"GIS Simulation of Settlement and Urban Expansion in the Kitengela Wildlife Dispersal Area"

By

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A project submitted in partial fulfilment for the degree of Master of Arts in Environmental Planning and Management, Department of Geography,

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DECLARATION

This project is my original work and has not been presented for a Degree award in any other University

Signed______________________

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(C/50/P/9308/2001)

This project has been submitted for examination with our approval as University Supervisors.

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To my parents: The late Jeremiah Arunga and Mary P. Arunga

Glossary of technical terms

GIS (Geographic Information System)

A computer based system that is capable of collecting, managing and analyzing geographic spatial data. This capability includes storing and utilizing maps, displaying the results of data queries and conducting spatial analysis.

Global Positioning System (GPS)

A system for providing precise location which is based on data transmitted from a constellation of 24 satellites.

Land use

The classification of land according to what activities take place on it or how humans occupy it; for example, agricultural, industrial, residential, urban, rural, or commercial.

Land cover

The classification of land according to the characteristic that best describes its physical surface; for example, pine forest, grassland, ice, water, or sand

NDVI (Normalized Difference Vegetation Index)

A model for converting satellite-based measurements into surface vegetation types. The NDVI uses a complex ratio of reflectance in the red and near-infrared portions of the spectrum to accomplish this. Reflectance in the red region decreases with increasing chlorophyll content of the plant canopy, while reflectance in the infrared increases with increasing wet plant biomass.

Georectification

The digital alignment of a satellite or aerial image with a map of the same area. In georectification, a number of corresponding control points, such as street intersections, are marked on both the image and the map. These locations become reference points in the subsequent

ABSTRACT

Over the years settlement within the Kitengela Wildlife Dispersal Area, hereafter referred to as KWDA has increased with high numbers of people continuously moving into and settling in the area. This area has therefore continued to witness both local and foreign influence with immigrants bringing with them foreign practices such as agriculture, quarrying and constructions of new settlements to an area that has largely been utilised by livestock and wildlife utilisation.

This study attempted to utilise spatial statistics, remote sensing and Geographic Information System (GIS) to examine some of these forces of land use change particularly, agriculture, settlement and urban expansion in the KWDA by examining the effects of the biophysical characteristics of the area. The study aimed at identifying areas where land use change had taken place using satellite imagery and linking these to significant biophysical variables thought to influence these changes. These variables were then used in a model to predict future expansion of settlement and urban centres together.

Results indicated that the occurrence of settlement and agricultural activities in this area were driven mainly by proximity to certain infrastructural facilities such as roads, man made water sources and towns and that areas near such facilities were most likely to be converted either to agriculture or settlement areas away from utilisation by livestock and wildlife which are the current practices.

The study concluded that with the rapid increase of human settlement coupled by foreign economic activities, the KWDA, which is a life line to the Nairobi national park, providing a dispersal area for wildlife during the wet season is likely to be converted to either settlement or agriculture with disastrous effects to the park unless urgent measures are taken to curb this situation.

Some of the recommendations include better incentives for conservation efforts, proper legislation and wildlife corridor protection.

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CHAPTER ONE: INTRODUCTION

1.1. Background information

Land-use change is a process that is usually determined by activities carried out in an area over a period of time and is a major contributor to habitat modification. It is a phenomenon that can have important implications for the distribution of species and the ecological systems as a whole (Serneels and Lambin 2001).

The process by which land is allocated to different uses is usually a complex process that is determined by many biophysical and socio-economic factors. These factors include but are not limited to factors such as soil fertility, precipitation, and temperature, which determine local potential for the production system. However there are other factors such as income, from other activities and government policies that also play a part in this allocation (Groeneveld *et al* 1999). For this study only the biophysical variables have been considered.

The consequences of land use change are more drastic in arid and semi arid areas, here after referred to as ASALs, due to the sensitivity of these systems to ecological changes. In Kenya changes occurring in these lands would have serious implications to the economy. This is because they provide livelihoods to more than 25% of the Kenyan human population and are home to 60% of total cattle, 70% of small stock and 100% of camel populations (Kariuki and Letitiya, 1996).

Pastoralism and wildlife utilisation of the ASALs are highly specialized systems that are adapted to the harsh ecological conditions and have coexisted in these environments for hundreds of years utilizing overlapping territories with minimum conflicts. One of the reasons why these interlocking strategies have coexisted is the pastoral morbidity occasioned by heterogeneity of the ASALS (Coughenour *et al* 1993, Gichohi 1996).

In the recent years, however, increasing human populations as well as increased change in land use practices have resulted in increased pressure on some of these less productive areas, a phenomenon that is likely to have important implications for the structure and functioning of these ecosystems (Worden *et al* 2003). Increasing population pressures coupled by increasing affluence levels and changing tenure systems within the ASALS, has necessitated a shift from pastoralism to sedentarization (Mwasi 2002), and has had serious implications on the land use practices in these areas. Pastoral habitats, which were often shared both by pastoralists and wildlife, have continued to be converted to other land uses.

The KWDA situated in the northern part of Kajiado district is one of such areas experiencing competition between wildlife utilization and other forms of land use. The Maasai pastoralists keeping mainly cattle, sheep and goats to sustain their livelihoods have traditionally utilized this area to the south of Nairobi national park. Those pastoralists neighbouring the park have long shared their land with the wildlife even in the presence of seasonal migration in which some 20,000 herbivores, mostly Wildebeest (*Connochaetes taurinus*), Grevys Zebra (*Equus qrevyi*) and Eland (*Taurotragus oryx*) move across the dispersal area (Chiemelu 2003, Birdlife International 2003). Its importance lies in the fact that the gazzeted National park covers only 114 km^2 of the 2200km^2 that make up the Athi-kapiti ecosystem and yet is home to approximately 50% of the total biomass of the park (Gichohi 2003).

Besides enabling the animals to make use of the ecological patchiness and therefore meeting their nutritional needs, wildlife migration alike pastoral morbidity ensured sustainable use of resources and therefore minimizing land use conflict. In the KWDA, wildlife migration is becoming constrained by the sprawling settlements and industrial development occurring in the area (Birdlife

International 2003).

These land use changes occurring within the KWDA are of various forms ranging from settlements involving construction of permanent residential dwellings, construction of industries, agriculture, commercial ranching, quarrying among other uses. Since the dispersal area is crucial for the survival of the NNP by enabling movement between the dry season grazing area in the park and the wet season grazing area at the Kaputei plains. It is important to characterize these land uses into types within this dispersal area into those that could be compatible with wildlife and those that are not.

Over the last few decades, the KWDA area has witnessed a steady immigration of settler populations, otherwise known as ecological refugees, especially along river Mbagathi as well as the establishment of an Export Processing Zone at Athi-river Township (Gichuhi 2002). This situation has led to more fragmentation of land and the cutting off of some of the migratory routes, further reducing the area of land available for pastoralism and wildlife.

This area, for example has over the past decade experienced sharp changes in the land use patterns. Many of the pastoralists have continued to embrace foreign land use practices such as irrigated agriculture and quarrying to supplement livestock production. Some of the landowners have also sold of their land to immigrants who have used the land to pt up residential units. Apparently these activities fetch more income per acre of land than pastoralism. For example, the average Gross annual income from livestock per acre is approximately Ksh.1,010 per year compared to a net income received from quarrying activities per household (Ksh.34,200) and market oriented agriculture (Ksh.3536) (Kristjanson *et al* 2002) Immigrant settlers are also offering good prices for land, which the pastoralists find very attractive.

The result of this has been that a lot of land has either been sold off or fenced by agriculturalists and settlers to prevent destruction by wildlife and livestock.

There have been efforts by conservation agencies to offer incentives for non-fencing of plots. This has not been very successful since the Ksh.300 offered per acre per year (Gichohi, 1996) is below what is obtained through plot sales, quarrying or market oriented agriculture.

1.2. Statement of the problem

The expansion of agriculture and settlements continue to take place at an elevated scale and have generally been cited as the main causes of land use change within the Kitengela wildlife dispersal area (Nkedianye, 2004).
Infrastructural development such as road networks, electricity and water have further enhanced the land use change process by making the land more suitable to other land uses *such* as agriculture and settlements. A recent study by Kristjanson *et el* 2000 indicated that a large proportion of family incomes come from alternative land use activities other than pastoralism. Although it is common knowledge that the economic activities of the people living in this area are fast changing from pastoralism to others, the extent to which these changes are affecting the dispersal area is still poorly understood and yet the economic activities currently being carried out within the KWDA are having serious implications on the ecosystem. This is evident by the reduction in the in wildlife population estimates within the dispersal area over the last decade (Western and Gichohi 1993).

Several studies have attempted to study the ecological changes that have occurred within the KWDA. A survey commissioned by the East African Wildlife Society (EAWLS) in response to numerous incidences of human-wildlife conflict in the area revealed that the conservation area was heavily developed and fenced and are virtually blocked to wildlife dispersal (Nkedianye, 2004). It further reveals that the Kitengela area is the worst affected since the land ownership per head stands at 0.92 ha compared to 70.35 ha 1979.

Many researchers have highlighted the need for more information to help in understanding the spatio-temporal relationships between the changing land uses

and their drivers. This kind of information is particularly important because as concerns for the environment heightens, the importance of investigating land cover dynamics as a baseline requirement for sustainable management of natural resources becomes increasingly important (Shu 2003)
Spatial models are therefore useful tools for describing land cover change and for predicting where land use change is likely to take place. These models utilise statistical analysis to establish the quantitative relationships between the actual land use distribution and (potential) driving forces of change.

This study therefore seeks to identify and map, based upon the results of the analyses, the areas with potential for change especially in relation to agriculture and settlement, which seem to jump out as being the major types of land use changes occurring within the KWDA. In a general sense, we aim to better understand the land requirements inferred by these human activities, as well as the implications of those requirements to the dispersal area. Specific research questions addressed in this study are:

- What are some of the land cover features in KWDA can be detected and mapped using Landsat imagery?
- Which are the areas that experienced major land use change over the study period?
- What are some of the biophysical features affecting land use changes experienced in this area?
- What is the future scenario for settlement expansion based on the existing scenario?

1.3. Aims and Objectives

The general objective of the study was to utilize GIS techniques, particularly time series remotely sensed data to determine the main biophysical characteristics influencing choice of land use activities in KWDA and use these to predict possible future scenarios in urban development and settlement as well as examine possible implications for conservation in the dispersal area.

1.3.1. Specific objectives

- To establish the biophysical characteristics influencing land use activities occurring within the KWDA.
- To identify and quantify the major changes in land cover for the study area over a period and determine the amount of land lost to other forms of land use from the dispersal area over the study period.
- To produce land cover maps that indicate possible areas of the dispersal area at risk of conversion to settlement and or urban expansion.

1.4. Research Assumptions

The research hypotheses used in this study in an attempt to achieve the objectives above are:

- There have been significant changes in land cover within the KWDA between 1887 and 2000.
- Changes in land cover within the dispersal areas have led to a reduction in land available for the dispersal area.
- The anthropogenic activities occurring within the dispersal area are as a result of certain biophysical characteristics occurring within the dispersal area.

1.5. Justification

In the past few decades, the KWDA has experienced a process of land tenure reforms, taking place together with a transition from pastoralism and wildlife utilization to sedentary settlements and agriculture and industry based developments. Following the change processes taking place within the dispersal area, it is frequently taken for granted that these economic activities and drivers would push out of existence, the coexistence of pastoralism and wildlife within the area. Changing land use policies have created an enabling environment for immigrants to move into the area either to settle, farm or put up industries.

However, it is frequently ignored that most of the activities being carried out within this area is taking particular patterns and are increasing in intensity and yet conservation efforts are being targeted at these same areas. The irony here is that despites the incentives being offered by these conservation efforts not being very appealing to the would-be conservers, they would work well if the land was maintained it its current state. The reality however is that the land is actually being sold off as small parcels and being put into uses that are not compatible with conservation such as quarrying and residential properties

As a result, it might make sense to identify possible areas where these incompatible developments are more likely to take place and then exclude them from the conservation agenda. Furthermore, to ensure a successful integration of wildlife, pastoralism and human settlements, a careful and competent planning is required and this can only be done by examining "when" and "where" people, livestock and wildlife are compatible and where they are not (Reid *et al* 2003).

In an attempt to do so, this study tries to examine the spatial and temporal relationships between certain biophysical variables and the changes taking place in order to identify areas where the coexistence is viable and where they are not.

1.5. The study area

The study area (KWDA) is located within Athi-Kapiti plains in Kajiado district Kenya, which consist of open rolling land (GoK 1990) and are bordered by Ngong hills to the west, the Nairobi National Park to the north and Machakos district to the north east (ILRI 2004).

1.5.1 Location and size

KWDA is located in Kajiado district, which is found in southern Rift Valley Province. The district is mainly inhabited by Maasai people whose livelihoods have traditionally revolved around livestock – primarily cattle, sheep and goats but are increasingly seeking to diversify their livelihoods. The study location is bordered by Ngong division to the west, Central division to the south west and mashuru division to the south east (GoK 1990). The study area is primarily in Isinya division with parts of it extending into Ngo'ng and Central divisions. The size of the study area is approximately 170,000 hectares.

The general topography of the district is characterized by plains and a few volcanic hills and valleys. The land rises in altitude from about 500 metres around Lake Magadi to about 2,500 metres in the Ngong Hills area.

1.5.2. General topography

The Athi-kapiti plains consist of open rolling lands that extend to the west upto the Ngong hills that are also the catchments area for Athi River (GoK 1990). The northern part is bodered by the Nairobi National Park, and to the northeast by Machakos district. The soils are characterized by successive layers of lava due to its proximity to the rift valley. The underlying rocks are composed of crystalline granitoid gneiss and are mostly residual weathering deposits (Gichohi 1996).

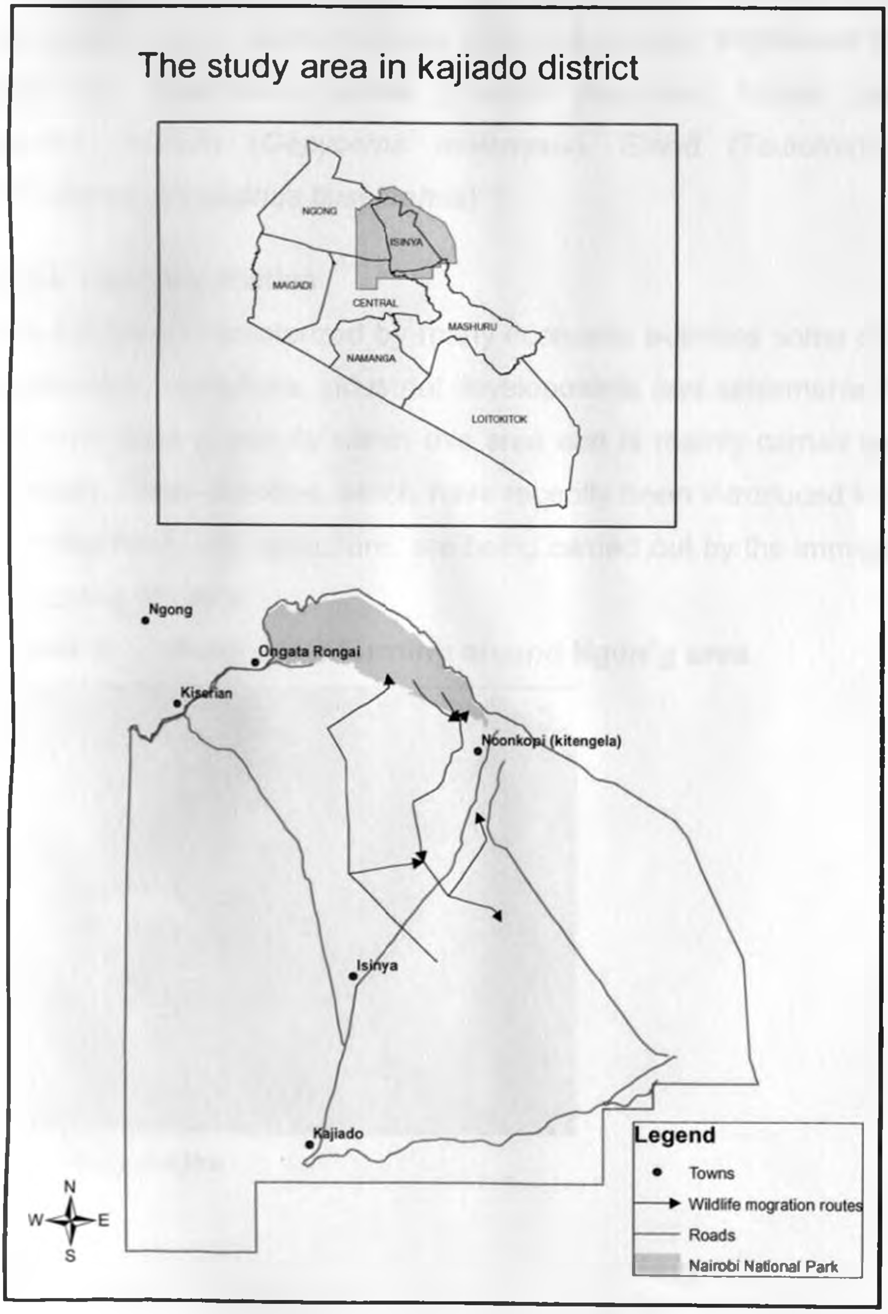
1.5.3. Climate

The area falls within eco-climatic zone IV, which is classified as semi-arid (Pratt and Gwyne 1977) and is characterized by a bimodal rainfall distribution with the short rains occurring between March and May and the long rains between September and November (Wasonga 2001). Rainfall amounts range from 400mm and 600mm per year.

