ASSESSMENT OF BIOMASS POTENTIAL FOR SUSTAINABLE CHARCOAL PRODUCTION IN KAJIADO COUNTY;TOWARDS INFORMED POLICY DECISIONS.

By

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DECLARATION

This Research thesis is my unique effort and has not been submitted for any examination in any other institution.

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ABSTRACT

Charcoal is the primary source of cooking energy in most African countries, where demand from a growing human population has frequently outstripped the availability of wood from forests and woodlands. Fuelwood and charcoal continue to be important energy sources for the majority of Kenyans, who have relied on them for decades to meet their energy needs. Kajiado County is one of Kenya's low-biomass-productivity rangelands, but it is known as a hotspot and a major supplier of charcoal in the neighbouring counties of Nairobi, Machakos, and Kiambu. An in-depth examination of the charcoal value chain in Kenya reveals that Nairobi accounts for 58% of the greater market share of charcoal, with figures indicating that both fuelwood and charcoal account for 48% of total residential energy demand sourced from Kajiado County. It is therefore critical to determine the sustainability of biomass potential for charcoal production, given the imbalanced harvesting rates and extremely low levels of regeneration caused by high demand and supply. Its specific goals were to evaluate the optimum biomass level for charcoal production, map the patterns/extent of land use cover changes as a result of logging/wood harvesting, and produce charcoal in time sequence. The study addresses the study objectives by utilizing remote sensing (RS) and Geographical Information Systems (GIS) to provide a means to assess land cover and thus the change in the state of the environment and biomass regeneration. When combined with socio-economic data, the demand and sources were evaluated, providing links and data to biomass and forest resource management planning. To accomplish these goals, a satellite imagery analysis provided spatial-temporal data in time series that were ground-sampled using a global positioning system to validate the findings. Landsat TM and Sentinel 2 images were analyzed spatially over 30 years at 10-year intervals between 1990 and 2019 to determine land cover changes, as well as NDVI and rainfall patterns using the NOAA/AVHRR over the same period. In-situ observation, household questionnaires and semi-structured expert interviews, literature review revealed the significance of charcoal production to local livelihoods and environment. Field interviews showed low awareness programs as well as absorption of appropriate technologies that could improve harvesting and charcoal production to minimize biomass wastage. The study findings indicated the major sources of wood for charcoal production are steadily decreasing. Forest cover that included woody biomass decreased by 60,455.25 Ha (23%) to 49,188.4 Ha (18.8%) in 2019. This was converted into cropland that saw an increase from 18,552.06 Ha (14.8%) in 1990 to 53,886.3 Ha(43.2%) in 2019 in the same period. This is change is attributed to the increased demand for fuelwood and charcoal combined with unsustainable harvesting of wood biomass due to the rapid increase and growth of the human population. The study revealed that the continued harvesting of charcoal is unsustainable due to predominant wood harvesting and inefficient charcoal production technologies. The resulting land cover change impacts have negatively affected forests and woodlands thus the future wood-energy supply sources due to slow regeneration rates emanating from high harvest rates. The charcoal producers must expand the use of charcoal with high conversion rates of biomass and low gas emissions to increase sustainability. The study contributes to the studies of land cover change and sustainable development in Kenya. It scrutinizes the land use and land cover change (LULCC) and deforestation; impacts of charcoal production on forest ecosystem services and biomass.

LIST OF ABBREVIATIONS AND ACRONYMS

AGB	Above Ground Biomass
AMESD	Africa Monitoring Of The Environment
CEOS	Committee On Earth Observations Satellites
DBH	Diameter at Chest Height
DRSRS	Directorate of Resources Surveys and Remote Sensing
DEM	Digital Elevation Model
EMCA	Environmental Management Coordination Act
EO	Earth Observation
ESMAP	Energy Sector Management Assistance Program
ETM+	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization
GFOI	Global Forest Observations Initiatives
GIS	Geospatial Information System
GOFC-GOLD	Global Observation of Forest Cover and Land Dynamics
GPS	Global Position System
Gt	Gigatones
IKONOS	A high-resolution satellite operated by Digital Globe.
IPCC	Intergovernmental Panel on Climate Change
IPCC	International Panel on Climate Change
KALRO	Kenya Agriculture and Livestock Research Organization
KEFRI	Kenya Forestry Research Institute
KFS	Kenya Forest Service
KNBS	Kenya National Bureau of Statistics
LAI	Leaf Area Index
LDIM	Land Degradation Index Map
LPG	Liquefied Petroleum Gas
LTM	Landsat Thematic Mapper
LULCC	Land Use Land Cover Change
Mha	Million Hectares
MSS	Multi Spectral Scanner
MUSLE	Modified Universal Soil Loss Equation

MVC	Maximum Value Composite
NDVI	Normalized Differential (Difference) Vegetation Index
NOAA/AVHRR	Advanced Very High Resolution Radiometer
PRA	Participatory Rural Appraisal
PROBA-V	European space agency vegetation satellite
RS	Remote Sensing
RUSLE	Revised Universal Soil Loss Equation
SPOT	Satellite for Observation of the Earth
SQE	Scientific Quality Evaluation
SSA	sub-Saharan African
UNDESA	United Nation Department of Economic and Social Affairs
UNECA	United Nations Economic Commission for Africa
UNEP	United Nations Environment Program
USGS	United States Geological Surveys
VGT	Vegetation Index
GoK	Government of Kenya
NCCRS	National Climate Change Response Strategy
NCCAP	National Climate Change Action Plan
IDDRSI	IGAD Drought Disaster Resilience Sustainability Initiative
IGAD	Intergovernmental Authority on Drought & Development
EAC	East African Community

1.0 CHAPTER ONE: INTRODUCTION

1.1 Background

Globally more than 2.4 billion people rely on the use of woodfuel, including charcoal for cooking, and small enterprises use fuelwood and charcoal as important energy providers (FAO,2014). FAO estimates that the global production of wood charcoal was about 53.2 million tons in 2018, of which 34.2 million tons accounting for 64% were produced in Africa. Data from FAO statistics in 2018 indicate that around 90% of the wood removed from the forests and woodlands in Africa are used as fuel, of which 29 % are converted into charcoal. Due to the steady increase in market demand, the production of wood charcoal in Africa has almost doubled in 20 years from 1998 to 2018 and accounted for two-thirds of the global production. The overall yearly worldwide tree cover loss between the years 2001 and 2017 was 337 million hectares (337Mha) proportionate to an 8.4 per cent diminish since 2000 and 24.7 Gigatonne (Gt) of carbon emanations. The overwhelming drivers of this loss; urbanization and commodity-driven deforestation, (FAO 2018). Africa's woodland cover is approximated at 650Mha, constituting 17% of the world's woodlands counting some international biodiversity hotspots. Over 50% of Africans are is secured by Afromontane, which could be a sort of vegetation found in good countries of Africa (FAO,2012).

Energy demand for biomass remains the most viable and easily accessible in sub-Saharan Africa (SSA) due to increased unemployment and the lack of alternative sources (May-Tobin, 2011). More than 80 per cent of households in fast-growing urban centres use charcoal as their primary source of cooking fuel (Zulu &Richards, 2012). Charcoal demand is expected to consistently remain higher in the coming decades with the projection indicating that this could double by 2030. Besides being inexpensive and lucrative for manufacturers, charcoal is popular due to its smaller size and lighter weight than wood, making it simple to carry (Arnold, 2006).

This booming industry is expected to exert tremendous pressure on scarce woodland resources in the semi-arid zones threatening the biodiversity landscape. (Arnold, 2006). Woody biomass used for charcoal production is either by open-cutting, in which most plants are felled only by big woods of desired species, irrespective of the species used, or systematic logging (Chidumayo, 2013). Gumbo (2013) points out that habitat loss is rampant in Eastern and Southern Africa, at least on a limited time scale, although selective cutting is more common in West Africa. However, selective logging in eastern Africa, especially in more dry areas (Kiruki, 2017) and (Ndegwa, 2016) are also being carried out mainly by subsistence local charcoal producers. For the scenario in Kenya, Ndegwa (2016), Mand Honan (2009) for Togo, focus on three species favoured in selective logging depending on the volume for charcoal production, with particular hardwood of more than 20cm in diameter at shoulder (breast) height. Multiple surveys in SSA have shown that forests with a breast height of as small as 5 cm are preferred, with large groves being reduced, with elevated charcoal costs left (Chidumayo & Gumbo, 2013).

The projected annual per capita intake of charcoal is 2.5 million tons (Ndegwa, 2016). Most of Kenya's charcoal is provided by forested Savannah, shrublands, and rangelands in the arid and semi-arid counties; Kitui, Kajiado, Kwale, Makueni, Kajiado, and Machakos. In 2000, total biomass fuel demand was estimated at 34.3 billion tonnes, of which 15.1 million was used for firewood and 16.5 million for charcoal (Mugo & Gathui,2011).while firewood is mostly collected freely within a radius of less than 5km, most of the wood for charcoal (75-90%) is harvested in woodlands and rangelands in the arid and semi-arid lands, that have low productivity of between 2-4% per annum and poor regeneration of harvested trees(Liyama,2010).

Charcoal in Kenya is a multi-billion-shilling industry that benefits the economy by Kshs.13.5 billion and employs more than 1 million people, including producers, transporters, and sellers, and supports a large number of livelihoods. (Mugo & Ong 2006). Urban expansion is a crucial driver of global change in land use/land cover (LULC) (Weiqi, Zhang & Weimin 2017). Urban development is a clear and present threat to land loss and degradation and a major cause of numerous environmental issues worldwide due to growing population growth requirements for its ingredients, such as wood fuel, (Zhou, Wang & Cadenasso, 2017).

Using a case study of Kajiado County, this study aims to provide information and bridge policy gaps in sustainable biomass harvesting for charcoal production and to determine the viability of wood vegetation harvesting for charcoal production using GIS and Remote sensed data. The spatial and temporal characterization will enable the development of accurate and consistent land cover maps using a Landsat Thematic Mapper (LTM). LTM allows visualization and distinguishing data attributes, a cross-correlation analysis, and subsequent classification trends showing the burnt areas and hotspots for degradation as a result of logging and charcoal production. This study will analyse images from the year 1986 up to 2018 with an 8-year interval (1986, 1994, 2002, 2010, and 2018) to generate GIS data. The resulting statistics will describe the vegetation characterization, transitional areas, and undetermined zones. The GIS / RS data will produce the interpretation of land cover material and landscapes in a practical and moment-efficient way to estimate a sustainable tree forage rate for the production of charcoal. (Macdonald's 1994).

Kajiado County has seen significant change, development, and growth activities such as design/settlements, road/railway building, deforestation, and many other anthropogenic activities. It has emerged as a transitional zone under pressure from the increasing population from the city and rural migration resulting in uncontrolled and unplanned landscapes. As a response, the growing population and rapid urbanization have increased demand for charcoal consumption leading to the exploitation of woody biomass in the available woodlands.

1.2 Statement of the Research Problem

The dependency on woodfuel energy has necessitated unsustainable charcoal production that often undermines the production of ecosystem services, agricultural production and human health with declining forest biodiversity and biomass regeneration((Liyama, 2016). This negative impact is exacerbated primarily due to unregulated wood fuel and charcoal harvesting systems. (Zhou, 2017). Both charcoal and woodfuel are easy to access and affordable due to high poverty prevalence to other available energy sources have led to increased deforestation through indiscriminate extraction for its production (Mugo,2011).

Reliance on charcoal as a primary source of energy needs, population growth and lack of timely reliable data for decision making has exacerbated a deeper problem in the human-nature relationship in sustainable energy prospecting in a low biomass production region. This imbalance correlates between biomass production and ecosystem service (ES) loss and human actions and tries to untangle the possibilities for sustainable co-existent of both humans and nature. These actions are combined in one objective: To contribute to the planning of sustainable management of land and forests, and sustainable livelihoods in Kajiado county in Kenya.

Kajiado County has no major plantations dedicated to the production of woodfuel or charcoal to meet its rising demands except the gazetted forest of the eucalyptus in Loitoktok. The majority of the landowners produce charcoal as a peripheral enterprise which nonetheless accounts for a larger segment (Ndegwa,2016). The gaps in policy-making and insufficient information for decision-making to adequately address the charcoal value chain have resulted in inconsistencies in the regulatory framework towards sustainable production to meet the demands. Presently, the formulated charcoal regulations remain ineffectively enforced, it does not indicate how to set and monitor the limit for viable biomass for charcoal production. The majority of the stakeholders in the value chains is unaware of the charcoal regulations policy and Act presence with 65.6% of Kenya's forested area projected to reduce by 2030. (Luvanda, 2016). With a steadily increasing demand for biomass energy, there is a need to adopt remote sensing technology to facilitate the continuous collection of accurate and reliable data that would support a remote sensed data decision support system (Wulder 2003).

1.3 Research Questions

To what extent does the available biomass stock in the Kajiado support charcoal production and what are the timelines for the regeneration of sustainable production.

Specific research questions

i. What is the potential biomass for wood fuel and charcoal production in Kajiado county?
ii. What are the impacts of charcoal production and wood harvesting on the land cover and the environment?
iii. How do the existing policy and institutional framework support sustainable biomass access and utilization?

1.4 Research Objectives

1.4.1 Overall Objective

Assessment of potential biomass for sustainable charcoal production in Kajiado County.

1.4.2 Specific Objectives;

i. To determine the optimal level of biomass for charcoal production;
ii. To generate land cover change maps depicting patterns of fragmentation due to woody biomass harvest and charcoal production;
iii. To assess how policy strategies and institutional regulatory framework can influence sustainable charcoal production in Kajiado County.

1.5 Justification

There is an immense significance of research on sustainable development, energy consumption patterns on environment and land cover change detection analysis using *in situ* data and satellite imagery in Remote Sensing and Geospatial application. Given the ongoing global call to preserve the environment against the ever-increasing demand and supply of wood fuel exacerbating the loss of biodiversity and land degradation. This study aims at providing reliable and repetitive remote sensed data and information that will inform data-driven policy decision-making mechanisms and regulatory frameworks. It will significantly contribute to the planning of sustainable management of land and forests, biomass production and sustainable livelihoods in Kajiado County. This will be achieved by studying the related themes in local context with varying remotely sensed data and *in situ* observation will reveal how interrelated factors contribute positively or negatively to the degradation of resources; untangle how the livelihoods, in particular the charcoal production, and the energy consumption patterns influence the environment but also acknowledge the role of charcoal production for livelihood and; enhancing the present strategies in the fight against global climate change, develop elaborate strategies, policies and programs that will enhance sustainable utilization of resources.

1.6 Limitation of Study

The choice of GIS and remote sensing was able to cover the entire county for the biomass study estimation. However, the time limit could not allow for systematic ground sampling on the specific trees species in the entire study area which is vital for building up the regulatory framework of specific preferences on charcoal production.

2.0 CHAPTER TWO: LITERATURE REVIEW

This chapter highlights a review of GIS and Remote Sensing on use/coverage applications on biomass estimation research studies towards a decision-making process. It also focuses on reviews of the policy framework that impacts on energy and charcoal sector in particular. Key areas include woodfuel and charcoal production impacts on diverse land use and patterns, the demand, supply and utilization of charcoal and the use of remote sensing applications to generate accurate, repetitive data for decision making.

2.1 Approaches of determining optimal biomass for sustainable charcoal production

2.1.1wood cover monitoring

Kenyan government is adopting digital platforms to achieve its development agenda thus geoinformation systems will be critical spatial analysis tools for the environment and natural resource managers for obtaining accurate spatial information on digital GIS platforms. Remote sensing is defined as the art and science of obtaining information about an object without being in contact with the object (Braaten,2015). It is an important tool that can be used to measure, visualize and analyze important biophysical characteristics and activities by a man on earth's surface (Weng 2007).

Remote sensed data can be acquired through satellite imagery. This is further interpreted and analyzed to identify events or patterns in a particular location over time. Multispectral analysis of the earth's surface is chosen to observe the various changes occurring over time. Remote sensing data is obtained using different instruments from big data that is available for a methodical local, regional and global analysis for a variety of ground spatial resolutions available for different uses.

The analysis of multispectral remote sensing datasets is in many instances restricted to simple change analysis patterns. Trend analysis will provide more meaningful results, but this will require quantitative and qualitative data. The application of remotely sensed data to illustrate changes in land cover and particularly wood cover over time has been reported by many investigators (Malek, 2016). Analyzing trends can be done to determine various parameters that may be derived from time-series satellite data combining different factors reveals additional information, which cannot be easily understood through other non-visual processing schemes (Wright,1994)

2.1.2 Biomass Estimation Using Remote Sensing

Geospatial systems are assembled on satellites or airborne devices, but significant refinements are routinely assessed at global and regional scales in estimating woodland biomass reserves (Defries *et al*. 2007). To determine forest carbon stocks, ground-based information will be derived using ground-truthing and remote sensing data. A satellite-based strategy is essential to the ability to provide wall-to-wall tracking for carbon stock proxies Satellite measurement accurately measured boreal, temperate forest carbon stocks, and reduced coal-forest residues. (Rosenqvist *et al.* 2003b). Tropical forests are among the richest in carbon and terms of structure.

2.1.3 Remote Sensing of Biomass

Remote sensing is an essential tool for determining the above-ground lad biomass. The resulting data compares supply and demand determining the rate of the land cover degradation and their causes; and potential carbon storage. Remote sensing and ground sampling can be used to determine the quantity and yearly yields of annual and perennial plants, the amount of animal biomass, especially dung. This correlation is used to determine the quality, number, and different types of biomass produced or growing on all land types.

An assessment conducted in Ethiopia estimated a standing stock of woody biomass at 435million with an annual yield of 39million tonnes. A detailed inventory using Landsat TM and subsequent ground truthing on all land types gave a wooden biomass figure of 1,200 million tonnes with an annual yield of 57million tonnes (FAO,2018)

2.1.4 Change Detection Analysis

Remote sensing procedures have been combined with GIS (geographic information systems) to test Landsat images to examine short-term land changes (Cohen & Goward, 2004). Remote sensing techniques have been applied comprehensively to investigate land-covering shifts over time and to assess designs of adaptations, to integrate social shifts with the environment, and to identify the hazards of environmental degradation (Sader *et al.,* 1994). Land use and land cover assessment are among the universal methods used to research environmental changes and the probability of biomass. For such functions, remote sensing images collected under similar conditions over specific durations are suitable for research using land use and cover the categorization of such vegetation variation for forests and landscapes. (Reid *et al*.,2000; Giri *et al*., 2003; Wilson, 2006; Bhattarai & Conway 2008.

TM images and Landsat MSS are significant in the field of land-covering adaptations in mountainous regions, despite compound physiography and shadow influences. The unavailability of aerial photographs and historic maps creates barriers to authentication of collected information when studying remote regions of developing territories. (Griscom *et al.,* 2010). The categorization approach utilizing GIS and remote sensing procedures assist to understand historic shifts. Lu and Weng (2007) stated a variety of problems with the categorization method have been exhausted when analyzing the remote sensing model and have shown that the landscape complication leads to the most interrupting aspects.

2.1.5 Estimating Above Ground Biomass using Remote Sensing and GIS applications.

Statistics from remote sensing have become an essential instrument that measures forest biomass. Biomass approximation applying isolated observed figures is a surfacing innovation and it is being extensively applied in registering forest biomass. According to (Gibbs, 2007) satellite-based measures of carbon supply are probably becoming more convenient over the succeeding years. Remote sensing figures can adequately offer a comprehensive outlook across the substantial region and considerably double organization as well as functionality of restricted standard approaches (Patenaude, 2005). Various procedures are applied to acquire isolated observed statistics and include; Optical, Radar, and Lidar remote sensing. First, Optical remote sensing is an unresisting technique; the sensors barely register the radiation in detectable bands, almost-infrared and short-wave infrared. The wavelength of the band measures 0.3mm to 15mm with the sun as the primary spring of energy (Scott *et al.*, 2009). Satellites applied in Optical remote sensing are categorized based on their geographical resolution into satellites with low resolution (Meteosat, GOES, and NOAA), satellites with medium resolution (Landsat MSS), and high-resolution satellites (Landsat TM, SPOT, GeoEye, Quick bird, IKONOS). Radar is a functional procedure that discharges radio waves and brightens the surface of the earth as well as registers the energy backscatter from the ground. Radar applies lengthy wavelengths that permit these structures to perforate through smoke, clouds, and vegetation.

These procedures have a microwave aspect that permits the approximation of specific object frameworks that cannot be retrieved through optical remote sensing (Hoekman, 1990). Radar can be controlled during the day or night. On the other hand, Lidar also referred to as optical radar, is mobile remote sensing that incorporates electromagnetic energy in the optical scale to identify an object. Lidar is a Laser sensor applied in remote sensing (Rosillo – Calle *et al.*, 2007). Lidar depends on the hypothesis of detecting vegetation through pulse energy, in this scenario from a laser working at the optical wavelength (Scott *et al*., 2009). Lidar provides a substantial possibility for tracking forest biomass with its primary significance of acquiring three-dimensional statistics of forest arrangement and figures on canopy covering (Rosillo – Calle *et al.,* 2007). Instances of the utilization of lidar statistics in forest research contain: to measure timber volume and stand height (Naesset, 1997), to calculate tropical forest biomass (Drake *et al.*, 2002), tree height (Nilsson, 1996), and canopy arrangement (Lovell *et al.,* 2003). The GIS approach is utilized for measuring and mapping the carbon supply of the forest ecosystem. The benefits of applying a GIS-developed framework are its low cost, clarity, and approximation of geographical direct arrangements, and short-term spatial driving projection of forest carbon (Deng *et al*., 2010). GIS is applied in shaping carbon evaluation, specifically in sizeable and challenging terrains. During the forest Preservation initiative, Arbolidar, a GIS-based software bundle utilized lidar images and various sample plots for shaping carbon supply for the study location (Ghana FPP, 2012).

2.1.6 Normalised Difference Vegetation Index

In determining the vegetation index, a normalized difference vegetation index (NDVI) coefficient gives a structured mechanism of contrasting green vegetation between various images of satellites (Schmidt and Karnieli, 2000). NDVI from multispectral satellite data is essential for monitoring plant growth (vigour), biomass production, and vegetation cover (Priess *et al.,* 2001). NDVI values range from 0.1 to 0.7, which signifies the lowest and highest cover, respectively (Schmidt and Karnieli, 2000). The NDVI calculation formula is NDVI = (close IR band-red band)/(near IR band + red band).

NDVI is an effective instrument for land cover change observation in the evaluation of recurrent satellite images (Lunetta *et al*., 2006). The NDVI tool is assisted by different identities of reflectances by different types of land cover in the visible and near-infrared areas of the electromagnetic pattern. NDVI can assist in monitoring factors such as precipitation relevant to land cover changes and biomass (Mingjun *et al.*, 2007). Also, remote sensing procedures may be used as additions for sociological studies. (Wilson, 2010). These methods are primarily quantitative, but they are favourably assisted by qualitative models such as interviews with local people. (Behrens *et al.*, 1994). The isolated images observed are useful for the exploration of adaptations and can be paired with socio-spatial statistics compiled from ethnographic approaches. (Sussman *et al.*, 1994; McCracken *et al*., 1999).Values between 0.2 to 0.3 denote grass and shrubby land while high values (0.6 to 0.8) indicate temperate and tropical rainforests.it is possible to use NDVI as an indicator of relative biomass and greenness. With sufficient ground data, the NDVI can be used to analyze and forecast primary production, grazing impact, and stock rates.

2.1.7 Challenges for using Remote Sensing and GIS applications in biomass estimation

Locating the appropriate merge of exactness of estimation and the innovations are critical obstacles in projects that incorporate remote sensing and GIS bundles for calculating forest biomass. The compound identity of lidar statistics demands competence and distinctive software. As a result, the utilization of the lidar image is mainly applied in extensive locations for biomass evaluation. Besides, satellite images demand substantial storage volume and elevated expenditures in capturing images.

2.2 Environmental Impacts of Woodfuel Extraction

Removal of woody biomass for fuel can have far-reaching consequences for the structure and functioning of ecosystems. woodfuel extraction has been cited in increasing soil erosion(Anderson 1986, Aweto 1995), reducing soil moisture content(Anderson 1986), and decreasing soil fertility as nutrient leaching is increased while vegetative recycling of subsoil nutrients (Aweto 1995).In extreme cases, such changes are expected to culminate in changes in weather patterns and drier regions/desertification thus making increased utilization of woodfuel by urban population one of the most critical environmental issues sub Saharan Africa must address(Anderson 1986).

2.3 Woodfuel Production and Consumption In Kenya

According to the international energy agency(IEA)(2017a), Africas total primary energy supply was dominated by biomass accounting for 48 per cent of the total primary energy. There is a noticeable decrease over years from 61 to 48 in the year 2015 of the traditional biomass due to improvement of access to electricity and development in the fossil fuel sector. woodfuel and charcoal remain the two main forms of energy sources. Only a few countries account for the woodfuel harvested in sub-Saharan Africa: the democratic republic of congo, Ethiopia, Nigeria and Tanzania. The fast-growing population implies an increasing demand for these sources exerting pressure on forests and other biomass sources.

2.3.1 Driver of Woodfuel Consumption

2.3.1.1 Population Growth

Rapid population growth is driving the increase in the production and consumption of woodfuels. tin the last decades, the Africa population has increased from 635million in 1990 to 1,049 million in 2010 and it is expected to reach 1,703 million by 2030. This results in increased demand for woodfuel across all sectors(households, towns and industrial zones). (UN-DESA,2014).

2.3.1.2 Increased Urbanization

Africa is the most rapidly urbanizing region worldwide, growing at a rate of 3.44 per cent between 1995 and 2015 (UN-Habitat). The proportion of the continent that is urbanised increased from 15 per cent in 1960 to 40 per cent in 2010, and is projected to reach 60 per cent in 2050 (UN-DESA,2014). The urban population is projected to grow from 400million to 761million urban dwellers between 2010 and 2030. Sub Sahara Africa in particular is urbanizing faster than any other region of the world. small and medium-sized cities with less than 1 million people are the fastest growing. This accounts for 62 per cent of the African urban population(UN-Habitat,2016).

The growth in urban populations has been linked to increased demand for woodfuels. charcoal is the predominant form of woodfuel mostly used in urban centres, while firewood is used mainly in rural areas (Njenga, 2018).In Kenya, the charcoal national consumption rate grew by 5 per cent a year between 2004 and 2015 which was higher than the rate of urbanization(2.7 per cent) over the same period (Liyama, *et al*., 2014).

2.3.1.3 Income Growth

Most of the Africa population in sub-Saharan countries live in extreme poverty with a lack of livelihoods. Traditional biomass is the energy source for the poor since it is generally freely available or can be obtained at a nominal price. Traditional biomass energy has been majorly used by the low-income population due to ease of access and availability in smaller quantities in the market easily affordable by the majority. Income is one of the drivers behind the increasing demand for certain types of energy sources(Adam, Brew-Hammond,& Essandoh, 2013). Rising prices of fossil fuels and electricity make switching to alternatives an option that is only open to those within certain income brackets. Between 4 – 10 per cent of consumers switch from fuelwood to charcoal per year (Sepp,2014).In Cote d`Ivoire, a combination of increased urbanization and a decrease in subsidies for LPG have led to increased use of charcoal as fuel (UNDP,2014).

2.3.1.4 Educational Level

Studies show that more educated households are more likely to transition away from using fuels on the lower end of the energy ladder. The more education one has, the greater value is placed on time. Thus, for more educated individuals, there is a higher opportunity cost in spending time collecting biomass fuel.

