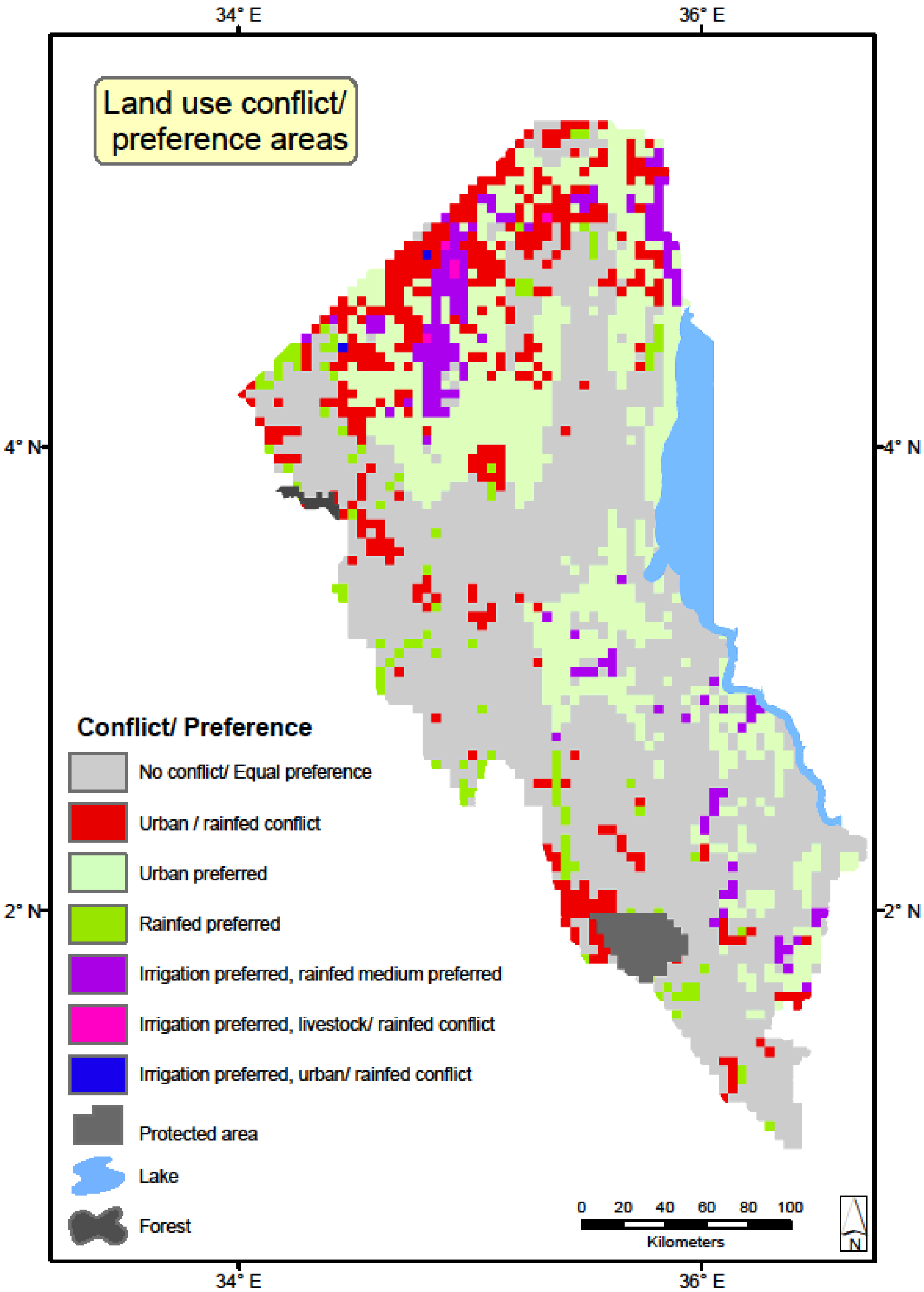

Figure 8: Map showing land use preference and conflict areas

4.2. Discussions

The project involved the determination of land use zones that can support rain fed agriculture, urban and settlement areas, irrigated agriculture and livestock. In contrast with most other land-use planning applications, the approach used does not focus on land use allocation but consists of various land-use categories that can give shape to the County.