1.5.4. Flora

The study area has relatively homogenous vegetation consisting primarily of dry savanna with open *Themeda triandra* grass plains and scattered acacia and balanites bushes also (Wasonga 2001). The park also has a permanent river with riverhine vegetation such as *Accacia xanthophloea*. Other vegetation types found in this area *Sporobollus pyramidallis* and *Aristida adoensis* grasses and *Croton macrostachyus* (Gichohi 1996).

Figure 1 Map of the study area



1.5.5. Fauna

The Nairobi National park in itself has a high diversity of wildlife species with over 400 species recorded since 1946. Within the Athi-kapiti ecosystem there are approximately 24 species of large mamals (Gichuhi 2002). Some of the most common species are Maasai Giraffe (*Giraffa Camelopadolis*), Lion (P*anthera leo*), Leopard (Panthera pardus), Cheetah (*Acynomix jubatus*), Spotted hyena (Crocuta crocuta), Buchell's zebra (*Equus burchelli*), Wildebeast (*Connochaetes taurinus*), Thompson's gazelle (*Gazella thomsoni*), Grants gazelle (*Gezella grantix*), Impalla (*Gepyceros melampus*), Eland (Tautotragus derbianus), Hartebeest (*Alcelaphus buselaehus*)

1.5.6. Human activities

The KWDA is characterized by many economic activities some of which include pastoralism, agriculture, industrial developments and settlements. Pastoralism is the main form of activity within this area and is mainly carried out by the local Maasais. Other activities, which have recently been introduced in the area such as settlements and agriculture, are being carried out by the immigrant population occupying the area.

Figure 2 Small scale farming around Ngon'g area

Source Ndegwa *et al* 2000

Figure 3 Maasai farmers practicing drip irrigation in Kitengela

(source: Arid lands information network)

Figure 4 Export processing zone, Kitengela

(source: Sameer group)

CHAPTER TWO: LITERATURE REVIEW

2.1. Changing land use in KWDA

The KWDA falls within an environment commonly referred to as arid and semi-arid (ASAL). These are areas where other land uses such as agriculture are not economically feasible (Herlocker, 1989). They are characterized by low and erratic rainfall, showing considerable variability, low humidity, high temperatures, poor soils and poor drainage (Southgate and Hulme, 2000). They are also known to support limited agricultural productivity; however, they support a significant population of human and livestock populations as well as wildlife.

This area adjacent to the Nairobi National Park has over the last decades experienced an influx of foreign economic activities such as agriculture and settlement as a result of increased pressure from the surrounding communities.

Broadly speaking, the process of land use and land cover change is closely related to a wide variety of socio-economic and environmental issues, land characteristics such as food production, housing, industry and habitat are examples of land uses that compete for these environments. The result is often an optimal or sub optimal allocation of land use (Groeneveld *et al* 1999).

KWDA provides a classical example of situations in which sub optimal allocation has been experienced. The changes occurring in the area are as a result of land tenure policies. Over the last few decades, this area adjacent to the Nairobi national park has witnessed a steady immigration of and an increasing population of cultivating, non-Maasai immigrants populations as well as the establishment of an Export Processing Zone (Gichuhi 2002), a situation that has led to fragmentation and changes in land cover for this area, substantially reducing the amount of land available for pastoralism and wildlife.

Most of these new development activities are focused in and around Kitengela, Isinya, Rongai and Ngong towns all falling within the dispersal area and have rapidly transformed this area from one occupied predominantly by pastoralism and wildlife into a rapidly growing settlement and industrial zone.

Historically, KWDA was the major migratory corridor linking the Nairobi National Park (NNP) to the rest of the Athi-kapiti plains to the south. It created an enabling environment for the wildlife, mainly the large herbivores to migrate in order to meet their nutritional requirements. During the rainy season the animals moved away from the park into the dispersal area in search of better forage but utilized the NNP as a dry season grazing ground. The continued existence of the dispersal area is therefore fundamental if the health and species richness of the park is to be maintained.

About 1946, the year that NNP was created, the population of Nairobi stood at 118,976 people; today, that number has soared to well over 2 million (CBS 2003). These growths has had dire implications for wildlife as well as pastoralism since the human populations in Nairobi spill over and continue to settle across the migration routes south of Nairobi Park that is part of the dispersal area (National Wildlife Federation 1996). Worse still is the fact that during the establishment of the park it was recognized that it was too small to meet the ecological requirement of the animals living in it. This prompted the setting aside of the Ngong hills and the Kitengela plains as drought refuge areas, however the areas were never gazzeted (Gichohi 1996). For a long time however, the dispersal area and the corridors for wildlife migration were kept open due to pastoral activities of the Maasai community. However immigration of other communities into the area has almost completely transformed the area. The establishment of the Export Processing Zone among other industries coupled with increasing population pressure in other parts of the country as well as the not very expensive cost of land in this area and the availability of titled plots has prompted people to move into this area.

The effects of urbanization and human population explosion, agriculture, industrial development and uncontrolled human settlement have steadily reduced the ecosystem of Nairobi National Park and the surrounding ecosystem, (Nkedianye 2004). More and more land is converted to other land uses. In the process the land is fenced off to keep away wildlife and livestock. The fact that these are now titled plots further complicates the problem. This is because despite the fact that there could be policy recommendations and initiatives that try to mitigate these changes, the decisions on what course of action to take will solely depend on the titleholders.

2.2. Evolution of land tenure reforms and conflicts in resource use

Enclosing of land in Kajiado district began even before independence and was pioneered by the so-called elite Maasai who opted to have individual enclosures (Njoka 1979). In a memorandum titled "A plan for the development of Masaai land" submitted to the ministry of agriculture in 1965, the representatives of the Maasai asserted that they were doing away with nomadic pastoralism and were opting to settle down. This wish was however not granted and instead they were granted the option of group ranches under the Land Group Representatives Act of 1968, which were divided according to families and were aimed at increasing livestock production.

The group ranch system did not take of very well, as it did not achieve its main objective of boosting livestock production. This failure resulted in the dissolution of the ranches and marked the beginning of land sub-division in Kajiado district to smaller group ranches as well as individual ranches. These ranches are now seen as major contributors to the development of pastoralists/wildlife conflict.

They are seen to intensify the conflicts that were not so much of a problem several decades ago but are now evident. Previously, as a result of migration, pastoralists were able to move about to avoid concentration of wildlife in their grazing areas at certain seasons in order to minimize transmission of diseases from the wildlife as well as to reduce competition for forage. With the assignment of property rights to discrete land owners, their movements have been constrained leading to reduced flexibility which they could use nomadic movement to minimize wildlife induced losses (Mbogo *et al* 1999).

2.3. Application of GIS and remote sensing techniques in environmental management

2.3.1. GIS

Geographic Information Systems (GIS) refers to an information technology designed to collect, structure, analyse and manage large volumes of spatial data and their attributes (Aronoff 1989). GIS can also be defined as special-purpose digital databases in which a common spatial coordinate system is the primary means of reference. It is composed of subsystems that allow for data input data storage, retrieval, representation, management, transformation, analysis and reporting (Sabins, 1997). It is therefore more of a process rather than a tool.

GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps (ESRI, 2004). These are some of the abilities that distinguish GIS from other information systems and also make it valuable to a wide range of applications such as predicting outcomes, and planning strategies. In this study, GIS has been used to simulate urban and settlement expansion in KWDA based on the relative contribution of the biophysical variables in a linear regression.

2.3.2. Remote sensing

Remote sensing is defined as the science and art of obtaining information through analyses of data acquired by a device that is not in contact with the object under investigation (Wilkie and Finn 1996). It includes all the activities from recording, processing, analyzing, interpreting and finally obtaining useful information from the data obtained from remote sensing systems.

There are various sensors that are often used to collect data that might be analyzed to obtain information about phenomenon being investigated. These sensors such as Landsat MSS, SPOT, and NOAA (AVHRR) acquire multiple images of the same target object at different wavelengths or bands in the visible, near infrared, short wave infrared, and thermal infrared or other regions of the electromagnetic spectrum. The relationship between the values measured and the land cover values allows us to then extract ground information from the image data obtained (Gorte 1999) through a process known as image classification that allows us to classify features on the image obtained into meaningful categories such as land use types.

Remote sensing can provide basic measurements of a range of biological as well as physical characteristics of a landscape such as position, shape, color, temperature and moisture content. The type of image used for a study will depend on the study aims (Wilkie and Finn 1996).

With the increase in the expansion of settlements and urban centers and continued fragmentation of ASALS, it is very important to monitor their conditions. One cost effective way of doing this would be to use remote sensing data. After the land use types have been mapped in the initial study, repeated collection of remote sensing data can be used to monitor and study the changes occurring in these areas.

Remote sensing methods have become increasingly important for mapping land-use/land-cover because: -

- The method gets round the problem of surface access that often hampers surveys.
- Image interpretation is also faster and less expensive, especially when large areas are to be surveyed, which is often the case in land resources.
- Images provides an objective, data set that may be interpreted for a wide range of specific land-uses and land covers such as urban expansion, forestry, or agriculture.
- Images provide a perspective that lacks in ground surveys.

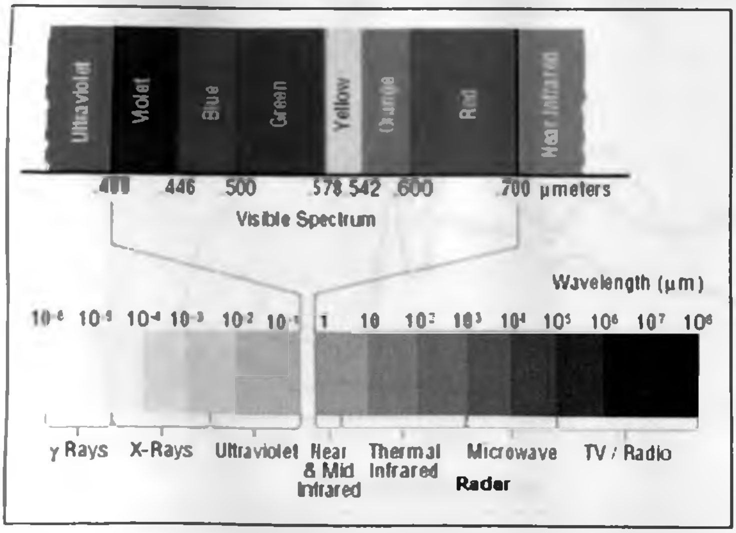
- Images can be acquired with a spatial resolution that matches the degree of detail required for the survey.

The data acquired through remote sensing techniques can be incorporated into a GIS and are easy to query, update, and analyze. Furthermore, GIS thematic maps can be combined with others to create specialized maps depending on the spatial information of interest. Simple queries can be performed to find specific information about these areas. In habitat planning for instance, one could carry out suitability analysis for the best location of a conservation area.

2.3.2.1. The Electromagnetic Spectrum

The basic principle of remote sensing is the measurement of electromagnetic energy reflected or emitted by various objects on the earth's surface. The entire array of electromagnetic radiation at its various wavelengths is referred to as the 'electromagnetic spectrum'. Wavelengths are measured in micrometers (DFID 2003).

Figure 5 Electromagnetic spectrum

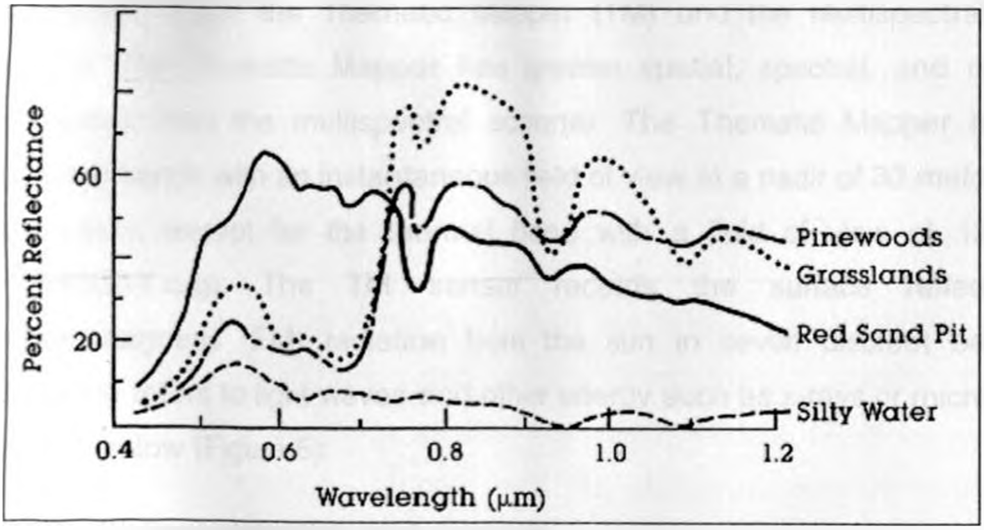


Source: www.geography.eku.edu

The wavelengths to the left are the shorter wavelengths and progress to the longer wavelengths to the right. The human visual is concentrated around the middle and this is where geographic remote sensing takes place.

Spectral bands found within images such as those of ETM+ data are used to discriminate between Earth surface materials through the development of spectral signatures. The amount emitted by and radiation reflected by any given material, varies by wavelength. These variations are used to establish the signature reflectance fingerprint for that material (NASA 2004). The assumption in this theory is that similar objects or classes of objects will have similar interactive properties with electromagnetic radiation at any given wavelength. On the other hand, different objects will have different interactive properties. A plot of the collective interactions at varying wavelengths on the electromagnetic spectrum should, according to the basic premise, result in a unique curve, or spectral signature that is diagnostic of the object or class of objects (NASA 2004) as shown in Figure 6.

Figure 6 Reflectance values for different objects



(Source: satellite impressions, 2004)

2.3.2.2. LANDSAT Imagery

The evolution of the LANDSAT program has been a fundamental genesis to an international attempt to better measure and monitors the Earth and its resources. The National Aeronautics and Space Administration, NASA, together with other federal agencies, successfully launched the first Earth Resources Technology Satellite (ERTS-1) in 1972. It was later renamed LANDSAT 1 (Brandon 1999). LANDSAT 1 through to 5 were successfully launched into orbit after LANDSAT 1 however LANDSAT 6 was destroyed during launch and LANDSAT 7, the latest of the satellites, was successfully launched in 1999 (Richards, 1986)

The LANDSAT program has for a long time provided high quality, well-calibrated, imagery of the earth and has opened new insights into geologic, agricultural, and land use surveys and research as well as an understanding of the Earth and its terrestrial ecosystems (Brandon 1999).

The data used in this study was obtained from the Thematic Mapper sensor onboard both LANDSAT 5, which has been in service since 1984 and LANDSAT 7, launched in 1999. The chief observing instruments on LANDSAT 5 and LANDSAT 7 are the Thematic Mapper (TM) and the Multispectral Scanner (MSS). The Thematic Mapper has greater spatial, spectral, and radiometric resolution than the multispectral scanner. The Thematic Mapper has seven spectral bands with an instantaneous field of view at a nadir of 30 meters, spatial resolution, except for the thermal band with a field of view of 120 meters (LANDSAT.org). The TM sensor records the surface reflectance of electromagnetic (EM) radiation from the sun in seven discreet bands. (EM radiation refers to light waves and other energy such as x-rays or microwaves as shown below (Figure 5).

2.3.3. Change detection and analysis

Studies done in which this technology has been applied to include, detection and analysis of land cover dynamics in a moist tropical rainforest, Cameroon in which GIS and remote sensing were used to detect and quantify land cover changes over a period of two decades. The results of the study provides information on the distribution of land cover types and used together with information distribution of species habitats provide useful information on identification of biodiversity hotspots (Shu 2003).