2.3.2 Production Patterns of Woodfuel and Charcoal

Woodfuel and charcoal production in Africa has increased steadily over the years (FAO,2016). Africa produced a total of 665.6 million m3 of woodfuel in 2015. Ethiopia was the largest producer of woodfuel, producing 108 million m3 in 2015 followed by DRC with 82.5 million m3 and Nigeria with 65 million m3 of woodfuel. other countries in the top-ten producers of woodfuel in Africa include Ghana, Kenya, Uganda, Tanzania, Egypt and Mozambique.

In Kenya, the generation of Charcoal relies on the particular cutting of functional hardwood tree species like Acacia spp., abandoning the ground controlled by softwood species like Commiphora spp., contributing to biodiversity decline. Nearly 75% of charcoal utilized in Kenya originates from the dry grounds with a change of charcoal points extending to hither grounds of Kajiado, Makueni, and Narok counties witnessed all-round the former years as beneficial tree species are exhausted. Accelerating urbanization has swiftly piled weight on dry land forests and woodland deterioration with energy requests mainly charcoal and fuelwood (Liyama et al, 2016).

Biomass is the primary spring of energy for Kenyan families and a critical energy origin for the entire country. Around 72% of the nation’s overall energy reserve originated from waste and bioenergy in 2013. A substantial percentage of the biomass utilized is charcoal, which accounts for 82% of family energy in urban locations, and 34% in rural regions, the inappropriate ancient ground kilns squander 85-91% of biomass piling weight on the drylands that generate hardwood for charcoal production (Kariuki 2013).

2.3.3 Biomass Fuel Utilization in Kenya.

Presently, biomass contributes to the majority of the energy specifications for rural families in Kenya. For example, biomass dispensed around 90% of the rural family energy demands in

2008 (Kimani, *et al.*, 2008). However, the absence of substitute energy choices has contributed to its considerable application in crude make. Reports provided by Sudha and Ravindranath (1999) indicated that 38% of the overall energy demands are being supplied by biomass in its crude make across a majority of developing territories.

Forest biomass has been the primary spring of wood energy in Kenya. A research carried out by Kituyi *et al.* (2001) pinpointed that around 15.4 tons of wood energy was utilized in 1997 and this was contributed by woodlands, farmland trees, indigenous forests, and timber cuts from various plants. Moreover, the research disclosed a very limited application of crop remnants as household energy, around 1.4 million tons. Unfortunately, fuelwood reserves have been decreasing in rural parts of Africa. Several scholars have demonstrated this decline in Kenya (Kituyi, Marufu, Huber, *et al.*, 2001; Mahiri, 2003; Ngetich *et al.*, 2009). Consequently, there is an expansion in the application of crop residue by farmers to sustain their energy specifications. For example, Mugo (1999) documented that a decline in fuelwood reserves contributed to an estimate of 40% of farmers from Western Kenya relying on crop remnants and cow dung as household energy sources. In other locations of Western Kenya, rural families have turned to purchase crop remnants to supplement their fuel requirements (Mahiri, 2003).

2.4 Woodfuel Value Chain and Impacts

2.4.1 Woodfuel Value Chain

Charcoal is the key fuel for urban homes in most developing economies (GIZ, 2014a) and is commonly used in small businesses such as supermarkets, bakeries, and street food stalls. Global production of wood fuel leads to the loss of some 52 million tons of forest (Mt) in 2015. (FAO, 2016a). In Africa, more than half (62.1%) were developed, followed by the Americas (19.6%) and Asia (17%), with small amounts emerging in Europe (1.2%) and

Oceania (0.1%) (FAO, 2016d). Output increased by 19 per cent in the last ten years to 2015 and by an initial 46% in the previous two decades (FAO, 2016a).

Kenya's annual charcoal consumption is estimated at between 1.6-2.4 million tons (Mutimba and Barasa, 2005), while Nairobi City consumes 10% of the total (Njenga *et al.,* 2013). Charcoal used in Nairobi County comes from some sources, such as Kitui, Makueni, Tana River, Kwale, Narok, Kajiado, Kajiado, and Garissa. The majority of urban households (87%) and 34% of rural households rely on charcoal as their primary energy source. (Mugo and Gathui, 2010). On the other hand, the use of firewood is prevalent among 89% of rural households as compared to 7% of urban households (Mugo and Gathui, 2010).

2.4.2 Biomass Supply

2.4.3 Production and Consumption Of Fuelwood And Charcoal

Production of woodfuel and charcoal entails cutting down trees, chopping the poles to the required size, drying and packing them ready for transport. This cost step in the wood-fuel value chain is most important in terms of creating livelihood opportunities. Charcoal is manufactured all year round, although seasonal quotas are different. While its demands across urban households have skyrocketed under rainy conditions, various producers have suggested an interruption in the output of charcoal either as a consequence of increased logistical difficulties or a lack of funding for agricultural initiatives. The average capacity of charcoal per producer is estimated at 30 bags per month. The estimates for producers employed around CPAs as expected in the Charcoal Regulations for all-round counties are approximately 28,201. The estimated amount of bags created each year based on the sample is approximately 700,000,000 bags converting to 2,500,000 tons of charcoal produced by regulation, legislative and organizational changes across the industry. (Mutimba and Barasa 2005).

Approximately 84% of the total landmass of Kenya, 57.6 million hectares is listed as arid and semi-arid (ASAL). Around 75% of the estimated 2.6 million tons of charcoal are produced annually by unsupported developments in the production of charcoal that lead to significant risks to the biophysical environment and the socio-economic environment of the nation. (Practical Action EA, 2010, Danida and RELMA, 2003). Fuelwood contributes above 93% of rural family energy requirements while charcoal is the primary spring of fuel in urban families (Ministry of Energy, 2002; Theuri, 2002; Kituyi, 2008). Apart from being the standard cooking energy for large Kenyan families, wood energy is an important fuel source for small-scale industries such as brick-making, bakery, tea drying, tobacco curing, and fish smoking. The sector recruits more than 700,000 breadwinners to more than two million beneficiaries. (GoK, 1999; Kibet 2014).

Makueni, Kitui, Kajiado, Kwale, Tana River, and Elgeyo Marakwet are the predominant producer of charcoal from Kenya; (Ministry of Environment, Water and Natural Resources 2013). 99% of the production of charcoal is mainly done by inadequate earth ovens (Kareko, 2001; Mutimba and Barasa, 2005). The charcoal producers and retailers are poorly paid, despite the substantial quotas of income accrued by the coal sector when matched to the other products. After tea and horticulture, Charcoal was ranked third (Luvanda *et al*., 2016).

In most dominant markets, charcoal traded in kiosks and roadsides is predominantly used by middle-class and under-standard families across urban locations. Charcoal is a reliable, suitable, and usable source of cooking energy that is economical when combined with other fuel sources, such as kerosene and electricity. (BTG, 2010, Mugo and Ong, 2006). Customers can be classified into; households that are charcoal for family use; commercial businesses such as restaurants, Jua Kali shades, hotels; and organizations such as hospitals and schools.

2.4.4 Transport

The mode of transport used to get woodfuels to the market depends largely on the distance to be covered ranging from people walking with loads on the head, bicycles donkey carts or trucks. The profit earned by a mode of transport in Kenya is approximately 4 per cent off the price per sack of charcoal (Sepp,2014).

2.4.5 Distribution and Sale

Woodfuel is an important business venture for the majority of the population in Africa. The supply chains are quite extensive to allow for ready and reliable suppliers across the continent to meet the demand (Sepp,2014). However, because of their informal (sometimes illegal) nature, they tend to be overlooked in policy research and national accounts. Woodfuel value chains are very lucrative and as a result, support a huge number of livelihoods. the charcoal sector in Rwanda is valued at US $77 million per year while in Kenya is about US $450 million a year (Morrisey, 2017)

2.5 Policies and Strategies for Biomass Energy

2.5.1 Challenges and Opportunities

The grand challenge is that by 2050, more than 1.8 billion people accounting for 65 per cent of SSA will still rely on woodfuels for cooking. The transition to cleaner cooking will be hampered by rapid rural population expansion. The United Nation projections show that the population in SSA will grow to 2.5 Billion by 2050, many of these people are likely to remain relatively poor and rural, due to both limited per capita economic growth and strong dispersion of that growth. This makes it more difficult to expand access to cleaner cooking fuels as biomass is almost free and often widely available, while more modern technologies require both infrastructure and recurring costs for cooking fuels. Cooking makes up about 80 per cent of domestic energy demands in Sub Saharan Africa. Most of the cooking is done using traditional biomass and inefficient technologies. These unimproved cookstoves consume double the energy compared to improved technologies and are more energy-intensive and polluting than electricity or LPG. As a result, per capita, residential energy consumption levels are higher in SSA than elsewhere in the world. Compared to modern technologies elsewhere in the world, Africa uses ten times as much energy to cook similar amounts of food. The main drivers of this dependence on biomass energy are population growth, income levels, increasing urbanization and lack of education. The majority of the population resides in rural areas where incomes are low. In Kenya, biomass is perceived to be a fuel for the poor since its easily available and ready for collection. However, opportunities could arise due to accelerating economic growth, attracting investments and innovation in the energy sector.

2.5.2 Strategies for Increasing Production and Reducing Demand for Woodfuel.

The strategies are both supply and demand-oriented which are aimed at either increasing the supply or reducing the demand. The supply strategies include; enhancing on-farm tree planting, efficient management of rangelands and woodlands, development of fuelwood plantations. The demand-oriented strategies include; reducing demand through the promotion of more efficient cooking stoves and charcoal conversion kilns, use of alternative sources of energy other than wood. Other strategies include the formulation of woodfuel policies that enhances decentralized sustainable wood energy planning at all levels. This can be achieved if the wood energy institutional framework is strengthened and facilitated to collect wood energy data to be used in national energy planning alongside the conventional fuels that are currently given more emphasis. Decentralized wood energy planning is important as the strategies to be used for sustainable woodfuel production may vary from one region to the other.

2.5.3 Improving Woodfuel Policy Framework.

An adequate regulatory framework is needed for effective policy implementation This comprises, in particular, the establishment of secure tenure or uses rights in the context of decentralization and devolution of power, accompanied by capacity building and organisational development at the sub-national level. In addition, incentive measures (e.g. differential taxation) and control and law enforcement systems are needed to foster economic benefits for sustainable producers and discourage non-formalized wood energy production. Incentive measures and systems of control ("Carrots and sticks ") is essential for wood energy modernization policy in practice and improvement. According to the lessons learned the most important incentives for a strategic shift from open access to sustainable forest management is secure tenure or use rights and economic benefits. Decentralisation and devolution of power for forest management (e.g. from state-owned forests to community forests) appear to be effective in many partner countries and might be used to create incentives and could be supported by the international community. This process should strongly be linked to respective capacity building and organisational development at sub-national levels. Governance bodies that are newly mandated with forest matters need structured support. This may (also) pertain to regional or community councils, forest user groups, local forest management structures and/or NGOs as long-term supporters for communities or households. As outlined above, a promising tool to foster economic benefits for sustainable producers in those countries that depend on wood energy supply from open-access areas (i.e. most African countries) is a differentiated taxation scheme. If backed by conducive policies, law enforcement and good sector governance it serves to protect wood energy producers who enter a formal, sustainable production system against informal/unsustainable producers. Support may include: (i) conducting economic studies to improve databases and understanding for the design of tax systems, (ii) elaborating and lobbying for such a taxation system; (iii) training. Initiatives, which aim to ban non-formalized wood energy production, should not be supported as this puts the energy supply for the population at risk. It is strongly recommended to the international community to enhance their support in the field of the law enforcement because land tenure reforms and theoretically provided economic incentives cannot display any impact without effective control including monitoring.

2.5.4 Regulating Charcoal Production and Trade.

Regulating charcoal production and trade is based on the introduction of a proof of origin (coupon system based on sustainable exploitation quota); installation of road checks; putting in place a traceability system (bar code system) and efficient tax collection.

2.5.5 Biomass Energy and The Sustainable Goals

The sustainable development goals are a universal call to action to end poverty, protect the planet and ensure all people enjoy peace prosperity. sustainable development goal 7 advocates for ensuring that there is access to affordable, reliable, sustainable and modern energy for all, it targets to ensure that by 2030, there is universal access to affordable, reliable and modern energy services with the majority of the population accessing electricity and primary reliance on clean fuels and technology.

2.6 Charcoal Policy and Legal Framework in Kenya.

2.6.1 Energy Act and Policy in Kenya.

The implementation of the Energy Act (2006) and immediately following the approval of the Energy Policy 2007 provided a current phase of energy organization in Kenya that was sufficiently powerful to allow responsiveness to address energy concerns over a short period.

The Energy Directive of 2007 underscored the value of energy accessibility, economic availability, and distribution to strengthen sustainable socio-economic development while safeguarding and preserving the environment. For the first time in history, there have been distinctive clauses to promote renewable sources of energy, such as biomass. The Energy Act (2006) stipulates that: "*the minister shall promote the development and use of renewable energy technologies, including but not limited to biomass, biodiesel, bioethanol, charcoal, fuelwood, solar, wind, tidal waves, hydropower, biogas, and municipal waste.*"

In terms of institutional and regulatory requirements, the legislation promises to ensure the implementation and harmonization of directives, initiatives, and acts of the energy industry and sub-industries, as well as the legislation of other economic industries, within the context of:

- Smooth positions of engagement in the provision of energy resources in isolated regions;
- Establishing an independent organization dedicated to rural electricity, such as electrification. In reality, this response to the long-term shift in rural versus urban energy distribution with the priority of urban centres.

The legislation promotes the appropriate generation and use of electricity, such as coal and firewood, as well as the promotion of cogeneration as an appropriate move. Besides, the strategy calls for a restructuring of the market, an improvement of distribution and pricing processes (tariffs). Research and growth are often integrated into the legislation as one means of increasing both the distribution of resources and the effective use of resources. It facilitates an up-to-date collection of statistics and the management of databases for beneficial organizations.

2.6.2 Policy and legislative frameworks for forestry Management in Kenya

This study explores the policy and legislative framework of forestry Kenya that includes: the Public-Private Partnership (PPP) policy, law and regulations, and sustainable forest management approach like forest management certification and chain of custody certification for forest products. Forest Management and Coordination Act (FMCA) 2016 contains most of the requirements outlined in the FAO Voluntary Guidelines on forest concessions, though there is a need to address some gaps such as the harvesting value of an area, forest revenue collection, management of rescinded concessions, evaluation of the concession process, the mode of bidding, gender inclusion and independent observation. With regards to certification, although the socio-economic and environmental benefits of certification are sometimes not clear, it has played a major role in the adoption of sustainable forest management practices in forest concessions. In conclusion, to promote willingness to invest in a long-term venture such as commercial forestry, there is a need for generating information that will support decision and management plans that secures land tenure, respect for private ownership, reliable economic guidelines and standards, transparent governance, effective measures for tackling corruption, forest biomass regeneration and efficient conflict resolution mechanism. Under the Forest Protection and Management Act, 2016 (No. 34 of 2016), there are facilities for the protection and conservation of public, communal, and private forests and forest lands that involve distinctive conservation, which explains the freedoms of forests and orders for forest land use.

2.6.3 Role of forest policy and legislation in enhancing commercial forestry in Kenya

The forestry sector has been guided by the Forest Act (2005), which was later revised to the Forest Conservation and Management Act (FCMA) of 2016 to conform to the governance structural changes in the Constitution of Kenya of 2010. Kenya forestry is also guided by the National Forest Policy of 2015. More recently, Kenya’s Ministry of Environment and

Forestry has initiated a review of the country's National Forest Policy to amend the existing Forest Conservation and Management Act of 2016. The Forest Act (2005) is quite patchy on aspects of forestry biomass harvesting. There is considerable improvement of commercial forestry in the (FCMA) of 2016 and the National Forest Policy of 2015. Based on the analysis of the existing legislation, there is a need for an integrated approach to forest management, conservation and development with commercial forestry development; Management to entail sustainable multiple forest uses and benefits and in the process identify ways through which forestry can be enhanced; Existence of adequate planning tools such as management plans, which aim to promote forestry and biomass production; Transparent in the potential of forest concessions and other contractual arrangements, with provisions for accountability for enhancing commercial forestry; and commitment to inter-sectoral development, sustainable use of forest resources and other agreements to promote funding for commercial forestry.

2.6.4 The Charcoal Regulation 2009

This was a legislation reaction to the charcoal obstacles. Throughout the years, charcoal has been criticized for its dominant role in activating deforestation and the majority of unsuccessful actions were directed towards the restriction of its generation. The charcoal generation had been outlawed for a long time but it prevailed as the most exchanged energy product on the markets of numerous cities and towns across the country. The truth that charcoal is a vital segment of Kenya's energy spectrum that requires control as opposed to a total ban has prevailed and as a result, charcoal regulation was introduced and supported within the Forest legislations.

This triggered the Forests (Charcoal) Directive of 2009, mainly referred to as the 'Charcoal Regulations' which relate to forestry and encourage the production, distribution, and exchange of charcoal. For the first time, the Charcoal Regulations set up an agency to regulate sustainable production of charcoal, license production, and exchange as well as order bans that breach the provisions. However, critics have pinpointed several omissions in the legislation, for instance, in the subject associated with a charcoal connection (does the utilization of enterprise charcoal indicates that individuals generate “non-enterprise” charcoal without representing any association?), it is still viewed as a critical measure towards controlling the sector.

2.6.5 Agriculture Strategies and Policy Reviews

In a bid to increase agricultural productivity, the Kenyan Government launched the Strategy for Revitalizing Agriculture (SRA) in 2004. The implementation of the SRA has been largely successful. As a result, the sector surpassed the growth target set of 3.1 per cent to reach a high of 6.1 per cent in 2007. The new Agricultural Sector Development Strategy (ASDS) was intended to build further on the gains made by the SRA. It provided a guide for public and private sectors’ efforts in overcoming the outstanding challenges facing the agricultural sector in Kenya. Besides ensuring food and nutritional security for all Kenyans, the strategy aimed at generating higher incomes as well as employment, especially in the rural areas. This had most of the land conversion to cropland.

2.6.6 Kenya Charcoal Policy Value Chain User Manual.

A charcoal policy study was documented in 2011 by Practical Action through the Practical Action Consulting Agency. The purpose of the document was to smooth the identification of policies and directives affecting the coal industry. It also promotes awareness and understanding of the provisions through major stakeholders in the charcoal chain. The document stipulated that the following benefits are expected following the thorough interpretation, acceptance, and application of the Charcoal Directives and legislation.:

2.6.7 Institutional Frameworks

In Kenya, the concerns of the biomass energy industry are answered by major government agencies such as Kenya Forest Services (KFS), the Renewable Energy Division of the Ministry of Energy and Petroleum (MoE&P), the Agroforestry Unit of the Soil and Water Conservation Branch (SWCB) under the Ministry of Agriculture, Livestock Development and Fisheries, Public Administration, the Kenya Forestry Research Institute (KEFRI), (Liyama,2017).

2.6.8 Kajiado County Integrated Development Plan 2018-2022

The 2018-2022 County Integrated Development Plan (CIDP) was prepared according to the Constitution of Kenya 2010, Article 220 which provides for National legislations to prescribe the structure of county plans and budgets. Section 126(1) of the Public Finance Management Act (PFMA) provides that every County Government shall draw up a development plan in compliance with Article 220(2) of the Constitution. The development plan shall include medium-term strategic goals that represent the priorities and strategies of the County Government, as well as a summary of major capital projects. The plan shall be prepared in compliance with the guidelines provided by the State Department for Planning and Statistics.

The Kajiado county integrated development plan of 2018 – 2022 covers a 4-year plan envisaged to promote equitable and sustainable s9ocio-economic development through efficient resource utilization and inclusive participation.it highlighted its spatial development framework, natural resources analysis, key county development programs, and strategies as identified by county stakeholders. This included the energy and environment development needs, objectives and strategies to be implemented in the plan focusing on key opportunities and threats.

The existing legal framework and policy interventions aimed at charcoal production regulations as discussed above have been inefficient in creating a balance in supply and demand making charcoal production unsustainable. In return, people resort to making illegal production of charcoal and evade levies imposed on the related activities in total disregard to the sustainable biomass levels that support manufacturing. The majority of the population that lives in Semi-Natural habitats depend on charcoal production as a primary source of energy demands. Determining levels of biomass production is crucial in promoting the biomass energy sector and enhancing the sustainable production of charcoal.

2.7 Sustainable Development Goals

The global agenda on sustainable development is best expressed through the SDGs, which one can best describe as the ultimate measure of progress which is about prosperity for people and the planet. The SDGs, a set of 17 "Global Goals", 169 targets, and 230 indicators, are a standard for evaluating if progress is being made across the world to reduce poverty, improve quality of life, and realize aspirations of the masses of people towards development.

2.7.1 Goal 7: Ensure Access to Affordable, Reliable, Sustainable and Modern Energy for All.

In 1.3 billion people, one in five globally still lack access to modern electricity; 3 billion people rely on wood, coal, charcoal or animal waste for cooking and heating; Energy is the dominant contributor to climate change, accounting for around 60% of total global greenhouse gas emissions; Energy from renewable resources – wind, water, solar, biomass and geothermal energy is inexhaustible and clean. Renewable energy currently constitutes 15% of the global energy mix.

2.7.2 Goal 13; Take Urgent Action To Combat Climate Change and Its Impacts

The greenhouse gas emissions from human activities are driving climate change and continue to rise. They are now at their highest levels in history. Global emissions of carbon dioxide have increased by almost 50% since 1990; The atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. Carbon dioxide concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from 1880 to 2012, average global temperature increased by 0.85°C. Without action, the world's average surface temperature is projected to rise over the 21st century and is likely to surpass 3 degrees Celsius this century with some areas of the world, including in the tropics and subtropics, expected to warm even more. The poorest and most vulnerable people are being affected the most.

2.7.3 Goal 15: Protect, Restore And Promote Sustainable Use Of Terrestrial Ecosystems, Sustainably Manage Forests, Combat Desertification, Halt And Reverse Land Degradation And Halt Biodiversity Loss.

Thirteen million hectares of forests are being lost every year; Around 1.6 billion people depend on forests for their livelihood. This includes some 70 million indigenous people. Forests are home to more than 80% of all terrestrial species of animals, plants and insects; 2.6 billion people depend directly on agriculture, but 52% of the land used for agriculture is moderately or severely affected by soil degradation; Due to drought and desertification each year, 12 million hectares are lost (23 hectares per minute), where 20 million tons of grain could have been grown; Of the 8,300 animal breeds known, 8% are extinct and 22% are at risk of extinction and As many as 80% of people living in rural areas in developing countries rely on traditional plant-based medicines for basic healthcare.

2.8 Climate Change Policy, Legislative and Institutional Frameworks

Given the enormous challenges created by climate change and disasters, the government has ratified several global agreements and put in place its policies and legislation that provide opportunities to pursue an integrated climate risk management approach. These are discussed in this chapter at four levels: international, regional, national and devolved.

2.8.1 International Frameworks

Kenya has domesticated a series of international conventions and agreements relevant to integrated climate risk management;

a. Sendai Framework for Disaster Risk Reduction, March 2015; The framework has four priority areas: understanding disaster risk; strengthening disaster risk governance to manage disaster risk; investigating disaster risk reduction for resilience; and enhancing disaster preparedness for effective response and to ‘Build Back BeĴer’in recovery, rehabilitation and reconstruction. The framework advocates the integration of both DRR and resilience-building into policies, plans, programmes and budgets at all levels.

b. United Nations Framework Convention on Climate Change, 1992; This sets out the framework for action to stabilize the atmospheric concentration of GHG at a level that will prevent dangerous anthropogenic interference with the climate system. Developing countries are required to undertake Nationally Appropriate Mitigation Actions in the context of sustainable development, supported and enabled by technology, financing and capacity building. Countries are also expected to prepare and implement National Adaptation Plans.

c. Paris Agreement Conference of the Parties (COP21), November-December, 2015; The agreement bridges today's policies and the goal of climate-neutrality by the end of the century. Governments will aim to limit the temperature increase to 1.5°C, significantly reduce the risks and impacts of climate change and strengthen societies' ability to deal with these, and enhance international support for adaptation in developing countries. The agreement acknowledges the need for cooperation and enhanced action in areas such as early warning systems, emergency preparedness and risk insurance. It also acknowledges the adoption of the insurance. It also acknowledges the adoption of the Addis Ababa Action Agenda and the Sendai Framework.

d. Sustainable Development Goals (SDGs), September 2015; 25 targets related to disaster risk reduction in 10 of the 17 SDGs, including explicit links to the Sendai Framework. This firmly establishes disaster risk reduction as a core development strategy.

2.8.2 Regional Frameworks

The regional frameworks relevant to integrated climate risk management that shapes national policies and strategies and provide mechanisms to address challenges that extend beyond national borders include the following;

a. **Draft African Strategy on Climate Change, 2014**; The strategy was developed by the African Union to help the continent achieve climate-smart socio-economic development. It is organized around four thematic pillars: climate change governance; promotion of research, education, awareness-raising and advocacy; mainstreaming and integrating climate change imperatives in planning, budgeting, and development processes; and promotion of national, regional, and international cooperation. This framework is aligned with Its objectives and pillars. (AU, 2014);

b. **East African Community Climate Change Policy,2011;** This guides the preparation and implementation of collective measures to address climate change in the short and medium term. It highlights adaptation to climate change as the priority for the region and seeks to mainstream adaptation into national and regional development plans by sector: water resources, agriculture and food security, energy, and ecosystem services. (EAC, 2011a);

c. **East African Community Climate Change Strategy 2011/12-2015/16**; This implements the EAC Climate Change Policy. It sets out a range of measures and directs the policy's implementation over a shorter time frame. (EAC, 2011b);

d. **East African Community Climate Change Master Plan,2011-2031;** This provides a comprehensive framework for adapting to and mitigating climate change in line with both the EAC Protocol on Environment and Natural Resources Management and international climate change agreements. (EAC, 2011c);

e. **East African Disaster Management Act;** The Act represents the culmination of a five-year process and is a key instrument to Risk Reduction and accelerate the implementation of the Sendai Framework in the region. It has the provision to establish a ministerial-level EAC Disaster Risk Reduction and Management 2016 Authority. (EAC, 2016);

f. **IGAD Drought Disaster Resilience;** This aims to address the effects of drought and related shocks in the IGAD region sustainably and holistically. It recognises the need for a and Sustainability comprehensive and holistic approach to the challenges of the food and nutrition insecurity Initiative (IDDRSI) and to build resilience. Kenya's contribution to IDDRSI is the Common Programme Strategy, 2013 Framework for Ending Drought Emergencies. (IGAD, 2013).

