MAPPING LAND COVER CHANGES AND IDENTIFICATION OF DRIVERS OF DEGRADATION TO INFORM REHABILITATION STRATEGIES IN WENJE, TANA RIVER COUNTY

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DECLARATION AND APPROVAL

This thesis is my original work and has not been submitted for award of a degree in any other University.

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DEDICATION

I dedicate this thesis to parents, Washington Chepyegon and Eunice Kobilo, Daughter Nova Chemutai and Love Jocyline Kosgei. Brother Jacob Limo and Sisters Irine Kangogo, Eva Jeruiyot and Naomi Jemator.

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ACRONYMS

AOI- Area of Interest

ARCGIS- Aeronautical Reconnaissance Coverage Geographical Information System

ASALs- Arid and Semi-Arid Lands

DNC- Dresden Nexus Conference

ERDAS- Earth Resource Data Analysis System

FAO- Food and Agricultural Organization

GDP- Gross Domestic Product

GIS- Geographical Information System

GLEF- Global Land Cover Facility

GOK- Government of Kenya

ICPALD- IGAD Centre for Pastoral Areas & Livestock Development

IEBC- Independent Electoral and Boundaries Commission

IUCN- International Union for Conservation of Nature

KIRA- Kenya Interagency Rapid Assessment

KNBS- Kenya National Bureau of Statistics

LADA- Land Degradation assessment

LULC- Land Use and Land Cover

MT- Metric Tones

NDVI- Normalized Difference Vegetation Index

PGIS- Participatory Geographical Information System

ROK- Republic of Kenya

SPSS- Statistical Package for the Social Science

TRC- Tana River County

TRCSSR- Tana River County Smart Survey Results

UNCCD- United Nations Conventions to Combat Desertification

UNEP – UN Environment Programme

US- United States

USGS- United States Geological Survey

WISP- World Initiative for Sustainable Pastoralist

GENERAL ABSTRACT

Land degradation is a global issue that needs to be addressed with greater concern. Land rehabilitation is an expensive exercise but very important for reducing ecosystem degradation and increasing the productivity of the rangelands. Sustainable use of vegetation is necessary because it helps to address the effects of climate change by reducing the amount of carbon (iv) oxide in the atmosphere. Rangelands are also a critical biome that is a source of livestock feed, but with the recent challenges of increased loss of productivity from degradation leading to biodiversity loss. This study aimed to work with the communities, use satellite images, and ecological studies in understanding land degradation and land cover changes over the years, identifying the best approaches to land degradation mitigation and the best-suited rehabilitation strategies and species of interest to the communities for rehabilitation efforts. This study had three objectives. 1. Evaluate community perception on drivers of vegetation cover changes, land degradation, land rehabilitation, and the impacts on their livelihood 2. To assess the land cover changes 3. To evaluate vegetation species composition, cover, and density.

A semi-structured questionnaire was needed to conducting household interviews. The number of the household interviews was 180 out of 2946 households. SPSS and Microsoft excel were used in the data analysis. The majority of the respondents (60%) indicated that vegetation cover had declined by 80%. The main effect of land degradation indicated by the communities was declined livestock feed (38.3%).

The key invasive species recorded was *Prosopis juliflora*. Majority of the respondents who indicated that the invasive species has economic beneficial are (60%), while (20%) indicated that the invasive species do not have any economic value. The majority of the respondents indicated

that they used the *Prosopis juliflora* for forage (71%), while the most negative effect of *Prosopis juliflora* was pasture encroachment and road blockage (71.79%).

Landsat images with different sensors and resolutions were downloaded from the USGS earth explorer of paths 166 and 61. Supervised classification was done using maximum likelihood in ArcGIS 10.7 to show six classes namely 1. Water 2. Mango plantation 3. Built-up areas 4. Grassland 5. Forest 6. Bare ground. The results from the analysis indicated the following changes; bare land had increased by (41.16%), the forest had declined by (25.40%), grassland had declined by (24.27%), Mango plantation had increased by (6.80%), and built-up areas had increased by (2.05%) and water bodies had declined by (0.32%) over 20 years.

A Belt transect of 100M×10M was used in the study, a quadrant of 1-meter square was required to collect data on herbaceous species while a 5-meter square was used for woody species. A total of 5971 herbaceous species was recorded. The five (5) most dominant herbaceous species in decreasing order were *Cyprus rotundus* (30.41%), *Cynodon dactylon* (19.38%), *Cucumis pustulatus* (10.65%), *Ruellia patula* (9.55%) *and Corchorus olitorius* (8.78%). Then a total of 676 woody species was recorded in the study area. The five (5) most dominant woody species in decreasing order were *Ricinus communis* (14.05%), *Acacia reficiens* (11.24%), *Cordia goetzii* (10.95%), *Prosopis juliflora* (9.47%) and *Acacia zanzibarica* (8.14%). The values of Shannon Weiner's diversity index (H') were 2.2, and 3.0 for herbaceous species and woody species respectively, which indicates high biodiversity. The study area had an average of (20%) vegetation cover, which was very low.

Sustainable vegetation use is recommended in this study, this is because vegetation is an important source of feed for livestock. Vegetation also helps in reducing greenhouse gas in the atmosphere thus mitigating climate change. The highest percentage of the study area is highly degraded

especially during the year 2017 this has been attributed by climate change and overgrazing. It is expected that land degradation will increase in the future due to increasing climate change and land degradation. The study recommends land rehabilitation.

The study show that the land is severely degraded. The community indicated that land degradation could be solved by reseeding with the following four types of grass species which are more adapted to the Tana River, *Cynodon dactylon, Echinochloa haploclada, Panicum maximum,* and *Cyprus rotundus*. The study recommends involvement of communities in solving land degradation as a priority since communities play a greater role in mitigating activities contributing to degradation.

CHAPTER ONE

General Introduction

1.1 Background

The world's dryland makes up 41 % of the terrestrial land, this land supports over 2.1 billion people. While, Africa's drylands are 42%, it supports approximately 280 million people (FAO, 2004). East Africa's dryland makes up to 79% (Nyariki *et al*., 2005). Supporting over 45 million people (IUCN, 2007).

Kenya's dryland makes up 84% of the total land surface (Republic of Kenya, 2012b). This land supports over 15 million people (IUCN, 2011; Machan *et al.*, 2022; Njora & Yilmaz, 2022). The communities in these drylands derive their livelihood from livestock keeping, but also, practice crop farming. There are 17.5 million cattle, 27.7 million goats, 17 million sheep, 3 million camels, 31.8 million domestic birds, and 1.8 million donkeys (KNBS, 2010). About 70% of the total livestock herd is found in the drylands (Odhiambo, 2013; Rahimi *et al.*, 2022). The livestock sector generates 45% of agricultural Gross Domestic Product GDP annually and 10% from agricultural production (KNBS, 2012). Livestock production contributes more than 4.54 billion dollars (ICPALD, 2013). This indicates that livestock production is an important sector of the Kenyan economy.

The traditional system of pastoralist has been nomadic and transhumance but nowadays pastoralists are increasingly becoming sedentary. This due to increasing human population, global development, and initiatives by government donors and Non-Governmental Organizations (NGOs). Which has helped the community in the provision of water and feeds for livestock (Mbote, 2005). The ever-increasing population pressure has also fueled the expansion of agriculture to meet the demand for food (Maitima *et al.*, 2009; Singh *et al.*, 2020).

