A DRY SEASON GRAZING RESERVES SITE SELECTION MODEL FOR DROUGHT MANAGEMENT IN THE PASTORAL PRODUCTION SYSTEMS

A case study on the Maasai pastoral communities living in the “Kendong rectangle” – an arid and semi-arid land (ASAL), south of L. Naivasha in Kenya

Richard Kyuma
March 2008

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A case study on the Maasai pastoral communities living in the "Kendong rectangle" – an arid and semi-arid land (ASAL), south of L. Naivasha in Kenya

By
Richard Kavila Kyuma

Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation, Specialisation: Sustainable agriculture

<u>Thesis Assessment Board</u>

Chairman	**Prof. Dr. Ir. Eric Smaling, NRS Department, ITC**
External Examiner	**Dr. H. van Keulen, Wageningen University**
Internal Examiner	**Dr. Robert Becht, WRS, Department, ITC**
First Supervisor	**MSc. Valentijn Venus, NRS Department, ITC**
Second supervisor	**Dr. A.G. Toxopeus, NRS Department, ITC**

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Abstract

One of the strategies of pastoral drought management is the adjustment of the livestock population in relation to the available forage resources. This strategy often involves movement of livestock herds to the drought refuge areas. These are areas which, even under the poorest environmental conditions i.e. at the absolute peak of the dry season, still have water and forage. They are oases of NPP surplus which even under very severe drought conditions help sustain livestock. The siting of appropriate areas for use as drought refuge areas, henceforth in this study called the dry season grazing reserves (DSGRs) has been a challenge.

GIS and Remote sensing techniques are used to develop a method for integrating spatial and temporal data for drought management in the pastoral systems. The method is a dynamic, easy to use and flexible model which provides a logical process of identifying the DSGRs and enhancing reliability of the locations of the DSGRs sites by determining the confidence interval of the repetition time within which the DSGRs can reliably be sited.

The spatial and temporal modelling system developed is a user friendly tool for decision makers for e.g., managers, planners and others involved in the sustainable drought management of the ASALs of Kenya. The “Kendong rectangle”, a drought prone area south of L. Naivasha, is used as the case study area. This area is inhabited mainly by the Maasai pastoralists, who make use of livestock movements to take the stock to favourable areas for grazing as forage declines in one area, as a drought coping mechanism.

The dry season grazing reserves model combines both spatial and temporal vegetation data with livestock density distribution in such a way that it is able to integrate the man made drivers of drought impacts (mainly the infrastructural development) through simulation.

Sustainable forage availability, accessibility to watering points, proximity to settled areas and road networks; and accessibility of the land cover and terrain to livestock utilization are discussed as the main drivers of dry season grazing reserves site selection processes.

The result of the DSGR model indicates clearly where and to what extend within the study area, there is forage shortage and forage surplus (hazard analysis) during the dry season. To enhance reliability of the DSGRs and forage surplus, a confidence interval on the repetition time of the forage surplus (risk assessment) is incorporated in the model. The overall result is a spatial presentation (with qualitative and quantitative data) of the locations of the DSGRs sites and the forage surplus. These DSGRs provide the user with reliable and informed choices when making decisions on the drought management interventions.

Keywords: DSGR sites; Forage surplus; Livestock demand; Drought management; Pastoralists; Modelling; MODIS NPP; ASAL; TLUs; Confidence interval; hazard analysis and risk assessment.

Acknowledgements

I am indebted to many institutions and individuals whose contributions were invaluable during my MSc research work.

First, my profound gratitude goes to my first supervisor, MSc. Valentijn Venus for his guidance, critical analysis and very useful comments he gave me during all the stages of this piece of work. Through his support I have learnt a lot of interesting issues applicable in day to day activities of my work. I also acknowledge the logical comments by my secondary supervisor Dr. A.G. (Bert) Toxopeus which helped to shape this thesis.

I would also like extend my sincere appreciation to Prof. Dr. Ir. Eric Smaling, Dr. C.A.J.M de Bie, Ms. Dr. I.C. (Iris) van Duren, Dr. R. (Robert) Becht and Dr. Jan de Leeuw for their comments and advise.

I express my gratitude to the Government of Kenya, through The ASAL Based Livestock and Rural Livelihoods Support Project, under the Ministry of Livestock and Fisheries Development; for sponsoring me for my Msc. Studies. Worthy mentioning is the project coordinator, Mr. James Tendwa, who has ensured my studies go on with minimal interruption. Special thanks also go to Joseph Matere of ILRI (AAR-NET – Community based Livestock early warning systems), a collaborator in the ASAL livestock project for his technical and logistical support throughout my study.

Likewise, I would like to thank the Director of the Department of Livestock production and the Chief of Range Management; Ministry of Livestock and Fisheries Development – Kenya, for releasing me to pursue my studies.

I would like to extend my great thanks to the employees of Oserian flower company in Naivasha, Kenya; especially Sean Finlayson, Herbert Masinde, Stephen Musyoka, for their support during my field work.

I would like also to thank all my student colleagues at NRM in ITC for their team work spirit and friendly interactions, which made my stay in ITC in Enschede bearable.

Last but not the least; the deepest gratefulness is due to my wife, my three sons and my parents; sisters and brothers for their support, inspiration and encouragement during my studies.

Again, thanks all of you and God bless.

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Acronyms

ACT	Almanac Characterization Tool
ALRMP	Arid Lands Resource Management Project
ANPP and BNPP	Above and Below ground Net Primary Production
AIRS	Atmospheric Infrared Sounder
AMRS- E	Advanced Microwave Scanning Radiometer - Earth Observing System
ASAL	Arid and Semi-arid Lands
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resolution Radiometer
C.I.	Confidence Interval
CO2	Carbon Dioxide
DM	Dry Matter
DMO	Drought Management Officer
DSGR	Dry Season Grazing Reserve
DRFS	Demanded repetition time of Forage Surplus
DRSRS	Department of Resource survey and Remote sensing
ECS	EOSDIS Core System
EOSDIS	Earth Observing System (EOS) Data and Information System
EOS	Earth Observation System
ETM	Enhanced Thematic Mapper
EWS	Early Warning Systems
FAO	Food and Agriculture Organization
FPAR	Fraction of Photosynthetically Active Radiation
GoK	Government of Kenya
GPP	Gross Primary Productivity
GPP_1KM	Gpp_1km: Gross Primary Production
GIS	Geographical Information Systems
HEG	HDF-EOS to GeoTIFF conversion tool
HDF-EOS	Hierarchical Data Format - Earth Observing System
IUCN	International Union for the Conservation of Nature and Natural Resources.
IS	Integerized Sinuoidal
ILRI	International Livestock Research Institute
JICA	Japan International Co-operation Agency
LAI	Leaf Area Index
LP DAAC	Land Processes Distributed Active Archive Center
MISR	Multiangle Imaging SpectroRadiometer
MoLF&D	Ministry of Livestock and Fisheries Development
MOD17A2	MODIS/Terra Net Photosynthesis 8-Day L4 Global 1km ISIN Grid
MOD17A3	MODIS/Terra Net Primary Production Yearly L4 Global1km SIN Grid
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NDMC	National Drought Monitoring Centre
NDVI	Normalised Difference Vegetation Index
NEMA	National Environmental Management Authority
NPP	Net Primary Productivity
NPP_1KM	MODIS Gridded 1KM Net Primary Productivity (NPP)
NPP QC_1KM	MODIS Gridded 1KM Net Primary Productivity (NPP) Quality Control
ORFS	Observed repetition time of Forage Surplus
P hat	Population Proportion

PSN	Photosynthesis
PSNnet_1KM	PsnNet_1km: Net Photosynthesis (GPP – maintenance respiration)
PSN QC_1KM	PsnNet_1km: Net Photosynthesis Quality Control
SDP	Smallholder Dairy Project
S.E.	Sample Error
SHOAT	Sheep and Goats
SMCE	Spatial multi-criteria evaluation
t	t-statistic
TLU	Tropical Livestock Unit
TM	Thematic Mapper
UTM	Universal Transverse Mercator
UNEP	United Nations Environmental Programme
UNU	United Nations University
VPD	Vapour Pressure deficit
VTCI	Vegetation Temperature Condition Index
WB	World Bank
WCMC	World Conservation Monitoring Center
WFP	World Food Programme
WGS84	World Geodetic System 1984

Terms and Definitions used in this study

i. **Net primary production (NPP)**

NPP refers to the net carbon uptake by the ecosystem, and is a fundamental property describing ecosystem performance (Reeves, 2002; Running, 1986). It is defined as the difference between total carbon uptake through photosynthesis and losses (through maintenance or growth respiration). NPP is a sum of two components, above (ANPP) and below (BNPP) ground net primary production. Because of its direct relationship to atmospheric CO2 it plays a strong role in the seasonal integration of biomass production and drought monitoring (Reeves, 2002).

ii. **Tropical livestock units**

Tropical livestock units (TLUs) are an expression of biomass. One TLU =25kg = 1 mature zebu cow = 10 sheep = 12 goats (Herlocker, 1999).

iii. **Dry season grazing reserves**

Dry season grazing reserves are those which, even under the poorest environmental conditions i.e. at the absolute peak of the dry season, still have water and forage, and are thus irreplaceable as reserves during the cyclical periods of scarcity. Dry season grazing reserves are utilized intensively over long periods, receiving disproportionate grazing pressure during times that allow no other option (Schwartz, 1994).

iv. **Candidate DSGRs sites**

DSGR are oases of NPP surplus which even under very severe drought conditions help sustain livestock. The seasonal demand (Long dry season and Short dry season) is deducted from the seasonal "sustainable forage availability" map to get the forage shortage and surplus map. This follows the principle of supply versus demand. The grid cells with values of less than zero (0) are the overgrazed areas (forage shortage); and those with values greater than 0 are the under-utilized areas (with surplus forage). These are the potential locations for the DSGRs sites, herein called the "candidate DSGRs" sites.

v. **Final DSGRs sites**

The Confidence interval and risk assessment gives an indication of the repetition time of the forage surplus in the DSGRs sites. With a 95% confidence interval and in an agreeable number of dry seasons out of the total number of dry seasons, the DSGRs should have a high repetition time of forage surplus in the same locations and approximately the same quantities. This gives assurance to the user that those constellations of DSGR sites will cover dry season forage shortage (demand), thereby minimizing expenditure on drought related interventions.

1. Introduction

This study aims at contributing to poverty reduction among pastoral and agro pastoral livestock keepers by developing a model for drought management in the arid and semi-arid lands of Kenya. GIS indexed map overlay techniques and remote sensing data from polar orbiting satellite (MODIS) are used for modelling drought impacts in the arid and semi arid lands (ASAL), otherwise known as the rangelands. It will form part of the basis for formulating interventions which mitigate against the vulnerability of pastoral communities using computer simulations.

Computer simulations are powerful tools for site selection analysis and saves a lot of time (Toxopeus, 1996). The computer simulations provide us with the opportunity to explore other options without necessarily doing the actual implementation in the field hence avoiding or minimising the rate of intervention failures.

A large part of our study area is located on the floor of Great Rift Valley of Kenya. This area, which is classified as arid and semi arid lands (ASAL) can naturally support livestock production as the production system which can be sustained with minimal capital inputs. Conversions of large areas in this part of Kenya to capital intensive and high revenue earning land use practices have left the local people (Maasai) more vulnerable to the vagaries of weather, mainly the droughts, which have increased in frequency and intensity.

One of the ways the pastoral communities have employed over time in coping with drought is the concept of mobility. This is an inherent strategy of pastoralists to optimise production of a heterogeneous landscape under a precarious climate. The search for water (for human and livestock consumption) and forage, trigger mobility. These strategies are most intensive during the drought periods (Ndikumana, 2000).

1.1. General Background

Only several decades back, pastoralists were the primary users of the arid and semi-arid lands (ASAL) of the rangelands of Kenya. Strategies such as mobility, matching livestock species to the environment and herd splitting ensured their survival as well as the dynamic equilibrium of the ecosystem such that environmental degradation was insignificant (Herlocker, 1999). However, human and livestock populations have tremendously increased over the years. Pastoralists have lost their most valuable grazing resources to other uses and tenure systems such as agriculture, game reserves and private ranches. This has greatly constrained pastoral mobility and eroded the rangelands' ability to support the increasing sedentary pastoral population. The overall trend in these rangelands is depicted by decreasing productivity, increasing degradation and diminishing ability to cope with ecological stress (Herlocker, 1999).

1.1.1. Impacts of drought on water and forage resources

The Government of Kenya spent more than Ksh 10.5 billion on emergency relief food during the 2000/2001 financial years. The 1999-2001 La Nino drought cost the country at least Ksh

220 billion as compared to the 1997 El Nino floods that cost approximately Ksh 70 billion (UNEP, 2002).

In drought years, forage and water become limiting to livestock, hence their populations decline either through the effects of reduced reproduction, starvation-induced mortality or migrations. The drastic change in vegetation cover due to severe lack of available moisture results in massive loss of large herbivores (UNEP, 2002).
Key inputs into livestock production in the ASALs are water (for both livestock and human consumption) and forage, both of which are highly susceptible to the vagaries of the climate. Tracking of the forage resources and water sources are therefore important facets of the pastoral strategy, affecting the capacity of the pastoralists to produce in the ASALs (Ndikumana, 2000).

Tracking of water of consumable quality for livestock is one of the major occupations for pastoralists, and one of the key determinants of pastoral movement and migration. Various types of livestock water sources are found in the ASALs: boreholes (established by use of drilling equipment), hand dug wells, dug stream beds (excavated dry or sluggish stream beds), ponds, concrete tanks in the ground, concrete tanks above ground, and reservoirs/dams (Ndikumana, 2000). Water sources reflect the climate and thus the number and proximity of the water sources will change with climate. Extended dry periods result in the drying up of water sources resulting in a dwindling water supply, unfit for livestock and human consumption (Ndikumana, 2000).

Pastoralists utilise highly heterogeneous landscapes, in terms of forage type and species, forage quality, forage availability (quantity) and terrain. Lateral movement is a key strategy among others utilised by pastoralists to optimise production from the heterogeneous landscape. It is common practice among pastoralists, to designate forage sources as primary grazing sites (i.e. those routinely used during favourable periods and usually located close to the household) or as emergency grazing sites (i.e. those specifically reserved for use during stress periods).

During the drought, some pastoralists divide herds into core and satellite groups. The core herd includes the breeding stock (pregnant and lactating), and young, old and vulnerable animals. The satellite herd includes the hardy males and nonlactating females, and the larger and hardier livestock species such as cattle and camels. The satellite herds are usually trekked to the emergency grazing sites located further from the households than the primary sites (Ndikumana, 2000).

Table 1-1: Mean distances (km) travelled to primary and emergency grazing sites for the zones surveyed across the climatic phases (Ndikumana 2000).

Zone	Pastoral Category[1]	Pre-drought	Drought	Minor rains	El Nino rains	La Nina dry
N.Kenya	PP	9	22 (46)[2]	6	3 (4)	6
S. Kenya	AP	4	7 (9)	3	2 (2)	4
S. Kenya	PP	4	6 (20)	3	2 (4)	2
N. Tanzania	AP	7	33 (18)	4	2 (2)	3
N. Tanzania	PP	5	8 (12)	4	2 (2)	3
Means	AP	3	10 (9)	5	3 (3)	5
	PP	8	22 (38)	5	3 (4)	4

[1] AP = agro pastoral; PP = pure pastoral.

[2] Figures in parentheses are distances to emergency grazing sites.

1.1.2. Pastoral drought coping mechanisms

Mobility is an inherent strategy of pastoralists to optimise production under a heterogeneous landscape and a precarious climate. The search for water (for human and livestock consumption) and forage, trigger mobility and migration; these strategies were most intensified by drought (Ndikumana, 2000).

Distance trekked to livestock water sources is almost tripled during the drought, from an average (across zones) of 5.9 km pre-drought to 15.8 km during the drought; pure pastoralists trek greater distances than agropastoralists. Distances to grazing sites also increase, from an average (across zones) of 5.5 km pre-drought to 20.4 km during the drought, with pure pastoralists trekking greater distances than agropastoralists (Ndikumana, 2000).

Pastoralists divide herds into core and satellite herds; the satellite herds being constituted of hardy males and dry females of the generally larger livestock species, such as cattle and camels. Small ruminants and breeding stock (core herds) are left at the homesteads where women and children care for them. Generally, in drought, the main homesteads remain intact with family members (especially women, children and the elderly) in occupancy while herders move the livestock. Sometimes, one or two household members migrate to find work in towns or villages. Children are also sent to boarding schools to ensure that they receive adequate food and shelter (Ndikumana, 2000).

1.1.3. The Maasai pastoralists

The Maasai are pastoral people who keep mainly cattle, goats and sheep as their main livestock species for their livelihoods (Toxopeus, 1996). They depend heavily on the natural vegetation and water sources whose availability is influenced by the rainfall patterns. The rainfall is erratic and the increased variations in the amounts received and the localities where it occurs have led to increased incidences of drought. The drought coping mechanisms of the Maasai have been constrained over time by among other things the change of land use in an area which was originally a livestock grazing area. This has further contributed to the increased vulnerability of the Maasai.

The Maasai, who are the traditional inhabitants of Narok, Kajiado and Naivasha Districts, are nomadic pastoralists. Cattle, sheep and goat provide the Maasai in their basic demand for food (e.g., milk and meat). However, nowadays livestock becomes economically more valuable, since cattle, sheep and goat are sold at local markets (Toxopeus, 1996).

Cattle are the main livestock type though very often supported by sheep and goats. In this study, sheep and goat are considered as one species called shoats. The main livestock products are milk and meat though blood and skin are also produced. Apart from occasional sale of cattle, the produce is basically for subsistence. Other uses of the livestock and/or livestock produce includes gifts and traditional ceremonies (Toxopeus, 1996).

Two dominant factors dictate pastoralists' use of the land in arid areas i.e. rainfall variability and intra seasonal difference in relative productivity. Pastoralists respond to these factors by employing flexibility in risk spreading by changing livestock breeds, loaning out parts of the stock to their relatives in other localities, diversification of livelihoods and sources of incomes; and mobility of livestock and people. Risk spreading includes keeping large herds and different species of livestock. The Maasai and their livestock respond to the erratic climate by converging near perennial pastureland and permanent water sources in the dry season, whereas in the wet season they disperse to areas with better pasture (Toxopeus, 1996).

Livestock numbers vary often depending on the climate, with numbers building up in times of adequate rain and decreasing when there is drought. The rangelands, belongs to all the community members thus everybody has equal rights to the lands (Toxopeus, 1996).

1.1.4. Drought management in the "Kendong rectangle"

The pastoral production system of the Maasai living in the "Kendong rectangle" is under threat of extinction due the land use changes which have taken place in the area south of L. Naivasha for the last 20 to 30 years. Originally the Maasai had unlimited access to the riparian zones of Lake Naivasha; high-rainfall uplands in Mau-Inosupukia, south-west of Lake Naivasha and the Ngong hills in Kajiado District, where they could take refuge during the dry periods. Today this is no longer the case as most of the areas where they used to utilise or have access to during the dry season have been converted to other land uses. The human population have increased tremendously over the same period and livestock numbers have also gone up. Competition for the available forage resources has increased, leading to increased vulnerability of the Massai and their animals

The current drought interventions in this area are based mainly on information from the reports which are prepared monthly in the ASAL Districts by drought management officers (DMOs). They collect household data, which they use to analyse the impacts of drought. The data is collected in a monthly basis using questionnaires which contain information about the household indicators of stress levels. The household information then analysed to give an indication of the drought situation and recommendations for possible interventions. This information is delivered in the form of a drought early warning system (EWS). This EWS is implemented through the arid and semi arid resource management project (ALRMP) in the office of the president and it is co-financed by the Government of Kenya (GoK) and the World Bank (GoK &WB, 2003).