2.8.3 National and County Frameworks

The Fourth Schedule of the Constitution allocates the function of disaster management to both the national and county governments. The Bill of Rights further emphasises the right of every person to a clean and healthy environment and to be free from hunger. The following frameworks are instrumental in implementing the international and regional agreements ;

a. **National Drought Management Authority Act, 2016;** The NDMA is a statutory body established under the NDMA Act, 2016. The Act gives the NDMA the mandate to coordinate all matters relating to drought management, including the implementation of policies and programmes and drought response initiatives undertaken by other actors. The NDMA is also tasked with promoting the integration of drought management in development policies, plans and programmes. (GoK, 2016a);

b. **Draft National Policy for Disaster Risk Management, 2013;** The vision of the draft policy is a safe and disaster-resilient nation. It aims to reduce disaster risk and loss through an integrated multi-hazard approach that contributes to and protects the achievements of Kenya Vision 2030. The policy embraces the paradigm shift from managing the response to managing risk and aims to integrate DRM in planning and budgeting. Several institutions related to the policy are already in place, including the NDOC, the National DRR Platform, and the National Disaster Management Unit (NDMU). Some line ministries also have units that address disaster and climate risk management. (GoK, 2013b);

c. **National Climate Change Response Strategy (NCCRS), 2010;** The strategy represents the government’s formal recognition of the climate change challenge. Its primary focus is to ensure that adaption and mitigation measures are integrated with all government planning, budgeting and development objectives. It advocates collaboration and joint action in tackling the impacts of climate change, as well as stronger planning and institutional capacity development, including at the community level. (GoK, 2010);

d. **National Climate Change Action Plan (NCCAP), 2013-2017;** This operationalises the NCCRS and provides guidelines for mainstreaming climate change across all sectors of the Medium Term Plan (MTP). It has nine sub-components which are now being implemented. (GoK, 2013a);

e. **Climate Change Act, 2016;** The purpose of the Act is to develop, manage, implement and regulate mechanisms that enhance climate change resilience and low-carbon development. It will anchor all actions relating to climate change across all sectors. It also creates a climate change governance structure at the national and county level. Some institutions are already in place, such as the Climate Change Secretariat. (GoK,2016b)

2.9 Carbon Stocks Estimates

The intergovernmental panel on climate change (IPCC,2006) has listed five terrestrial ecosystems carbon pools involving biomass; above-ground biomass, below-ground biomass, litter, wood debris, and soil organic matter, of these five,above-ground biomass is the most visible, dynamic, dominant and important pool of the terrestrial ecosystem, constituting 30% of the total terrestrial ecosystems carbon pool. Carbon assessment is the most critical phase in the statistical analysis of levels of carbon and forest fluxes in aboveground vegetation estimation (IPCC 2006).

For estimating carbon stocks in other ponds, the frequently used scores from reference sheets and aboveground biomass correlations are sufficient. Underlying biomass, for instance, is invariably estimated to be 20% of the above-ground coal reserves (Liyama, 2007) based on an exhaustive literacy evaluation statistical relationship the same way, reduced carbon stockpiles of bodies or waste are normally projected to be around 10-20 per cent of the above-ground estimates of wood biomass in permanent forests. bare, bare seat, broken branches, and leaves. (Harmon and Sexton 1996).

2.10 Study Gaps from the literature

a. There is a need to establish reliable baseline data and information on woodfuel and charcoal production, identify opportunities for sustainable use and key challenges at all levels in the woodfuel and charcoal value chains;

b. Past initiatives have shown a lack of accurate and reliable information and data on land cover changes that are instrumental in the policy formulation to bridge the existing gaps, systematic regulation to access and harvesting of biomass.

c. Limited, inaccurate, and up-to-date data on the estimation of sustainable biomass harvesting. This study intends to use remote sensing techniques to build models through simulations to provide accurate, reliable and repetitive data to be used for decision support mechanism;

d. Identified models that integrate above-ground biomass and spectral data for mapping and biomass estimation using alternative imaging technology such as LiDAR for capturing textural characteristics of forests and woodlands land covers for biomass estimation.

2.11Theoretical Framework.

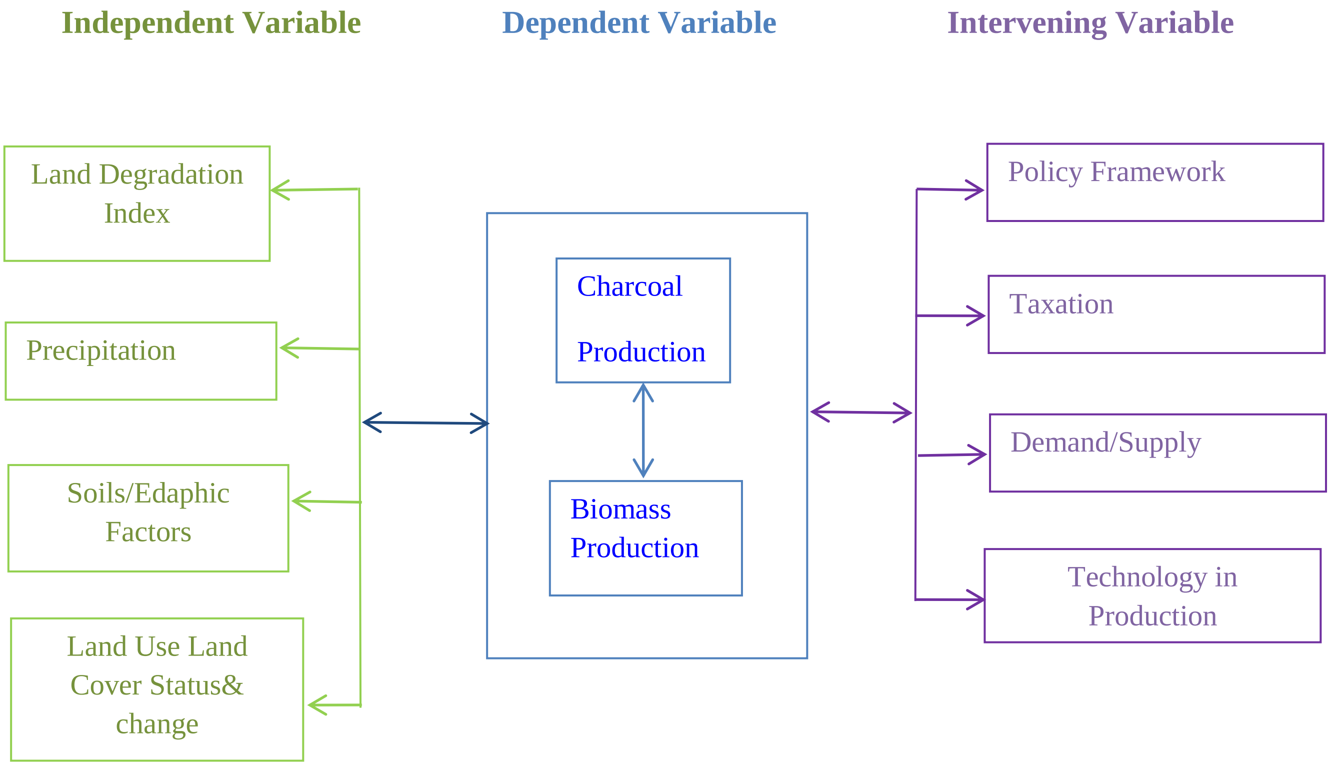
The Systems Theory advanced by the biologist Ludwig von Bertalanffy and later supported by Ross Ashby was used for this study due to its relevance (Mwaniki, 2010). A system refers to a configuration of different parts, which are joined together by a unique network of relationships. According to this theory, real systems interact with their environments and are bound to acquire new qualitative properties by ongoing evolution. Unlike the reductionism approach, System Theory proposes that there are specific arrangements and relationships between different parts that make a whole. One of the principles in System Theory is that a system is not static and consists of a complex whole, which interacts as a structured functional unit. Another belief is that there is information flow in different composites of the system. The third principle is that networks consist of various entities, which seek an equilibrium state, and in the process, they can manifest oscillation, exponential growth, or decay (Mwaniki, 2010).

In this study, the System Theory helps explain better various components that work around the intricate system of charcoal trade as a form of community livelihood. Knowledge sharing among local communities, stakeholders, and the government through different relevant sectors on various aspects such as charcoal policies, legal framework, and biomass estimation significantly determines the production levels for sustainable charcoal production. This chain among the producers, regulators, and users forms a pattern of a complex system in charcoal production and trade.

2.11.1 Conceptual Framework

This study is based on the following conceptual framework.

Conceptual framework



Source: Author 2019

Figure 2. 1:Conceptual Framework

2.11.2 Influence of independent variable the dependent variable

Monthly earnings and steady demand from Charcoal will differ inversely in proportion to the number of earnings from charcoal. The lower the profits, the higher the degradation would be due to the demand imposed to fill income gaps from the same land resources, plus the lack of ability to cover the cost of treatment. Although the level of health would be directly proportional to the earnings from charcoal. Higher earnings mean the opportunity to afford better treatment, and vice versa. Access to education would be directly proportional to earnings from charcoal Higher earnings mean a higher capacity to provide or fund education, and vice versa.

The estimate of biomass using remote sensing and technology in the production of charcoal would differ inversely in proportion to the rate of land degradation. The lower the technology, the higher the land degradation would be due to high feed waste resulting in lower yields. Low yields would lead to higher feedstock extraction to realize the same degree of subsistence needs. Health quality can differ directly in proportion to the technologies used in the manufacture of charcoal. Better technology would result in cleaner charcoal harvesting and fewer emissions and less exhaustion or physical strain, resulting in better health, and vice versa.

Challenges in the production of charcoal would be directly proportional to the rate of land degradation. The lower the challenges with appropriate technology, the easier it is to manufacture charcoal sustainably and profitably. Inversely, the level of health can differ in proportion to the difficulties faced in the processing of charcoal. Higher obstacles will result in a decreased capacity to access good health care, as insufficient resources will be available.

3.0 CHAPTER THREE: STUDY APPROACH AND METHODOLOGY

3.0 Introduction

This chapter gives a detailed description of the study approaches, methodology and study site.

3.1 Study Site

3.1.1 Study Location and Description.

Kajiado County is situated in the southern tip of the former Rift Valley province between $36^0$5 and $37^0$5 longitudes and 100^0 and 300^0 south latitudes (Amwata, 2013). It occupies a surface area of 19,600 km^2 (CBS, 1981). A field study was performed with the communities of Kajiado East Sub-County. The Sub-County has five administrative offices (Oloosirkon / Sholinke, Kitengela, Kapetui North, Kenyawa-Poka, and Ilmaroro). Kajiado East has an area of 2,610,30 km^2 and the major cities include Kitengela, Isinya, and Imaroro.

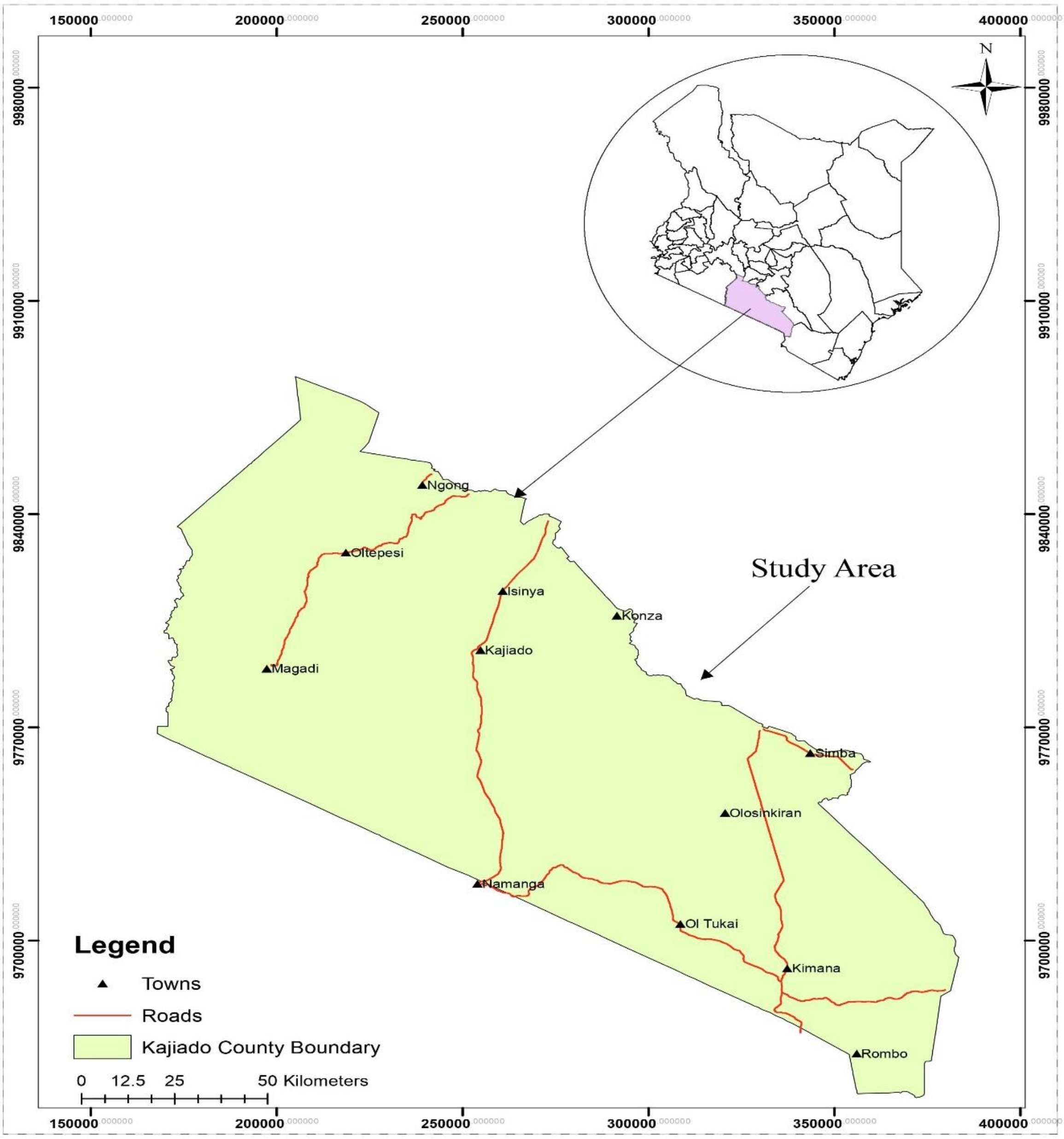


Figure 3- 1: Kajiado County Location Map

3.1.2 Climate

Kajiado County has a bimodal rainfall pattern that is influenced by altitude. It has a mean annual rainfall of between 300–800mm. However, areas with high altitudes like Ngong and Loitokitok experience heavy rainfall that can be as much as 1200mm of rain per annum. Kajiado County has two main rainy seasons: the long rainy season from March to May and the short rainy season from October to November. Analysis of rainfall for the two rainy seasons reveals that most areas receive 50 per cent of annual rainfall during the March to May period and 30 per cent during the October to December period (ROK, 2009). Temperatures in Kajiado County vary with altitude and season. The highest temperatures of about 340C are recorded around Lake Magadi while the lowest of 100C is experienced at Loitokitok on the eastern slopes of Mt. Kilimanjaro (ROK, 2009). The coolest months of the year are between July and August, while the hottest months are from November to April. The livestock system mainly pastoralism, agropastoralism, cropping and mixed crop dominate the main sources of livelihood in Kajiado County. In the high rainfall areas of Loitokitok, farmers grow millet, sorghum, groundnut, maize, pigeon peas and cowpeas. Most of the Kajiado County lies between arid and semi-arid zones. Most of the County falls within agro-climatic Zone V (55%) and VI (37%), which are semi-arid and arid respectively. Agroecological zone V receives 450 to 800mm of annual rainfall and has a moisture index of 25 to 40%. Pastoralism and agropastoralism are the main sources of livelihood of people living in agroecological zones V and VI. The rest of the district falls in agro-climatic Zone II, III and IV, accounting for a sum of only 8% of the County. The County has a total of 92% of ASAL ecosystems with only Athi-Kapiti ecozone free of arid patches. Rift Valley ecozones lead in a percentage of semi-arid lands (71%) while vast areas of Amboseli ecozones are arid (69%).

3.1.3 Demographic Features.

Kajiado County is predominantly inhabited by the Maasai. The 2009 population census **(Table 3.1)** showed that Kajiado County had a population of 687,312, which increased to 1,117,840 in 2019 (CBS 2019). This indicates that Kajiado County has an annual growth rate of 4.5 per cent, which is higher than the national annual growth rate of 2.9 per cent. (ROK, 2009).

Table 3 - 1: Kajiado County/Sub County Population Distribution

County/sub county	Sex			Total
	Male	**Female**	**Intersex**	
Kajiado central	81,514	80,343	5	161,862
Kajiado north	150,675	155,908	13	306,596
Kajiado west	91,607	91,237	5	182,849
Loitokitok	94,613	97,225	8	191,846
Mashuuru	33,082	31,131	1	64,214

Source; 2019 Kenya population and housing census

3.1.4 Biophysical Features

Kajiado County varies in altitude from about 500m above sea level (a.s.l.) around Lake Magadi to about 2500 a.s.l. in the Ngong Hills. The three main topographic features in the county are Rift valley, Athi Kapiti and Central Broken Ground (CBS, 2019).

3.1.5 Charcoal Production Hotspots

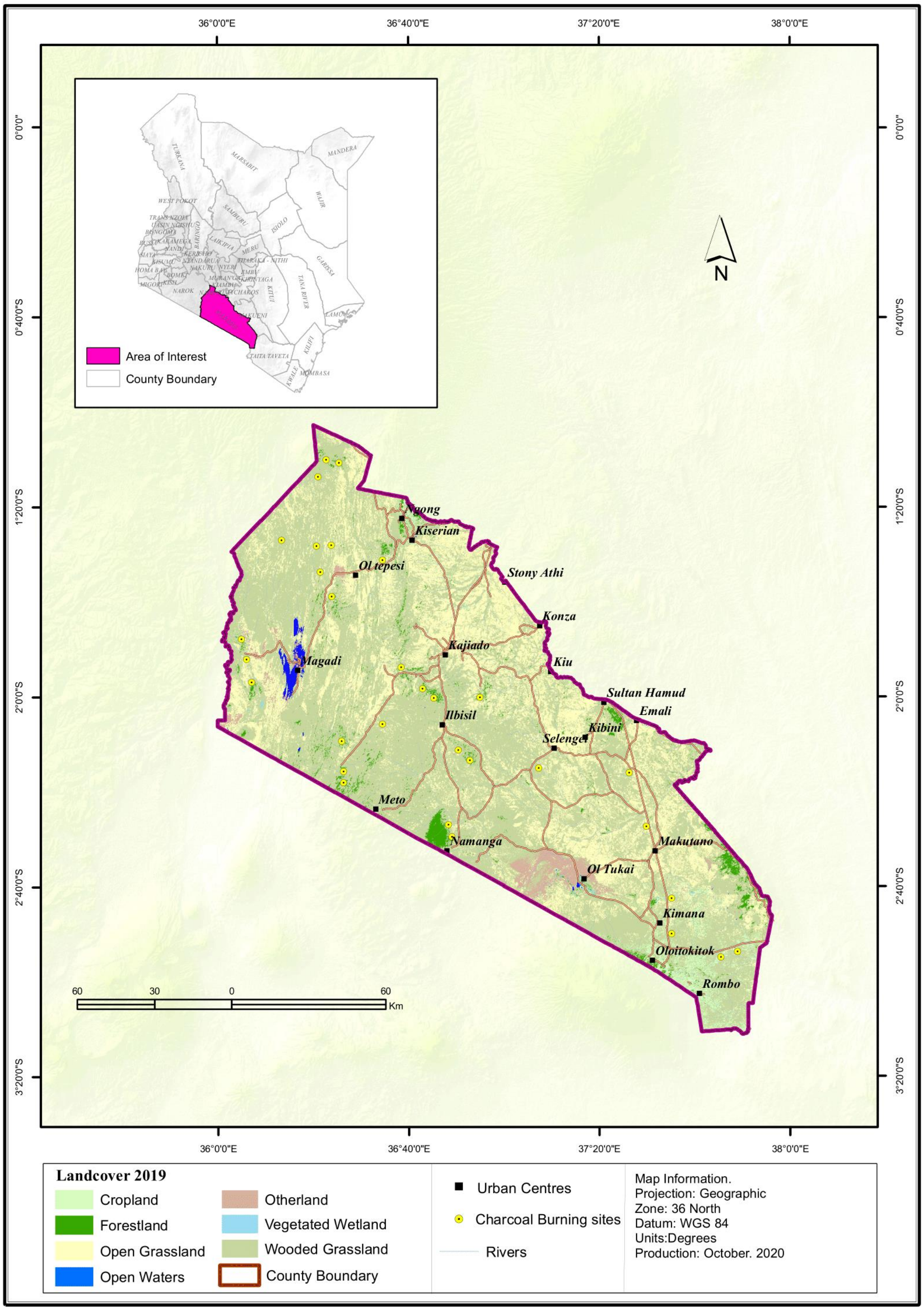


Figure 3- 2: Charcoal Production Hotspots In Kajiado

3.2.Research and Design

The study was designed to generate and utilize both qualitative and quantitative data types to respond to the set objectives. Using experimental research design, time-series data on land use and land cover changes were developed to show the relationship between biomass utilization and energy demand/supply. The Earth Observatory methods that included remote sensing and satellite imagery analysis were used to evaluate the impacts of woodfuel/charcoal harvesting on the environment. This enabled depiction of the demand for charcoal by the population intensity and biomass production by overlaying spatial and non-spatial data over a selected period to achieve the project objectives. This enabled a comparison of different perspectives on both quantitative and qualitative data in the study area. By estimating the biomass production and land cover changes over time series, the researcher aimed to find out their environmental impacts, growth patterns and thus devise sustainable harvest patterns that would be vital to sustainable charcoal production in Kenyan drylands.

3.3 Nature and Sources of Data

The study used a dataset of unclassified commercial satellite images with a cloud cover of less than 20% for the 1999-2019 study site. These datasets included images from Sentinel 2 and Landsat LTM. The images detail the annual analysis of the study site from 1990 to 2019 and limited coverage of the sites from 2016 to 2019. The research used data from non-spatial and spatial (GIS) layers. The spatial data in the study area were collected from the GIS Research Laboratory at the Directorate of Resources Surveys and Remote Sensing (DRSRS), located in Nairobi, Kenya. DRSRS is a government-run geospatial data agency and has been selected because its data is modified and available periodically. The collected and analysed data from DRSRS includes:

- A population data with spatial details in the administrative areas of Kenya. These data were mainly collected during the population census of 2019 and revised during the latest economic survey in 2019. This shapefile was used to identify the boundary of the study and to prepare population intensity maps showing the settlement heat index;

- The land cover data that was initially owned by the Africover underwent an update in 2018. The Africa cover is a project that was established by the United Nations and it had the main goal of ensuring that there was the collection of the geographical information about land cover, the conditions the climate, and the natural resources that are found within Africa and this was based on the applications of the remote sensing method. The project is based on the use of a legend file that has captured the themes of the land covers that are found within any country in Africa. The data that is contained in the file has been considered by the current study.

- Normalized Differential Vegetation Index is a dimensionless index that is indicative of vegetation photosynthesis activity. NDVI is readily available on daily basis covering the entire country and provides a more accurate index of actual vegetation conditions. NDVI is highly responsive to rainfall anomalies, allowing it to be used as a good indicator of primary productivity. According to Kogan, (1995.,) NDVI has been extensively used in vegetation monitoring, crop yield assessment forecasting and drought monitoring and mapping. NDVI characteristics of high detection during vigorous plant growth and response to environmental induced stress such as due to drought make it important for vegetation monitoring and vice versa. NDVI is both qualitative and quantitative. The study utilised the Kenya Climate-Smart Agriculture Project data, a partnership project between the Kenya Agricultural and Livestock Research Organization (KALRO) and DRSRS funded by the world bank, together with the secondary data on Census and land-based classification data from the Kenya National Bureau of Statistics (KNBS) to overlay scenarios using the GIS platform to project population intensity and land-use trends for energy needs, consumption, and projections. The non-spatial data used in the study included the population census, economic survey, and interviews using research questionnaires.

3.4 Methods of Data Collection

Both secondary and primary data was collected from the field to provide useful information regarding the factors that influence the local actors' strategies and perceptions. The research covered the entire Kajiado county using GIS and remote sensing, ground sampling, participatory rural appraisal and field observations.

3.4.1 Participant Observation and Survey

Through direct observation, the researcher recorded how different land uses where charcoal production had taken place, and the different biomass management, within the study area. This involved close interactions with the charcoal burners, observing their daily activities and monitoring the changes made on woody-plant vegetation. The major issues were recorded in a notebook for further analysis.

3.4.2 Key Informant Interviews

This method involved the collection of data by interviewing key resource persons in the study area including the local chief, national environmental management authority officers, Kenya forest research institute, Kenya wildlife service and the environment officer at the sub-county level. this method provided in-depth information pertaining status of charcoal production, the socio-economic contribution of the charcoal industry and the impacts of charcoal production on the environment as discussed in chapter five of this thesis.

3.4.3 Focused Group Discussion

A group interview was done to find out positive and negative impacts of charcoal enterprise and the economic benefits from the industry to the residents of the study area. A focused group discussion was conducted amongst Maa youth group and kitengela charcoal production association group members selected through random sampling. The research used open-ended questions to obtain wide-range information from the groups.

3.4.4 GIS and Remote Sensing

The GIS and geostatistical techniques and approaches were crucial in handling both the spatial and nonspatial analysis by storing, selecting, manipulating, exploring, analyzing, and displaying georeferenced data. The researcher used GIS technologies to refine datasets, data models, and the relation between attributes. The existing attributes were easy to link with newly defined datasets for accuracy. The identified sites formed sample points for the interviews.

The researchers used medium-resolution satellite data including Landsat 5 and 7 and Landsat for analysis with 30 m resolution swath distance. This was easy in separating different land use classes. using the IPCC identification system thus separating the forest from non-forest, identification of woodlands from shrubland,bareland from grasslands and tabulated in **Table 4-1**. The land cover classification approach was domesticated from the IPCC land cover classification scheme with six classes (Forestland, Cropland, Grassland, Settlement, Wetland, and other lands), which were broken down to ten classes; Forestland, Cropland, Open Grassland, Wooded Grassland, Vegetated Wetland, Open Water and Other lands.

Land-use cover maps were created from Landsat satellite imagery (1990-2019) but the Geographic Information System (GIS) and remote sensing techniques were used in wall-to-wall assessment and mapping of land-cover types. ArcGIS mapping software was used including Ms Excel, which is a statistical software was used to run a random land cover algorithm for classification purposes. All datasets were re-projected to the Kenyan local projection system (Arc 1960 UTM zone 37s).

Image quality assessment was done to determine the availability of Landsat images that were suitable (Especially for dry season) for mapping. Suitable imageries (with 10% or less cloud cover) were therefore selected via *United States Geological Survey* Global Visualization Viewer and the available good quality images downloaded for the exercise.

Table 4- 1: Land Cover Description

Land Cover Class	Description
Dense Forest	Forest with canopy cover > 15% and above
Wooded Grassland	Refer to woodlands that do not qualify as forestlands. They have a tree canopy ≥of 10%. These are mainly the woodlands that support wildlife in the rangelands of Kenya and have a mixture of trees, shrubs, and grasses.
Open Grassland	These refer to grasslands devoid of trees. They are grasses in wildlands, moorlands, wetlands, recreational areas, and glades. They include areas that support nomadic pastoralism in the rangelands of Kenya.
Cropland	Refer to the treeless agricultural fields. They comprise the mechanized farms in the breadbaskets of Kenya (wheat and maize growing areas of the Rift Valley), extensive irrigation farms largely dominated by rice and other mixed farming, and Include crops that stay on-farm for more than one season before maturity.
Vegetated Wetland	Refer to a wetland that is covered with vegetation, including marshy land, swamps, and related.
Open Water	Refer to areas with a pool of open water including lakes, rivers, oceans, dams, ponds, and related.
Other Land	Include land that does not fall into any of the above categories. For this case, include settlements, infrastructure, bare rocks, ice on Mt Kenya, and sand beaches along seashores.

The spatial and non-spatial data were collected, corroborated, and analyzed to the main objective of the assessment was to estimate the spatial capacity of biomass in the county of Kajiado and to present a method for automating the assessment process. Four measures have been followed by the method used in this analysis. The first step consisted of land use land cover mapping in a time series of 5 epochs. The NDVI values were also derived from the maps; the assessment of the geographical position in terms of vegetation groups existing in the region and other crop residues; and a GIS-based study was used to analyze the relationship between existing biomass and other crop residues. The demand for charcoal was depicted by the population intensity in the study area using both spatial and non-spatial data.