According to the Land Degradation Assessment (LADA, 2016). Climate change is a driver of land degradation. With the effects of flooding and prolonged droughts. This affects the growth and production of forage species for livestock. This has negatively impacted vegetation availability with a succession of droughts as a result of climate change causing the death of their livestock (Barrow, 2007).

Land degradation as a result of land use by a human is a major challenge in the 20th century and will extend to the 21th century (Eswaran, 2001). Land degradation reduces the resilience of the land to provide essential ecosystem services. (Wairore *et al.,* 2016; Chaigneau *et al.,* 2022; Chen *et al.,* 2023). These ecosystem services include the provision, of regulatory services, cultural services, and ecosystem services (Mercy, 2017; Hasan *et al.,* 2020).

1.2 Problem statement

Kenya is an agricultural nation with over 12 million people relying on degraded land for agricultural production (Mulinge *et al.,* 2016; Dongmo *et al.,* 2022). In Kenya, 64% of the total land is degraded while 27.2% is highly degraded with 2% being severely degraded. ASAL counties are the ones majorly affected by land degradation including Tana River County. The causes of land degradation include both natural causes such as drought and floods as well as human activities which include unsustainable land management such as poor grazing patterns which leads to overgrazing, cutting down of trees, and over-cultivation (Mganga, 2015; LADA, 2016; Kgaphola *et al.,* 2023). Assessment of land degradation is not an easy task but researchers have come up with techniques such as satellite remote sensing, modelling, and the use of special indicators to map the area needed for rehabilitation (Aly *et al*., 2016). Land degradation in east Africa has been increased by activities such as farming, grazing, human settlement, and urban centre at the expense of natural resources. (Maitima *et al*., 2009; Talukder *et al.,* 2021).

There is a need for informed planning for rangeland rehabilitation and the use of vegetation types and species that are best suited to specific areas. The study seeks to use satellite technology to determine vegetation changes over the years, and identify degraded areas and areas under the progression of degradation to inform interventions.

This study will also seek to work with the communities in understanding land degradation and vegetation cover changes over the years, and identify the best approaches to land degradation mitigation. Also provide for the best-suited rehabilitation strategies and species of interest to the communities for rehabilitation efforts. The community knowledge and the satellite evaluation will also help in planning targeted rehabilitation intervention efforts for improved livestock productivity.

1.3 Justification

This study will help inform the land users on the extent of land degradation. Advise the county government of Tana River and stakeholders on rangeland rehabilitation. By use of local grass species to improve vegetation biodiversity and reduce the scarcity of pasture. Pastoralism is an important sector in the country. Decline in pasture and forage production is caused by increased climate change and land degradation which has undermined pastoral production in Tana River, Kenya.

It is necessary to understand the extent and nature of land degradation because it is a challenge facing the entire world, especially the drylands. Rangeland degradation can be reversed through reseeding technology. Especially with the native grass species that are identified by the community. There is a need to come up with an approach to reseeding the rangelands (Mganga *et al.,* 2015). The correct method to come up with a reseeding plan is by conducting a baseline survey to determine the best suit grass species that are well adapted to the area. This is to increase the success rate in rehabilitation. After the degraded areas, the county government and stakeholders will reseed the areas which need quick rehabilitation. The grass used in reseeding should be sourced locally from Tana River County because it is well adapted to the geographical area. The studies will provide information on the exact place which needs quick rehabilitation.

Mapping of degraded land using satellite images will contribute to the timely and targeted response to rangeland rehabilitation by county government and stakeholders. This will help in improving livestock production, reducing climate change, and generating income. Through the sale of hay and seeds by local communities (Omollo, 2017). There are four grass species that are native and well adapted to Tana River. They have a higher capability of surviving than Rhode grass and alfalfa which have been introduced to Tana River County (Koech, 2015). When this grass species is used in the rehabilitation of the rangelands in Tana River County it will boost livestock production.

Past efforts on rehabilitation lacked mapping of the vegetation cover before doing rangeland rehabilitation. It's very important to map the area to identify the areas which require quick rehabilitation

1.4 Objectives

1.4.1 Broad objective

The broad objective of this study is to assess land cover dynamics, identify degraded areas and generate information that can be used in planning rehabilitation, and to improve Tana River County pastoral community' livelihoods.

1.4.2 Specific objectives

1. Evaluate community perception on drivers of vegetation cover changes, land degradation, rehabilitation and the impacts on their livelihood in Wenje, Tana River County.

2. To assess the land cover changes over the last 20 years in Wenje, Tana River County.

3. To evaluate vegetation species composition, cover and density in Wenje, Tana River County.

1.5 Research questions

1. What is the status of local community knowledge on land cover changes over the past years and how has it affected their livelihood?
2. How has land cover changed in the study area for the last 20 years?
3. What is the vegetation density, cover and composition present in the study area?

CHAPTER TWO

Literature review

2.1 Rangeland degradation and rehabilitation

Land degradation is defined as the reduction or loss of biological or economical productivity of the land, land degradation in arid, semi-arid, and dry sub-humid areas. Resulting from various factors including climatic variation and activities (UN, 1994; Chasek, 2019). The major causes of degradation include climatic conditions, causing drought and arid conditions, and human factors. Leading to the overuse of natural resources (Abdelhak, 2022; Hossini *et al.,* 2022). Livestock density and grazing patterns lead to overgrazing, which is one of the major causes of land degradation. Overgrazing results when livestock density becomes excessive and too many animals are grazed in the same area of rangeland, leading to the degradation of vegetation and the compaction and erosion of the soil. The uncontrolled browsing of trees and shrubs is another aspect of overgrazing and a patent cause of deforestation, leading to flooding and siltation in adjacent areas because rains are no longer held back by the sponge effect of the trees and carry with them large loads of eroded soil (Zerga, 2018; Haddad *et al.,* 2022). Land degradation is a major problem in most drylands especially those with limited moisture supply (Ibrahim, 2017; Diop *et al.,* 2022). Rangeland degradation is a serious challenge in the arid and semi-arid. Rangeland degradation causes environmental constraints such as increased climate change and declined feed for livestock. Land degradation is majorly caused by overgrazing and mismanagement of resources.

Pastoralism through reduced mobility increased livestock, and increased privatization of the land has become the major cause of land degradation. If local institutions are put in place for land management, it will be so beneficial to conservation and management. To reverse land degradation rangelands, require the government to create policies, goals, and political agenda for promoting pastoralism, policies are needed also for proper management of the resources and governments also should create livestock diversification to strengthen pastoral rangeland management capacity (WISP, 2008).

Grass reseeding technology is the perfect method to restore degraded land. Reseeding technology restores the functioning of the degraded dryland ecosystem (Mganga, 2015; Svejcar *et al.*, 2023). Some factors that contribute to land degradation include increased sedentary by agro-pastoralist has led to increased land degradation through the increased population, agricultural activities, and economic developments this has led to increased pressure on the limited land (Nyberg, 2019).