4.2.1 Land cover

Land cover classification involved the determination of land cover. Six land cover classes were identified: urban and settlement areas, bare areas, shrub areas and lake.

4.2.2 Land suitable for rain fed agriculture

The resulting raster had 680 pixels for the most suitable areas, 2644 pixels for medium suitability areas and 68 pixels for the least suitable areas. This translates into the areas that are most suitable for rain fed agriculture covering 20% of the whole County, areas of medium suitability covering 78% of the whole County and the areas which are least suitable for rain fed agriculture covering 2% of the whole County. This agrees with the land cover classification as most of the land was covered in shrubs and the vegetation only covered certain parts and the bare areas were very few. Rain fed agriculture can therefore not be solely relied upon as its most suitable area is not big enough to provide enough food for the people.

4.2.3 Land suitable for irrigated agriculture

The resulting raster had 162 pixels for the most suitable areas, 2897 pixels for medium suitability areas and 333 pixels for the least suitable areas. This translates into the areas that are most suitable for irrigated agriculture covering 5% of the whole County, areas of medium suitability covering 85% of the whole County and the areas which are least suitable for irrigated agriculture covering 10% of the whole County.

4.2.4 Land suitable for livestock

The resulting raster had 1010 pixels for the most suitable areas, 2377 pixels for medium suitability areas and 5 pixels for the least suitable areas. This translates into the areas that are most suitable for livestock use covering 29.8% of the whole County, areas of medium suitability covering 70.1% of the whole County and the areas which are least suitable for livestock use covering 0.1% of the whole County. This agrees with the current practise in the area as most of the Turkana people are pastoralists.

4.2.5 Land suitable for urban and settlement areas

There are few urban areas in the County and this is mostly due to the pastoralist nature of the people. The resulting raster had 1200 pixels for the most suitable areas, 2176 pixels for medium suitability areas and 16 pixels for the least suitable areas. This translates into: the areas that are most suitable for urban and settlement use covering 35.4% of the whole County, areas of medium suitability covering 64.1% of the whole County and the areas which are least suitable for urban and settlement use covering 0.5% of the whole County.

4.2.6 Future land use conflict areas

Areas of potential land use conflict were identified as well as the specific conflicting land uses. The resulting raster had 1919 pixels for areas of no conflict/equal preference for all the land uses, 405 pixels for areas with urban/settlements use and rain fed agriculture use conflict, 793 pixels for areas where urban/settlements areas were preferred, 113 pixels where rain fed agriculture is preferred, 155 pixels where irrigated agriculture is preferred and rain fed agriculture is medium preferred, 5 pixels where irrigated agriculture is preferred and there is livestock use and rain fed agriculture conflict, and 2 pixels where irrigated agriculture is preferred and there is urban/settlement use and rain fed agriculture conflict.

This translates into the areas of no conflict/equal preference for all the land uses covering 56.6% of the whole County, areas with urban/settlements use and rain fed agriculture use conflict covering 11.9% of the whole County, areas where urban/settlements areas were preferred covering 23.4%, areas where rain fed agriculture is preferred covering 3.3% of the whole County, areas where irrigated agriculture is preferred and rain fed agriculture is medium preferred covering 4.6%, areas where irrigated agriculture is preferred and there is livestock use and rain fed agriculture conflict covering 0.15% of the whole County, and areas where irrigated agriculture is preferred and there is urban/settlement use and rain fed agriculture conflict covering 0.05% of the whole County.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The main objective of this project was to apply GIS and remote sensing technologies to identify efficient and environmentally sound land use zones for the Turkana area as well as identify possible conflict areas for the proposed land uses.

This was achieved and it is concluded that

1. Turkana County can support urban and settlement areas, rain fed agriculture, irrigated agriculture and livestock.
2. Suitable areas for these land uses were identified and ranked from the least suitable, medium suitable and most suitable
3. Conflict areas of the land uses were identified.
4. A large area of the County has equal preference for all the four land uses and can be used for either of them through optimal allocation.

5.2. Recommendations

From the study, it is recommended that;

1. The use of high resolution imagery for identification of urban areas in arid areas like Turkana County when carrying out land cover classification.