Akotsi *et al* (2003) examined the changes in forest cover in Kenya's five water towers namely Cherengani, Aberdare, Mau complex, Mount Elgon and Mount Kenya between 2000 and 2003 using landsat imagery. These are critical areas in as far as water catchments are concerned. They were able to utilise image-differencing techniques as well as Normalised Difference vegetation Index (NDVI) to highlight key areas where forest cover was being depleted. The objective of this study was to alert the key stakeholders in forest management about the critical forest cover changes by highlighting the changes occurring in all the five catchments. In this study NDVI and Image differencing procedures were performed to highlight areas where changes had taken place.

Esukuri (1998) studied land use changes and their effects on elephant habitat quality in Amboseli Basin, Kenya. In this study he used visual interpretation to analyse land use changes from satellite images for 1975, 1988, and 1993. Based on these analyses, he developed a dry season habitat suitability index (HSI) model for the African elephant based on the density of acacia trees and distance to water sources in the basin. Although visual interpretation was used in this study, the habitat suitability model was not considered useful in this instance.

Noe (2003) explored the dynamics of land use changes and their impacts on the wildlife corridor in Tanzania using aerial photographs and satellite images. The focus was on the dynamics of land use change taking place between Mount Kilimanjaro and Amboseli national park. The study revealed that there has been expansion of agriculture thus reducing the amount of land for the wildlife grazing and dispersal area and increasing conflict among competing land uses.

Pozzi and Small (2001) in a study to analyse suburban land cover and population density in U.S.A, investigated the consistency of suburban" population densities and land covers. They investigated the question of whether suburban areas can be defined based on population density and vegetation cover. Using the hypotheses that suburban areas are greener than urban centres, and that the predominant suburban land cover is vegetation, they attempted to quantify the extent to which suburban areas are vegetated in different U.S.A. cities. The cities were considered based on population density and spectral reflectance using Landsat data to quantify the relationship between the two variables looking at the cities of Atlanta, Chicago, Los Angeles, New York, Phoenix and Seattle. This concept was considered suitable for this study and the areas that have undergone change were discriminated based on their measure of greenness.

In a study to monitor the long-term urban expansion by the use of Remote Sensing Images from Different Sensors, Tachizuka, (2002) investigated the long-term land-cover changes with remote sensing data from different sensors. In order to detect land-cover changes from different sensors, he employed a new method that did not compare the spectral signature directly but compared the land-cover category-mixing ratio in each pixel derived from different sensors. His methods were applied to the city of Bangkok as a case study, and the long-term changes in and around the same were evaluated with LANDSAT TM and ETM+ during a period of ten years. In our study both LANDSAT ETM and ETM+ were used for the analysis.

2.4. Computing NDVI from LANDSAT TM and LANDSAT ETM data.

From a scene of LANDSAT data, we can calculate a vegetation index, which is a measure of the land's "greenness". This is because healthy vegetation absorbs visible light, especially red light, and reflects near infrared. Therefore if a pixel has a large difference between MSS bands 4 and 3, we could use these bands and utilize the simple vegetation index formula (band 4-band 3) to represent high and low values representing vegetation (Holme *et al* 1987).

Band 3 is a chlorophyll absorption band important for vegetation discrimination. It is higher for rocks and soils rich in iron, especially ferric iron. Band 4 is useful for determining healthy vegetation and for delineation of water bodies. It peaks strongly for chlorophyll in healthy vegetation, resulting in a characteristic 'red-edge' between bands 3 and 4.

The reality however is that, two identical patches of vegetation could have different values if one were for example in bright sunshine and another under a hazy sky in that the bright pixels would all have larger values, and therefore a larger absolute between-bands difference. The Normalized Difference Vegetation Index (NDVI) is an index that helps to compensate for these problems with the simple vegetation index. It is a quasi-continuous field that is calculated as a normalized difference between the reflectance of two biologically meaningful bands of the electromagnetic spectrum.

Actively photosynthesizing leaves absorb the red wavelengths (LANDSAT TM band 3) as a source of energy for photosynthesis. Leaves reflect the short-wave infrared (LANDSAT TM band 4), so the difference between the two is proportional to the amount of photosynthesis. NDVI responds to changes in biomass and chlorophyll content, and hence serves as a useful measure or primary productivity (Roderic *et al* 1996).

2.5. Change detection using Image differencing technique

Change detection is the process of identifying differences in the state of objects or phenomena under consideration by observing them at different times. This process is important for monitoring and managing natural resources, urban development and environmental changes (Habib *et al* 2004). There are several techniques available for carrying out change detection some of which include but not limited to write function memory insertion, enhancement, image differencing, image regression, principal components analysis and tasseled cap transformations (Landstrom, 2003), each of which could be recommended depending on the nature of the study.

Image differencing is probably the most widely applied change detection algorithm (Singh, 1989). It involves subtracting one date of imagery from a second date that has been precisely registered to the first. According to recent research, image differencing appears to perform generally better than other methods of change detection (Coppin & Bauer, 1996).

In the image differencing procedure, the corresponding pixel values (DNs) from one image (t1) are simply subtracted from those of the other (t2).
The difference in areas of no-change will be very small approaching zero (0). On the other hand areas of change will manifest larger negative (-) or positive (+) values. When image differencing is employed, the analyst must find meaningful "change/no- change threshold" within the data (Lee *et al* 2002)

2.6. Spatial modelling

Spatial modelling is a process that utilises a set of tools that aid in understanding the spatial context of ecological interactions (Maniatty *et al,* 2000) by providing insights into how these interactions are distributed in time and space. They provide important methods for describing change processes in quantitative terms and also allows for the prediction of where these changes are likely to occur in the future by indicating which interactions between spatial determinants explain the distribution of different land cover processes (Serneels and Lambin, 2001).

To describe these change processes, scientists are increasingly relying on spatial models since landscapes are continuously being fragmented by human activities and therefore predictive approaches that could be used for estimating the magnitude and direction of landscape changes is crucial for proper planning and sustainable resource use.

For example, Konin (1991) investigated land use change in Ecuador by means of statistical analysis with the purpose of deriving quantitative estimates of the relative areas of land use change on the basis of bio-geophysical, socio-economic and infrastructural conditions. He was able to discriminate six different land use types, which were then used to analyse the effects of the drivers that were thought to influence the land use change patterns. Scenarios studies with the model allowed for the exploration of possible future land use changes. The results demonstrated that the biophysical and/ or socio-economic drivers heavily influenced the types of changes occurring in each land use class.

In another study of the proximate causes of land use change in Narok district Kenya by Serneels and Lambin (1999), they describe a comprehensive spatial statistical model of land-use and land cover change dynamics, based on different drivers of these changes. The model distinguishes three different land use types namely mechanised agriculture, small-scale agriculture and woodlands. They also examine the factors that were thought to influence the land use types found in these areas such as distance to roads, towns, villages and water. For example, the study revealed that the expansion of small-scale agriculture was as a result of migration into the district by immigrants from other districts or population growth. They also observed that the transition of landscapes from woodland was mostly as a result of abiotic factors such as fires and heavy browsing by large mammals. The study also revealed that land tenure also played an important part in determining the kind of use that land was put into. This being a pastoral area, most of the land was previously owned communally and mainly used for grazing but after sub-division, many opted to sell of their land to people wishing to pursue mechanised agriculture.

In a study conducted in Central America in which relationships between land use and their spatial determinant were investigated Kok (2001) revealed that socio-economic, soil-related, climatic and sometimes political factors played an important role in determining land use patterns. This is because they heavily affected the activities that the land was in to They however also realised that these spatial determinants of land use change were sometimes counterintuitive and contradicted the prevailing hypotheses on causes of land use change depending on the scale at which the analysis was done.

2.7. Logistic Regression

Logistic regression is a technique for making predictions when the dependent variable is a dichotomy and the independent variables are continuous and/or discrete. It is used with binary data when modeling the probability that a certain outcome will occur. Specifically, it is aimed at estimating parameters (a) and (b) in the following model:

$$\text{Logit}(p) = \log[p/1-p]$$

$$= \exp\,(\alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta n X n) \qquad (1)$$

Where α is the intercept and βn are slope parameters.

The probability values can thus be expressed as

$$P = \frac{\exp\,(\alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta n X n)}{1 + \exp\,(\alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta n X n)} \qquad (2)$$

Logistic regression is one of the most commonly used statistical techniques. It is used with data in which there is a binary (success-failure) outcome (response) variable. Similar to the linear regression, it estimates the relationship between predictor variables and an outcome variable. In logistic regression, however, we estimate a probability that the outcome variable assumes a certain value (rather than estimating the value itself)

Modeling with logistic regression allows us to contrast different sets of predictor variables and are similar to multiple linear regression methods when the dependent measure is binary (0 and 1).

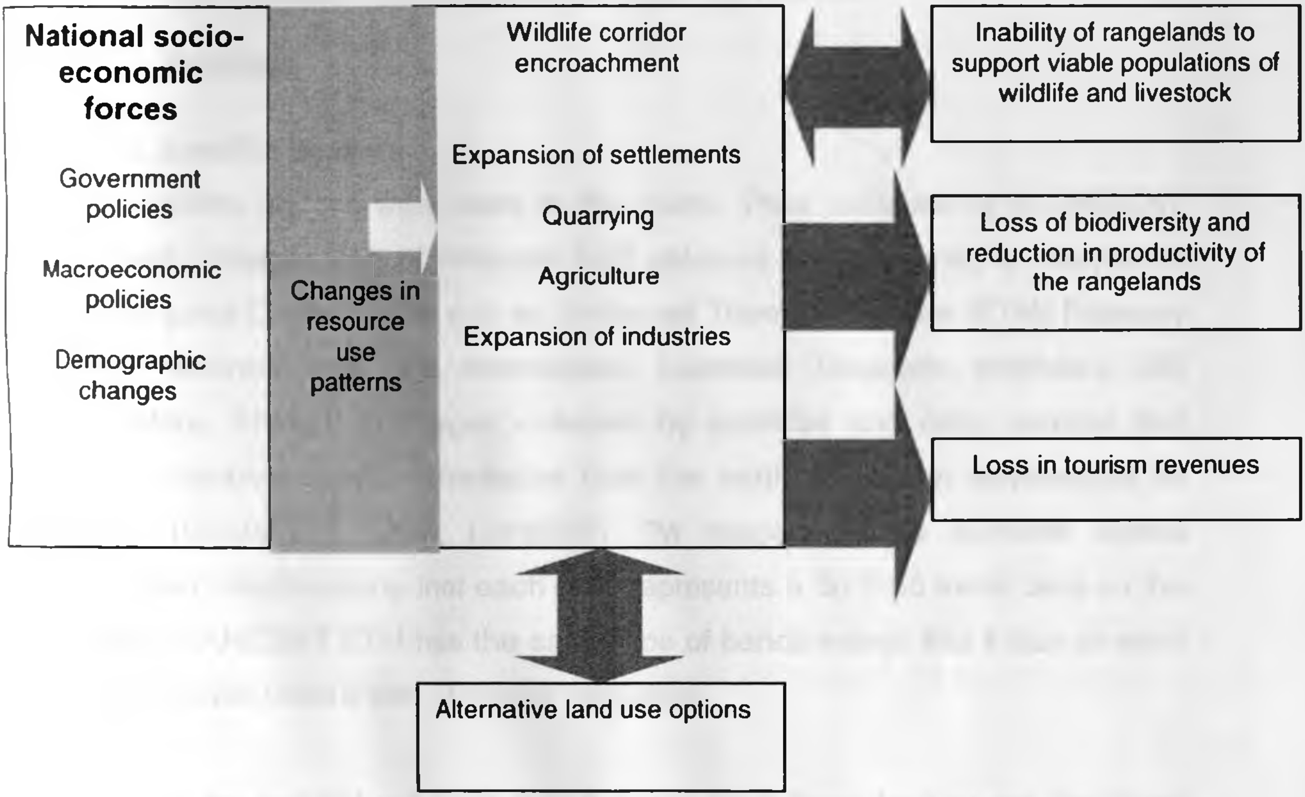
2.8. Conceptual model and theoretical framework

This paper adopts the conceptual framework developed by Wood *et al* (1999) in analyzing the causes of biodiversity loss in Vietnam. They identified forest reduction and loss as the main causes of biodiversity loss. Despite the fact that these activities are occurring at the local level, they are greatly influenced by policies at national and institutional levels.

In the KWDA, for example, the choice of land use activities adopted are as a result of greater socio-economic forces occurring national and international levels that often shape the decisions made at the local level. Such policies made at national level include those regarding land subdivision. Introduction of land policies allowing of subdivision of pastoral lands have resulted in people adopting practices such as construction of settlements, quarrying, agriculture and expansion of industries that are not well suited for these ecosystems. These activities have resulted in the loss of biodiversity and reduction in productivity of the ecosystem. The area can therefore not adequately support a viable population of livestock and wildlife leading to reduced income both from pastoralism and wildlife. The result is that people living in these lands are seeking alternative livelihood strategies.

Figure 7 shows the conceptual model applied in this study.

Figure 1 Conceptual model



CHAPTER THREE: MATERIALS AND METHODS

3.1 Materials

3.1.1. Satellite Imagery

Two satellite images were used in this study. They consisted of a LANDSAT Thematic Mapper (TM) of February 1987 obtained from University of Maryland's Global Land Cover Facility and an Enhanced Thematic Mapper (ETM) February 2000 obtained from the International Livestock Research Institute's GIS laboratory. These are images collected by satellites and carry sensors that record electromagnetic reflectance from the earth in several wavelengths or bands (Gustafson, 1998). LANDSAT TM imagery has a 30-meter spatial resolution, which means that each pixel represents a 30 X 30 meter area on the ground. LANDSAT ETM has the same type of bands except that it has an extra panchromatic band 8 with 15-meter resolution.

It should be pointed out here that it would have been best to get the latest satellite image for the study area to reflect the most current changes occurring on the ground. The reality however is that the current images were too costly to obtain and this was one of the major shortcomings of this study. For the purpose of this study, we therefore used the most current image (2000) that we could find from the International Livestock Research Institute's GIS laboratory.

3.1.2 Topographic maps

Scanned topographic maps for the study area, Nairobi, Sheet number 148/4 and Ngon'g, Sheet number 148/3, of scale 1:50,000, originally sourced from Survey of Kenya were obtained from International Livestock Research Institute's GIS laboratory. These maps although not current (1985) were used as they were the only ones available. Recent maps could have been ideal, as they would reflect the current state of the study area. These topographic maps were used to georectify the satellite images, delineate the boundary of the study area and to update features such as roads and towns.

3.1.3 Soil map

A soil map of scale 1:1000, 000 was obtained from Kenya Soil Survey. This map contained a variable known as soil texture, which in this study was used as a measure of suitability for agriculture. The soils were initially categorised into 3 drainage classes (POOR, GOOD, EXCESS). We aggregated these to have only two classes (GOOD and POOR) for the purpose of our analysis. The scale 1:1000,000 would be considered too coarse a scale for this type of study, however it was the best available option in terms of available soil information in the public domain.

3.1.4 Road Map

A road map for the whole country of scale 1:50,000 was obtained from International Livestock research Institute's GIS website (http://www.ilri.cgiar.org/gis/). The road network for the study area was extracted using the "clip" command in ArcView 3.2.

3.1.5. Moisture availability map

For moisture availability, an index of climatic condition that is a ratio of precipitation and potential evapo-transpiration was used. It is often referred to as PPE and was derived from the database contained in the Almanac Characterization Tool (Corbett 1999)

3.1.6. Hydrography map

A hydrography map of scale 1:250,000 was obtained from the Ministry of Water Resources Management and Development's JICA National water master plan report of 1990.

3.1.7. Man made water sources map

A map showing all the man made water features for the study area was obtained from International Livestock Research Institute's GIS laboratory. These man-made features included dams, pans, boreholes, shallow wells and rock catchments. For our analysis however, they were not categorised but just the physical location was included.

3.1.8. Other relevant reports

Various relevant reports were also used in order to obtain relevant literature about similar studies done and the methodologies used. These reports formed the basis on which this study was carried out. Some of the reports used included relevant theses, workshop papers textbooks and other materials deemed appropriate.

3.2. Methods

3.2.1 Georefferencing the 1987 image

The satellite image of 1987 was georeferenced against the scanned topographic map sheets of scale 1:50,000 from Survey of Kenya utilising a total of 16 ground control points. This is the process of adding "real world" coordinates to scanned or digitized images. This is because scanned images have coordinate systems that are based on the cells or pixels of the scanned image, while satellite images have coordinate systems that are based on the spectral resolution of the satellite sensors. In order to make these satellite images compatible with other digital data, a common frame of reference has to be established. These are reference points whose correct coordinates are known, and can be matched to points in the image. The difference in the location between the two points is used to compute the transformation matrix needed to rectify the image. The image was considered fit for use with an Root Mean Square (RMS error of 15m). It is recommended that the maximum RMS error should not exceed half the pixel size (Sloans 2004) and since our cell sizes were 30 meters, this was considered adequate. The projection used was Universal Transverse Mercator (UTM) and datum Clarke 1880.

