Modelling pastoral mobility to accommodate pastoral land use in land administration, a case study of the Isiolo Area, Kenya

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by

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Abstract

Pastoral land use involves mobility in space and time in search of temporally variable rangeland resources for herds. Such movements are prohibited across privately registered cadastral objects, unless by consent from the land owner, leaving pastoralists marginalized by land rights. This study was undertaken in Isiolo area Kenya, an area characterized by diversified climatic conditions, land uses and land tenures. The overall aim of this study was to accommodate pastoral land use in land administration (LA) through seasonal land rights (SLR). Remote Sensing and GIS tools were used to investigate relationships between temporal pasture fluxes and pastoral seasonal migrations. To achieve the research objectives, multitemporal SPOT NDVI and GIS data were utilized together with field data which was obtained through semi structured questionnaires and participatory mapping. Unsupervised classification of SPOT NDVI data using ISODATA clustering algorithm delineated the land cover into 9 spatial mapping units. Time series analysis on the 9 mapping units realized spatiotemporal NDVI patterns which revealed the bimodal dry and wet climatic seasons that characterized the pastoral migration pattern to and from key dry and wet season grazing areas. GIS animal movement and tracking analyst tools simulated temporal movements of pastoralists based on the migratory routes whose ends defined the seasonal grazing areas using start and end dates of the migration. A GIS multi-criteria decision making method (MCDM) investigated most suitable locations for seasonal land sharing (SLS) among the non pastoral land uses where dry season grazing occurs. Soft systems methodology utilized unified modelling language (UML) to develop conceptual models which integrated the suitable areas for SLS and stakeholder behaviour with the cadastral system. Uniqueness of the developed models was the temporal aspect introduced through SLR which lacked in the existing cadastral system. Other driving forces that influenced the migratory pattern besides demand for herbaceous pastures were deduced from field findings as: access to water, land rights, proximity to grazing sites, security, diseases, pests and cost of grazing. Results of the study presented a strong correlation between the temporal NDVI fluxes in land cover and the spatiotemporal migration of pastoralists. The most suitable areas for SLS included specific locations within the farming, ranching and forestry land uses. The developed conceptual models demonstrated conditions for successful SLS between pastoralists and non pastoralists through SLR in space and time. Comparison of the conceptual models with the real world concluded that SLR would be achieved by public participation, documentation of the migratory corridor, sensitization of stakeholders on benefits of SLS, establishment of regulations to govern SLS and reengineering of land acts. Conclusively, pastoral seasonal migration was mainly influenced by seasonal variability of pastures and

SLR was proposed to accommodate pastoral land use in LA. Implementation of SLR however requires inclusion of cadastral information in suitability analysis and instruments to govern the documented migratory corridor.

Key words: pastoralists, remote sensing, GIS, spatiotemporal, multi-criteria decision making, soft systems methodology, SPOT NDVI, property rights, seasonal land sharing, seasonal land rights

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Acronyms

CATWOE	: Customers, Actors, Transformation, World view, Owner and Environment
GIS	: Geographic Information Systems
ILRI	: International Livestock Research Institute
LA	: Land Administration
MCDM	: Multicriteria Decision Making Method
MoL	: Ministry of Lands
NDVI	: Normalized Difference Vegetation Index
RS	: Remote Sensing
SLR	: Seasonal Land Rights
SLS	: Seasonal Land Sharing
SPOT	: Satellite Pour I’ Observation de la Terre
SSM	: Soft Systems Methodology
UML	: Unified Modelling Language

1. Introduction

1.1. Background

Pastoralism refers to a form of livestock production that involves spatiotemporal movement in search of pasture and water (Macopiyo, 2005) usually in the rangelands of the world. The rangelands comprise the arid and semi arid ecological zones, covering 40% of Africa and supporting 40% of her inhabitants. These rangelands contribute to national and global economies by supporting livestock development, wildlife and tourism among others (Mwangi and Dohrn, 2006).

A range succession model proposed by Hardin,(1968) suggests that rangelands have been exposed to environmental degradation due to poor management that may have resulted from the 'tragedy of the commons'. He argues that there being no limitation on the number of animals a pastoralist keeps on the communal land, each increases their herds at will, but the damage caused by competitive grazing is felt collectively in the limited space (Hardin, 1968). In this model, it is viewed that vegetation of a given rangeland would regenerate in the absence of grazing with a distinct stocking rate either slowing or halting the succession trend (Macopiyo, 2005). The succession model has been applied in rangeland management strategies in the west (Westoby et al., 1989), but the arguments professed about common land set precedence that perceived pastoralism negatively (Widenstrand, 1975). In respect with African pastoralists, tragedy of the commons theory has been contested by ecologists and anthropologists, who argue that pastoral knowledge of their environment facilitates sustainable management of resources (Bollig and Schulte, 1999).Additionally, each spatial extent is governed by some form of legislature be it communal or statutory. In Kenya for example, each spatial extent is treated as a cadastral object owned by an individual, state or community and the idea of the commons does not therefore apply.

It has also been argued that private, state and communal properties are all possible resource management options and that institutional arrangements regulate the use of such resources (Feeny et al., 1990). The contest against Hardin's theory also argues that individual exploitation of land leads to over-exploitation, retrieving as much benefit from land as a commodity unlike when land would be commonly used. Communal tenure has therefore been favoured just like other forms of tenancy such as sharecropping (Toulmin and Quan, 2000) as they promote access to resources as required by pastoralists.

The rangelands have been subjected to different tenure systems with different arrangements that regulate the access, utilization and management of natural resources (UNDP, 2003). To achieve this, land administration (LA) provides property rights which restrict access and use of natural resources (Feeny et al., 1990); to enhance the social stability, economical development and environmental management of the resources in these rangelands (Behnke, 1992). This however impedes access of pastoralists to resources such as water and pasture for their herds. The natural resources in these drylands vary from one ecological zone to another depending on variability of precipitation. As observed by Adriansen (1999), natural reproduction of forage in the different ecological zones arises from seed banks from the dry season which mature and germinate within 6 weeks of sufficient precipitation, providing biomass for livestock. It is difficult to save such biomass for the late dry seasons since the unutilized biomass gets lost by weathering (Behnke, 1992) creating room for pasture search away from the drylands. Productivity of dry land ecosystems is therefore controlled highly by the variable precipitation and that the productive potential targeted by pastoralists is on land, as they seek to utilize the varied natural resources available on the surface (Adriansen, 1999).

Rangelands in East Africa are not of exception. With a bimodal rainfall comprising of short rains in October to December and long rains in March through May/June (Debasso, 2006; Ellis, 1994; Galvin et al., 2001). 70 % of Kenya's, 50% of Tanzania's and 40% of Uganda's rangelands have provided occupation for the less than 1.5 million pastoralists in East Africa (Fratkin, 2001). With a heavy dependency on livestock and livestock products, increasing human population and decreasing land use area due to alienation of land to game parks, conservationists and agriculturalists through LA; pastoralists' access to sufficient pasture has been hampered (Galvin et al., 2001). This is because optimal use of the available natural resources by pastoralists requires seasonal migrations at different scales depending on the spatial and temporal variability of the resources as adapted to other physical and biotic factors of the production system (Adriansen, 1999; McAllister et al., 2006). This is done either through regular small scale migration, utilizing key resources and harvest fields, or irregular large scale migrations comprising the potential of land appropriated by pastoralists (Monheim, 1997).

In Kenya, small scale migrations occur during the two dry seasons between January and March and June and October (Mutai and Ward, 2000), with pastoralists maintaining regular routes in accordance with pasture availability. Such areas considered as high potential areas include highlands and private lands within the rangelands. During the seasonal migrations, pastoralists face competition for resources such as pasture, diseases and predation from wild game (Mizutani et al., 2005). Resource use conflicts arise due to property rights which empower land owners to exclude others from their private land subjecting both the pastoralists and land owners to land use conflicts.

1.2. The Pastoralists' Land use and Management

Pastoralists relate to land on spatiotemporal terms through migrations exuding transhumance. This is because their landscape is partitioned into wet and dry season ranges (Dyson-Hudson and Dyson-Hudson, 1980; Fratkin, 2001) with an indiscernible collection of resources that encourage opportunistic migrations following pasture resources. Wet season ranges are the result of seasonal rains besides the areas being dominated by annual vegetation and except for a dry period of the year, they remain waterless and uninhabited. Dry season ranges, are high potential areas and include pockets of highlands, ecosystems with natural water bodies such as rivers and flood plains; traditionally being considered as areas for drought grazing reserves (Oba and Lusigi, 1987).

Oba and Lusigi (1987) argue that the dry seasons are most demanding for pastoralists, since their drought coping mechanism depends on previous drought knowledge. During dry spells, pastoralists move to areas with higher rainfall where the vegetation persists, and move to drier zones when the rains begin, so as to utilize the new grass that regenerated when they moved away (FAO, 1999). The migratory pattern is geared towards communities that are friendly and those with whom they share similar language and cultural practices (Fratkin, 2001). This is aimed at encouraging company, security and sharing of herders among the communities.

Pastoral experience is built up around the deep knowledge on interaction between herds, vegetation and the landscape, rather than around the environment (Bollig and Schulte, 1999; Oba and Kaitira, 2006). This ecological knowledge enables herders to select migratory routes and potential grazing areas (Debasso, 2006) for their livestock. This is aimed at enhancing nutritional value of the cattle from foliage and undergrowth, which has been reduced from the pasture through drought, while 15 to 25 km distance from water sources enables the cattle to be watered regularly (Thébaud and Batterbury, 2001). The migratory routes have predetermined camping areas close to available water sources and fall back grazing (Macopiyo, 2005; Said, 2003). From these camping sites, herders are able to relay information back home regarding need for food, fodder status and disease outbreaks. Through this mobility, pastoralists are able to address cost-effective objectives that include accessibility to markets and exchange of manure and cost of grazing between farming communities and themselves. In addition, they opportunistically utilize spatiotemporal resources; develop enhanced resistance of livestock to epidemics, while alleviating vulnerability to disease outbreaks (Roeder, 1996) in (Macopiyo, 2005). Pastoral knowledge has therefore instituted the indigenous systems of pasture utilization through communal pasture management as sustainable and compatible modes of exploitation (Fratkin, 2001). They therefore need to balance their knowledge of biomass, rainfall, disease and national boundaries with access to markets and infrastructure (Blench, 2000) to ensure flexibility in management of resources.

1.3. The Role of Land Administration

Cadastres support economic development, environmental management and social stability in both developed and developing countries (Williamson, 2004). These are achieved through legal, regulatory, fiscal and information management which form the LA components (Palmer, 1997). Rights on cadastral objects are exercised through several property rights regimes depending on tenures in which land is owned (Dale and McLaughlin, 1999). The processes of land survey and registration of rights allow property rights to be exercised on land with qualities to exclude others, transfer property rights to others and enforce a penalty structure that prevents others from encroaching on land without agreement with the owner (Dale, 1999; Tietenberg, 1992).

These institutions form the norms and regulations in LA (Molen, 2003). The LA concepts are recognized by citizens in developed countries and are backed by legislative frameworks, unlike in developing countries which have not realised the same (Bennett et al., 2008). The role of cadastres in Kenya has been to provide a sustainable LA infrastructure that provides all citizens with rights of access, occupancy and beneficial use of land. The Kenya draft land policy embraces these notions, aimed at an economical, social and environmentally sustainable system, with transparent land dispute resolution mechanisms (NLP, 2007).

1.4. Land tenure systems in Kenya

There are two land tenure systems in Kenya: i) Customary tenure- which allows people to make use of land communally while being administered under the local authorities usually the county council; and ii) Statutory tenure- which allows people to own cadastral spatial objects privately. In communal ownership, each community member has equivalent rights to access and utilize land resources; while in statutory ownership the owner solely accesses resources on his land. The tenure systems are governed under the Kenya Land Acts such as the Government land act, forest act, wildlife conservation and management act, group land act, registration of land act (Kenyalaw, 2008) among others. The property rights granted by LA seasonally induce conflicts between mobile pastoralists who continue to relate to the land communally in search of resources for their livestock, and non pastoralists who relate to the land under statutory tenure. Penalties have been attached to any breach of these rights, including cash settlement that does not exceed the market value of the bush or trees upon which the cattle has grazed. The seasonal conflict encounters of non pastoralists with the migrating pastoralists are spatially temporal and are recurrent each year implying that the land rights favour sedentary land uses against pastoralists. A land policy could have been resourceful in alleviating these conflicts yet Kenya did not have one until 2007. The draft policy contains the provision on conflict resolution mechanisms but this only favours cadastral objects while communal land under local authorities is not covered. Two of the probable resolutions proposed by Fratkin and Mearns (2003) in (Mwangi and Dohrn, 2006) for the East African drylands include; i) developing suitable institutions to mediate conflicts with an objective to encourage herder movement and opportunistic systems within certain bounds, and; ii) devolving authority to suitable establishments, with possibilities to allow pastoralists to reformulate rules within specific guidelines to meet their need for pasture. The Kenya draft land policy lacks such inclusions that would carter for pastoral mobility and this has introduced a gap between pastoralists and non pastoralists.

1.5. Overlapping land rights

Land administration addresses 'who' owns 'what' and 'where' but neglects the temporal relationship 'when', of pastoralists to land. Restricted rights are not favoured by pastoralists who live in environs marked with seasonal variability hence preferring access to natural resources through overlapping rights (Behnke, 1994). Negotiation for access for overlapping rights is unending and requires commitment from all land use actors to share forage and water (Thébaud and Batterbury, 2001) in their respective locations and time. Thebaud and Batterbury, (2001) argue that a new legislation is a prerequisite to provide pastoralists with secure access rights to vital resources and strengthen user rights for all land use actors. This argument is aimed at conflict mitigation and provision for coexistence among the land use actors (Delville, 1999).

In Mauritania for example, a pastoral code was drafted to regulate access to water and pasture and mitigation of resource use conflicts (Wabnitz, 2006). The government of Kenya has used Cap 8 of the law to provide free access to water for all her citizens (Kenyalaw, 2008) while access to pasture in key resource areas is left in the power of the private land owner. Overlapping rights are exercised in the ministry of lands (MoL) lease and land renting regulations through leasehold, cautions and caveats (MoL, 2009). This provision however leaves pastoralists to local negotiations for access to pasture on neighbouring environs due to the temporal dynamism of their pasturage demands. This research has proposed the introduction of seasonal land rights (SLR) to capture the temporal aspect in ownership depicted by dynamism of pastoral need in the study area. The term seasonal was preferred by this research against temporal because the access to pasture resources on private land was required during the dry seasons, when demand for pasture was critical (Omiti and Irungu, 2002).

1.6. The Research Problem

Pastoralists prefer to move to areas with available pasture to graze their herds, to fetching the forage for the animals. This is seen as a scheme to realize sufficient feeds for their livestock throughout the year (Chang and Koster, 1994; Dyson-Hudson and Dyson-Hudson, 1980; Fratkin, 2001; Ng'ethe, 1992). Climatic conditions affect temporal availability of pastures thus driving the seasonal mobility patterns adopted by pastoralists besides other temporal and organic aspects (Dyson-Hudson and Dyson-Hudson, 1980; Fratkin, 2001). The need for investigation into a temporal aspect of the various land cover types and pastoral land use is important for this research, to understand the causal factors for pastoral mobility. Critical moments are experienced during the desiccated months of the year, (Oba and Lusigi, 1987) causing pastoralists to migrate to regions that receive high precipitation that sustains pasture. On commencement of rainfall, they return home to utilize the regenerated pasture (Blench, 2000). The seasonal strategy of utilizing forage by pastoralists is regarded economical despite the indistinct definition of spatial locations of the utilized areas (Goodhue and McCarthy, 1999; Scoones and Graham, 1994; Toulmin, 1993) whereas property rights in LA do not address nor support such spatiotemporal movements.

Pastoralists and non pastoralists within the vicinity of pastoral migratory routes encounter land use conflicts during seasonal migrations due to their encounters with overlapping interests which are not supported by the Kenya land acts (Kenyalaw, 2008). Pastoralists move to non pastoral areas in bid to access natural resources on non pastoral land often leading to competition for resources. This competition for resources has been worsened in the landscape that is increasingly being surveyed, demarcated and allocated (Homewood, 2004), usually being appropriated for other land uses such as national/reserve parks, forests and agriculture (Galvin, 2001). The demarcated land is surveyed and registered with private property rights by LA. These property rights impede pastoral movement depriving the pastoralists access rights (Brink et al., 2005) to fodder and leaving them marginalized.

Pastoralists sometimes rely on piecemeal agreements that allow them seasonal access to the resources on private property under an agreed compensation. The security of these agreements to both the pastoralists' and non pastoralists' need is untold as it is not envisaged in LA. The Kenya draft policy supports statutory rights and this has rendered pastoralists' access rights to resources insecure. An example of multiple user need currently addressed by LA is through leasehold and land renting tenure which grants rights to use land for a fixed period of time in exchange of a defined compensation (NLP, 2007). The case of pastoralists is unique due to its seasonal dynamism; and has hampered the possibility of leasehold or land renting systems to address the pastoral need.

Most of the past researches have observed the case of pastoral mobility and discussed conflicts that ensue. The researches have advocated for the need for flexibility in access rights and the need to reengineer tenures in bid to accommodate the pastoral mobility (Lengoiboni et al., Under Review; Mwangi and Dohrn, 2006; Toulmin and Quan, 2000). This research utilizes spatial and temporal information to identify key resource areas and priority periods, to model the seasonal relations between the variable pasture resources and pastoralists' pattern of migration in the Kenyan rangelands. Non pastoral land uses in the key resource areas will be investigated in such form that suitable locations are identified where seasonal land sharing could occur between non pastoralists and pastoralists. The research will then develop conceptual models through soft systems methodology to demonstrate how seasonal land sharing could accommodate pastoral mobility through seasonal land rights in LA. The seasonal land rights are aimed at minimizing resource use conflicts and enhancing tenure security in priority areas in a sustainable framework to land use management and administration.

1.7. Research objectives

The general objective of this research is to use Remote Sensing and GIS tools to investigate relationships between temporal pastures and pastoral seasonal migrations, in such away that their mobility could be accommodated in land administration through seasonal land rights.

The specific objectives include:

1. To correlate temporal NDVI fluxes in land cover types with the spatiotemporal movements of pastoralists in the study area using multi-temporal SPOT vegetation data
2. To investigate non pastoral land uses and suitability of their locations where seasonal land sharing with pastoralists could occur
3. To develop conceptual models that demonstrate how seasonal land sharing could occur between pastoralists and non pastoralists through seasonal land rights in space and time

1.8. Research questions

1. Is there a correlation between the temporal NDVI fluxes in land cover types with the spatiotemporal pattern of pastoralists' migrations?
2. Which land use locations are most suitable for seasonal land sharing?
3. Can conceptual models demonstrate seasonal land sharing between pastoralists and non pastoralists through seasonal lands rights in space and time?

1.9. Research Hypotheses

1. H_0: There is no correlation between temporal NDVI fluxes and the pastoral migration pattern

   H_1: There is a correlation between temporal NDVI fluxes and the pastoral migration pattern
2. H_0: Not all non pastoral land uses are most suitable locations for seasonal land sharing

   H_1: All non pastoral land uses are most suitable locations for seasonal land sharing
3. H_0: Conceptual models can not demonstrate seasonal land sharing through seasonal land rights in space and time

   H_1: Conceptual models can demonstrate seasonal land sharing through seasonal land rights in space and time

2. Materials and Methods

This chapter describes the study area, the materials and methods that were used in data collection, processing, analysis and modelling in order to realize the stated objectives and answer the research questions. This research utilized multiple methods to provide specific results to the objectives. Figure 2-1 is the research framework illustrating the materials and methods adopted in this study.

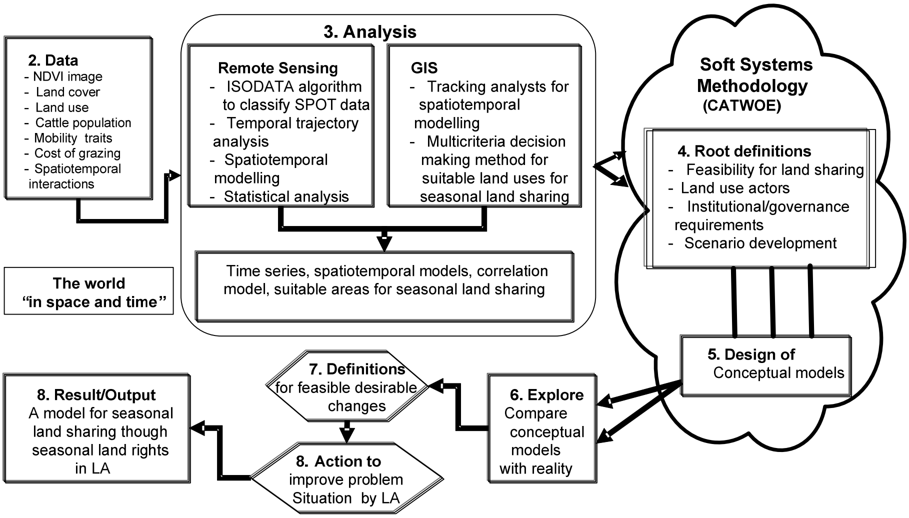


Figure 2-1: The Research Framework

2.1. The Study Area

The study area is the Isiolo, Samburu, Laikipia and Meru landscape of Kenya in figure 2-2, covering an area of 24972 km^2. The area has been chosen due to its diversity in ecological zones, land use systems, climatic variability, as well as diversity in tenure forms. This area experiences two wet seasons in the months of April to June and October to December; and two dry seasons in January to March and July to October (Mutai and Ward, 2000). Five categories of land use actors have been identified as units of analysis for this study. They include: farmers who practice large scale farming and those who practice small scale farming as well as small scale livestock keeping; game wardens who manage conservation activities of national parks; and foresters who guard the state owned forests. These are found in the high potential area of Meru landscape which receives an average rainfall above 700 mm (Mutai and Ward, 2000). Other land use actors include: pastoralists and private ranchers who practice farm ranching, forestry as well as wildlife conservation; and game wardens who guard the wildlife parks. These are found in the low potential areas which receive an average of 200 mm to 500 mm of rainfall per a year (Mutai and Ward, 2000; Omiti and Irungu, 2002).