2. The use of one model from the ESRIs' ArcGIS 10.0 Model Builder for the all the processes and analysis carried out, as compared to the individual models used during the analysis.

3. Identification of preferred land uses in areas where future land use conflict occurs.

4. Optimal land use allocation of the land uses in areas where the land uses have equal preference in consultation with all relevant stakeholders.

5. Extension of such studies to other arid and semi-arid areas in the country.

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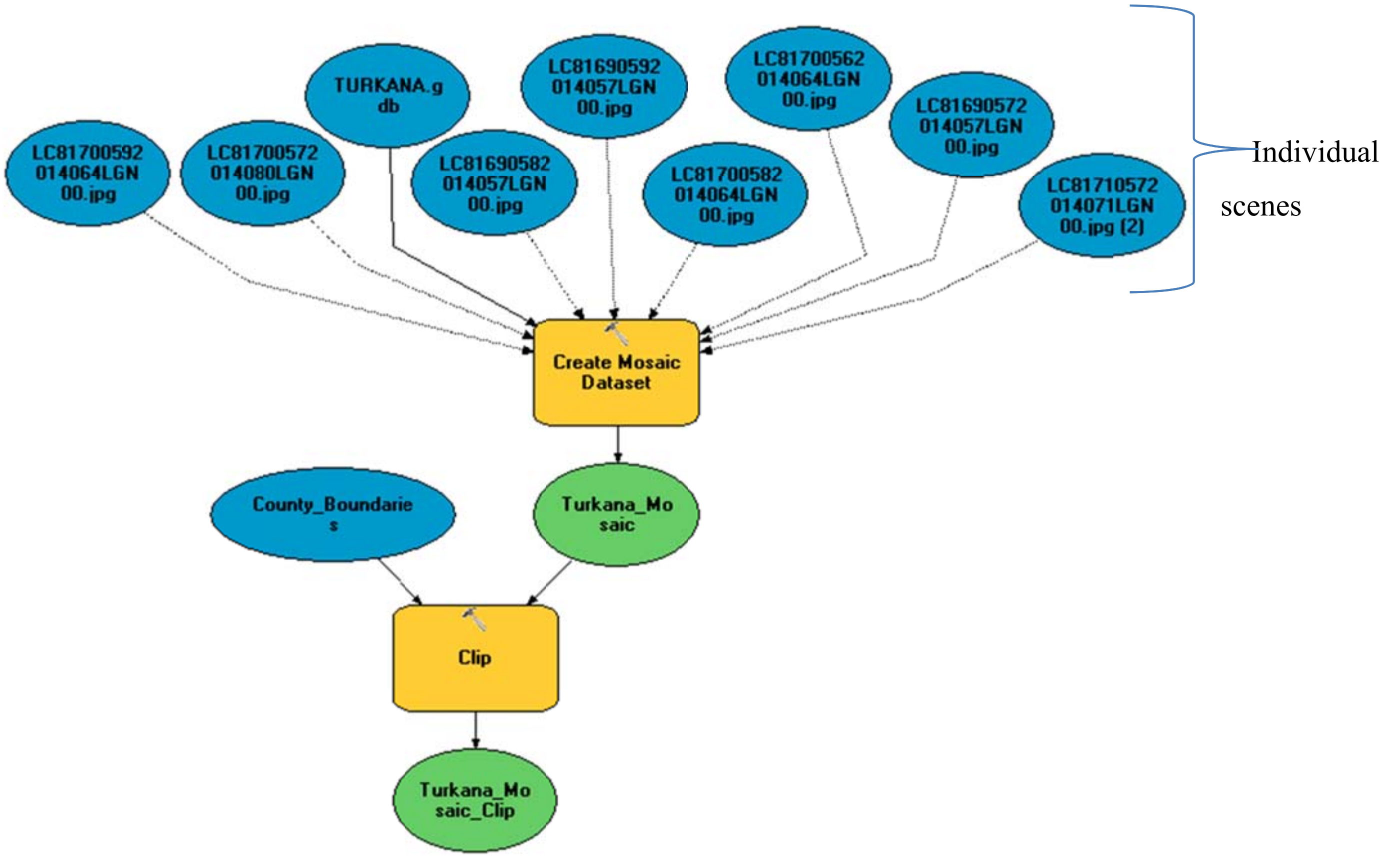
APPENDICES