3.2.2 Image to image rectification for the 2000 image

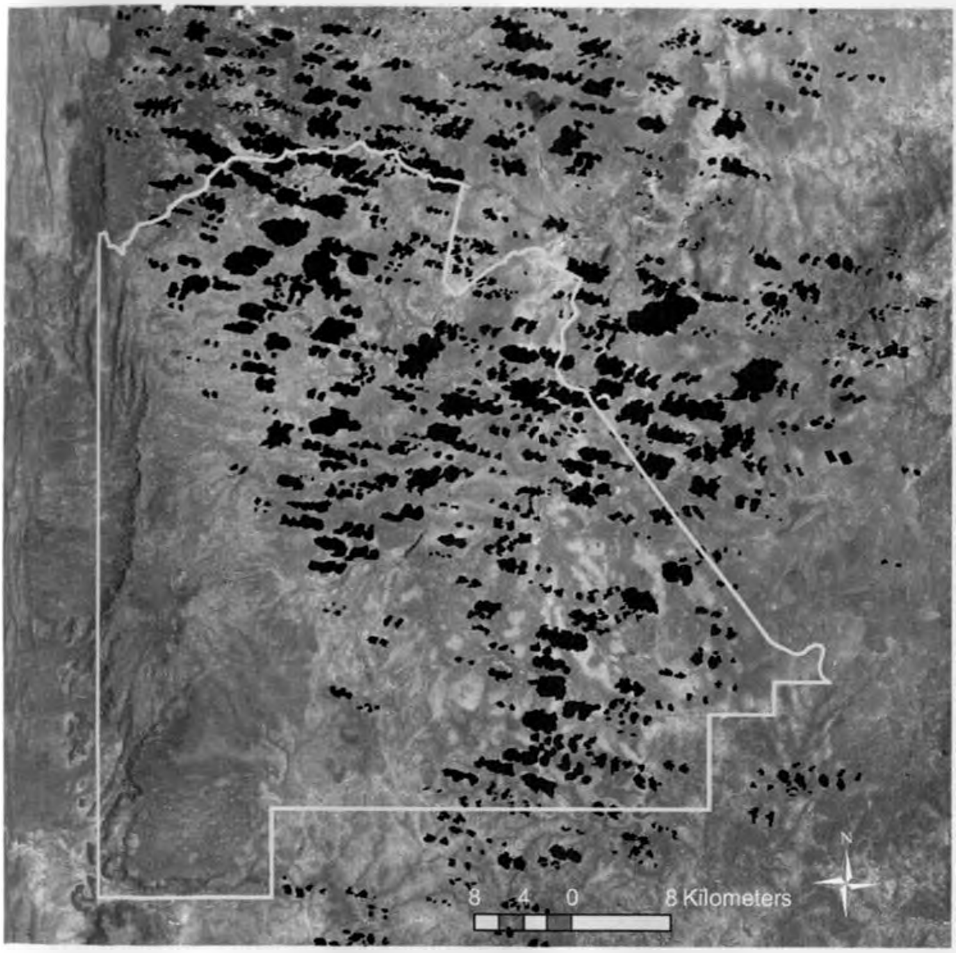
Taking the 1987 image as the reference, the 2000 image was referenced against it using a procedure known as image-to-image rectification in Erdas Imagine software. This was to ensure that the grid cells of each of the images were in line with each other. After this procedure, the images were visually inspected by opening the two images in different windows and then resizing the windows so they were large enough to show detail and could fit side by side on the screen at the same time. The two windows were geo-linked and zooming and panning was performed to ensure that common features in both images were aligned.

3.2.3 Masking out cloud cover

The 1987 image that we used for this analysis had a lot of cloud cover (>20%). It was therefore necessary to remove areas covered by clouds from the analysis prior to the image-differencing step that would follow. After sub setting the TM images to my study area boundary, the areas that were covered by clouds were masked out as much as possible.

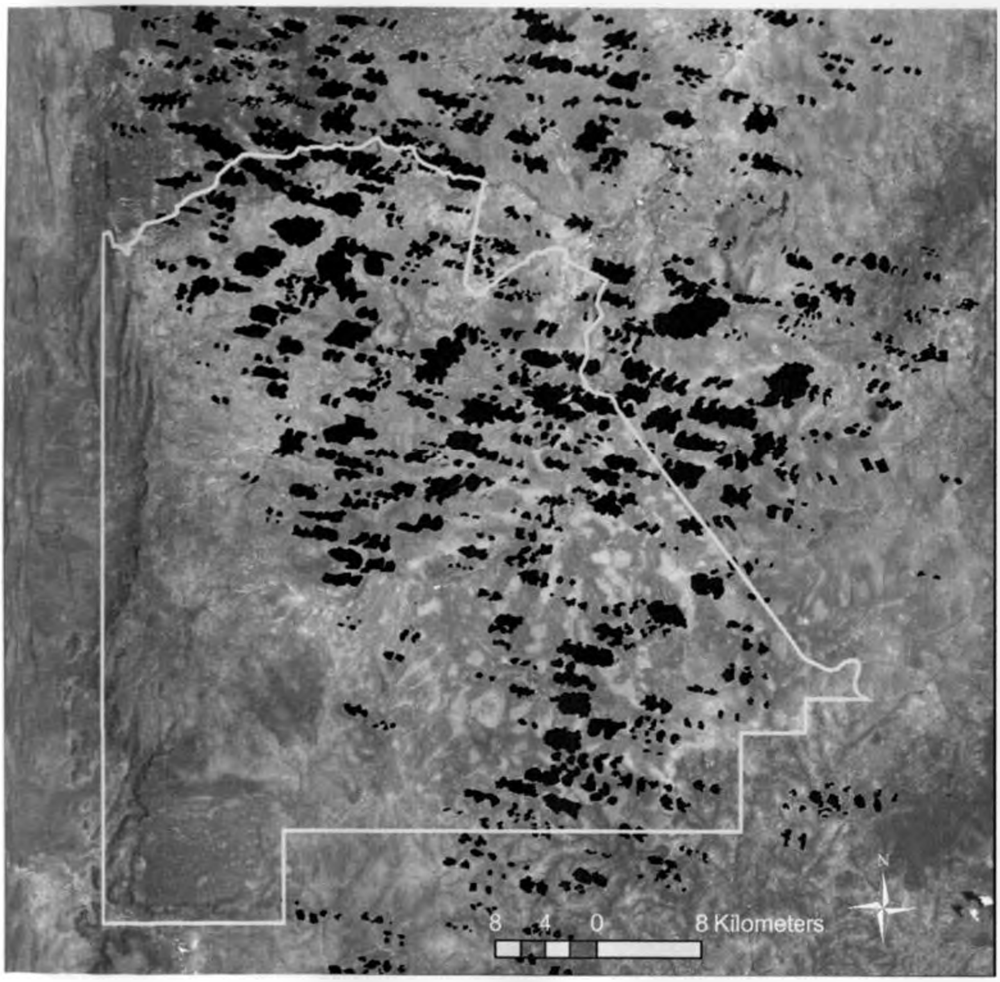
These areas were first digitised on-screen and then using these digitised maps (also known as Areas of Interest), they were masked from the analysis. Because the clouds were masked in the 1987, the corresponding areas had to be masked out in the 2000 image to avoid getting biased results during the image differencing. The resultant maps were as shown (see figure 8 and figure 9).

Figure 2 **Masked image of 1987**



Key: Dark patches indicate areas that have been masked out

Figure 3 Masked image of 2000



Key: Dark patches indicate areas that have been masked out

3.2.4 Normalised Difference Vegetation Index

Normalised Difference Vegetation Index (NDVI) is a ratio often used to determine the density of vegetation based on the visible and near infrared sunlight reflected by plants. Healthy vegetation absorbs most of the visible light that falls on it, and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light. NDVI for 1987 and 2000 were visually compared to assess the areas where changes had occurred and also to corroborate the results of the change detection procedure. It is calculated using the formula below:

NDVI = (NIR-red)/ (NIR+red)

(Where the nIR=band 4 and red =band 3)

3.2.5. Change detection

Change detection is the process of identifying differences in the state of an object (in this case represented by the pixel), by observing it at different times (Shu 2003).

There are several techniques of carrying our change detection such as the Multi-date Visual Composite Image Change-Detection, Post-Classification and image differencing (Tardie et al 2001).

In this study the method employed was the image differencing, the reason being that it has been widely used for change-detection and presents lower change-detection errors compared to other methods (Jensen and Toll, 1982). This process involved the digital number (DN) value of one pixel for one image is subtracted from the DN value of the same pixel for a different time period (Singh, 1989) as shown in the equation below.

$$DX^k_{ij} = Xkij\,(t_2) - Xkij\,(t_1)$$

Where, X^k : pixel value (DNs) of band k,

ij : pixel coordinate

There are, however problems that could cause differences between images that are not necessarily as a result of land cover changes. One is that if there is a cloud in the Time 2 image and none in the Time 1 scene, it will create a big patch of "difference." Seasonal variations could also lead to erroneous results that don't mean much in terms of long-term landscape change. Another source of error is when two images of interest aren't accurately registered to each other beforehand; the mis-registrations will appear as "changes."

It was therefore important to enforce certain conditions before the image differencing was carried out:

- It was ensured that both images were taken during the same season (February for both years)
- The two images had to be accurately registered to the ground and to each other (image to image rectification).
- Cloud-affected areas must be removed from analysis.

This sort of strictly statistical presentation of change occurring within the dispersal area doesn't show the actual causes that have taken place other than showing where they have taken place. Because this area is mainly used as a dispersal area, meaning herbage utilization by domestic and wild ungulates, we seek to know which areas have actually experienced decrease in herbage production by carrying out Normalized differential Vegetation Index (NDVI).

3.2.6 Land cover mapping

This process was aimed at realising a land cover map for the year 2000. This was done for the sole purpose of showing the type of land cover occurring in the areas indicated as having undergone some change (more than 15%) in the change detection (image differencing) carried out above between images of 2000 and 1997.

3.2.7 Image classification

During the classification process, the image was first segmented into smaller pieces with each piece covering areas of almost similar characteristics. This was very important as initial unsupervised classifications grouped certain land cover types such as built up areas and rocky areas as one since both had the same reflectance values. It was therefore important that each of these areas be classified differently.

These segments of the study areas were run through an unsupervised classification algorithm that clustered the image into spectrally similar pixels. Each of the patches outlined in the steps above were then labelled with their correct cover types in a process similar to supervised classification. This method relies on areas of known cover types (training sites), to assign labels to the rest of the regions created during the image segmentation. This type of two-stage method of classification has been recommended as an effective way of carrying out land cover classification (Gustafson 1998). As a result of this method, several classes of land cover types were discriminated including but not limited to the following (1) urban or built-up land, (2) Agricultural land, (3) forests and various forms of grasslands.

3.2.8 Field observations

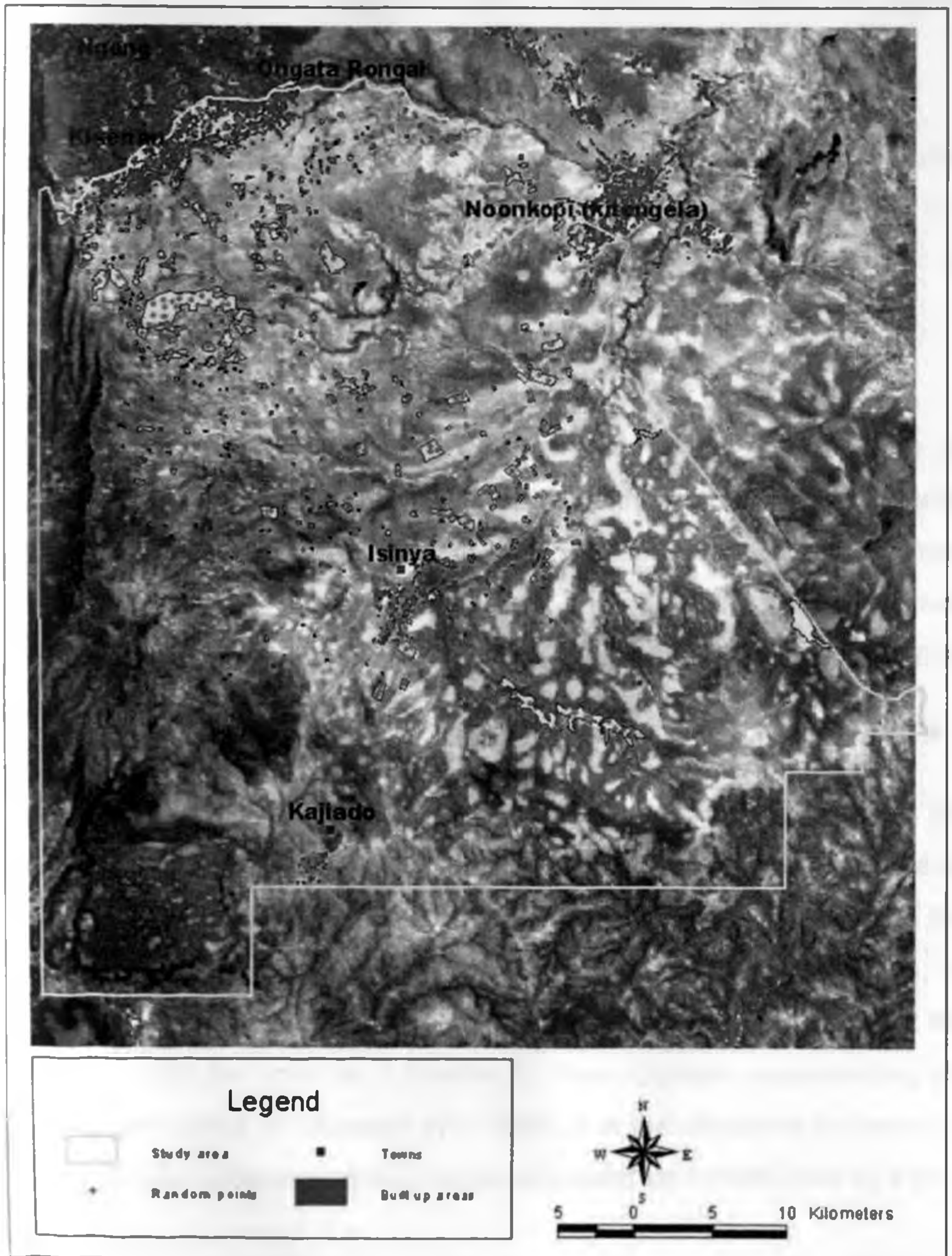
Field observations were conducted, after preliminary image interpretation, as a means of resolving uncertainties during the interpretation process and also as a confirmation of the preliminary maps. Field observations were conducted in order to verify uncertainties in the interpretation and confirm consistency of the interpretation.

3.2.9 Sampling procedure to select independent variables

Using the land use classes obtained in the classification, two clusters of change mainly agriculture and settlements were selected for analysis. They were selected because they were the main interest for this study.

From each of these clusters, delineated from the 2000 image, several random points were selected using ArcView's random point generator extension (ESRI, 2004). This functionality selected random points from within polygons from each of the two land cover classes, which were then used to extract biophysical information including soil texture, distance to roads, distance to major towns and distance to rivers. A total of 300 and 200 points were generated from agricultural farms and settlements respectively and were considered adequate for this study.

Figure 4 Random points generated for the study.



3.2.10. Statistical analysis and spatial modelling

The relationship between the main land cover changes and biophysical and human factors affecting these changes were investigated statistically with the objective of associating land cover change to their biophysical and human drivers (Shu, 2003).

Based on these factors, a probability surface map for settlement and urbanisation were generated for the study area depicting areas prone to change in the near future as well as indicating the amount of conservation land likely to be lost to settlement and urbanisation.

3.2.11. Creating the independent variables

Since the main causes of land cover change in the KWDA could be caused by human activities, it was important to consider the biophysical characteristics that influence human activities in this area (Shu, 2003). It was very important for the analysis that we convert the map information such as roads, PPE, rivers, water points, soils and towns into useful information that could be used in the analysis (Kristjanson et al 2002).

Some of the GIS layers such as PPE and soils could be used as they were. Some of the layers however had to be translated into some kind of accessibility measure (e.g. how far are these areas experiencing change from the biophysical characteristics representing the independent variable such as towns, roads and rivers. The location of towns for example is not that useful in itself but information about how far the town is in relation to these clusters experiencing changes is much more useful (Kristjanson *et al* 2002). For the distances to towns, roads and rivers, simple distance surfaces were calculated as shown (See fig 4.5)

These spatially explicit biophysical variables were calculated and using ArcGIS Desktop* and ArcGIS Workstation* (ESRI 2004) and statistically significant information were extracted from the various geo-spatial data sets collected. Appendix 1 shows the variables used for analysis

3.2.12. Generation of dependent variables

The major land cover changes of interest to this study that were obtained from change detection section were categorized into

- Expansion of towns and settlements
- Expansion of agriculture.