There is also the generation of drought status information using GIS and remote sensing techniques in other organizations. They include FEWSnet, Drought monitoring center and ILRI, LEWS by USAid and Texas A&M (Jerry Stuth, 1997) among others. They are mainly drought information products derived using qualitative methods. This has not had a significant impact on the pastoral communities due to the inability of the drought status products to provide viable drought intervention measures which resonate with the aspirations of the local people and the other stakeholders.

This study will be aiming at bridging this gap by providing a logical way of evaluating the drought situations through simulation models and recommending viable intervention options.

This study will use RS products and tools, GIS overlay procedures (i.e. weighted index overlay) to identify the viable areas for establishing dry season grazing reserves (DSGRs).

1.2. Defining dry season grazing reserves and the peak standing crop

Dry season grazing reserves (DSGR) are those which, even under the poorest environmental conditions i.e. at the absolute peak of the dry season, still have water and forage, and are thus irreplaceable as reserves during the cyclical periods of scarcity. Dry season grazing reserves are utilized intensively over long periods, receiving disproportionate grazing pressure during times that allow no other option (Schwartz, 1994). They are oases of net primary productivity (NPP) which even under very severe drought conditions help sustain livestock.

Thus, we define DSGRs as the forage situation during the dry season; referred to by Toxopeus (1996) as the peak standing crop (PSC), which is expressed as the forage shortage and/or forage surplus after the principle of forage supply and demand is applied to the NPP taking into account the proper use factor (Toxopeus, 1996). This is the recommended maximum level of forage utilization to ensure sustainability. This is expected to remain constant across seasons. For reliability, the DSGRs should have a high repetition time of forage surplus to minimise the risks of forage shortage in these areas.

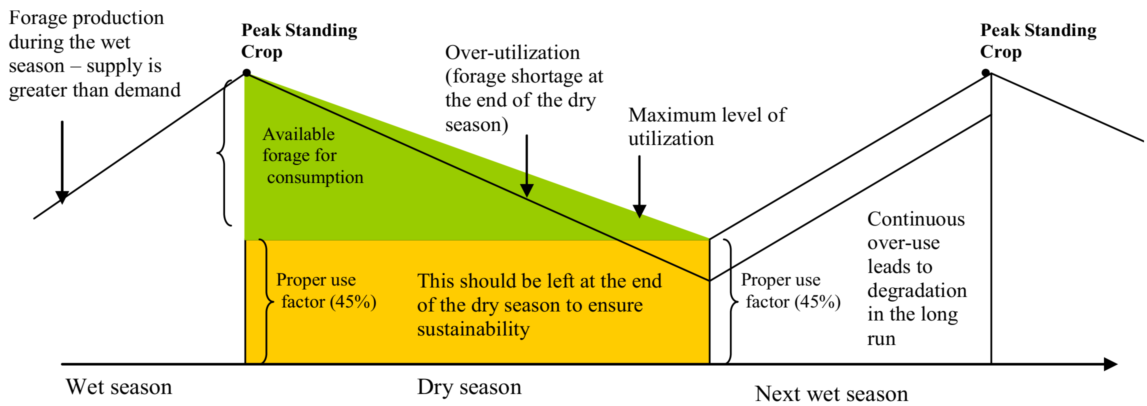


Figure 1-1: Peak Standing Crop and the proper use factor

Peak standing crop (PSC) is the potential total forage available during the dry season. For sustainable use, the PSC should not be utilized beyond the proper use factor threshold (Toxopeus, 1996). The proper use factor is recommended at 45% (FAO, 2000) of the PSC at the end of the dry season should be left unutilised to enable the forage recover adequately during the next rainy season. The peak standing crop at the end of the rainy season is depended on a number of factors such as nutrient availability, the contribution of perennial and annual grasses and forbs, the amount of rainfall during the growing season and the length of the growing season (Toxopeus, 1996).

The fluctuations in the scheduling or timing of the start of the rainy season affect the length of the dry season. This causes variations in the length of the dry season as shown in the diagram below. It is recommended that the proper use factor be placed at a higher level e.g. 55% to cater for these fluctuations, ensuring sustainability. It is assumed that the effect of this variance is averaged out over the 7 years' vegetation data used in this study.

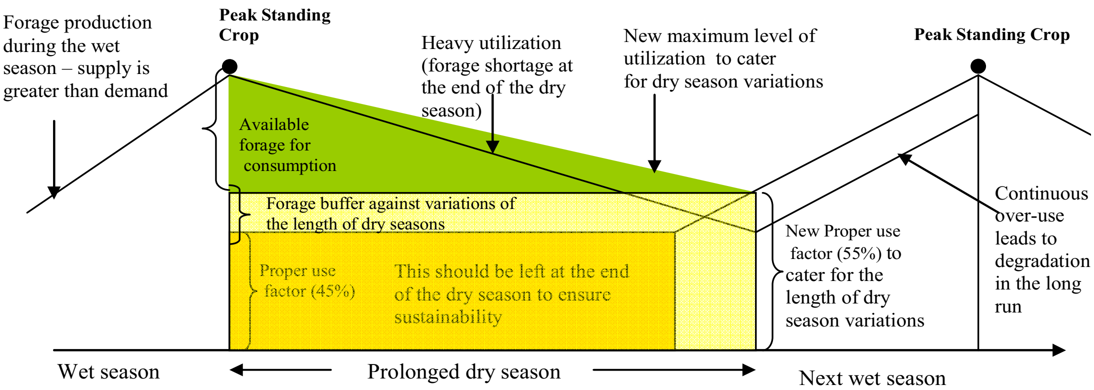


Figure 1-2: The Peak Standing Crop with the variations in the length of the dry season

1.2.1. MODIS land surface products for drought management

Near real-time vegetation indices derived from MODIS (MODerate resolution Imaging Spectroradiometer) observations (NASA, 1958) provide a first opportunity to monitor ecohydrological systems globally at a spatial resolution consistent with biophysical processes at the field scale (Gebremichael and Barros, 2006).

Water stress is one of the most important limiting factors controlling terrestrial primary production, and the performance of a primary production model is largely determined by its capacity to capture environmental water stress. The algorithm that generates the global near-real-time MODIS GPP/NPP products (MOD17) uses VPD (vapor pressure deficit) to estimate the environmental water stress (Qiaozhen Mu and Running, 2007).

Improved remote sensing capabilities

The MODIS sensor is unique because it combines both spatial and spectral resolution of several satellites on a single platform. It exhibits greater radiometric resolution than traditional sensors providing a broader range of measurement and therefore increased sensitivity to small changes in spectral reflectivity (Reeves, 2002).

MODIS offers 36 spectral channels, as compared to 5 on the AVHRR instrument, 7 on Landsat TM or 8 on the Landsat Enhanced Thematic Mapper Plus (ETM+). Although Landsat satellites offer greater spatial resolution they exhibit a revisit time of 16 days and with clouds often yield only 2 to 3 scenes per growing season. In addition the MODIS offers multi-spatial resolution for different applications. Calibration of the sensor is performed on-board allowing adjustments to be made while in orbit. In contrast the AVHRR has no comparable on-board calibration for visible and reflected infared channels. Another weakness of the AVHRR data is the lack of orbit timing control creating inconsistent overpasses and associated sun-angles (Reeves, 2002).

In addition to improved sensor characteristics and temporal and spatial resolution the MODIS data stream undergoes unprecedented processing and quality assurance tests before distribution. For example, spectral radiance data are cloud filtered, atmospherically and topographically corrected using sun and look angle information to yield an accurate surface reflectance. These procedures are part of the unique MODIS data processing system (Running et al. 1994 and Justice et al.1998). This means that MODIS data is validated and ready to use in customized applications immediately (Reeves, 2002). The MODIS NPP data will be used in this study as the basis for modelling forage availability.

1.2.2. Modelling livestock Distribution in Kenya

The official cattle population statistics in Kenya come from the Ministry of Livestock and Fisheries Development (MoLFD), through its field reports (SDP, 2004). The data are compiled by extension officials, who use diverse and sometimes rather imprecise methods to estimate livestock numbers in their assigned areas. Concerns have been expressed as to the reliability of these estimates, particularly as no national cattle census has been carried out to provide base figures (SDP, 2004). The Smallholder Dairy Project (SDP) has used a variety of statistical methods in an attempt to validate the official cattle numbers in Kenya (SDP, 2004). The results indicate that official figures may greatly underestimate the size of the national herd.

The livestock estimated population figures are presented in accordance to the administrative boundaries. This doe not adequately represent the true distribution of the livestock numbers. Several studies have been done to estimate the livestock densities (Jan de Leeuw and Prins, 1998; Toxopeus, 1996) and others. These studies have varying strengths and weaknesses. Modelling pastoral livestock distribution is not easy; the animals are always moving from one place to another in search of forage and water.

In order to identify the dry season grazing reserves (DSGR), forage demand (livestock distribution and animal requirements) model is necessary. In this study the forage demand (livestock distribution and animal requirements) is modelled using man made infrastructural development (roads, water points, towns) and the topography (terrain) as the principal factors influencing the density distribution of livestock.

1.3. The Goal and boundaries of this study

The goal of this study is to contribute to poverty reduction among pastoral and agro pastoral livestock keepers by developing a model for drought management in the arid and semi-arid lands of Kenya. It will form part of the basis for formulating interventions that will mitigate the vulnerability of pastoralists. This will be achieved through DSGRs site selection modelling aimed at minimizing expenditure on drought related interventions as described in the various Government of Kenya policy documents (ALRMP, 2005; MoE&NR, 2002; MoL&FD, 2005).

A 7 years' forage (NPP) analysis is used in this study for DSGR site selection. In this time-span, the area witnesses a full cycle of weather variations, including the extreme climatic phenomena. The El-Niño phenomenon incidences and periods of severe droughts have shown recurrence within the 7 year period. Rainfall data in this period also show patterns for repeatability and the forage shortfalls during the critical periods (dry seasons) are clearly identified.

Equidistance projections are used in this study in order to accurately determine distance functions, which is a fundamental requirement for the site selection procedures.

There are two dry seasons and two wet seasons in a year in the study area. The short dry season is from January to March (001 Julian day to 089 Julian day 8-day time step) and the long dry season is from July to October (185 Julian day to 297 Julian day 8-day time step). The short wet season is from November to December (305 Julian day to 361 Julian day 8-day time step) and the long wet season is from April to June (097 Julian day to 177 Julian day 8-day time step). These are the normal dry and wet seasons in Kenya. Julian day dating system is used in conformity with the MODIS naming system.

This DSGR site selection procedure is depended on the accuracy of the data available, the validation of the RS data, stable livestock growth rate and the goodwill of all the stakeholders in this area. It will also depend on availability of enough time-span of weather data to be able to detect variability of a full cycle of weather patterns. These are some of the assumptions we make in the course of our study.

Research motivation

The increasing vulnerability of the pastoral communities and the growing tensions, which sometimes converts to conflicts, between the livestock keepers and the owners of the other land use types in this area has prompted us to carry out a study to find the viable sites for the establishment of dry season grazing reserves. This will enable the livestock keepers cope with drought and at the same time sustain the environment. The study will give insights into ways of decreasing the land use conflicts, which arise when a drought occurs.

The desire to improve DSGR site selection techniques has motivated this research, as available methodologies are currently not adequately well suited for that purpose. Near real time forage data has been a limitation in DSGR site selection. The NPP data from MODIS satellites is reliable, readily available and likely to remain available over time (Running and

Nemani). The continuous data availability will enable drought status index calculation in a timely manner and the index can be meaningfully correlated to actual conditions

1.4. The Problem and challenges of DSGRs site selection

One of the problems facing of pastoral drought management strategies is the adjustment of the livestock population in relation to the available forage resources. To strike a balance between the interests of various drought management stakeholders has not been easy either.

The siting of appropriate areas for use as dry season grazing reserves has been a challenge. This challenge has been compounded by the pastoral production practices, where people are continuously moving from one place to another in search of pasture and water for the animals and the livestock population is continuously changing.

Statistical evaluation models have proven to be useful in this regard. They however have limitations because they are based on adequate empirical study material, which is usually expensive and time-consuming to collect (Store and Kangas, 2001). Thus, the empirical evaluation models (Store and Kangas, 2001), for all the livestock species, for example, cannot be expected to be available.

The existing models for drought management in the arid and semi-arid lands (ASAL) are far from perfect. A dynamic, iterative, easy to use and flexible model using GIS map overlay techniques and remote sensing data is currently lacking. Such a model can provide a logical process of identifying the right mix of the livestock population densities in relation to the available forage resources. This approach will give impetus to the challenge of identifying the viable and reliable sites for dry season grazing reserves (DSGRs).

In site selection studies spatial datasets from various sources are involved, which sometimes the user is not sure of their accuracy levels. Many of these datasets are usually poorly compiled. Data homogeneity and the large pixel size associated with many of the remote sensing datasets are all issues of concern. The effects of uncertainty and poor data sets in site selection studies have long been a challenge.

1.5. Objective

The objective of this study is to identify viable and reliable sites for the establishment of the DSGRs under pastoral livestock management systems; with the aim of minimizing dry season livestock losses and governmental expenditure.

1.6. Research Questions

a. Where and how much forage is available in the ASAL ecosystem, in this case the whole of the study area; based on supply and demand (the amount of forage available – NPP versus the livestock densities)?
b. Which constellation of the DSGR sites will reliably cover dry season forage shortage and minimize expenditure on drought related interventions?
c. How is the infrastructural development influencing the constellations of the DSGR sites?

1.7. Hypothesis

Hypothesis 1

H_o - There is significant difference between the estimated demand (the modelled livestock densities) and the observed demand (actual livestock densities).

H_a - There is no significant difference between the estimated demand (the modelled livestock densities) and the observed demand (actual livestock densities).

Hypothesis 2

H_o - In more than 70% of the dry seasons, a forage surplus is observed at the candidate DSGRs sites.

H_a - In more than 70% of the dry seasons, a forage surplus is not observed at the candidate DSGRs sites.

Hypothesis 3

H_o - There is significant difference between influence of the man-made infrastructural factors (roads, water points and towns) on the location of the DSGRs.

H_a - There is no significant difference between influence of man-made infrastructural factors (roads, water points and towns) on the location of the DSGRs.

1.8. Assumptions

a. The accuracy of DSGRs sites depends on the NPP images from MODIS; hence this study assumes the NPP images have been validated for the study area.
b. Vegetation cover in this area is heterogeneous. This study assumes the MODIS datasets captures the heterogeneity in the vegetation composition of the study area.
c. The GIS datasets used in the study are also assumed to be accurate and current. They will affect the accuracy of final product of this of this study.
d. It is assumed that livestock densities current and remain constant/stable throughout entire period. The livestock densities are also assumed to include beef cattle, goats and sheep
e. Wildlife and livestock both feed on forage. It is assumed that it's only livestock species feeding on the forage in this area.
f. Sustainable forage production is a requirement for this study. It is therefore assumed that the peak standing crop is equivalent to the aggregated seasonal NPP (forage situation) during the period of the dry season.

2. Study area

The study area is located in three Districts of Naivasha, Kajiado and Narok. It is in the southern part of Naivasha District; the northern part of Kajiado District, in Ngong Division and the north western part of Narok District in Mau Division.

The greater part of this area is situated along the floor of the Great Rift Valley, to the south of the Lake Naivasha. Plains and occasional volcanic hills and valleys are the main physical features in the area. The land varies in altitude from about 500 meters to about 2,500 meters in height. Topographically, the area is at the bed of the Great Rift Valley.

The area has a bimodal rainfall pattern. The short rains fall between October and December while the long rains fall between March and May. Annual rainfall ranges from a high of 1,000 mm to a low of about 500mm. Temperatures in the area range from 30^0 C to 20^0 C. The coolest period is between July and August while the hottest months are from November to March. The area has the geological region of Quaternary volcanic, found in the Rift Valley floor; there is a close relationship between the geological formation, topography and soils.

The area does not have adequate surface water resources for livestock and human consumption or irrigation. It depends to a greater extend on ground water reserves. The occurrence of the ground water in the area is mainly influenced by climate and topography as well as origin of underlying parent rock. The other alternative source of water for domestic and livestock are sub-surface resources such as water pans, dams and shallow wells. The amount of surface water varies from area to area.

Land use in the area

Originally the Maasai had unlimited access to the are the riparian zones of Lake Naivasha and high-rainfall uplands in Mau-Inosupukia, south-west of Lake Naivasha and Ngong hills, where they could take refuge during the dry periods. Today this is no longer the case as most of the areas where they used to utilise or have access to during the dry season have been converted to other land uses. The human population have increased tremendously over the same period and livestock numbers have also gone up. Competition for the available forage resources, in the remaining dry season grazing reserves (DSGRs), has as result escalated, leading to increased vulnerability of the Massai and their animals

South of Lake Naivasha, a transect runs from a completely conserved area (National park); to a semi-conserved (large private farm with cattle and game) and into a non-conserved (mainly small holders, overgrazed) area. Several fenced protected areas also exists (KWS-TI and Kigio conservancy).

The main land use practices in the area include pastoralism and small scale mixed farming in the floor of the rift valley and Mau escarpment; and the large scale agricultural farms in the highlands of Mau escarpment and the areas surrounding L. Naivasha.

The main agro climatic zones in this area include the humid, sub-humid and the semi-humid zones in the highlands and the arid and semi-arid zones at the floor of the rift valley.

The main vegetation types in this area are the *Panicums, Pennisetum Clandestinum, Cynodon dactylon, Eragrostis spps and Hyperrrhenia* grasses species; and the *Acacia drepanolobium, Acacia xanthophloea, Acacia sayel and Taconanthus caphoratus* tree species.

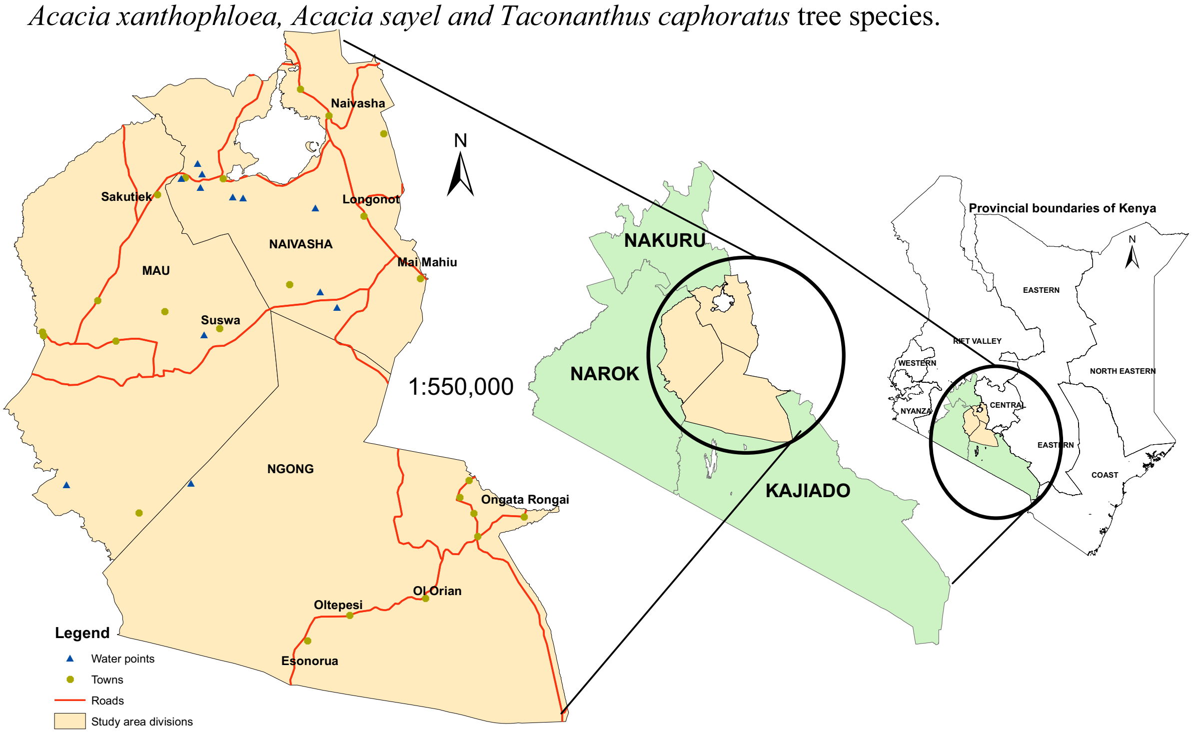


Figure 2-1: Location of the Study Area

The names in capital letters are the administrative units of Naivasha, Mau and Ngong Divisions in the study area. The small letters represents name of towns and settlements in the study area.