In this study, the farmers, private ranchers, game wardens and foresters are categorized as non pastoralists and their tenures are mainly individual, state or local authority owned. Pastoralists are found in the dry lands of Isiolo, Samburu and Laikipia. Their land use practices are characterized by seasonal migrations in search of pastures whose availability varies with climatic conditions. Their tenure is customary, their land being held in trust by the county council. Diversity of land uses and tenure exhibited in the study area provides an ideal setting to explore spatiotemporal interactions between mobile pastoralists and non pastoralist land use actors in relation to property rights.

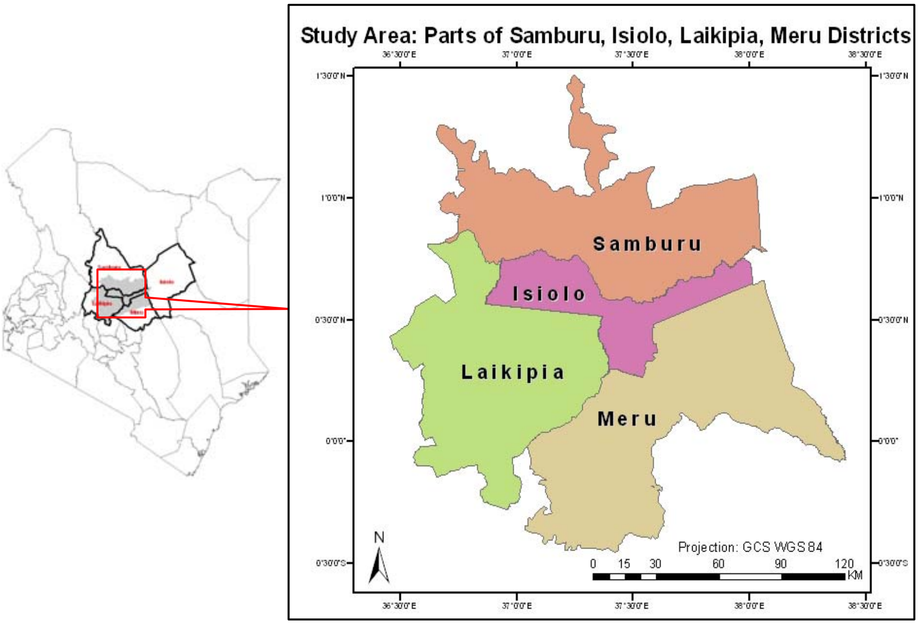


Figure 2-2: Parts of the Isiolo, Samburu, Laikipia and Meru Districts; Data Source: (ILRI, 2007)

2.2. Data description

Data for this research was collected from both primary and secondary sources using different methods. Data from primary sources included remotely sensed data from ITC repository and field interviews through both open and close ended questions and office visit. Secondary data was obtained from online GIS databases, office visits and from existing literature.

2.2.1. Remotely Sensed Data

Studies on animal movement in arid environments have used NDVI data in combination with other biophysical parameters to predict livestock mobility (Ngugi and Conant, 2008). Studies on terrestrial properties have also involved the use of NDVI data to model time based trends in land cover properties to assess seasonal variability in vegetation (Chen et al., 2004; Weiss et al., 2004). In this research, SPOT (Satellite Pour I' Observation de la Terre) vegetation data was used since it is provided while already processed of cloud cover that contaminates NDVI datasets, making it suitable to directly fit application studies (Campbell, 2006) such as spatiotemporal patterns of pasture variability in this research. A stacked and geo-referenced SPOT NDVI ten day multi-temporal satellite data of 1 km spatial resolution, covering the period April 1998 to April 2008 was acquired from ITC repository (de Bie, 2008). The multi-temporal image data was selected due to its provision of opportunities to recognize changes within land cover in a region (Jakubauskas et al., 2002). The stack reduced the number of classes for the image by combining annual NDVI values; aimed at removing inter annual differences within the ten year period studied. NDVI value was computed using the difference of infrared and red spectral bands by their sum to express the active biomass (Sarkar and Kafatos, 2004). This data was utilized in spatiotemporal modelling of land cover through temporal trajectory analysis using time series of vegetation index compared across months of the year in each respective land use. This was done for the purpose of correlating NDVI fluxes with the pastoral migratory pattern during different climatic seasons of the year.

2.2.2. Field work Data

This research utilized a case study approach and participatory mapping in collecting data from the field. The case study approach was used so as to understand interactions of the phenomena in the real life perspective (Yin, 1994; Yin, 2003). Longopito and Namelok pastoral communities were selected as case studies due to their ability to move into the entire study area during the dry seasons of the year.

Data from these two communities was collected using semi structured questionnaires, where open and close ended questions were asked to the pastoralists. The questions asked were about the short and dry season grazing areas, month of departure to the grazing area, month of return to base camps, period of stay in the grazing area, condition of land cover on arrival and departure, speed of movement, sources of water, reasons for selecting such grazing areas, cattle population, cost of grazing in the grazing areas and the mode of payment. Participatory mapping involved pastoralists indicating on the migratory routes map (Lengoiboni et al., Under Review), areas where they moved to during dry seasons, their regularity on the migratory routes, areas where they moved faster or slowly and reasons why there might be difference in speed of movement.

This data was collected in October 2008. Cluster sampling was used to identify interviewees within the selected cases in order to remove the within stratum variance(Thompson, 1992). A total of 52 questionnaires were filled by the interviewees depending on spatial representation and accessibility. Each of the target groups were independently asked the questions that were enlisted in the questionnaire. This was done to generate confidence in the data collected for the purpose of statistical analysis. Out of the 52 questionnaires that were completed, n= 50 were utilized for this research as two were incomplete. There were 50 respondents (n=50), where each of the two communities' response was n=25. This data is presented in table 2-1 below.

Table 2-1: Field data from Namelok and Longopito

Area of grazing		Cattle density (no/ha)	Month of departure to grazing area	Months of retreat home	Cost of grazing (Euro/ month)	Mode of payment & to whom	Condition of land on arrival	Condition of land on departure
Farms	Count 21 Measure 42 %	8	February	April	0.25 per cattle	Cash or cattle, owner	Crop residues	Bare soil
Losesia	Count 29 Measure 58 %	6	February	April	0	N/A	Plenty of pasture	Scanty vegetation
Ranches	Count 22 Measure 44%	9	July	November	0.25 per cattle	Cash or cattle, owner	Plenty of pasture	Scanty vegetation, crop
Lerochi forest	Count 13 Measure 26%	11	July	November	0.25 per cattle	Cash, guard	Plenty of pasture	Scanty pasture
Mt Kenya forest	Count 15 Measure 30%	11	July	November	0.25 per cattle	Cash, guard	Plenty of pasture	Scanty pasture

2.2.3. Secondary data sets

Livelihood zones map was obtained from the community based livestock early warning systems (CB-LEWS) of arid and semi arid lands based livestock and rural livelihood support project (ALLPRO) in Nairobi. This map comprised layers showing the land use activities in the study area. Africa Wildlife Foundation (AWF) in Nanyuki Kenya provided the property map which was used to delineate the area with private ranching activity. The existing land cover map, and other GIS layers for the forests, wildlife parks, rivers, water points, administrative boundaries, and place names were downloaded from ILRI online GIS database (ILRI, 2007). The land cover map was necessary in providing classification names for the NDVI classes; while the other vector files were used in land use classification. The agro-ecological zones map was obtained from ESRI GIS database to provide insight on biotic factors that influenced pastoral mobility (Omiti and Irungu, 2002). These vector files were in the geographic coordinate system GCS-WGS-1984 and GCS- Arc-1960; while the NDVI data was in Plate Carree projection. Table 2-2 summarizes these data.

Table 2-2: Secondary data sets

Shape file	**Source**	**Year drawn**
Livelihood map	Arid lands project (ALLPRO)	2007
Land cover map	Online GIS database (ILRI)	2007
Forests	Online GIS database (ILRI)	2007
Wildlife parks	Online GIS database (ILRI)	2007
Rivers	Online GIS database (ILRI)	2007
Water points	Online GIS database (ILRI)	2007
Administrative boundaries	Online GIS database (ILRI)	2007
Place names	Online GIS database (ILRI)	2007
Agro-ecological zones map	ESRI GIS database	2008

2.2.4. Dealing with different scales

To analyse the different vector files in the same scale, the Arc-1960 datum was transformed into the WGS-84 datum due to its universality of use (Longley et al., 2005b) and this provided all the vector files in GCS-WGS-84 coordinate system. The NDVI data in plate carree coordinate system was then harnessed with the GCS-WGS 84 coordinate system through resampling (Campbell, 2006) of the NDVI data using nearest neighbour technique into the scale of the vector files. This was done to allow for data classification, analysis and modelling in GCS-WGS-84 coordinate system as used in this study.

2.3. Data analysis and Modelling

To correlate NDVI fluxes with spatiotemporal pattern of pastoral movements, the NDVI data and migratory routes were used. Remote sensing, statistical, GIS and soft systems methods were applied in this analysis and modelling.

2.3.1. Multitemporal NDVI Image classification

NDVI image was classified to sort pixels into their respective classes basing this on data values (Leica, 2008). The image had undergone a linear transformation using a formula (NDVI + 0.1)/ 0.004 transforming the NDVI values into DN values (de Bie et al., 2008). This was performed for all the 363 NDVI image layers acquired on a 10 day basis for each month from April, 1998 to May, 2008. Unsupervised classification was performed on 363 bands of SPOT decadal data using ISODATA clustering algorithm to locate inherent clusters in data and lessen Euclidean distances to form clusters. Using unsupervised classification implied no influence was drawn from the author. To choose an optimal number of classes that would best classify the data, a method previously used to generate a crop map for small study areas (de Bie et al., 2008) was innovatively applied to this image data. Iterations were set to a maximum of 25 and a threshold of 1.0. Divergence tests were then performed statistically to measure distances between divergence signatures for each classification and assess the mean signature seperability. The minimum and average values from the signature listings were then plotted. To choose the optimal number of classes for this image, peaks were observed in both the average seperability and minimum seperability. 80 classes provided seperability peaks both in the average and minimum plots. This formed the reason for choosing 80 classes to best classify the image. Figure 2-3 illustrates why 80 classes were selected to best classify the NDVI data.

This NDVI image was classified into 80 classes. The study area map was then used to extract the NDVI map covering the region of interest and 61 out of the 80 classes were found to cover the study area (appendix 1). The 61 NDVI profiles for the 61 classes were then plotted as legend. The unsupervised classification of the NDVI image was then followed by a supervised classification where profiles that had similar signature were merged through ERDAS, yielding 9 classes. The profiles that contributed to each of the 9 NDVI classes were plotted in appendix 2 while the 9 profiles were used in temporal trajectory analysis. Profiles 1, 3, 7, 8, 9, 10, 11, 13, 14, 16, 19, 23 and 24 were combined to form class 1. Profiles 22, 35, 43, 45 and 60 formed class 2. Profiles 31, 58, 65, 76 and 79 formed class 3. Profiles 72, 73 and 74 formed class 4. Profiles: 25, 27, 28, 29, 30, 32, 34, 37, 38, 39, 44, 46, 50, 51, 54, 55, 56, 57, 59 and 70 formed class 5. Profiles 41, 61, 62, 66 and 67 formed class 6. Profile 42 formed class 7; while profiles 52, 63, 69 formed class 8 and 68, 75, 78 and 80 formed class 9. The merged signature file was then used to classify the NDVI image using a maximum likelihood classifier (Campbell, 2006).

An averaging technique was used, considering images that were taken on successive dates in each month and for each class, while computing their averages. This was done to assess the spatial location of the classes which also formed the mapping units (MU). The NDVI map units were then overlaid with the land cover map (ILRI, 2007) in figure 2-4, to obtain names for the respective MU. Description of the represented units was done using a global land cover classification scheme at 1 KM spatial resolution (Hansen et al., 2000) due to its universality and similarity to the scale of this data. The area covered by each MU was computed using the pixel count and compared with the area for each land cover class as shown in appendix 3.

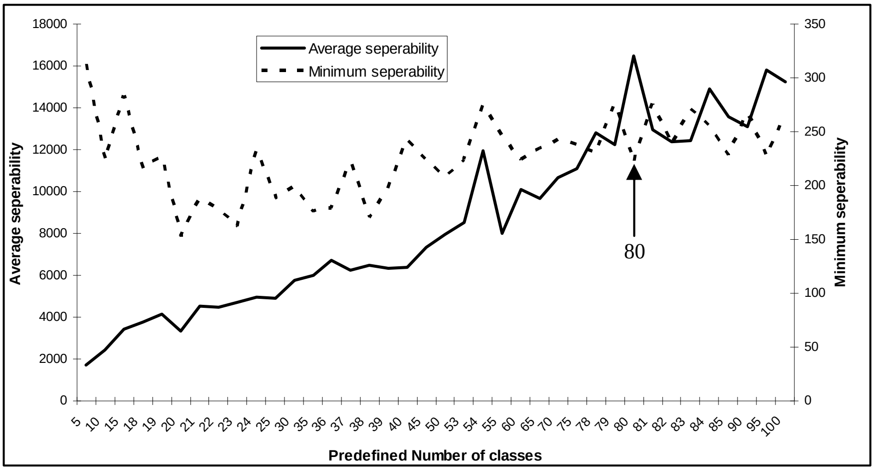


Figure 2-3: Average and minimum seperability divergence statistics to identify the optimal number of classes (=80) on 363 stacked layers of NDVI data

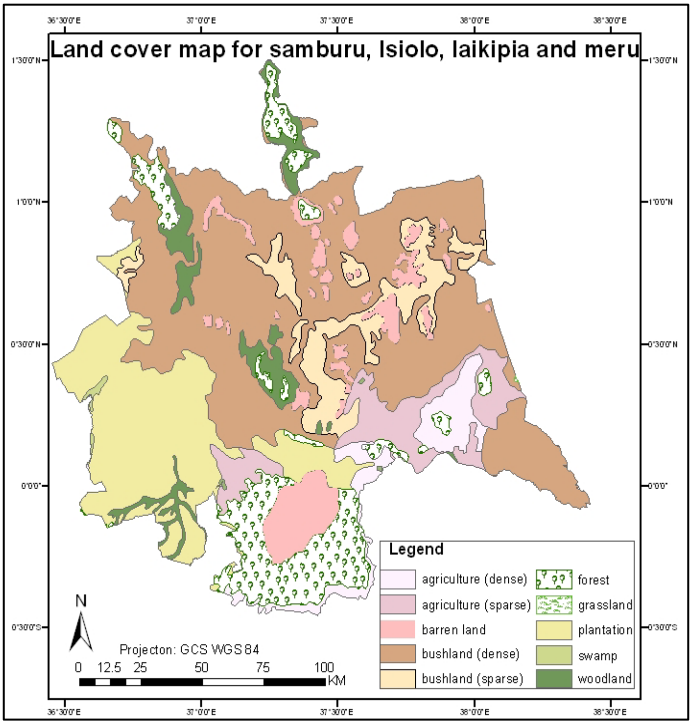


Figure 2-4: Land cover map; Source: (ILRI, 2007)

2.3.1.1. Accuracy assessment

The quality of a classified image dataset depends on the degree to which the assumed correct image agrees with a classified image. Accuracy assessment therefore plays a significant role in the authority, dependability, predictability, exactness, validity, and authenticity of maps prepared from remote sensing images (Campbell, 2006; Zhan et al., 2005). Spatial data contains uncertainties derived from space, time and handling, which leads to mislocation and misallocation of an area's classes (Longley et al., 2005a). The standard of classification is necessary to provide guidelines on user implications and uncertainty. This research used the existing land cover map, to evaluate the classified NDVI map. 450 random points were generated using the accuracy assessment tool in Erdas Imagine to provide a minimum of 50 points per each of the 9 MU. This was done in order to minimize bias in evaluation (Longley et al., 2005b). In the Erdas viewer, an algorithm compared pixels in the reference map and the classified map, while determining the number of correctly and incorrectly classified pixels in each class, to give an accuracy report. The confusion matrix expressed the degree of NDVI map quality that included the kappa statistic, overall accuracy, and the user and producer accuracy. Kappa coefficient is most useful as it gets rid of any chance of agreement, that would have occurred between the fields and the database (Longley et al., 2005a). The producer accuracy explained the percentage of pixels on the reference map that were classified correctly; while the user accuracy explained the percentage of pixels that were correctly extracted.

2.3.1.2. Creating mapping units

The nine NDVI classes formed 9 mapping units (MU). MU1 covered the ice cap peak of Mt Kenya in Meru district, and barren lands in parts of Samburu and Isiolo districts. MU2 mainly covered Samburu, parts of Isiolo and Laikipia districts. MU3 covered Meru and Laikipia districts. MU4 covered Meru district. MU5 covered a vast area of Isiolo, Samburu, and less area of Laikipia and Meru districts. MU6 covered Laikipa district. MU7 covered the western end of Meru district. MU8 covered pockets of Isiolo, with larger patches of Laikipia, Meru and Samburu districts. MU9 covered Meru district, mostly the slopes of Mt Kenya, parts of Laikipia and Samburu districts.

2.3.2. Correlating temporal NDVI fluxes with pastoral mobility

Methods used in this step included; spatiotemporal modelling of pasture variability through analysis of NDVI time series and spatiotemporal movements of pastoralists. The classified NDVI data, migratory routes and field data in table 2-1 were used. Other driving factors for pastoral migratory pattern were then assessed using results from the two methods and table 2-1.

2.3.2.1. Spatiotemporal modelling of NDVI fluxes

Temporal trajectory analysis was used to investigate the spatiotemporal pattern exhibited by NDVI in the study area, using time series (de Bie et al., 2008; Parmiggiani et al., 2007)of the ten day temporal NDVI images for the ten years (1998 to 2008) under study. This was done to facilitate quantitative analysis of the NDVI fluxes in order to assess the temporal trend of the vegetation cover over time (Serneels et al., 2001). The ten day image values were plotted in Excel for each MU and their trend investigated through statistical analysis. The decadal trend for each MU is shown in appendix 4. Through statistical analysis, the mean, range and standard deviations were computed for the decadal images in each MU, the range being used to capture temporal responses in land cover which could not be reflected by the average (Barbosa et al., 2006; Weiss et al., 2004). The average NDVI values were computed using the ten day image values in each MU for each month in each year. The range for each MU was computed by differencing the maximum and minimum NDVI value. The means for the range and standard deviation values was then calculated to underscore outliers in the data. These means were then used to plot the error bar to determine the significance of means for each MU and overlaps therein. An ANOVA test was used to assess whether NDVI means in the 9 MU were equal; while descriptive statistics included the mean, standard deviation, standard error, minimum and maximum NDVI values, which were used to determine the magnitude of deviation in each MU.

The average NDVI values for the years 1998-1999 and 2007-2008 were used as the start and end of the study period respectively, to examine the yearly trend of the vegetation patterns and deduce the revealed seasons therein (appendix 5). However, to counter respective variations in annual patterns, the decadal mean was used to define the climatic seasons represented by the profiles (Weiss et al., 2004) to deduce critical moments for pastoralists mobility. Inter-annual fluxes were investigated using annual averages for the entire 9 MU to assess the NDVI trend for the MU used as grazing areas during the defined climatic seasons.

Change trajectory was performed to assess inter annual changes in NDVI between each successive year under study. A time related analysis utilized a differencing procedure (Serneels et al., 2001), subtracting annual NDVI mean values for each successive years. The differences in these image values were used to reveal the scale to which vegetation changed over the years. This was used to understand the spatiotemporal pattern of pasture in the study area.

2.3.2.2. Spatiotemporal modelling of pastoral mobility

Pastoral mobility was executed in GIS to relate their spatiotemporal pattern of movement to the spatiotemporal pattern of pasture. GIS models have been used in studying such behaviour patterns (Macopiyo, 2005). Data used here included the averaged seasonal NDVI series, the migratory routes and the speed of herder movement. Spatiotemporal patterns of NDVI were defined by the average NDVI for the months forming the wet season and each of the dry seasons. The wet season grazing series was the mean for January, April, May, June, Nov and December NDVI series. The short dry season grazing series was the mean for February and March series; while the long dry season grazing series was the mean for July to October series. NDVI averages were rescaled using the least maximum values while maintaining the 9 MU to realize the spatiotemporal pattern of the land cover. Route destinations defined the grazing sites, while the district boundaries illustrated spatial extents to which the herders moved. A spatiotemporal model used an averaging function to extract the mean NDVI values for each grazing site to facilitate correlation of the NDVI fluxes with the pastoral migration pattern.