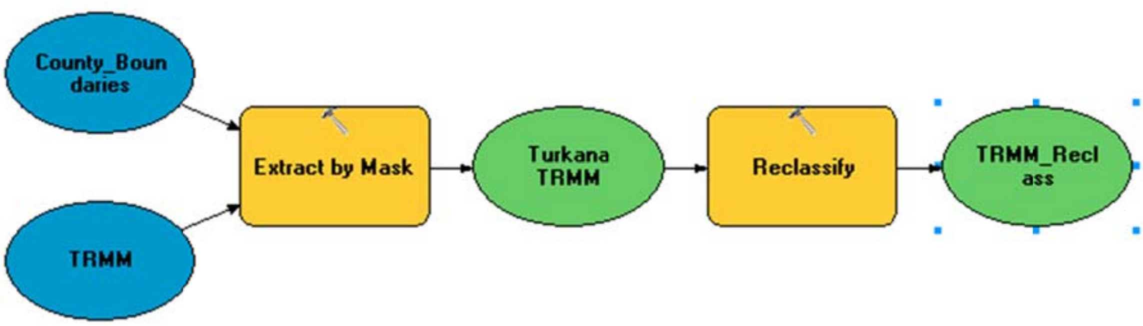
Appendix A: Rating values for pairwise comparison suggested by Saaty (1980)

AHP pair-wise comparison scale		
Intensity of importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practise
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation

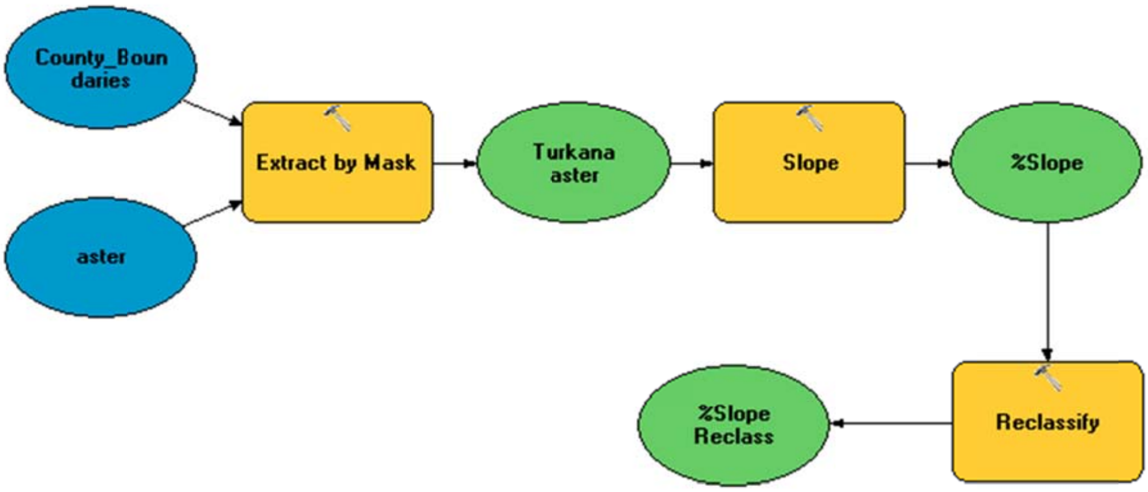
Appendix B: Land cover model



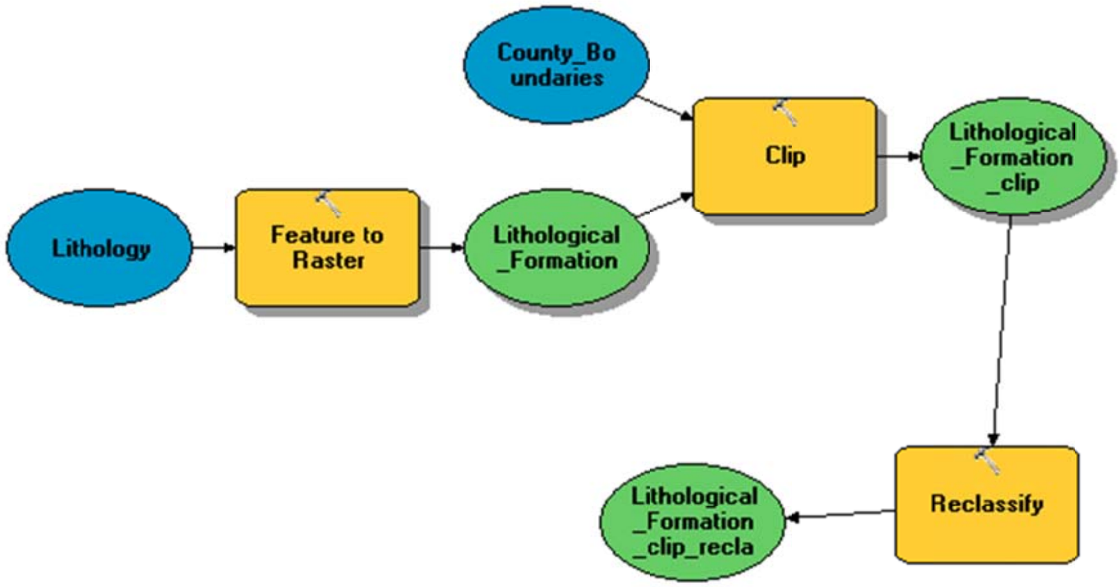
Appendix C: Rainfall model