GIS software was applied as the platform that analyzed the data and also on product management. The following methods and datasets were used:

- Topographic 1:25000 scale maps provided by the Kenya survey have been used for the development of contour lines as well as the Digital Elevation Model (DEM) map for the NDVI data;
- Different land cover maps have been developed using Landsat Tm Imaging (DRSRS) for the years 1990, 2000, 2010, and 2019.
- A population distribution/density map was developed using the scale of 1:10,000 cadastral maps (Kenya National Bureau of Statistics, 2019).
- Polygon boundaries have been digitized on-screen, for topographic maps, satellite imagery for the years 1990, 2000, 2010, and 2019.

Landsat satellite images for the years 1990,2000,2010 and 2019 and non-spatial data (population census data) were analyzed and the data were then categorized to accurately examine the land cover and also the land cover changes between 1990 and 1919. There was a standard coordinate projected by the use of satellite images and other charts, and a similar spatial resolution of (60 cm) was used. There was an improved visual representation of the images that were collected by the satellite to chart the land cover for 1990, 2000, 2010, and 2019 using ArcGIS 9.1 software.

3.4.5 Ground Sampling.

The researcher collected ground data specifically for the precise evaluation of the final results of the image classification. The output classification generated by the image classifier is compared with the measurements and observations made at random points generated by the interpreted satellite imagery and the maps in terms of the coordinates used to determine the accuracy of the classifier. These points were fed to the GPS for navigation and clarity. The verification and evaluation of the imaging research carried out included the spatial distribution of the phenomenon being mapped, the size of the sample, the number, form, and frequency of its occurrence.

Field visits were undertaken to verify the results of the interpretation of land cover and to provide a summary of the characteristics of each land cover class and land use. For this reason, a selective sampling technique was used with household questionnaires. Based on the available quantities of biomass and growth, a theoretical comparison of the maximum energy production capacity for two scenarios (full condensing plants and cogeneration plants) was made using the ArcGIS Extension Model Builder, which established a tool that automated the biomass assessment process and defined capacity suitability for the production of charcoal.

3.4.6 Participatory Rural Appraisal

A Participatory Rural Assessment (PRA) was conducted to understand the different production systems in the study field. The PRA covered situational analysis, different lead agencies on the ground on charcoal production value chains, custodians of the source resource, spatial distribution, demand, and supply.it also tried to establish the gap in both the policy and sustainable production systems. There were three lead agencies in this regard, NEMA Kajiado county, KFS, KEFRI, KALRO, and the charcoal producers association. The other participants included selected households that gave an in-depth on the supply and demand of charcoal. Mobilization of the participants was made possible with the help of the local leaders.

3.5 Instruments for Data Collection

3.5.1 Satellite imagery

The research used satellite imagery as the main data collection instrument. This provided much more information on the earth's surface on a large scale within a very short time. In forestry, satellite image has been used widely for resource management, planning, monitoring, predicting and more important, modelling for different early warning systems. The remotely sensed data however require accurate assessment using other research methodology such as interviews, observations and ground-truthing for verifications.

3.5.2 Questionnaires

The use of questionnaires was less expensive since it allowed saving of time, financial resources and convenience (Kumar, 1999). The study used different categories of questionnaires: household, suppliers/producers and stakeholders. Questionnaires were developed by adopting previous related studies experiences divided into six sections. Section 1 and 2 focused on spatial data especially land-use patterns, section 2 on participants knowledge of the charcoal value chains (producers, transport and consumers), section 4 on the current production systems, section 5 on socio-economic trends and lastly section 6 on existing policy and regulatory frameworks. The questionnaire was administered through personal interviews to encourage the respondent to actively participate and share their opinion. Closed-ended questions presented the respondent with the opportunity to choose one answer from a series of options. Open-ended questions allowed the respondents to have freedom in giving a response.

3.5.3 Interview schedules

This involved collection of data through pre-coded questions. The interviewer explained the purpose of the study with the required information. This was administered to relevant institutions including KFS, KEFRI, NEMA, KWS, DRSRS, NGOs and CBOs.Various groups and individuals in the charcoal industry to acquire diverse information about the study are including the source of livelihood, potential investment opportunities and threats to environmental conservation, existing institutional framework and enforcement capacity and the constraints to the charcoal industry.

3.5.4 Observation Guides

This was used for quick recording and in verifying the information as data was collected using questionnaires. Observations as a method of data collection also increased the precision and reliability of data collected and validate remotely sensed data.

3.6 Sampling Techniques and Procedures

According to fellows and Liu (1997), and Naoum (2007), sampling is necessary, it is almost impossible to examine the entire population. To obtain a good presentation of the respondents, it is possible to use a sample of the population, which is much smaller than the total population, but sized and structured to be statistically representative. The results from such sampling would not be the same as if the whole population had been consulted, but the result is adequate for the purpose for which the information was required (Fellows and Liu (1997) assert that population parameters and sampling procedures are vital to the success of a study.

Below is a formula used in determining the sample size for the study,

$n= (Ncv^2)/ (cv^2+(N-1)e^2)$

whereby n=sample size, N=population is 197,768 (KNBS, 2018), cv=coefficient of variation (took 0.5), e=tolerance at a desired level of confidence took 0.05 at 95% confidence level

(Neuman, 2000). Based on the formula above and the variables indicated, the sample size of n=99.96 was selected, which was rounded off to 100. This comprised 50 charcoal producers households, 40 charcoal business merchants, 4 institutions, 1 CPA, 5 Key resource persons.

3.6.1 Cluster Sampling

It is a random sampling technique in which the population is subdivided into groups(Clusters) so that there is small variability within clusters and large variability between clusters(orodho,2004). The researcher selects groups or clusters, and then from each cluster, the researcher selects the individual subjects by either simple random or systematic random sampling (ibid). This technique ensured that the relevant respondents are targeted as the researcher can opt to include the entire cluster and not just a subset of it. This research had 4 major clusters; institutions, households, the business community and the key informants.

3.6.2 Simple Random Sampling

In administering the household questionnaires, the researcher identified major transects along the administrative boundaries on the administrative divisions of the study area. Along these transects, 10 household questionnaires were administered at random amongst charcoal producers' households in each of the 5 administrative locations of the county.

3.6.3 Purposive Sampling

Purposive sampling is a non-representative subset of some larger population and is constructed to serve a very specific need or purpose(Mugenda and Mugenda,1999). Purposive sampling represents a group of different non-probability sampling techniques and the researcher will attempt to zero in on the target population group, interviewing whoever is available(begin,2009). Also known as judgemental, selective or subjective sampling, purposive sampling relies on the judgement of the researcher when it comes to selecting the units such as households that are to be studied (Fraenkel and Wallen,1993). Usually, the sample being investigated is quite small, especially when compared with probability sampling techniques (Mugenda 1999).

The ultimate goal is to identify and focus on a particular characteristic of a population that are of interest to address the research questions. This was employed by selecting 70 charcoal production households in the study area and key resource persons which included KFS, KEFRI, NEMA, KWS and county officials.

3.6.4 Snowball Sampling

It entails the identification of someone who meets the criteria for inclusion in the study (Berg,2006). Though the method rarely leads to representative samples, it may be the best method available. It’s useful when attempting to reach inaccessible populations. This was crucial for the study as charcoal producers in the study area could not be easily located as they could not be at all times be found in the kiln site. Charcoal producers therefore found in the kiln sites directed the researcher to where other charcoal producers they knew of could be located.

3.7 Methods of Data Analysis

3.7.1 Data Types

Geospatial technology and remote sensing were used to generate both the spatial and non-spatial data, corroborate, and analyze to estimate the spatial capacity of biomass in the study site and to present a method for automating the assessment process. The non-spatial data used a structured questionnaire to collect data. These data included socio-demographic information, sources of raw materials for producing charcoal, types of charcoal production techniques, and sustainability strategies to ensure the availability of raw materials for production. Other data included a legal requirement for running charcoal related activities in the research site with their challenges.

Spatial data used four measures were followed; the first step consisted of land use land cover mapping in a time series of 5 epochs. The NDVI values were also derived from the maps; the assessment of the geographical position in terms of vegetation groups existing in the region and other crop residues; and a GIS-based study was used to analyze the relationship between existing biomass and other crop residues. The demand for charcoal was depicted by the population intensity in the study area using both spatial and non-spatial data.

The collection of GIS data in this study was achieved through four key steps. The initial step consisted of forest cover mapping and classification using satellite imagery; the second step was the calculation of available forest biomass and annual growth using NDVI values derived from classified images; the assessment of the geographical position of established plant groups and other crop residues and the use of spatial (GIS) layers was evaluated.

The research of the field of study using the Geographical Information System (GIS) for the research, management, and representation of the real world was to provide real-time data for decision-making. Since satellite remote sensing allows for a retrospective, synoptic viewing of broad areas, it has provided the opportunity for a geographically and temporally detailed assessment of changes in land use/land cover in Kajiado County. Remote sensing provided information on various spatial parameters, including land use/land cover, population density, topography, etc. In combination with GIS software, RS allowed data integration and interpretation. This has helped to save time and produce good data quality that can locate possible new scenarios that require immediate attention.

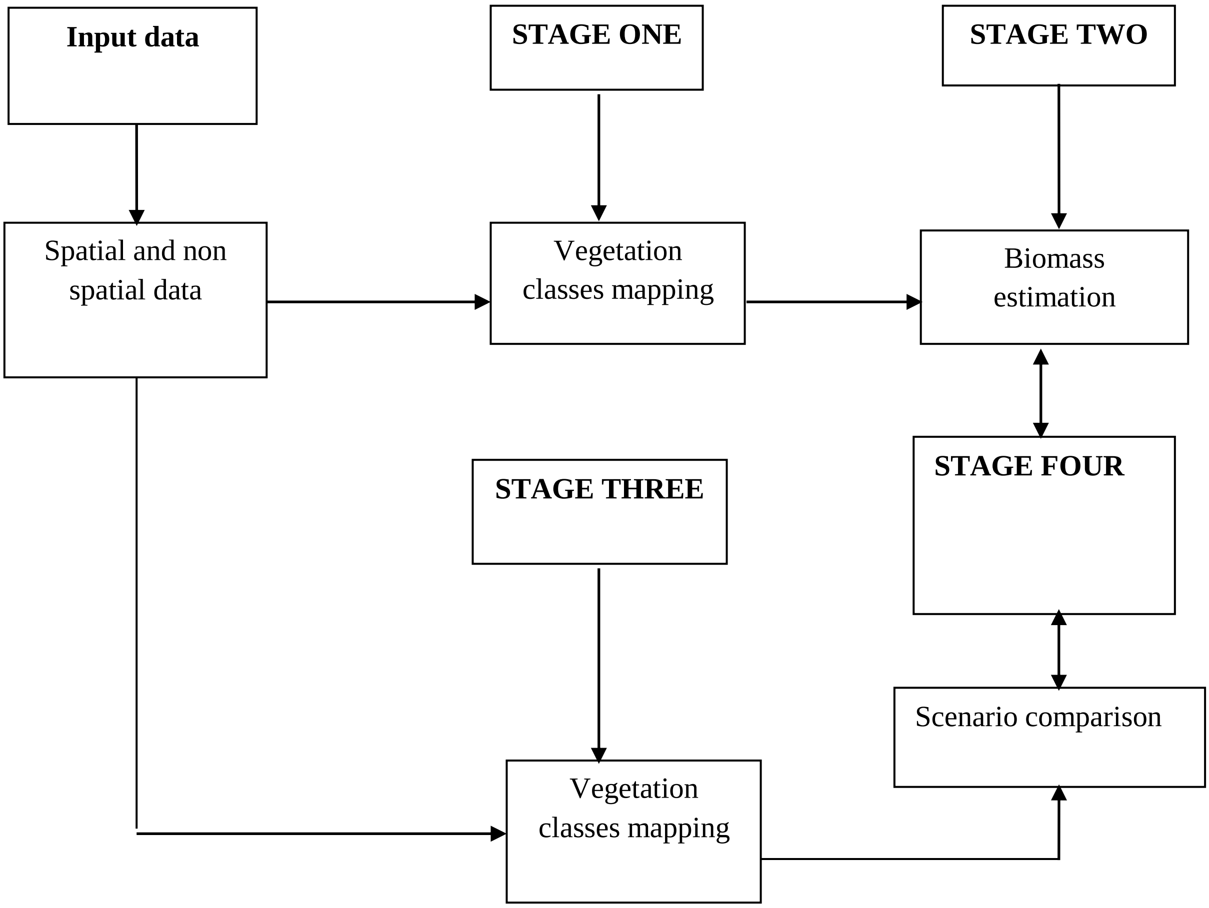


Figure 4- 1: Overview of the Study Stages

A data resource includes;

i. Land Cover Types,

ii. Digital Elevation Model,

iii. Forest and Energy Management Plans,

iv. Land Management Plan,

v. Population Plan

Once the land cover classifications have been derived, the Arc Geographic and Information System (ArcGIS 10.1) was used to prepare the LULC maps of 1990, 2000, 2010, and 2019. The areas of the LULC groups were then estimated from the maps, and the LULCC analysis and change rates were estimated.

Total LULCC between the two periods is calculated as follows:

Total LULCC Gain/loss = Area of the final year - Area of the initial year…….…..……. (1)

Percentage of LULCC Gain/loss = (Area of the final year - Area of the initial year) 0ver Total area of the catchment…………………………………………………………… (2)

A LULCC matrix was developed by ArcGIS to analyze LULCC cross-category transitions. The matrix was developed for the transformations 1990–2000,2000–2010–2019. The spectrum of gains, losses, persistence and switching between the LULCC forms was measured using the matrix. The terrain slope – LULCC relationship was established by overlaying the slope created by the DEM of the study area and the classified maps. The distribution of LULCC with slope was then quantified. As a result, it was beneficial to see how the continuous demand for agricultural land had led to improvements in the LULCC of higher slope areas **(Table 4-1).**

3.7.2 Data Entry and Analysis

Data entry was done using global navigation satellite systems by obtaining three-dimensional geodetic coordinates. The GPS points were analyzed spatially with the coordinates converted to Microsoft Excel for analysis to depict locations of charcoal production points/sources. The population data were also analyzed using Microsoft excel. Satellite imagery was used to overlay the collected points to get time-series data of the research site from 1990-2019 using ArcGIS and ERDAS IMAGINE software. The data were analyzed using descriptive statistics and results presented as summary frequencies, maps, charts, and tables.

3.7.3 Ethical consideration

Before administering questionnaires, the researcher sought permission from relevant authorities mainly chiefs. The randomly chosen respondents were also asked voluntarily to participate in the study. For instance, the researcher assured the respondents of their confidentiality of information as data collected represents the situation holistically on the ground and hence policy recommendations given will not be biased in any way.

4.0 CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Kajiado Land Cover Land Use Changes.

Landsat TM Satellite images from 1990, 2000, 2010, and 2019 were analyzed and categorized during the period from 1990 to 2019 to investigate ground cover and land cover changes. Interpreted data presented using maps of the contributing factors of LULCC, the magnitude, and consequences of these changes for sustainable biomass development. Three remote sensed data at a period of 10 years were used to establish land use maps and to measure changes by supervised classification.

Using the approaches adopted in the methodology, land cover maps have been created for all thirty years with 10 years (**Figures 4-4,4-5,4-6 and 4-7**) and area estimates and change statistics have been computed. Class area and change statistics have been summarized for the 30 years **(see Table 4-1).**In the study period covered, the mainland cover groups listed include forests, woodlands, grasslands, etc. The socio-economic data from the 2019 Kenya Economic Survey and Census and the interviews were thematically analyzed with an emphasis on past and current LULC situations, drivers, demand for fuelwood energy, and the implications of the LULCC. The ranking was used to classify the most popular drivers and consequences of the shift in biomass

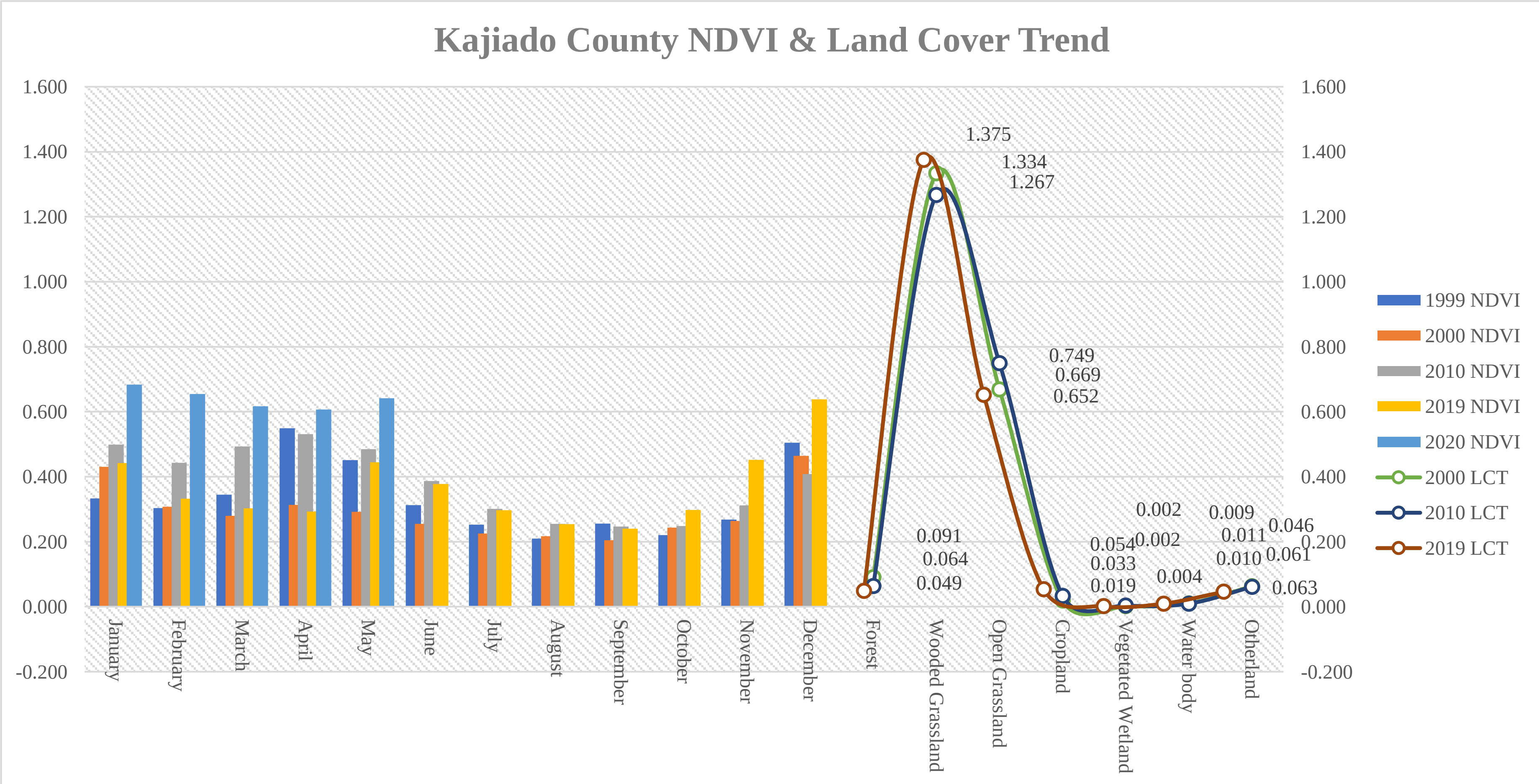
The land cover change in Kajiado county is depicted a negative trend from the year 1990 – 2019. Forestland had a negative trendline with 60455.25 (ha) in the year 1990, 90601.56 (ha) in the year 2000, 63,899.37 (ha), and 49,118.4 (ha) respectively in the year 2019(**Figure 4-2**). Cropland had a tremendous increase with an area of 18,552.06, 19,195.38, 33,060.33, and 53,886.33 (ha) for the years 1990, 2000, 2010, and 2019 respectively (**Figure 4-3).** This is associated with increased average aboveground biomass, as the average pure biomass is drawn down by low biomass organisms, rather than by niche complementarity or improved resource quality.

Table 4- 1: kajiado Land Use Land Cover Statistical Data

Land cover	1990	2000	2010	2019
Forest	60,455.25	90601.56	63899.37	49118.4
Wooded Grassland	1378825.38	1334045.34	1267161.48	1375025.76
Open Grassland	681495.75	668658.87	749435.85	652204.8
Cropland	18552.06	19195.38	33060.33	53886.33
Vegetated Wetland	3786.48	1670.13	3805.29	1537.92
Water body	9564.93	10533.33	9220.05	9703.17
Otherland	34780.32	62755.56	60893.55	45982.89

SOURCE: **Remote Sensed Data, 2019.**

The major land use of cropland had an increase in extend with forests decreasing in the same period. Other declining trends were exhibited by vegetated wetlands, open grassland, and wooded grassland. During the period from 1999 to 2019, about 60,455.25 Ha (23%) of forest decreased to 49,188.4 Ha (18.8) to cropland that increased from 18,552.06 Ha (14.8%) to 53,886.3 Ha(43.2%).Generally, the change values in **Table 4-1** and **Figure 4-3** indicated an increase in cropland mainly emanating from forests during the past 30 years(1990 – 2019) with a negative trend of vegetation cover in the same year **(see figure 4-1)**



Source: Remote Sensed data 2019

Figure 4- 1:The Ndvi and Land Cover Trends

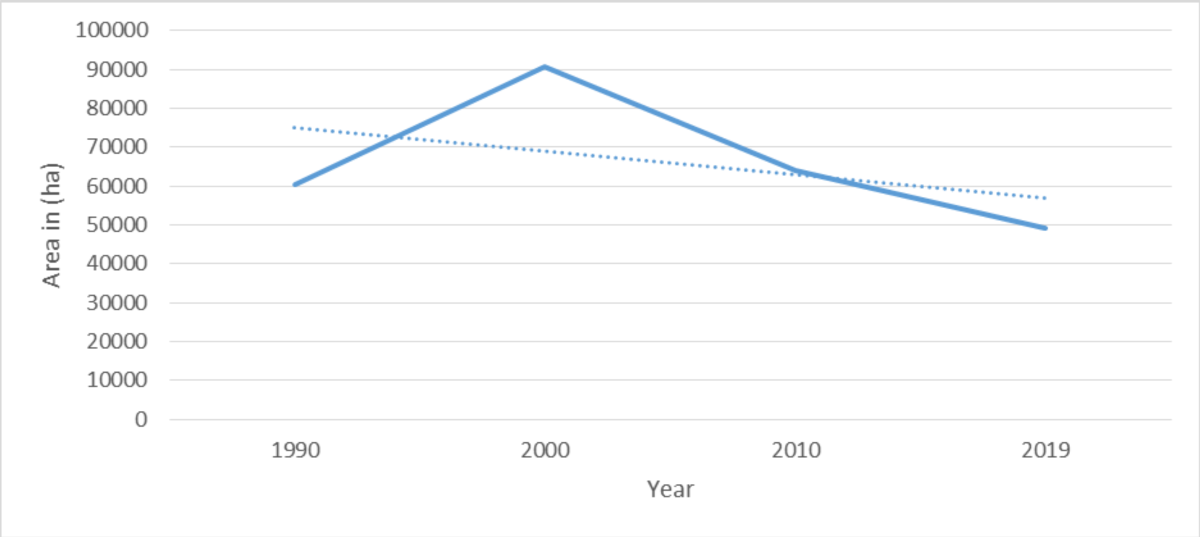


Figure 4- 2: Forest trend from the year 1990 to 2019

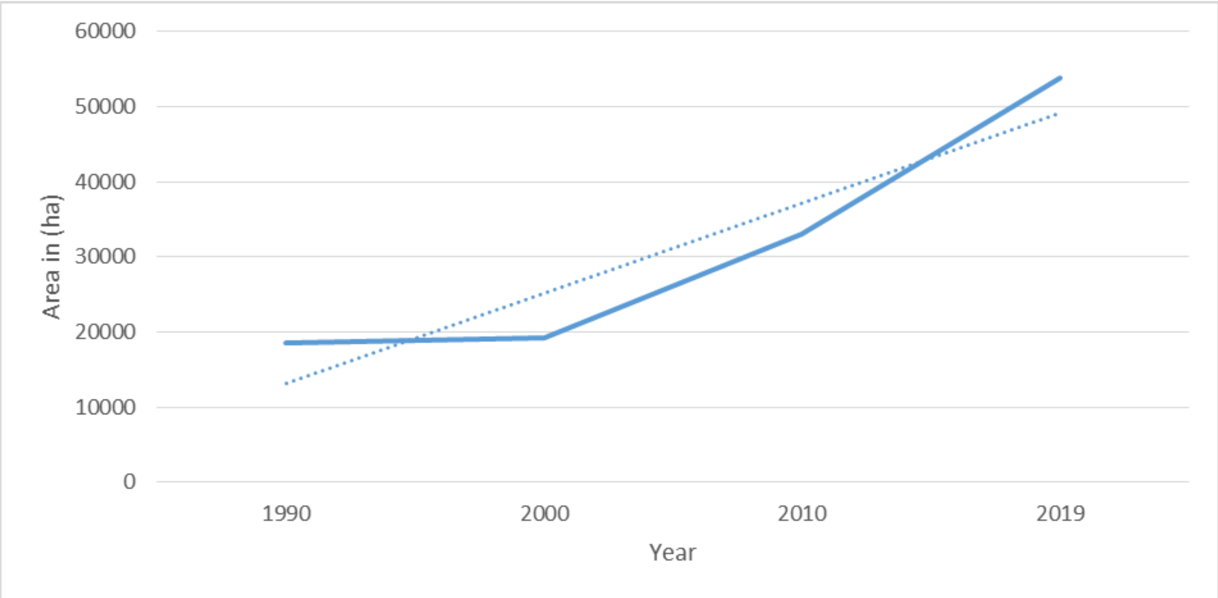
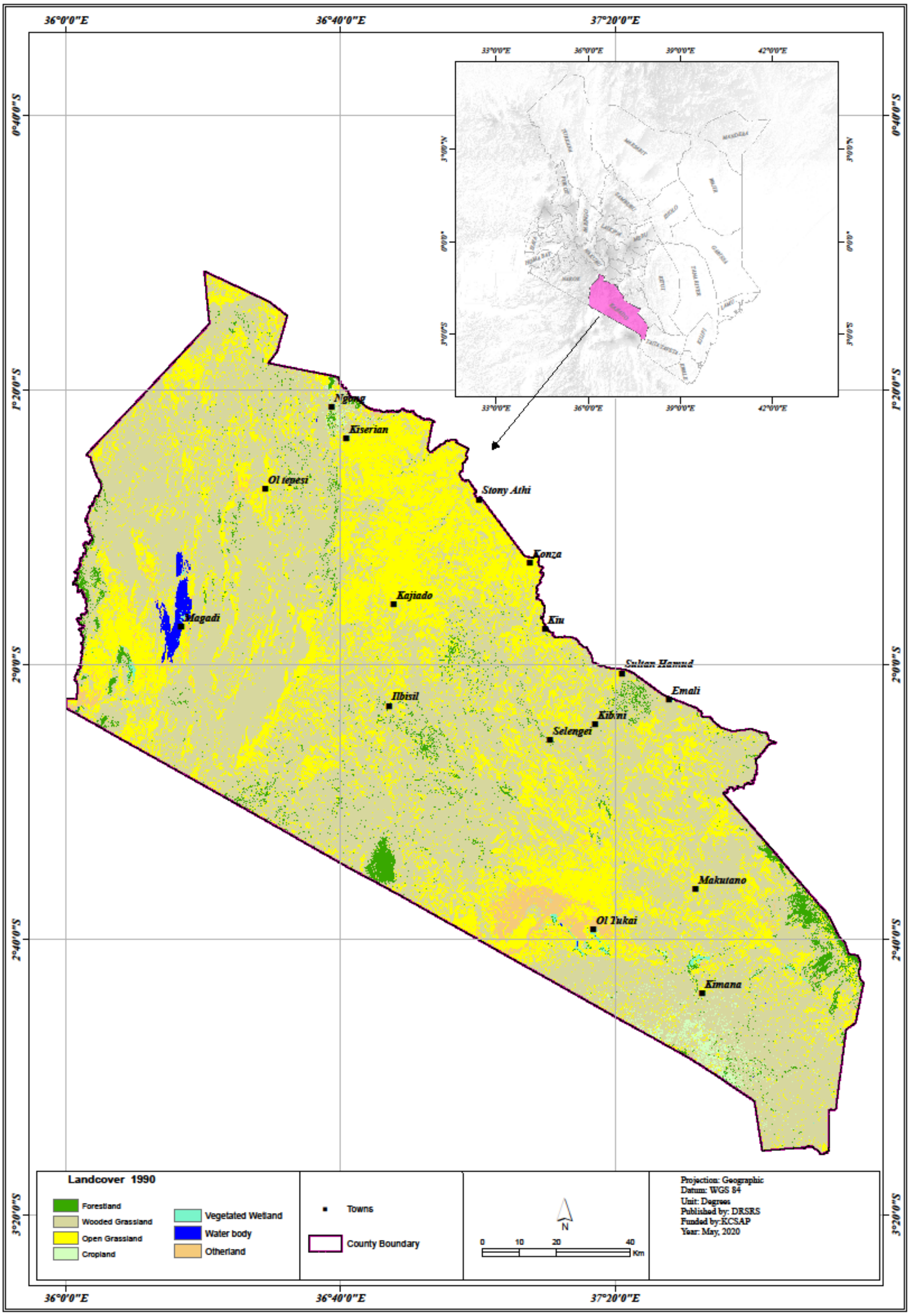


Figure 4- 3: Cropland Trendline From 1990 To 2019

4.1.1 The Trend Line

The trend line for the forest change in Kajiado county is gradual with a negative gradient (Figure). This trend is an important tool to monitor the effect of future rehabilitation activities in the forest. There is, therefore, a need to reverse this trend to a positive gradient. This can be achieved through a change from focusing on short-term benefits of the resource to medium and long-term benefits. Rehabilitation of degraded sites and introduction of resource management planning, as well as forest conservation and sustainable utilization practices by the communities. This will sustainably safeguard the needs of future generations with an increased alternative to biomass energy as a primary source.