Degradation of rangeland has resulted in a substantial decline in rangeland condition, water potential, soil status, and animal performance (Shackelford *et al.,* 2021). Livestock held at the household level and community become poor. Another consequence of rangeland degradation is linked to food insecurity, poverty to the extent of food aid. Expansion of aridity, and the need for alternative livelihood and income diversification (Abdulahi, 2016). Rangeland rehabilitation has positive impacts it leads to increased food security, and reduced livestock mortality. This is because of harvested fodder. Also, there is the improvement of the environment through control of soil erosion, mitigate climate change, and maintained of soil moisture, there are also other benefits which come from rangeland rehabilitation (Wairore, 2015).

2.2 Vegetation resource mapping in selected regions using remote sensing

Digital change detection technique by using multi-temporal satellite imagery helps in understanding landscape dynamics in the area. Examples of the studies done are the spatial-temporal dynamics of the land use/ cover of Hawalbagh block of district Almora, India. Landsat

Thematic Mapper (TM) of 1990 to 2010 was acquired from Global Land Cover Facility (GLEF) and earth explorer. The supervised classification method was employed using the maximum likelihood technique in Earth Resource Data Analysis System (ERDAS 9.5) software. The different classes obtained are Vegetation, Agriculture, barren, built-up, and water bodies. (Rawat, 2015).

In developing countries including Ghana shifting cultivation is predominant in agriculture practiced by farmers. These small scales shifting agricultural practices based on clearing and burning off has been the factor responsible for the conversion of forest to cropland. The construction of the Akosombo dam in 1965 resulted in many settler farmers and fishers in the area. The increased population led to increased pressure on natural resources that eventually led to landscape transformation where the vegetation cover declined. (Ampofo, 2015).

Classification of vegetation communities on Sheldon National Wildlife Refuge in northwestern Nevada. The objective was to create detailed vegetation and habitat information that can be referenced to make better decisions regarding wildlife resources, fuel and fire risk, and landscape management. (Tagestad, 2010).

The study was to determine the effect of land use on the high-density population that is located at the edge of Lake Victoria. The data that was collected is household data accompanied by remote sensing data. Farming is the major activity in the wetland. Farming supplies 70% of food to the household. This has led to the continuous opening of the wetland to meet the ever-growing population this has been indicated by the use of remote sensing. Swamp conversion to farmland is expected to increase this is because increase of the population in the area. (Thenya, 2017).

From the studies done in different countries, spatial data plays an important role in natural resource management, special data create information on important decision-making processes of the future by increasing monitoring, accountability, and improving the condition of natural resources (Okuku, 2014)

Geographical Information System (GIS) is increasing all over the world. GIS is an organized collection of data using computer software, hardware, geographical data, and personnel. They are assigned to efficiently collect, capture, update, manipulate and display all forms of GIS. However, the information produced may not reflect what is on the ground this makes communities not participate. It is very important to use simple methods of GIS in describing the changes in land cover. (Mbau, 2013).

Participatory Geographical Information System (PGIS) is the process by which the local community participates in the geographical representation of their problems by use of a sketch map. Communication is required to gather knowledge from the locals on natural resource management strategies in remote areas. PGIS is very important in understanding the socio-cultural and socio- economy of a community in the context of the natural resource. PGIS does not only help in looking for local knowledge on resources on the ground. Also helps capture historical perspectives in understanding the present and past dynamics and potential mitigation measures. PGIS method helps a lot in understanding the real situation occurring on the ground and developing adequate proof on ensuring the sustainability of any plan and technique. (Mbau, 2013).

The use of remote sensing in conjunction with geographic information systems (GIS) provides an invaluable tool for rangeland monitoring (Feng *et al.*, 2006). Spatial data plays an important role in natural resource management. Special data create information on important decision-making processes of the future by increasing monitoring, accountability, and improving the condition of natural resources. (Okuku, 2014).

2.3 Land use and land cover changes in Kenya

Land use changes in Kenya have transformed vegetation cover into grazing lands, urban centers, croplands, and settlements. This has led to increased land degradation due to loss of plant cover and biodiversity. Land use changes have also made native plants to extinct or become endangered. (Maitima, 2009).

Increased expansion of agriculture, uncontrolled grazing of livestock, increased livestock population, increased fire frequency and reduced rangeland resources. This are casual of land degradation in African rangelands. An increase in human population has also led to increased livestock. This increases the removal of vegetation cover leading to land degradation. Excessive demand for woody vegetation for fuel, house construction, and construction of livestock enclosures has led to a continuous decline in vegetation cover (Wasonga, 2009).

Rangelands in Africa are being faced with climate change this is a major change in rainfall and seasonality patterns, which affects the availability of the pasture and fodder for the livestock. (Marchant, 2018). Climate change including temperature, rainfall, and rise of sea level affects the vegetation cover, it also affects the water ran off and sedentarization in coastal regions. (Al-Nasrawi, 2018). There is a correlation between vegetation cover, temperature, and rainfall. Low precipitation with the presence of high temperatures reduces vegetation cover that is the negative correlation. Positive correlation is when there is high precipitation and high temperature there will be increased vegetation cover. (Guo, 2008).

Pastoralist has many techniques they employ to protect the resources on their land. The major resources in the drylands are land, vegetation, and water. There is traditional knowledge that the pastoralist is employed in conservation this includes mobility, herding, and use of fires to replenish pasture and grazing reserves. This has contributed to improving rangeland diversity. Pastoralists have knowledge of the uses of very important trees which is very important in the management of vegetation cover. The very important knowledge they have is seasonal grassland and livestock mobility have influenced vegetation composition, abundance, and cover in the rangelands positively (Seid, 2016).

Therefore, there are internal and external factors that have affected the traditional management of livestock mobility affecting the vegetation cover. Example sedentary has led to the confinement of livestock in one area putting pressure on land degradation. Replacement of nomadic pastoralism with sedentary will be vital to rangeland biodiversity and vegetation cover (Seid, 2016).

2.4 Feeding livestock in the drylands

Pastoralism is the major livestock production system majorly practiced in the drylands, nomadic, transhumance and agro-pastoralism. This are the type of pastoralism found in the dryland, mimics the practice that of wildlife. It involves the movement of livestock from one place to the other by grazing. Pastoralism is recognized as the sustainable management of the land. (Hartmann, 2010). It is an extensive livestock production system it requires a large tract of land. Pastoral production utilizes 25% of the world's entire land. It supports over 20 million households and 10% of meat produced in the world comes from the drylands (Blench, 2005). In Africa pastoralism is practiced from West Africa to the horn of Africa and East Africa, nomadic pastoralism supports 280 million people in Africa. It makes a lot of contribution to the economy of drylands and beyond it can convert scarce resources in the drylands to meat, milk, and other animal products which are very important in food security. (FAO, 2018). The annual meat consumption in Kenya is 553,200, 28 % (154,968 tonnes) of the total meat consumed comes from pastoral despite this contribution pastoralism has not been well appreciated. (Amwata, 2019).

One-third of households in pastoral communities are faced with inadequate feed. The dry season comes with a lot of challenges such as reduced general performance of livestock, increased susceptibility to diseases, and reduction of palatable forage species, reduced palatability of forage, increased trekking for the search of water and pasture. Livestock are sold at a loss and increased cost of production such as buying a bale of grass. There are some strategies if done well the challenges of the dry season could be addressed this includes the utilization of crop residues. Agro-industrial by-products, cultivated fodder crops, utilization of fodder plants, improvement of pastures through irrigation, fertilization and manure application. Dry season feeding poses a great challenge in livestock production for products such as milk, meat, hide, and skins and the by-products such as manure (Salem, 2006; Lamidi, 2014). Agro-pastoralist is not affected by the drought. But they are reactive in intensifying exploitation of resources and the commons which are scarce in the drylands. The agro-pastoralists use crop residue to feed their livestock. To reduce the impact of feed shortage pastoralists have come by desired adaptive capacity. Interventions such as saving, improvement of extension services, and improved infrastructure. The savings are used to buy feeds during the drought (Poggi, 2004).