These two classes were coded as shown: (1) Expansion of towns and settlements and (2) Expansion of agriculture.

These class codes were then input into a statistical analysis package (SPSS) where the analysis was carried out.

3.3. Statistical method

3.3.1 Logistic Regression

Logistic regression is a technique for making predictions when the dependent variable is a dichotomy and the independent variables are continuous and/or discrete. It is used with binary data when modeling the probability that a certain outcome will occur. Specifically, it is aimed at estimating parameters a and b in the following model:

$$\text{Logit}(p) = \log[p/1-p]$$

$$= \exp(\alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n) \qquad (1)$$

Where α is the intercept and βn are slope parameters.

The probability values of the occurrence of the dependent variables can therefore be quantitatively expressed in terms of the independent variables by the following equation.

$$P = \frac{\exp(\alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta n X n)}{1 + \exp(\alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta n X n)} \qquad (2)$$

We estimated the probability that the outcome variable assumed a certain value (rather than estimating the value itself).Since our dependent variable was binary (0 and 1) the analysis done here was similar to that performed during multiple linear regressions since modeling with logistic regression also allows us to contrast different sets of predictor variables.

3.3.2. Testing the Collinearity among the Independent Variables

A correlation analysis was first carried out to determine the unique effect of each of the independent variables on the dependent variable. This was to avoid ambiguous results that are often the case when two or more variables have the same effect on the dependent variable. The resultant matrix was as shown in table 1.

Table 1 Results of the correlation analysis

		ppe	dist_roads	dist_town	dist_river	dist_water
ppe	Pearson Correlation	1	-.160(*)	-.141	-.298(**)	-.275(**)
	Sig. (2-tailed)		.030	.056	.000	.000
	N	184	184	184	184	184
dist_roads	Pearson Correlation	-.160(*)	1	.362(**)	.056	.237(**)
	Sig. (2-tailed)	.030		.000	.421	.001
	N	184	207	207	207	207
dist_town	Pearson Correlation	-.141	.362(**)	1	-.142(*)	.510(**)
	Sig. (2-tailed)	.056	.000		.042	.000
	N	184	207	207	207	207
dist_river	Pearson Correlation	-.298(**)	.056	-.142(*)	1	-.057
	Sig. (2-tailed)	.000	.421	.042		.415
	N	184	207	207	207	207
dist_water	Pearson Correlation	-.275(**)	.237(**)	.510(**)	-.057	1
	Sig. (2-tailed)	.000	.001	.000	.415	
	N	184	207	207	207	207

(ppe: Available moisture, dist_roads: Distance to roads, dist_town: Distance to towns, dist_river: Distance to rivers, dist_water: Distance to a man made water source)

3.3.3 Mapping of settlement and urban expansion probability

A surface map showing the probability of settlement expansion was generated based on the parameters obtained from the regression results.

The area was first subdivided into small pixels each measuring approximately 200x200 meters similar to the pixel size used for extracting information on biophysical variables. Each of these pixels was then given a unique identification number and the type of land use that it was occupying was taken into consideration.

Each of the values of the biophysical environments were multiplied by the probability values obtained during the regression. For example for each pixel, the value given as its distance to a river was multiplied by the parameter estimate obtained during the regression.

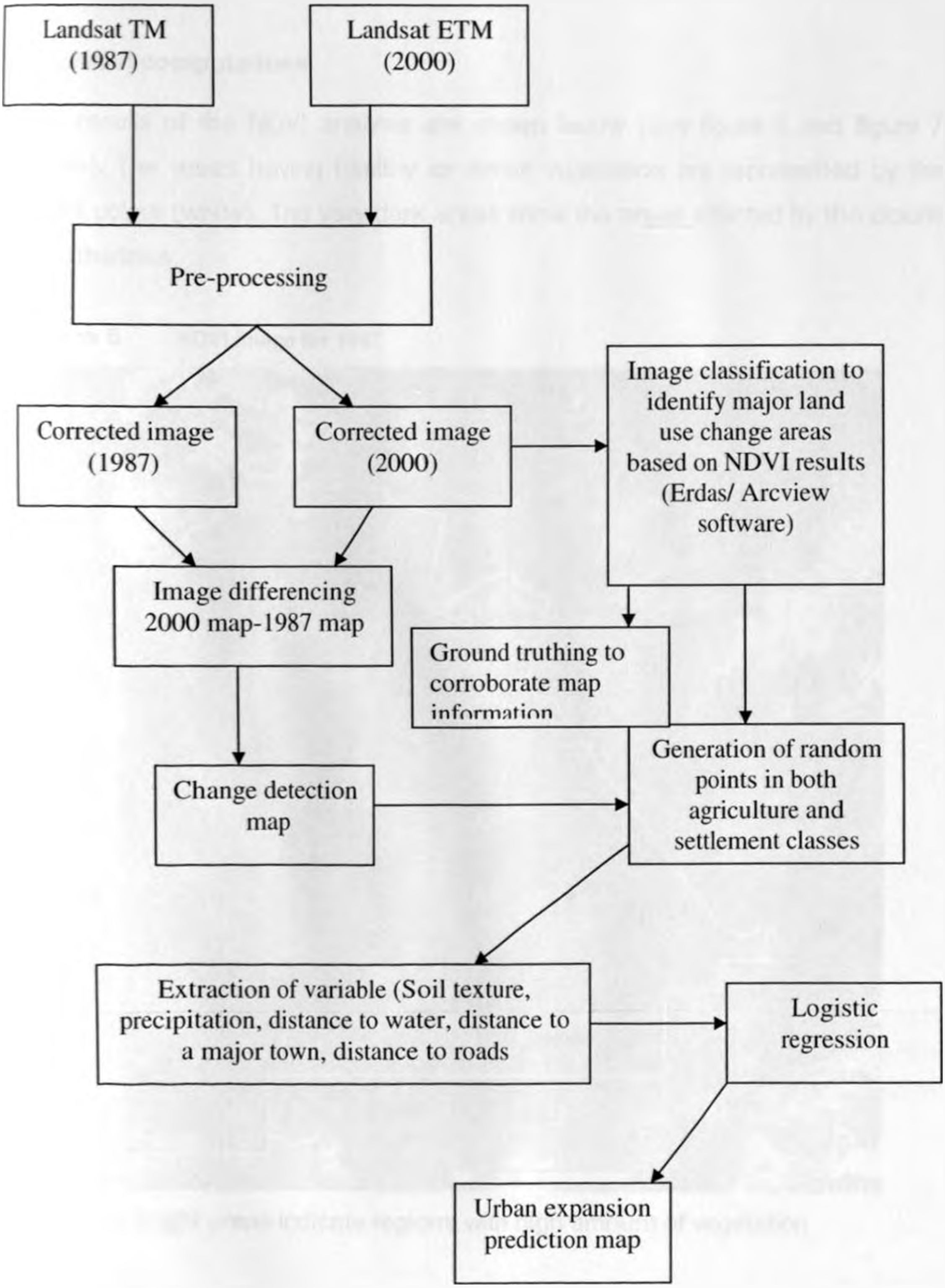
Each of the predictor values for the biophysical variables obtained from the regression were built in MS Excel and a resultant prediction value obtained and plotted. These values were then exported back to Arc View 3.2 where the surfaces were generated.

3.3.4. Summary of methodology

The research involved two main steps. In the first step, change detection was employed to identify broadly areas where land use change had taken place (figure 8). The second step concentrated on the specific problem of detecting the exact types of activities that were occurring in the areas indicated as having changed and identifying what the drivers of these changes were. These drivers were then used to produce a probability maps showing possible expansion of settlements within the study area.

Figure 5 below summarises the basic steps followed in the methodology described above.

Figure 5 Summary of the steps

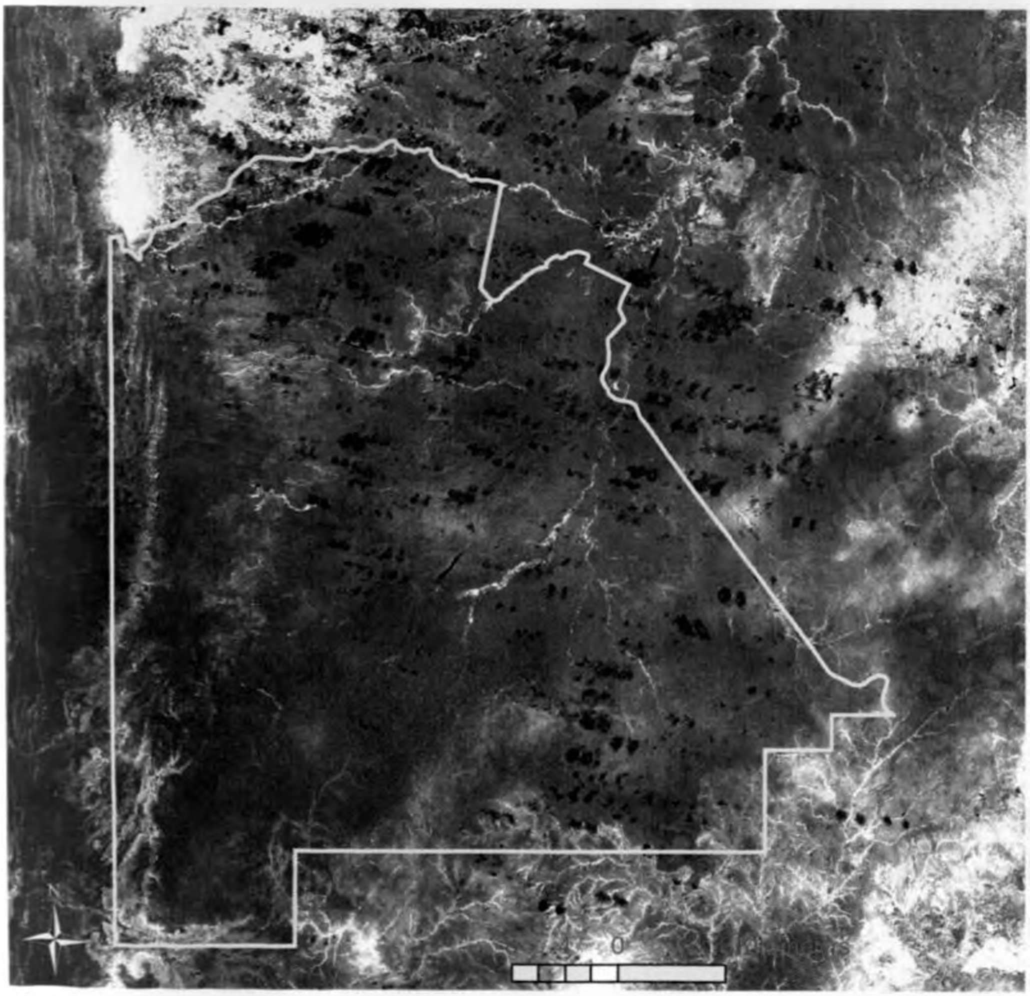


CHAPTER FOUR: RESULTS

4.1. NDVI computations

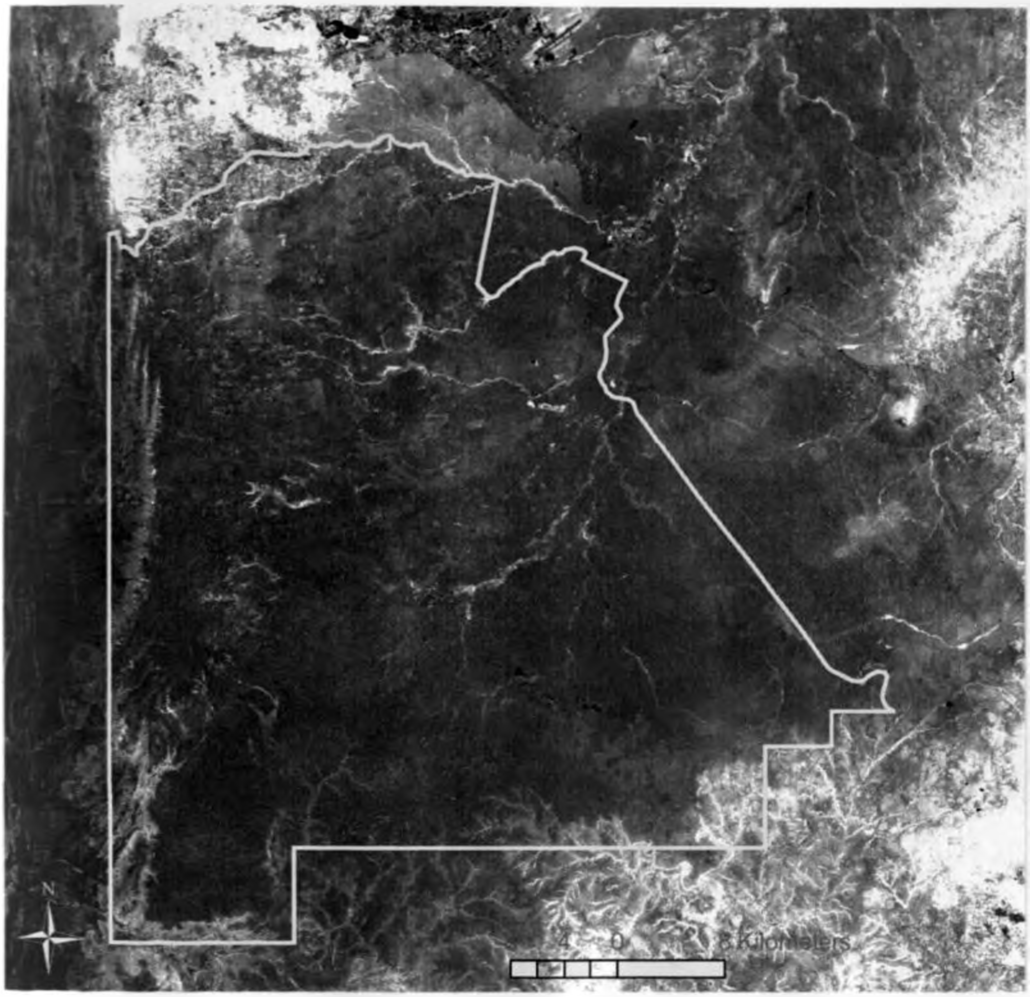
The results of the NDVI analysis are shown below (see figure 6 and figure 7 below). The areas having healthy or dense vegetation are represented by the bright colour (white). The very dark areas show the areas affected by the clouds and shadows.

Figure 6 **NDVI image for 1987**



Key: The bright areas indicate regions with high amount of vegetation

Figure 7 **NDVI image for 2000**



Key: The bright areas indicate regions with high amount of vegetation

The results shown below of the image differencing procedure technique illustrate the pixels that have changed between 1987 and 2000.