Source: Remote sensed data 2020

Figure 4- 4: Kajiado County Landcover Map 1990.

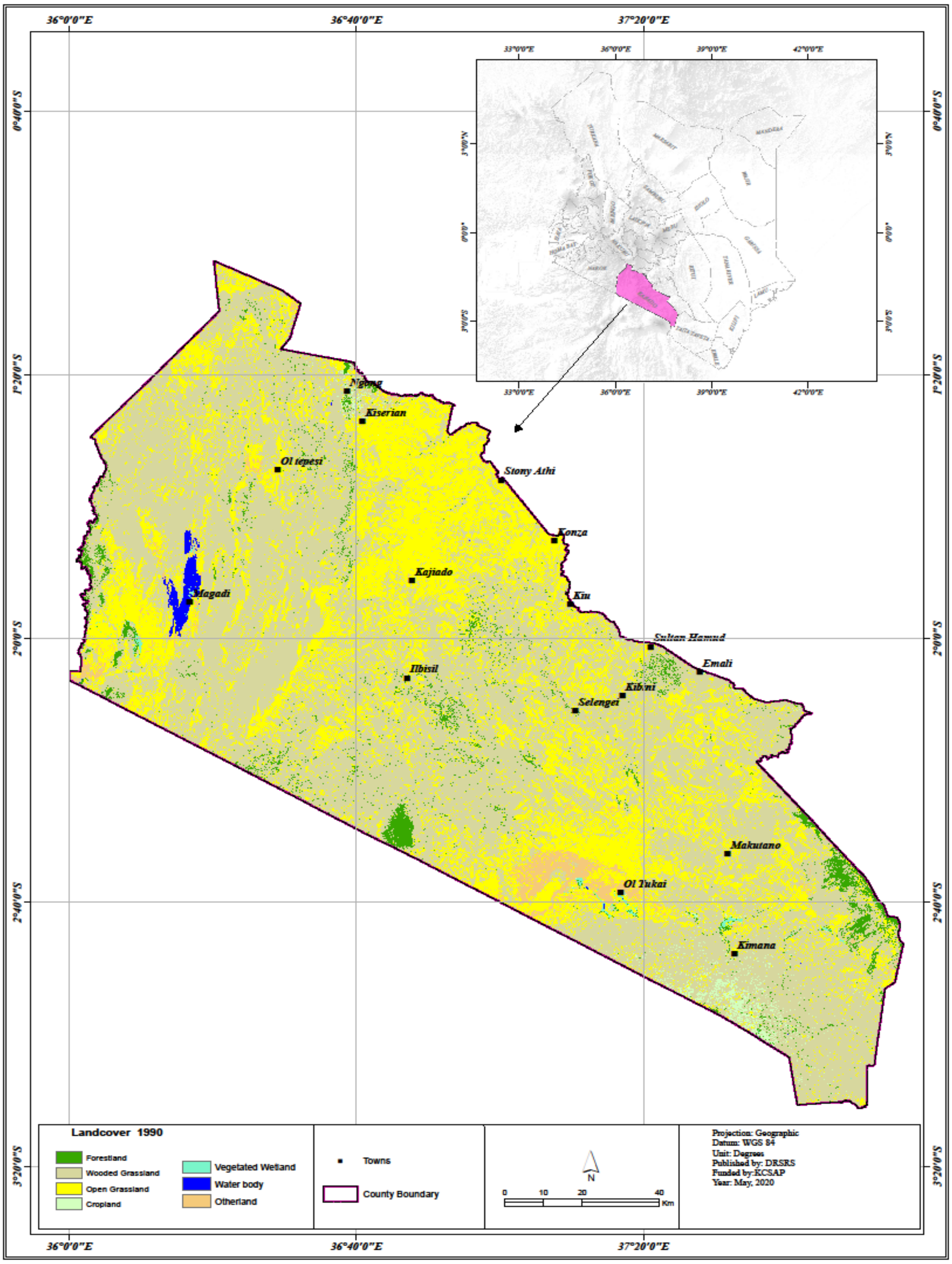


Figure 4- 5: Kajiado County Landcover Map 2000

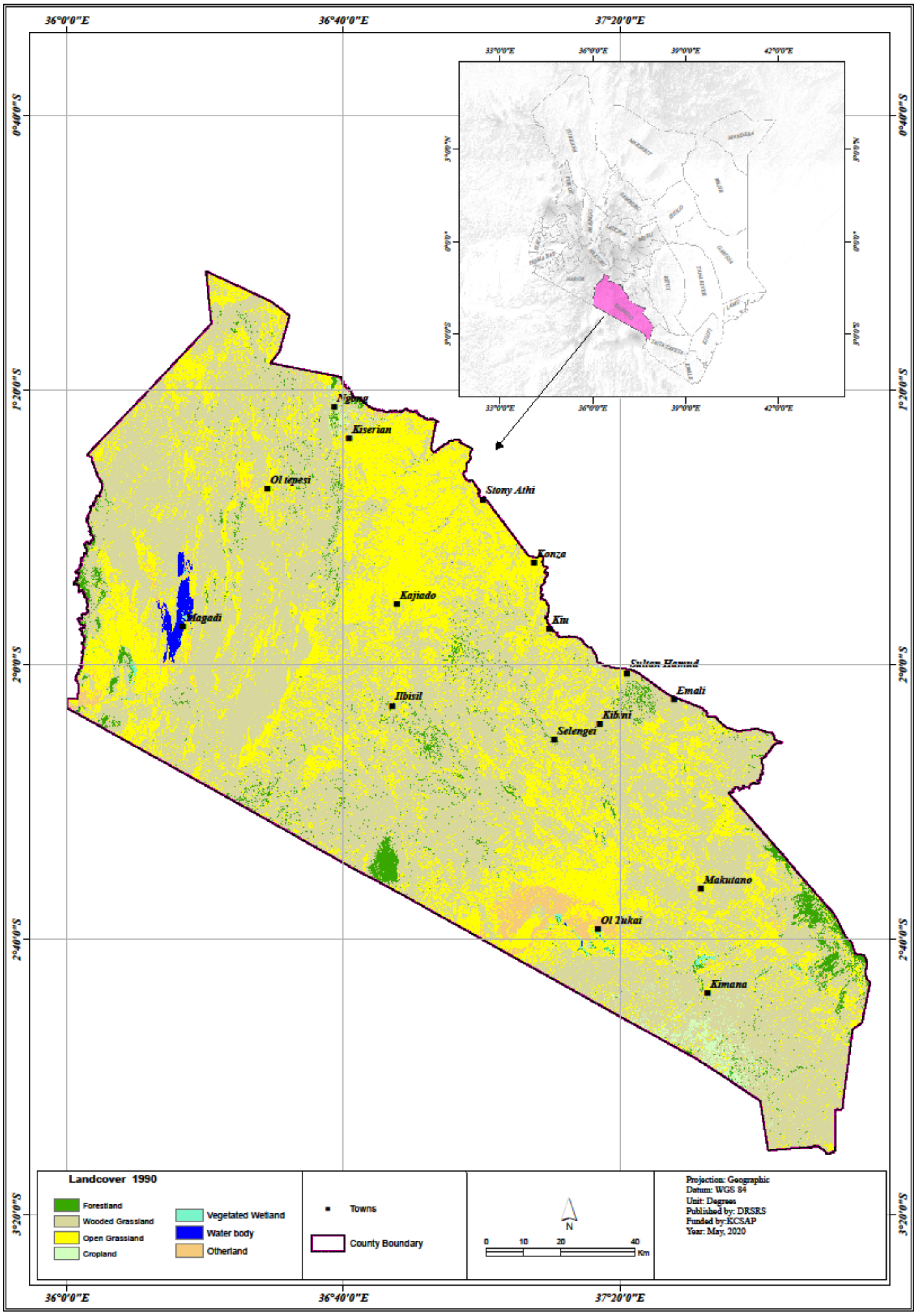


Figure 4- 6:Kajiado County Landcover Map 2010

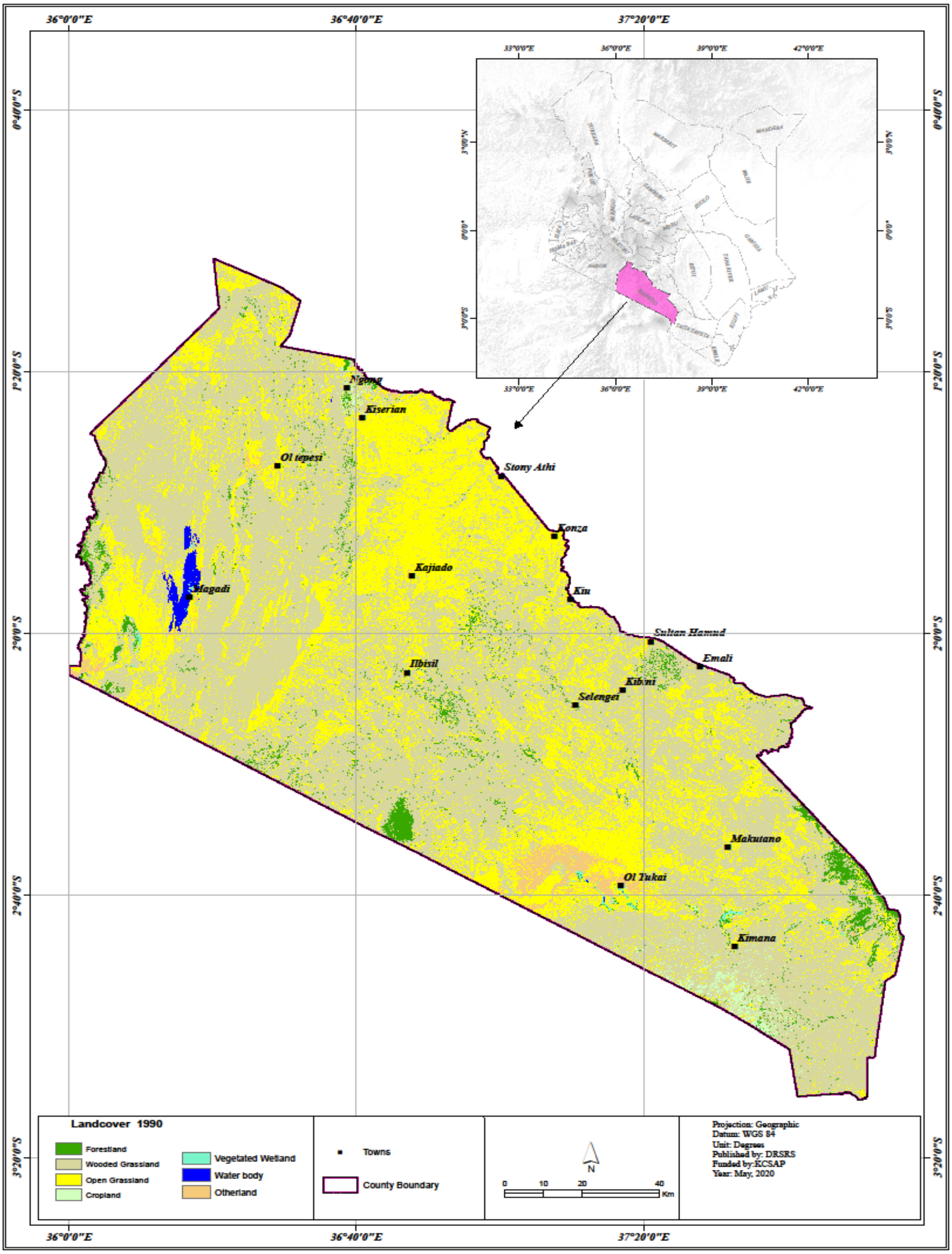


Figure 4- 7: Kajiado County Landcover Map 2019

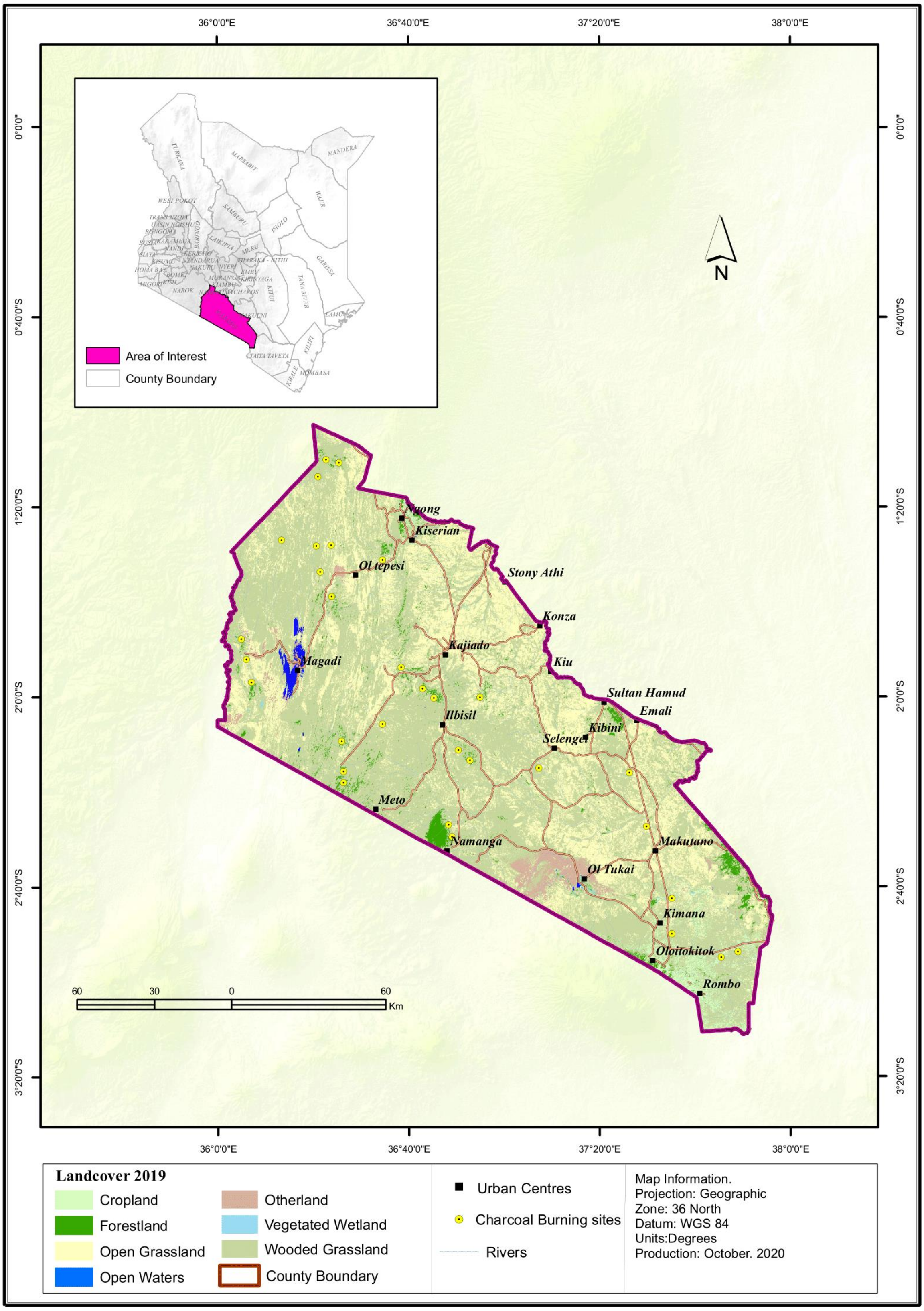


Figure 4- 8: Sampled Charcoal Production Sites In Kajiado County

Wood charcoal production is rapidly depleting natural resources especially wood biomass in kajiado county. Using the population and land cover change trend data, the analysis of the change is significant between 1990 to 2019**. (Figure 4-1)** The result helps in understanding the dimension and impact of charcoal production in kajiado county and thus a step towards the development of a charcoal production monitoring system through biomass assessment.

4.1.2 Normalized Difference Vegetation Index

4.1.2.1 Scientific Quality Evaluation Methodology

The SQE of 2019 is based on the comparison of the NDVI Collection 300m Version 1 product of 2019 (36 dekads) with the same product of 2010 (36 dekads) since the data of 2003 was validated in the study. While NDVI is not a biophysical component, quality monitoring was carried out following the protocols, guidelines, and metrics as specified by the Land Product Validation (LPV) group of the Earth Observation Satellite Committee (CEOS) to be used for the validation of land products based on the use of satellites for indirect validation. A small collection of analyzes is used for the SQE.

To evaluate the product completeness, the number of valid pixels, i.e. not flagged as 'invalid', overland was quantified. **Table 4-2** illustrates the temporal evolution of the product completeness of the NDVI 300m Version 1 product for 2019 compared to 1999. The larger amount of missing values in 2019 is linked to the new cloud screening method that was applied in PROBA-V Collection 1 from December 2016 onwards, resulting in a higher amount of gaps

Table 4- 2: Overall Procedure For The Scientific Quality Evaluation Of The NDVI 300m.

Criterium	Method/and or validation metric
Product completeness	Temporal evolution and spatial distribution for 2019,2010 and 2003 at global and

	at a regional scale and; Frequency distribution (in %) of the length of the gaps (in dekads) in the products of 2019,2010 and 2003 at a regional scale
Spatial consistency	Spatial distribution of the validation metrics expressing the similarities/differences between 2019,2010 and 1999 at a regional scale; Histogram of bias between 2019 and 2003; Overall and per biome at global and a regional scale; Distribution of values per biome for 2019 and 1999 at a regional scale.
Temporal consistency	Temporal variations and realism: temporal profiles of average NDVI for 2019 are compared to temporal profiles of 1999-2010 mean for a forest. cropland and other lands; Temporal variations and realism: temporal profiles of NDVI are extracted for specific locations, and 1° x 1° NDVI maps before and after the event are visually inspected.

Source: Copernicus land scenarios 2020

4.1.2.2 The Normalized Difference Vegetation Index Validation

The NDVI was used to validate and monitor the vegetation state and disturbances to address the impact of biomass harvest for sustainable charcoal modelling. The Normalized Difference Vegetation Index (NDVI) is an indicator of the greenness of the biomes. Even though it is not a physical property of the vegetation cover, it's a very simple formulation

$$NDVI = (REF\_nir – REF\_red)/(REF\_nir + REF\_red)$$

where REF_nir and REF_red are the spectral reflectances measured in the near-infrared and red wavebands respectively, making it widely used for ecosystem monitoring.

The study utilized;

- A Standard 10-day synthesis (S10) from the **PROBA-V** program: they are already cloud screened, atmospherically-corrected Maximum Value Composites (MVC) over 10 days;

- Re-scaling to include the quality information (status map) in the main NDVI layer.
- Pixels wrongly identified as "land" in the S10 **NDVI** status map are re-classified with the trend data maps.

The validation procedure of NDVI follows as much as possible the CEOS Land Product Validation (LPV) guidelines defined for the validation of Leaf Area Index (LAI). Hence, the completeness of the products and the circumstances that are involved in terms of the temporal, spatial, and statistical aspects was assessed. Because the NDVI is an index that is used mathematically, it makes it irrelevant to have it compared with the ground measurements. In this study, there was a comparison of Landsat imagery and the EO-derived NDVI products because the NDVI is mainly dependent on the sensors. The procedure was based on an application that involved the collection of about 300m NDVI. The findings from the analysis are captured in **Figures 4-9,4-10 and 4-11** using the 300m resolution NDVI Version 1.

The vegetation greenness in the study area for the period 2003-2010 and 2019 produced Normalized Vegetation Difference Index (NDVI) with a mean of 0.5. The driest period in the area was observed in January 2010 while the wettest was in January 2003. The study found a significant relationship between NVDI and land-use change between 2003, 2010, and 2019 respectively as indicated in **Tables 4-3 and 4-4.**

Table 4- 3: VGT Month NDVI Filtered (1999 To 2020)

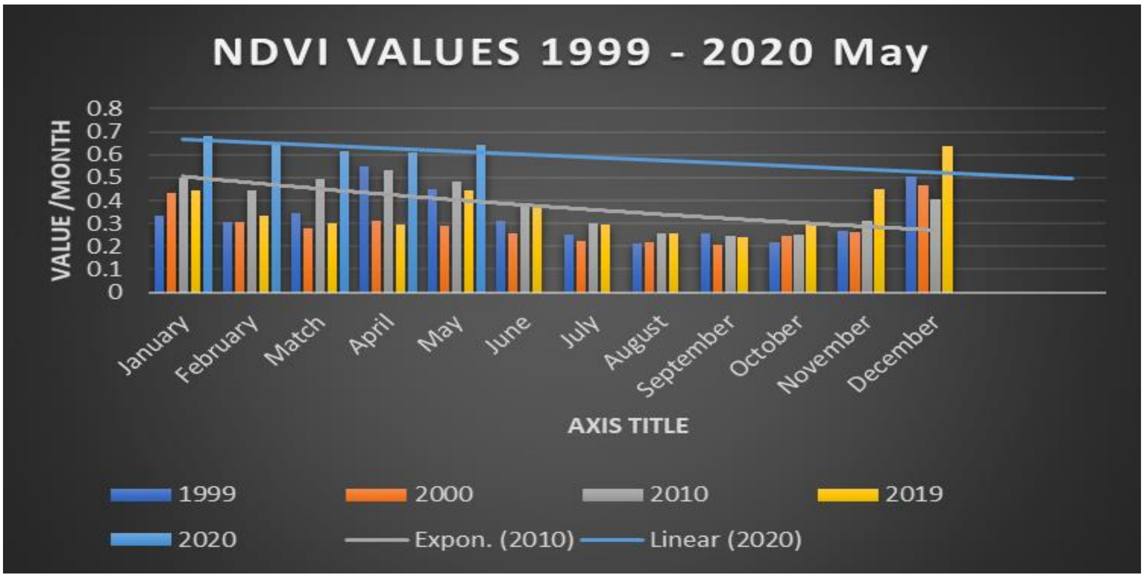
Kajiado VGT Monthly NDVI Filtered (1999 to 2020 May)

	1999	**2000**	**2010**	**2019**	**2020**
January	0.333191	0.430735	0.499154	0.441694	0.683359
February	0.30369	0.30741	0.443119	0.332772	0.654474

Match	0.3451	0.279555	0.493105	0.302647	0.616635
April	0.548904	0.31347	0.530993	0.292733	0.607111
May	0.451135	0.291956	0.485036	0.444427	0.64119
June	0.312671	0.255001	0.386375	0.377633	
July	0.252187	0.225408	0.301154	0.29714	
August	0.209973	0.217203	0.254635	0.254231	
September	0.255951	0.20434	0.246726	0.240309	
October	0.219953	0.243493	0.248427	0.297736	
November	0.268252	0.264259	0.311633	0.451576	
December	0.504812	0.464	0.407979	0.637868	

Source: DRSRS AMESD MAY 2020

Table 4- 4: Temporal Evolution of the Number of Valid Values in NDVI300 V1 for 1999 to 2019 (Linear-Blue 2020) and (Exponential -Gray 2010)