Migratory routes were converted into point instances spaced at a distance of 15km using the Hawths animal movement tool in ArcGIS. 15 km was used as the mean for the speed of movement to both directions. X, Y coordinates together with the turning angles were generated automatically by this tool to deploy the spatial position of the herder and the angle at which the herder was turning along the migratory track. The turning angles enabled pastoralists to trace their route and disperse at the grazing sites. The tracking analyst tool of ArcGIS was used to simulate the temporal movement of pastoralists to potential grazing areas using its querying functionality. The X, Y location of the pastoralists and date of departure at each instance, provided the spatiotemporal movements of pastoralists as shown in appendix 6. In these models, the position where the pastoralists were at each instance was referred to as "step ID" and was represented spatially using the X, Y coordinates. The time (date) when they were at that position was represented by "day", while the distance covered after each instance "distance covered", was cumulated in a database. Figure 2-5 illustrates the space and time components of the pastoral movements.

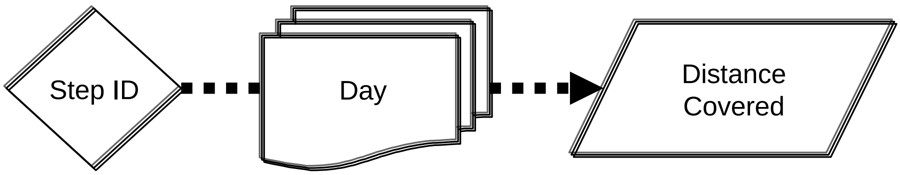


Figure 2-5: Schematic representation of a spatiotemporal model for pastoral movements

2.3.2.3. Assessing other driving forces for migratory pattern

Based on the pastoral spatiotemporal patterns revealed, a percentage of measure was calculated on field data in table 2-1 to explore the distribution of herds in respective grazing areas and their sources of water. This was aimed at assessing other factors that influenced the choice of respective grazing sites during respective seasons besides pasture variability being studied using SPOT data.

2.3.3. Suitability analysis for seasonal land sharing areas

Having defined grazing areas, non pastoral land uses and suitability of their locations were investigated. The purpose for this was to identify areas with overlapping land use interests, which could be prioritized for seasonal land sharing (SLS). Data used included the migratory routes, livelihood map, forest and wild life parks shape files, field data in table 2-1, water sources and seasonal interactions between pastoralists and non pastoralists. These shape files were preferred to the land cover map since land use attributes were detailed to the sub-location level (the smallest administrative unit in Kenya) while the land cover map was prepared at national level. Categorization of land uses was based on the land use activities defined for each area in the shape file used. The private ranches were categorized as ranching, areas with intense agriculture as farming, areas with agricultural and livestock keeping as mixed farming, pastoral land as pastoral, forested areas as forestry, protected areas as conservation and urban areas as urban. Sources of water such as wells and rivers were not categorized under land use classes as they were not influenced by human activity in this objective. Appendix 7 shows the resultant land use map.

Suitability analysis was performed using a multi-criteria decision making (MCDM) method (Longley et al., 2005a; Malczewski, 2004) while utilizing the land use classes. This method was selected as it combines several criteria to provide results of suitability (Longley et al., 2005a) as required in this study. The first criterion was the tenure system. In this case, pastoral land being under communal tenure was considered unsuitable while all land under private tenure was considered suitable for SLS. The second criterion was land use. This criteria excluded areas purely designated for both conservation as livestock were generally excluded from such areas (Kenyalaw, 2008; Said, 2003) and areas with permanent crop as crop is always on the farms. Conservation areas included the national parks. Forestry, farming, ranching, mixed farming, agriculture-forestry and urban were found to have overlapping land use interests as they formed dry season grazing sites besides their defined land uses, hence were selected for suitability analysis. Another consideration was proximity to water points as animals are watered at least once after every 1 to 3 days, forcing herdsmen to remain close to water sources (Coppock et al., 1988).

The land use vector map was converted to a raster file to facilitate suitability analysis. Weights 0 to 5 were assigned with 0 being for unsuitable area, 1 for the least suitable, while 5 was for the most suitable area in this analysis. The criteria for assigning the weights were based on the magnitude of pastoralists' choice of grazing sites and proximity to resources. Ranches were assigned the highest suitability weight 5 since 44% of the pastoralists chose the site; while urban areas were assigned the least suitability weight 1 due to long distances to such areas and insignificant sizes of such land areas. Areas with horticultural crop were also assigned the least weight 1 since the crop is majorly on farms but crop residues on harvest could be used for animal feed. Proximity to water sources was assigned a value 3 as cattle needed both pasture and water for survival. Proximity to roads was not considered in this analysis as the routes were designed by herders through participatory mapping, hence considered as suitable in accordance with local knowledge of the pastoralists to reach available fodder. Table 2-3 below, summarizes these criteria. A MCDM was preferred over weighted linear combination (WLC) method in performing a weighted overlay since it compensates between pixels that overlap within classes (Heywood et al., 1995; Malczewski, 2004). A land use suitability model by Malczewski, (2004) gave insight into innovation of a model for this suitability exercise.

The suitability areas were obtained using the innovated formula:

$$R = W * [(S-C) + (F-P)]$$

Where R is the result for suitable land sharing areas; W is proximity to water sources; S is statutory rights; C is communal rights; F is forest areas and P is protected areas. A buffer of 30 km was run around the wells, and along the rivers using Euclidean distance. The buffered distances were reclassified into suitable (0-25km) and unsuitable (25-30km) areas. The potential grazing sites that fell within the buffered distance were selected by intersecting the potential grazing areas and the reclassified distance using Boolean operators in spatial analyst.

The result was then reassigned a suitability index according to the 1 to 5 scale of suitability used in this study. From the suitability map obtained, only three highest scales of suitability: the most suitable, highly suitable and suitable locations were considered suitable and these land uses were prioritized for SLS.

Table 2-3: Criteria for selecting suitable areas to be prioritized for SLS

Category	Criteria for selection	Weight
Ranching	Include all	5
Mixed farming	Include all	4
Forestry	Include all	3
Farming areas	Include agro-pastoral farms where migratory routes lead to	2
	Include agro- forestry farms where migratory routes lead to	2
	Include horticultural cropland	1
	Exclude areas with permanent crop	0
	Exclude all farm areas under communal tenure	0
Urban	Include all	1
Proximity to water sources	Buffer 30 km to rivers Buffer 30 km to wells	3
Conservation	Exclude all game/national parks	0

2.3.3.1. Assessing feasibility for seasonal land sharing

Data used in this case included: a) the cost of grazing, b) cattle population for Northern Kenya and c) spatiotemporal interactions of land use actors during dry season migrations. The cost of grazing was computed per cattle density acceptable in each dry season grazing area. Cattle population for Isiolo and Samburu districts was used to assess their impact on the economy. Data on interactions of the land use actors and regulations for land sharing between the stakeholders, and analysis of conflict occurrences was used to evaluate the depth of the conflict and possibilities for SLS in the study area.

2.3.4. Designing conceptual models for seasonal land sharing

Soft systems methodology (SSM) was adopted for this section, due to its ability to absorb human behaviour in systems. SSM also provides a framework to the analyst to ensure all points of interest are extracted for the desired situation (Gregory, 1995). Having structured the problem in the preceding sections of this research, it was necessary to define the root definitions for the SLS system due to their effectiveness in capturing the requirements for the system and modelling such problems of complexity in nature (Checkland, 2000). Stages: 3 (root definitions), 4 (design of conceptual models) and 5 (comparison of the conceptual models with the real world) of SSM were adopted. To design the models, the suitable areas for SLS together with data from feasibility for land sharing were used in defining roots to simulate the behaviour of the system (Basden, 2006; Lane, 2000). Requirements for the design of these models included other systems thinking to facilitate descriptions of what was happening at a given time, how it happened and why it happened (Finegan, 1994). Ministry of lands (MoL) regulations on land renting was used as a basis for other systems thinking.

A CATWOE (customers, actors, transformations, world view, owners and the environment) approach (Waring, 1996) of SSM was used for the root definitions in this research. Logical linguistic models were adopted from the unified modelling language (UML) (Rumbaugh et al., 1999) to provide logical connectivity for information systems which SSM through CATWOE lacks (Basden, 2006; Gregory, 1993). The models described transition of the system, from the moment the pastoralist submitted a request for land sharing to the non pastoralist in the current situation, to the desired situation when the pastoralist submitted the agreement to the registrar to issue SLR for access to land resources. The procedure for acquiring SLR was based on institutional and governance requirements.

The root definition, in this research describes the transmission of messages between the stakeholders illustrating who was doing what to whom at what time, who was answerable to the action, and any assumptions made in the process (Nidumolu et al., 2004). This was required to enable the system to express its core purpose in each process (Basden, 2006; Moores, 2000). In this research, the financial benefit of 0.25 Euro per cow per month for the non pastoralists, seasonal duration of four months, seasonal agreements made between pastoralists and non pastoralists in land sharing and cattle population of 364,433 heads from Samburu and Isiolo districts (ILRI, 2007) were considered. Stakeholders in this research are the government who is the policy maker, the non pastoralist who is a land owner and the pastoralist who is the client. Institutional and governance requirements were used to capture the environment within which the transformation element was defined.

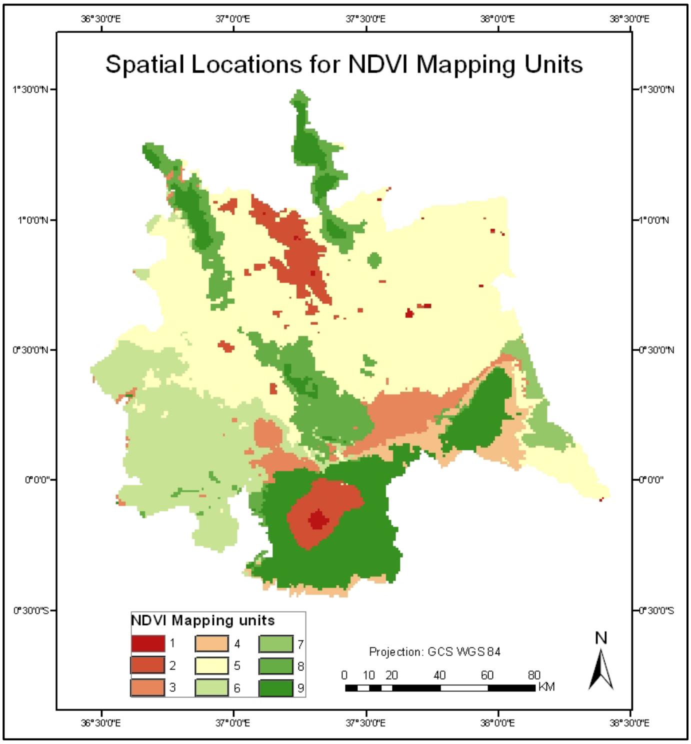
A UML class diagram was developed to capture the prioritized areas for land sharing in order to model the static components of the system into the cadastral system. The object classes, attributes and their associations were modelled based on object oriented analysis and design method (Shlaer and Mellor, 1988). The dynamism of the system was modelled using the sequence diagram due to its ability to demonstrate the transfer of messages in time between stakeholders (Tuladhar, 2002). This functionality allowed the sequence model to reveal the behaviour and intent of objects in the system (Larman, 2002) in time and space.

Three different alternatives were modelled using the sequence diagram: Alternatives 1 and 2 were used to depict the situation as was currently practiced between the stakeholders. Alternative 3 presented the desired situation. The desired model envisaged alternative 1 into the land renting transaction procedures provided by MoL guidelines (appendix 8) in Kenya (MoL, 2009), in view of the transformation and environment components of CATWOE. A temporal aspect was introduced in LA through SLR in order to accommodate the dry season migrations of pastoralists in space and time. A comparison of the modelled alternatives with the real world provided definitions for the desirable changes and actions for improving the problem situation by land administration.

3. Results and analyses

3.1. Spatial Location for NDVI Mapping Units

Figure 3-1 below shows the classified NDVI map with spatial locations for the 9 mapping units (MU) (at the top). The bottom figure shows the 9 averaged profiles as legend for each MU.



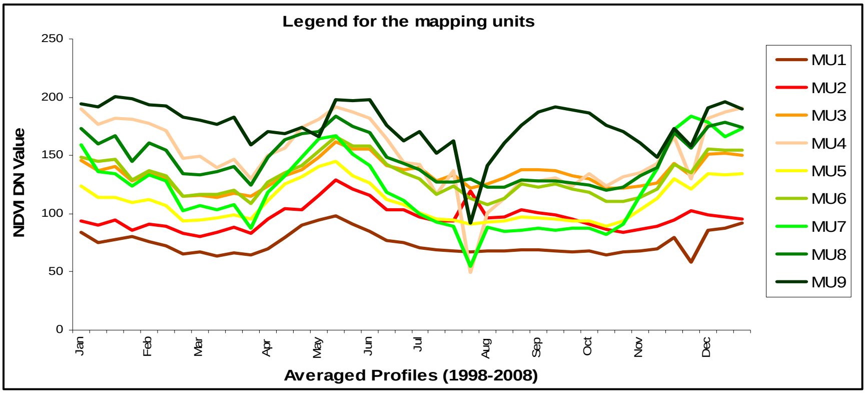


Figure 3.1: Spatial location of the averaged 9 NDVI Mapping Units formed from the 9 NDVI classes (top) with 9 profiles describing each MU (bottom).

Names for each NDVI mapping unit were obtained from the land cover map classes as explained in table 3-1 below.

Table 3-1: Description of NDVI mapping units

NDVI units	Land cover class	Description using the global land cover I KM spatial resolution classification scheme
MU 1	Barren	Places with < 10% vegetation cover during different times of the year. In this category are; exposed soils, sandy, rocky or ice caps.
MU 2	Bush sparse	Plants with canopy cover >10% and < 40 % with height < 2m).
MU 3	Agriculture sparse	Areas covered by < 80% cropping fields
MU 4	Agriculture dense	Areas covered by > 80% crop, and horticultural farms.
MU 5	Bush dense	Plants with canopy coverage > 40% and height < 5m).
MU 6	Plantation	Areas covered with > 80% crops for commercial or planted trees for commercial purposes.
MU 7	Grassland	Unremitting cover of herbs with < 10% tree cover and perennial grasses 0-0.2 m high.
MU 8	Woodland	Scattered trees >5m in height with open canopy cover > 40% and <60%.
MU 9	Forest	Trees of height > 5m, with closed canopy cover > 60 %

3.1.1. Classification Accuracy

The accuracy statistics presented below are an output from comparing the existing land cover map (2007) as reference data, with the classified NDVI map. The first column and row show the maps used in the evaluation. The rows show the pixels in the reference map while the columns show pixels in the classified map. The diagonals show the correctly classified pixels. The producer's accuracy is the accuracy of the vegetation class based on the reference map, while the user's accuracy is the accuracy of the vegetation class based on the classified map. The kappa statistic presents the accuracy of the classification after removing instances of chance. The result of this classification obtained an overall accuracy of 90% with an overall kappa statistic of 89 % implying only 11% of the pixels were left to chance. The lowest kappa statistic was 76% in the barren unit. The results of this classification are shown in table 3-2 below.

Table 3-2: The error Matrix for classification accuracy

	NDVI mapping units												
		MU 1	MU 2	MU 3	MU 4	MU 5	MU 6	MU7	MU 8	MU 9	Total	Producer accuracy	Kappa Statistic
Land cover map	Barren	20	5	0	0	2	0	0	0	0	28	71%	76%
	Bush sparse	2	60	0	0	3	0	0	1	0	66	91%	89%
	Agriculture sparse	1	0	31	0	0	0	0	0	0	32	97%	93%
	Agriculture dense	0	0	2	75	0	1	2	2	1	81	93%	92%
	Bush dense	1	0	0	1	73	0	0	0	0	74	99%	94%
	Plantation	0	0	0	2	0	35	3	0	0	40	88%	96%
	Grass	0	0	0	2	0	0	33	0	0	35	94%	72%
	Woodland	0	0	0	1	0	0	5	28	0	34	82%	89%
	Forest	2	0	0	3	0	0	4	0	51	60	85%	97%
	Total	26	0	33	84	78	36	45	31	52	450		
	User's Accuracy	77%	92%	94%	89%	94%	97%	73%	90%	98%			
	Overall accuracy = 90%												
	Overall kappa statistic = 89%												

3.2. Correlating temporal NDVI fluxes with pastoral mobility

3.2.1. Spatiotemporal patterns of NDVI fluxes

Temporal trajectory analysis in each of the mapping units in figure 3-1 revealed a bimodal pattern of the NDVI fluxes with seasonal oscillations through the year. High peaks of NDVI were mainly observed in the months of May and December while sinks were observed in the months of February to March and July to October as shown in appendix 4.

Figure 3-2 shows significance of differences in the means between the 9 MU at 95% confidence interval. There was no overlap between MU 1, 2, 3 and 5. Overlaps were witnessed between MU 7 (grass) and 8 (woodland) and MU 4 (dense agriculture) and 9 (forest). Among the overlapping MU, MU4 maintained the highest deviation of 5.55 with an error of 1.67, followed by MU9 with a deviation of 5.16 and an error of 1.57. MU7 had a deviation of 4.26 and an error of 1.28 while MU8 had a deviation of 4.20 and an error of 1.26. Overlapping MU implied the means between the vegetation classes were not significantly different as such means were probably within similar limits. The ANOVA result revealed significance of these means while the standard error and standard deviation show the magnitude of the error and deviation from the mean for each MU.

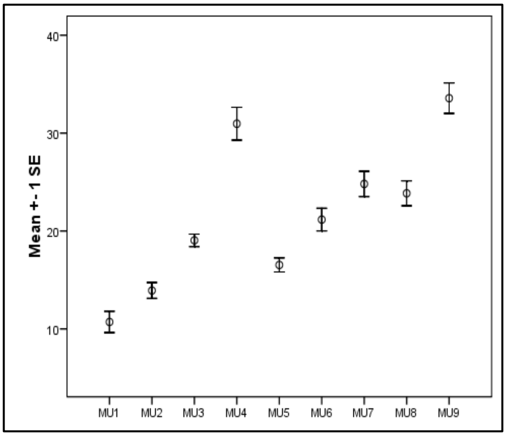


Figure 3-2: Error bars at 95% confidence level

A significance of 0.001 between the NDVI means for the 9 MU implied during similar climatic conditions, NDVI means in respective MU is different and each unit follows a particular NDVI behaviour pattern.

ANOVA					
Model	Sum of squares	df	Mean square	F	Sig
Regression	44.39	1	44.39	33.98	0.001
Residual	11.76	9	1.31		
Total	56.15	10			

Table 3-3 shows the highest error of 1.67 in MU4, compared to the lowest error of 0.01 in MU2; and highest deviation of 5.55 in MU4 compared to the lowest deviation of 2.12 in MU 3.

Table 3-3: Descriptive statistics

MU	mean	Standard deviation	Standard error	Lower bound	Upper bound	Min	max
1	10.7	3.62	1.09	8.26	13.1	5.37	18.6
2	13.91	2.68	0.01	12.1	15.7	9.42	18.3
3	19.04	2.12	0.02	17.6	20.4	15.5	21.39
4	30.9	5.55	1.67	22.2	34.68	23.11	40.59
5	16.52	2.37	0.71	14.93	18.11	12.87	21.78
6	21.11	3.82	1.15	18.59	23.72	15.27	24.78
7	24.80	4.26	1.28	21.93	27.67	17.76	34.51
8	23.84	4.20	1.26	21.02	26.67	18.74	33.61
9	33.56	5.16	1.57	30.10	37.03	27.58	43.03

Annual NDVI time series for the starting year April 1998 to march 1999 presented slightly different spatiotemporal patterns with time series for the year April 2007 to March 2008 in mid January of the latter. In both cases, however, a bimodal pattern was depicted in response to climatic seasons. This necessitated the use of the decadal mean series to synchronize the annual series.

The mean decadal NDVI time series defined a seasonal trend for the study area. Two dry seasons, represented by the sink pair, and two wet seasons, represented by the peaks, were revealed by all the MU profiles. The two months dry season from February through March was considered the short dry season while the four months dry season from July through October was considered the long dry season. The peaks from the wet seasons in each case covered three months hence were both named as wet season. The months covered were April through June and November through January. Figure 3-3 below illustrates the decadal NDVI seasonal trend with marked climatic seasons. As noticed in the figure 3-3, NDVI value during dry seasons in MU5 is below 110 units and these are the months when pastoralists depart for dry season grazing areas. NDVI value 110 was therefore set as threshold for departure and return to pastoral home areas. The MU with NDVI above 110 units were considered key potential grazing sites during the two dry seasons, while MU5 remained the wet season grazing site being the dominant land cover in the pastoralists' home area.