Drought proceeds with rainfall, during the onset of the wet season grass sprouts early and quickly. This is the critical time for the livestock to quickly begin feeding on a more nutritious diet, also herders look for leguminous herbs which grow faster with little rainfall. (Krätli, 2010).

2.5 Status of livestock feed, forage availability and productivity in Kenya

The feed availability and quality in Kenya depend on season, there is a need to store feeds to be used during the dry season (Lanyasunya, 2006). Cattle require a consistent source of protein, energy, minerals, vitamins, and water to maintain productivity and health (Kubkomawa, 2015). The demand for feed in Kenya has been on a constant rise in the past this is due to increased livestock. The main sources of feed are roughages, concentrates, vitamins, protein, and minerals. The raw materials come from legumes, cereals, fish meals, and seed cakes. The annual demand for livestock feeds in Kenya is 30 million Metric tonnes in 2019 compared to 10 million MTs in 2016. Supplements needed are over 1 MT. The installed feed program produces 1 million MT. There are many challenges in establishing feeds for the livestock including lack of raw materials and erratic rainfall patterns experienced in the country (ROK, 2019).

Rainfall in the drylands is erratic and unpredictable this affects the growth of pasture and forage in pastoral land, pastoralist and farmers have made real-time adjustments to their strategies concerning forage variability (Krätli, 2010). Therefore, there is a need for storage of hay and other forages to be used in the dry season is a very important strategy; due to the variability of rainfall in the drylands of Kenya irrigation of pasture is necessary to increase productivity to curb feed shortage in the country (Kipngetich, 2016). Most pastoralists are faced with meeting the livestock feeds in terms of forage this challenge have been increased by climate variability. Rainfall pattern is correlated with the amount of forage produced months with high rainfall have a high amount of forage. The time of stay by a livestock keeper in an area, frequency of grazing, the presence of governing rules, and knowledge of pasture location, restricted movement, and presence of conflict are the perceived drivers of forage availability (Eguru, 2015).

Fodder and forage production is very important in pastoral and agro-pastoral communities of Kenya. This is through the sale of seeds and baled hay this will not only earn income for the farmers but also it will increase fodder availability in the country. The issue of drought will be addressed if the feeds are stored well. (Omollo, 2017).

Fodder production especially the Napier grass (*Pennisetum purpureum*) grown on a small scale in contour strips acts both as a fodder source as well as a biological barrier to soil erosion. Therefore, there is a need to broaden the choice of fodder crops on such farms to provide a wide range of harvesting management options and to avoid total loss in case of pest or disease outbreaks. Intercropping Napier grass with leguminous fodder trees could boost the quantity and quality of herbage production, especially during the dry season (Nyaata, 2000).

CHAPTER THREE

Perception of pastoral communities on land cover changes, land degradation and rehabilitation in Wenje, Tana River County

Abstract

Land degradation is a major concern globally, leading to the loss of biological and economic productivity of the land. It has negatively impacted the community's livelihood, food security, and peace due to the diminishing pastures and water. Community perceptions are important in combating degradation. However, they are not always clearly elucidated. In this study community knowledge and perceptions on land cover changes, land degradation, and rehabilitation were evaluated to help come up with solutions to land degradation. Semi-structural questionnaires were used by conducting in the household interviews. The number of the household interviews was 180 out of 2946 households. Data collection were done using an Online Data Kit (ODK) on the KMACHO® application.

The main effect of land degradation indicated by the communities was reduced livestock feed (38.3%). The community has indicated that land degradation could be solved by reseeding the land with the following four types of grass species which are more adapted to the study area. *Cynodon dactylon, Echinochloa haploclada, Panicum maximum* and *Cyprus rotundus*. The community also indicated their understanding of vegetation cover changes and invasive species distribution. The majority of the respondents (60%) indicated that vegetation cover has decreased by 80%. The key invasive species recorded was *Prosopis juliflora*. Majority of the respondent who indicated Prosopis to be beneficial are (60%), while (20%) indicated that the invasive is harmful. The majority of the respondents indicated that they used the *Prosopis juliflora* for forage (71%), while the most negative effect of *Prosopis juliflora* is pasture encroachment and road blockage (71.79%).

Through land degradation, there is reduced livestock feed, which has caused increased livestock loss. This has really affected the communities that rely greatly on livestock for their livelihood. The community is more concerned about land degradation and they have identified four range grass species proffered for rehabilitation which include *Cynodon dactylon, Echinochloa haploclada, Panicum maximum,* and *Cyprus rotundus,* and they are useful in reducing land degradation for increased livestock production thus improving pastoral livelihood.

Keywords: Land Degradation, Rehabilitation, Land Cover, Invasive Species, Pastoral Communities and Climate Change.

3.1 Introduction

Land degradation is a global concern that requires concern by all nations (Xie, 2020). Land degradation manifests itself through prolonged drought and increased flooding during the rainy seasons (Karienye & Macharia, 2021; Chagas *et al.,* 2021). This has been a major concern in the study area. This has been affecting the livelihood of the communities through the loss of livestock which is the main source of income. According to Food, Agriculture and Environment discussion paper number 14 there is a need to develop an initiative where more food will be produced to address food security (FAO, 2017). As the population grows more pressure is put due on the high demand for food eventually leading to soil fertility depletion and increased soil erosion. Through increased farming activities most of the forests are cleared to pave way for farming. Sustainable land use is necessary this includes the need for conservation agriculture (Scherr, 1996; Jat *et al.,* 2020). Other causes of land degradation include; Climate change, deforestation, and bushfires (Kangalawe, 2011). Cultivation on steep slopes, population pressure, and overgrazing are other causes and drivers of land degradation (Manjoro, 2006). The degraded lands are generally reclaimed by invasive plant species that have various consequences on the communities. This hurts land use, and livestock production and generally affects the livelihood of the community, and indigenous knowledge on planning the use of natural resources (Alkama, 2016: Solomou, 2017). The surface of the earth has been modified by humans and it is mostly increased due to the high demand for land for farming and settlement (Vitousek; 1997; Ellis, 2011).

Local knowledge of land rehabilitation is important because the community directly feels the impact of land degradation affects. Thus, it is recognized that community-based strategies to reduce land degradation stand the best chance of success (Tsozué, 2014). Local communities can identify suitable indigenous grass species for their region (Koech, 2014). *Prosopis juliflora* is an invasive species that was introduced in Tana River County to combat land degradation and provide benefits to humans and animals. (Haverou, 1978; Pasiecznik *et al.*, 2001; Binggeli, 2011). However, its spread became difficult to control and the community's attitude towards it turned negative (Wahome, 2008).

The study was carried out to document the community's knowledge and perception of land cover changes, land degradation, and rehabilitation. Such information is useful in designing community-based strategies for land rehabilitation.