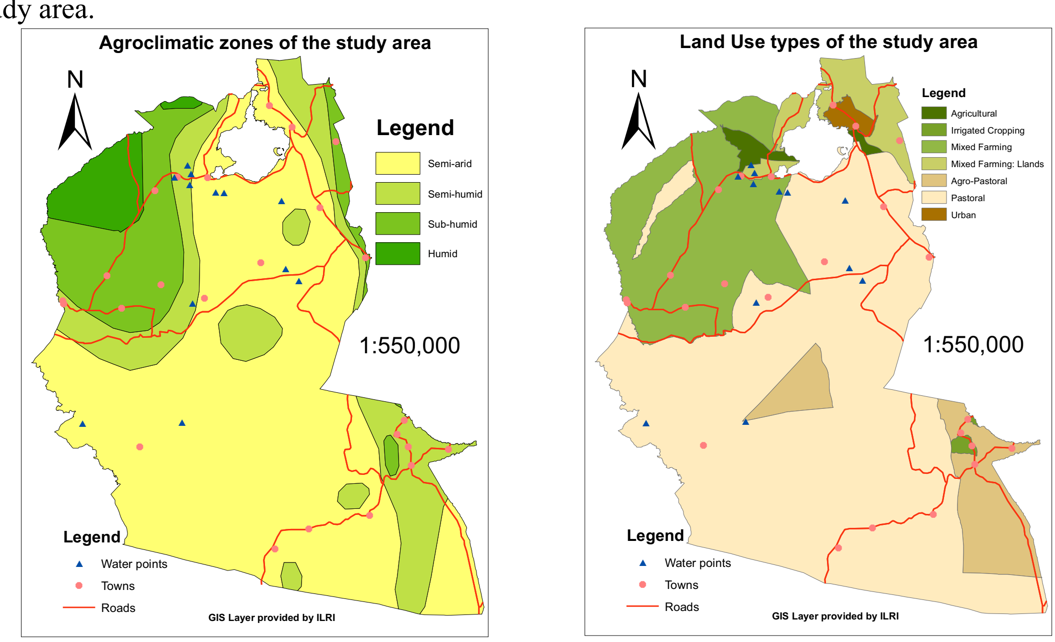


Figure 2-2: Agro-climatic (Pratt and Gwynne 1977) and Land use/livelihood Zones (GoK &WB 2003) of the Study area

3. Forage Production and Livestock Demand

3.1. Primary productivity and Forage production

The use of seasonal integration techniques in estimating Biomass Production in ASAL Ecosystems is based upon the logic of Monteith (1972 and 1977). Monteith (Monteith, 1972; Monteith, 1977), suggested that the net primary productivity (NPP) of a well-watered and fertilized annual crop is linearly related to the amount of absorbed photosynthetically active radiation (APAR). The amount of APAR depends on the quantity of solar radiation reaching a site and the ability of the vegetation to absorb that radiation. The amount of radiation intercepted by vegetation is directly related to vegetative leaf area that can be detected using remote sensing. This makes the radiation conversion efficiency logic an attractive avenue for predicting NPP from remotely sensed inputs (Prince 1991, Prince and Goward 1995 and Hunt et al. 1994). Relying on the radiation conversion efficiency logic requires measures or estimates of global, daily photosynthetically active radiation (PAR), hence accurate estimates of NPP will depend on the quality of PAR estimates.

Monteith's formulation included a maximum radiation conversion efficiency (ε_{max}) that is attenuated by the influence of environmental factors thought to reduce growth efficiency (Monteith, 1972; Monteith, 1977). Early applications of these principles assumed a universal constant for (ε_{max}) across vegetation types. Later studies showed important differences in maximum efficiency between types (Russell et al., 1989). Other studies have shown that time integrals of APAR correlate well with observed NPP (Goward et al., 1985) but different relationships exist for different vegetation types, and for the same vegetation type under different growth conditions (Russell et al. 1989). It is therefore likely that plant growth and maintenance respiration costs are responsible for these differences (Monteith, 1972; Reeves, 2002).

3.2. Quantifying Biomass in ASAL ecosystem using MODIS land products

Space technology has made substantial contribution in all the three phases such as preparedness, prevention and relief phases of drought and flood disaster management. The Earth Observation satellites which include both geostationary and polar orbiting satellites provide comprehensive, synoptic and multi temporal coverage of large areas in real time and at frequent intervals and 'thus' - have become valuable for continuous monitoring of atmospheric as well as surface parameters related to droughts. Geo-stationary satellites provide continuous and synoptic observations over large areas on weather including cyclone monitoring. Polar orbiting satellites have the advantage of providing much higher resolution imageries, even though at low temporal frequency, which could be used for detailed monitoring, damage assessment and long-term relief management. Advancements in the remote sensing technology and the Geographic Information Systems help in real time monitoring, early warning and quick damage assessment of drought disasters (Domenikiotis et al., 2004; Jeyaseelan, 2003).

Until recently, the Advanced Very High Resolution Radiometer (AVHRR) was the only broad scale, globally applicable satellite that provided direct spectral data suited for continual monitoring of vegetation. As such, many studies have successfully used AVHRR normalized difference vegetation index (NDVI) to infer photosynthetic monitor growing season phenology and estimate vegetation. On 18 December, 1999 the first Moderate Resolution Imaging Spectroradiometer (MODIS) was launched on the Terra platform of the Earth Observing System (EOS). The MODIS instrument provides new and improved capability for terrestrial remote sensing intended for global change research including a suite of standard products designed to remove the burden of most data processing requirements (Reeves, 2002).

To determine the practical usefulness of MODIS products, Reeves (2002) studied the relationship between MODIS leaf area index (LAI), vegetation temperature condition index (VTCI) and fraction of the photosynthetically active radiation (FPAR) and the above-ground herbaceous green biomass in an arid and semi-arid grassland ecosystem.

The great spatial extent of rangelands combined with recent emphasis on rangeland health has prompted a need for more efficient and cost effective management tools. The Moderate Resolution Imaging Spectroradiometer (MODIS) sensor of the Earth Observing System (EOS) offers improved and timelier monitoring of rangeland vegetation and drought and, unlike any previous satellite sensor, the publicly available MODIS data stream includes estimates of rangeland productivity. These estimations of rangeland productivity can be used regionally for measuring biomass production and is available every eight-days, with global coverage at 1-km^2 resolution (Reeves, 2002).

MODIS derived estimates of rangeland productivity combine remote sensing information with daily meteorological data as inputs to a mathematical model of photosynthetic conversion of solar radiation into plant carbohydrates. Vegetation productivity is a measure of rangeland vigor and vegetation growth capacity, which are important components of rangeland management and health assessment. These components are in turn very crucial for drought management.

Using MODIS data, it will be possible to characterize rangeland vegetation seasonality, estimate herbage quantity and, monitor the rates and trends of change in primary production (Reeves, 2002). These newer methods of evaluating rangeland productivity will never entirely replace traditional methods, however, EOS weekly productivity data can be used to greatly increase timing, frequency and spatial extent of monitoring (Reeves, 2002).

3.3. Spatial distribution of livestock in southern Kenya

In the arid and semi-arid lands, the rains are often inadequate and highly variable both in temporal and spatial scales. The primary productivity closely follows the rainfall patterns, which also determines the pattern of spatial distribution of animals and in turn regulates the population size and home range. The resultant species densities will vary according to whether the underlying habitat changes are regular in space and time, and in accordance to magnitudes in terms of forage quantity and quality (UNEP, 2002).

The livestock populations have fluctuated over the years in the arid and semi-arid lands, but they have declined drastically over the last two decades, due to recurrent droughts. The rapid decline in livestock populations can be attributed to a combination of factors including the estimation (counting) error, drought, land use change, and competition for water and forage among others (UNEP, 2002).

At the peak of year 2000 drought, livestock were widely scattered in Narok District. Large concentrations occurred within the highlands of the Mau escarpment and Ol-Pusimoru forest. Large concentration of livestock occurred within the highlands and cultivation areas in Kajiado district, especially within the Oloitokitok and Rombo areas, Chyulu hills, Athi-Kapiti plains, Ngong hills and the periphery of Nairobi city (UNEP, 2002).

Distribution, abundance and type of livestock in Kenya is influenced by environmental, social/cultural and economic factors, of which environmental influences are the most crucial (Herlocker, 1999).Climate is a critical environmental factor. Total stocking rate levels of livestock (all species) reflect the patterns of rainfall – usually expressed as mean or median annual rainfall, although variability (or reliability) of rainfall is also very important (Herlocker, 1999). The stocking rate of animals in the ASALs is, on average, about 20TLU/sq.km

Tropical livestock units (TLUs) are an expression of biomass (Herlocker, 1999).

Equation 3-1: Tropical livestock units

$$\text{One TLU} = 25\text{kg} = 1 \text{ mature zebu cow} = 10 \text{ sheep} = 12 \text{ goats} \quad \text{……………..}\textbf{Equation 3-1}$$

Herd structures have been defined in terms of number of heads of animal as well as in terms of reference Tropical Livestock Unit (TLU); defined as a mature animal weighing 250 kg (Kassam, 1991-1993). Livestock conversion factors for pastoral systems in areas with less than 120 days growing period are taken from Houerou and Hoste (1977), (Kassam, 1991-1993) and are:

Cattle in Herd	= 0.70 TLU	Goat	= 0.08 TLU
Cow	= 1.00 TLU	Donkey	= 0.50 TLU
Sheep	= 0.10 TLU	Camel	= 1.25 TLU

A study commissioned by the Smallholder Dairy Project (SDP, 2004) found that there are probably far more cattle in Kenya than is officially reported. A conservative estimate of the size of the national dairy herd using the detailed Smallholder Dairy Project survey data suggests that it could be more than twice the officially reported figure of cattle. The survey-based figures also suggested that there are at least 40–50 percent more zebu cattle. These cattle are mostly owned by rural smallholder farms (SDP, 2004).

The study by the Smallholder Dairy Project projected that cattle population is more than twice the officially reported figures for the national herd (SDP, 2004).

3.3.1. Livestock density distribution and study area stratification

Livestock in Narok and Kajiado Districts

The southern rangeland districts of Narok and Kajiado covers approximately 15118 km2 and 21,852 km2, respectively. The region is composed of highlands in the northwest and rolling plains covered by grasslands, shrubs and bushes in the larger portions of Narok and Kajiado districts (UNEP, 2002).

Table 3-1: Livestock numbers in Narok and Kajiado districts between 1996 and 2000

Year	Narok		Kajiado	
	Cattle	Sheep&goats	Cattle	Sheep&goats
1996	524,886	560,589		
1998			377,268	560,589
2000	559,252	595,588	251,052	486,031

Source: (UNEP, 2002)

ILRI and FAO livestock distribution and densities

Cattle density Maps from ILRI's databases and FAO at the country level. (Thornton, 2002) analyses the distribution of cattle, sheep and goats indicates that cattle and sheep/goats are found in the same areas in most of Africa. Most of the cattle are in or near the Sahel, the higher-potential areas of East Africa (Thornton, 2002).

These maps give the range of livestock density (TLUs) distribution in the study area as follows: much of the Ngong Division, the southern parts of the Nivasha and Mau Divisions– 10 to 25 TLUs; the L. Naivasha basin – 25 to 50 TLUs; and the Mau escarpment – 50 to 100 TLUs (Corbett, 2001; FAO, 2005; ILRI, 2007; Thornton, 2002).

FAO and ILRI Cattle densities are based on the total land suitable for livestock production Density land area (LU/sqkm). Vast majority of cattle are kept by the pastoralists in mixed herds. In the last two decades the cattle densities have been stagnant (FAO, 2004; FAO, 2005; ILRI, 2007).

Table 3-2: Livestock populations from Ministry of Livestock. Source: (ILRI, 2007) and (MoL&FD, 2002).

(in '000')									
Year	**District**	**CATTLE**		**SHEEP**		**GOATS**		**DONKEY**	**CAMELS**
		DAIRY	**BEEF**	**WOOL**	**HAIR**	**MILK**	**MEAT**		
1998	Nakuru	234.25	108.03	38.67	112.87	1.34	68.46	0.00	0.00
	Kajiado	6.23	677.59	0.00	525.90	0.29	511.97	17.20	0.52
	Narok	4.21	0.00	167.77	512.27	1.56	711.00	0.00	0.00
2000	Nakuru	110.8	83.0	52.3	53.8	2.6	51.2	-	-
	Kajiado	76.2	426.6	-	416.0	-	351.5	26.7	0.8
	Narok	40.0	356.1	179.6	553.0	0.8	558.1	-	-
2001	Nakuru	222.2	90.5	52.7	85.8	4.2	79.9	-	-
	Kajiado	76.2	279.0	-	416.2	-	351.6	20.0	0.8
	Narok	39.6	361.9	185.9	572.3	0.9	578.2	95.5	0.1

Table 3-3: Local cattle density figures (No. /km^2) and area (km^2) for the Study area Divisions in the period 1994 to 1998

DIVISION	AREA	DENS98	DENS97	DENS96	DENS95	DENS94
Naivasha	1851.81	9.61	12.15	14.04	16.20	20.25
Mau	2557.51		30.21	30.21		25.42
Ngong	3502.55					

Source: (MoL&FD, 2002) and (ILRI, 2007)

Study area stratification and livestock density estimates

Study area is stratified into regions according to the river basins of the study area (ILRI, 2007). The river basins are a characteristic of the hydrological properties, which have been shown to influence livestock distribution by various studies (Bake, 1994; Herlocker, 1999; Jaetzold, 1982; Schwartz, 1994). They are the Lake Naivasha basin, the Mau escarpment region and the southern region of the study area - this includes Ngong area and the flow of the Rift valley (the Kendong area, Longonot, Mahimahiu Suswa and the area toward Magadi).

Kendong ranch is situated in an area south of L. Naivasha, covering an area of 40,000 ha. It is located within the two regions; L.Naivasha basin and the southern region of the study area. The ranch currently has 1,000 heads of boran beef cattle and 600 dorpers (a cross-breed of goat and sheep). The livestock density of this ranch is 25 TLUs, which compares very well with the livestock density (25 TLUs) distribution map for the Kendong area in the study area.

From the livestock population and density figures from the above sources, the information from the Livestock distribution data from Kendong ranch and survey done by the small holder dairy project (SDP), which found out that a conservative estimate of the size of the national livestock herd could be more than twice the officially reported figure of cattle, we make conservative estimates of livestock densities for our study area as follows:

Table 3-4: Livestock Density estimates used in this study

Division	Cattle density (nos./km2)	Shoat density (nos./km2)	TLU/km2
Naivasha	15	40	25 - 50
Mau	35	50	50 -100
Ngong	15	25	10 - 25

The SDP survey-based figures also indicated that there are at least 40–50 percent more zebu cattle, than the official figures.

3.3.2. Livestock forage demand and animal requirements

When the location and density of livestock is known, the livestock forage demand can be calculated by combining it with the dry matter intake values (kg/day) per livestock species and the length of the dry season (Toxopeus, 1996).

Table 3-5: Daily dry matter intake of grass of free ranging herbivores during the dry season and the percentages of dry matter intake in relation to their life body weight

Species	Live body weight (kg/animal)	% grass in diet (%/animal)	DM grass requirement (kg DM/day)	% life body weight (%)
Cattle	205	100	3.1	1.5
Shoat	25	50	0.6	2.4

Source: An interactive spatial and temporal modeling system as a tool in ecosystem management (Toxopeus, 1996).

Animal requirements

Animal requirements are calculated as kg dry matter forage per tropical animal unit (TLU) per day. One TLU is equivalent to 250kg live weight. Considering the types and breeds of livestock prevalent in Naivasha, Kajiado and Narok Districts, one TLU is equivalent to 1.0 head of cattle, 10 sheep or 12 goats (Walsh, 1994).

Table 3-6: Animal requirements (kg dry forage matter/TLU/d)

Animal	Maintenance only	Maintenance/ production	Production levels
Cattle	4.8	6.4	300gm daily gain or 2.5l milk/day
Sheep	6.2	7.9	80gm daily gain
Goats	6.4	7.3	60gm daily gain or 0.45l milk/day
Camels	6.1	7.3	450gm daily gain or 4l milk/day

Source: Range management handbook of Kenya – volume 1 and 2 (1994)

The requirements for maintenance level i.e. with no body weight changes and no other outputs like milk or work, were based on the assumption that the available forage contains a minimum of 1.8 meal metabolisable energy and approximately 40 grams digestible protein per kg dry matter. This is a quality commonly found at the beginning of the dry season on semi-arid and arid rangelands of East Africa.

The levels of production used in this study for modelling is the animal requirements for maintenance plus a moderate production as shown in table 3-3 above.

To achieve these levels of production the available forage needs to contain a minimum of 2.2 mcal metabolisable energy and approximately 60 grams digestible protein per kg dry matter. Such qualities are available in the herb layer only during the growing phase of the vegetation. In the shrub layer, and in particular in larger bushes and small trees, qualities in this range can be available for much longer periods (Walsh, 1994).

4. Materials and Methods

Materials and methods used in this study are based on adaptations of best available materials and methods used in previous and related studies. These adaptations aim to improve on the weaknesses of the existing methods and tapes into the current developments and advances in the GIS and remote sensing technologies.

4.1. DSGRs Conceptual framework

To construct a dynamic model, which is flexible, calculating and displaying the spatial and temporal distribution of dry season grazing reserves (DSGRs), data is collected concerning the forage production, the suitability of the rangelands for grazing, animal numbers and distribution and density for the wet and dry seasons. The model consists of forage availability, the accessibility of the rangelands for livestock, the forage demand (animal requirements) and the assessment of the reliability of the of the forage surplus in the DSGRs

Conceptual description of the DSGRs

Conceptually, DSGRs are defined as the forage surplus, which is a function of forage situation during the dry season. Forage situation is a function of macro-economics, weather, man-made infrastructural developments, land cover and land use.

The forage situation is the forage shortage and/or forage surplus after the principle of forage supply and demand is applied to the NPP taking into account the sustainable availability (proper use factor) and accessibility factor (FAO, 2000; Toxopeus, 1996).

Functional description of the DSGRs

Functionally, DSGRs are a function of the following: - forage supply; forage demand by livestock, proximity to man-made facilities (water points, towns, roads etc); duration of the dry season and physical features e.g. terrain, highlands and lowlands, river catchment basins.

Equation 4-1: Functional description of the DSGRs

$$\text{DSGRS} = f\ (\text{FSS}, \text{FDD}, \text{PID}, \text{terrain}, \text{Duration of DSSN and Landforms})$$ **..Equation 4-1**

Where:

DSGRs	=	Dry season grazing reserves
FSS	=	Forage supply
FDD	=	Forage demand by livestock
PID	=	proximity to man-made infrastructural development
Terrain	=	Accessibility to terrain
Duration of DSSN	=	Duration of the dry season
Landforms	=	Highlands and lowlands

In this study the functional description of the DSGRs is as adopted as the relationships' between the forage supply and demand; the influence of the man-made infrastructural developments on DSGRs and the duration of the dry seasons.