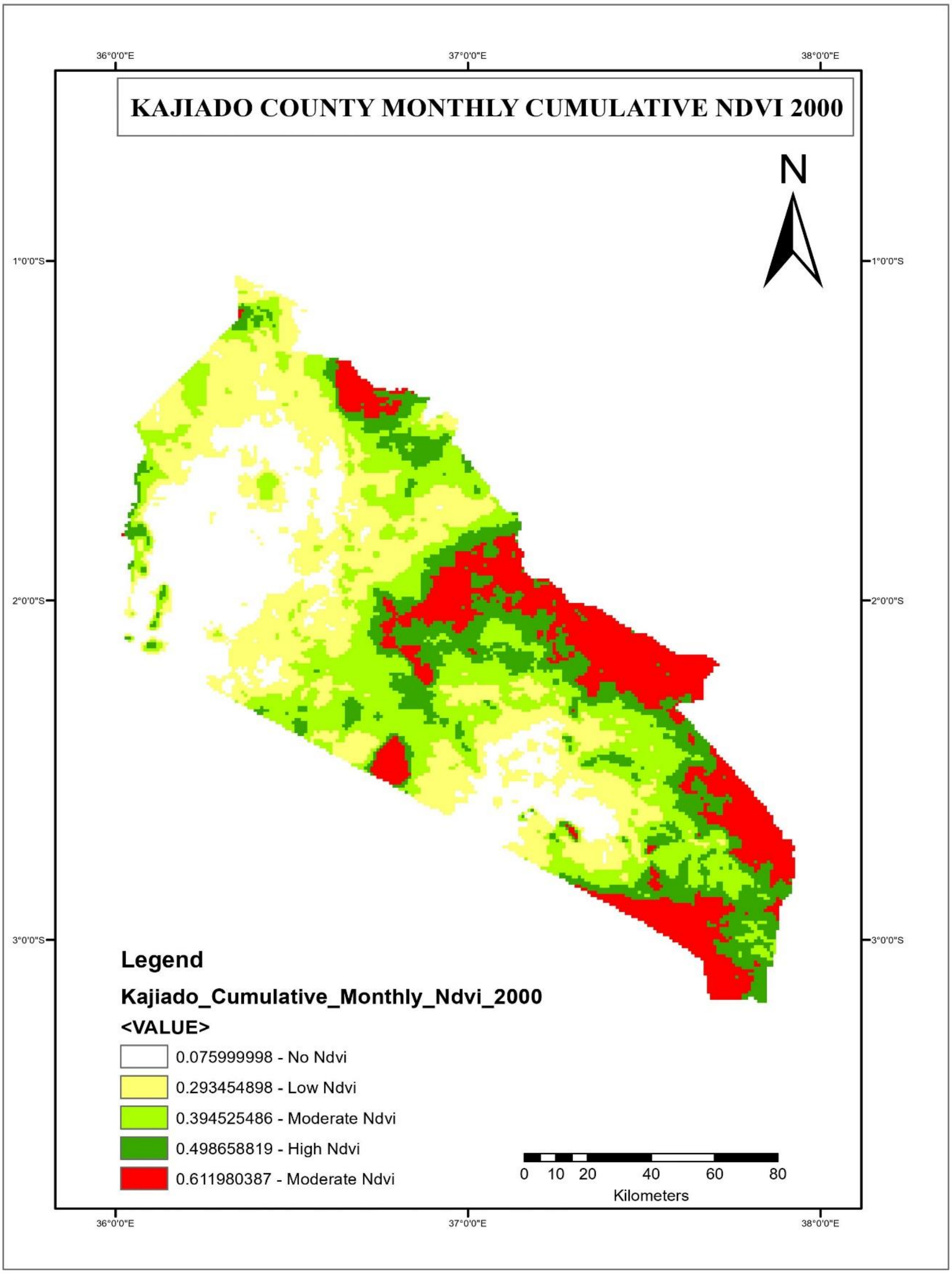


Figure 4- 9: Kajiado county NDVI values spatial patterns in 2000

Source; Copernicus Global Land Operations – Lot 1 Date Issued: 07.04.2020

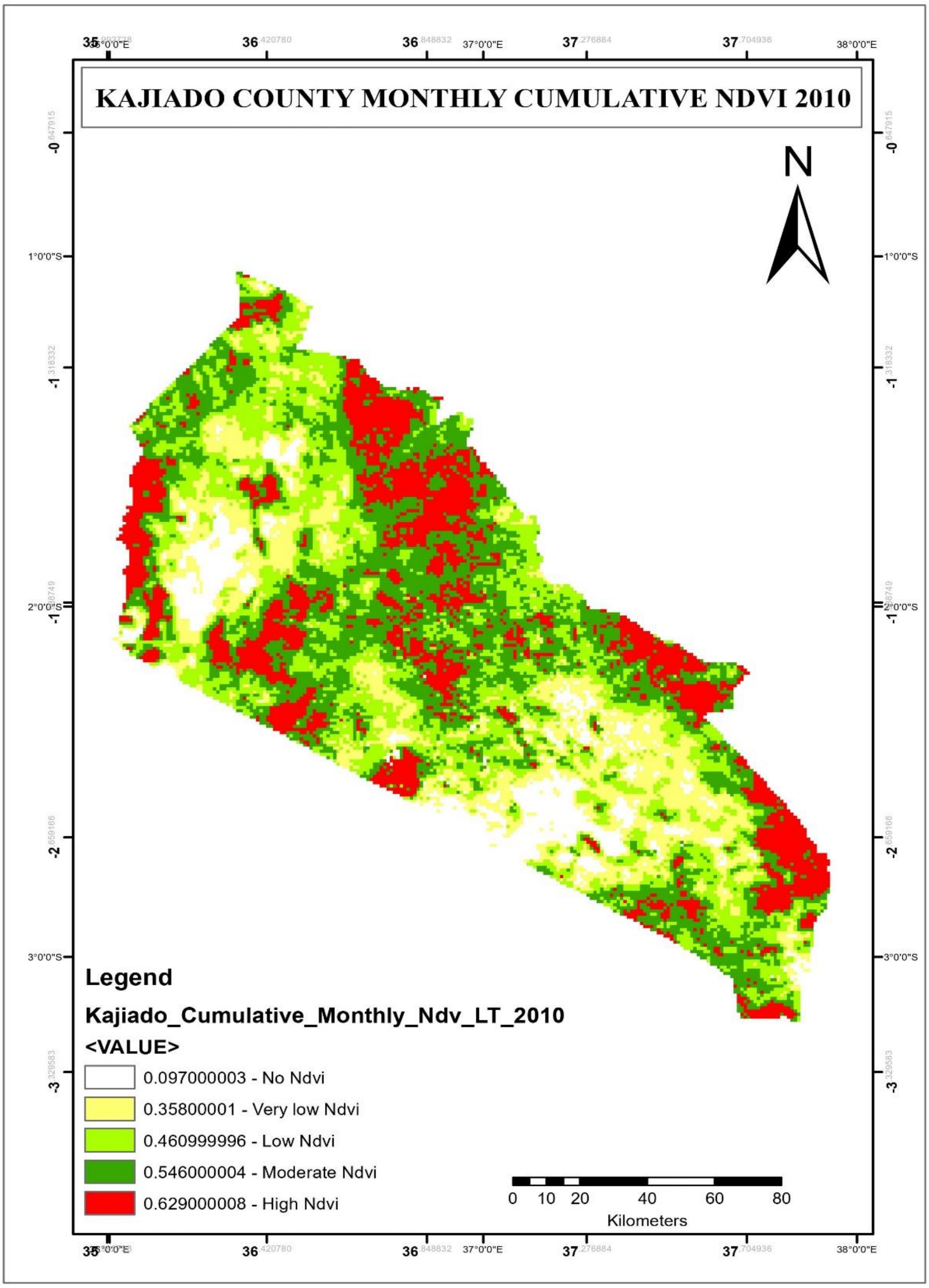


Figure 4- 10: Kajiado county NDVI values spatial patterns in 2010

Source; Copernicus Global Land Operations – Lot 1 Date Issued: 07.04.2020

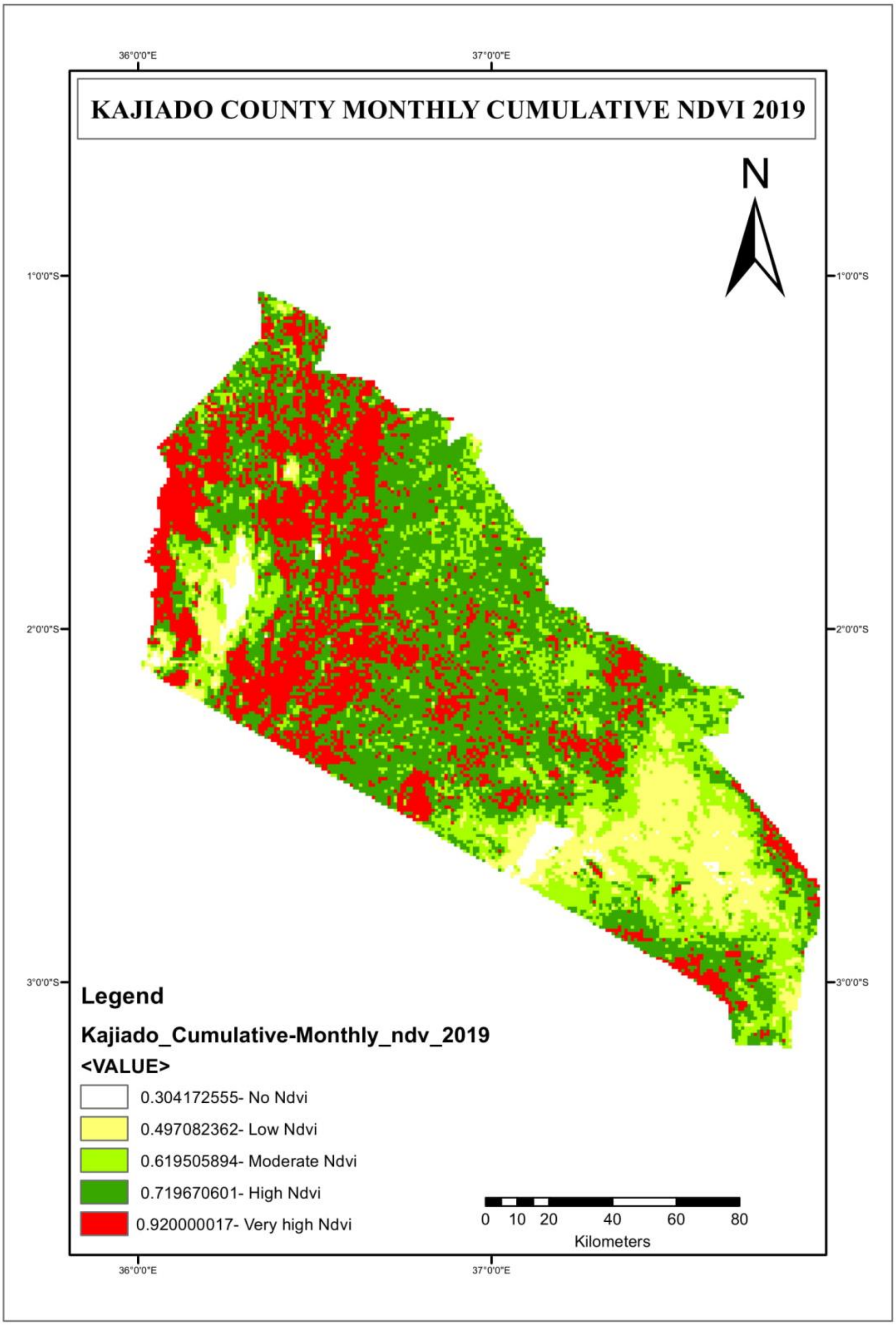


Figure 4- 11: Kajiado county NDVI values spatial patterns in 2019

Source; Copernicus Global Land Operations – Lot 1 Date Issued: 07.04.2020

4.1.3 Rainfall patterns and NDVI anomaly 1990 – 2019.

The rainfall and NDVI values for the selected year and their average, i.e. combine the rainfall and NDVI values based on the years selected and the average rainfall values such as the one that combines the two plots used in the left are key. This is because they give more information about the relationships and the timings that the vegetation and the rainfall various with the season and how they unfold. The Landsat analysis that has been based on an interval that has taken 10 years in Landsat image 1 indicates that different patterns have been captured and this is based on the different conditions of the area such as the wet and the dry season and the link that they have with the vegetation and the rainfall that is experienced within the region. The average data that is shown indicated that the usual cycle and the timings that are involved too. Earlier rainfall, based on evidence, suggests that it is increasing and then followed by NDVI; and this is the reflection of peak rainfall in NDVI and there is a reduction in rainfall at the end of the season.

At wet locations in the county, year-round rainfall is correlated with a very flat NDVI curve with high values. It is therefore easy to equate current seasons with previous years by showing average results. **Figures 4-12,4-13 and 4-14 maps** plots display both rainfall and NDVI anomalies for the selected years. A 3-month rainfall anomaly was analyzed and shifted to a 1-month anomaly (and turned off a 3-month anomaly) as evidenced by land cover changes and decreasing rainfall volumes and linkages between rainfall and NDVI deviations from their average. This is a clear indicator of low biomass regeneration.

Further, the average rainfall and NDVI data showed major variations within the linkages based on the strength and the clarity that is involved. In wet climates, the variations based on the growth of the vegetation is based on some other factors that are not linked to the rainfall. However, in dry regions, rainfall is demanded as the only limiting factor when it comes to the growth of the vegetation, and such links are strong and there is clear evidence of the association. The time difference when it comes to the anomaly that is linked to rainfall and the subsequent NDVI anomaly in terms of how the vegetation is responding to the rainfall and its variation is also different based on the region that is being analyzed. The two rainfall anomalies (1 or 3 months) linked better with NDVI anomalies with the variation exhibited by the type of soil and vegetation as depicted in **Figures 4-15,4-16,4-17,4-18,4-19 and 4-20**