3.2 Materials and methods

3.2.1 Description of the study area

The study was carried out in Wenje, which is situated in Tana River County. The image of the study area is shown in chapter three (Figure 3.1). Tana River County is one of the coastal counties of Kenya. It borders 5 counties, Isiolo to the north, Garissa to the north, Kitui to the west, Lamu to the south east, and Kilifi and the Indian Ocean to the south, the ocean only extends for 76 KM (GOK, 2018). Tana River County is located 02°30'S, 40°20'E. (SMART T.R.C, 2016).

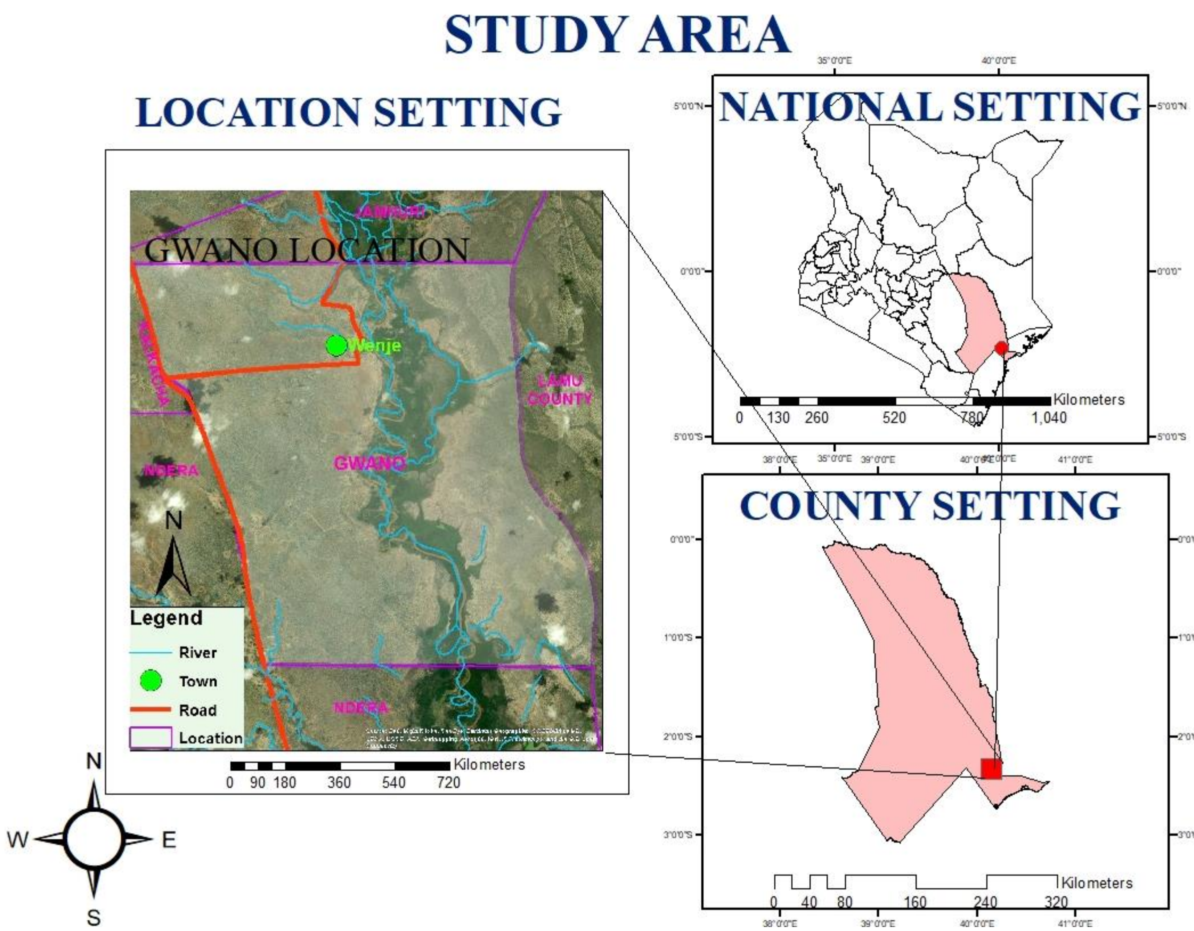

Figure 3.1: A Map of the study area Wenje in relation to Tana River County and Kenya

3.2.1.1 Physiographic and natural conditions

The major physical feature is the underlying plains. Bura administrative area is the highest point in the county. The land is a very important resource it stretches from 0- 200m above sea level. The striking and most important natural resource is the Tana River which provides water for irrigation, watering livestock, and domestic use. It traverses the county it flows from the North (Abadere) to the south (Indian Ocean). It covers 500KMS. Besides the Tana River has other small seasonal rivers that flow from Kitui and Makueni to the Tana River and then to the Indian Ocean, there are shallow wells and subsurface dams all these water sources are important for livestock, wildlife, and irrigation agriculture (GOK, 2018).

3.2.1.2 Climate

Tana River County is one of the ASAL counties in the country with a hot climate. The annual temperature is 30ºC with the highest from January to March and the lowest being 20ºC from June to July. The rainfall is low and erratic the annual rainfall ranges from 280 mm and 900 mm with long rains in April and May, and short rains from October to December. November is the wettest month of the year. The dry climate supports pastoralism (ROK, 2018).

3.2.1.3 Soil

Most soils are shallow depth of 40- 140 cm. there is sandy levees deposited in riverbeds during the rainy season. The soils that are found in the riverside forest are neither saline nor alkaline and they have good permeability and high-water retention capacity (Maingi, 1998).

3.2.1.4 Population

Tana River County has a population of 313,374 as of 2018, 157, 282 being female and 156,092 males. It's expected there will be an increase in population to 344, 595, and 366,595 in 2020 and 2022 respectively which is a 17% increase from 2018. The population increases every year (ROK, 2018). According to the baseline survey of 2019 Wenje had a population of 15,885 people; 7672 males and 8213 females, and the study area had 2946 households.

3.2.1.5 Vegetation

Grassland is a most dominant habitat with different types of grass including *Echinochloa haploclada* with River *Bothriochloa glabra* and *Setaria splendid* being the most common type of grass. These grasses are used majorly by Wardei and the Orma for grazing their livestock.

Bushlands have both grass and woody tree species mostly dominated by species such as *Acacia sp*. The bushlands support both wildlife and livestock. Goats and camels browse on both trees and shrubs. Orma and the Warden use the bush lands as browse for their livestock. Bushlands provides also firewood for the communities.

3.2.1.6 People and livelihoods

There are diverse livestock types found in Tana River County that are kept by the three communities that are Wardei, Orma (pure pastoralists), and the Pokomo (Agro pastoralists). Livestock keeping by these communities is an important source of household food and income. The key livestock products are milk, meat, hides, and skins. The manure is also a source of income. (Givens, 2000; Lutta, 2021).

The people who are deriving their livelihood from pastoralism are 40%. The remaining 60% derive their livelihood from farming, formal employment, and business, communities are Pokomo (Tana North District KIRA Report, 2013).