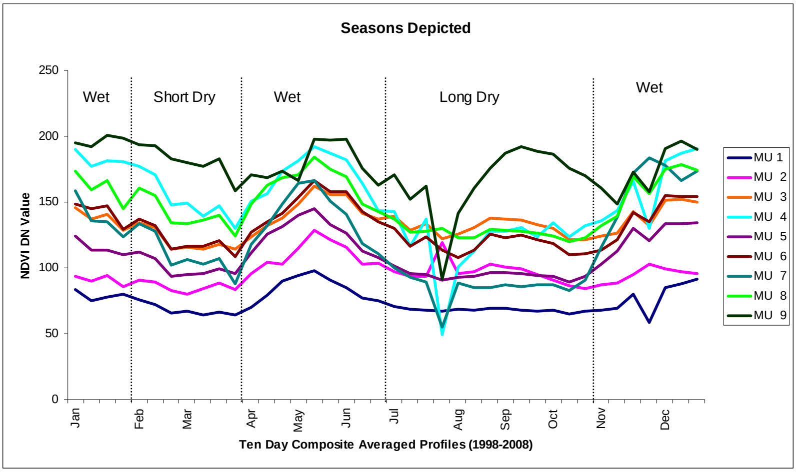


Figure 3-3: Averaged NDVI (1998-2008) time series for each of the 9MU. The climatic seasons (wet and dry) were also marked.

Annual means were then used to examine inter-annual fluxes in each land cover during the dry and wet seasons. In the scale of 0-255 used in this study, the lowest

NDVI of 60 units was depicted by MU1 (bare soil) in 2001 and 2006. MU2 depicted an almost uniform trend from 2001 to 2008 except 1999 and 2000 when NDVI in this MU was 85 and 70 respectively. MU5 depicted 93 units at the lowest in the year 2001, followed by 102 units in 2002 and 2006. In the rest of the years, MU5 maintained an average of 110 units, while the rest of the units maintained NDVI above 110 units. Figure 3-4 illustrates the inter-annual trend in the respective MU.

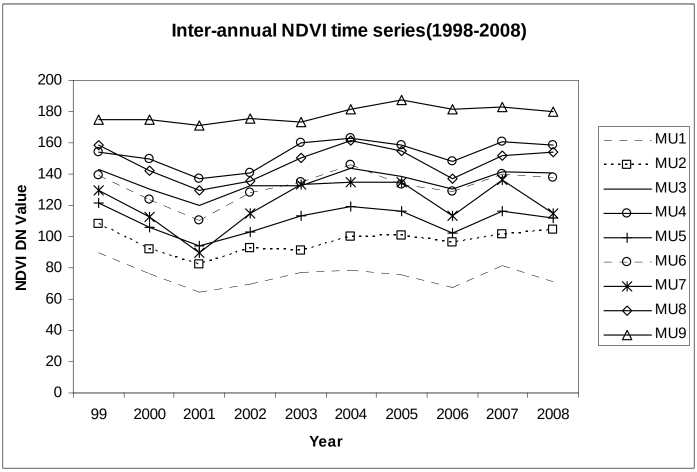


Figure 3-4: Inter-annual NDVI time series (1998 to 2008) for each of the 9 MU

A change trajectory performed on the annual means revealed the highest increase by 12.4 units in 2000 and the highest decrease by -11.90 units in 2007 as shown in figure 3-5. Factors that affect this disparity are likely to be attributed to difference in the amount of rainfall received in the preceding years.

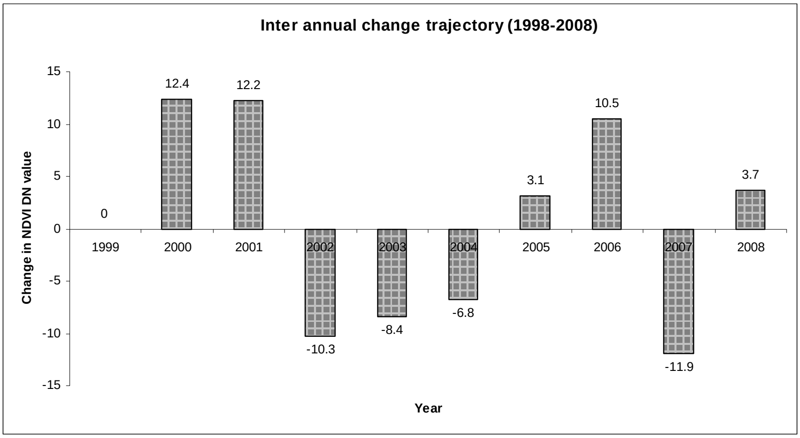


Figure 3-5: Change trajectory in Inter-annual NDVI series (1998-2008)

3.2.2. Spatiotemporal modelling of pastoral mobility in correlation with spatiotemporal pattern of NDVI fluxes

Destinations for pastoral migratory route defined the dry season grazing areas, being marked with higher NDVI and qualifying them as key resource sites by this study. At the destinations, pastoralists adopted a bird's foot style of dispersion, to pasturage locations during dry seasons. In the dry season locations, they remain resident for the period pasture is available depending on their cattle population and amount of biomass before they plan the next move since free movement is restricted by statutory tenure. During wet seasons, pastoralists graze freely in home areas being under communal tenure. The wet season grazing area is illustrated by figure 3-6, with NDVI value ranging from 82 to 181 units. The home area is defined by the two, blue grazing events and projects NDVI above 126 units during the wet season. Figure 3-7 shows the NDVI map for short dry season grazing areas, with NDVI value ranging from 80 to 185 units. The home area at this time projects NDVI value below 119 units which is less than that in the agriculture sparse area. Pastoralists migrate to Losesia and agriculture sparse area defined by the grazing events in blue during this period. Figure 3-8 shows the NDVI map for long dry season grazing areas with NDVI value ranging from 68 to 171 units. The home area projects NDVI value below 94 units. Pastoralists migrate to the ranches and forests areas defined by grazing events in blue, orange and pink, during this period. Grazing events along the migratory route express pastoralists in motion to the dry season grazing areas.

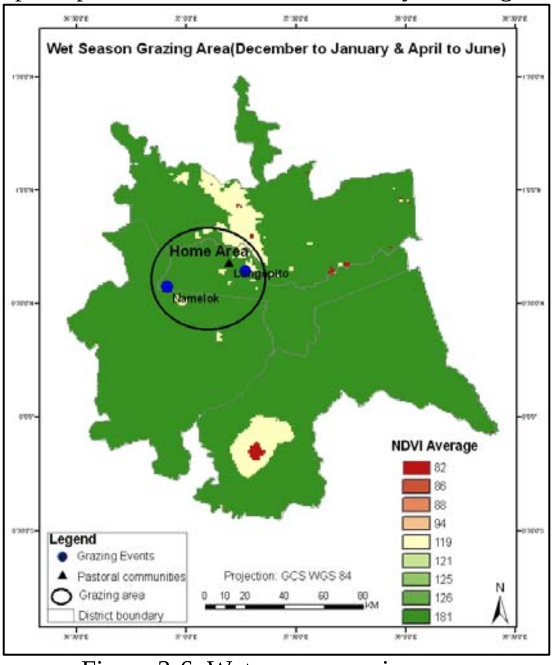


Figure 3-6: Wet season grazing area

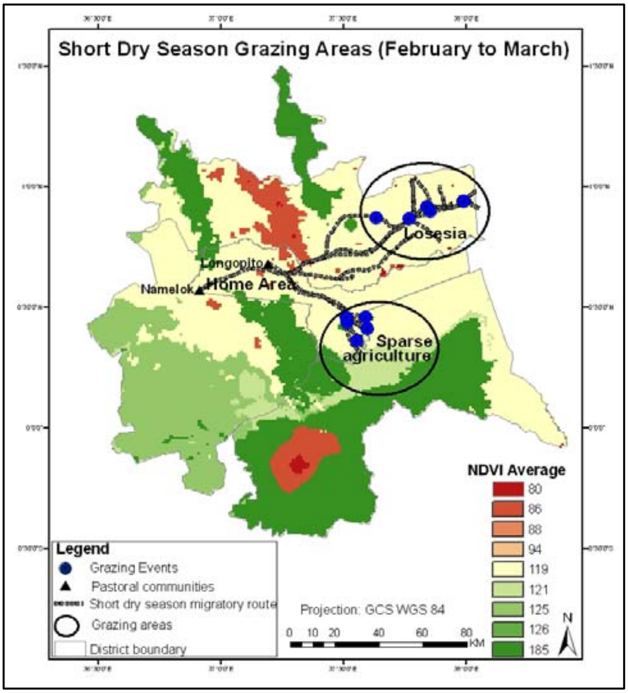


Figure 3-7: Short dry season grazing areas

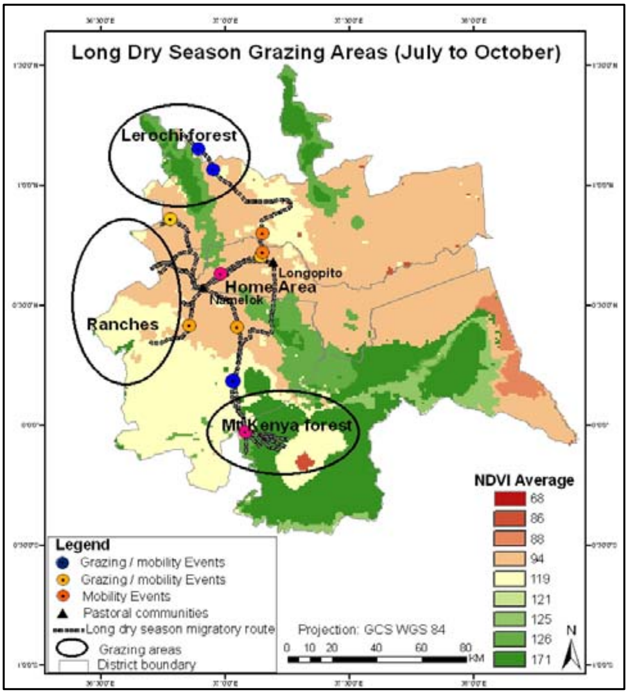


Figure 3-8: Long dry season grazing areas

Figure 3-9 illustrates the correlation between the temporal NDVI fluxes in all the grazing areas with the pastoral migration pattern. All pastoralists from Isiolo area claimed to move their cattle away during dry seasons and return them during wet seasons. In February, averaged NDVI in the home area drops to 104 units causing departure1 to two short dry season grazing areas with NDVI value of 110 units and higher. These include Losesia, an area covered by MU 5, 8 and the agricultural sparse area (MU3). In April, the increase in NDVI to 128 units in the home area attracts the pastoralists back home where they graze till June. In July, the drop in NDVI in the home area causes departure 2, to three long dry season grazing areas: plantations (MU6), woodland (MU8) and forest (MU9), where they graze till October. NDVI in home area regenerates to above 110 units in November attracting the pastoralists back home where they graze until January. A strong correlation is realized between the temporal NDVI fluxes and the spatiotemporal migrations of pastoralists; hence null hypothesis 1 is rejected.

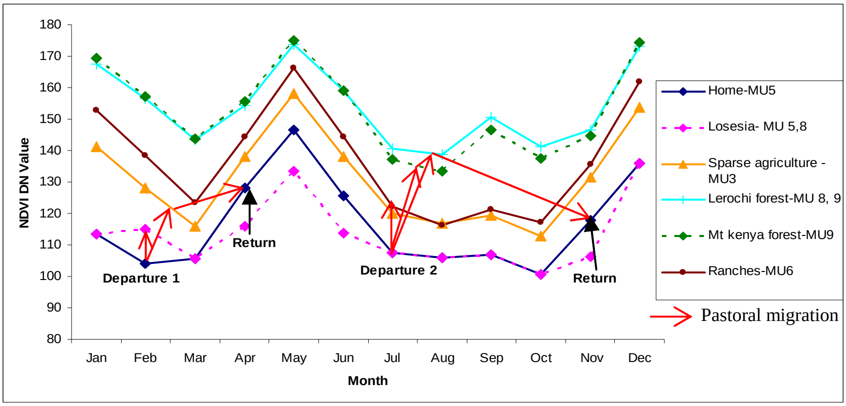


Figure 3-9: Correlating temporal NDVI fluxes with pastoral mobility pattern

3.2.3. Other driving forces for pastoral migratory pattern

Besides search for the variable pasture, other factors that determined the spatiotemporal pattern of herd distribution to respective grazing sites were drawn from field findings in table 2-1 and answers to questionnaires. During the short dry season, 58% of the herds are taken to Losesia for free grazing in the ecotourism area and utilization of available water from river Losesia; while 42% are taken to the sparse agricultural areas to graze on crop residues at a cost in farming areas. The reason for choice of costed grazing against free grazing is to minimize on intensified competition for resources from other pastoral communities. Proximity to grazing areas was another reason respondents alleged determines the migratory pattern. Although forests and ranches project high biomass in February, pastoralists preferred the agriculturally sparse area which took them 2 days to reach fodder, against the 3 to 4 days to ranches and 5 to 8 days to forest sites. 95% of the respondents asserted they migrate away from areas prone to diseases, pests and insecurity caused by attacks from cattle rustlers. They claimed Losesia being a practice ground for military services, assures herders of security during the short dry season grazing.

During the long dry season grazing, 44% of the herds are taken to the ranches, 30% to Mt. Kenya forest, while 26% move to Lorechi forest. Reasons attributed to this pattern are: unavailability of access to farming areas which have crop on farms at the time. They also asserted they move towards friendly communities which grant additional labour and security for their herds at the time. Additionally, their 30% preference for Mt Kenya forest against 26% for Lerochi forest is clarity of route to Mt Kenya against the rugged terrain to Lerochi. The sources of water for 33% of the herds in both short and long dry seasons are rivers, while 67 % of the herds depend on both rivers and wells. The research realized that cattle require water besides fodder, and the absence of one compels the pastoralists to depart from an area. Pastoral mobility is seen to be driven away from seasonal river basins, towards perennial river basins such as Ewaso Ng’iro for water and fall back grazing along the rivers. Results also show that pastoralists move across different ecological zones (appendix 9) located within different districts in bid to reach the variable herbaceous pasture.

3.3. Suitable areas for seasonal land sharing

Suitable locations for SLS were analyzed from among the land uses found within the grazing areas. Distribution of land use classes and their respective land ownership is shown in table 3-4.

Table 3-4: Distribution of land use classes and tenure in the study area

Land use class	Distribution (%) Coverage	Land Ownership
Pastoral	37%	Communal
Forestry	14%	State
Conservation	11.6%	State
Ranching	20%	Private
Farming	10%	Private
Mixed farming	7%	Private
Urban	0.4%	Private

Figure 3-10 shows suitability of locations for SLS as visualized in their order of suitability. The most highly suitable areas were located within specific parts of the ranches, farming, agro-forestry, and mixed farming areas. The ranches and agro-forestry areas had planted forests whose undergrowths the herders utilize while mixed farming areas provide crop residues and reserved pastures to the cattle. The areas considered as highly suitable are located within the ranches, parts of farming areas and mixed farming areas. Areas categorised as suitable are specific parts of forests. Moderately suitable and least suitable areas fall within the 25-30km water buffer. The moderately suitable areas include urban, ranching and horticultural farm lands, while least suitable areas are dominated with woodland. Unsuitable areas include: communal tenure land, permanent cropland and national parks. Therefore, not all non pastoral land use locations are most suitable for seasonal land sharing hence null hypothesis 2 is not rejected.

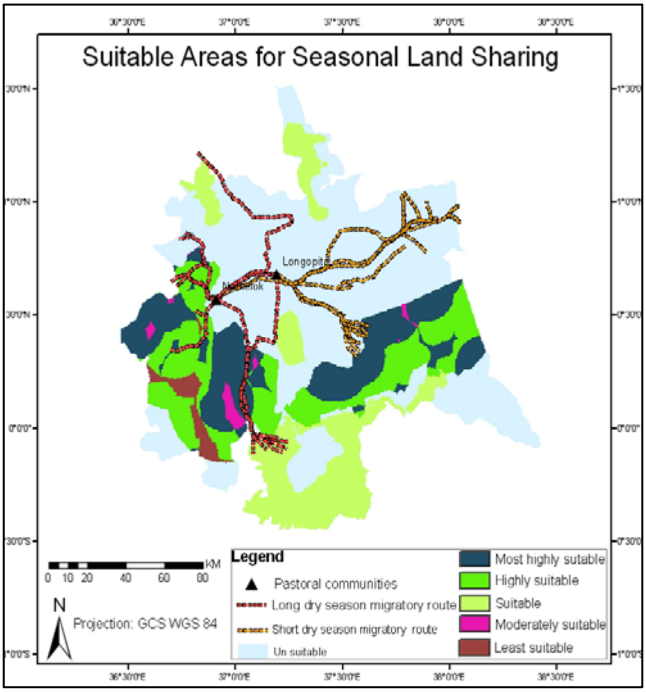


Figure 3-10: Suitable areas for seasonal land sharing

3.3.1. Feasibility for seasonal land sharing

Table 2-1 shows pastoralists were charged 0.25 euro per cattle per month for grazing. Considering the average capacity of 8 cattle per hectare that each non pastoralist accepted in each month with SLS, an extra 2 euro monthly income was made from each cattle grazed above normal farm income in most suitable locations. Monthly income from the 364,433 cattle from Isiolo and Samburu would thus be 91108.25 Euro. Magnitudes for SLS agreements made between the land use actors in the suitable locations for SLS were highest among the ranchers with 50% and lowest among the farmers with 6.2%. In principle, 79% of the interviewees never made land sharing agreements while 12.5% sometimes made and 8.5% always made such agreements. Among land use actors who rejected land sharing, 95% claimed to always experience conflict while 5% sometimes experienced the conflict. August, September and October were depicted as months with highest conflicts, with the highest magnitude being 81% in September and the lowest being 31% in July, among all categories of land use actors. Reason for this disparity is the crop calendar which determines the period when crop is on farms. Pasture variability, income from grazing, gravity of conflicts and existing land sharing were considered basis for seasonal land sharing. Table 3-5 summarizes results for making SLS agreements.

Table 3-5: Making agreements to allow SLS (adopted from (Lengoiboni, 2008))

		Do you make agreements with pastoralists to allow access on your land?			
Land use actors	Responses	Never	Sometimes	Always	Total
Farmers	Count % within RESPONSES	15 93.8%	1 6.2%	0 0%	16 100%
Forest officers	Count % within RESPONSES	4 66.6%	1 16.7%	1 16.7%	6 100%
Private ranchers	Count % within RESPONSES	0 0%	1 50.0%	1 50%	2 100%
Total	Count % within RESPONSES	19 79%	3 12.5%	2 8.5%	24 100%

3.4. Conceptual models for seasonal land sharing

The root definition in this objective was, to design conceptual models to demonstrate SLS between pastoralists and non pastoralists through SLR. CATWOE definitions of root elements in this study are presented in table3-6 below, as follows: The stakeholders are pastoralists and non pastoralist land use actors. The customer is the beneficiary or one who is affected by system outputs. These include the pastoralist who needs pasture for his herd and the non pastoralist whose land resources are in demand by the pastoralists. Actors are the stakeholders involved in land sharing, and the land registrar who is authorized to grant land rights to applicants. The transformations in the system involve inflexible land rights which need reengineering of land tenure to adopt SLS as part of conflict mitigation strategy. The perspective of the world view is to mitigate conflicts in order to provide a sustainable livelihood to all stakeholders. Owners in this system are decision makers such as non pastoralists and the government when they decide to accept or reject requests for access to pastures by the pastoralists. The environment element observes uncertainties of the system in cases of changed policy, climate and land markets. These root elements were considered when developing the models to capture the root definition for the system.

Table 3-6: A CATWOE analysis for this research

Root	**Elements in this study**	**Description**
Customer	Pastoralists and Non pastoralists	Beneficiaries from or those affected by the system
Actor(s)	Pastoralists, Non pastoralists, Land Administrator (Land Registrar)	Performers of activities
Transformation	Reengineering land tenure to adopt SLS in LA aimed at mitigating conflicts	Requirement of the system
World view/ Weltanschauung (employability)	Mitigate land use conflicts & provide better livelihood opportunities for the stakeholders during dry seasons	View point held of the system in search for a solution
Owners	Non pastoralist and the government	Decision maker
Environment	Changes in policy, climate, land markets	Uncertainties

3.4.1. Institutional and governance requirements

The transformation and world view parts of CATWOE provide requirements for designing models for the system, while integrating the customer, actor and owner elements. Institutional requirements are rules that guide the running of such systems and require governance to implement them, while aiming at mitigating resource use conflicts to provide better livelihood for all stakeholders as illustrated in figure 3-11.