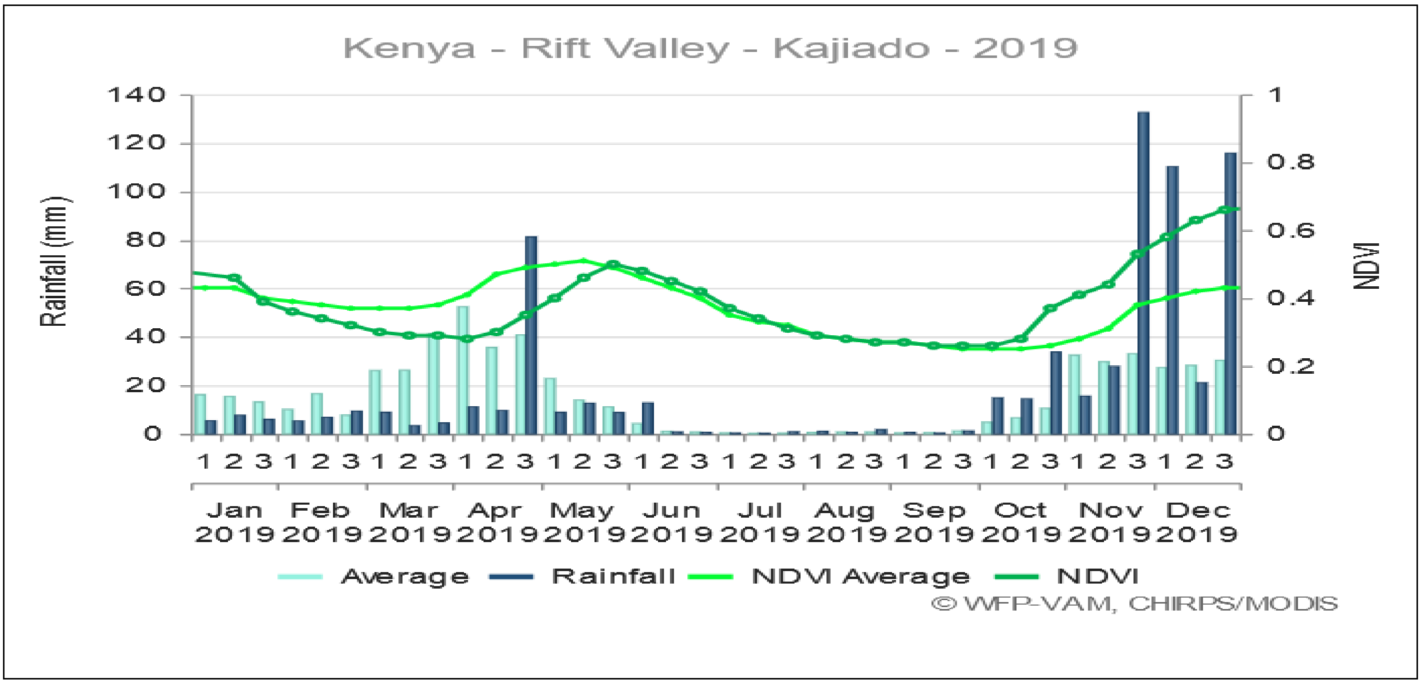


Figure 4- 12: 2019 season Rainfall/NDVI

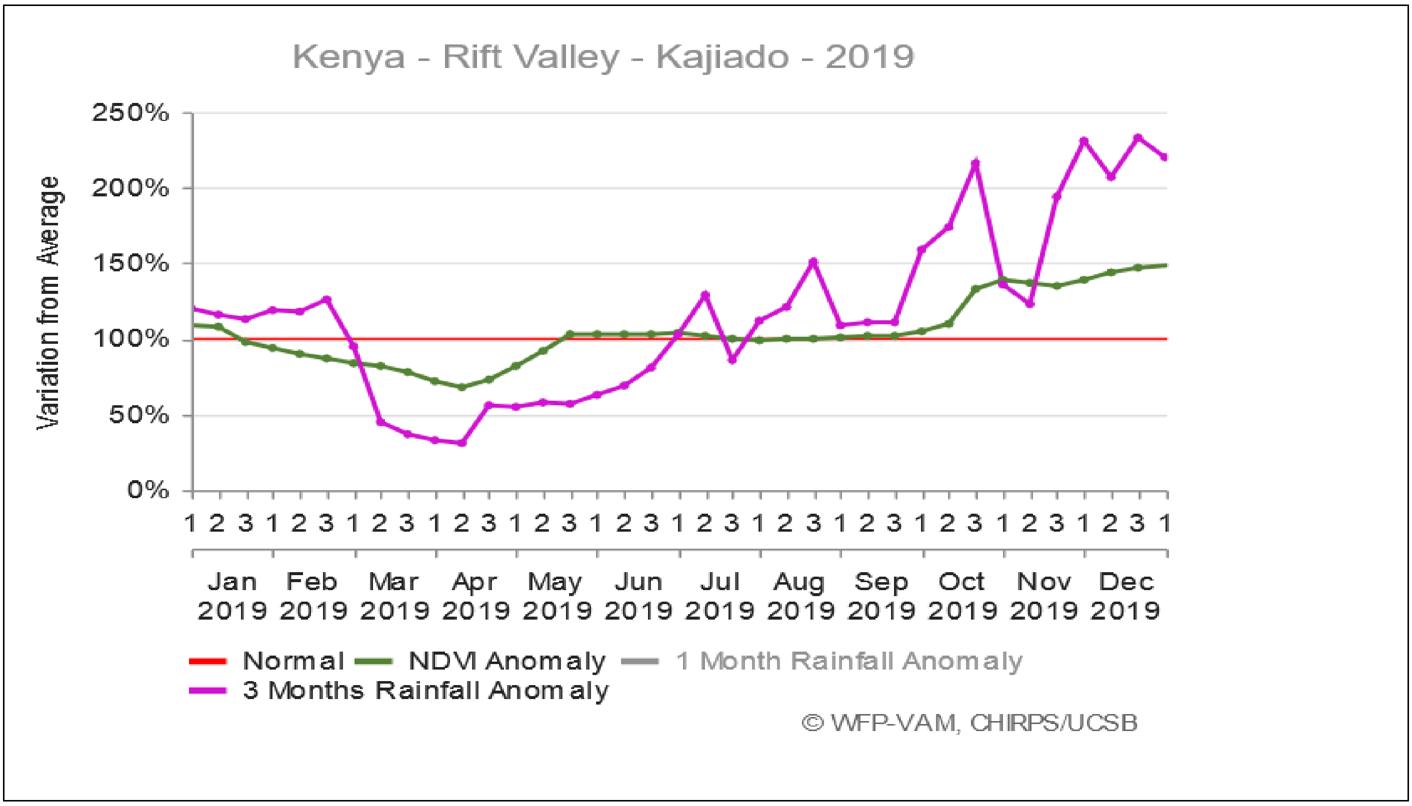


Figure 4- 13:2019 season Rainfall/NDVI Anomalies

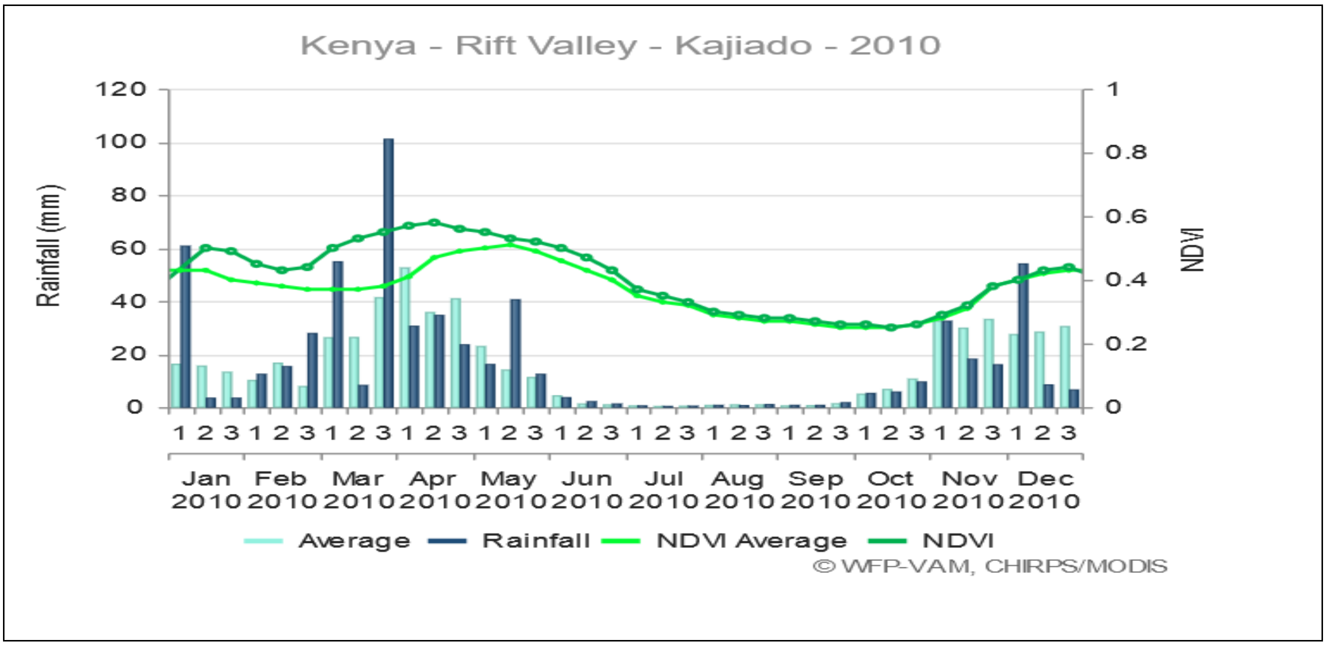


Figure 4- 14: 2010 season Rainfall/NDVI

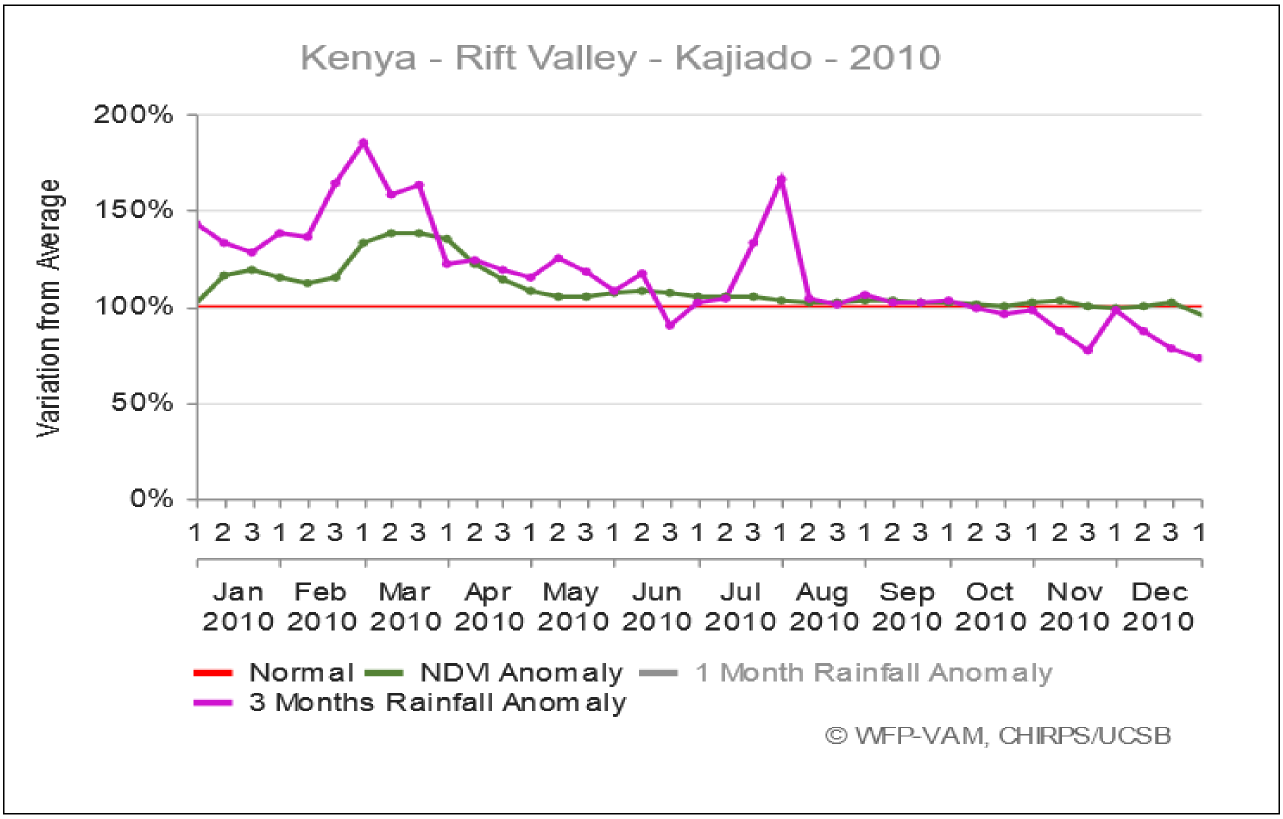


Figure 4- 15: 2010 Reason Rainfall/NDVI Anomalies

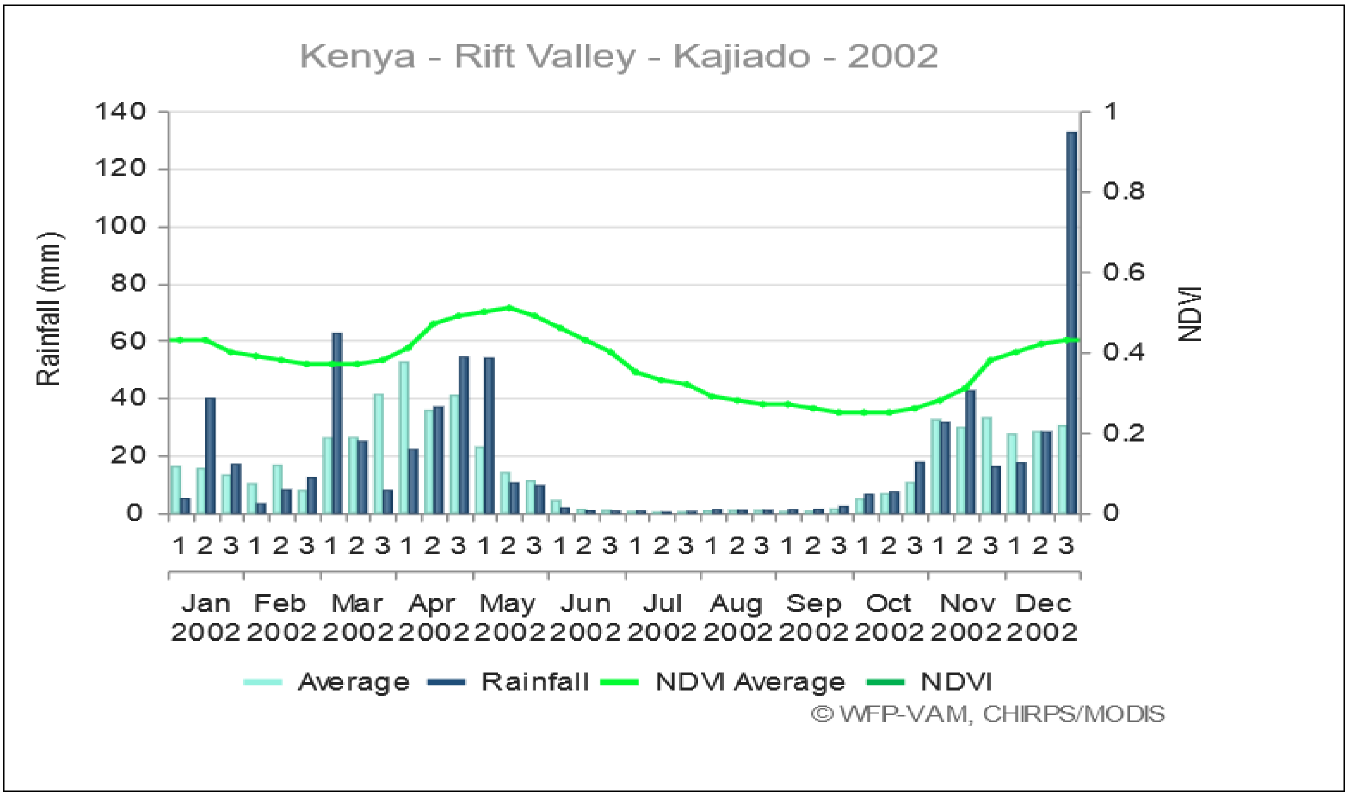


Figure 4- 16: 2002 Season rainfall/NDVI

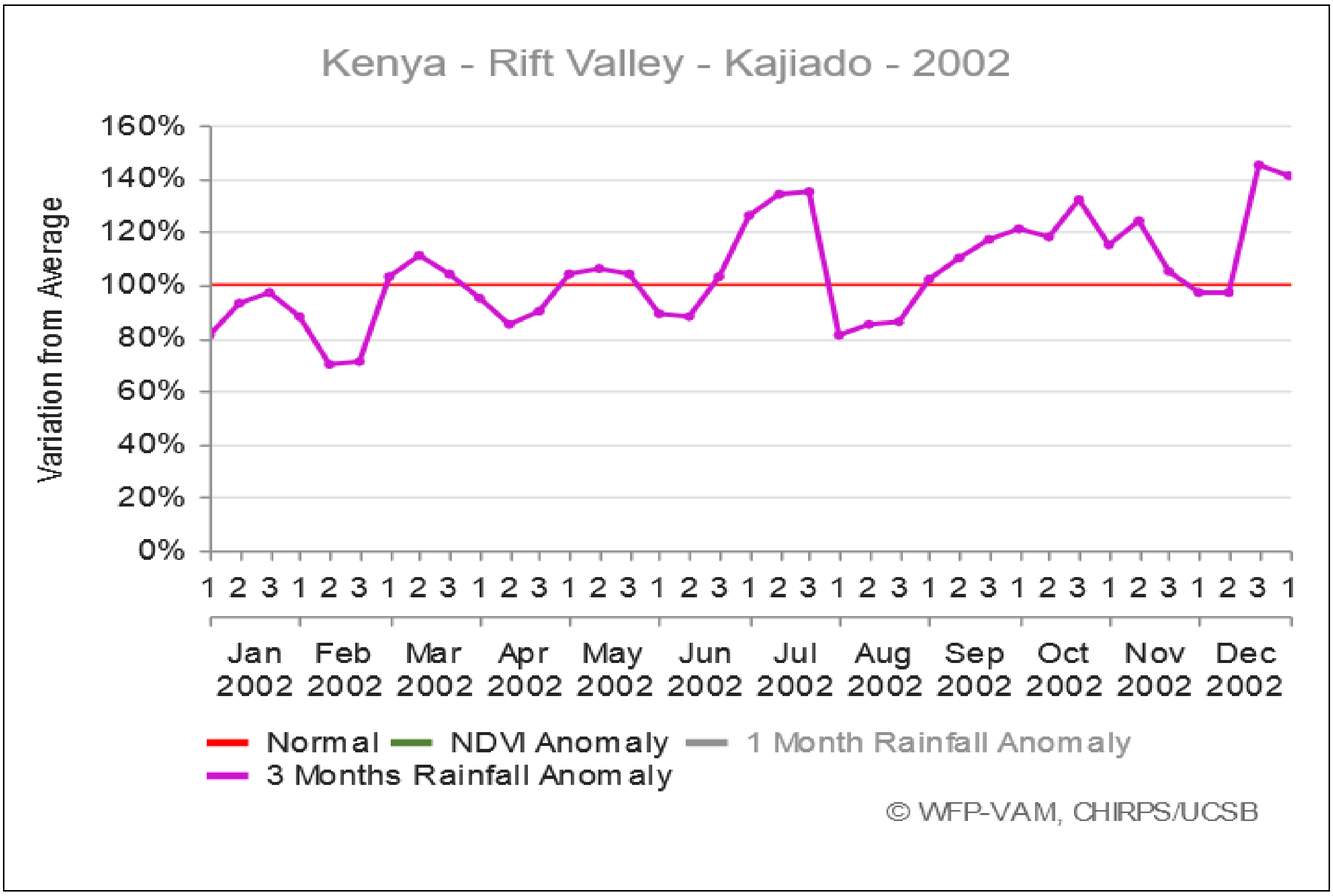


Figure 4- 17:Reason Rainfall/NDVI Anomalies

4.2 Sustainability Of charcoal Production In Kajiado County

The status of land cover in Kajiado county is presented in **Table 4-1**. In 2019 Forest covers was at 49,118.4 (ha) Cropland 53886.33 ha,wooded grassland 137,5025.76 ha,open grassland 652,204.0 ha and other lands occupied 45,982.89 ha.This was also influenced by the land tenure systems that depicted interaction and land use patterns(**Figure 4-18).**

As observed during the field surveys and respondents in the charcoal value chain, a variety of wood materials needed for production are acquired from the indigenous trees and a few woodlots. The survey revealed that as many as 70% of the respondent obtained indigenous trees from privately owned land,25% obtained from the community land and the remaining 5% obtained from government gazetted forests. The privately-owned farms(70%) was the most preferred source for charcoal production due to ease accessibility as opposed to government-protected forests and community guarded sources.

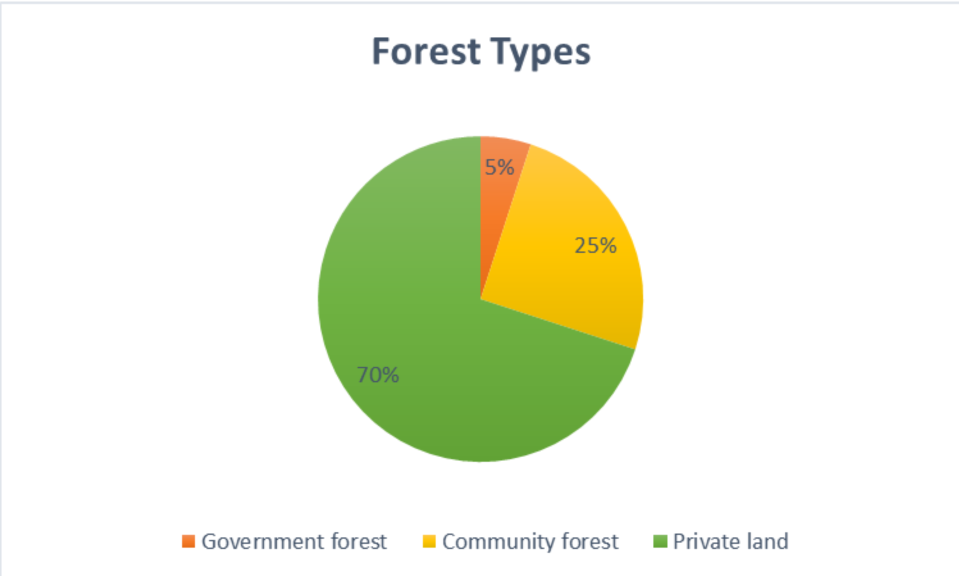


Figure 4- 18:Forest Types in Kajiado County

Source: field survey 2019

The technologies used for charcoal production in Kajiado County are traditional earth mound kilns. lead stakeholders such as KFS and UNDP had trained/ built capacity amongst the members of the CPAs on efficient charcoal production techniques and best practices to The woodland often selected for charcoal production are private or family-owned and communal lands. Thus they often harvest without acquiring a permit. Charcoal producers (28%) interviewed had a strong feeling that the establishment of specific tree species plantations in the study area would improve and make the charcoal industry sustainable. Legalization (22%) of sustainable commercial charcoal production and movement will be a boost to the industry and an end to the illegal and unsustainable charcoal practice in the study area. Strengthening and formation of more charcoal producers associations(16%) ensure sustainable charcoal production. However, all charcoal producers surveyed used traditional earth kiln technology in charcoal production in the study area. This makes regeneration of the indigenous trees take long thus hindering biomass growth and production for sustainable production.

4.3 Socio-Economic Impacts of Charcoal Production in Kajiado County

4.3.1 Kajiado Human Population Density.

This is an important indicator because human activities are the main cause of land degradation (UNEP 1997). The Kenya 2019 census results indicate that the human population grew exponentially in the northwest part of the study area.

Table 4- 5: Distribution of Population, Land Area and Population Density in Kajiado County

National/county	**Population**	**Land area(sq.km)**	**Population density(no.per sq-km**
Kenya	47,564,296	580,876.3	82
Kajiado	1,117,840	21,871.10	51

Source; 2019 Kenya Population and Housing Census.

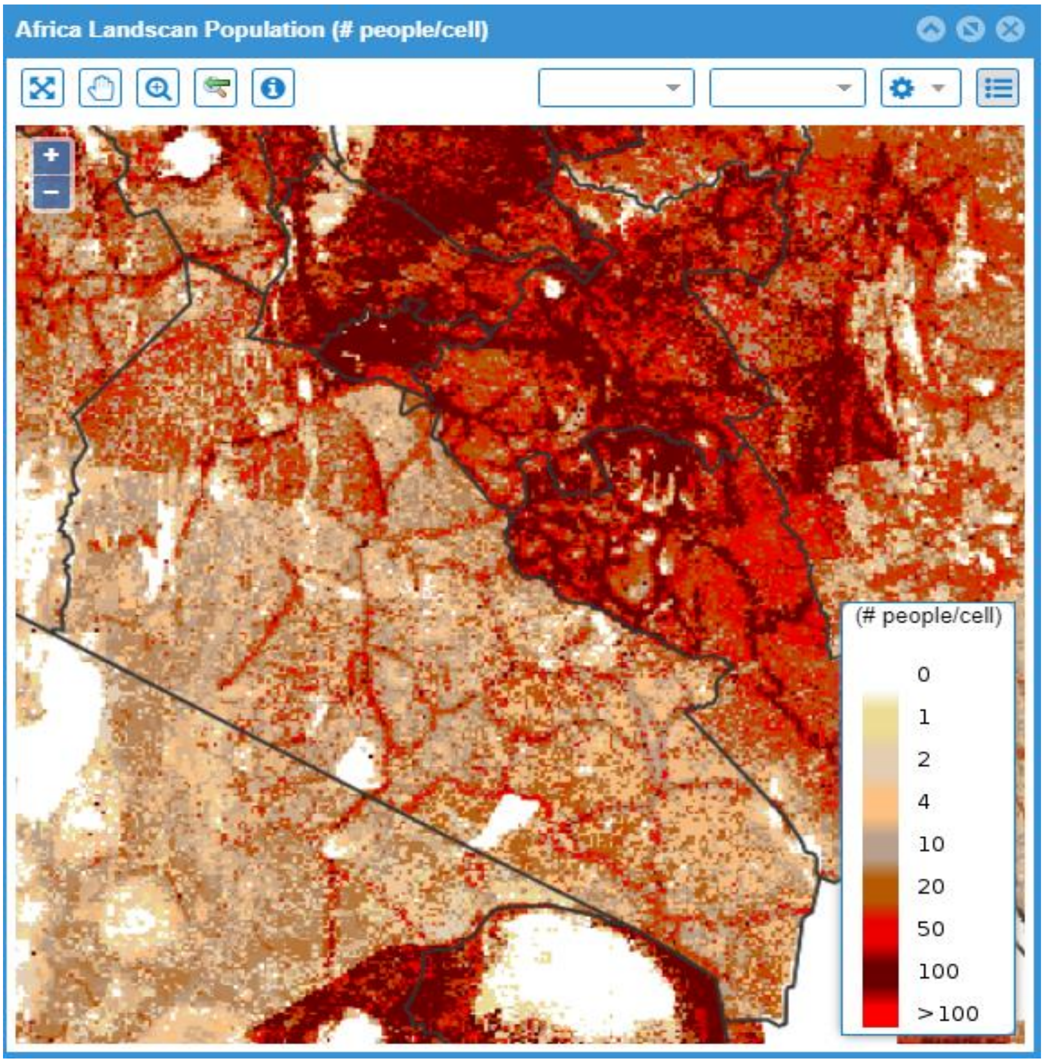


Figure 4- 19: Kajiado County Population Density Map

4.3.2 Kajiado Household Energy Sources

The 2009 Kenya housing and population census indicated 92.9%,4.8%,1.4%, and 0.9% of rural households used firewood, charcoal, kerosene, and LPG, and other fuels respectively, as either their primary or secondary source of cooking fuel(KNBS,2010).In comparison,71.3% of peri-urban households used firewood, while 25.5% used charcoal,68.8%,14.0%,7.9%, and 5.0% of the urban population use charcoal, paraffin, firewood, and LPG respectively as either primary or secondary fuel, the KNBS in 2018 indicated that by 2017, the proportion of the urban population using firewood as their primary cooking fuel stood at 16.1%, charcoal 21.9%, and LPG 27.6%.In 2004, Mutimba and Barasa(2005), estimated the per capita consumption of firewood to be at 741kg and 691kg respectively in the rural and urban areas and that of charcoal at 152kg and 156kg. These statistics show that there is a huge disparity in the fuel-use data in the country which is associated with the use of multiple fuels at household levels making it impossible to place a household into a category. A clear indication though is the rapid growth of LPG and declining use of firewood in the provision of energy in the urban areas over the last decade.

The 2012 Empirical Study on Living Conditions, Services, and Household Properties reveals that the proportion of households using electricity is 39.8, the tin lamp 39.8, and the lantern 18.9 per cent. Liquefied Petroleum Gas (LPG), paraffin, firewood, and charcoal are the main sources of cooking energy. The number of households using smoky cooking fuels (paraffin, firewood, and charcoal) in rural areas is 94.6 and 74.5 per cent in urban areas. Firewood is the most commonly used cooking fuel in rural areas with 75.3 per cent of households, while charcoal is mainly used in urban areas with 35.6 per cent of households. LPG is primarily used for cooking in urban areas, followed by electricity at 21.4 and 2.0 per cent, respectively.

4.4 Environmental Impacts Of Charcoal Production In Kajiado County.

4.4.1 Land Degradation Index In Kajiado

The land-use cover maps were generated from Landsat satellite imageries from (1990-2019). The land cover classification approach was domesticated from the IPCC land cover classification scheme with six classes (Forestland, Cropland, Grassland, Settlement, Wetland, and other lands), which were broken down into ten classes; Forestland, Cropland, Open Grassland, Wooded Grassland, Vegetated Wetland, Open Water and Other lands. (**See Table 4-2).** The status of land cover in Kajiado County was presented in **Table 4-1.** Statistics of the same indicate that the dominant land cover type across the 30 years was wooded grassland covering approximately 80% of the study area. The wooded grassland increased from 81.9% in 1990 to 82.8% in 2019. Forestland showed a non-linear change across the years with an increase in the year 2000 and then decreased significantly in the year 2019 while that for open grassland showed a less significant change across the years with 10.5% in 1990 to 11.9% in 2000 and later a decrease in 2019 to 10.3%.

To compare the land cover percentage, within the period of 30 years from 1990 to 2019, there were increments in land cover for wooded grassland, croplands, water bodies, and other lands while forests, vegetated wetlands, and open grassland went down a pointer to unsustainable harvesting of the products. The major land cover types changed significantly; forest trendlines declined**(Figure 4-2)** and an increase to cropland **(Figure 4-3).** The analyzed satellite images indicate that a big percentage cover change was cropland which increased exponentially across the particular years from 80.19ha in 2000 to 916.74ha in 2019 (**Table 4-1**).

From the generated data, the degradation index results from the land-use patterns. The study adopted a land degradation model based on RUSLE and MUSLE to undertake the land degradation analysis. Several parameters are considered as input into this equation including land cover, NDVI, rainfall, population, DEM, Soil erodibility data amongst others. The end product was considered as a potential Land Degradation Index Map (LDIM). Exponential growth had an impact on land cover and NDVI as an indicator of biomass trend. (**see figure 4-21)**. The targeted mass area for Kajiado County is 20,970.82 km sq. The levels of degradation have been classified into five (5) categories. These categories include the following classes as indicated on the base map **(Figure 4-21);**

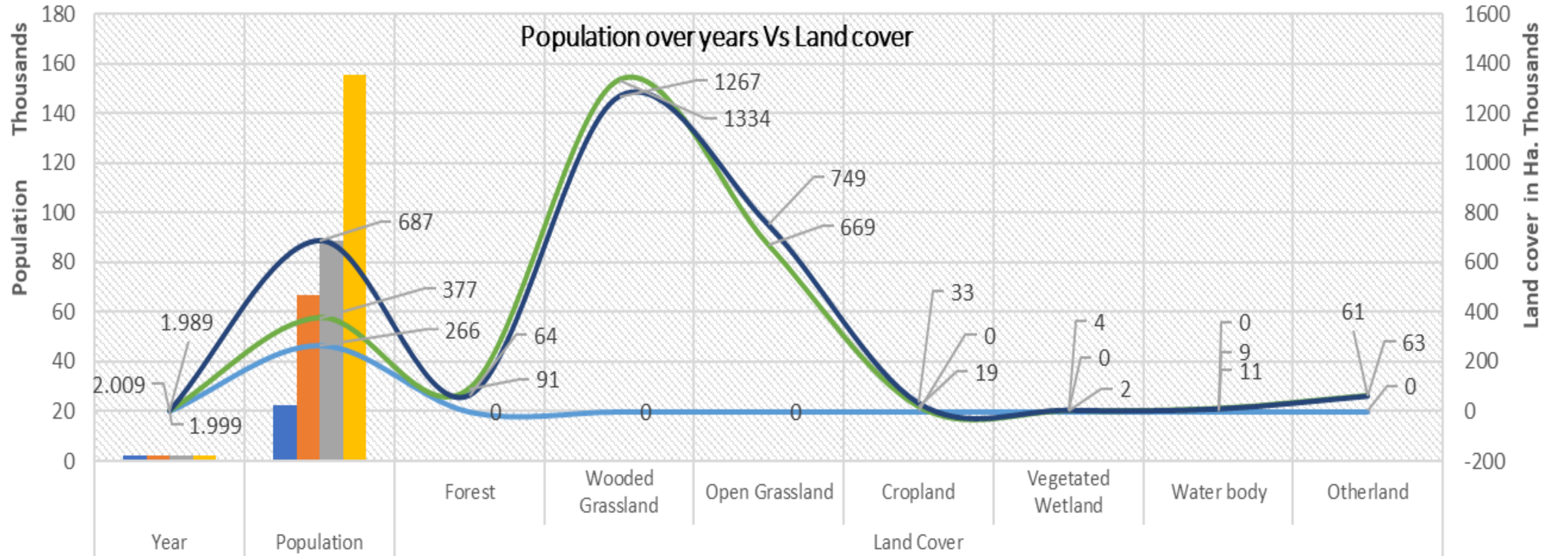
a. Very low degradation represented by (**20.60%);**
b. Low degradation (**41.63688%);**

c. Medium degradation **(27.85423%);**

d. High degradation **(8.573814%)** and;

e. Very high degradation **(1.326287%).**

POPULATION AND LAND COVER TABLE



	Year	Population	Forest	Wooded Grassland	Open Grassland	Cropland	Vegetated Wetland	Water body	Otherland
Series1	1948	22171	0	0	0	0	0	0	0
Series2	1962	66514	0	0	0	0	0	0	0
Series3	1969	88685	0	0	0	0	0	0	0
Series4	1979	155199	0	0	0	0	0	0	0
Series5	1989	266056	0	0	0	0	0	0	0
Series6	1999	376913	90602	1334045	668659	19195	1670	10533	62756
Series7	2009	687312	63899	1267161	749436	33060	3805	9220	60894

Figure 4- 20: population and land cover changes from 1990 to 2019

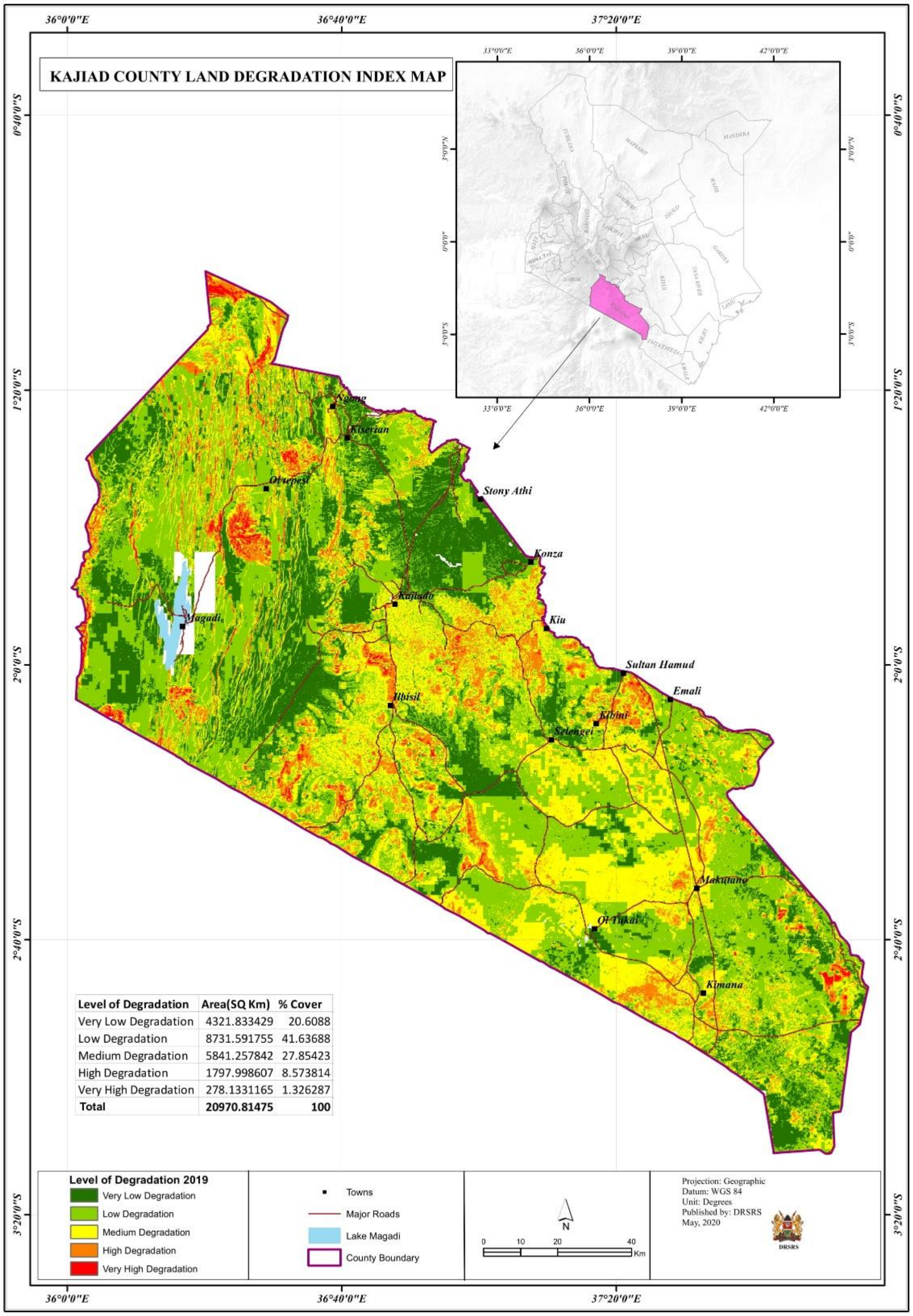


Figure 4- 21: Kajiado Land Degradation Index

4.4.2 Household Survey Site Selection

Remote sensing data were collected using the Garmin GPS, the Household Census Questionnaires were provided for the assessment of socio-economic features, and a picture assessment was also given to provide a map description based on the picture taken of the households and the social facilities available. The survey targeting the household was conducted in five sub-counties, namely Kajiado West, Kajiado North, Kajiado South, Kajiado East, and Kajiado Central. Areas have become part of the four eco-zones. The four areas were the Athi Kapiti Plains, the Rift Valley, the Amboseli Plains, and the Central Hills. Areas were chosen based on the time and financial considerations that were faced during the process, and this is also due to the availability of the respondents. The site selection in the ecozones was guided by land cover changes trend data derived from the satellite images. The focus was given to a sample point in each change epoch zone.

4.4.3 Survey Sampling Procedure

A total of 88 households were surveyed (each respondent represents an individual household). The survey was undertaken between Monday 18th May 2020 up to 30th June 2020. Based on the estimation, It took 30 minutes for each interview. Different measures were employed to ensure that there was accuracy in the data that was collected. The enumerators used a preloaded GPS point (coordinates) to select the household for the interview other measures included, For example, it was expected that the participants of the study were either the owner or head of the homes that took part in the study and that they were residents of the area. Where necessary, the survey and data triangulation were used to determine the credibility and authenticity of the data collected. Besides, the data collected data (and analysis in the case of qualitative data) were entered as soon as possible to ensure proper recall and enhance the quality of interpretation.

The survey team installed the sub-county Shapefiles in the Garmin GPS and used the ArcPad to classify each household by plot boundaries and identified hotspot data applied to the land cover shift map **(see figure 4-8).** Contours and control point layers have been applied to the plot boundary map to further enhance the accuracy of the data obtained and enhance field navigation.

Table 4- 6:Detailed Distribution Of Respondents By Administrative Units.

Constituency	**Wards**	**Number Of HH Respondent**
Kajiado West	Keekonyokie,Iloodokilani,Magadi	18
Kajiado North	Ongata Rongai,Oloolua,Ngong	19
Kajiado South	Entonet,Keikuku,Rombo	17
Kajiado East	Kitengela,Kaputei North,Imaroror	18
Kajiado Central	Purko,Ildamat,Dalalekutuk	16
TOTAL		**88**

Table 4- 7:Percentage Distribution of Households by Number of Habitable Rooms in Main Dwelling and By Residence

Residency/county	**Number of rooms**						**Not stated**	**Mean number of habitable rooms per household**	**No.of households(000)**	**No. of person per habitable room**
	1	2	3	4	5	6+				

National	40.0	26.6	20.6	8.1	2.6	1.7	0.3	2.1	11,415	2.3
Rural	27.6	31.3	26.2	9.7	2.9	2.0	0.2	2.4	6,442	2.4
Urban	56.0	20.5	13.4	6.1	2.2	1.3	0.4	1.8	4,972	2.1
Kajiado county	52.9	26.4	14.4	3.4	1.0	1.0	0.8	1.8	250	2.3
Nairobi county	69.5	13.4	9.8	4.3	1.2	1.1	0.7	1.6	1,503	2.3
Kiambu county	38.5	18.1	24.5	12.7	3.7	2.1	0.0	2.8	600	1.6
Machakos	37.5	20.5	21.0	11.9	6.0	2.9	0.1	2.4	328	1.9

Source: Kenya Integrated Household Budget Survey 2015/16

Table 4- 8:Distribution of population, households, and average household size in Kajiado, Nairobi, Machakos, and Kiambu County.