3.2.2 Data collection

Semi-structural questionnaires were used by conducting in the household interviews. The following equation was used to determine the sample size.

$$N = \frac{z^2pq}{d^2} \text{..} \textit{ Equation 1}$$

N= the required sample size, z= the selected critical value of desired confidence level (at 1.96% confidence level), p= the proportion in the target population estimated to have characteristics being measured; q=1: d= the level of statistical significance set at 5% (standard value of 0.05%). The number of the household interviews was 180 out of 2946 households. Data collection were done by using an Online Data Kit (ODK) on the KMACHO® application. However, there was connectivity challenges subsequent use of a paper questionnaire. All the data was entered later into the KMACHO® database and downloaded into excel data sheets for analysis.

3.2.3 Data analysis

Statistical Package for the Social Science (SPSS) and Microsoft excel was used in analyzing the data. The data were analyzed to show descriptive statistics which include charts, tables and bars generated to show the results to the understanding of the cause, effects of land degradation, and knowledge of land cover changes and the impacts of invasive species on their livelihoods.

3.3 Results and discussion

The majority of the respondent was male (54%), while females (46%), who head the households. Most of the respondents also had Formal education (58%) while 42% had informal education. The age of 41 to 50 was the majority of respondents with (25%) followed by age between 31-40 with 23%, then 21-30 with (23%), followed by the age 51-60 with 17%. The least respondents were of age 60 years and above with (11%). About 39% of the whole population keeps livestock. Those who are pure pastoralist account for (17%) while those who practice both livestock keeping and crop farming (Agro-pastoralist) is (22%). Crop farmers account for (14%) (Table 3.1).

Table 3.1: Socio and demographic characteristics of the respondents

Variable	Respondents (n)	Percent (%)
Household characteristics		
Male respondent	97	54%
Female respondent	83	46%
Age of the respondent		
21-30	41	23%
31-40	43	24%
41-50	45	25%

51-60	31	17%
> 60	20	11%
Education		
Formal education	105	58%
Informal education	75	42%
Economic activities		
Livestock keeping	30	17%
Crop farming	26	14%
Agro- pastoralist	40	22%
Others (Business, employment)	84	47%

The majority of the pure pastoralist is the Wardei and Orma and agro-pastoralist are the Pokomo communities. Agro-pastoralist uses crop residue to feed their livestock during the drought. While pastoralists, during the wet season graze their livestock on the plain but during the drought, the cattle are moved to the rivers mostly the Tana delta especially in the dry months of September to July this is because the rivers contain productive and palatable pastures. The crop producers and the livestock producers interact well, the crop producer sale crop residues such as maize stovers while the livestock keeper sale livestock products such as meat and milk.

3.3.1 Land degradation, rehabilitation and the communities

The increasing land degradation in the area needs to be understood well to be addressed by rehabilitation technology. The respondents who indicated that there was reduced livestock feed were (38.3%). The main effect of land degradation is increased vegetation loss which accounts for (13.3%) and reduced food security and livestock feed at (13.3%), those who indicated all four effects were (28.3%). The four effects have affected the livelihood of the communities. Similar finding by (Waswa, 2012) that land degradation is a threat to both environmental services and the ability of farmers to meet the demand of their food and feed for their livestock.

Table 3.2: How land degradation has affected the communities

Effects of land degradation	Respondent(n)	Percentage (%)
Reduced livestock feeds	69	38.3
Vegetation loss	24	13.3
Reduced food security and reduced livestock feed	24	13.3
Increased poverty level	12	6.7
Other factors	51	28.3
Total	180	100%

Studies were done in Botswana and Zimbabwe (Carr, 2013). Found that there is a direct effect of land degradation on livestock and the people, this is by soil erosion, removal of topsoil which is good for crop and forage production, changes in soil structure affects the underground water. The soils are unable to hold enough water to sustain the vegetation therefore, there is a decrease in palatable species which are nutritious to the livestock, and an increase in unpalatable species which is less nutritious to the livestock. Also, decrease in perennial grasses which is an important source of pasture during the dry season, a decline in secondary productivity of the rangelands with the effect of reduced food for the communities and forage for their livestock, the decline in the welfare of the livestock producers, because increased land degradation will leave the land bare which will make livestock keepers lose their livestock due to lack of feeds, in which pastoralist mostly rely on the sale of their livestock to get income, as a result, this will cause an increase of poverty level. A study by (Eswaran, 2019) found that land degradation is a global issue now that affects the environment, agricultural productivity, reduced food security, and general decline in quality of life. The decline of quality land for production has declined due to increased land degradation.

(Barbier, 2018) found out that land is an important asset owned by households. Land degradation has increased in African countries this has threatened the livelihood of the community.

3.3.2 Community knowledge on land rehabilitation

The main four grass species suggested by the communities for rehabilitation in Wenje *Cynodon dactylon, Echinochloa haploclada, Panicum maximum,* and *Cyprus rotundus*. *Cynodon dactylon* is the most preferred grass species since it is a palatable livestock feed. It has a good ground cover, and also is drought tolerant. *Echinochloa haploclada* and *Panicum maximum* were the second preferred species of the total four species since they were both livestock feed and also have rapid growth rates. *Cyprus rotundus* is just livestock feed. The communities in Wenje were mostly Agro-pastoralist and pastoralists. They prefer grass that has faster growth, was drought resistant, had a good ground cover, and was highly palatable for their livestock.

Table 3.3: Preferred grass species for land rehabilitation as suggested by the community and the reason for selection

Scientific name	Reason for selection			
	Livestock feed	Rapid growth	Good ground cover	Drought tolerant
Cynodon dactylon	*		*	*
Echinochloa haploclada	*	*		
Panicum maximum	*	*		
Cyprus rotundus	*			

Land rehabilitation help in improved livestock productivity and reduction of climate change through the reduction of carbon (iv) oxide in the atmosphere. Studies done by (Mureithi, 2012) found that the use of rangeland enclosures and community-based conservation are increasingly being adopted in pastoral areas. The use of community conservation management and enclosures in Kenya has increased success in restoring degraded rangelands. The use of enclosures involves the erection of fences to prevent wildlife and grazing animals. The same study also found that the use of enclosures increases grass composition and cover since enclosures foster the regeneration of annual and perennial grasses. Also, the community noted that there was a lot of importance in using enclosures to manage pasture and address land degradation, since it allows natural regeneration. Results showed that communal enclosures provide a source of income through the sale of fattened livestock, harvested grass seeds, hay, honey, and charcoal. Indirect products like milk, blood, and meat are essential for household nutrition. The grasses also provide a cheap source of thatching materials, livestock feed, and dry season grazing. Other minor enclosure products include wood, roots, and herbs for various remedies. Increased soil and biomass carbon storage could come with other indirect environmental benefits including increases in soil fertility, land productivity for pasture production and food security, and prevention of land degradation, thus leading to economic, environmental, and social benefits for the local agro-pastoralist communities. The use of enclosures in the study area will also increase the success of rehabilitation.

Another way of ensuring success in rangeland rehabilitation, especially in areas like Tana River which experience low and highly variable rainfall is through implementation programs such as elaborate irrigation systems this possible because Tana River traverses the region and abundant water is available during all seasons. Irrigation boosts the productivity of the grass through increased length and densities. Indigenous grass that is capable of surviving in harsh conditions should be introduced to the study area, these grass species can be selected by the communities (Koech, 2014).