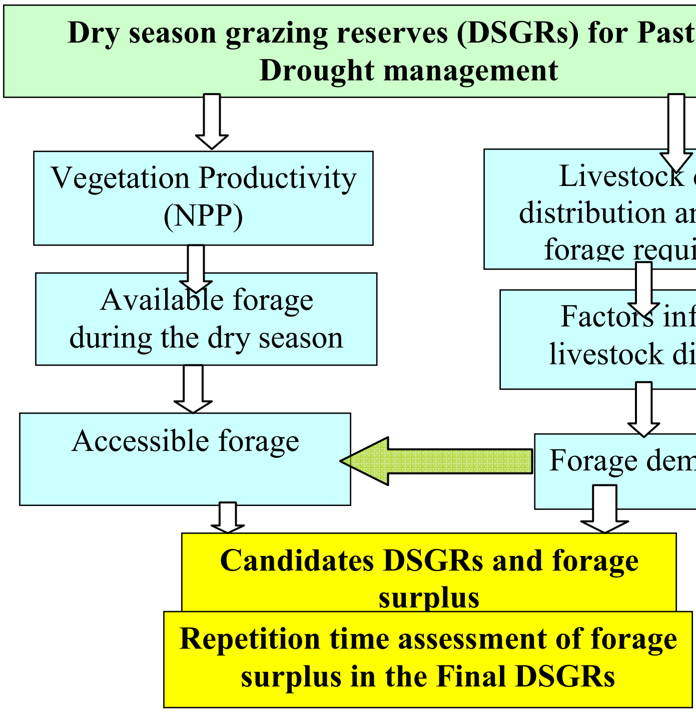


Figure 4-1: Conceptual Framework diagram

4.2. Materials

The materials used in this study are mainly the MODIS vegetation products, the livestock distribution datasets and the GIS layers of the study area, which are relevant to this study.

MODIS Daily Photosynthesis (Psn) and Annual Net Primary Production (NPP) Product (MOD17)

Probably the single most fundamental measure of "global change" of practical interest to humankind is change in terrestrial biological productivity. Biological productivity is the source of all the food, fiber and fuel that humans survive on, so defines most fundamentaly the habitability of the Earth. The spatial variability of NPP over the globe is enormous, from about 1000 gC/m2 for evergreen tropical rain forests to less than 30 gC/m^2 for deserts (Running, 1986). With increased atmospheric CO_2 and global climate change, NPP over large areas may be changing (Running and Nemani).

Understanding regional variability in carbon cycle processes requires a dramatically more spatially detailed analysis of global land surface processes. The NASA Earth Observing System produces a regular global estimate of near-weekly photosynthesis and annual net primary production of the entire terrestrial earth surface at 1km spatial resolution, 150 million cells, each having PSN and NPP computed individually.

These PSN and NPP products are designed to provide an accurate, regular measure of the production activity or growth of terrestrial vegetation. These products have both theoretical and practical utility. The theoretical use is primarily for defining the seasonally dynamic terrestrial surface CO_2 balance for global carbon cycle studies such as answering the "missing sink question" of carbon (Tans et al. 1990). The spatial and seasonal dynamics of CO2 flux are also of high interest in global climate modeling, because CO_2 is an important greenhouse gas (Keeling et al. 1996, Hunt et al 1996).

Currently, global carbon cycle models are being integrated with climate models, towards the goal of integrated Earth Systems Models that will represent the dynamic interaction between the atmosphere, biosphere and oceans. The weekly PSN product is most useful for these theoretical CO_2 flux questions.

The practical utility of these PSN/ NPP products is as a measure of crop yield, range forage and forest production, and other economically and socially significant products of vegetation growth. The value of an unbiased, regular source of crop, range and forest production estimates for global political and economic decision making is immense. These products will be available for all users worldwide. This daily computed PSN more correctly defines terrestrial CO_2 fluxes than simple NDVI correlations currently done to increase understanding on how the seasonal fluxes of net photosynthesis are related to seasonal variations of atmospheric CO_2.

4.2.1. MODIS vegetation products

The MODIS EOS PSN and NPP land science algorithms are global scale, 1KM resolution, daily timestep ecosystem models driven from MODIS instrument data and selected ancillary datasets. Photosynthesis (PSN) is the foundation ecosystem variable computed. PSN represents plant productivity and is expressed in terms of carbon mass per unit area per day. Annual net primary productivity (NPP) is derived directly from PSN, with the effects of maintenance respiration costs taken into account. While the PSN and NPP pixel wise measures are computed daily, the archived EOSDIS Core System (ECS) PSN product is computed once per 8-days and the NPP product is computed once annually. The archived PSN and NPP data products are projected in the standard MODIS Land Integerized Sinuoidal (IS) tile map projection and are stored in NASA HDFEOS format files. Each processing tile represents approximately 1200 km by 1200 km land region (Running and Nemani).

4.2.2. The LP DAAC and the HEG tool

The Land processes distributed active archive center (LP DAAC) was established as part of NASA's Earth Observing System (EOS) Data and Information System (EOSDIS) initiative to process, archive, and distribute land-related data collected by EOS sensors, thereby promoting the inter-disciplinary study and understanding of the integrated Earth system. The role of the LP DAAC includes the higher-level processing and distribution of ASTER data, and the distribution of MODIS land products derived from data acquired by the Terra and Aqua satellites.

The HDF-EOS to GeoTIFF conversion tool (HEG)

The HDF-EOS to GeoTIFF Conversion Tool (HEG) (http://newsroom.gsfc.nasa.gov/sdptoolkit/HEG/HEGHome.html) is a tool developed to allow the user to reformat, re-project and perform stitching/mosaicing and subsetting operations on HDF-EOS objects. The output GeoTIFF file is ingestible into commonly used GIS applications. HEG will also write to HDF-EOS Grid & SWATH formats (i.e. for Subsetting purposes) and native (or raw) binary. HEG presently works with MODIS (AQUA and TERRA), ASTER, MISR, AIRS, and AMSR-E HDF-EOS data sets.

4.2.3. GIS Databases documentation

Kenya livelihood Zones Map (2006 administrative boundaries, 1999 population census and Land use)
The coverage shows total population numbers, population density, as well as households and household densities (according to the 1999 population census), done up to the sub location level in 2006 for Kenya. It is also shows general land use classes derived from data by the World food programme (WPF) and the arid lands resource management project (ALRMP), Kenya

Kenya towns: The coverage shows the towns and urban centers in Kenya derived from the Kenya topographic sheets of scale, 1:250,000 for Northern Kenya and 1:50,000 for the rest of Kenya. There are approximately 1620 towns and urban centers captured in this layer.

Kenya cattle density, crop and livestock figures: Dairy and zebu cattle density data done at the third administrative level and derived from the 1995-1997 division dairy and zebu cattle density reports from the Ministry of Agriculture, Livestock Development and Marketing; and data on crop yield and area planted for major crops as well as livestock populations in Kenya between 1993 and 1999 done up to the third administrative level (Divisions) All target crops are covered and livestock data is reported as exotic and local cattle

Kenya contours: The coverage shows the elevation of Kenya according to Almanac Characterization Tool (ACT) database. It is at an interval of 1000 meters.
Land cover map: Coverage showing general land cover/land use classes derived from 1980 landsat data by the Japan International Co-operation Agency, JICA, National Water Master Plan, Kenya

Kenya protected areas: This coverage shows the Kenya protected areas. It is a subset of the Africa protected areas database from the World Conservation Monitoring Center's (WCMC), which manages a database on the worlds protected areas.

Kenya rainfall distribution: This coverage shows the annual rainfall distribution in millimeters per year for Kenya. It was done by the Japanese International Co-operation Agency (JICA), National Water Master Plan, Kenya

Kenya roads: This coverage shows the road network of Kenya excluding western Kenya. It was created by the World Food Programme, WFP.

Kenya water points: The coverage shows distribution of water points and related features in Kenya as described in the Almanac Characterization Tool (ACT) database. The water points in this coverage include dams, falls, rapids, springs, wells and water holes.

Kenya river basins: The coverage shows the river basins of Kenya as defined by Japanese International Co-operation Agency (JICA), National Water Master Plan, Kenya.

4.3. Research methods

The methods listed below are used to guide this research.

4.3.1. Photosynthesis and MODIS net primary productivity

The Photosynthesis (PSN) and Net Primary Productivity (NPP) are some of the MODIS GPP/NPP (MOD17) products (NASA, ; Running, 1986; Running and Nemani). They are designed to provide an accurate regular measure of the growth of the terrestrial vegetation. Production is determined by first computing a daily net photosynthesis value which is then composited over an 8-day interval of observations for a year, to produce a Net Primary Productivity (NPP) measure.

The Photosynthesis (PSN) and Net Primary Productivity (NPP) vegetation production products are designed to provide an accurate regular measure of the growth of the terrestrial vegetation. Production is determined by first computing a daily net photosynthesis value which is then composited over an 8-day interval of observations over a year, to produce a Net Primary Productivity (NPP) measure.

MODIS NPP data characteristics

The MODIS vegetation productivity data stream consists of three biophysical products:

- 8-day summation GPP MOD17A2,
- 8-day summation PSNnet MOD17A2 and
- Annual NPP MOD17A3 (NASA).

To properly visualize and interpret any of these products, it is necessary to convert them from scaled digital images to a biophysical quantity. This can be accomplished using the equation:

Equation 4-2: Conversion from scaled digital images to a biophysical quantity

$$\text{Biophysical\_pixel} = \text{scale\_factor} * \text{digital\_value}$$ **……………..………Equation 4-2**

Where:

Biophysical_pixel	=	sequestered carbon (kg C m-2),
Scale_factor	=	gain for the MODIS productivity products (dimensionless);
Digital_value	=	numeric value of a file pixel.

For example, if a mid-summer digital_value of 421 for Gpp_1km obtained from an HDF file (Running and Nemani), an 8-day summation of Gpp_1km would be:-

Equation 4-3: Example of computing a biophysical quantity

$$\text{Biophysical\_pixel} = 0.0001 * 421 = 0.0421 \text{ kg C m - 2.}$$ **………………..Equation 4-3**

In order to obtain a daily estimate of Gpp_1km, this number is divided by 8,
0.0421 kg C m-2/8 = 0.00526 kg C m-2 d-1.
Where:
Kg C m-2 d-1 = kilogram of carbon of gross primary productivity per square meter per day.

PSNnet_1km is equal to Gpp_1km minus the maintenance respiration from leaves and fine roots. In other words, Gpp_1km should always be greater than or equal to PSNnet_1km at any given pixel.

Table 4-1: Summary of MOD17 output variables

Variable	Data type	Units	Fill value	Scale Factor	Valid Range	Product
Gpp_1km	Int16	Kg C m-2	32766	0.0001	0 - 30000	MOD17A2
PsnNet_1km	Int16	Kg C m-2	32766	0.0001	-30000 - 30000	MOD17A2
Npp_1km	Int16	Kg C m-2	2766	0.0001	-30000 - 30000	MOD17A3
Psn_QC_1km	Uint8	N/A	255	N/A	0 - 254	MOD17A2
Npp_QC_1km	Uint8	N/A	255	N/A	0 - 254	MOD17A3

Source: User's Guide GPP and NPP (MOD17A2/A3) Products MODIS Land algorithm

4.3.2. MODIS NPP image processing

MODIS NPP image is downloaded from the EOS Gateway site. It is converted from HDF formats to Geotiff formats and the image is reprojected to UTM zone 37S equidistance projection and WGS84 ellipsoid. 8-day PSN images are summed to annual NPP images and multiplied with a scalar factor to convert from digital numbers to quantitative values and check the quality of the image with the PSN-QA image. The study area NPP image is extracted using the study area boundary as masking shapefile

8-day time step PSN_net images for 7 years (2000 – 2006) from MODIS TERRA and AQUA are downloaded from NASA website (NASA).

The HEGTOOL (http://newsroom.gsfc.nasa.gov/sdptoolkit/HEG/HEGHome.html) software is used to convert the downloaded images in HDF formats to Geotiff format (compatible with ESRI ™ ArcGIS®) and reprojected to UTM zone 37S projection (an equidistant projection) and WGS84 ellipsoid in HEGTOOL software

The study area NPP is extracted in ESRI ™ ArcGIS® by masking using the study area boundary for all images. The sum of all the 8-day time step PSN image products within the months which constitute the respective seasons (wet and dry seasons) to constitute the seasons NPP is then computed. In ESRI ™ ArcGIS®, cell statistics tool is used to compute the sum of the 8-day time step NPP. The result is the NPP of the respective seasons. The missing data is filled in using long term means)

Missing NPP datasets

Long term means of the same period (8-day time step) used to replace the missing data. In ESRI ™ ArcGIS®, we used cell statistics tool to compute the means of the missing time steps and added the computed means to the other time steps within a season

4.3.3. Weighted index map overlay and factors influencing DSGRs sites

Weighted indexed overlay technique' is often used in 'spatial multi-criteria analysis' (van Westen and Farifteh, 1997; Venus, 2006)

Vegetation Productivity (MODIS NPP): Medium to High biomass production (kg/m2) will be favourites for DSGRs (Herlocker, 1999; Oba and Kaitira, 2006; Toxopeus, 1996).

Land cover: Grasslands, bush lands and woodlands will be favourable areas for DSGRs while populated areas (towns and villages) and land ownership (private ownership) will not be favourites.

Land use: Agro pastoral and mixed farming systems are good for DSGRs sites; other land use types: Agriculture (commercial farms), forests are not good for DSGRs sites.

Elevation, landforms and terrain: Level lands (plain gradient and plateau) and sloping lands (medium gradient) will be favourable areas for DSGRs while mountainous and high places, steep slopes, swamps and wetlands, water bodies; sendentarization/settlement/mushrooming trading centers; human population (areas with high human populations) and biodiversity conservation (game parks, sanctuaries, game reserves) will be hindrances to the location of DSGRs (Jaetzold, 1982; Schwartz, 1994; Toxopeus, 1996).

Distance to permanent water points and Roads network - The effect of accessibility on watering livestock: In easily accessible terrain like plains, cattle and small stock will normally graze up to 10-15 km away from the water source. In hills or mountains and/or bouldery, rocky, flooded, muddy surfaces, the wandering speed of animals is less than on the dry plains. Little or no research has been done on this area and it is assumed that the slight restrictions, moderate restrictions and severe restrictions reduce animal speeds by 10%, 25% and 50% respectively (Bake, 1994; Schwartz, 1994; Toxopeus, 1996).

Table 4-2: Estimated daily drinking requirements of non-lactating livestock under African range conditions according to Bake (1994).

Livestock		Daily requirements in liters		
Species	Weight (kg)	Mean	Max	For planning purposes
Goat	30	2.0	5.4	5.0
Sheep	35	1.9	5.2	5.0
Bovine	350	16.4	56.1	25.0

Source: Range management handbook of Kenya – volume 1 and 2 (Bake, 1994).

4.3.4. Animal requirements and forage demand for the dry seasons

Animal requirements have been calculated as kg dry matter forage per tropical animal unit (TLU) per day (Walsh, 1994). One TLU is equivalent to 250kg live weight. Considering the types and breeds of livestock prevalent in Naivasha, Kajiado and Narok Districts, one TLU is equivalent to 1.0 head of cattle or 10 sheep (Walsh, 1994).

Table 4-3: Animal requirements (kg dry forage matter/TLU/day)

Animal	**Maintenance/ production**
Cattle	6.4
Sheep	7.9
Goats	7.3

Source: Range management handbook of Kenya – volume 1 and 2 (1994) (Walsh, 1994)

The requirements for maintenance level i.e. with no body weight changes and no other outputs like milk or work, were based on the assumption that the available forage contains a minimum of 1.8 meal metabolisable energy and approximately 40 grams digestible protein per kg dry matter. This is a quality commonly found at the beginning of the dry season on semi-arid and arid rangelands of East Africa (Walsh, 1994). The levels of production used in this study for the calculation of the requirements are for maintenance plus a moderate production

Table 4-4: Livestock densities by regions

Region	**Cattle density (nos./km2)**	**Shoats density (nos./km2)**	**TLU/km2**
Lake Naivasha	15	40	25 - 50
Mau escarpment	35	50	50 -100
Southern region	15	25	10 - 25

4.3.5. Forage demand for the dry seasons

In order to determine the location and extent of the forage demand by livestock for the dry season, the length of the dry season should be combined with the average number of days per month, the dry matter (DM) intake value of a species and the distribution of the species (Toxopeus, 1996).

Equation 4-4: Forage demand for maintenance and production during the dry season

DD = DN * AR * LDS ……………………………………………………..**Equation 4-4**

Where:

DD = demand in TLUs (kg/m2)
DN = density (TLUs/km2)
AR = animal requirements (kg/TLU/day)
LDS = length of dry season in days

Length of Long dry season = 120 days
Length of Short dry season = 90 days

4.3.6. Flow chart of methods – Data processing

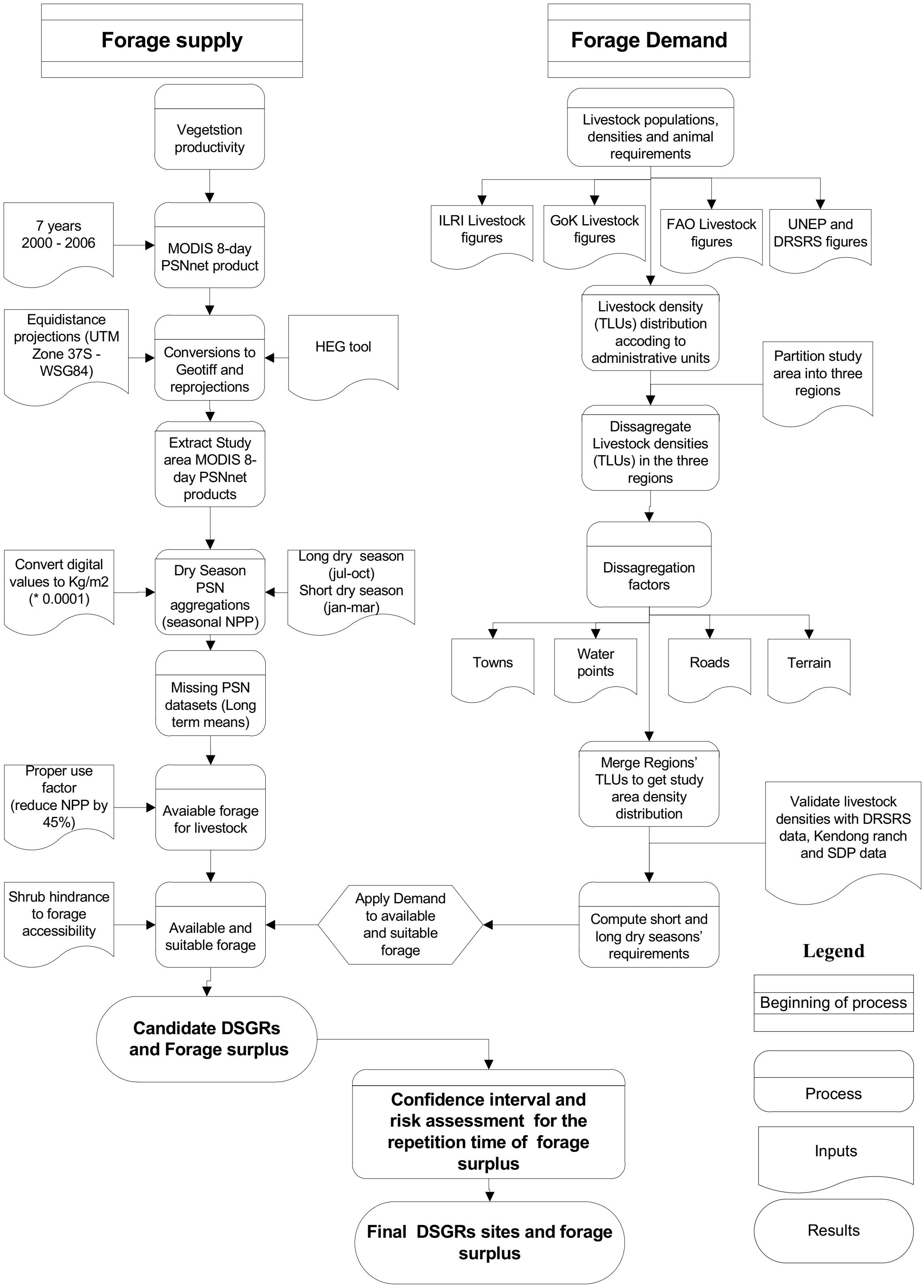


Figure 4-2: Flow chart of methods

4.4. Proper use factor and forage availability for livestock

According to FAO (FAO, 2000; Toxopeus, 1996), a combined factor, called edible forage, should be deducted from the NPP available to the animals to account for the grazing efficiency, forage loss and a "proper use factor" to account for sustainability. This factor may vary according to different researchers and the different situations from 30% in south Ethiopia, to 45% in Tsavo, Kenya (Toxopeus, 1996). The situation in Tsavo in Kenya is most comparable with the situation in the Naivasha, Ngong and Mau administrative units in our study area and therefore these estimates will be used in our study.
(FAO, 2000; Toxopeus, 1996) estimates that not more than 55% of the grass cover should be removed in one way or another to keep the grasslands at least in the same condition as it was before. So, if utilizing the grasslands should be sustained, to prevent degradation, at least 45% of the available NPP should be left at the beginning of the next rainy season. Additionally about 10% of the NPP will be reduced because of invertebrate consumption and natural decay, resulting in 45% of the NPP to be used.