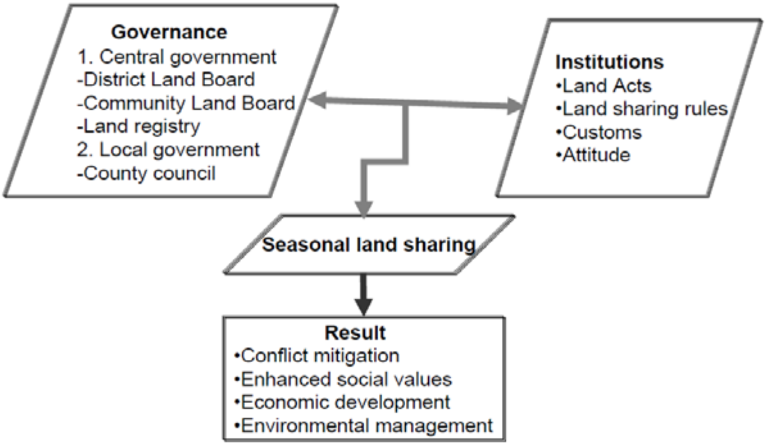


Figure 3-11: Institutional and governance requirements

3.4.1.1. Institutional requirements

Pastoral land in this study is governed by customary law while non pastoral land is governed by statutory law. Access to land under statutory law requires regulations to authorise such access by the stakeholders providing room for land sharing on such private land. Examples of laws applicable to land sharing in Kenya are conducted through leasehold section 47 of the Government land act (GLA) Cap 280; and land renting through registration of land act (RLA) Cap 300 (caution), or registered titles act (RTA) Cap 281 (caveat). Through these acts, the lessee is granted a licence of interest in the land leased. Repealing of these acts together with the conservation and management sections by the Kenya law forums; will provide for SLS during dry seasons under predefined regulations for effectiveness of SLR among stakeholders. The latter proposal is however subject to field studies that will establish the impact of dry season grazing on forest undergrowths.

The custom of the stakeholders in the study area involves setting up individual rules to regulate land sharing during dry seasons. The attitude of the people towards SLR will determine their flexibility from tradition to official means allowing institutions to govern SLS for success of the system. Proposed SLS is aimed at promoting customs and values across the involved communities to enhance culture exchange, while observing conflicting customs that are likely to subject the communities to social strain.

The existing tribunal act No.18 of 1990 was found ineffective in resolving conflicts, prompting the draft land policy to propose alternative instruments. Community elders are involved in settling some arising conflicts, but since they are not mandated by the law to undertake such a task, such forums are unsuccessful. The local authority through the county council officials is also limited on resolving conflicts between pastoralists and non pastoralists as the latter's lands are governed by private law. Public participation will utilize the exchanged values among the stakeholders to promote commitment among the people to SLR to minimize on resource use conflicts, improve livelihoods and realize environmental management.

3.4.1.2. Governance requirements

The ministry of lands (MOL) governs statutory land while the local authority governs communal land on behalf of the central government. The public are responsible for their participation through adherence to the established institutions. Owing to the fact that SLS will occur on private land, the MOL will utilize the central authority bestowed upon it to uphold public participation regarding democracy on all land issues through the district land control boards (DLB). The

DLB will implement recommendations from the community representatives and evaluate land reform programs at the district level to promote economic development and environmental management.

In this research, the community members either will recommend or reject land sharing requests from the stakeholders during DLB forums, depending on adherence to specifications on land sharing. On recommendation, an approval by consent will be granted allowing the pastoralists to submit the consent to the land registrar to request for SLR. The registrar will issue SLR using the authority of the land owner, evidenced by the consent from the DLB. The registrar will then grant SLR to the pastoralist and encode a caution or caveat in the encumbrances section of the owner's title as a dry season grazing right. This LA information will commit the sharing parties with responsibility of land use management. At the end of the dry season, SLR will cease automatically, while any arising conflicts, will be resolved by DLB.

3.4.2. The UML class model

The modelled classes demonstrate the objects, attributes of objects and associations between the objects. Objects include: Party, RRR, Recorded object, spatial unit, and LA-Document. The party is the stakeholder in this research who is either a natural person or a non natural person. The natural person includes a pastoralist or an individual land owner in this case, the farmer or rancher. The non natural person is the state. The farmer, rancher and state are all categorized as non pastoralists in this study. RRR stands for property rights defined with 3 R as: rights, restrictions and responsibilities that a stakeholder has over land. During the wet season, the right of stakeholders on land is either private for non pastoralists or communal for pastoralists. The two kinds of right grant power of ownership to both parties. Additionally during dry seasons, when pastoralists acquire seasonal land rights over the private land, their right of ownership on the private land is seasonal. Restrictions applicable on private land are the encumbrance and grazing right. Responsibilities the stakeholders have on land include land use management and regulations that govern SLS in a sustainable land use management system.

Recorded object is the land information encoded regarding all transactions on land. The spatial unit is the land where RRR is applied. This includes the most suitable locations for dry season grazing identified in figure 3-10 as within: farms, ranches and forests. LA-Document is the legal land administration document issued to the party in association with the current state of land. The document type is either a title for the land owner or seasonal land rights permitting the pastoralist access to pasture on the non pastoralist's land during dry seasons. The association between classes can either be “0” implying no relation, “1” to imply a single relation, or “*”, to imply many relations. In each instance, we may find either none, one or more than one pastoralist relating with a non pastoralist on their land through SLS. On a spatial unit where seasonal land rights applied, we find more than one right type (private and seasonal ownership). Figure 3-12 illustrates the UML class model.

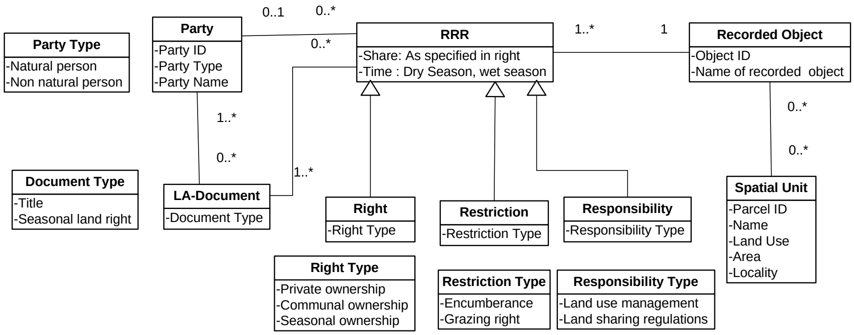


Figure 3-12: The UML class model showing parties and their association with the spatial unit in the cadastral domain

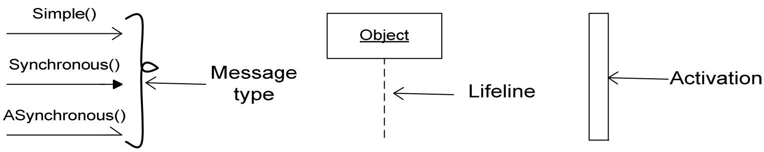
3.4.3. The UML sequence model

The sequence model used the class diagram objects to demonstrate the flow of messages in space and time, between the stakeholders. The horizontal axis of the sequence model represents the entities involved, while the vertical axis shows the time component expressed through the lifeline. The arrows show the type of message sent at each instance.

Types of messages in the sequence diagram include:

i) Simple messages: When transferring control from one object to another
ii) Synchronous messages: Await response before proceeding with transaction
iii) Asynchronous messages: Proceed with transactions without waiting for response.

The symbols used in the sequence models are as follows:



3.4.3.1. Scenario development

Three alternatives are developed in the sections below. Alternatives 1 and 2 (figures 3-13 and 3-14) are based on the existing situation as practised between pastoralists and non pastoralists; while alternative 3 (figure 3-15) presents the desired situation where seasonal land rights will be granted to the pastoralists by LA.

Assumptions when modelling the alternatives

The assumptions to be made in modelling the 3 alternatives are based on the environment element of CATWOE. These include:

- Climatic conditions will not change adversely from the current trend to deplete pasture in potential grazing areas. This research assumes the suitable locations for SLS will always have sufficient pasture to feed the herds during dry seasons. In the event pasture is depleted however, pastoralists are likely to migrate to different localities in search of fodder and this will extrapolate SLR to other regions in Kenya.
- Changes in land policy will be effected as proposed in the Kenya national draft land policy and by this research. This will reinforce SLS through provision of acts that will permit documentation of land sharing information to realize SLR.
- The value of land market will not appreciate to render SLS unattractive. This is because the cost of grazing is depended on the current land market. If land market appreciates, the cost of grazing each cattle will increase and pastoralists may find it costly to pay for dry season grazing exacerbating conflicts. In case the land market appreciates alongside the value of cattle however, SLS will still be attractive and SLR will be realized.

Results of these assumptions show that SLS is still favourable amidst the environment uncertainties. Scenarios were therefore modelled as follows:

<u>Alternative 1: The current situation when request to access pasture is accepted</u>

The pastoralist approaches a non pastoralist for access to pasture. On acceptance, the two parties sign an agreement to share the spatial unit (land) for a flexible timeline upon settlement of the agreed cost for grazing. Compensation is made by the pastoralist to the non pastoralist either in cash or by cattle of equivalent agreed cost. The pastoralist then commences use of pasture depending on pasture availability. During this sharing period, the land owner holds private ownership to the land, while the pastoralist has no documented right of use over the land. Figure 3-13 demonstrates this scenario.

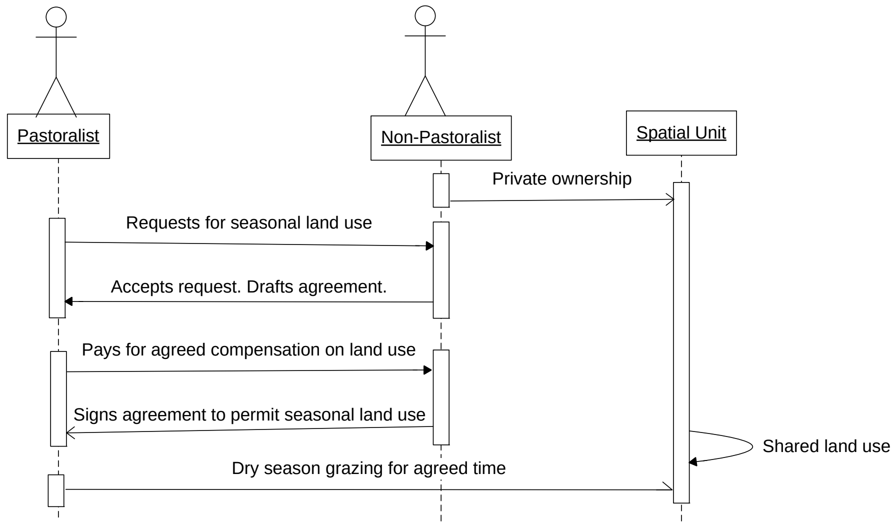


Figure 3-13: A UML sequence model showing the current land sharing practice between pastoralists and non pastoralists

Alternative 2: The current situation where conflicts occur over resource use

A case where request for land sharing is rejected, the pastoralist in many cases invades available pasture on accessible land in the vicinity, causing resource use conflict as shown in figure 3-14. The non pastoralist whose land is invaded uses exclusive land rights to counter such invasion through dispute handling mechanisms.

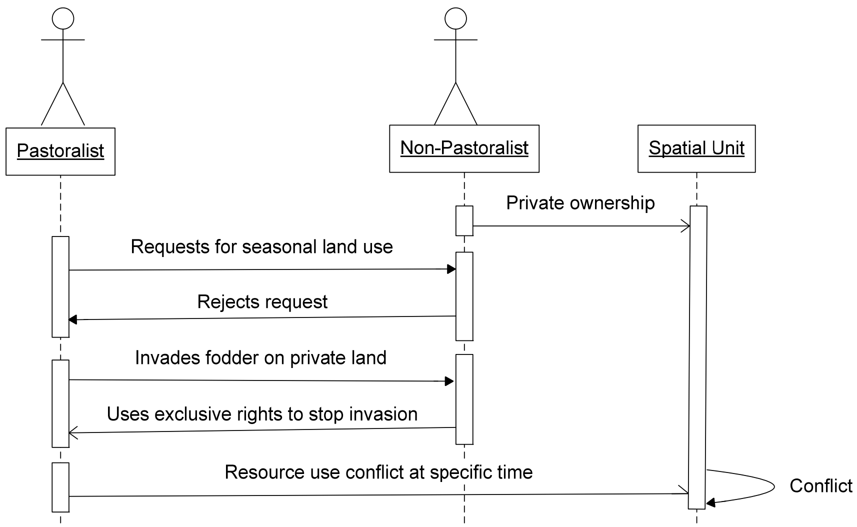


Figure 3-14: A UML sequence model showing the current situation when resource use conflicts occur

Alternative 3: The Desired Situation

The pastoralist identifies the spatial location of land with pasture and contacts the non pastoralist for land sharing. If the request is granted, they apply for SLS consent from DLB who act, based on conditions for SLS which will be established by LA. The DLB grants consent for SLS to the non pastoralist for onward transmission to the pastoralist. By authority of this consent, the pastoralist applies for SLR from the registrar. The registrar records the transactions on such spatial unit as land information (Recorded object) and may authorize a land surveyor to establish the spatial extent being shared when such land is not whole. The cost for this transaction by the government is 2.5 Euro. Upon this payment, a restriction is encoded in the non pastoralist's title as an encumbrance for grazing rights during the dry season and the registrar issues SLR to the pastoralist as a LA-document. SLR governs SLS over the period specified in the consent at the end of which SLR ceases. During SLS period, the land owner uses private ownership rights while the pastoralist uses seasonal ownership rights on the same spatial unit. Figure 3-15 demonstrates this scenario.

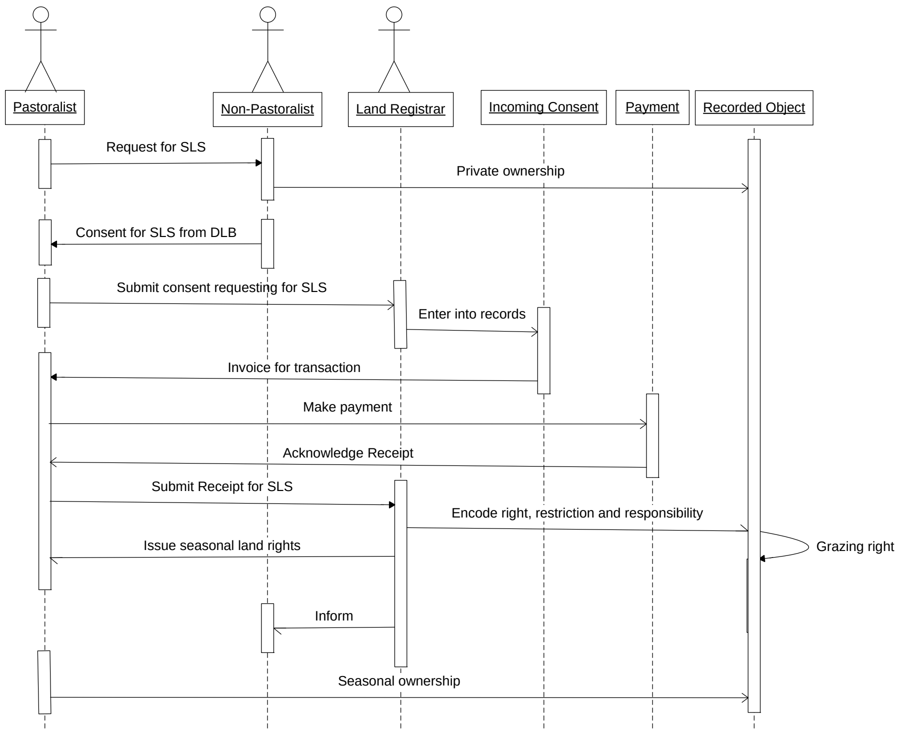


Figure 3-15: A UML sequence model showing a pastoralist acquiring SLR in the desired situation where the land being shared is whole

Comparing SLS steps in alternatives 1 and 3 with MoL steps

Figure 3-16 illustrates comparison of steps of SLS in alternatives 1&3 with steps in MoL as external system thinking. The initial four steps are similar in all cases except for step 3 which has an extra sub step for alternative 3 and MoL. In this case: when the request for SLS is granted in alternative 1, the pastoralist commences use of resources, while in alternative 3 and MoL guidelines, the agreeing stakeholders require to apply to the DLB for consent to allow SLS. Steps 5, 6, 7, and 8 involve alternative 3 and MoL only, where: survey is involved, regulations drafted and land information is encoded. Step 9 involves introduction of the temporal aspect through SLR in alternative 3 which MoL system lacks.

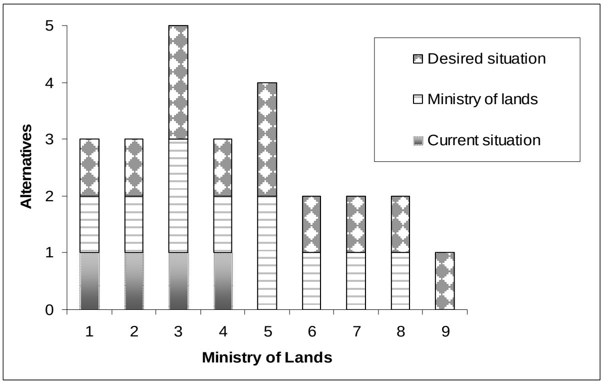


Figure 3-16: Comparison of SLS steps in alternatives 1&3 with MoL

3.4.4. Comparing the conceptual models with the real world

Comparison between the modelled alternatives with the defined real world problem identified benefits and limitations of the alternatives which require the attention of LA. Considering economic sustainability in alternative 1; the land sharing parties profit from each other while the government looses on revenue. Additionally, land information for such transactions is not available thus in case of breach of contract, land use is insecure. Alternative 2 requires LA to devise timely conflict resolution mechanisms between conflicting stakeholders in cases of pasture invasion and encourage willingness for SLS among non pastoralists. Alternative 3 is the desired situation, where all stakeholders including the government profit economically and land information is encoded. Each of the stakeholders will acquire a LA document for security of land use. However, the migratory routes are not defined officially in LA, with some parts of the routes passing through narrow paths of agricultural areas. This is still likely to cause conflicts during migrations to SLS areas. Table 3-7 summarizes this comparison. The notes section indicates benefits and limitations in the alternatives which require attention of LA to realize SLR.

Table 3-7: A comparison of the conceptual models with the real world

Activity	Exist? (Y/N)	How is it done?	How is it judged?	Notes
Alternative1 (Current situation)	Yes	Local agreements made for SLS by stakeholders	-Unofficial. -Sharing stakeholders profit, but LA looses on revenue	-Marked with uncertainty when contract is breached. - Lack of Land information -Insecurity of land use
Alternative2 (Current situation)	Yes	- In cases when hungry cattle invade accessible pasture on private land	-Resource use conflict. -Pastoralists compensate land owner if proved guilty of trespass.	-Need for timely conflict resolution mechanisms due to persisted conflicts -Require public participation to encourage willingness of populace into SLS
Alternative3 (Desired situation)	Not fully	-Partly documented through MoL land renting guidelines Cautions and caveats section -Seasonal land rights introduced to capture the temporal aspect lacking in LA	-Official, -Secure rights and profitable economically for all stakeholders	-Secure tenure through SLR -Temporal aspect introduced - Land use information will be available - No breach of contract -Conflict mitigation institutionalized - No official migratory corridor. Conflicts may arise during migrations - No established regulations for SLS -Reengineering of land acts is required

Conceptual models have successfully demonstrated conditions necessary for seasonal land sharing through seasonal lands rights in space and time. Further, the models have identified actions that require the attention of LA to realize SLR. Null hypothesis 3 is therefore rejected.

4. Discussion

4.1. Correlating temporal NDVI fluxes in land cover types with spatiotemporal pattern of pastoral migration

Results of this research signify a strong correlation between temporal NDVI fluxes and pastoral pattern of migration. It is evident that the migratory route destinations point to areas of higher NDVI and the bird’s foot pattern of dispersion at destinations reveals a search to key resource areas of sufficient biomass. SPOT NDVI data as used in this research has successfully revealed how the seasonal migration pattern of pastoralists responds to temporal variability in land cover types. Additionally, the spatiotemporal patterns of the nine land cover types were sufficient to distinguish divergent phenology in land cover and their seasonal influence on pastoral mobility. The kappa statistic for this data was 89% qualifying it as good quality data as used in this study. Previous studies have shown that accuracy above 85% is considered to be of good quality for application into land cover and land use studies (Treitz and Rogan, 2004).

This study has proved that temporal variability portrayed by the land cover types is influenced by seasonal climatic changes. The profiles revealed a trend where NDVI oscillated seasonally to form a bimodal trend of two wet and two dry seasons within the year. This result is in agreement with other studies which have proved that a trend which oscillates over time series reflects the dryness and wetness of an area (Lu et al., 2001). Trend analysis of biomass in this study revealed lowest NDVI values in February to March and July to October. This research used this result to define February to March as short dry season and July to October as long dry season grazing months respectively. High NDVI values were eminent in the months of April to June and November to January thus this research defined these as wet season grazing months. Considering similarity in trend for all the vegetation units under this study, areas with analogous climatic conditions and vegetation types ought to yield similar NDVI trend.

This study realized that dry season grazing months drove pastoralists into migration in February and July, to key resource areas in the highlands. Pastoralists migrate so as to graze their herds on foliage, undergrowths and permanent grasses to enhance nutritional value of the animals (Thébaud and Batterbury, 2001) which has been depleted by drought in the home area pasture. The wet seasons attract pastoralists in April and November to graze back in the home area, when pastures have regenerated and revived their nutritional value which the animals needed. This study also attributes this return to competition for resource use with non pastoralists who wish to resume their defined land use activities at the onset of rains (ALRMP, 2007). These findings are in agreement with other studies in East Africa which used NDVI to reveal a bimodal pattern of wet and dry seasons, in response to the bimodal rainfall in the region (Anyamba et al., 2002; Mutai and Ward, 2000). NDVI was used in this research as a climatic indicator owing the fact that vegetation availability is influenced by rainfall and moisture of the soil (McAllister et al., 2006; Tucker et al., 1986). It is argued that NDVI is not a direct indicator of biomass, but annually integrated NDVI is used as a surrogate for biomass production (Adriansen and Nielsen, 2005). The seasonal variations revealed by this research are analogous to variable responses of different vegetation types to fluxes in rainfall and temperature in different spatial locations (Lu et al., 2001; Weiss et al., 2004). Other studies have also found that high biomass corresponds to wet seasons while low biomass corresponds to dry seasons (Barbosa et al., 2006). This research also realised that the onset of rainfall in March and October causes herbaceous plants to regenerate as plants need rainfall to grow (Weiss et al., 2004) and this attracts the pastoralists back home to the lower lands in April and November respectively. The response of vegetation to seasonal rainfall circles thus influenced pastoralists into seasonal migrations (Macopiyo, 2005).