According to studies done by (Mganga, 2015), the communities must be involved to determine the cause of land degradation, most communities have acceded that land degradation is attributed to the low amount of rainfall, unsustainable fuelwood production, and overgrazing. Other studies have confirmed that climate change such as recurrent drought is a major contributor to land degradation. Sustainable Land Management (SLM) practices such as reseeding, rainwater harvesting, soil conservation, and dryland agroforestry are a holistic way of combating land degradation and improving the livelihood of local communities. The highest percentage of the communities agreed that the most cause of failure in land rehabilitation is low rainfall in the rehabilitation areas. Community memory is an important explanation regarding the ability of a community to manage and cope with land degradation. Loss of community memory and the learning pathway associated with land degradation has been constrain for stakeholders in responding to land degradation (Wilson, 2017). The study relied on community memory and knowledge of land rehabilitation.

3.3.3 Community Knowledge on Vegetation cover changes

The table below shows respondents' knowledge of the change in vegetation covers in Wenje. Those who indicated that the vegetation had decreased by 80% were (60%), and those who indicated that vegetation cover has increased by 50% and 20% were (20%) respectively, the land had lost its ability to sustain livestock production due to drought, this has made them believed that most of the vegetation has been lost.

Table 3.4: Response on decrease in vegetation covers over the past years

Percent in reduced Vegetation cover (%)	Respondent (n)	Percent (%)
80%	108	60%
50%	36	20%
20%	36	20%
Total	180	100%

Livestock grazing has contributed to altering the vegetation composition and cover (Cubley, 2022). Overgrazing is the main cause of reduced vegetation cover and increased unpalatable pastures in the ASALS, reduced vegetation has affected the livelihood of the communities who depend on livestock for their livelihood (Podwejewski, 2002; Hao 2018). This has caused increased land degradation and soil erosion which is attributed to unsustainable land use (Kohli, 2021).

Traditional knowledge is very important in the protection of vegetation composition, abundance, and cover in the rangelands (Seid, 2016). The communities are aware that the vegetation cover is declining and they know well that reduced vegetation cover has negatively impacted the quantity and quality of forages. There has been a need to establish grass and planting fodder this will not only improve vegetation cover but also improve livestock production. This can be achieved by the use of reseeding technology and rangeland agroforest. Planting forage trees will not only help in mitigating climate change, and increase vegetation cover but also improved livestock production, protect the land from soil erosion, and reduced drought and floods.

3.3.4 Knowledge of the communities on invasive species

Bulla is the village which is highly affected by *Prosopis juliflora* with (80%), Wenje (6%), Kipendi (5%), Hara (5%) Maroni and Vukoni indicated (2%) each. The number of respondents who indicated invasive species in their land is (4%). Makere village did not indicate any invasive species.

Table 3.5: Distribution of invasive species per villages in Wenje, Tana River County

Village	Respondent (n)	Respondent(%)
Bulla	144	80%
Wenje	10	6%
Hara	9	5%
Kipendi	9	5%
Maroni	4	2%
Vukoni	4	2%
Total	180	100%

According to (Maundu, 2009). *Prosopis juliflora* is a fast-growing tree. Its pods can be used as livestock feed. When the livestock eats the pods, the seeds are easily passed through the gut and dropped to the ground which lie dormant for long till favorable weather for them to germinate.

Due to its superior adaptations, characteristics to climate variability, deep tap roots, tolerance to aridity, and massive seed production *Prosopis juliflora* is taking over the grazing land and farmlands (Pasiecznik *et al.*, 2001). *Prosopis juliflora* is hard to eradicate, first spreading tree, the tree quickly replaces the natural vegetation which is very important in feeding the livestock.

3.3.5 Impacts of invasive species to the communities

The respondents who indicated that the invasive species has encroached on their pasture, blocked roads (71%), homestead encroachment and injuries are (21%) and blockage of roads and injuries is (8%).

Similar studies by (Maundu, 2009) found that *Prosopis juliflora* has aggressiveness that has affected livelihood and biodiversity through encroaching paths, homestead, irrigation schemes, cropland, and pastureland significantly affecting biological diversity and community livelihood.

Table 3.6: Negative impacts of Invasive species on the community

Reason stated	Respondent (n)	Respondent percent
Pasture encroachment and road blockage	128	71.30%
Home encroachment and injuries	38	21.01%
Road blockage and encroachment to farms	14	7.69%
Total	180	100%

A study done by (Van der maarel, 2012) in Netherland found that invasive species become dominant in the new environment and are known to transform the landscape. The major effect known is affecting the livelihood of the local native community. The species invade the area and it is hard to eradicate, the community is very important in the assessing the ecological and the voluntary process of the vegetation also, addressing the problems associated with vegetation change.

3.3.6 Positive impacts of invasive species

Despite the negative impacts of the invasive species, it has also positive impacts. The respondents indicated beneficial benefits, about (71%) indicated that they used the *Prosopis juliflora* for forage, medicine (14%), used for food (4%) while as medicine is (4%) and for other uses (4%).

Table 3.7: Local community knowledge on land covers effect – Segregated positive effect of invasive species on livelihood

Reason	Respondent (n)	Respondent percent
Forage	128	71%
Firewood/ timber	25	14%
Food	7	4%
Medicine	7	4%
Others	13	7%
Total	180	100%

Prosopis juliflora pods are used for feeding livestock as shown in (Table 3.7). It is a good source of protein and good nutrients, the pods were sold by the local communities thus, promoting income and providing employment to the locals. The pods can be dried and stored to be used during the dry season.

There were those who like the *Prosopis juliflora* despite this negative perspective the species can provide much-needed resources for the poor household. The popularity of the *Prosopis juliflora* is the income for those who cannot afford cooking gas because it's a source of fuel and fodder for their livestock (Pasiecznik, 2001). To understand the effects of *Prosopis juliflora* on other plant species it is important to understand the biomass production, density, and nutrient intake from the soil (Rotich, 2016).

The grass is the most preferred plant species with (62%). Shrubs are partially preferred with (24%) while trees are last with (14%). All categories of plants play a critical role in livestock production in Wenje.

Table 3.8: Most prefered forage for livestock

Prefered feed for livestock	Respondent (n)	Respondent percent
Grass	112	62%
Trees	43	24%
Shrubs	25	14%
Total	180	100%

Both agro-pastoralist and pure pastoralism preferred the use of grass for their livestock. The type of livestock species that are kept determined the type of vegetation that will be preferred by the livestock keepers, trees and shrubs fodder have a great value in extensive livestock production in arid and semi-arid lands, especially for the small ruminants goats, and sheep mostly these fodder trees were also used as a supplement for the large ruminants such as cattle, donkey, and camels. Acacia species is widely used (Lefroy, 1992). Those who indicated that they use both improved forage and natural forage are only 13%. While those who use only natural forage are 87%.

Drought has a substantial effect on livestock feed and resources this has threatened the livelihood security of the pastoral communities who rely on livestock for their income (Angassa, 2012). The study found that grass, trees, and shrubs have a great contribution to livestock production.

3.4 Conclusion and recommendation

Through land degradation, there is reduced livestock feed, which has caused increased livestock loss. This has really affected the communities that rely greatly on livestock for their livelihood. The community is more concerned about land degradation and they have identified the four range grass species which include *Cynodon dactylon, Echinochloa haploclada, Panicum maximum,* and *Cyprus rotundus* as it helps in reducing land degradation and increase livestock production thus improving pastoral livelihood. *Prosopis juliflora is* an invasive species in the area, apart from negative impacts the communities were also able to identify positive uses of the species. The major use recorded was feeding the pods to livestock.