The proper use factor can be combined with the NPP map to create a map with the amount of forage that can be used for grazing in a sustainable basis.

Equation 4-5: Sustainable forage availability

Sustainable forage availability = (NPP * proper use factor %) /100% **…… Equation 4-5**

4.4.1. Livestock grazing probability due to shrub hindrance

Factors like hindrance by vegetation will reduce the amount of forage to what is actually available for grazing. The reduction factors and methodology applied to estimate the suitability of the rangelands for grazing are according to the FAO (1988) classifications (Toxopeus, 1996).

After calculating the forage availability for livestock for the dry season, a livestock grazing probability due to shrub hindrance is applied to cater for the effect of shrub density influence on the availability of forage for livestock grazing.

Table 4-5: The different shrub hindrance classes and the estimated probability (%) for livestock grazing (Toxopeus, 1996)

	Shrub hindrance	**Probability**
1	0 - 2% shrub cover	100%
2	2 - 20% shrub cover	89%
3	20 - 40% shrub cover	70%
4	40 - 60% shrub cover	50%
5	> 60% shrub cover	20%

There are several other factors that prevent or impede livestock movements. Natural ones are, for example, extreme high or low temperature, often in relation to altitude, diseases, predators, flooding, etc (Toxopeus, 1996). However, in our study area these limiting factors are not really relevant and therefore not considered as a limitation for livestock grazing.

The livestock grazing probability map according to shrub hindrance is generated by applying the user-defined shrub hindrance values [%] to the classified shrub hindrance map.

4.4.2. Sustainable forage availability and probability for livestock grazing

The shrub hindrance probability factor map is applied, as a reduction factor to the potential forage availability for livestock grazing, to calculate the available forage left, after taking into account the different shrub hindrance probability aspects of the study area (FAO, 2000; Toxopeus, 1996).

The available forage (kg/m2) for livestock, after taking into account the shrub hindrance probability factor of the rangelands is the product of sustainable forage availability map multiplied by shrub hindrance probability for grazing (%).

Equation 4-6: Available forage (kg/m2) for livestock

$AF = SFA * SHP$ ……………………………………………………………**Equation 4-6**

Where:

AF = Available forage (kg/m2)

SFA = sustainable forage availability map

SHP = shrub hindrance probability (%)

4.5. Livestock distribution and forage demand for the dry Season

The Maasai livestock mainly consists of large herds of cattle but also sheep and goat herding is commonly practiced. Cattle, sheep and goat provide the Maasai in their basic demand for food (e.g., milk and meat). However, nowadays livestock becomes economically more valuable, since cattle, sheep and goat are sold at local markets.

Livestock distribution maps provide the user with information on the location and the number of animals per species in space and time.

When the location and density of livestock is known, the livestock forage demand for the long dry season can be calculated by combining it with the dry matter intake values (kg/day) per livestock species and the length of the dry season.

4.5.1. Suitability factors and Study area stratification

Study area stratified into regions according to the hydrological properties. This is an adaptation from the river basins of the study area (ILRI, 2007). Lake Naivasha basin, the Mau escarpment region and the southern region of the study area - this includes Ngong area and the flow of the Rift valley (the Kendong area, Longonot, Mahimahiu, Suswa and the area toward Magadi)

Suitability factors for livestock density distribution in the regions (Lake Naivasha region, the Mau escarpment region and Southern region) were assessed according to the proximity of livestock to watering points, towns, terrain and distances from roads.

A 3 km buffer from towns is the distance far enough from the settlement areas to avoid conflicts between humans and livestock and within reasonable distance accessible enough to provide the town residents with animal products (meat and milk).

In easily accessible terrain like plains, cattle and small stock will normally graze up to 10-15 km away from the water source. In hills or mountains and/or bouldery, rocky, flooded, muddy surfaces, the wandering speed of animals is less than on the dry plains. Little or no research has been done on this area and it is assumed that the slight restrictions, moderate restrictions and severe restrictions reduce animal speeds by 10%, 25% and 50% respectively (Bake, 1994).

According to Toxopeus (1996), the accessibility classification according to drinking water availability in the dry season is from 0 - 5 km (daily regime) and from 5-12 km (every other day regime). More than 12 km (other day or third day regime, but under severe conditions) is considered in principle as inaccessible, because the condition of livestock under these range conditions will become worse and worse.

Euclidean distance ESRI ™ ArcGIS® function is used to create continuous distance surfaces from the features (factors) and weighted overlay ESRI ™ ArcGIS® function is used to develop factors suitability and ratings. The closer to the towns 3km buffer zone, the more likely to find livestock; the nearer to the watering points the more likelihood of finding livestock; the higher the altitude, the less likelihood of getting livestock and the further from the main roods the more likelihood of getting livestock (Bake, 1994; FAO, 2000; Herlocker, 1999; Toxopeus, 1996).

4.5.2. Livestock population distribution Model

Livestock population and density figures is based on the data information from ILRI, MoL&FD, UNEP, Department of Resource survey and Remote sensing (DRSRS, 2004) and the validation survey done by the small holder dairy project (SDP), which found out that a conservative estimate of the size of the national livestock herd could be more than twice the officially reported figure of cattle. The SDP survey-based figures also indicated that there are at least 40–50 percent more zebu cattle, than the official figures.

In this study the reported TLUs figures are doubled for each of the study areas' regions. A livestock density range is assigned to the TLU values, covering the lowest reported TLU values and the highest (doubled) TLU values, as indicated in table 3-5 below.

Euclidean distance maps are constructed for each of the suitability factors and an interpolation is done based on the relative likelihood of population occurrence in cells due to proximity to main roads, watering points, towns and settlements and terrain.

Table 4-6: Livestock Density ranges in the three regions of the study area

Region	TLU/km2	Density Range
Lake Naivasha	25 - 50	25 - 50
Mau escarpment	50 -100	50 -100
Southern region	10 - 25	10 - 25

Source: Adaptations from MoL&FD, ILRI, UNEP, DRSRS, SDP

One TLU is equivalent to 250kg live weight of a zebu cow. Considering the types and breeds of livestock prevalent in Naivasha, kajiado and Narok Districts, one TLU is equivalent to 1.0 head of cattle or 10 sheep

Reclassification

ESRI ™ ArcGIS® reclassification function is used to reclassify/change cell values in the Euclidean distance maps to livestock density values, according to the respective regions' livestock density ranges and the factors' suitability ratings for grazing.

The classes are assigned to each range of cell values of each input variable (the euclidean distance maps). Reclassification for all regions is based on the following factors: Roads, weighted by distance from major roads; elevation, weighted by favourability of terrain categories; watering points, weighted by the distances from the water point and towns, weighted by the distances from the towns 3-km buffer zones.

Table 4-7: Regions density classes

Region	Class	Density values
Southern region	1 (far from the feature)	10
	2	15
	3	20
	4 (close to the feature)	25
Lake Naivasha	1 (far from the feature)	25
	2	30
	3	40
	4 (close to the feature)	50
Mau escarpment	1 (far from the feature)	50
	2	60
	3	75
	4 (close to the feature)	100

Source: Adaptations from (Bake, 1994; FAO, 2000; Herlocker, 1999; Toxopeus, 1996)

The resulting classes will be used to distribute the livestock population and density counts within any particular area of interest. Classes vary from region to region and even within a particular region.

4.5.3. Weighted Indexed Overlay for livestock density distribution.

Distance classes for each of the different features influencing the DSGRs sites are given ratings ranging from 1 (far from the feature) to 4 (close to the feature). The rating near the feature (4) has the highest livestock density values and the rating far from the feature (1) has the lowest livestock density values. Then the features are assigned weights according to their relative influence on the distribution of livestock densities. Proximity to water points has the highest influence (40%); proximity to towns follows with 30%, followed by proximity to roads 20% and lastly terrain (contours) 10%.

The reclassified Euclidean distance maps are combined using indexed overlay GIS technique (Venus, 2006). Each of the factors (roads, watering points, towns and settlements and terrain) is assigned suitability ratings according to the tables 3-6, 3-7, 3-8, and 3-9 and 3-10 below. These ratings are based on the relative likelihood of population occurrence in cells due to proximity to the features (Venus, 2006). Weighted indexed overlay technique' can also be referred to as a simple 'spatial multi-criteria analysis'

In ESRI ™ ArcGIS®, weighted Overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. It overlays several rasters using a common measurement scale and weights each according to its importance.

The three regions of Mau escarpment, L. Naivasha and Southern region have livestock densities reclassified according to the proximity to roads, towns, water points and the contours (Table 3-6). These are assigned weights according to the probable livestock densities in relation to the distances from the particular feature. The weights range from 1 (low livestock densities) to 9 (high livestock densities). The weighted livestock densities are then assigned measures of influence ranging from 0% to 100%. This is in accordance with the individual feature contribution to the overall livestock density distribution.

The factors and methodology applied to estimate the livestock density distribution (suitability of the rangelands for grazing) are according to the (Bake, 1994; FAO, 2000; Herlocker, 1999; Jaetzold, 1982; Schwartz, 1994; Toxopeus, 1996).

Table 4-8: Distant classes to watering points

Proximity to water points	Class	Distances(km)
	4	0 – 5
	3	5 - 10
	2	10 - 15
	1	> 15

Source: Adaptations from (Bake, 1994; FAO, 2000; Herlocker, 1999; Toxopeus, 1996)

Table 4-9: Distant classes to towns and settlements

Proximity to Towns (3 km buffer)	Class	Distances (km)
	4	0 – 5
	3	5 - 10
	2	10 - 15
	1	> 15

Source: Adaptations from (Bake, 1994; FAO, 2000; Herlocker, 1999; Toxopeus, 1996)

Table 4-10: Distant classes to roads and stock routes

Proximity to roads	Class	Distances (km)
	4	0 – 5
	3	5 - 10
	2	10 - 15
	1	> 15

Source: Adaptations from (Bake, 1994; FAO, 2000; Herlocker, 1999; Toxopeus, 1996)

Table 4-11: The different slope steepness classes and surface roughness; and the estimated suitability (%) for livestock grazing

Proximity to Terrain	Class	Suitability rating for terrain Steepness and roughness (%)
	4	100
	3	75
	2	50
	1	0 - 25

Source: Adaptations from (Bake, 1994; FAO, 2000; Herlocker, 1999; Toxopeus, 1996)

A field is added in the attribute table for each of the regions' weighted livestock density distribution maps. The regions' livestock densities are then distributed according to the weighted scale values. The created field is then used to merge the regions' livestock densities into a livestock density distribution map for the whole study area.

The product is a weighted distribution of livestock densities within the three regions (Mau escarpment, L. Naivasha and Southern region) of the study area, according to the proximity of livestock to towns, roads, water points and elevation.

A weighted overlay of the suitability factors is performed as follows: - (see Table: 3-11 below; a result of which is depicted in the livestock distribution map of Figure 4-3.

Table 4-12: Weighted distribution of livestock densities in the regions

Regions	Suitability factor	Classes	Density values	Weighted scale values	Influence (%)
Southern region	Water points	1	10	1	40
		2	15	4	
		3	20	7	
		4	25	9	
	Towns (3-km buffer)	1	10	1	30
		2	15	4	
		3	20	7	
		4	25	9	
	Roads	1	10	1	20
		2	15	4	
		3	20	7	
		4	25	9	
	Contours	1	10	1	10
		2	15	4	
		3	20	7	
		4	25	9	
Lake Naivasha	Water points	1	25	1	40
		2	30	4	
		3	40	7	
		4	50	9	
	Towns (3-km buffer)	1	25	1	30
		2	30	4	
		3	40	7	
		4	50	9	
	Roads	1	25	1	20
		2	30	4	
		3	40	7	
		4	50	9	
	Contours	1	25	1	10
		2	30	4	
		3	40	7	
		4	50	9	
Mau escarpment	Water points	1	50	1	40
		2	60	4	
		3	75	7	
		4	100	9	
	Towns (3-km buffer)	1	50	1	30
		2	60	4	
		3	75	7	
		4	100	9	
	Roads	1	50	1	20
		2	60	4	
		3	75	7	
		4	100	9	
	Contours (terrain)	1	50	1	10
		2	60	4	
		3	75	7	
		4	100	9	

4.6. Confidence interval and risk assessement for the final DSGRs

Confidence interval is a range of values for a variable of interest (e.g. relative risk reduction or absolute risk reduction) constructed so that this range has a specified probability of including the true value of the variable. The specified probability is called the confidence level, and the end points of the confidence interval are called the confidence limits (Wei and Sugahara, 2002).

It is a widespread convention to create confidence intervals at the 95% level so this means that 95% of the time properly constructed confidence intervals should contain the true value of the variable of interest e.g. relative risk reduction or absolute risk reduction (Wei and Sugahara, 2002).

The Confidence interval of a proportion of the forage surplus assesses the reliability of the DSGRs (forage surplus) maps. With a 95% confidence interval, an agreeable number of dry seasons should have more than 70% of the repletion times of surplus availability of forage in the same locations and approximately the same quantities. The Confidence interval of a proportion is testing which constellation of DSGR sites will cover dry season forage shortage (demand), thereby minimizing expenditure on drought related interventions in an agreeable minimum number of seasons out of 14 dry seasons.

The agreeable "true" repetition time (out of 50+ years making up 100+ dry seasons) based on the sample of 14 seasons is such that 70% of the seasons are showing consistency in the repetition times of the forage surplus maps, at a confidence interval of 95%. This is the demanded repetition time.

The 95% confidence interval is expressed as a range of the population proportion, denoted by $\hat{p}$ ± SE*t, where SE is the standard error and t is the t-statistic at 95% confidence interval. A 95% confidence interval has the form of estimate ± margin of error. The estimate of $\hat{p}$ is the guess for the value of the unknown parameter p. The margin of error (± SE*t) indicate how accurate the guess is. The confidence interval of 95% shows how confident we are that the procedure will catch the true population proportion p (Jan de Leeuw, 2006).

The procedures for calculation of confidence intervals are outlined in Moore and McCabe (Moore and McCabe, 2003). They are based on the normal approximation. In reality counts and proportions follow a binomial distribution. The normal approximation provides reliable confidence intervals for counts and proportions under particular conditions. Moore and McCabe recommend usage of the normal approximation when the number of successes (true) and the number of failures (false) are both greater than 10. This satisfies the requirements of the underlying statistics for normal approximation (Jan de Leeuw, 2006).

5. Results

The results of the analysis using the materials and methods outlined in the immediate past chapter are detailed below. The main results of our study include the NPP and the so called the "peak standing crop", sustainable forage availability, livestock density distribution, hazard analysis of the DSGRs, risk assessment of the DSGRs and the risk management i.e. the influence of infrastructural development on the DSGR sites.

5.1. NPP and the peak standing crop

The aggregated dry season NPP in this study is assumed to be the equivalent of the so called the "peak standing crop" (Toxopeus, 1996).

The NPP is aggregated according to seasons (2 dry seasons and 2 wet seasons). This is summing all the 8-day NPP images for the entire season. The seasons aggregate NPP is multiplied with the scale factor – 0.0001 (NASA) to convert the pixels values to kgCm-2. Then the unmodelled pixels are removed from the images (NASA).

Dry seasons: Short dry season – January to March (001 Julian day to 089 Julian day 8-day time step) and the Long dry season – July to October (185 Julian day to 297 Julian day 8-day time step)

Wet seasons: Short wet season – November to December (305 Julian day to 361 Julian day 8-day time step) and the Long wet season – April to June (097 Julian day to 177 Julian day 8-day time step)

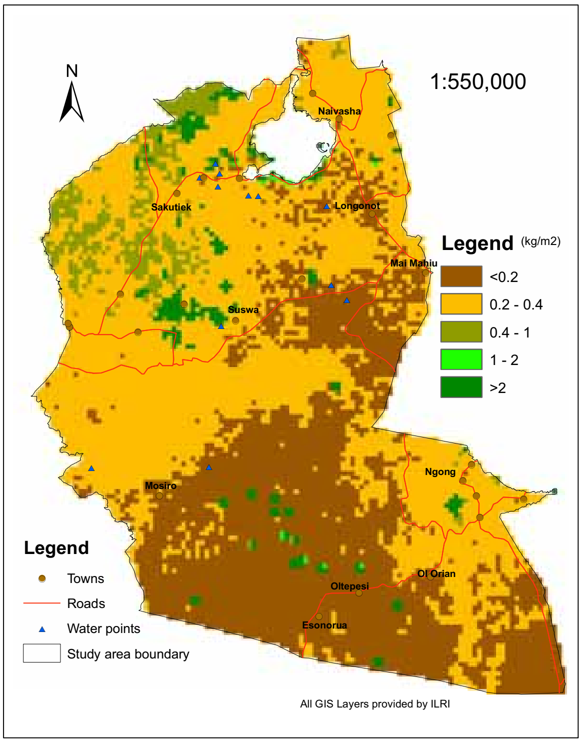


Figure 5-1: NPP (Kg/m2) – Long dry season July to October (2006)

5.2. Sustainable forage availability map

The proper use factor and grazing probability due to shrub hindrance [%] is applied to the NPP map to create a so called “sustainable forage availability” map with the amount of forage that can be used for grazing in a sustainable basis.

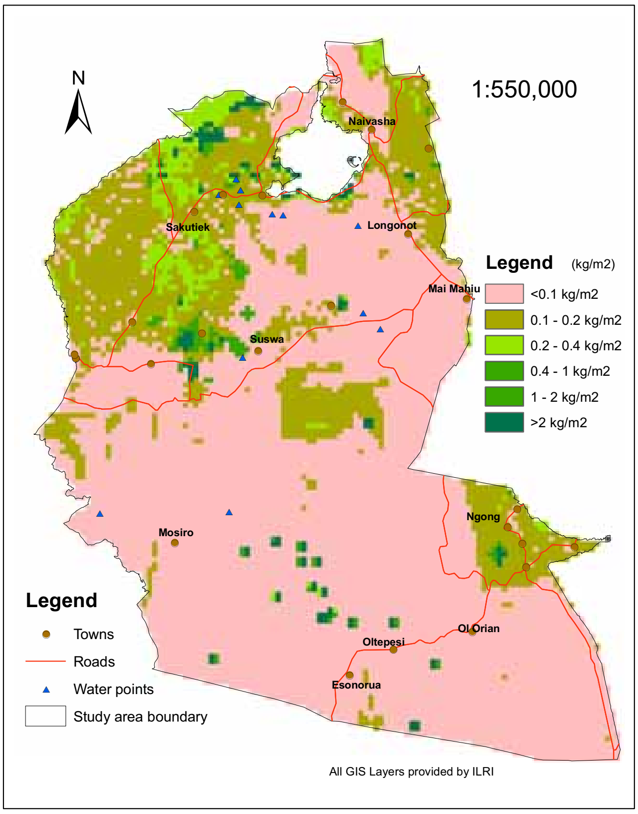


Figure 5-2: Sustainable forage availability (kg/m^2) map

5.3. Forage demand in the study area

The livestock density ranges in the Lake Naivasha, Mau escarpment and Southern regions are 25 to 50, 50 to 100 and 10 to 25 TLUs respectively (Table 4-1: Livestock Density ranges in the three regions of the study area) and animal requirements for cattle, sheep and goats are 6.4, 7.9, and 7.3 kg dry forage matter/TLU/d for maintenance and production (Table 4-2: Animal requirements (kg dry forage matter/TLU/d)).