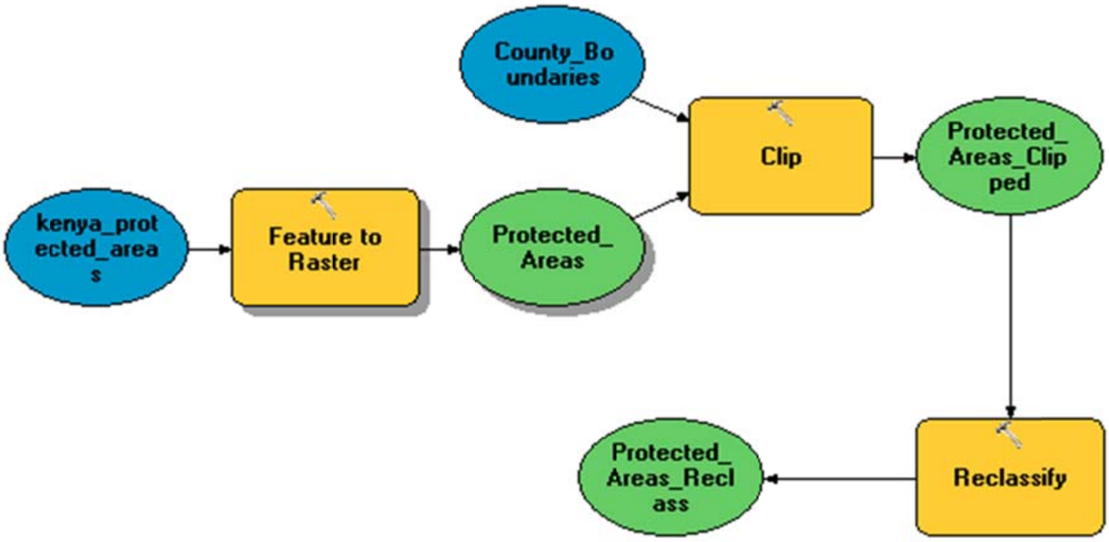
Appendix D: Slope model



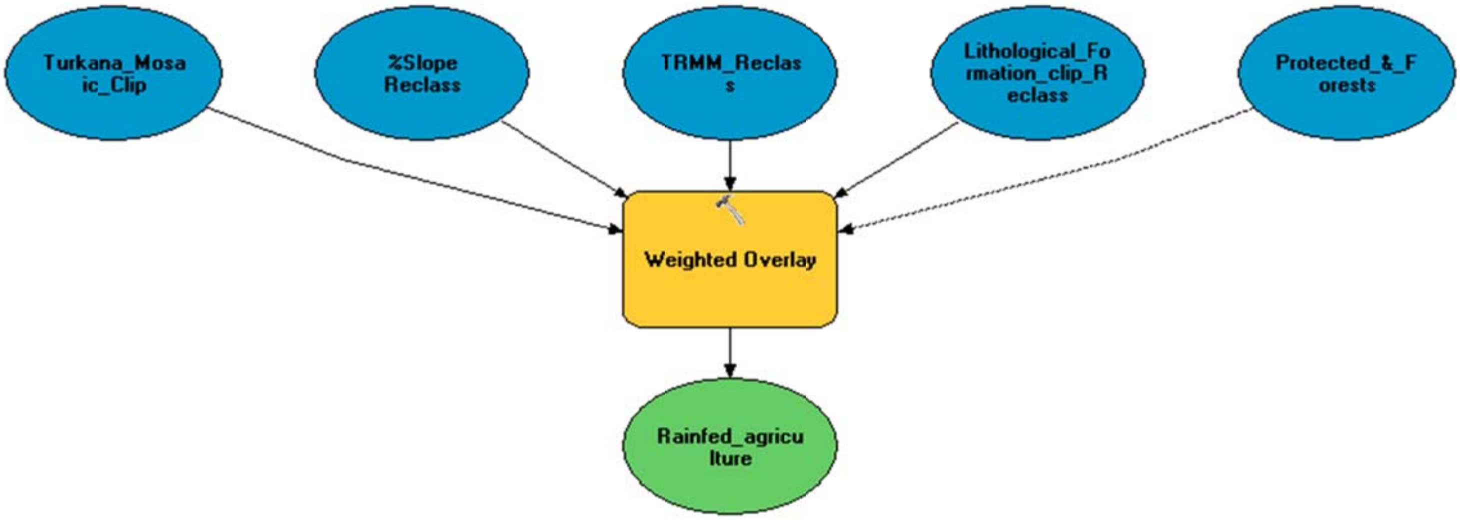
Appendix E: Lithological formation model