This research used a scale of 0 to 255 to analyse the spatiotemporal trend of the land cover types. The results attained NDVI values below 100 in the barren and bush sparse units throughout the year except for May and June when NDVI in bush sparse rises to 110 units. In February, March, July through October, bush dense unit depicted NDVI below 100 units, while agriculture communities depicted this low value in July, being a period for cultivation on the crop calendar. This study considered NDVI below 100 units to be from surfaces with no vegetation, while the low NDVI values in bush dense unit were probably from increased moisture stress on the vegetation cover (Serneels et al., 2001), or from exposed soils from grazing. The rest of the vegetation units yielded NDVI above 100 units portraying them as vegetated areas. A study on vegetation communities in an arid area used NDVI scale of 0-200 and realized a similar result (Weiss et al., 2004). This study considered the response of bush sparse NDVI to 110 units during wet seasons and similar ecological characteristics of arid areas, to recognize this result as acceptable within both scales. Considering bush dense unit as the dominant vegetation in the pastoralists' home area, this study disclosed such low NDVI as the likely basis for pastoral migration to dry season grazing areas when drought commences.

The legend units: barren, bush sparse, bush dense, grassland and woodland reveal a gentle slope of NDVI profile decline from the December peak. The steepest NDVI profile slope is seen in February and this served as an indicator for depleted pasture. Other studies have associated steep decline in NDVI with disturbances such as drought or vicious wind in dry environments (Lu et al., 2001) as studied in this research. Vicious winds are also associated with pests infestation and disease prevalence in dry conditions (ALRMP, 2008). Results of this study show that steep declines and peaks in NDVI profiles are synonymously related with pastoral migration to dry season grazing areas during droughts in Isiolo and retreat back home during wet seasons. This study thus considers this pattern of migration a strategy to alleviate the drought related pests and diseases during droughts (ALRMP, 2008), besides finding pasture for the herds. Wet seasons minimize such threats and attract pastoralists back home.

This study revealed a trend in forest unit showing a steady NDVI decline from January to April when it regains with a steep increase to the peak in May. This biomass decreases steeply to June and with gentle oscillations to August through October when the profile picks a gentle increase to another peak in December. Results of this study suggest that the steep drop between July and August was either from increased evapotranspiration (Allen et al., 1998) causing moisture stress to the foliage or from forest fires (Lu et al., 2001). Despite increased evapotranspiration, in this research, cattle utilize the undergrowths of forests which do not depict their NDVI trend due to foliage cover from trees. Additionally, the high NDVI trend maintained in forest is likely to be from its homogeneity as compared to heterogeneity in other land cover (Fuller, 1998) thus attracting pastoralists.

Results for legend units: Agriculture sparse, agriculture dense and plantation show a low NDVI trend in February through March and July through October. This study claims that the drop in biomass in agriculture units was from dry crop residues that depict low greenness index after crop harvest (ALRMP, 2007; ALRMP, 2008); while the increase in September was from the undergrowths that regenerate after the harvest. These residues serve as fodder for the cattle and are basis for attracting pastoralists to parts of Meru district during the short dry season.

Inter-annual variations and change trajectory in the NDVI series

Annual NDVI mean below 100 NDVI units was realised in the legend units: barren and bush sparse over the decadal period 1998-2008. Bush dense yielded NDVI below 110 in 2001 and 2002 with a standard deviation of 2.12 units from the mean, while the rest of the years show bush dense with annual NDVI above 110 units. This study attributes annual NDVI below 110 units to undesirable NDVI conditions in response to below 500mm expectancy of rainfall in the arid low lands (Anyamba and Tucker, 2005; Omiti and Irungu, 2002) that are unattractive to pastoral demands. In this study, bush dense being home for Isiolo pastoralists, the low NDVI realized in the years 2001 and 2002 was in response to drought of the year 2000 (Abbas, 2008). Results of this study show desirable NDVI conditions in agriculture, plantations, woodland and forests with NDVI value above 110 units and attributes these conditions to rainfall expectancy of above 700mm in the highland areas where such land cover types are found (Omiti and Irungu, 2002). This finding is supported by results of this research which show a standard deviation of 5.55 and 5.16 units in dense agriculture and forest respectively being higher than bush dense unit with 2.37. Reasons attributed to this disparity by this study are: cattle presence which consumes the pastures in bush dense unit being their home area and low rainfall in the pastoralists' area causing undesirable NDVI conditions. Other studies have shown that high standard deviation is associated with favourable NDVI conditions (Anyamba and Tucker, 2005; Tucker et al., 1986) which is similar to desirable NDVI conditions as found by this research.

This study considers the high standard deviation as possible reason why forest and dense agriculture maintain high NDVI during dry seasons unlike bush dense unit which is home to the pastoralists. NDVI alone does not therefore explain why pastoralists move back home at the onset of rains. Findings of this research are however, harmonious with field findings which show pastoralists from Isiolo area migrating from bush dense during dry seasons to agriculture, forest, plantations, and woodland areas to graze their herds. The return of pastoralists to home area in bush dense unit may be attributed to desirable NDVI conditions restored at onset of rains and other factors besides biomass such as competition for resources and security reasons in grazing areas. Other studies have also shown that pastoral mobility is influenced by more than one factor (Omiti and Irungu, 2002) and pastoralists from other communities also graze in such areas during dry seasons intensifying competition for pasturage resources (ALRMP, 2008; Mizutani et al., 2005).

Change trajectory in this research reveals fluxes in NDVI range, with positive changes corresponding to rainfall conditions, while negative changes correspond to drought conditions. Other studies have shown that NDVI fluctuations in 2000 and 2004 correspond to La Nina and drought of the years 1999/2000 and 2004/2005 (Abbas, 2008; Anyamba et al., 2002). This research considers the negative NDVI changes in 2002 and 2003 to have been influenced by other biotic factors not explored by this research. In this study, the annual fluxes affirm the reason why pastoralists from Isiolo migrate seasonally each year, in search of pasture during dry seasons, adopting transhumance in their land use.

Spatiotemporal pattern of pastoral mobility

The spatiotemporal model designed by this research used the assigned temporal rules to set pastoralists in motion after every 15 km based on the date, start and end points to and from the dry season grazing areas. The turning angles determined the direction of the grazing events at the end of which they dispersed in a bird's foot pattern to define grazing sites. The use of this modelling tool was similar to other studies which have used animal movement tool in GIS to demonstrate herd movements (Macopiyo, 2005). The result of this study was in agreement with other studies which have shown that objects move in space and time when both start and end positions are given and temporal rules are established to set the phenomena in motion (Vazirgiannis and Wolfson, 2001). The models revealed that the defined short dry season grazing sites were found in areas with desirable NDVI conditions and not definite areas that projected the highest NDVI as was the case for the long dry season grazing sites. Similarly, NDVI in the wet season grazing area was lower than that of dry season grazing sites where pastoralists returned from. This research realized at the onset of rains biomass condition was desirable for animal feed in home areas, thus pastoralists returned home to allow non pastoralists to commence their classified land use activities (ALRMP, 2007).

The model performance in this study was in accordance with field findings that claimed pastoralists covered approximately 15-20km daily to dry season grazing areas and 10-15km daily back home. A distance of up to 200km was covered in this movement, while responding in correlation with the spatiotemporal pattern depicted by the NDVI fluxes. This finding agrees with studies which revealed a distance of 160km was covered by pastoralists during migrations in Kenya (Macopiyo, 2005). Although movement back to home area was downhill, this study discovered other reasons that affected the difference in pastoralists' speed. These included: animal calving at the end of October, the young calves slowing the movement; poor body health of animals resulting from competition for resources during the dry spell slowing movement; and, at the onset of rains, pastoralists moving in unclear vicinity with rain interruptions, thus slowing their movement. Other studies have also shown that animals calve at the onset of rains, and herds and herders loose body weight during dry seasons due to insufficient feeds. Lose of body weight was related to poor health conditions (ALRMP, 2008), findings which are in agreement with results of this study. Poor vicinity has however not been researched on in this area.

This study used the spatiotemporal models to deduce other factors that influenced the migratory pattern besides pasture availability. Land rights for example, prohibit migrations, any encroachment and grazing of livestock unless by way of written consent by involved parties across cadastral objects (Kenyalaw, 2008). This research realized that pastoralists restricted themselves to migrations into areas where they were able to secure such agreements for seasonal land sharing. In such areas, they reside and graze on farms where they are granted access as they plan their next move. The period of stay on such farms is as long as pasture is available during dry seasons. This result agrees with a different study which realized herds dwelt in an area as long as pasture and water were available (Macopiyo, 2005). In this study, preference for shorter distance grazing areas such as farm lands was a strategy to save herd and herder energy on movement. Other studies also realized short distances help pastoralists to save on energy (Goodhue and McCarthy, 1999). In this research, the short dry season pattern is also headed to the ecotourism area in Losesia for free grazing. Other studies found that 80% of Kenya's ecotourism areas exist among pastoral areas within different agro-ecological zones, promoting free dry season grazing (Abbas, 2008) for pastoralists. The different agro-ecological zones have diversified soil nutrients which support variable pasture. Pastoralists live in environments marked with poor soil nutrients that do not support their much needed pasture during dry spells (Omiti and Irungu, 2002). Soil texture and temperatures influence evapotranspiration (Allen et al., 1998) which in this study, contributes to fluxes in vegetation cover, strongly influencing pastoral mobility.

Results of this research also show that pastoralists migrate away from areas of insecurity, diseases and pests. In their quest for pasture, they move towards friendly communities in the higher areas to safeguard their herds. This finding agrees with other studies which have shown that pastoral migration mitigates animal loses to diseases and pests (ALRMP, 2008; Roeder, 1996) and attacks from cattle rustlers (Omiti and Irungu, 2002). This research also realized that pastoral migration is geared toward water sources where fall back pasture is found. Institutions in Kenya, under Cap 8 of the law, vests all water in the state, to ensure all citizens gain free access to water (Kenyalaw, 2008). Studies have realized water availability and fall back pasture niches during dry seasons influences pastoralists into migration, while upholding their livelihood through access to pasture (Adriansen, 2008; Said, 2003).

Correlating the temporal pattern of NDVI fluxes with pastoral mobility

This research realized a strong correlation between pastoral pattern of migration and the spatiotemporal pattern of NDVI fluxes in the land cover types. Field findings revealed 100% response on departure from Isiolo to key resource areas during dry seasons, a time when there is low biomass in the home area. The return back to home area is during the wet seasons when pastures have regenerated presenting desirable NDVI conditions. This result is in agreement with other studies which realized strong practical correlations between variability in NDVI and grazing patterns of herbivores (Macopiyo, 2005). In this research, spatial correlation was performed in order to identify dry season grazing locations that would be analyzed for their suitability for SLS between pastoralists and non pastoralists. A linear relation could not have been performed as distribution of herds in respective grazing areas was determined by other factors besides abundance of forage. This argument is in agreement with a different study which realized linear correlations were not suitable as pastoralists utilized their landscape in a heterogeneous manner (Macopiyo, 2005).

4.2. Suitable locations for seasonal land sharing

Among the grazing sites, non pastoral land uses included: forestry, farming, mixed farming, ranching, urban and conservation which together formed 63% of the study area, being found in the higher lands. Areas designated for conservation were unsuitable for seasonal land sharing (SLS) since they promoted biodiversity and the tourism sector of the economy. This study categorized the most suitable locations within forestry, farming and ranching land uses as areas with overlapping land use interests since they formed grazing sites besides their classified land use. Results of suitability analysis on these land uses were based on prioritising them for SLS. This does not however imply that grazing should be permitted in every part of the most suitable locations without observing implications for such a strategy on the defined land use. This method of analysis agrees with other studies which performed suitability analysis based on goals of the plan (Knudsen, 2007).

The study found locations within farming and ranching land uses falling in two suitability categories for SLS: the most highly suitable and highly suitable. Farming areas formed short dry season grazing sites with herders utilizing crop residues. Farmers who practiced mixed farming additionally preserved areas for dry season grazing for their livestock (ALRMP, 2008), which in this study, were shared with the pastoralists at a cost. The ranches consisted of plantations whose undergrowths the cattle utilized, together with reserved pasture areas and fall-back grazing within the swamps. This result is different from a study in northwest Nigeria which revealed dependency of sedentary farmers on manure and urea from the large pastoral herds in exchange for pasture, to mitigate soil infertility which their few animals could not provide (Hoffmann et al., 2001). In this study, interviewed farmers within the highly suitable category indicated spatiotemporal interactions with pastoralists despite the migratory route not reaching such locations. Similarly, although ranchers interacted with herders, permanent fences were used on their farms to protect their plantations, and this barred access of herders to such locations. This result agrees with studies which found the use of permanent fences on farms with permanent crop impeding accessibility of herders to such environs (Hoffmann et al., 2001; Lengoiboni et al., Under Review). In this research however, such fences were seen as conflict mitigation measures as they impeded mobile cattle from invading crop on private land in the study area unless by agreement with sedentary users.

Results of this study show forestry in the suitable category due to competition for resource use to protect biodiversity. Studies on wildlife habitats in Kenyan rangelands have shown that the proposal to utilize forests for cattle grazing is aimed at promoting economic development of the livestock sector while jeopardizing biodiversity (Said, 2003). This research however considers this suitability index for forests based on measures the state takes in provision of resources for her citizens (MoL, 2009). In such cases, the state issues permits for seasonal use of the forest undergrowths by cattle, under regular checks by the forest officers during the dry seasons.

Moderately and least suitable areas were found within the 25-30km buffer of water sources and included urban and parts of ranching and farming areas. Respondents asserted the most distance covered each day was 20 km, being an allowable distance to water cattle each day as required when pasture is dry (Macopiyo, 2005). Other studies have shown a distance up to 25km allowed cattle to be watered regularly (Thébaud and Batterbury, 2001). In this study, the moderately suitable and least suitable areas were not prioritized for SLS as they were beyond the 25km distance to water the cattle, while urban areas were unrealistic for SLS as they are mainly built up. Critical moments for pasture demand however may utilize such areas for SLS and have cattle watered within 3 days depending on forage moisture index (Coppock et al., 1988). The study area being so dry, cattle require water regularly thus most highly suitable, highly suitable and suitable areas were prioritized for SLS.

Feasibility for seasonal land sharing

Studies prove that alternatives such as introducing agriculture on pastoral land to provide fodder for their herds during dry seasons was not feasible on a landscape receiving less than 500 mm of rainfall on average (Omiti and Irungu, 2002). This research realized vegetation variability was in response to climatic conditions and impoverished soils which would not supportive crops. Similarly, irrigation measures are not sustainable in the long term due to involved costs (Ribot et al., 2005). This research preferred SLS for dry season grazing as a system to support livestock as an economic endeavour, being contributor of a 40% of agriculture's gross domestic product (GDP) and 10% of the total GDP (Atlas, 2003). The agriculture sector is also promoted through use of fertilizer from the herds during dry season grazing. This finding was supported by the Kenya government asserting the importance of pastoralists in Kenya as holding a 50 to 70% of the national livestock stake (GoK, 2004; Omiti and Irungu, 2002). The government further proposed development of infrastructure to foster interaction between the pastoralists and non pastoralists for economic development (GoK, 2004). Interactions in existence among the land use actors included pastoralists supplying animal products such as milk, dung and beef in exchange for money, grain or forage (Omiti and Irungu, 2002).

4.3. Conceptual models for seasonal land sharing

Conceptual models developed in this research through soft systems methodology (SSM), incorporated unified modelling language, to investigate how real world situations would be integrated in a cadastral system. The models demonstrate the stakeholder behaviour on SLS through seasonal land rights (SLR), on a given spatial unit (space) during dry seasons (time) in a cadastral setup. Other studies have also shown that SSM is capable of modelling human behaviour in cadastral systems (Barry and Fourie, 2002). This study compared the models with the real world to identify feasible changes that land administration would adopt as action to improve the existing SLS limitations through SLR. Other studies also compared conceptual models with real world situations to realize actions to change defined problems (Checkland, 2000; Reeve and Petch, 1999).

This study developed a UML sequence model for a desired cadastral system showing how SLS would benefit all the involved stakeholders through sustainable land use and management, using SLR in space and time. The uniqueness of this model over existing systems is that it captures the temporal aspect of climate variability which is critical for the stakeholders but lacks in LA. This model also allows flexibility in the cadastral system to resume whenever the dry seasons occur since climatic changes are not definite. The existing land renting model only captures fixed dates when a lessee shows interest in land renting (MoL, 2009). In this research, the effectiveness of SLR requires that land information is encoded for authenticity. Land information is documented under established land acts and requires that involved parties adhere to it. The existing land acts require reengineering though the Kenya law forums to accommodate the desired SLR provisions on documentation of land information and security of tenure for stakeholders sharing land use. The Kenya draft land policy also states there is need to reengineer land acts to accommodate needs for marginalized groups and pastoral demands (NLP, 2007). Other studies also realized tenure security was vital in commitment of all stakeholders (Thébaud and Batterbury, 2001) to SLS. A different study on tenure security in Kenya realised that stakeholders were motivated to observing appropriate land use and conservation measures when their tenure was secure (Kabubo-Mariara, 2007).

This research realized SLS has been practised between pastoralists from Isiolo area and few farmers in Meru highlands without documented regulations to govern the system. Establishment of regulations on responsibilities for each party on sustainable land use where SLS is applied is required from LA. This proposal agrees with a study which realized land use and environmental management was achieved through adherence to established regulations as a sign of commitment from all stakeholders to conservation (Atlas, 2003; Kabubo-Mariara, 2007). In this study, regulation of thresholds for spatial extents that are feasible for SLR by LA is necessary for maximum profit of all stakeholders. The purpose for regulations is to ensure income is received by the involved stakeholders, and to alleviate risks faced by pastoralists from drought within inadequate institutional framework (Atlas, 2003), with worst incidents leading to deaths of herders (ALRMP, 2008). Whereas this may be necessary, it is important to observe how the resources will be utilized at different times and scales. Other studies also realised that regulations were necessary for the success of dry season grazing (Thébaud and Batterbury, 2001) as proposed by this study. Successful SLS is practised in northwest Nigeria where pastoralists graze on crop residues to sustain their livelihood, while non pastoralists benefit on enhanced farm yields from cattle dung (Hoffmann et al., 2001; Omiti and Irungu, 2002).

Results of this study realized that Kenyan situation was unique in that the non pastoralists attached a grazing fee besides the dung received from the herds. The current SLS is associated with breach of contracts from mistrust, and this has worsened resource use conflicts. SLR has been proposed to alleviate such sources of conflict through the effort of LA by awareness campaigns regarding provisions in the existing land rights and public participation on conflict mediation. Another study realized most pastoralists and non pastoralists in Isiolo environs were not aware of provisions in land rights (Lengoiboni et al., Under Review). In this study therefore, sensitization of the populous on land rights is deemed important for the success of SLR. Based on occurrence of fewer conflicts when pastoralists were allowed access to resources through SLS, this study suggests that sustainable rules, rights and conflict mediation mechanisms established through public participation are likely to achieve SLR. This is in agreement with other studies which proposed conflict mitigation strategies by encouraging herder movements through involvement of all stakeholders (Fratkin and Mearns, 2003). In Mauritania, conflicts were alleviated through a code that conferred rights of resource use to socio economic groups during dry seasons (Wabnitz, 2006). This research realized if such law is provided in the Kenyan land acts, it will improve the socio economic benefit between non pastoralists and pastoralists and observe timely conflict mitigation mechanisms. In the proposed model, it is observed that non pastoralists willingly permit pastoralists to apply for SLR from LA after being motivated through settlement of the agreed compensation. Motivation for SLS is useful for the satisfaction of all participants (Ostrom, 2005) in enhancing their social values. In this research, it was found that grazing compensation had existed among some farmers in Meru highlands, ranchers in Laikipia and herders from Isiolo and this has encouraged grazing on crop residues, milk, manure and money swap among them (Omiti and Irungu, 2002). In this study, this compensation is similar in all dry season grazing areas, being paid in cash and kind to non pastoralists. It is needful however for LA to sensitize the populace on benefits of SLR through governing bodies such as local elders, in order to promote willingness among stakeholders to participate in SLS.