Length of Long dry season = 120 days and the length of Short dry season = 90 days

Equation 5-1: Forage demand during the long dry season

$$DD = (DN * AR * 120)/1000000 \ldots\ldots\ldots\ldots \textbf{Equation 5-1}$$

Where:

DD	=	Demand (Long dry season)
DN	=	density (TLUs/km2)
AR	=	animal requirements (kg/TLU/day)
120	=	length of long dry season (days)
1000,000	=	conversion factor to kg/m^2

Equation 5-2: Forage demand during the short dry season

$DD = (DN * AR * 90)/1000000$ ………………………………………..…....**Equation 5-2**

Where:

DD	=	Demand (Short dry season)
DN	=	density (TLUs/km^2)
AR	=	animal requirements (kg/TLU/day)
90	=	length of the short dry season (days)
1000,000	=	conversion factor to kg/m^2

5.4. Study area livestock distribution map

The weighted distribution of livestock densities in the regions is combined to form a weighted distribution of livestock densities in the whole study area. This will used for further analysis together with the dry season forage availability maps derived for the analysis of the NPP data.

The combination of the seasonal livestock densities and the dry season forage availability maps creates the so called DSGRs or the forage shortage and surplus maps. These are maps are showing the dry season' forage shortage and surplus.

The weighted distribution of livestock densities contain a weighted scale values column with values ranging from 1 to 9. This field is used to distribute the of livestock densities according to each of the three regions' range of livestock densities. The resulting map is a livestock distribution map for the whole study area, with an attribute field containing the livestock densities. This attribute field is the combination of the three regions' (Mau, L. Naivasha and Southern region) range of livestock densities

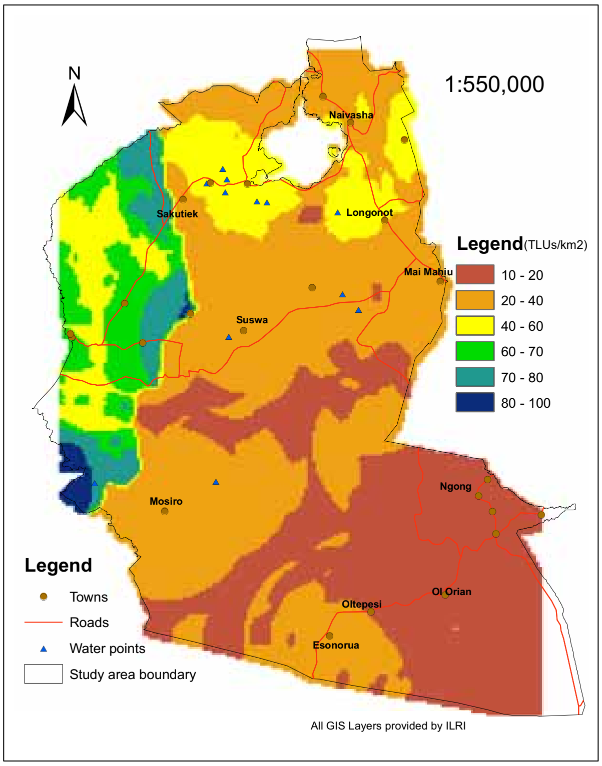


Figure 5-3: Study area livestock density distribution (TLUs/km^2)

Small pockets of the study area in the lower south eastern part and the western side are showing missing data (blanks). This is attributed to the limited extend (lack of data) for the factors influencing the livestock density distribution. All the GIS data layers were provided by ILRI

5.5. Hazard analysis of candidate DSGRs

One of this research questions is to find out where and how much forage is available; based on supply and demand. The hazard analysis was carried out to evaluate the distribution of forage shortage or surplus in the study area. The areas with surplus forage are the potential candidate DSGRs sites.

Dry season grazing reserves (DSGRs) are those which, even under the poorest environmental conditions i.e. at the absolute peak of the dry season, still have water and forage, and are thus irreplaceable as reserves during the cyclical periods of scarcity. Dry season grazing reserves are utilized intensively over long periods, receiving disproportionate grazing pressure during times that allow no other option.(Schwartz, 1994).

The seasonal demand (Long dry season and Short dry season) is deducted from the seasonal "sustainable forage availability" map to get the forage shortage and surplus map. This follows the principle of supply versus demand. The grid cells with values of less than zero (0) are the forage shortage areas; and those with values greater than 0 are the forage surplus areas. These forage surplus areas are the candidate DSGRs sites.

The "sustainable forage availability" map is the NPP map after proper use factor and grazing probability due to shrub hindrance have been applied.

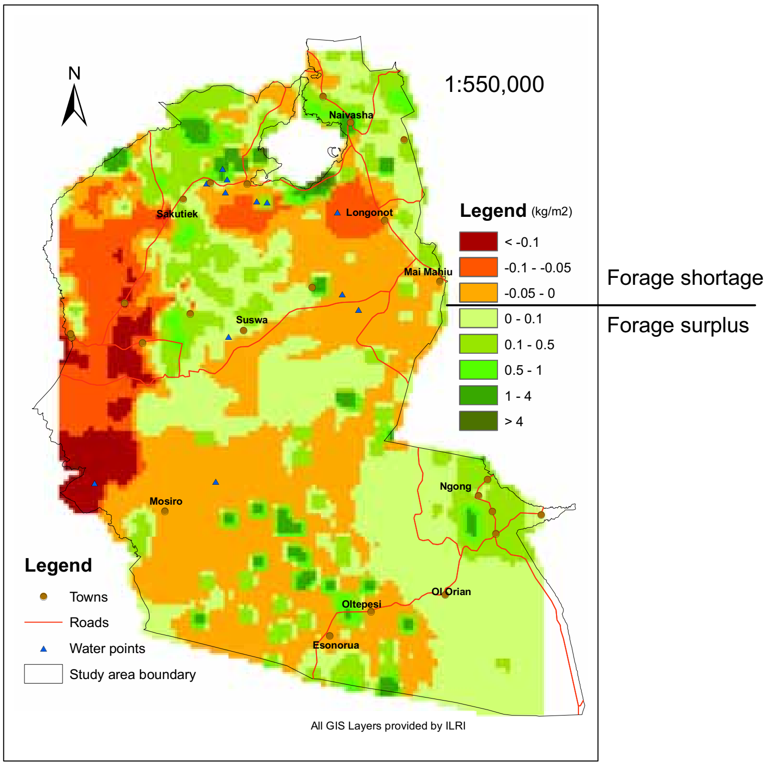


Figure 5-4: Candidate DSGRs and Long term means (kg/m^2) of forage shortage and surplus

Small pockets of the study area in the lower south eastern part and the western side are showing missing data (blanks). This is attributed to the limited extend (lack of data) for the factors influencing the livestock density distribution. All the GIS data layers were provided by ILRI

5.6. Risk assessment of the forage surplus in the final DSGRs

The confidence interval of a proportion is used to assess the reliability of the repetition time of the surplus forage in the DSGRs for the 14 dry seasons.

A level C confidence interval for a parameter is an interval computed from sample data by a method that has probability C of producing an interval containing the true value of the parameter (Moore and McCabe, 2003). Confidence interval is a method to express the level of risk (risk assessment)

In this study, risk assessment is done using confidence interval of the repetition time of the DSGRs forage surplus. The demanded repetition time according to one of the hypotheses of this study is that more than 70% of the dry seasons should have forage surplus. This becomes the lower limit of the confidence interval for the observed repletion time of forage surplus.

Confidence intervals are equivalent to encapsulating the results of many hypothesis tests. They explicitly show the region where you’re likely to find the true answer. A confidence interval at the 95% level means that 95% of the time properly constructed confidence intervals should contain the true value of the variable of interest e.g. relative risk reduction or absolute risk reduction (Wei and Sugahara, 2002).

In ESRI TM ArcGIS®, the forage shortage and surplus maps are reclassified into two classes of surplus (1) and shortage (0) for each map, for the 14 dry seasons in the 7 year period. Using the cell statistics tool, the 14 classified maps are summed up to get a new map of 14 classes with values ranging from 0 to 14.

Statistics and histogram for the forage surplus map

Statistics and histogram for the new forage surplus map of 14 classes with values ranging from 0 to 14 is analysed and the following statistics and histogram are derived: Maximum Value: 14.0, Minimum Value: 0.0, Mean: 5.87, Median: 4.0, Mode: 0.0, Standard Deviation: 5.345.

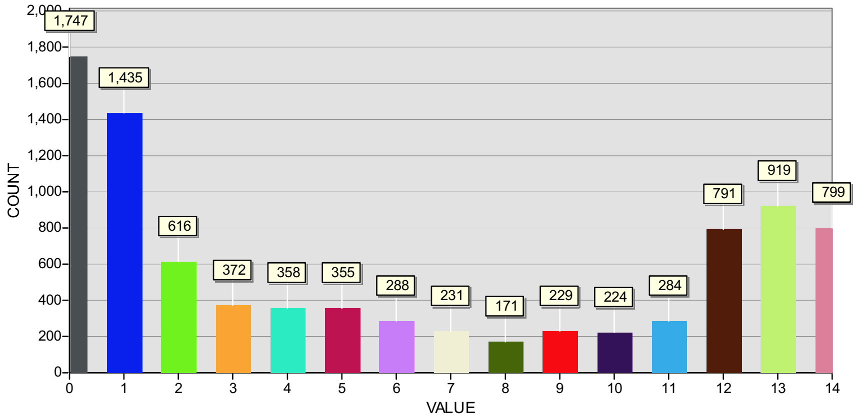


Figure 5-5: Observed repetition of dry season forage surplus (ORFDS) 2000-2006.

Based on these descriptive statistics and histogram, our data allow for the normal approximation. The sum of the individual pixel values at the two ends of the histogram (1747+1435+616+372 = 4170) expressed as a percentage of the total pixel values 4170/8819*100 = 47.28% and (284+791+919+799 = 2793) expressed as a percentage of the total pixel values 2793/8819*100 = 31.67%. This shows that about 80% of the pixels with the true or false values are located in this region. This translates to more than 11out 14 times in our sample size, where the true or false pixel values will be located. This meets the minimum requirement that there are more than 10 chances of getting a true or false in order to use the t-test table for normal approximation.

5.6.1. The temporal repetition time of forage surplus in the DSGRs

After showing through the histogram that the requirements of the underlying statistics for normal approximation are met, for most of the pixels, the 95%-C.I. is set once and for all (constant for every pixel). Testing the "observed repetition of forage surplus" (i.e. count/N) against the "demanded repetition of forage surplus" (i.e. 10/14) follows: if (ORFS >= DRFS - 95%-C.I.) AND (ORFS <= DRFS + 95%-C.I.) flag pixel as "true" else flag pixel as "false" end if where: "observed repetition forage surplus" (ORFS) = count/14 “demanded repetition of forage surplus" (DRFS) = 10/14

The 10/14 is chosen because the target or "the demanded repetition time" is "> 70% out of all seasons". A confidence interval equals p hat ± t * SE. The value of t depends on the confidence level. For confidence level 95% and N=14, the t--value = 1.771 (a single sided test), and the 95% CI equals p hat ± 1.771*0.12

The t-value used in this study is for a single-sided test because all the cells with values greater than the maximum requirement for a forage surplus within the 95% confidence interval are needed. Any cell with values greater than the maximum value is included in the final selection. Therefore the range within which to expect p to be located with N = 14, X = 10 and P hat = 0.70, at 95% confidence interval as follows:
SE = √ (0.70*(1-0.70)/14)
SE = 0.12
Upper Limit (UL) in the 95% C.I. = 0.70 + 1.771* 0.12 = 0.913824

The demanded repetition time (r) of forage surplus of 70% is used to determine the range in the observed repetition time (r) of forage surplus with a confidence interval (CI) of 95%. This CI analysis uses a small sample size of 14 seasons for the statistical evaluation, which is done in Microsoft™ Excel® spreadsheet, to determine whether the observed repetition time (r) of forage surplus covers the demanded repetition time (r) of forage surplus of 70%.

The demanded repetition time of forage surplus (hypothesis) of more than 70% falls within the range of the 95% CI of repetition time in 7 out of 14 seasons in our observed repetition time of forage surplus. The repetition time is such that the forage surplus in the dry seasons has repetition time of more than 70% which means that it is a single sided confidence interval.

Table 5-1: Observed repetition time of forage surplus in 7 out of 14 seasons.

	CI on "observed r"		Absolute nos.
	t	1.771	
7	phat	50%	7
	N	14	
	SE	0.13	
	95% CI = 0.50 + 1.771* 0.13		
	UL:	74%	10.36

In seven (7) out of 14 seasons, our observed repetition time of forage surplus gives a CI range of 0.26 and 0.74. The demanded repetition time of forage surplus of 70% (equivalent to 9.8 of 14) falls within this range. The upper limit is 0.74 which corresponds to 10.36 in absolute numbers the upper limit.

The upper limit (UL = 10.36) of the 95% CI observed repetition time is greater than 9.8 (70%) repetition times in our single sided t-test. This means that out true repetition time is a minimum of 10.36 minus 5% of 10.36, approximately 10. This becomes the minimum threshold for the single sided 95% CI test.

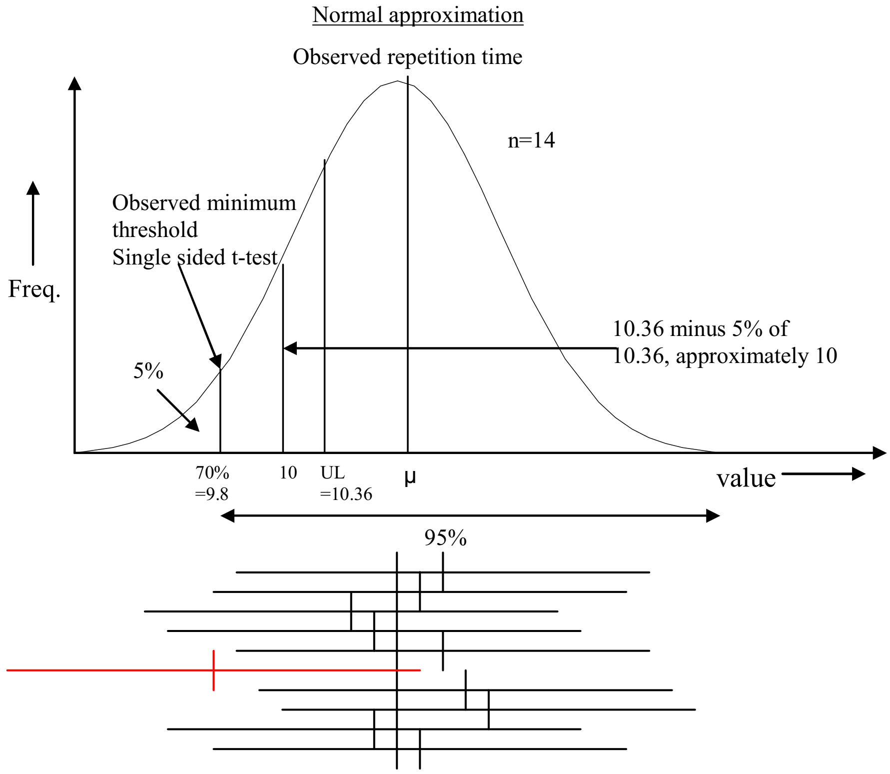


Figure 5-6: Single sided CI of repetition time for the forage surplus

In the above diagram, a level of 95% single sided confidence interval for the 70% of the repetition time of a forage surplus in the dry seasons is constructed. The cross marks the sample mean, which is the centre of the interval. The lines on each side of the cross span the confidence interval. They represent the number that "hit" (i.e., confidence interval did not contain μ) and the red line represents the numbers of hits outside the 95% CI (Moore and McCabe, 2003). Here again it is assumed that the forage surplus is normally distributed.

At 95% confidence interval, the true repetition time of the demanded forage surplus is located at a minimum of 10 in our observed repetition time of forage surplus.

In our small sample of 14 dry seasons, the 95% CI of the true repetition time of forage surplus is more than 10 times in our observed repetition time of forage surplus.

The CI for the forage surplus repetition time is temporal risk assessment of only one pixel. The CI for the forage surplus repetition time will be replicated in all the pixels in the study area. This becomes a spatial risk assessment. In order to replicate the CI for the forage surplus repetition time in all the pixels in the study area, the critical p-value needs to be adjusted using the Bonferroni correction.

5.6.2. Determining spatial and multiple repetition time hypotheses

The Bonferroni correction states that if an experimenter is testing n independent hypotheses on a set of data, then the statistical significance level that should be used for each hypothesis separately is 1/n times what it would be if only one hypothesis were tested (Delgado et al., 2007).

The Bonferroni correction is a safeguard against multiple tests of statistical significance on the same data (Delgado et al., 2007), where 1 out of every 20 hypothesis-tests will appear to be significant at the $\alpha = 0.05$ level purely due to chance. It was developed by Carlo Emilio Bonferroni.

A less restrictive criterion is the rough false discovery rate giving (3/4)0.05 = 0.0375 for n = 2 and (21/40)0.05 = 0.02625 for n = 20.

Bonferroni correction: 1/n*significant level
Where n = sample size
A less restrictive criterion is the rough false discovery rate giving (3/4)0.05 = 0.0375 for n = 2 and (21/40)0.05 = 0.02625 for n = 20.

Bonferroni correction is used in this study to correct for the p-value when determining the repetition time for every pixel in the spatial extent of the study area.

Less restrictive correction: (n+1)/(2*m)*significant level
Where:
n = the sample size
m = total number of pixels
Total number of pixels: 8819 (see figure 5-5)
15/28*0.05=0.026785714
Therefore the critical p-value = 8820/17638*0.05=0.025

This is the critical p-value which is used to determine the t-statistic in the spatial risk assessment of the forage surplus for all the pixels in the DSGRs.

In a single sided t-test the 95% CI = 0.50 + 2.16* 0.13 = 10.9312, approximated to 11 repetition times for all pixels in the study area.

5.6.3. Conditional evaluation of risk assessment in a GIS

In seven (7) out of 14 seasons, our observed repetition time of forage surplus gives a CI range of 0.26 and 0.74 repetition times. The demanded repetition time of forage surplus of 70% falls within this range.

However the true repetition time of the demanded surplus forage map is located at a minimum of 10 observed repetition times of forage surplus maps in 50% of the dry seasons. This is the minimum threshold within which our observed repetition time will be located at 95% confidence interval. In ESRI TM arcGIS®, the conditional evaluation function (Con) is applied to the 95% confident interval of the surplus forage map, which is located at a minimum of 9 repetition times in 50% of 14 seasons. This range is applied to the sum of the reclassified forage shortage and surplus map for the 14 dry seasons.