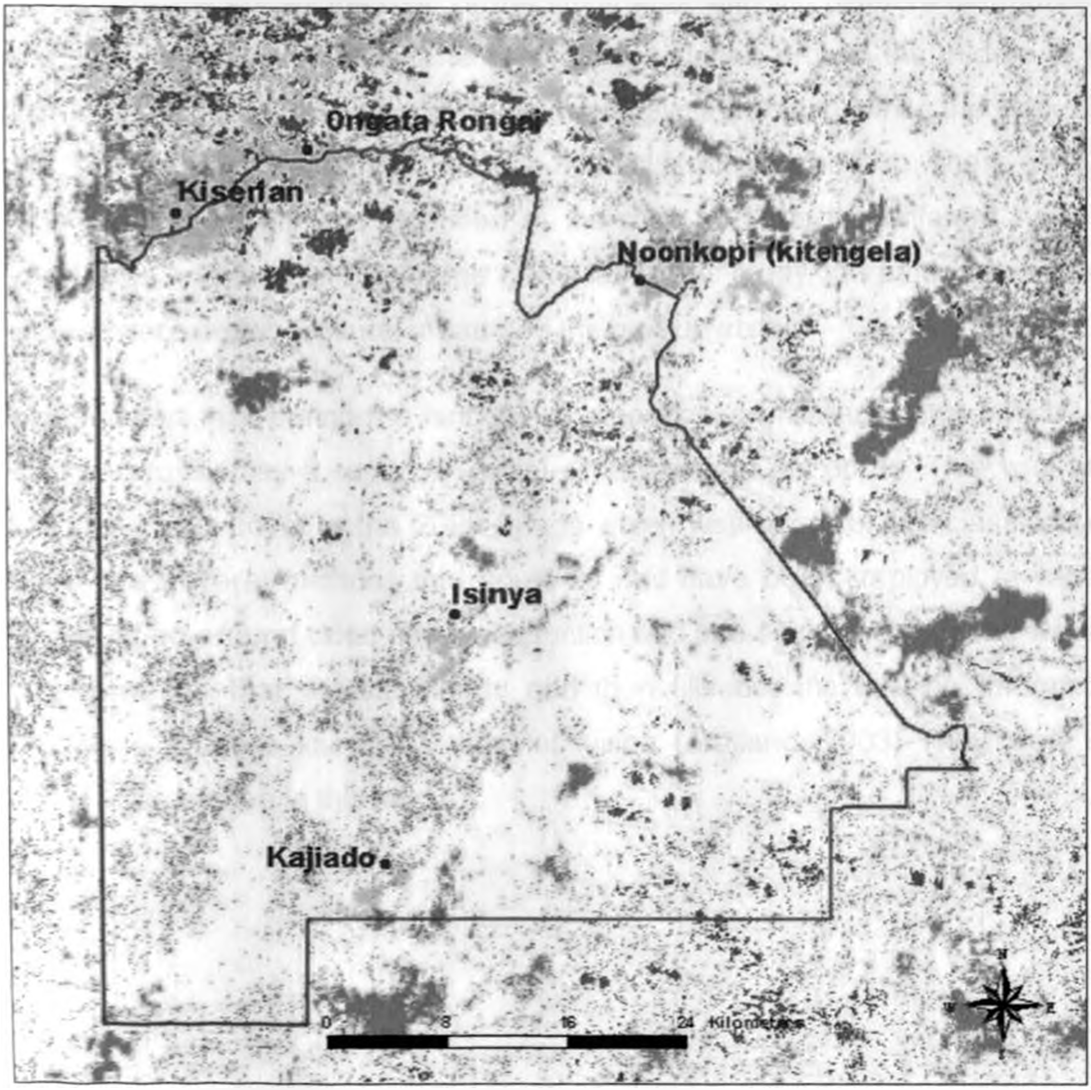
4.2. Change detection

Areas that had no significant change had values close to zero but for areas that had change, the values were either positive or negative. For any meaningful distinction of areas that have undergone change, a threshold of 15% was set.

Figure 8 below shows the resultant map from the image differencing procedure. The areas coloured green indicate areas where the difference in pixel values were positive while the red shows areas where the difference in pixel values were negative. For the purpose of this study both negative and positive changes were considered together just as areas where change had occurred.

KEY: Both the dark greens as well as the red patches on the map indicate areas where differences of more than 15% were realised from the image differencing algorithm.

Figure 8 Change detection map



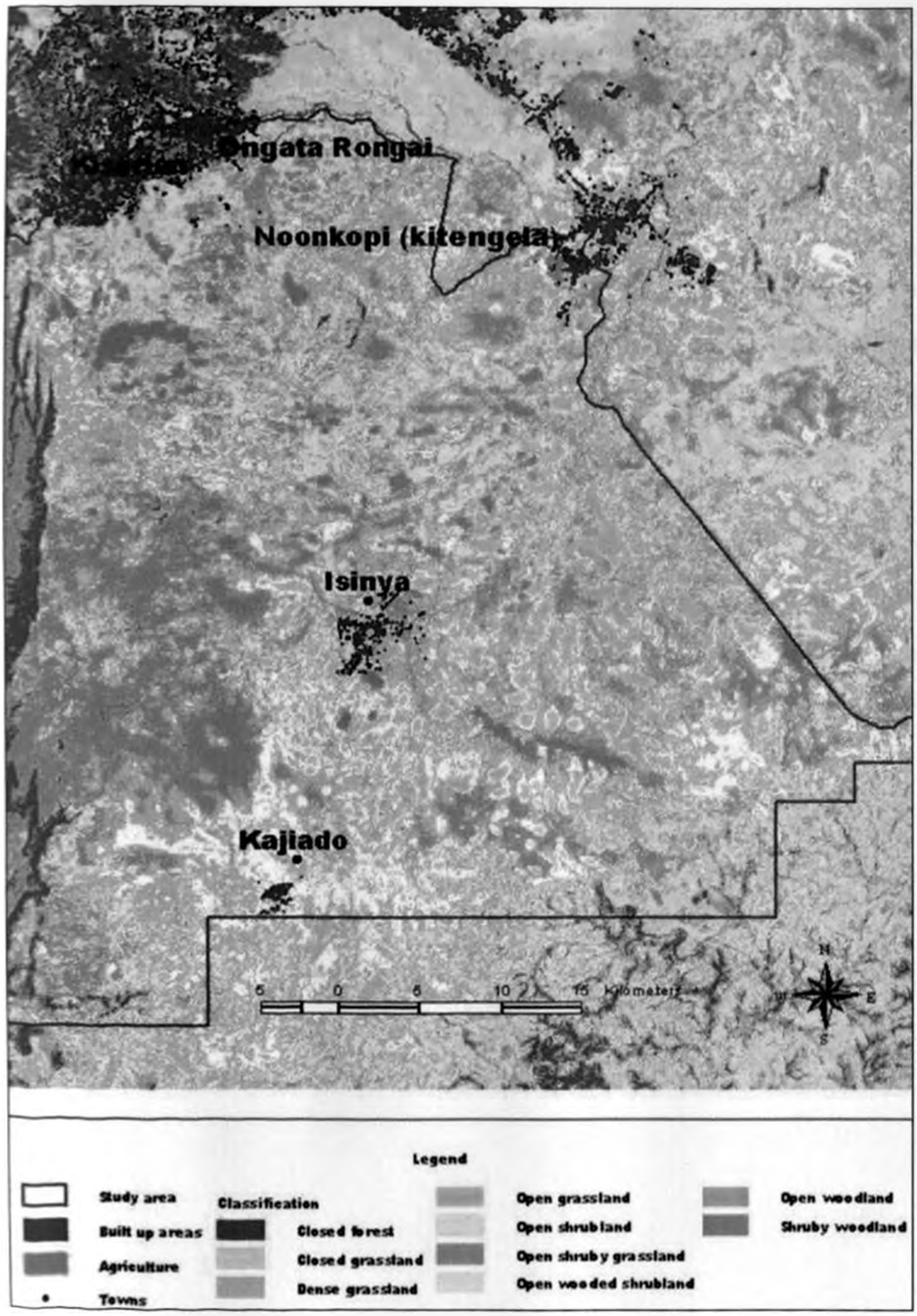
4.3. Land cover mapping

Several land cover classes were discriminated based on spectral characteristics of the 2000 satellite image however the important classes for consideration for this study included Expansion of settlements and towns and expansion of agriculture. They were important since they were used as the dependent variable in the analysis.

Figure 9 below shows the map of the study area with the different categories of land cover classes realised. The light green patches around the middle of the map indicate areas that were classified as agricultural land, while the dark blue coloured areas indicate area that have been classified as built up. There are also other land cover classes identified in the map such as the different types of grasslands and forests, but for the purposes of this study, the particular areas of interest were the agricultural areas and the built up areas.

It was noted that during the land cover classification, Kajiado town which was expected to display a superior spatial dimension did not do so. This was as a result of cloud cover in the 2000 image which was used for the classification. There are several methods that could be and have been employed in various studies to go around cloud cover obstruction and one such method is the wavelet transformation that detects clouds and then fills out the missing information through a process known as wavelet fusion (Arellano, 2003) They were not however employed in this study.

Figure 9 Land cover classes for the study area.



4.4. Ground Truthing

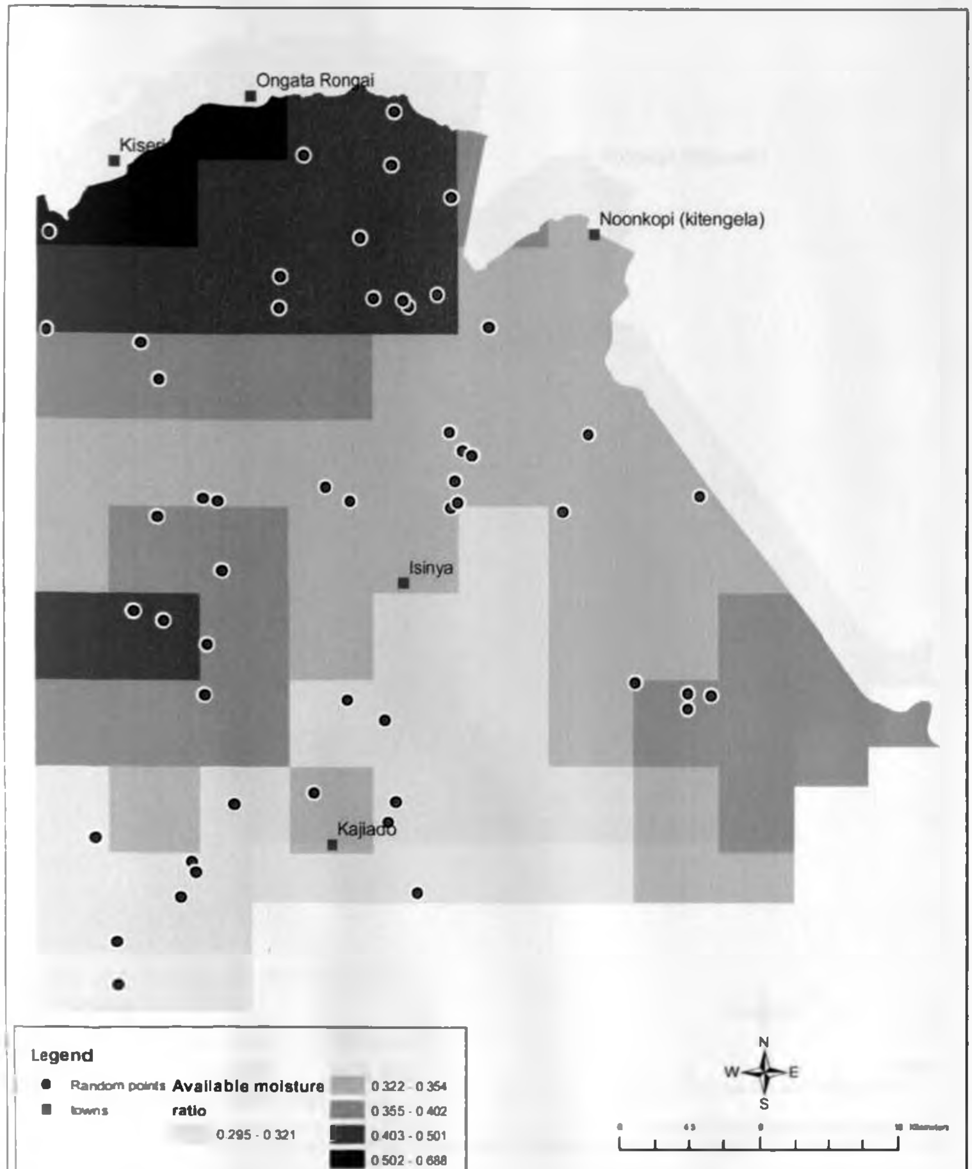
After the land cover map was produced, several points were selected among the major land use classes. Using GPS equipment, these sites were visited to verify that the classification was correct. A total of 28 points were visited using the "go to" command using garmin 12xl GPS units.

Based on the result of the land map above, ArcGIS 9.0 was used to derive the dependent variables, which were mainly settlements and urban centres represented in the land cover map as built up areas and agriculture respectively.

4.5. Biophysical variables.

Figure 10-14 shows the results of the analysis maps used to derive information about the biophysical environment. ArcGIS 9.0 was used to extract information on the biophysical environments associated with each random point as shown in the maps.