This research realized that the migratory corridor used by pastoralists was not documented in LA records. Pastoralists in this study found their way from home areas, connected with defined livestock marketing routes, and then used narrow paths within farming communities to reach the grazing areas. Conflicts were reported along the narrow corridors during mobility. A standardized migratory corridor established by LA is important in enhancing interactions between pastoralists and non pastoralists by minimizing conflicts that arise from hungry cattle feeding on farm crops along the narrow paths during mobility. This proposal implies that parts of the private land within which the corridor will be established are acquired by LA under established guidelines for such corridors and acquisition of land regulation in Kenya (Kenyalaw, 2008). Land information regarding the spatial units through which the corridor is established will thus be encoded for administration by the state. Other studies revealed that migratory corridors that are unstandardized (too short or too narrow) lead to invasion of private land by hungry cattle during migrations, intensifying conflicts (Blench, 2004). In this study, official documentation of the migratory corridor will underpin relations between the stakeholders involved in SLS and promote access to key resources. The proposal of SLR is aimed at accommodating pastoral land use in land administration.

4.4. Limitations of the study

The following limitations are attributed to time constraints during field work:

- Lack of cadastral information for land owners who experienced spatiotemporal interactions with pastoralists as input for suitability analysis. This data would have provided information on specific farmlands which will be available for seasonal land rights.
- Lack of biomass information at farmland level in dry season grazing areas limited estimation on calculation of area of land used by pastoralists at dispersion for the entire dry season.

5. Conclusions and Recommendations

5.1. Conclusions

This research has successfully used Remote sensing (SPOT NDVI data) and GIS methods to show how divergent phenology in the land cover types strongly influences pastoral pattern of migration in an area. Soft systems methodology has successfully embedded the remote sensing and GIS results in stakeholder behaviour, through unified modelling language to accommodate pastoral land use in land administration. The research methodology has successfully prioritized areas for seasonal land sharing and demonstrated how pastoralists will share land with non pastoralists during dry seasons through seasonal land rights. Based on results of this study, approaches in natural resource management can be input in land administration studies. Additionally, NDVI data analysis can be applied in similar studies investigating priority areas for seasonal land sharing in other regions with pastoral land use.

This research has realized there are other factors which influence the seasonal migration pattern of pastoralists. These factors include: access to water, land rights, competition for resources, proximity to grazing sites, security, movement away from disease and pests prone areas and the cost of grazing. However, these factors only support the critical demand for sufficient pasture during dry seasons. Among the dry season grazing sites, most suitable locations have been prioritized for seasonal land sharing. Soft systems methodology has embedded the most suitable locations for land sharing into the cadastral system to develop the unified modelling language conceptual models which demonstrate how pastoral land use will be accommodated in land administration through seasonal land rights in space and time. The developed conceptual models introduced the temporal aspect (season), which is lacking in the current land administration in Kenya.

Comparison of the conceptual models with the real world has realized that: public participation in conflict mitigation, documentation of the migratory corridor, sensitization of stakeholders on benefits of seasonal land sharing, establishment of regulations to govern seasonal land sharing and reengineering of land acts will achieve seasonal land rights in Isiolo area, Kenya.

In summary, the research questions are answered as follows:

1. Correlation between the temporal NDVI fluxes in land cover types with the spatiotemporal pattern of pastoralists' migrations

There is a strong correlation between the temporal NDVI fluxes in various land cover types with the spatiotemporal pattern of pastoralists' migration in Isiolo area.

2. Land use locations that are most suitable for seasonal land sharing

Land use locations that are most suitable for seasonal land sharing include specific locations of ranching, farming and forestry areas.

3. Ability of conceptual models to demonstrate seasonal land sharing between pastoralists and non pastoralists through seasonal lands rights in space and time

The developed conceptual models demonstrate conditions for successful seasonal land sharing between pastoralists and non pastoralists through seasonal land rights in space and time.

5.2. Recommendations

The following suggestions are made by this research:

1. Implement the developed model for seasonal land sharing through seasonal land rights in the study area.
2. Explore cadastral information of suitable areas for seasonal land sharing such that their spatial extents can be included in suitability analysis for specific locations where seasonal land rights could be applied.
3. Perform a detailed assessment of available biomass at farmland level to provide information on how much area of land is required by pastoralists for seasonal land sharing for the entire dry period.
4. Investigate which instruments will require strengthening in order to govern the documented corridor from encroachment by stakeholders within its precincts, which would exacerbate the resolved situation.

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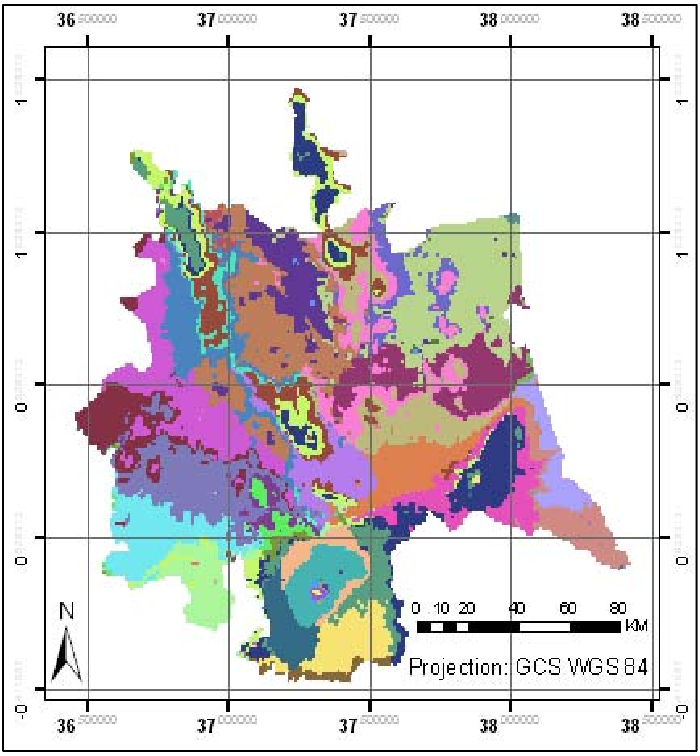
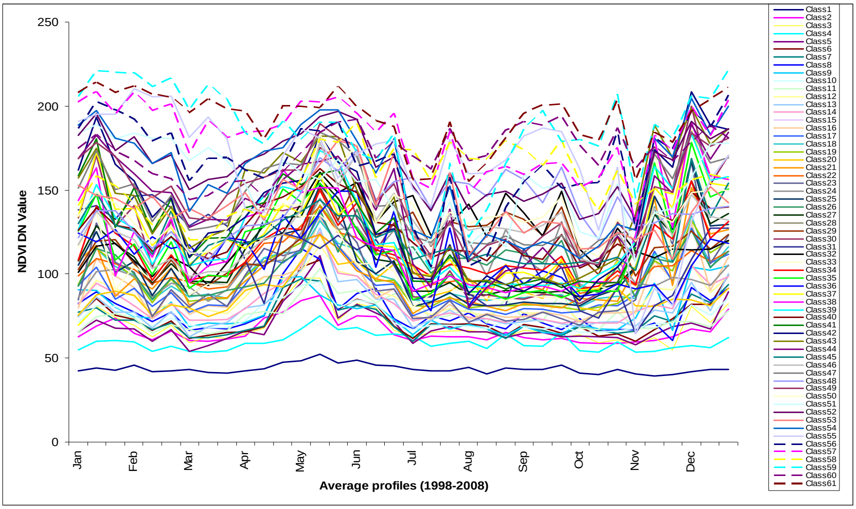
Appendices

Appendix 1

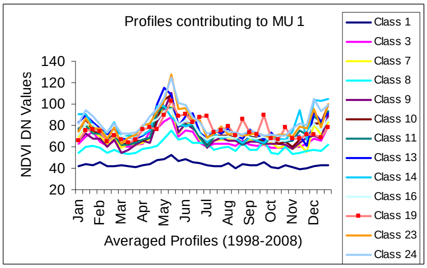




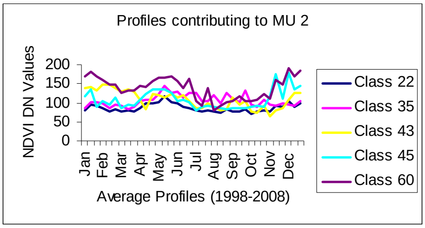
Appendix 1: Spatial location for 61 unsupervised NDVI classes (top) and the NDVI profiles (bottom) as legend

Appendix 2: Merging of NDVI profiles to obtain spatial locations for each mapping unit

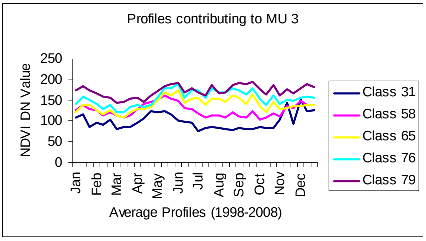
MU 1: Profiles 1, 3, 7, 8, 9, 10, 11, 13, 14, 16, 19, 23, 24



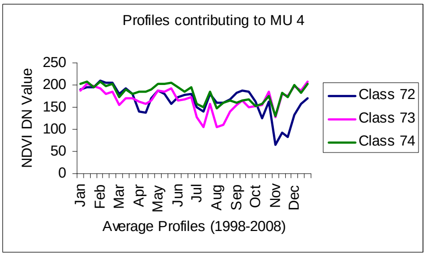
MU 2: Profiles 22, 35, 43, 45, 60



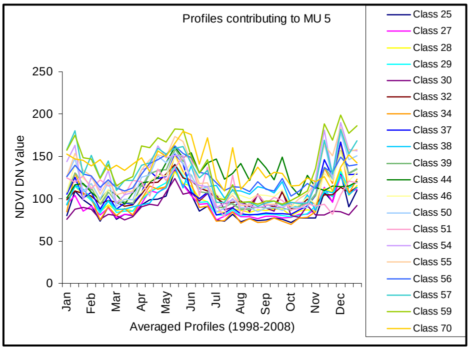
MU 3: Profiles 31, 58, 65, 76, 79



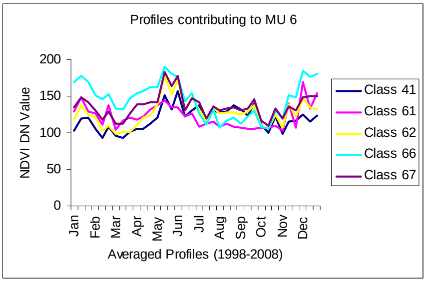
MU 4: Profiles 72, 73, 74



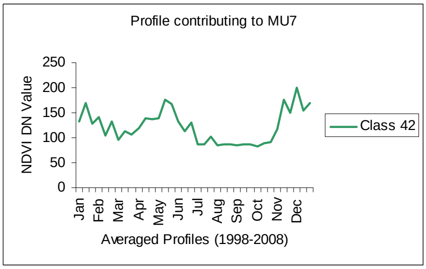
MU 5: profiles 25, 27, 28, 29, 30, 32, 4, 37, 38, 39, 44, 46, 50, 51, 54, 55, 56, 57, 59, 70



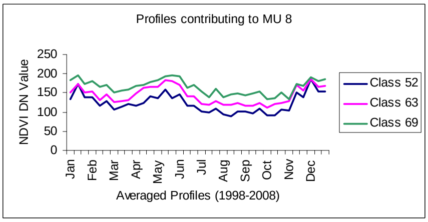
MU 6: Profiles 41, 61, 62, 66, 67



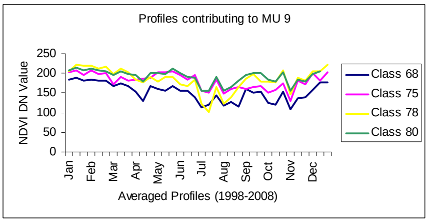
MU 7: Profile 42



MU 8: Profiles 52, 63, 69



MU 9: Profiles 68, 75, 78, 80



Appendix 3: Correlating the land cover map with NDVI units

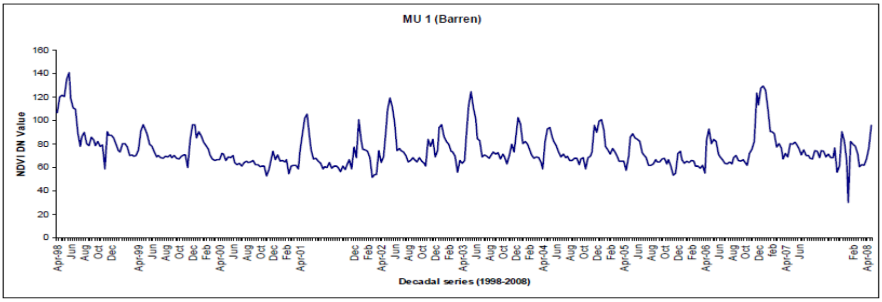
The percentage coverage of the classes in the land cover and NDVI map has been summarized as below.

Comparing the land cover map classes and the NDVI mapping units

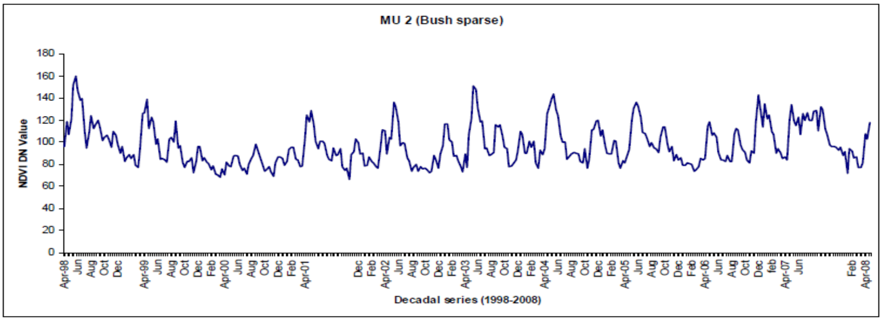
% age cover of classes in the existing land cover map and the NDVI map			
Land cover class	(%) coverage	NDVI unit	(%) coverage
Barren	6.4	1	7.0
Bush sparse	7.2	2	5.0
Agriculture sparse	6.5	3	7.0
Agriculture dense	4.2	4	5.0
Bush dense	42.0	5	45.0
Plantation	18.2	6	12.0
Grassland	0.3	7	3.0
Woodland	4.5	8	7.0
Forest	10.8	9	9.0

Appendix 4: Temporal trajectory trend in each Mapping unit

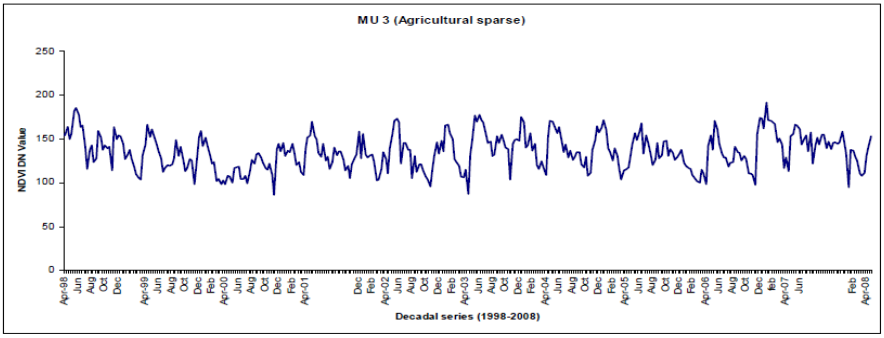
i.) MU 1 (Barren)



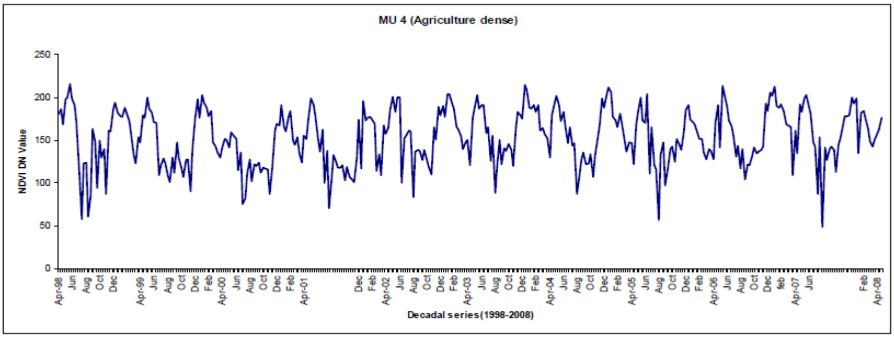
ii.) MU 2 (Bush sparse)



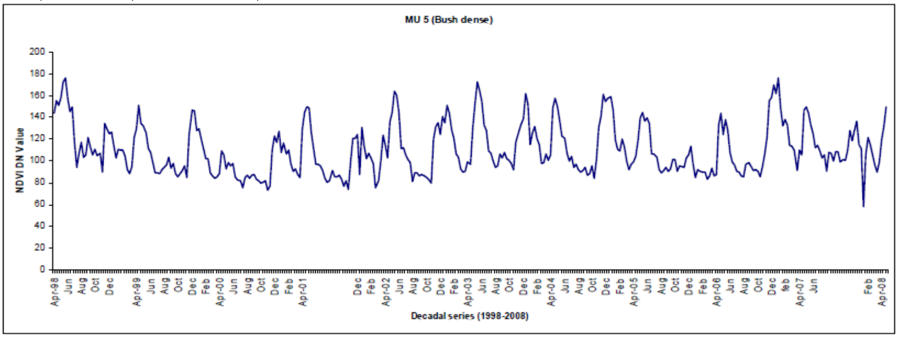
iii.) MU 3 (Agricultural sparse)



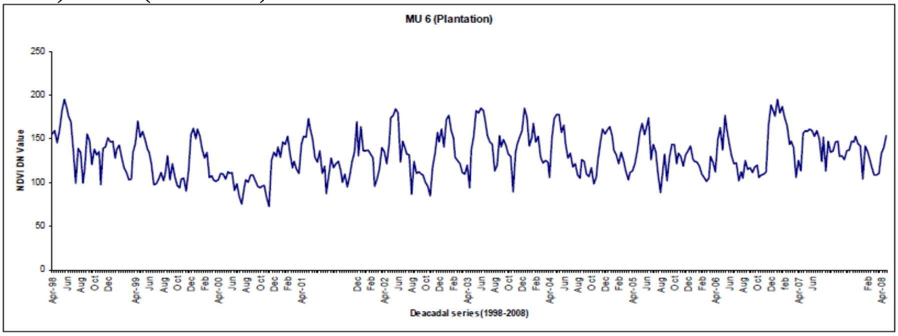
iv.) MU 4 (Agricultural dense)



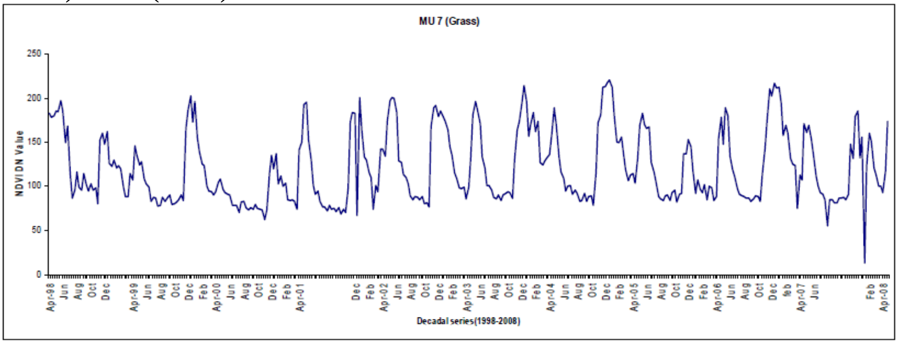
v.) MU 5 (Bush dense)



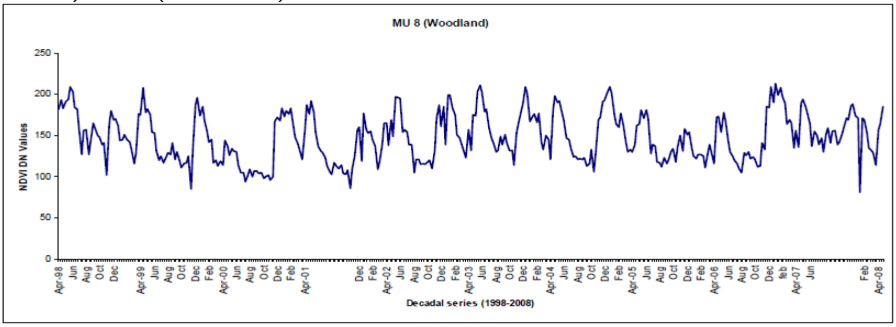
vi.) MU 6 (Plantation)



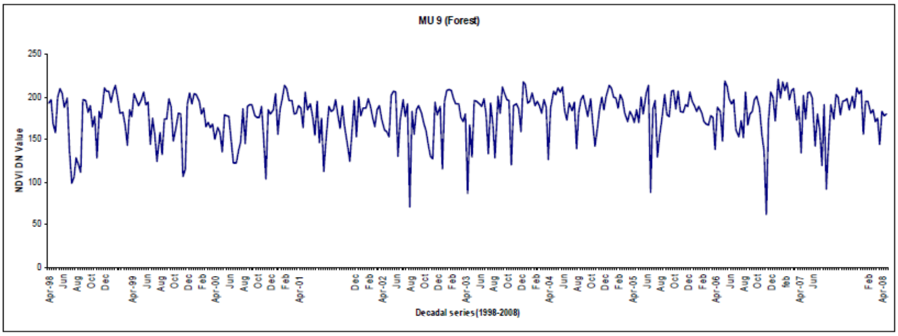
vii.) MU 7 (Grass)



viii.) MU 8 (Woodland)

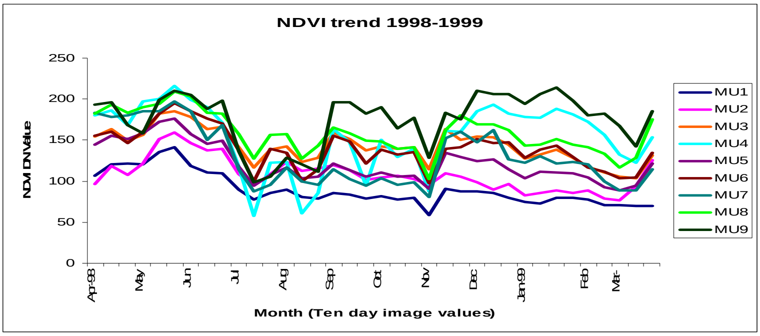


ix.) MU 9 (Forest)

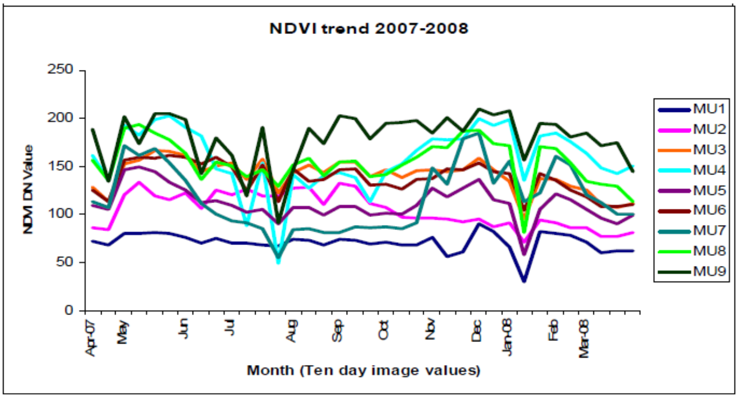


Appendix 5: NDVI time series for each of the 9 MU in 1998-1999 and 2007-2008

i.)