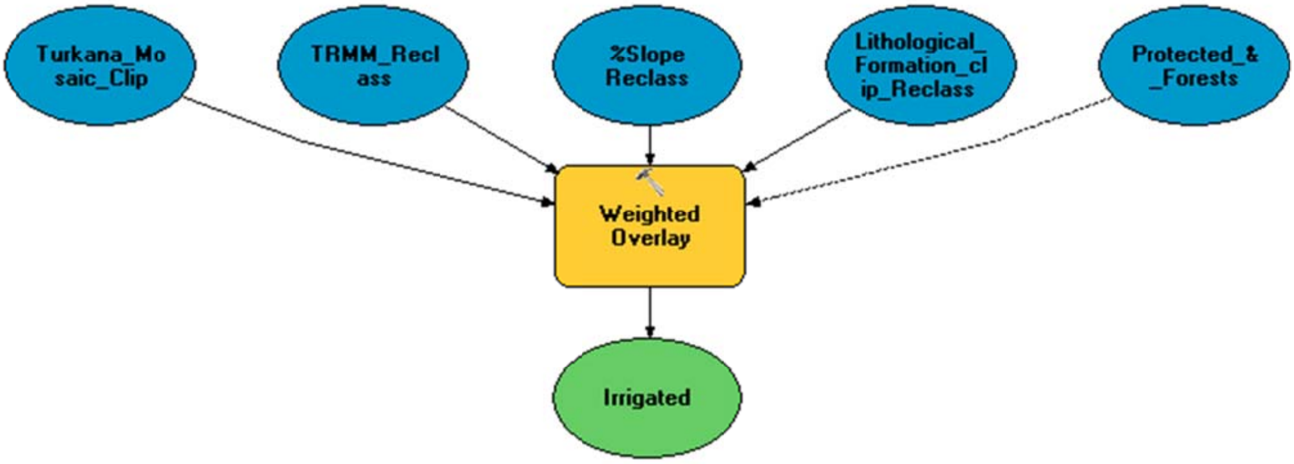
Appendix F: Protected areas model



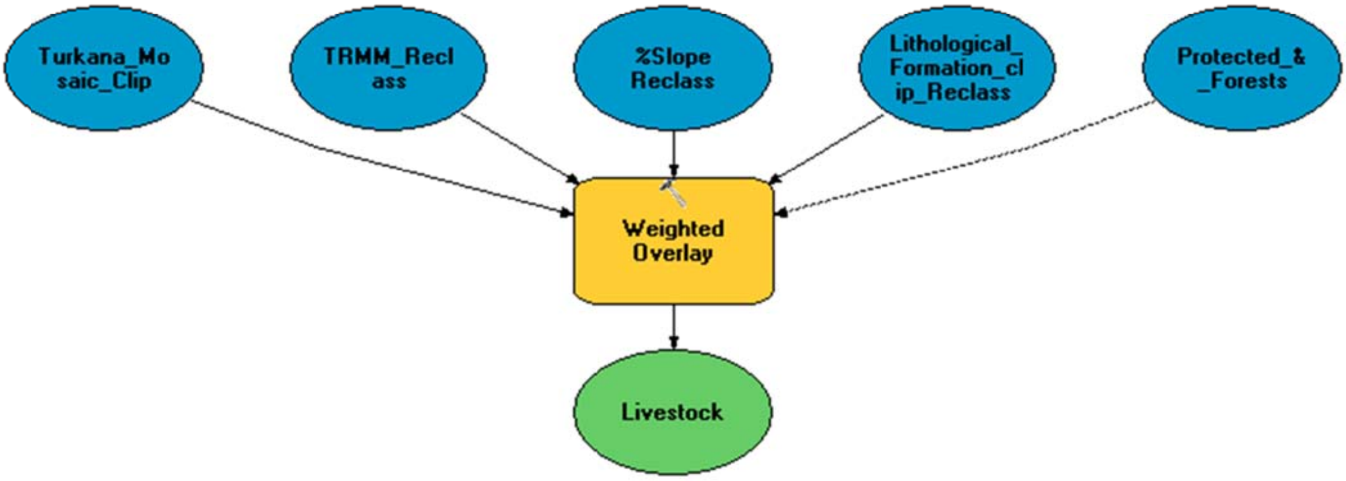
Appendix G: Rain fed agriculture land use model



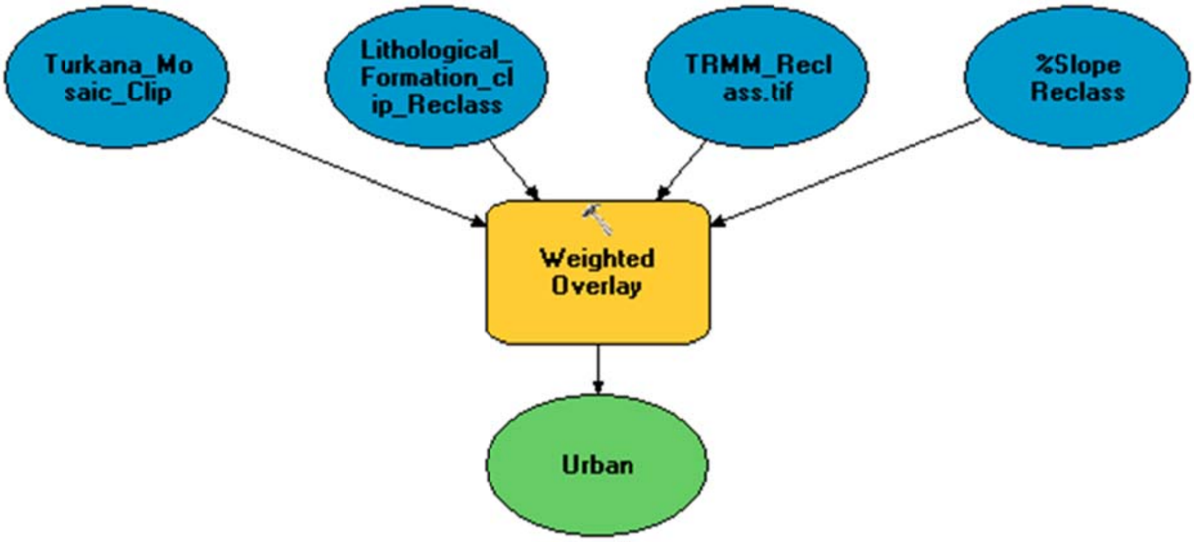
Appendix H: Irrigated agriculture land use model



Appendix I: Livestock land use model



Appendix J: Urban and settlements land use model



Appendix K: Land use conflict identification model