Figure 10 Moisture availability



Source: ILRI, Almanac Characterisation Tool

Figure 11 Soil texture

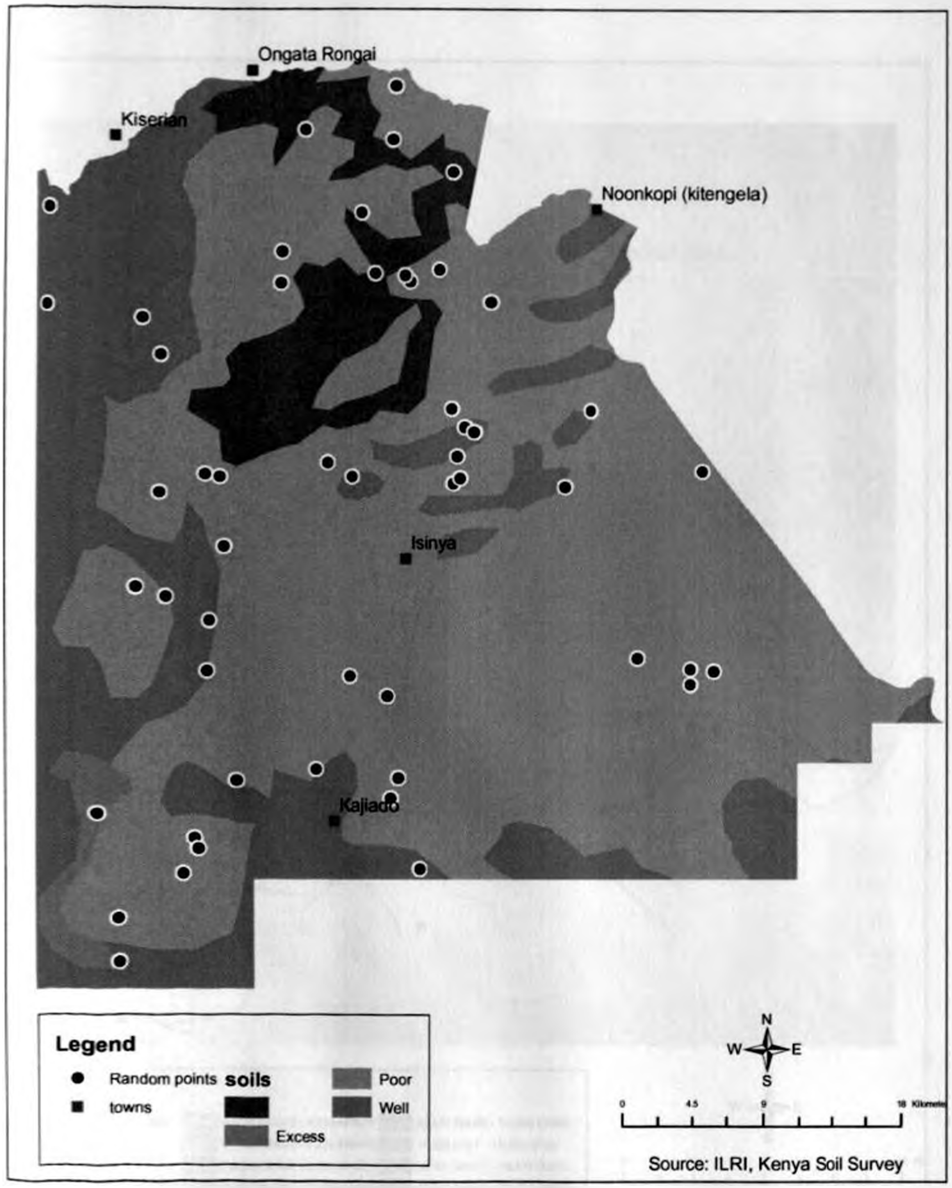


Figure 12 Distance to roads

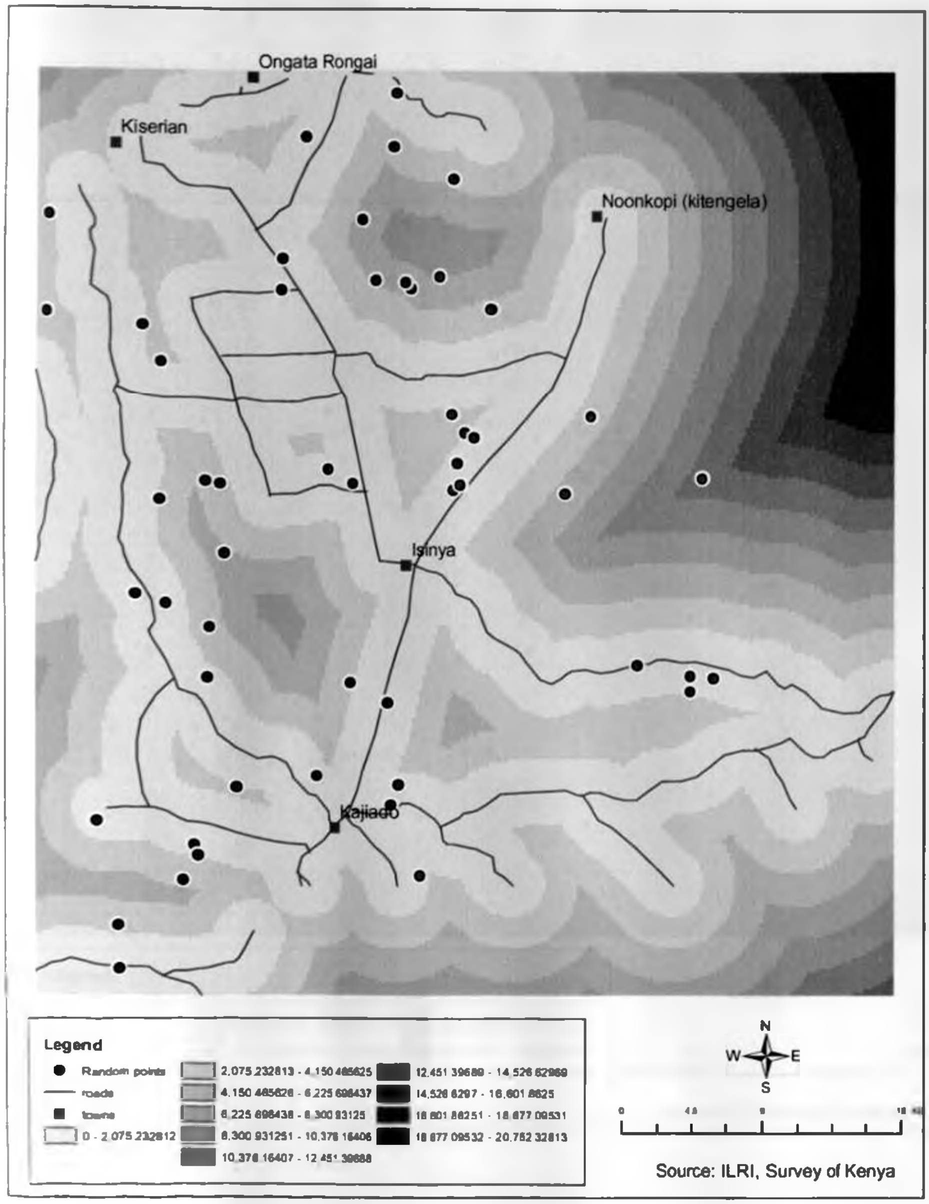


Figure 13 Distance to water points

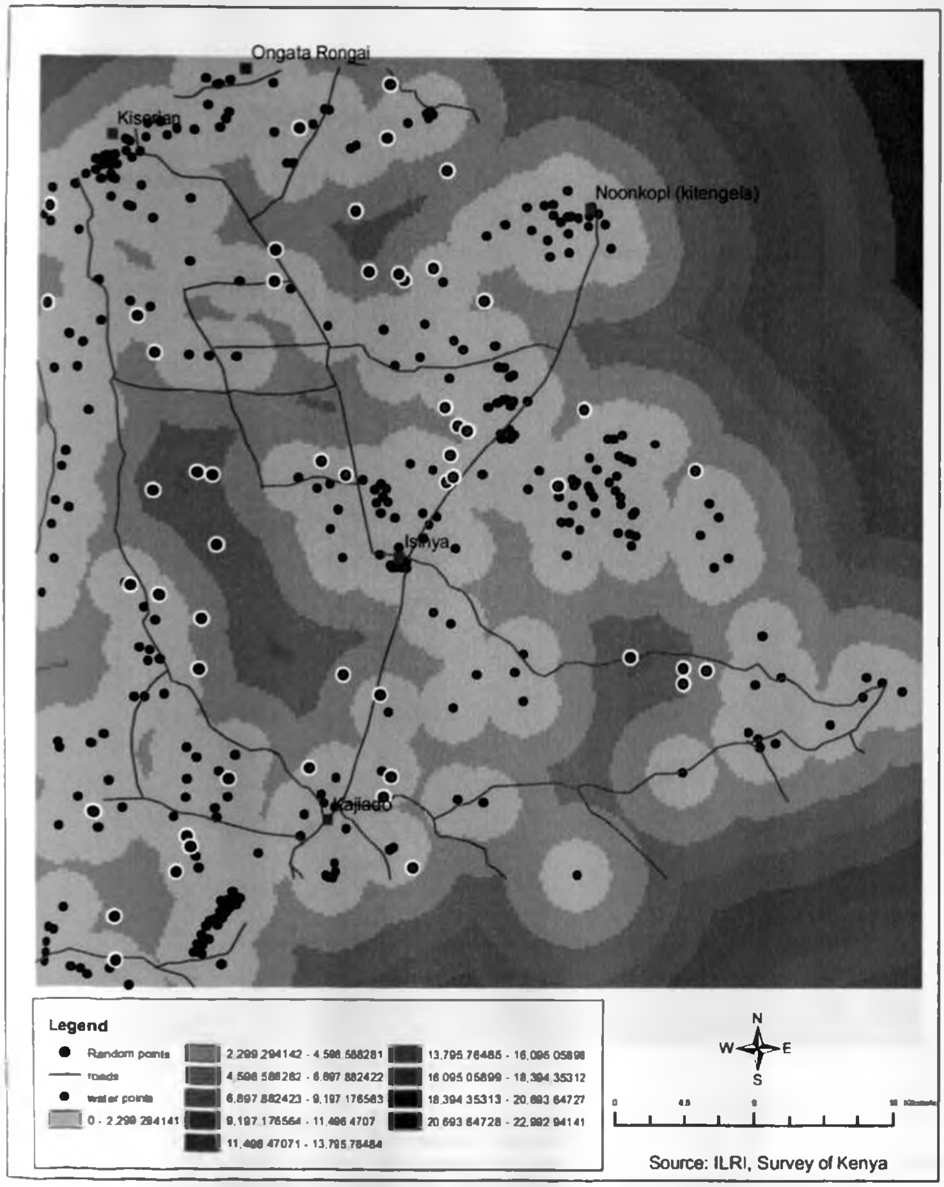


Figure 14 Distance to towns

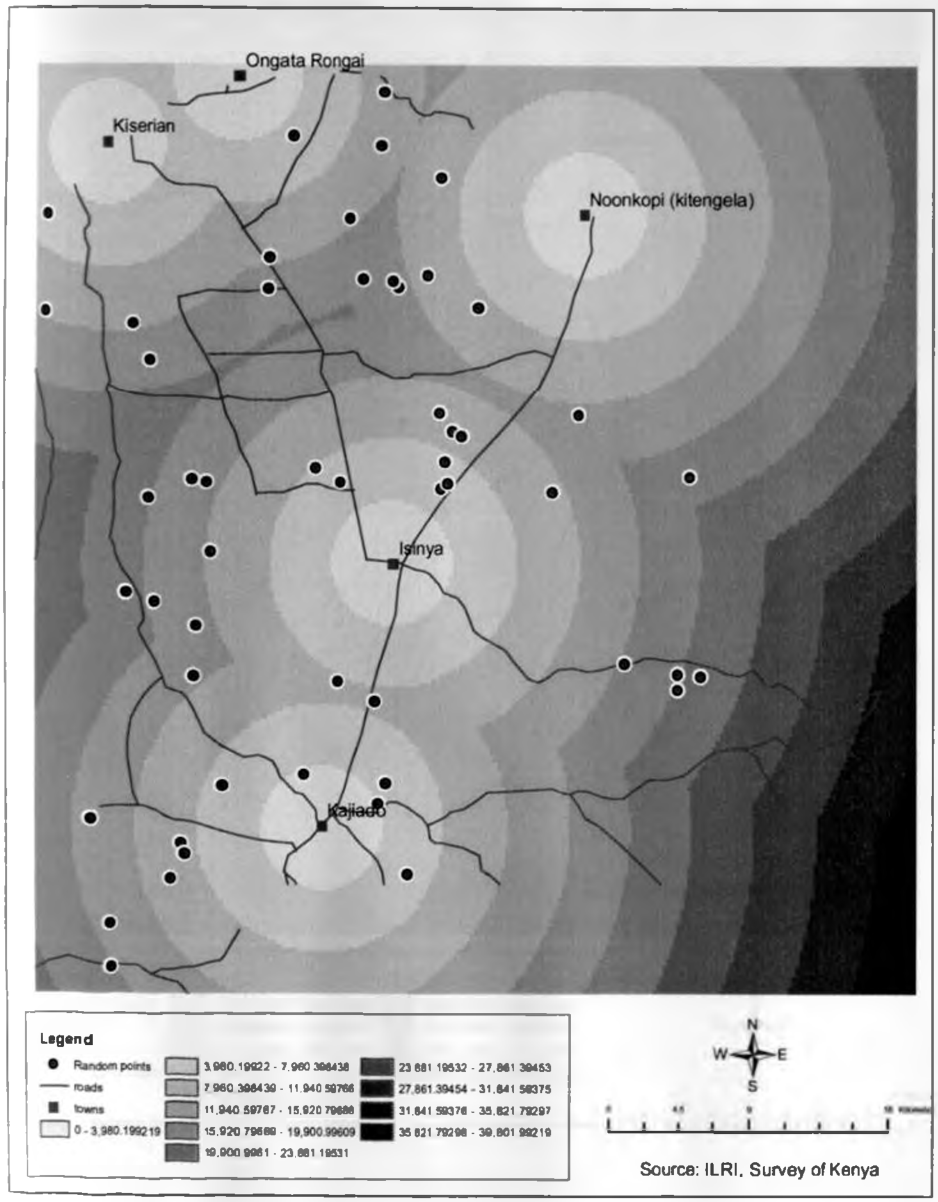
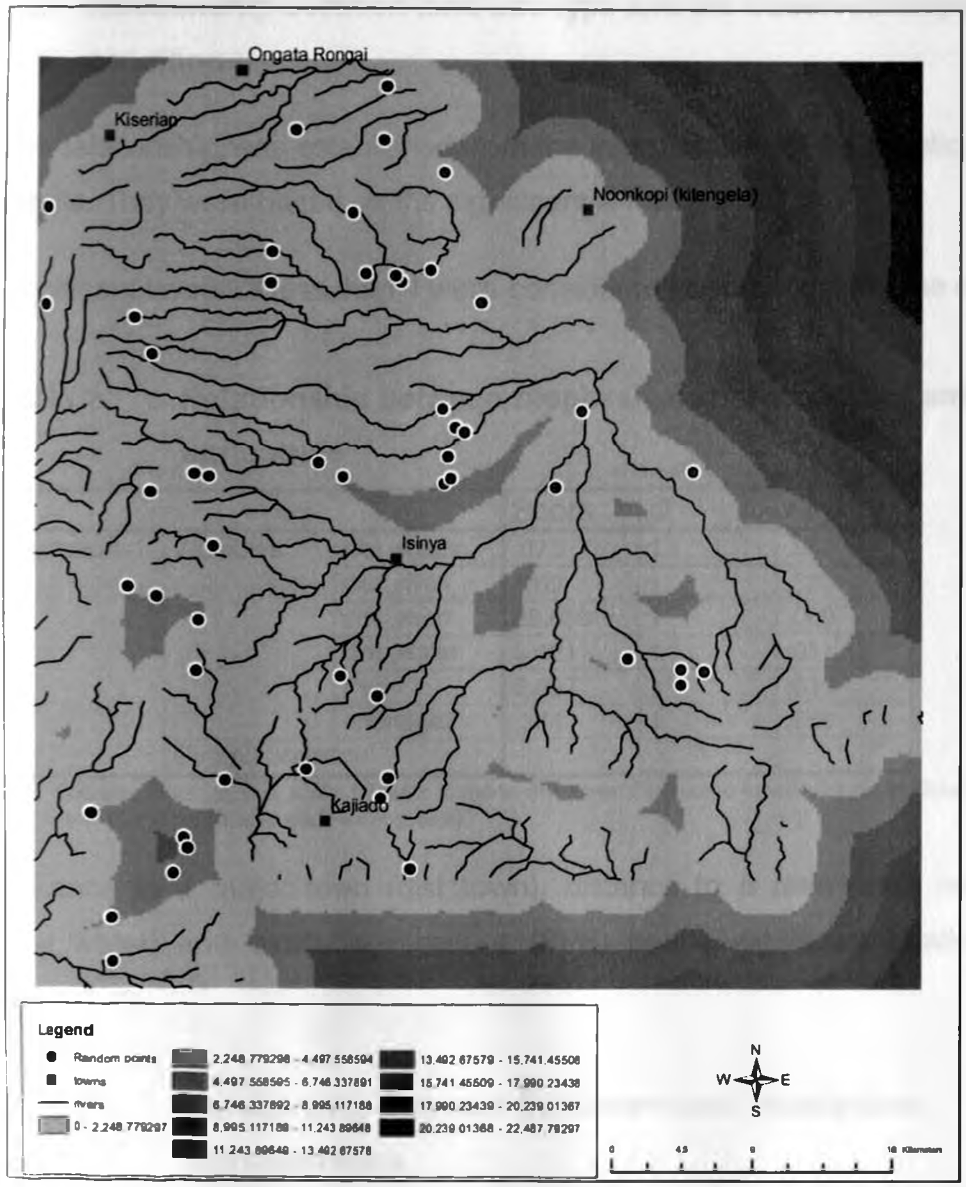


Figure 15 Distance to rivers



4.6. Relationship between land use type and the observed biophysical conditions.

This relationship was established from the interpretation of the logistic regression results. They were based on the significant levels.

Significant levels of less than 1 were considered good enough for the model.

Table 2 Relationship between biophysical characteristics and agriculture

			Score	df	Sig.
Agriculture	Variables	dist_roads	.873	1	.350
		dist_river	.969	1	.325
		dist_town	26.656	1	.000
		dist_water	6.421	1	.011
		Ppe	6.627	1	.010
		drainage2	.344	1	.558
	Overall Statistics				

(ppe: Available moisture, dist_roads: Distance to roads, dist_town: Distance to towns, dist_river: Distance to rivers, dist_water: Distance to a man made water source)

Distance to a major town (dist_town), distance to a man-made water source (dist_water) and available moisture (PPE) had a significant relationship with agriculture.

Table 3 Relationship between Settlement and biophysical characteristics

		B	S.E.	Wald	df	Sig.	Exp(B)
Built up areas	dist_roads	.000	.000	.705	1	.401	1.000
	dist_river	-.001	.000	6.449	1	.011	.999
	dist_town	-.001	.000	20.422	1	.000	1.000
	dist_water	.000	.000	1.352	1	.245	1.000
	ppe	-7.912	2.061	14.738	1	.000	.000
	drainage2	-.022	.408	.003	1	.958	.979
	Constant	5.233	1.179	19.687	1	.000	187.369

(ppe: Available moisture, dist_roads: Distance to roads, dist_town: Distance to towns, dist_river: Distance to rivers, dist_water: Distance to a man made water source)

From the analysis of it was found that the significant variables are distance to river, distance to town and Ppe. Settlements tended to be located near rivers and places with high Ppe, however, the same could be said about distance to town because it had a very low parameter estimate of 0.000. Distance to the road and drainage system didn't show any significant relationship.

4.7. Mapping probability for settlement

Based on the results obtained in the analysis above, we selected expansion of settlements as a dependent variable and put this into a model to try and predict the expansion of the same. We selected this variable since it is the single most challenging phenomenon as far as changing land use practices in KWDA is concerned.

The following independent variables were input into the predictive model to indicate likely areas for expansion based on the drivers selected from the regression results.