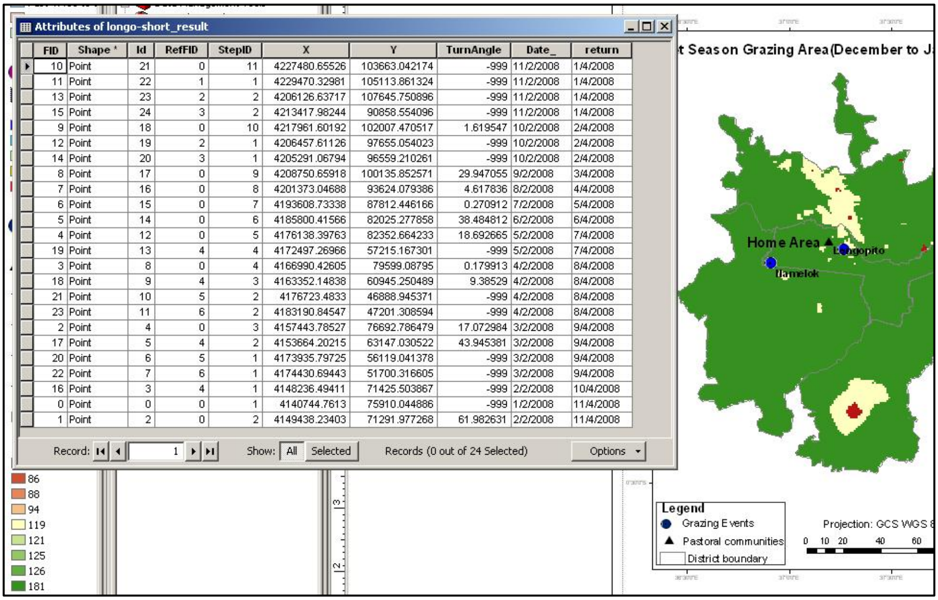


ii.)



Appendix 6: Spatiotemporal data for pastoral movements

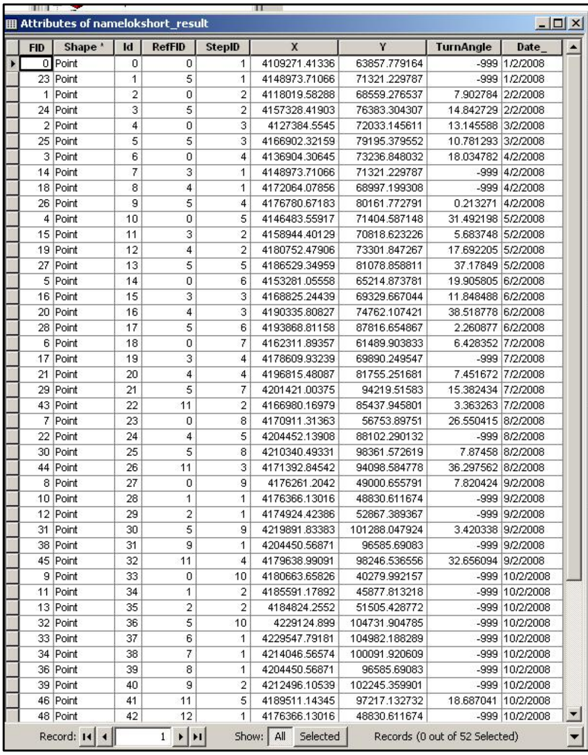
i) Spatiotemporal movements to wet season grazing areas (Back home)


Attributes of longo-short_result

FID	Shape *	Id	RefFID	StepID	X	Y	TurnAngle	Date_	return
10	Point	21	0	11	4227480.65526	103663.042174	-999	11/2/2008	1/4/2008
11	Point	22	1	1	4229470.32981	105113.861324	-999	11/2/2008	1/4/2008
13	Point	23	2	2	4206126.63717	107645.750896	-999	11/2/2008	1/4/2008
15	Point	24	3	2	4213417.98244	90858.554096	-999	11/2/2008	1/4/2008
9	Point	18	0	10	4217961.60192	102007.470517	1.619547	10/2/2008	2/4/2008
12	Point	19	2	1	4206457.61126	97655.054023	-999	10/2/2008	2/4/2008
14	Point	20	3	1	4205291.06794	96559.210261	-999	10/2/2008	2/4/2008
8	Point	17	0	9	4208750.65918	100135.852571	29.947055	9/2/2008	3/4/2008
7	Point	16	0	8	4201373.04688	93624.079386	4.617836	8/2/2008	4/4/2008
6	Point	15	0	7	4193608.73338	87812.446166	0.270912	7/2/2008	5/4/2008
5	Point	14	0	6	4185800.41566	82025.277858	38.484812	6/2/2008	6/4/2008
4	Point	12	0	5	4176138.39763	82352.664233	18.692665	5/2/2008	7/4/2008
19	Point	13	4	4	4172497.26966	57215.167301	-999	5/2/2008	7/4/2008
3	Point	8	0	4	4166990.42605	79599.08795	0.179913	4/2/2008	8/4/2008
18	Point	9	4	3	4163352.14838	60945.250489	9.38529	4/2/2008	8/4/2008
21	Point	10	5	2	4176723.4833	46888.945371	-999	4/2/2008	8/4/2008
23	Point	11	6	2	4183190.84547	47201.308594	-999	4/2/2008	8/4/2008
2	Point	4	0	3	4157443.78527	76692.786479	17.072984	3/2/2008	9/4/2008
17	Point	5	4	2	4153664.20215	63147.030522	43.945381	3/2/2008	9/4/2008
20	Point	6	5	1	4173935.79725	56119.041378	-999	3/2/2008	9/4/2008
22	Point	7	6	1	4174430.69443	51700.316605	-999	3/2/2008	9/4/2008
16	Point	3	4	1	4148236.49411	71425.503867	-999	2/2/2008	10/4/2008
0	Point	0	0	1	4140744.7613	75910.044886	-999	1/2/2008	11/4/2008
1	Point	2	0	2	4149438.23403	71291.977268	61.982631	2/2/2008	11/4/2008

Record: 1 Show: All Selected Records (0 out of 24 Selected) Options

ii) Spatiotemporal movements to short dry season grazing areas


Attributes of namelokshort_result

FID	Shape *	Id	RefFID	StepID	X	Y	TurnAngle	Date_
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23	Point	1	5	1	4148973.71066	71321.229787	-999	1/2/2008
1	Point	2	0	2	4118019.58288	68559.276537	7.902784	2/2/2008
24	Point	3	5	2	4157328.41903	76383.304307	14.842729	2/2/2008
2	Point	4	0	3	4127384.5545	72033.145611	13.145588	3/2/2008
25	Point	5	5	3	4166902.32159	79195.379552	10.781293	3/2/2008
3	Point	6	0	4	4136904.30645	73236.848032	18.034782	4/2/2008
14	Point	7	3	1	4148973.71066	71321.229787	-999	4/2/2008
18	Point	8	4	1	4172064.07856	68997.199308	-999	4/2/2008
26	Point	9	5	4	4176780.67183	80161.772791	0.213271	4/2/2008
4	Point	10	0	5	4146483.55917	71404.587148	31.492198	5/2/2008
15	Point	11	3	2	4158944.40129	70818.623226	5.683748	5/2/2008
19	Point	12	4	2	4180752.47906	73301.847267	17.692205	5/2/2008
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5	Point	14	0	6	4153281.05558	65214.873781	19.905805	6/2/2008
16	Point	15	3	3	4168825.24439	69329.667044	11.848488	6/2/2008
20	Point	16	4	3	4190335.80827	74762.107421	38.518778	6/2/2008
28	Point	17	5	6	4193868.81158	87816.654867	2.260877	6/2/2008
6	Point	18	0	7	4162311.89357	61489.903833	6.428352	7/2/2008
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21	Point	20	4	4	4196815.48087	81755.251681	7.451672	7/2/2008
29	Point	21	5	7	4201421.00375	94219.51583	15.382434	7/2/2008
43	Point	22	11	2	4166980.16979	85437.945801	3.363263	7/2/2008
7	Point	23	0	8	4170911.31363	56753.89751	26.550415	8/2/2008
22	Point	24	4	5	4204452.13908	88102.290132	-999	8/2/2008
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8	Point	27	0	9	4176261.2042	49000.655791	7.820424	9/2/2008
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38	Point	31	9	1	4204450.56871	96585.69083	-999	9/2/2008
45	Point	32	11	4	4179638.99091	98246.536556	32.656094	9/2/2008
9	Point	33	0	10	4180663.65826	40279.992157	-999	10/2/2008
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32	Point	36	5	10	4229124.899	104731.904785	-999	10/2/2008
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46	Point	41	11	5	4189511.14345	97217.132732	18.687041	10/2/2008
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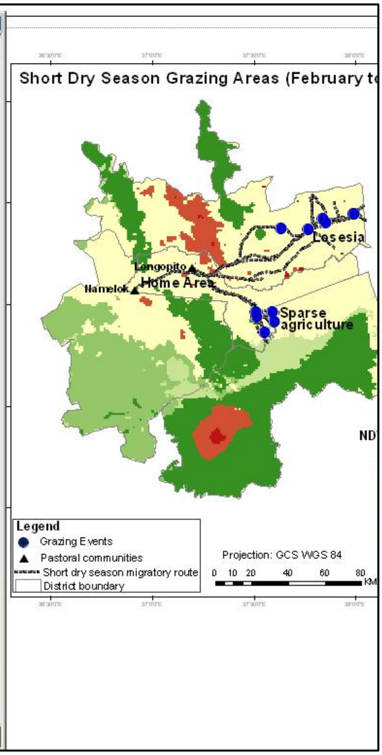

iii) Spatiotemporal movements to long dry season grazing areas

Attributes of nameloklong

FID	Shape *	Id	RefFID	StepID	X	Y	TurnAngle	Date
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44	Point	0	24	2	4125067.02729	36454.23668	-999	1/8/2008
12	Point	0	6	1	4109181.40794	64141.532089	-999	2/7/2008
27	Point	0	13	2	4138442.39924	96844.653684	-999	2/8/2008
33	Point	0	17	1	4108490.59806	63830.123915	-999	3/7/2008
45	Point	0	25	1	4124553.28403	32278.436419	-999	3/8/2008
39	Point	0	22	1	4109458.27946	63487.74266	-999	4/7/2008
19	Point	0	9	2	4115396.56362	115745.18234	-999	4/8/2008
0	Point	0	0	1	4103784.86871	69366.455798	-999	5/7/2008
1	Point	0	0	2	4105447.98109	79043.964134	-999	5/7/2008
51	Point	0	28	1	4128039.58489	-2867.247719	-999	5/8/2008
18	Point	0	9	1	4122996.82381	109531.584427	-999	6/8/2008
9	Point	0	4	2	4102936.67254	56082.293059	-999	7/7/2008
52	Point	0	28	2	4128126.25113	-12866.87216	-999	7/8/2008
6	Point	0	3	1	4096399.80012	72764.851969	-999	7/13/2008
10	Point	0	5	1	4099949.76295	41831.385601	-999	7/14/2008
32	Point	0	16	2	4125799.1148	75905.763896	-999	7/15/2008
34	Point	0	18	1	4095429.44438	77116.228353	-999	7/16/2008
36	Point	0	20	1	4103046.71507	80346.311229	-999	7/17/2008
41	Point	0	23	1	4119345.21411	58424.411795	-999	7/18/2008
3	Point	0	1	1	4102048.91858	89706.750634	-999	7/19/2008
5	Point	0	2	1	4095665.17885	94278.960847	-999	7/20/2008
7	Point	0	3	2	4087616.92295	74246.126202	-999	7/21/2008
11	Point	0	5	2	4090782.19197	38830.023932	-999	7/22/2008
29	Point	0	15	1	4125914.3038	75959.518766	-999	7/23/2008
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38	Point	0	21	2	4102991.95145	46316.459765	-999	7/28/2008
43	Point	0	24	1	4124210.48023	45843.346759	-999	7/29/2008
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48	Point	0	26	2	4121850.82636	11485.102517	-999	8/21/2008
21	Point	0	10	2	4124064.38923	108370.010725	-999	8/23/2008
49	Point	0	27	1	4122458.50949	9607.689001	-999	8/24/2008
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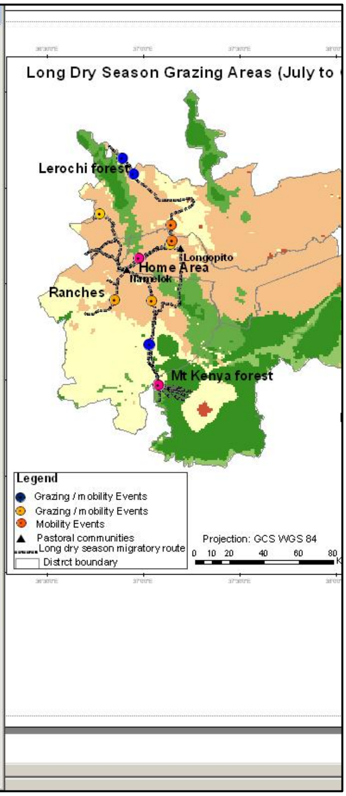
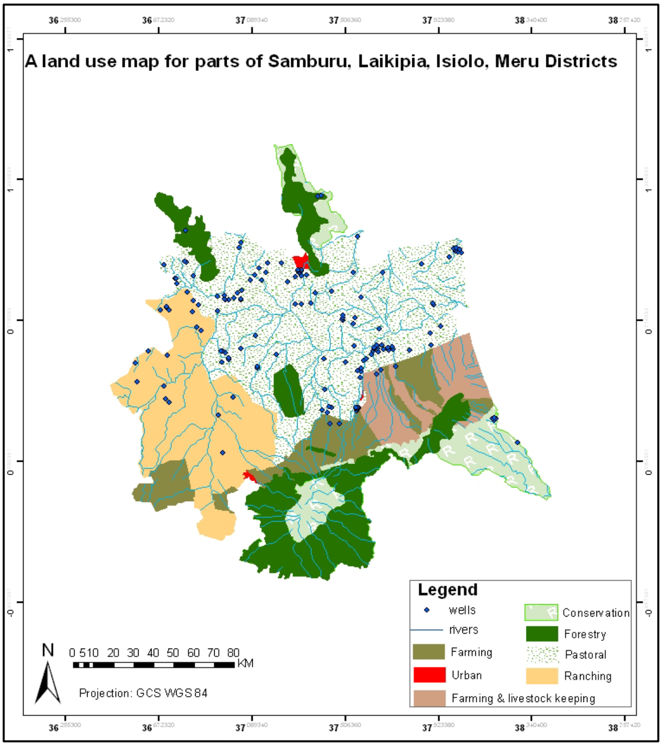


Appendix7: Land use map for parts of Samburu, Isiolo, Laikipia and Meru Districts

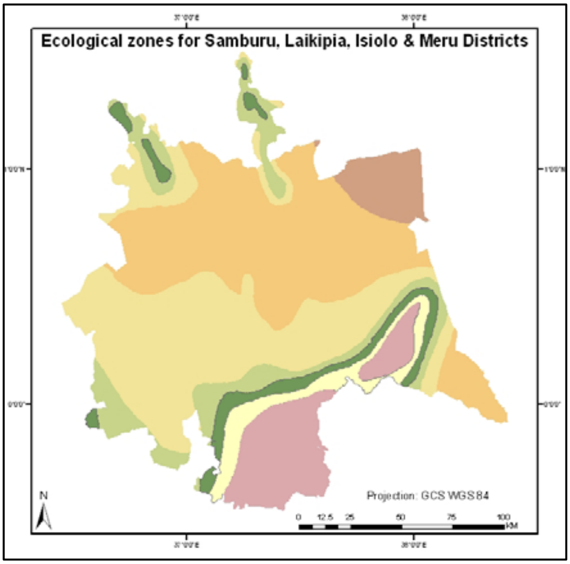


Appendix 8: Ministry of Lands' guidelines for land renting in Kenya

Step Description	Result
1.1 Identify the land	Spatial location of the land
1.2 Contact the owner	Willingness to rent land
1.3 Institute regulations	Assign land to be used
2.1 Compensation by a lessee to a lesser	Consent from owner
2.2 Seek consent from DLB	Consent granted or rejected
3.1 Field survey in case portion of land otherwise go to step 3.3	Data on spatial extent of land to be rented
3.2 Plot field data on mutation form	Authority for land registrar's action
3.3 Submit consent for land renting	Registrar encodes lease and advises on transaction cost
3.4 Pay for registry transaction	Registrar enters a caution in title
4.1 Issuance of licence for fixed period to applicant	Commence land use

Compiled from MoL online database: http://www.ardhi.go.ke/ on 02/01/2009

Appendix 9: Ecological zones for parts of Samburu, Isiolo, Laikipia and Meru Districts: Source: GIS/ESRI 2008



Appendix 10: Questionnaire used to interview the pastoralists

<u>1. Inquiring about the dry season grazing area:</u>

1. Please show me on this map where you started your journey ………………
2. Is this a range land, game park, forest, crop land or a ranch? ……………….
3. What was the condition of the land use when you arrived to your dry season grazing area (the place where you have come from)? Please select one:
   [Plenty of pasture] [Crop residues] [Scanty vegetation] [Bare soil]
4. What was the condition of the land use when you left the place? Please select one:
   [Plenty of pasture] [Crop residues] [Scanty vegetation] [Bare soil]
5. How many days did you live in this dry season grazing area? …..…………
6. Do you have any reason for choosing this grazing area? ……………………..…
7. Please show me on the map where you went to during the first dry season.
8. What was the condition of the land cover when you arrived to this first dry season grazing area? ....
9. Which month do you leave for this area? ....
10. Which month do you leave the area? ....
11. How many days does it take you to arrive to this area? ....
12. Are there any places you take longer than others along this migratory route? Please show me on the map.

13. Do you have any reason for choosing this grazing area? ....
14. Where did you get water for your livestock? Please select one:
    [Bore hole] [River]

2. Inquiring about cattle density:

15. How many pastoralists were in the dry grazing area you have just come from? …………………………………………………………………......
16. How many cattle did each of you have on this land?
    ………………………………………………………………….
17. How many cattle were allowed on the land?
    ………………………………………………………………….
18. About how many cattle does this community own and do you take all cattle with you? ………………………………..…………………………….

3. Inquiring about the distance, speed and pattern of movement:

19. Which day did you leave the place? ………………………………………….
20. Which day did you arrive here? ……………………………………………
21. How many days have you taken to walk back from the dry season grazing area? ………………………………………………………………………….
22. How many days did you take to reach the dry season grazing area when you left here? [this is asked to determine the consistency in the time aspect asked a above] ……………………………...……………………………..
18. About how many kilometres do you walk each day along this migratory route? ……………………………………..…………………………………
19. a) Are there areas you spend more days than others?
    [Yes] [No]

    Please show me on the map the areas you spend more days.

    Give reason for either of the answers in 19 (a)

    ………………………………………………………………………………
20. Do you maintain a similar trend each year? Please select one:
    [Yes] [No]

4. Inquiring about the cost of grazing:

21. How much are you charged for grazing each animal in:
    a. Forests…………………………………………………………..
    b. Game park……………………………………………………
    c. Cropping land…………………………………………………..
22. Who determines the cost? …………..…………………………………
23. How do you make this payment? ....……………………………………