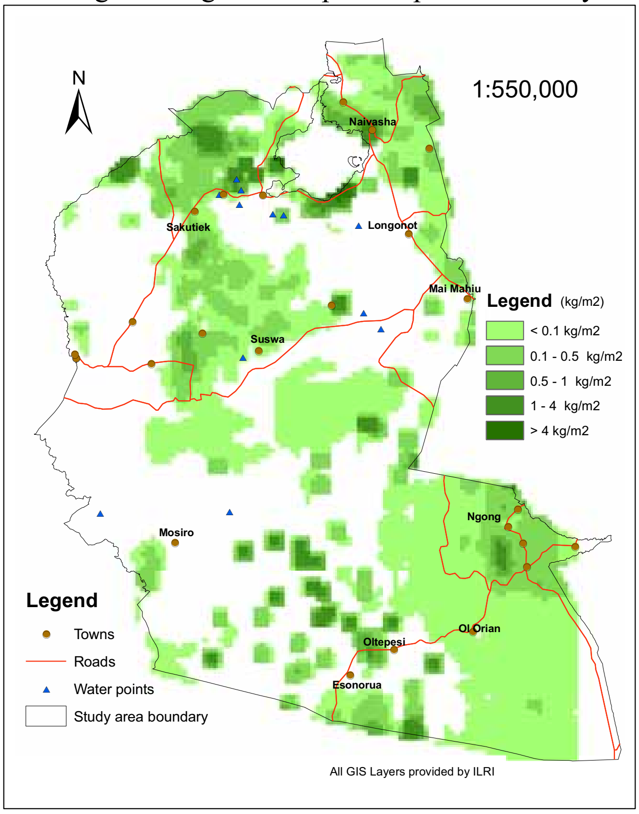


Figure 5-7: Long term means - dry season forage surplus (candidate DSGRs)

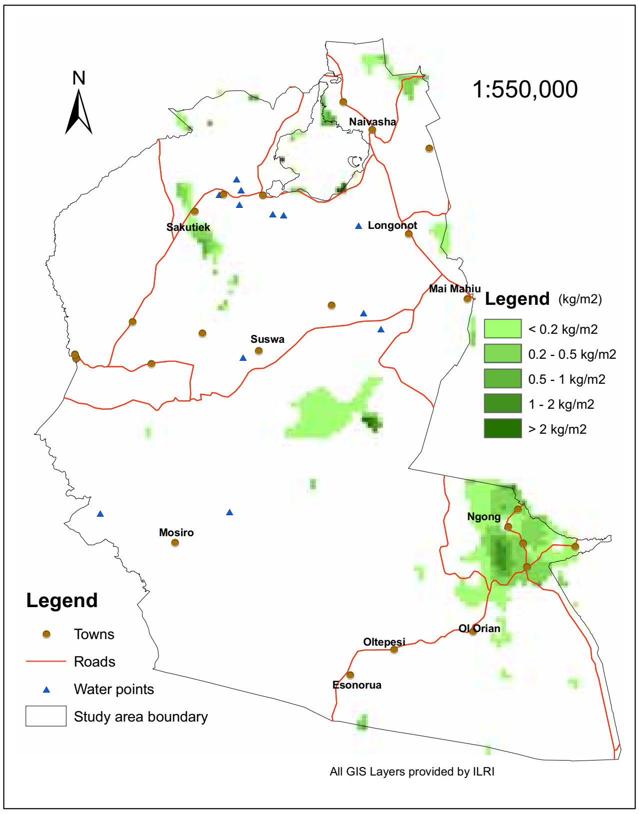


Figure 5-8: Forage surplus in the final DSGRs

There are 11 repetition times in the 14 dry seasons at 95% CI in a single sided t-test. These are the final DSGRs in the study area.

The 95% CI forage surplus analysis reveals that the final DSGRs sites are in the following areas: the Ngong area, the area in the hills south of Suswa township, the area near Sakutiek township in the Mau escarpment, the area around L. Naivasha and the areas north west of Naivasha town and west of Longonot town.

5.7. Testing hypothesis 1 and the findings

This hypothesis is testing whether the model has addressed the research question: - where and how much forage is available in the candidate DSGRs; based on supply and demand (the amount of forage available – NPP versus the livestock densities)? To test this hypothesis the modelled (estimated) livestock densities is validated with the observed livestock counts (DRSRS livestock data)

H_o - There is significant difference between the estimated demand (the modelled livestock densities) and the observed demand (actual livestock densities).
H_a - There is no significant difference between the estimated demand (the modelled livestock densities) and the observed demand (actual livestock densities).

5.7.1. Validating the livestock distribution model using DRSRS data

DRSRS carried out, on seasonal/yearly basis, both livestock and on wildlife aerial census to estimate the distribution and the number of large herbivores in ASAL areas of Kenya (DRSRS, 2004).

During the execution of this study, the only available DRSRS livestock counts data was for Narok District in 5 km grid. This dataset does not cover the whole of the study area. It covers the Mau Division of the study area only. It is used to validate the livestock density distribution model developed in this study

Mau DRSRS livestock counts data and testing hypothesis 1

Narok 5km grid is reprojected using the equidistance projection, UTM Zone 37S and WSG84 ellipsoid. DRSRS observed livestock counts data in dbf formats, for the years 1980, 1983, 1985, 1986, 1987, 1989, 1990, 1991, 1992, 1993, 1994, 1996 and 2002, is appended to the Narok 5km grid (DRSRS, 2004). Mau DRSRS observed livestock counts data is extracted from the Narok data, converted to TLUs and long term medians and means calculated.

Random sample points are generated for the Mau Division of the study area. These sample points are used to generate samples of the Mau division observed (long terms medians) and estimated (modelled) forage demand. Using the table of the created samples in MS Excel, regression analysis and ANOVA (analysis of variance) is done.

The observed (actual) DRSRS livestock data for Mau Division (a part of our study area) in Narok District is used to assess the reliability of our modelled livestock densities using regression analysis and ANOVA

5.7.2. Single variable regression and ANOVA

Single variable regression: the estimated TLUs (modelled livestock densities) versus the observed long term median TLUs for all years of available data (DRSRS data).
The long term median of the observed TLUs is used because the observed TLUs (DRSRS data) is so skewed that using the long term means will introduce a bias.

Table 5-2: Single variable regression analysis

Regression Statistics	
Multiple R	0.2702
R Square	0.0730
Adjusted R Square	**0.0701**
Standard Error	22.3478
Observations	320

The estimated TLUs (modelled livestock densities) versus the observed long term median TLUs for all years of available data (DRSRS data).

Table 5-3: Single variable ANOVA

	Coefficients	***Standard Error***	***t Stat***	***P-value***
Long term TLU medians	-0.3055	0.0610	-5.0044	<0.05

Findings
A very low Adjusted R Square value of 0.0701, the small p-value of <0.05 and the negative t-stat value of -5.0044 are all showing a significant difference between the estimated and the actual Long term actual TLU medians.

This finding suggests that there is a significant difference between the observed livestock counts and the modelled (estimated) livestock densities, meaning therefore that the variability in observed TLU's is not explained by the model; hence the null hypothesis cannot be rejected at 95% confidence interval.

5.8. Testing hypothesis 2 and the findings

Confidence interval for the repetition time of the forage surplus is determined in testing this hypothesis. The 95% C.I. of the repetition time of the forage surplus attempts to answer the research question: which constellation of the DSGR sites will reliably cover dry season forage shortage and minimize expenditure on drought related interventions?

H_o - In more than 70% of the dry seasons, a forage surplus is observed at the candidate DSGRs sites.
H_a - In more than 70% of the dry seasons, a forage surplus is not observed at the candidate DSGRs sites.

Risk assessment for the repetition time of the forage surplus
The demanded repetition time of forage surplus of 70% (hypothesis) was used to determine the confidence interval (C.I.) of the observed repetition time of forage surplus. A sample size of 14 seasons is used in a statistical evaluation, to determine the range within which the observed repetition time of forage surplus covers the demanded repetition time of forage surplus of 70%.

Findings
There are 11 observed repetition times for all pixels in the 14 dry season of the study area. These are the pixels satisfying the requirements of the demanded repetition time of forage surplus of more than 70% (hypothesis 2).

In the 14 dry seasons we are 95% confident that the true repetition time of the demanded surplus forage map is at a minimum of 11 in our observed repetition time of forage surplus maps

Therefore the null hypothesis (H_o) - In more than 70% of the dry seasons, a forage surplus is observed at the candidate DSGRs sites, cannot be rejected.

5.9. Influence of infrastructural development on the DSGRs: Risk management

5.9.1. Testing hypothesis 3 and the findings

This hypothesis attempts to answer the research question: how is the infrastructural development influencing the constellations of the DSGR sites?

H_o - There is significant difference between influence of man-made infrastructural factors (roads, water points and towns) on the location of the DSGRs.
H_a - There is no significant difference between influence of the man-made infrastructural factors (roads, water points and towns) on the location of the DSGRs.

In answering this question the model will be explaining the variability in the location of the DSGRs due to the influence of man made infrastructural factors (roads, water points and towns), which are within the Governments control.

A surplus forage map is extracted from the forage shortage and surplus long term medians map. It is converted to a polygon shapefile in ESRI ™ arcGIS®. Random points are generated within the generated polygon shapefile. These random points are used to generate random samples in the other variables used in testing this hypothesis.

The long term means of the surplus forage (DSGRs) in the dry seasons are derived using cell statistics in ESRI ™ arcGIS®. These are used as dependent variables and are regressed against the medians of the observed livestock density medians derived from the DRSRS animal counts data; together with the man made infrastructural factors (roads, water points and towns); the terrain, the type of dry season and the lowland/highland factors. These are the independent variables.

The DRSRS livestock density data for the Mau administrative unit of our study is used together with the forage surplus data from the same area to find out the relationship between forage surplus and the observed livestock demand and other independent variables. The Mau 2002 dataset is used because it is the only overlapping dataset in the forage supply and livestock demand datasets.

The dry seasons' Mau livestock demand is determined by applying the seasonal animal requirements factor in annual livestock densities

5.9.2. Stepwise multiple linear regression and analysis of variance

Stepwise multiple linear regression statistics and analysis of variance (ANOVA) is used to evaluate the influence of various independent variables to the forage surplus (DSGRs) dependent variable.

The independent variables used include:-

a. The seasonal medians of the observed livestock demand, which is a market driven variable;
b. The infrastructural development variables (proximity to water points, towns and roads). These are man made variables which influence the DSGRs sites and are within the Governments control;
c. The type of dry season (where short or long dry season), restrictions due to terrain and the lowland/highland factors are also included as independent variables.

Functionally this can be expressed thus: - Forage surplus (DSGRs) is a function of observed livestock demand, proximity to infrastructural developments (water points, towns and roads), restrictions due to terrain, type of the dry season, and the lowland/highland factors

Equation 5-3: Functional form for the regression analysis and ANOVA

$$Y = a + bx + cz + ds + et + fu + g(\text{if } Q) + h(\text{if } R) \quad \textbf{.........................Equation 5-3}$$

Where:

Y	=	forage surplus (DSGRs)
a	=	constant
b	=	coefficient of demand
c	=	coefficient of proximity to water points
d	=	coefficient of proximity to towns
e	=	coefficient of proximity to roads
f	=	coefficient of restriction due to terrain
g	=	coefficient of type of dry season factor
h	=	coefficient of lowland/highland factor
x	=	observed livestock demand
z	=	proximity to water points
s	=	proximity to towns
t	=	proximity to roads
u	=	restrictions due to terrain
Q	=	type of dry season
R	=	lowland/highland factor

The medians of the observed livestock demand are used because the data is highly skewed (not normally distributed). This will help to avoid introducing a bias. The 95% confidence interval is used in the regression analysis.

The observed livestock demand is the TLUs from DRSRS data and infrastructural factors are the proximities to water points, towns and roads. The Livestock demand (TLUs) and forage surplus (DSGRs) are continuous variables, and as such have been aggregated (medians) over time and per season.

The type of dry season (where short or long dry season) and the lowland/highland factor are introduced in the stepwise linear regression as independent variables.

The adjusted r^2, the coefficient, P value and t-statistic of the independent variables are evaluated for significance of influence on the forage surplus and the acceptable sign of the correlation coefficient.

Correlation coefficient is a summary of the strength of the linear association between the variables. If the variables tend to go up and down together, the correlation coefficient will be positive. If the variables tend to go up and down in opposition with low values of one variable associated with high values of the other, the correlation coefficient will be negative (de Bie, 2006; de Bie et al., 2000).

If the p-value is greater than 0.05, then the variable has no significance influence on the observed demand and if the p-value is less than 0.05, then the variable has significance influence on the observed demand (de Bie, 2006).

The t statistic is a measure of how extreme a statistical estimate is (de Bie, 2006; de Bie et al., 2000). If the t-value is > 2 (or smaller than -2), the independent variable is significantly related to observed demand – TLUs medians (the depended variable).

The independent variables that do not meet the p-value and t-statistic requirements for significance of influence on the forage surplus and the acceptable sign of the correlation coefficient are dropped from the independent variables list and the regression and ANOVA analysis done again without these variables.

Findings

The first round of stepwise multiple linear regression statistics and ANOVA uses all the independent variables. The small correlation coefficients and a low adjusted R square suggest a weak correlation between the dependent and the independent variables. The low p-value and the t-statistic value, which is greater than 2, suggest that the livestock demand has significant influence on surplus forage. The lowland/highland factor also has significant influence on the surplus forage (low p-value and t-statistic value greater than 2).

An interesting finding is the infrastructural development influence on forage surplus. Proximity to water points has the most significant influence on surplus forage (a very low p-value), this is followed by proximity to towns, but the proximity to roads has no influence on the forage surplus (p-value greater than 0.05 and t-statistic is between -2 and +2).

Whether it is a short dry season or a long dry season does not seam to have significant influence the forage surplus - p-value greater than 0.05 and t-statistic is between -2 and +2. In this range of t-statistic values, the independent variables do not have significant influence on the dependent variable. The lowland/highland factor is has a negative coefficient. This has no meaning in relation to forage surplus

In stepwise multiple linear regressions, the three independent variables of proximity to roads, restrictions due to terrain and whether long or short dry season factors are dropped in the next round of stepwise multiple linear regression analysis. The lowland/highland factor is also dropped because of the negative sign of the coefficient.

In the second round of stepwise multiple linear regression statistics and ANOVA, Observed demand and proximity to towns and water points are used as the independent variables.

Table 5-4: Stepwise multiple linear Regression Statistics and ANOVA

Regression Statistics				
Multiple R	0.5075			
R Square	0.2576			
Adjusted R Square	0.2496			
Standard Error	0.2629			
Observations	378			
ANOVA				
	Coefficients	***Standard Error***	***t Stat***	***P-value***
Observed demand	0.661	0.299	2.21	0.03
Proximity to towns	0.000016	<0.05	2.97	<0.05
Proximity to water points	-0.000015	<0.05	-6.61	<0.05

Small correlation coefficients for the proximity to towns and watering points are due to the Euclidean distance units used in the analysis. They should be multiplied by 5 km (5000m) in accordance with the proximity map distance ranges. For example, the coefficients of proximity to towns and water points are 0.000016 and -0.000015 respectively. They are multiplied by 5000m to get 0.08m (corresponding to 40g/m2 of forage surplus) and -0.075m (corresponding to -38g/m2 of forage surplus) for towns and water points respectively. These coefficients are showing that increase in the proximity to towns' leads to an increase in the forage surplus, and the increase in the proximity to water points leads to a decrease in the forage surplus; though the rate of change in both cases is low.

A weak correlation exists between the independent variables (observed demand, proximity to towns, and water points) and dependent variable (forage surplus). A low adjusted R square value suggests a poor relationship. However individually all the independent variables have substantial influence on demand. They all have large t-statistic values and very small p-values, suggesting significant influence on forage surplus. The observed livestock demand, which is a market driven independent variable, has the highest influence on the forage surplus. The infrastructural developments, which are driven by the Government development agenda, are showing little influence in the forage surplus.

We therefore cannot reject the null hypothesis (H_o) that there is significant difference between influence of the man-made infrastructural factors (roads, water points and towns) on the location of the DSGRs.

6. Discussions

These discussions are centred on the relevance and implications of the findings of this study.

6.1. Validation of the estimated livestock densities

This research has shown that there is a significant difference between the observed livestock counts (DRSRS livestock data) and the estimated (modelled) livestock densities, meaning that the variability in observed TLU's is not explained by the model.

There are several reasons for this finding; among them being the quality of the infrastructural GIS datasets (roads, water point's towns), used in this study as the factors influencing the livestock density distribution. These datasets were complied at different times compared to the time the observed livestock counts were taken. The land tenure system and land use has an effect on the distribution of livestock (Thornton, 2002) as private ownership of land will not be available for grazing by the to the pastoralists' livestock. This has not been taken into account in this study. On the other hand, the quality of the DRSRS livestock counts is also questionable as the exercise has since been abandoned, together with the exercise being expensive as well.

Some of the reasons why the DRSRS Aerial surveys have been abandoned are that it was an expensive method and several validation studies (Jan de Leeuw and Prins, 1998) have questioned the accuracy of the data collection method. Four possible sources of error have been identified by de leeuw (Jan de Leeuw and Prins, 1998) which could make the DRSRS datasets unreliable. The counting errors made by the observers, the variation in the strip width covered by the census, the under-estimation of animal numbers in relation to tree cover and vegetation colour, and the misidentification of animal species during the census.

However, there is a pattern between the modelled forage situation and the information from the pasture situation on the ground. Personal observations revealed a forage availability and accessibility that was at equilibrium with the demand in normal years see pictures below. During the drought years, the available and accessible forage is far below the demand, leading to animal looses. This is based on the information from the pasture situations on the ground.


Forage surplus at equilibrium with demand in normal years.

6.2. Assessment of the repetition time of forage surplus

The forage surplus repletion time was assessed for the final DSGRs maps. With a 95% confidence interval, there is a repetition time of 11times in the 14 dry seasons with excess (surplus) availability of forage in the same locations and quantities able to sustain the increased influx of livestock in the DSGRs. This study has therefore shown which constellations of DSGR sites will reliably cover dry season forage demand, thereby minimizing losses and expenditure on drought related interventions. These constellations of DSGR sites have a repetition time of 11 times in the 14 dry seasons.

In 14 seasons we are 95% confident that the true repetition time of the demanded surplus forage map is located at a minimum of 11 in our observed repetition time of forage surplus during the dry seasons. Only in 5% of the cases the repetition time would be located outside this interval in repeated sampling the true repetition time.

This means therefore that in more than 70% of the dry seasons, a forage surplus is observed at the specified DSGRs locations, with a confidence interval of 95%.

This research has shown that there is need to apply a risk factor in the DSGRs site selection studies. This finding agrees with the risk mapping studies, where a factor of uncertainty is accounted for in order to enhance the reliability of the site selection results (Jan de Leeuw, 2006; Wei and Sugahara, 2002).

Caution is however needed when evaluating the confidence interval of a proportion for a small sample size because this can introduce a bias. We used a small sample size of 14 dry seasons. A Larger sample size, preferably 100 dry seasons, is recommended for a comprehensive conclusion on the confidence interval for the demanded repetition time of the forage surplus (Jan de Leeuw, 2006).

It should also be noted that, although uncertainty and reliability were used in determining the true repletion times of the forage surplus in the final DSGRs, strictly speaking, the uncertainty in the reliability of the site selection studies is not what has been achieved here. Uncertainty assessment could ideally have involved determining the error propagation as a result of the cumulative errors in the datasets used in this study - the MODIS NPP datasets and the GIS data layers and the other dataset from different sources.

6.3. Infrastructural developments' influence on DSGRs and forage surplus

The adjusted R square has been shown to be marginally weak in the stepwise linear regression analysis. This suggests a weak relationship between all the independent variables including infrastructural development and the forage surplus. The low and negative coefficient value for the proximity to watering points shows that this is the most limiting variable in the forage surplus (DSGRs).

Proximity to water points, towns; the lowland/highland factor and livestock demand are the principal factors influencing the location of the DSGRs (forage surplus). Proximity to roads, restrictions due to terrain and whether it is a long or short dry season are not showing significant influence on the location of the DSGRs (forage surplus). These findings lead to the conclusion that some infrastructural developments have more influence on the location of the DSGRs compared to others.

Although the impacts of infrastructural development on livestock distribution and forage availability has been studied by many researchers, (Herlocker, 1999; Ndikumana, 2000; Schwartz, 1994; Toxopeus, 1996) little research has been directed toward understanding the influence of infrastructural development on the sustainability of surplus forage production.