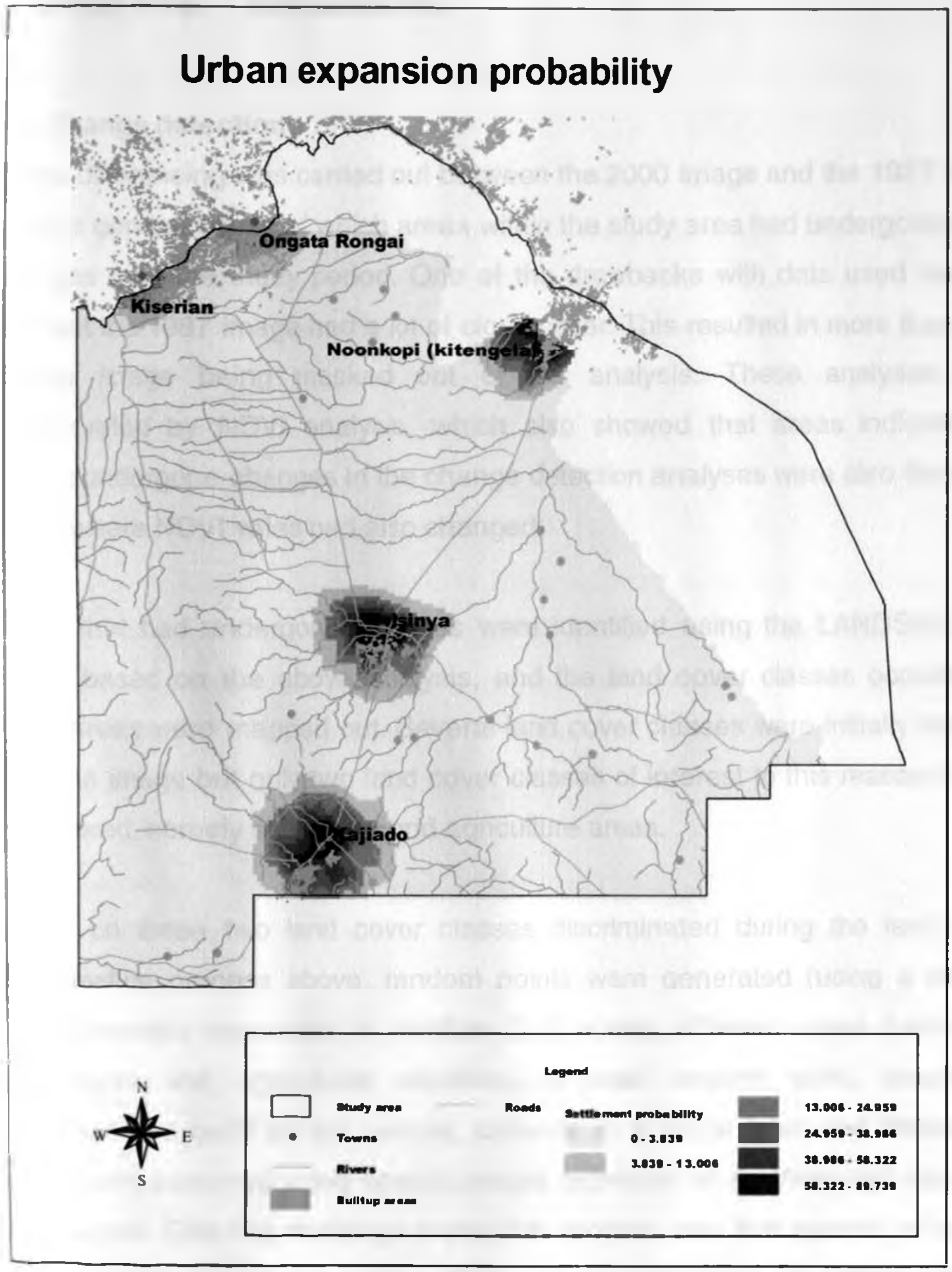
- Distance to a river (dist_river)
- Distance to town (dist_town)
- Available moisture (PPE)

Model

$$P = \frac{\exp(5.233-(7.912*PPE)-(.001*dist\_river)-(.001*dist\_town))}{1+\exp(5.233-(7.912*PPE)-(.001*dist\_river)-(.001*dist\_town))}$$

Each of the variables (distance to river, distance to roads and PPE) were each multiplied by the coefficients in the model shown above to determine the probability values for each of the grid cells. The result was a settlement expansion probability map for KWDA as shown in Figure 17.It is based on the prediction model outlined above. The dark brown areas indicate areas that are most likely to be converted to settlement while the lighter areas are those that are less likely to be converted to settlements.

Figure 16 Surface map of possible expansion of settlements



CHAPTER FIVE: DISCUSSIONS

5.1. Change detection

Image differencing was carried out between the 2000 image and the 1987 image to get a general sense of which areas within the study area had undergone some changes over the study period. One of the drawbacks with data used was the fact that the 1987 image had a lot of cloud cover. This resulted in more than 20% of the image being masked out of the analysis. These analyses were corroborated by NDVI analysis, which also showed that areas indicated as having undergone changes in the change detection analyses were also the same areas where NDVI vales had also changed.

Areas that had undergone changes were identified using the LANDSAT ETM image based on the above analysis, and the land cover classes occurring in these areas were mapped out. Several land cover classes were initially mapped from the image but only two land cover classes of interest to this research were considered, namely settlement and agriculture areas.

Based on these two land cover classes discriminated during the land cover classification process above, random points were generated (using a random point generator extension in ArcView 3.2) across different areas having the settlements and agricultural activities. At each random point, biophysical characteristics such as soil texture, distance to a major town and distance to roads were extracted using spatial analyst extension in ArcView and input into the analysis. One big challenge during this process was that several other land cover classes shared the same reflectance characteristics as settlements and agriculture, for example rocky mountain areas had the same reflectance values as settlement areas. Agricultural areas also had the same reflectance values as forested areas. The image therefore had to be chopped into smaller areas contrasting pixel characteristics and then analysed differently using our knowledge base and expert opinion.

5.2. Land cover changes and biophysical factors

Many of the anthropogenic activities occurring within the KWDA are as a result of a variety of processes and have huge implications on the existence of the dispersal area.

One of such processes is the land tenure change. The local committees have currently transferred many of the land parcels around this area from group ownership to private ownership after the government authorised their subdivision in mid-1980s owing to inefficient management. Many of the parcels now owned and settled by non-Maasai communities who have settled in the area. The land ownership per head today stands at 0.92 ha compared to 70.35 ha at the time of the Group Ranch incorporation in 1979 (ACF 2004)

One of the reasons why this area is targeted is its proximity to Nairobi. Many housing companies have acquired huge tracks of land and are targeting these areas to construction of residential estates. There are also plans to put in some learning institutions such as universities as well as adding more industries to the already existing ones (NEMA 2003).

Many people can afford to work in pursue their livelihoods in Nairobi and live in the smaller towns within the dispersal area. Middle-income earners who cannot afford houses in Nairobi are also buying parcels in towns and putting up houses. The result is that towns such as Isinya, Ngong, kitengela, Rongai and Kajiado have continued to grow as settlements increase.

From the results of the analysis, settlements were generally located in areas where there were rivers and also good moisture availability. This could indicate that availability of water is an important consideration for those settling in these areas, as is usually the case for many residential places of choice. The settlements were also in areas that were closer to the major roads for easy access to and from other towns. It could also indicate that some of the immigrants were either coming to settle in these areas to practice agriculture or that some of the immigrant settlers were doing small scale agriculture to supplement their diets.

In the case of agriculture, the demand for food products within these areas that has increased with the growth of these towns has created an opportunity for the people living around these areas to involve themselves in agriculture to meet the food deficit. Other non-residents have also seen an opportunity to produce food and supply to these residents and have therefore moved into these areas to trade.

Some of the areas visited showed that these observations were actually true. One of the areas visited was actually along the river Embakasi near the Nairobi national park. This area was mainly occupied by people of the Kamba community who were engaged in irrigated agriculture utilising the waters of this river and mainly growing vegetables and a little maize for sale within the nearby Kitengela Township. These agricultural areas were also located in proximity to high moisture availability areas. They were also located near man-made water sources such as boreholes and dams. This would suggest that some of these agricultural activities are actually irrigation plots. They were also located near towns, as these areas would provide markets.

The fact that distance to roads and soil drainage were not significant in as far as agriculture was concerned raises several hypotheses. Perhaps scale is a critical factor to consider when analysing many small and use types over a large area and that the scale at which we captured the roads from the roads map (1: 50, 000) was not good enough to capture the smaller access roads that would have been used to ferry product to the markets. Or that soil drainage was not an important factor in choosing an area for cultivation in the rangelands. This hypothesis could also be used to question the sustainability of rangeland farming if the soils being cultivated are not of proper drainage and that issues of leaching should also be looked into.

5.3. Implications of settlements and agriculture expansion on the future of KWDA

Analysis carried out in this study indicates that the area, within the study site measuring about 221,684 hectares that are likely to be converted to settlements alone is more than 23,865 hectares. This is approximately 20% of the total study site being converted to settlements and expansion of towns alone. This loss combined with other losses such as conversion to agriculture indicates a very grim picture for the dispersal area.

As indicated in a lot of literature, the KWDA is a lifeline for the existence of the Nairobi National Park (NNP). This is because many large herbivores utilise this area as a migratory corridor when to migrate into and out of the national park during the dry season and wet seasons respectively. With the expansion of settlements and agriculture, these areas will not be available for utilisation by both the wildlife and livestock. The result of this reduction would result in declines in the number of animals utilizing these areas.

Some of the Maasai, who were originally utilising this land for livestock production as well as allowing wildlife to utilize it, have sold off some of their parcels. Also taking into account the fact that pastoralism was a system that was adapted to utilising large tracks of land at different times, the livestock and wildlife occupying these areas are facing stiffer competition for pasture due to the reduction in land size and therefore overgrazing. The result is that there is now a faster rate of retrogression through over utilisation by these ungulates Recent studies have indicated that the total biomass of both wildlife and livestock have reduced by half over the last quarter of a decade in the KWDA (Reid et al 2003. In prep) but the scenario is quite different within the protected NNP where populations of some animals such as zebra and rhino have actually grown.

Due increased fragmentation, pastoralists are finding it more and more difficult to depend only on livestock production due to the reasons discussed above. They are therefore looking for alternative land uses to supplement the deficit left by the reduction in the pastoral economy. Some of these include such activities such as quarrying and small-scale agriculture. The result is that more and more land is being converted to uses that are incompatible with wildlife conservation.

Land use changes occurring in KWDA are occurring at an alarming rate. There is continued increase in the price of land as more and more people are moving into these areas. The amount that money at which these parcels are being bought are way above what is being offered by conservation efforts such as Friends of Nairobi National Park's lease program. Coupled with the poverty levels in these areas, residents are increasingly finding it more lucrative to sell of their land as opposed to getting the 4-dollar incentive that they get per year to participate in the lease program by not fencing their land to allow wildlife to migrate.

Due to the private nature of the land being targeted for the conservation area, the conservationists are being faced by a challenging task since the continued existence of the conservation area requires efforts from the whole community. The reality however is that decisions on whether on not to participate in the conservation programs such as the lease program are being made at individual level. Therefore the fact that only some individuals would agrees to participate in such programs due to the better returns from alternative land uses such as sale or quarrying, brings with it huge challenges. Perhaps even options such as purchasing of the conservation area to be used for the sole purpose of conservation could be worthwhile to explore among other options.

The finding of this work compare closely to those found by Serneels and Lambin, 2001 in a study of the proximate causes of land use change in Narok district. Their study suggested that their dependent variables such as mechanised agriculture were determined by factors such as the distance to the market, as a well as distance to water points. They also identified land rent, (defined by proximity to permanent water, land suitability, location near a tourism market, and vicinity to villages) as a major contributor to the probability of land being used for smallholder agriculture or settlements.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

From this study, the following conclusions can be made:

LANDSAT TM data could be very useful in looking at the changes occurring in a tropical savannah despite the fact that they are usually quite homogenous in nature. It is however very important to carefully examine the images for use in these analyses to detect interference by clouds. A major drawback to the method used in this study (image differencing) in carrying out change detection such as the one described in this study is that the technique only gives a value, either positive or negative for the changes. It doesn't explicitly show what kind of changes actually took place. There could also be errors brought about by seasonal variations that this technique might not pick up. It does not also give a lot of information in as far as land cover dynamics is concerned. It assumes for example that land use changes occur at a constant rate through out the study period.

The combined use of remote sensing and GIS allowed for an illustration of the possible impact of urban expansion on KWDA. The results showed that urban land development within the dispersal area could have dire consequences on the NNP ecosystem as well as the dispersal area that is very crucial to the existence of the park. If no action is taken this scenario could eventually lead to the collapse of this park ecosystem, whose lifeline is the dispersal area. This would result in lost revenues for the economy. Currently the park realises revenues of up to Ksh. 50,000,000 annually (Nkedianye 2004).

Spatial prediction models also provide very useful tools for utilising information available for different biophysical drivers of land use changes and using these to predict future scenarios. These could provide very useful information for planners as well as policy makers in terms of knowing what kind of repercussions their decisions could have on fragile environments such as KWDA. This information could also be utilised in identifying biodiversity hotspots for targeted conservation.

6.2. Recommendations

It is not enough to say that biophysical drivers such as the ones used in this study are adequate to model the future land use scenarios based on the occurrences today. There are many other drivers such as policies, preference and management options as well as interactions within these drivers of change that are important to make certain conclusions about the state of an environment.

Before models such as this one is used anywhere to make any policy interventions, it would be important to validate the model and there are several techniques that are available to do this such as using the goodness of fit of the observed and the predicted values. This is important in ensuring that the model being used is representative of the happenings on the ground as variables are as varied as the ecosystems themselves.

National land policy

The government should push for the formulation and implementation of a national land policy that would provide a framework for land use in Kenya. This policy should among other things describe explicitly "what" type of land can be used for "what" kind of activities such that land set aside for such activities, for example industrial development should only be used for the set purpose irrespective of the financial implications of any alternative land use.

Legislation

It would also be worthwhile to attempt the integration of wildlife conservation into comprehensive land use plans by the municipal council. Institutions such as the National Environment Monitoring Authority (NEMA) need to make it a requirement for any development efforts within this area to be vetoed accordingly. Such initiatives could also impose strict constraints on development projects that may impact negatively on the survival of this ecosystem as well as the wildlife utilising this area.

Wildlife corridor protection

From the general observation made in this study and the current events occurring within the dispersal area, it would be worthwhile to put in place measures that would protect the dispersal are from further intrusion.

Tourism revenues paid in the form of cash to the communities

One of the reasons why this dispersal area is experiencing land use change is because there are alternative land use practices that are offering much more than conservation to the communities (Nkedianye 2002, Kristjanson *et al* 2002). Other practices such as land sales are proving to be more profitable than conservation. Money paid back directly to the communities in the form of cash would create an incentive to the communities to protect the dispersal area.

6.3. Suggestions for further research

There is need to carry out further research in evaluating the effectiveness of the conservation initiatives such as the lease program to ascertain whether they are effective or not and whether an increase in the amounts paid as incentives would result in the strengthening conservation efforts.

Another area of research would be to examine the exact effect of the developments occurring within KWDA on the actual numbers and distribution of livestock and wildlife species utilising this area and whether these populations would remain viable considering the current developments occurring in these area.

It would also be worthwhile to look at the implications of managing the NNP as a closed entity and not intervening in the developments occurring within the dispersal area.

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Appendix 0.1 Sample table of extracted variables

ID	TYPE	DRAINAGE	PPE	DIST_ROADS	DIST_RIVER	DIST_TOWN	DIST_WATER	DRAINAGE1	ID_AGR	ID_BUILT
1	agriculture	2	0.537	1835.7560	500.0000	2308.6792	412.3106	2	1	0
1	agriculture	2	0.537	400.0000	100.0000	2137.7559	282.8427	2	1	0
1	agriculture	2	0.688	1931.3208	141.4214	3634.5564	500.0000	2	1	0
1	agriculture	2	0.688	316.2278	100.0000	3492.8499	1063.0145	2	1	0
1	agriculture	1	0.516	1868.1542	447.2136	3488.5527	412.3106	1	1	0
1	agriculture	1	0.516	500.0000	360.5551	1503.3296	1220.6555	1	1	0
1	agriculture	1	0.516	400.0000	728.0110	2334.5234	608.2762	1	1	0
1	agriculture	1	0.426	3522.7830	565.6854	12209.0127	4036.0872	1	1	0
1	agriculture	1	0.334	1077.0330	1615.5494	670.8204	360.5551	1	1	0
1	agriculture	2	0.485	1503.3296	100.0000	10404.3262	1220.6555	2	1	0
1	agriculture	1	0.485	500.0000	608.2762	10667.7080	1236.9316	1	1	0
1	agriculture	2	0.485	1529.7058	360.5551	8002.4995	1562.0499	2	1	0
1	agriculture	2	0.501	300.0000	1200.0000	8372.5742	948.6833	2	1	0
1	agriculture	2	0.532	1565.2476	900.0000	5326.3496	781.0250	2	1	0
1	agriculture	1	0.330	400.0000	583.0952	8381.5273	3059.4116	1	1	0
2	Settlement	2	0.326	3201.5620	608.2762	7858.7529	2080.8652	2	1	0
2	Settlement	1	0.326	905.5385	583.0952	11892.8555	632.4555	1	1	0
2	Settlement	1	0.324	721.1102	282.8427	8065.3579	3736.3083	1	1	0
2	Settlement	1	0.326	806.2258	1140.1754	10245.9746	1878.8295	1	1	0
2	Settlement	1	0.320	1272.7922	2469.8179	5161.3950	1649.2423	1	1	0
2	Settlement	1	0.314	848.5281	806.2258	2580.6975	1788.8544	1	1	0
2	Settlement	1	0.314	707.1068	447.2136	5115.6621	2500.0000	1	1	0
2	Settlement	1	0.309	200.0000	860.2325	7924.6450	2247.2205	1	1	0
2	Settlement	1	0.537	1100.0000	608.2762	6440.4971	300.0000	1	1	0
1	Settlement	1	0.476	848.5281	300.0000	6549.0459	2886.1738	1	1	0
1	Settlement	1		2906.8884	3580.5027	6074.5371	3352.6108	1	1	0