National/County	Population	Number of Households	Average Household Size
Kenya	**47,213,282**	**12,143,913**	**3.9**
Kajiado County.	1,107,296	316,179	3.5
Nairobi county	4,337,080	1,506,888	2.9
Machakos county	1,414,022	402,466	3.5
Kiambu county	2,402,834	795,241	3.0

Source: 2019 Kenya Population And Housing Census Volume 1

Demand for wood fuel

Household wood fuel demand was created by assigning fractions of different types of cooking fuels available at different administrative levels to the 2019 gridded map of population density distribution as shown in **Figure 4-19**. The average household size for Kajiado County of 3.5 is higher and closer to the national index of 3.9 equating to a steady rise in population and thus increasing demand for fuelwood and charcoal. It the gridded distribution of the available population based on the differences when it comes to the nature of the households and fuels that were being used and this was either alone or based on the use of the combination. The 2019 census showed that about 20% of Kenyans used combined energy sources, i.e. LPG, fuelwood, or charcoal. For these households, half of the energy intake was believed to be from Kajiado.

Integration of supply and demand

The study did a projection of the harvest that involved charcoal and fuelwood to have an accurate prediction of consumption of the wood fuel and this was based on the distance of the resources. The study noted that all the locations involved be it where the harvest can happen or not, they all have the potential of accumulating the biomass. 1999 was selected as the base year for the assessment of the simulation to have it align with the demographic data that was collected from the census studies. The AGB stocks for 2019, based on LULC collection and the data for the forest cover have been mapped in

Summary

Assessment of potential biomass for charcoal production using remotely sensed data will provide reliable and repetitive data that will compliment both the qualitative and qualitative approaches that have been previously used to study the charcoal and wood fuel energy situations. Remote Sensing provides a platform to develop earth observatory tools that will provide policy makers and regulators real-time data that will be essential for a decision support system. The use of land cover change, rainfall pattern, and NDVI scenario analyses start from the acknowledgement that one cannot predict the future. Instead, scenario analyses serve to explore what the future may look like under a set of coherent assumptions on key factors driving change. Examples of land-related policy questions addressed in scenario

analyses are: What changes (where, when, which kinds) in land use and land condition will happen? How will land productivity (of crops, livestock, forest products) change? What will be the implications on the use of other resources (e.g. water, fertilizers, labour)?- What will be the implications on rural livelihoods (energy demands and available alternatives, ways of lives)This thesis undertook temporal(when and where) and spatial (distribution patterns) using remote sensing and field observations to answers to such questions depending on different outcomes of key underlying drivers, such as population growth, energy demand, and sources, land use patterns, energy and land policies, as well as environmental drivers such as climate change and land degradation. The results of the study analysis provided policymakers with insights into the variety of various scenarios and anticipated future changes. This is evident through the identification of key drivers of land use (change) agriculture, wood and coal demand, and degradation. The land-use shift is due to the conversion of natural or semi-natural areas for agricultural purposes, and increased pressure from increased demand for coal and fuelwood to meet energy demand. The rate at which such conversion takes place is the result of both changes in demand and, on the other hand, changes in supply (woody biomass), including increases in crop yields and additional land under cultivation. Demand is determined by changes in the population, wages, and prices of renewable energy sources for households.

5.0 CHAPTER FIVE: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This chapter summarizes the key findings and suggestions made as a result of the study. Overall the study found out that the temporary and spatial assessment of biomass is a critical method of assessment for preparation, evaluation, and monitoring in the energy fuel sector. The use of remote sensing data must be strongly recommended for the future assessment of biomass estimation, although their use in policy evaluation and implementation is still rather the exception than the rule. Remote sensing data becomes essential when undertaking resource mapping and monitoring in a particular area of interest.

Primary observations were made based on trend data using indicators; rainfall, land use cover shifts, and NDVI values for 30 years with 10 years from 1990 to 2019. An analysis of the key recommendations was drawn up using the analyzed data. The main goals outlined in the project methodology were the assessment of the optimum biomass levels for charcoal production; the creation of maps showing patterns/range of land use covered changes as a result of wood fuel harvesting and production of charcoal in time series(1990-2019); and the assessment of policy discrepancies and the scale of land use. The main objective of the study was to assess biomass production levels that would support sustainable charcoal production in Kajiado county. Specifically, generate land cover maps depicting land use land cover changes associated with woody biomass harvesting and identify policy gaps and data required on streamlining existing legal and regulatory frameworks on charcoal production.

The major increase of cropland in Kajiado county was due to the government of Kenya new strategy to revitalize the economy. The Economic Recovery Strategy for Wealth and Employment Creation (ERS; 2003–07) identified agriculture, trade and industry, and tourism as the key sectors to drive the recovery process and contribute to improving food security and reducing rural poverty. It was followed by launching the Strategy for Revitalizing Agriculture (SRA) to provide an enabling environment for increasing agricultural productivity, promoting investments, and encouraging private sector involvement in agriculture. The long-term objective was to contribute to a sustainable increase in Kenya's agricultural productivity and improvement of the livelihoods of its rural communities." This The overarching objective led to the conversion of forest and woodlands to crop land as identified in the change detection analysis using remotely sensed data.

5.1 Results and Discussion.

5.1.1 Role of forest policy and legislation in enhancing commercial forestry in Kenya

For a while, the forestry sector was been guided by the Forest Act (2005), which was later revised to the Forest Conservation and Management Act (FCMA) of 2016 to conform to the governance structural changes in the Constitution of Kenya of 2010. Kenya forestry is also guided by the National Forest Policy of 2015. More recently, Kenya's Ministry of Environment and Forestry has initiated a review of the country's National Forest Policy to amend the existing Forest Conservation and Management Act of 2016. The Forest Act (2005) is not elaborate on biomass energy and is quite patchy on aspects of commercial forestry. There is considerable improvement of commercial forestry in the (FCMA) of 2016 and the National Forest Policy of 2015. The use of remotely sensed data is to provide data for a decision support system on forest policy and legislation in enhancing biomass trends and monitoring in Kajiado County and Kenya at large. Based on the analysis of the existing legislation, there is a need for developing an earth observatory tool that will provide a scientific platform for adequate planning tools such as management plans and conservation.

5.1.2 Charcoal Production and Consumption.

Charcoal production was identified as a major occupation in the study area. Fifty (50) per cent of the producers were between 31 and 40 years while 40 per cent were between 21 and 30 years. Overall, 90% of the producers were between 21 and 40 years. This shows that it is the youthful population that is engaged in charcoal production. Women were the dominant charcoal producers as well as users in the two communities. Seventy-three (73) per cent of producers were females. While the men preferred to farm and hunt, the women folk engaged in charcoal production as an income-generating activity. As poverty levels increase, poor people, particularly women, will be forced to produce charcoal as an income-generating activity. The majority of producers said they were engaged in charcoal production because of poverty, with a few taking it as a source of employment. Like in most rural areas where charcoal is produced, the activity had a social and economic benefit on the producing community by opening up the rural communities to trade and commerce with traders from other towns and cities. Traders from the neighbouring counties of Machakos, Nairobi and Kiambu to kajiado county to buy charcoal. All the charcoal producers interviewed did not replant trees after cutting. Generally, trees considered to have spiritual benefits as well as economic trees were not cut down for charcoal production.

Firewood was the commonest source of wood energy in the study area, used by 70% of respondents for heating and cooking compared to 20% who used charcoal. In Kenya, 90% of rural household energy is from fuelwood (firewood) and only 5% from charcoal (O‟Keefe et al. 1984), underscoring the key role of firewood in the rural economy. Firewood is however a very inefficient biomass energy source and its widespread use poses a serious challenge to sustainable forest management. Furthermore, producers of charcoal in Kajiado preferred to sell the charcoal for cash rather than use it in domestic cooking since firewood provided a cheaper option. Thus, even though charcoal is produced in rural areas, its use is actually in urban areas where it is used to supplement energy from electricity and kerosene. this has impacted negatively biomass regeneration.

5.1.3 Use of remote sensing for policy information and decision support systems.

Satellite images are becoming an increasingly important data source in forest policy formulation and implementation. The use of satellite images should be considered in the inventory of Woodlands and forest resources in real-time using earth observatory tools. Landsat-TM data is already used in the Multipurpose forest inventory and has the capability of creating an inventory structure for a County forest and biomass inventory enabling the acquisition and integration of information from different sources at various levels. The integration of both qualitative and quantitative data from the field observation and surveys data with satellite and other remote sensing data is highly desirable to inform policy decisions.

5.1.4 Charcoal Livelihood.

In the study area, charcoal production is a source of income, and residents' participation in this activity is a means of survival. Charcoal production remains a significant source of employment as well as an economic activity among rural residents. Apart from trading, all other employment sources in the study area were directly related to the forest ecosystem, posing a threat to the environment and biomass regeneration. As a means of generating a living, 65% of producers said they produce charcoal due to poverty, while 35% said it was a source of income. These producers are aware of the environmental consequences of their activities, but they lack a reliable alternative source of income.

5.1.5 Preference for Different Energy Sources.

Close to 70% of the residents used firewood in household heating and cooking while 20% used charcoal. Firewood was the cheapest wood fuel in the study area and residents acquired it by gathering from the wild. It is however inconvenient to use due to the smoke and sparks.

5.2 Conclusions

The first objective of this study was addressed by comparing the normalized difference vegetation index derived from the Landsat and AVHRR for Kajiado county. The NDVI values were derived using the observations from the Advanced Very-High-Resolution Radiometer for the 30 years from 1990-2019. The results illustrated a strong correlation between the NDVI derived from the Landsat and AVHRR with a statistical correlation between 0.79 – 0.77 between them. The linear slope of NDVI for each pixel throughout 1990 -2019 displayed a difference of green biomass (NDVI) change within the 10-year interval. The time series of the average NDVI (1990-2019) with the AVHRR sensor showed a decrease in values over the 30 years. The average NDVI data in the year 2019(0.30-0),2010(0.35-0.62), and 2000(0.29-0.61) indicated that there is the reflection of peak rainfall in NDVI and there is a reduction in rainfall at the end of the season due to change in land cover and rapid vegetation degradation.

The decline in biomass productivity shows that charcoal production is not sustainable using the current systems in meeting the steady rising demand and supply. Further, this study generated land cover maps depicting land use land cover changes associated with woody biomass harvesting. To compare the land cover percentage, within the period of 30years from 1990 to 2019, there were increments in land cover for wooded grassland, croplands, water bodies, and other lands while forests, vegetated wetlands, and open grassland went down a pointer to unsustainable harvesting of the products. The land degradation map generated using several parameters such as rainfall, soil and NDVI values showed a high degradation rate of 8.57% across the study area.

According to this study, a correlation between charcoal production and decline in biomass regeneration was evident. The high demand and supply of charcoal and fuelwood are attributed to increased population growth that depends highly on biomass fuel for their household needs. This growing demand for charcoal has exerted pressure on the woodlands in the arid and semi-arid regions of Kajiado. The continued harvesting of the woody biomass in both agricultural and forested areas will result in a decline and or reduced size of this class by the year 2030. The main class will remain cropland, grassland, and bareland if not checked. This negative trend is set to continue with the growing demand for charcoal and fuelwood and inaccessible alternatives and prohibitive process

There are major policy areas for concerted actions that can be implemented using Temporal and spatial evaluation as an excellent method for energy-fuel sector analysis, assessment, and monitoring. Frequent updating of remotely sensed data would help to recognize wood energy issues, form the basis for public/private sector commitments and coordination actions to boost national and county fuel/charcoal awareness. This will create baseline data for Information flows to strengthen the networks and activities for the sharing of information, data, and experiences of established charcoal user associations (producers, users, and regulators). It will also assist in the transfer, adaptation, and application of technology to promote substitution of fuelwood/charcoal by alternative fuels both at the rural and urban household and promote the establishment of multi-purpose plantations.

In summary, there is a need for carrying out periodic environmental impacts and social assessment of wood fuel harvesting; taking industry analyses of fuelwood/charcoal supply and demand. This will inform Research and development activities for households, especially rural areas, with improved wood energy conversion equipment; Develop suitable fuelwood/charcoal substitute and analysis of sufficient fuelwood/charcoal production and use of local and high-yield species

The results of the study indicate that there is a low presence of woody biomass within Kajiado County and this is based on the current demand and land use patterns making it unsustainable as an alternative source of energy. Wood energy sources are and will remain a significant part of the economic sub-sector in Kajiado County, with a steady demand for charcoal in and around the counties of Machakos a, Kiambu, and Nairobi. Consumption of wood biomass fuels will rise shortly. Forest land remains the main source of wood fuel.

a) The future wood-fuel supply exceeds woodfuels demand based on population growth and estimates of sources. Agricultural fuel is an important complementary element for available wood fuels and increased production of timber on farmland will play a central role in increasing the availability of timber fuels as the cropland increases.

b) The lack of accurate data on the use of wood fuel makes it difficult to determine changes in consumption. Due to the consumption and proportion of wood fuel contribution, remotely sensed data have shown patterns of land cover transition.

c) The potential supply of wood fuel exceeds the demand for wood fuels using population growth and sources projections. The key player in complementing available wood fuels is the agricultural sector, and increasing the production of wood fuels on agricultural land can play a key role in increasing the supply of wood fuels as the cropland grows.

d) The lack of reliable wood fuel consumption data makes it difficult to assess the changes that have occurred in consumption. The remotely sensed data has depicted the land cover change patterns as a result of consumption and proportion of wood fuel contribution.

e) Need for improvement on the cropping system knowledge to understand the most efficient way of charcoal production that will not have adverse effects on the environment.

Although the model and documents with bans were coded with a simple version of production and transport of coal from the neighbouring countries to high demand in Nairobi, no simulations were carried out because of the absence of knowledge about the amount being transported. At present, this model is supposed to presume that all imports from the Kajiado County (Nairobi, Nakuru, Kiambu, and Machakos) will be used in neighbouring Countries, but no porous border or roads have been coded or identified yet. Dendroenergy capacity, such as spatial and temporal analysis of illegal exports of charcoal from Kajiado County, would directly achieve this.

5.3 Recommendations

Based on the results and findings of this study, the following recommendations can be made.

a. There is a need to use remote-sensing observational field-based data to measure forest degradation in areas and times by predicting wood fuel and charcoal degradation;

b. Create a geospatial database to record the spatial distribution of biomass resources and document any degradations that are associated with charcoal production within the study area;

c. Strengthen the Environment Policy 2013 and the Energy Policy 2004 with the introduction of a framework for incentivizing the use of improved production technologies among charcoal producers and for research and development to focus on selecting fast-growing tree species for wood energy crops, improve on survival and growth rates of trees at degraded sites;

d. The ministries of environment and forestry; tourism and wildlife and Energy together with the County government should develop and produce an up-to-date forest information database of the forest sector; develop and test methods to produce up-to-date land use and land cover database that will be used for decision support systems for policymakers;

e. To develop and test operative forest information and decision support system, with monitoring and revision capabilities, in a GIS environment;

f. The Kenya forest service with other lead agencies and stakeholders should use ancillary information such as forest type and/ or textural data to improve the relationship between spectral data and biomass;

Areas for Further Research

This study proposes further research to be carried out particularly in developing a geospatial database to calculate the fraction of non-renewable biomass harvests associated with the demand for wood fuel and to classify "high-risk areas" where biomass sustainability is a key issue. In turn, this will build a range of scenarios to analyze the possible effects of future charcoal demand in the county of Kajiado. The scenarios would examine the impact on non-renewable biomass across the country of spatial data and action initiatives based on demand reduction. Specifically;

a. Biomass energy, environment and land degradation policies reviews and decisions should be supported with accurate and repetitive data provided through scientific experiments;

b. Identify the possibility of using satellite images for the actualization of forest areas during forest inventorying due to recent changes in their administrative structures. Systematically stratify the sampling design where every stratum is derived from existing maps by grouping polygons of the forest map. Principal criteria for the stratification are species and forest types to enable policy makes review preferred species for charcoal production, spatial extend of regeneration or fragmentation;

c. Launch investigations to establish remote sensing technologies as a basis for the national inventory and for the system of monitoring the forest status in Counties. This monitoring system which includes the analysis of satellite images, enforced in the Kenyan forestry, will be an important contribution to the Kenyan environmental science and policy decision support system;

d. The use of alternative imaging technology (LiDAR or high-resolution imagery such as Quickbird and IKONOS) be considered and methods to better capture the horizontal (spatial) and vertical (height) characteristics of woodlands and forests should be further studied.

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Appendices

APPENDIX 1: HOUSEHOLD QUESTIONNAIRE
UNIVERSITY OF NAIROBI

Spatial and Temporal Assessment of Biomass Production for Sustainable Charcoal Production in Kenya. Case Study of Kajiado County

CONSENT FORM FOR HOUSEHOLD SURVEY QUESTIONNAIRE

My name is Silas Mulehi, from CASELAP, University of Nairobi. I am researching the **Spatial and Temporal Assessment of Biomass Production for Sustainable Charcoal Production in Kenya. Case Study of Kajiado County**. The research aims to determine the sustainability of biomass potential for charcoal production. Broadly, the study objective was to assess the biomass production levels and determine if charcoal production using woody biomass in Kajiado County is sustainable. I will be asking you some questions in the next 45 minutes**.** The information you share and data collected from you will be confidential, with no individual benefits or risks, and purely used for academic purposes particularly for thesis writing which is part of the requirements to complete a Masters of Degree.

Kindly, do you mind some time to answer my questions?
Yes ( )   No ( )
If yes proceed with the interview and if no the interview must be discontinued.

SECTION 1: QUESTIONNAIRE IDENTIFICATION

Date…………………	**Name of interviewer…………**
County…………………………….	**Sub-county…………………………….**
Ward …………………………….	**Sub location…………. ………………….**
Village…………………………	**Name of town/market………………**
Household ID No…………………	**Geographical location Latitude….. Longitude………**

SECTION 2: SPATIAL DATA

Question 1: Land Use Land Cover Types

Name of recorder				**Date**				**Plot radius**			
Sampling plot no.			**Coordinates**				**Elevation**		**Slope**		**Slope**
			X		**Y**						
Management type;											
Strata name ;											
Land use type(forest/woodlot);							**Crown cover %**				
Tree no	**species**	**DBH (cm)**	**Height (m)**	**Crown diam**	**remark**	**Tree no**	**Species**	**DBH (cm)**	**Height (m)**	**Crown diam**	**remark**

Question 2: Property Survey

The following questions regarding your forest land are very straightforward. Please, complete them as accurately as possible, and where the actual information is not available, please use your best guess.

PROPERTY INFORMATION

I. Approximately how many acres of forest land do you own?

O 1 - 9 acres O 10 – 49 acres
O 50 – 99 acres O 100 – 499 acres
O 500 – 999 acres O Over 1000 acres

II. Approximately what percentage of your forest land is covered by:
____ % - Pine ____ % - Hardwood

III. How important are the following reasons for ownership of forest land? (check one circle for each item)

	Not important		**Very important**		
	1	**2**	**3**	**4**	**5**
Nature conservation					
Charcoal burning					
Enjoy beauty scenery					

Other(please specify)…………………………………………………………………………

IV. What are your plans for your forest land in the next five years? (check all that apply)

O Leave as it is
O Commercial harvest (pulpwood
O Harvest firewood
O Collect non-timber forest products
O Buy more forest land
O Sell some or all forest land
O Convert the forest land to another land use
O Not sure
O Other (please specify)______________________________

SECTION 3: KNOWLEDGE OF THE TRADER AND CONSUMER PREFERENCE

Question 3: What are the main sources of trees/wood for charcoal production

- Is charcoal burning your main economic activity? (a) Yes (b) No
- Are all trees/wood favourable for charcoal burning? (a) Yes (b) No
- (If no) is it possible for you to mention the various types/species of trees used for charcoal production (Local or English name)?
- Are there some preferred species of trees/wood to others? Please list a few
- What are the reasons for the above preference?
  ....
  ....

  List the sources of wood for charcoal production?

  ....
  ....
- Select the most viable source and explain why?
- Which is the most predominant charcoal process?

  Traditional earth or sawdust mound procedure

Mobile metal kiln method

Pit kiln method

Others (specify

- Discuss the most prominent charcoal producing methodology
  Why? ....
- Name and describe specific parts of the tree/ wood used predominantly in charcoal processing?
  Branches /Roots /stems / All the above
- Which part is usually preferred?
  Please specify and why? ....

Question 4:Which of the following best describes your knowledge about trader and consumer charcoal preference

1. High ( )
2. Intermediate ( )
3. Low ( )

Question 5:Who are your main customers? (tick)

	customer	Tick
1	Local broker	
2	Transporter	
3	Wholesaler	
4	Retailer	
5	Consumers-household	
6	Consumers-institutions	

Question 6; Rank your main customer in terms of the amount (percentage/proportion) of charcoal you sold in the last 12 months.

	customer	location	Rank	% of charcoal bought
1	Local broker			
2	Transporter			
3	Wholesaler			

4	Retailer			
5	Consumers-household			
6	Consumers-institutions			

Question 7: What are the main land-use patterns and resource use

a) Please provide the following information regarding the household(correct circle answer)

Land tenure system; customary: private; leasehold: squatter

The acreage of(owned land)	
Homestead	
Cropland	
Woodlot	
Grazing land	

b) Is the land registered (have title deed)? Yes / No

c) What is the distance of the Household energy source(s) (specify which type):______________________________(km)

d) What is the distance of the homestead to forest edge:____ (km)

e) Name the household forest use(s) / benefit/s and the amounts per week: Tick as appropriate answers

Charcoal kg / head loads per week
Firewood kg / head loads per week
Agroforestry
Bushmeat
Medicinal plants
Source of Water (Irrigation, Livestock, Drinking water, other Domestic use)

f) If the house hold produces charcoal, is the charcoal produced in: own land /customary land /other (specify):__________________________

g) Who produces the charcoal in the household?

SECTION 4: CURRENT PRODUCTION SYSTEMS

Question 8:What methods of tree harvesting for charcoal production do you use, what are the reasons for adopting them?

1. Clear felling ☐ Reason……………………………………………
2. Selective harvesting ☐ Reason……………………………………………
3. Pruning ☐ Reason……………………………………………
4. Collection of deadwood/ stump ☐ Reason……………………………………………

Question 9; What tools do you use to cut trees?

1. ………………………
2. ………………………

Question 10: How often do you produce charcoal?

1. Weekly ☐
2. Fortnight ☐
3. Monthly ☐
4. Others, Specify ☐

Question 11; Which months are you usually involved in charcoal production? (tick)

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Nov	Dec

Question 12; What are the main reasons for your involvement in these months?

1. ____
2. ____
3. ____

Question 13; What kind of kiln do you use in making charcoal?

i. Earth-mound kiln ☐
ii. Drum kiln ☐
iii. Brick kiln ☐
iv. Casamance kiln ☐
v. Other ☐ Specify …………………………………

Question 14: Do you dry wood before carbonization? Yes/no If yes for how many days? ....

Question 15: What is the average size (in meters) of such a kiln?

i. Diameter…….
ii. Height…….

Question 16:On average how many bags of charcoal do you get from such a kiln? (   ) Bags

Less than 3	3-5	6-10	10-15	15-20	20-25	Over 25

SECTION 5: SOCIO-DEMOGRAPHIC AND ECONOMIC CHARACTERISTICS

I would like to ask you some questions about yourself and your household. The information provided will be confidential and will only be used to bring an understanding of the different responses given above for this study.

Question 17: what is your relationship with the household head?

Question 18; What is the Gender of the household head?

1. Male □   2. Female □

Question 19: What is the size of the household (residing together and eating from the same plot? ( )

Question 20: What is the total monthly income (before taxes) for the household? Please tick your monthly income range.

1. Under 20,000 □
2. 20,001-50,000 □
3. 50,001-75,000 □
4. 75,001-100,000 □
5. Over 100,000 □

Question 21:Do you own the land from which you produce charcoal?

YES □

NO □

SECTION 6: CURRENT POLICY REGULATIONS ON CHARCOAL PRODUCTION

Question 22: what are the policy regulations?

<table>
<tr><td colspan="2">Question</td><td colspan="2">Answer</td></tr>
<tr><td colspan="2">Policy, laws, and regulation</td><td>Charcoal</td><td>Other forest product</td></tr>
<tr><td colspan="2">Forest</td><td></td><td>Yes - no
other</td></tr>
<tr><td colspan="2">Wildlife</td><td></td><td></td></tr>
<tr><td colspan="2">Environment</td><td></td><td></td></tr>
<tr><td colspan="2">Urban planning</td><td></td><td></td></tr>
<tr><td colspan="2">Other(specify)</td><td></td><td></td></tr>
<tr><td rowspan="2">Gaps, Disincentives, and Incentives: Identify and describe any existing or in-pipeline incentives/ disincentives in control of charcoal production.</td><td>Gaps and Disincentive</td><td>Charcoal</td><td>Other forest product</td></tr>
<tr><td>Incentives</td><td></td><td></td></tr>
</table>

Question 23; what are the Key stakeholders on charcoal value chain (Kenya Wildlife Service, Kenya Forest Service, National Environment Management Authority, National Drought Management Authority among others

I. Do you have a map of land/forest under your jurisdiction?
   O Yes O No

II. If "yes", how it was generated?
   O By hand (drafting)
   O Computer generated
   O Not sure

III. Who made the map?
   O Does not apply
   O Forestry consultant
   O Industry forester

O State Forester
O Yourself
O Other ______________________

IV. Have you used mapping software (GIS – Geographic Information System) as an enforcement tool

O Yes
O No

V. If "yes", please check the mapping software that you are familiar with. Check all that apply.

O ArcInfo (ESRI)
O MapInfo
O Delorme
O Garmin/Magellan
O Microsoft Terra Server
O Google Earth
O Mapquest
O Other______________________________________

VI. Does remote sensing assist in the monitoring of land resources within your area of jurisdiction?

O Yes
O No
O Not sure

APPENDIX 2: FOCUS GROUP DISCUSSION GUIDE

UNIVERSITY OF NAIROBI

Spatial and Temporal Assessment of Biomass Production for Sustainable Charcoal Production in Kenya. Case Study of Kajiado County

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Participatory Rural Appraisal (PRA) Guide

My name is Silas Mulehi Osinde, from CASELAP, University of Nairobi. I am researching the **Spatial and Temporal Assessment of Biomass Production for Sustainable Charcoal Production in Kenya. Case Study of Kajiado County**. The research aims to determine the sustainability of biomass potential for charcoal production. Broadly, the study objective was to assess the biomass production levels and determine if charcoal production using woody biomass in Kajiado County is sustainable. The information you share and data collected from you will be confidential and purely used for academic purposes particularly for thesis writing which is part of the requirements to complete a Masters of Arts in Environmental Policy at the Center for Advanced Studies in Environmental Law and Policy (CASELAP), the University of Nairobi.
(Begin with laying down the rules of the discussion. Before we begin, everyone should know that their participation is highly regarded and that there are no rights or wrong answers. This is an open forum for everyone to be part of, and equal treatment applies to every member present. We will start with a quick introduction going around each to tell us their names and where they come from. Member of the research team will then introduce themselves)

1. What are your thoughts concerning our topic today?

2. According to you, what are the reasons for:

   i. Producing charcoal full time?

   ii. Producing charcoal periodically?

   iii. Choosing specific tree species for charcoal production?

APPENDIX 3: OBSERVATION MATRIX
University Of Nairobi

Spatial and Temporal Assessment of Biomass Production for Sustainable Charcoal Production in Kenya. Case Study of Kajiado County

CONSENT FORM FOR OBSERVATION MATRIX

My name is Silas Mulehi, from CASELAP, University of Nairobi. I am researching the **Spatial and Temporal Assessment of Biomass Production for Sustainable Charcoal Production in Kenya. Case Study of Kajiado County**. The research aims to determine the sustainability of biomass potential for charcoal production. Broadly, the study objective was to assess the biomass production levels and determine if charcoal production using woody biomass in Kajiado County is sustainable. Write a brief description of the following

Item	Description
Predominant kiln in use	
Nature of tree harvesting	
Predominant Wood management within the farms where charcoal production is taking place	
Packaging of charcoal produced	
Land use where charcoal has been harvested	

Thank you for your time!!