This research has shown that there is significant difference in the influence of the infrastructural development on the of forage surplus during the dry season. This is a critical period of resource management when the relationships between the supply and demand need to be understood clearly in order to adequately mitigate the impacts of droughts.

The coefficients have shown that increase in the proximity to towns' leads to an increase in the forage surplus, and the increase in the proximity to water points leads to a decrease in the forage surplus; though the rate of change in both cases is low. This means that water point development should be handled with care as it has the potential to affect the DSGRs sites and the forage surplus. The low rate of change in both the water points and the towns calls for further investigation before making a case for or against any of the two developments.

However it is expected that an increase in the proximity to towns' will lead to a decrease in the forage surplus (Herlocker, 1999; Ndikumana, 2000; Oba, 2001). This is not what has been observed in our study. This can partly be attributed to the inadequate estimation of the livestock densities and the general quality of the datasets used in the study.
It is therefore recommended that further investigation should be done to establish the strength of the influence of different infrastructural developments on the location of the DSGRs.

6.4. Implications of this study

Development planning

More often than not, the prioritization of developments agenda is usually done without feasibility studies to establish the probable impacts of the envisaged project. This study brings out clearly where the DSGRs are located and their reliability to withstand increased grazing pressure during drought. This will inform the decision maker on what development agenda to undertaken and its potential impact on the pastoral systems. It will improve and also form an important component of the drought early warning systems.

Indigenous knowledge of the Maasai and the new technologies

The Massai have lived in this area for centuries. They understand the area very well. Their pastoral way of live dictates that they are well informed about the dry season grazing areas, the so called DSGRs in this study (Ndikumana, 2000; Oba and Kaitira, 2006). This study helps to bring out clearly where these DSGRs are located and their reliability to sustain the expected increase of grazing pressure during the dry seasons. This will be useful information to the other stakeholders who may not have adequate knowledge of dry season grazing patterns of the Massai.

The advent of the cellular phone technology is a good complement for this study. It has been used by the pastoral communities to pass information, on timely basis, especially about the livestock marketing situations (Ochieng, 2006) in a project known as LINKS. LINKS stands for "Livestock Information Network and Knowledge Systems". This can as well be used to pass information about the state of the DSGRs. This helps to enhance reliability of the sites and prevent overgrazing as it discourages higher concentrations of the animals than the capacity of the DSGRs. It will enhance the quality of the drought early warning systems.

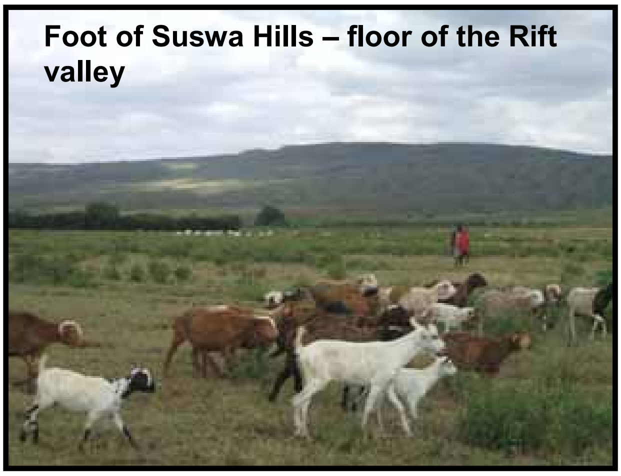
Land titles and land use

The location of the DSGRs is occasionally in conflict with the existing land use types and land titles. This study helps to engage the stakeholders in informed discussions in order to resolve any conflicts which may arise as a result of competition for the scarce resources especially during droughts. The 95% CI forage surplus analysis reveals that the reliable DSGRs sites in the following areas: the Ngong area, the area in the hills south of Suswa township, the area near Sakutiek township in the Mau escarpment, the area around L. Naivasha and the areas north west of Naivasha town and west of Longonot town.

In these areas, other land use types are increasingly taking over what were once pastoral drought reguge areas (DSGRs in this study).In the Sakutiek area, wheat farms are replacing the grazing areas; in the riparian zones of L. Naivasha, the commercial flower farms and the biodiversity conservation initiatives are now occupying the once dry season grazing reserves. In areas where pastoral grazing systems are still practiced, the forage is always at equilibrium with the demand in normal years, as shown in the photo for the foot slopes of Suswa and the Kendong area at the floor of Rift valley. In drought years, these areas experience forage shortages.

The frames below are pictorial representations of the various immerging land use changes in the areas which were typically pastoral grazing areas and the dry seasons grazing areas.

Sakutiek area – Mau escarpment



Foot of Suswa Hills – floor of the Rift valley

Kendong area - Floor of the Rift valley

L. Naivasha Riparian zone

An ideal DSGR site situation

7. Conclusions and recommendations

7.1. Conclusions

This research has revealed that there is a relationship between the forage surplus, the livestock forage demand; the infrastructural development and the landscape. Research by A. B.Toxopeus, and others show a strong relationship between the forage production and animal demand (FAO, 2000; Herlocker, 1999; Oba, 2001; Schwartz, 1994; Toxopeus, 1996). Although the relationships' are evident in this research, it is noted that they were weak. This is can be attributed to several reasons. The livestock density estimation model was far from perfect, due to the use of dataset of questionable quality. Also the livestock datasets we used in the validation of our distribution model has also been questioned by various other previous studies(Jan de Leeuw and Prins, 1998). This undoubtedly affected the final result of our forage surplus model. There is however a big room for improvement by enhancing the reliability of the actual livestock density datasets, which forms the basis for the accuracy assessment of our livestock distribution model.

The forage availability was derived from the MODIS NPP. It should be noted that we had only 7 years of MODIS data, which might not have been long enough to capture the long term trends in forage production in our study area. Anyhow, the MODIS data has shown dependability for this kind of studies (NASA, ; Running and Nemani), which could be improved on later as more data from MODIS becomes available. Heterogeneity of the landcover in the study area, the low resolution of the MODIS NPP data and the validation of the same remain issues for further investigation.

The research confirmed the relationship between the surplus forage, DSGRs, the livestock demand and the infrastructural development. Infrastructural facilities showed considerable influence on forage surplus, meaning that DSGRs are sensitive to these forms of developments.

To enhance the accuracy and dependability of the DSGRs and forage surplus model, a factor of uncertainty is paramount (Jan de Leeuw, 2006; Moore and McCabe, 2003). The confidence interval, hazard analysis and risk assessment have proved to be a usefully concepts in enhancing the reliability of our DSGRs sites and forage surplus. Here also, the amount of temporal datasets available was not enough to provide the undisputed accuracies for the DSGRs sites and forage surplus. However using the available data, the research has shown that there are significant differences between the DSGRs sites with and without the effects of the confidence interval, hazard analysis and risk assessment.

Interestingly enough the type of dry season, whether a short dry season or a long dry season did not show a strong influence on the DSGRs and the forage surplus. This is any area this research remains non-committal, implying that further investigation need to be carried out to establish whether these relationships exist or not.

7.2. Recommendations

The following recommendations are suggested as a result of this study.

1. The estimation of the livestock densities and distributions remain far from perfect. Further studies on this aspect are recommended.

2. The low resolution MODIS data is potentially a source of error for the final model product. A similar study based on the medium to high resolution remote sensing data is recommended. This is expected to capture the vegetation heterogeneity of the ASAL areas.

3. This area has undergone a lot of land related changes in the recent past. The impacts of these changes on the Land cover, Land use change and Livelihoods need to be investigated. These factors have tremendous influence on the forage surplus and the DSGRs.

4. After identifying the DSGRs sites, the aspect of management of the same becomes an issue of interest. Studies involving the frequency and intensity of DSGR use, the livestock density regulation in the DSGRs, the sites boundary management e.g. fencing, etc, are recommended.

5. A further sensitivity analysis is recommended to consider the temporal factor in the DSGRs analysis. More studies on the reliability assessment of the site selection.

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Appendices

Appendix 1: Pastoralism

Pastoralism is the mode of production best suited to an arid and unstable environment. Some 20 million people worldwide are engaged in pastoral production, of whom about 40 percent are in the pastoral zones of Ethiopia and Kenya (FAO, 2006; LEAD). High population growth, poor access to social and economic services and a diminishing resource base, however, are undermining traditional pastoral communities (LEAD). Resultant competition for productive resources has created new levels of insecurity and violent conflict, a situation complicated by the fact that most pastoral communities have no formal rights to land. Global warming adds a further uncertain, but likely deleterious impact to rangeland residents. Marginalised by their lifestyle and circumstances, pastoral communities have received little attention from their Governments, or, the donor community in recent years. A quick succession of droughts in Eastern Africa and several calamitous snow storms in Central Asia over the last decade, however, have changed this situation, although the focus of intervention in these situations has been to save pastoralist lives rather than livelihood (GoK &WB, 2003; LEAD).

The challenge is to increase the resilience and capacity of countries and their populations to cope with the impacts of disasters that affect national and household food security and, when disasters do occur, to contribute to emergency operations that foster the transition from relief to recovery of the food and agricultural sectors" (FAO, 2006). Unfortunately, the majority of current Early Warning Systems (EWS) are not capable of detecting drought stress on livestock, the foundation of pastoral livelihood, or of providing adequate information for intervention to support pastoralists during a drought.

The cost and staff capacity required to maintain these systems in pastoral areas, however, may be beyond the capacity of many developing country economies and many of the measured indices remain responsive to rather than indicative of disaster/drought (FAO, 2006; UNU - ITC, ; UNU - ITC geo-information for food security, 2007).

Appendix2: Drought concept and arid and semi-arid lands

Drought is a normal, recurrent feature of climate, although many erroneously consider it a rare and random event. It occurs in virtually all climatic zones, but its characteristics vary significantly from one region to another. Drought is a temporary aberration; it differs from aridity, which is restricted to low rainfall regions and is a permanent feature of climate (NDMC, 2006).

Drought is an insidious hazard of nature. Although it has scores of definitions, it originates from a deficiency of precipitation over an extended period of time, usually a season or more. This deficiency results in a water shortage for some activity, group, or environmental sector (Shunlin, 2004). Drought should be considered relative to some long-term average condition of balance between precipitation and evapotranspiration (i.e., evaporation + transpiration) in a particular area, a condition often perceived as “normal”. It is also related to the timing (i.e., principal season of occurrence, delays in the start of the rainy season, occurrence of rains in relation to principal crop growth stages) and the effectiveness (i.e., rainfall intensity, number of rainfall events) of the rains. Other climatic factors such as high temperature, high wind, and low relative humidity are often associated with it in many regions of the world and can significantly aggravate its severity (NDMC, 2006; Shunlin, 2004).

A universally accepted definition of drought does not exist, but four major types of droughts are broadly defined and agreed on in the literature (Shunlin, 2004): meteorological drought, agricultural drought, hydrological drought and socioeconomic drought. In this study, we discuss mainly the management of agricultural drought using GIS, and quantitative remote sensing techniques. Agricultural drought occurs when available plant water falls below that required by the plant community during a critical growth stage. This leads to below-average yields.(Shunlin, 2004).

Arid and semi-arid lands (ASAL), also known as the rangelands or the pastoral lands are characterized by low erratic rainfall of up to 700mm per annum, periodic droughts and different associations of vegetative cover and soils. Interannual rainfall varies from 50-100% in the arid zones of the world with averages of up to 350 mm. In the semi-arid zones, interannual rainfall varies from 20-50% with averages of up to 700 mm. Regarding livelihoods systems, in general, light pastoral use is possible in arid areas and rainfed agriculture is usually not possible. In the semi-arid areas agricultural harvests are likely to be irregular, although grazing is satisfactory (Goodin & Northington, 1985 (Pratt and Gwynne, 1977).

The majority of the populations of arid and semi-arid lands (ASAL) depend on agriculture and pastoralism for subsistence. These areas exhibit ecological constraints which set limits to nomadic pastoralism and settled agriculture. These constraints include (Salih & Ahmed, 1993)(Pratt and Gwynne, 1977):

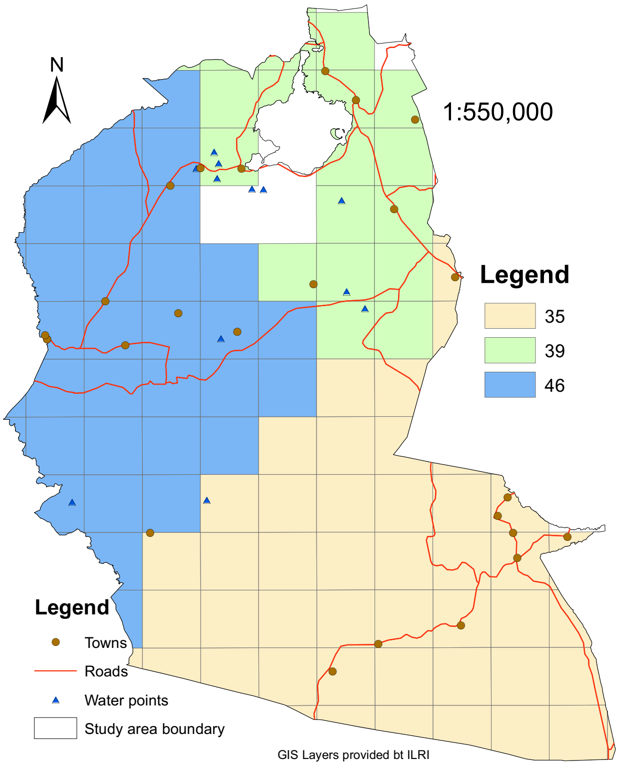
- rainfall patterns that are inherently erratic;
- rains which fall mostly as heavy showers and are lost to run-off;
- a high rate of potential evapotranspiration further reducing yields;
- weeds growing more vigorously than cultivated crops and competing for scarce reserves of moisture; and
- low organic matter levels, except for short periods after harvesting or manure applications (Pratt and Gwynne, 1977).

Stocking rate and carrying capacity

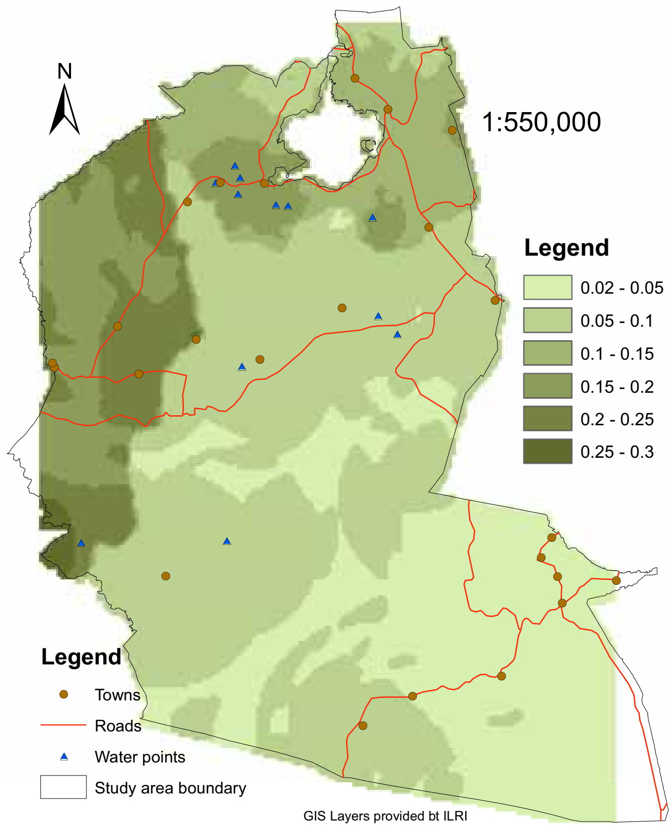
Stocking rate is the actual number of animals on a specific area for specific period of time, usually for a grazing season (Herlocker, 1999). This is the number of animals the livestock owner decides to put on the land.

Carrying capacity, on the other hand is the average number of animals (or stocking rate) a rangeland (ASAL) can sustain over time (Herlocker, 1999). In traditional range management, carrying capacity marks the point at which grazing pressure is balanced against the natural regenerative power of rangeland vegetation to yield a steady and profitable flow of animal products (Herlocker, 1999).

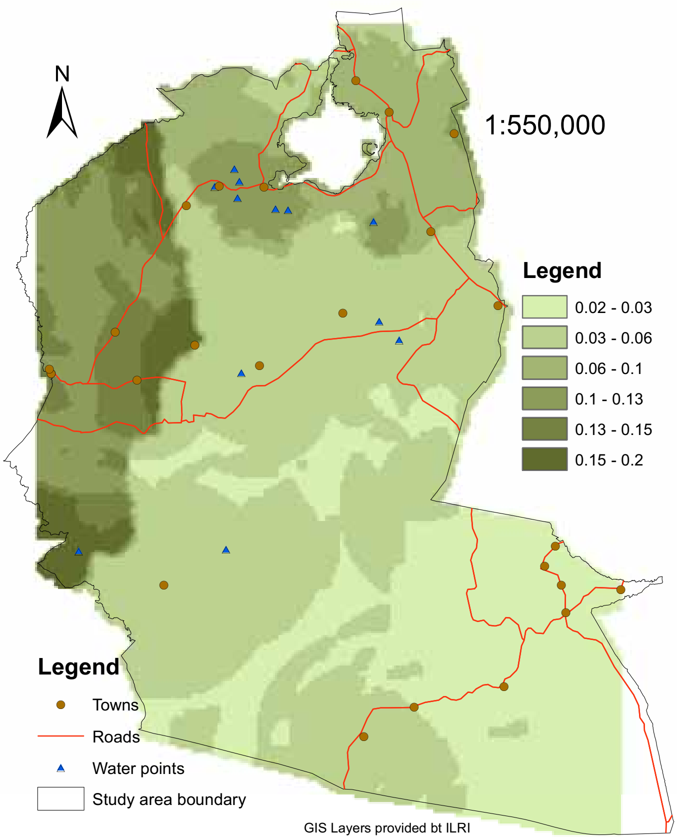
Appendix 3: Livestock density maps



Cattle densities in the study area Source: ILRI; ACT tools



Long dry seasons' forage demand



Short dry seasons' forage demand

Appendix 4: Stepwise multiple linear regression and ANOVA tables

The observed livestock demand - TLUs from DRSRS data, infrastructural development factors, the type of dry season (whether short or long dry season) and the lowland/highland factor are the independent variables; and the dependent variable is the forage surplus (DSGRs). The Livestock demand (TLUs) and forage surplus (DSGRs) are continuous variables, and as such have been aggregated (medians) over time and per season.

Regression Statistics				
Multiple R	0.5089			
R Square	0.2590			
Adjusted R Square	0.2450			
Standard Error	0.2637			
Observations	378			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	7	8.9910	1.2844	18.48
Residual	370	25.7212	0.0695	
Total	377	34.7122		
	Coefficients	***Standard Error***	***t Stat***	***P-value***
Observed demand	0.71	0.31	2.27	0.02
Proximity to roads	0.0000010	0.000003	0.35	0.73
Proximity to towns	0.0000163	0.000006	2.80	0.01
Proximity to water points	-0.0000151	0.000002	-6.09	<0.05
Restriction due to Terrain	0.000005	0.000013	0.36	0.72
Lowlands/highlands	-0.19	0.040	-4.67	<0.05
Long/short dry season	-0.02	0.028	-0.64	0.50

Second round of stepwise multiple linear regression statistics and ANOVA

Regression Statistics				
Multiple R	0.5075			
R Square	0.2576			
Adjusted R Square	0.2496			
Standard Error	0.2629			
Observations	378			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	4	8.9405	2.2351	32.3494
Residual	373	25.7717	0.0691	
Total	377	34.7122		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Observed demand	0.67	0.2989	2.21	0.0275
Proximity to towns	0.000016	0.000005	2.97	0.0031
Proximity to water points	-0.000015	0.000002	-6.61	<0.05
Lowlands/highlands	-0.20	0.036677	-5.35	<0.05