The study recommends the effective use of *Prosopis juliflora* for fuel, feeding livestock, and timber to prevent further spread to other areas and to benefit the communities.

Acknowledgement

The funding of this research was provided by Tana River Beef Project (TARIBE). They made the research possible.

CHAPTER FOUR

An analysis of Land Use and Land Cover Changes in Wenje, Tana River County

Abstract

Land degradation is linked to increased climate change, food insecurity, and reduced livestock feed which impacts the community's livelihood. The study was done to determine the land cover changes and identify areas that were severely degraded. Change detection by use of multi-temporal Landsat images of 2003, 2010, and 2017 was used to determine the land cover changes in Wenje, Tana River County. Images were downloaded from the United States Geological Survey (USGS) earth explorer. The images of path 166 and row 61 were sub-set to extract the Area of Interest (AOI). Supervised classification methodology was done using maximum likelihood in ArcGIS 10.7 to show six classes namely Water, Mango plantation, built-up areas, Grassland, Forest, and Built-up areas. The results from the analysis indicated changes with bare land increasing by (41.16%), the forest had declined by (25.40%). Grassland had decreased by (24.27%). Mango plantations increased by (6.80%). Built-up areas increased by (2.05%) and Water bodies decreased by (0.32%).

The study indicated land use and land cover changes. Mapping of degraded land using satellite images will contribute to the timely and targeted response to rangeland rehabilitation using local grass species this will help in improving livestock production and reducing climate change. To avoid overgrazing, sustainable land use is desired for improved livestock production.

Keywords: Remote sensing, GIS, Land Cover, Tana River County and Landsat Images.

4.1 Introduction

Among the drivers for land cover changes are increasing populations, poverty, logging, and forest fires (Lumbin, 2001). In developing countries shifting cultivation is the predominant practice by farmers who use fire to clear forests and bushes to increase land for cultivation (Allen, 1985; Kim, 2015; Veldkamp, 2020). The burning factor has the effect of turning Forest into agricultural land and pasture land causing reduced forest cover and increased fragmentation of the landscape. (Ampofo, 2015).

Studies by (Langat, 2019) show declining forest cover in Tana River as crop farming spread into semi-arid and arid areas and human activities. Such as the construction of upstream dams, regulated flooding, and expanded irrigation projects. Forest has an important role at the banks of the Tana River in reducing soil erosion and purifying water, but these services were less evident and effective (Glenday, 2005) According to Tana River County (TRC) Pokomo community grows crops along the river while the Wardei keep livestock along the river and in arid and semi-arid land. They also practice shifting cultivation this has cause clearing of trees to pave way for agriculture also overgrazing has increased land degradation. These communities play a greater role in the conservation of natural resources (Terer, 2004).

There are many studies done on the assessment of vegetation cover using satellite images (JD Tagestad, 2010; Ampofo, 2015; Rawat, 2015; Thenya, 2017). Multi-temporal satellite images have been used elsewhere to generate digital change detection tables that help in the understanding of land cover changes. The present study used the technique to assess the land use and cover changes in Wenje area of Tana River County to provide information on strategies and measures for sustainable land management and land use planning.

4.2 Materials and methods

4.2.1 Description of the study area

The study was carried out in Wenje, which is situated in Tana River County. The image of the study area is shown in chapter three (Figure 3.1). Tana River County is one of the coastal counties of Kenya. It borders 5 counties, Isiolo to the north, Garissa to the north, Kitui to the west, Lamu to the south east, and Kilifi and the Indian Ocean to the south, the ocean only extends for 76 KM (GOK, 2018). Tana River County is located 02°30'S, 40°20'E. (SMART T.R.C, 2016).

4.2.1.1 Climate

Tana River County is one of the ASAL counties in the country with a hot climate. The annual temperature is 30ºC with the highest from January to March and the lowest being 20ºC from June to July. The rainfall is low and erratic the annual rainfall ranges from 280 mm and 900 mm with long rains in April and May, and short rains from October to December. November is the wettest month of the year. The dry climate supports pastoralism (ROK, 2018).

4.2.1.2 Soil

Most soils are shallow depth of 40- 140 cm. there is sandy levees deposited in riverbeds during the rainy season. The soils that are found in the riverside forest are neither saline nor alkaline and they have good permeability and high-water retention capacity (Maingi, 1998).

4.2.1.3 Vegetation

Grassland is a most dominant habitat with different types of grass including *Echinochloa haploclada* with River *Bothriochloa glabra* and *Setaria splendid* being the most common type of grass. These grasses are used majorly by Wardei and the Orma for grazing their livestock. Bushlands have both grass and woody tree species mostly dominated by species such as *Acacia sp*. The bushlands support both wildlife and livestock. Goats and camels browse on both trees and shrubs. Orma and the Warden use the bush lands as browse for their livestock. Bushlands provides also firewood for the communities.

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There are diverse livestock types found in Tana River County that are kept by the three communities that are Wardei, Orma (pure pastoralists), and the Pokomo (Agro pastoralists). Livestock keeping by these communities is an important source of household food and income. The key livestock products are milk, meat, hides, and skins. The manure is also a source of income. (Givens 2000; Lutta, 2021).

The people who are deriving their livelihood from pastoralism are 40%. The remaining 60% derive their livelihood from farming, formal employment, and business, communities are Pokomo (Tana North District KIRA Report, 2013).

4.2.2 Data Collection

4.2.2.1 Availability Data for analysis

Several multi-temporal satellite imageries were used in the study. Landsat images of the years 2003, 2010, and 2017 with different sensors and resolutions were downloaded from the United States Geological Survey (USGS) earth explorer of path 166 and row 61. Landsat images (2003, 2010, and 2017) were used with the band 1-2-3 (Red, Green, and Blue) respectively. The images downloaded were free from the cloud cover. Supervised classification was done to show five land cover types 1. Water 2. Mango plantation 3. Built-up areas 4. Grassland 5. Forest.

Forest includes a river line forest, forest reserve, and patch of the forest. Grasslands are areas with grasses and few trees. Mango plantations are areas with mango trees. Bare ground is the exposed land surface, rocks, and cultivated areas. Built-up areas are settlements, livestock bomas, and buildings as indicated in (Table 4.2). The images are being downloaded from USGS for free

(Rawat, 2015). Interpretation of the images is used to map the past and the future land cover changes after interpretation (Mertens, 2000). The images acquired were downloaded on different dates as indicated in the table below.

Table 4.1. Data set and characteristics

Image date of acquisition		Type of sensor	Season during time of acquisition
1.	16/12/2003	Landsat 7	Dry season
2.	01/01/2010	Landsat 8	Dry season
3.	12/01/2017	Landsat 8	Dry season

4.2.2 Sub setting of the images

Independent Electoral and Boundaries commission (IEBC) Gwano location boundary polygon was used in the sub-setting study area image from the entire Landsat images of path 166 and row 61 by taking out geo-referenced line in ArcGIS tool (ArcToolBox) under Extraction by mask was used in processing the images. Sub-setting was necessary for better classification (Jain, 1997).

4.2.3 Data analysis

4.2.3.1 NDVI analysis

The images were imported to ArcGIS 10.7 software for Analysis. ArcToolbox was launched then map algebra to calculate the raster images, NDVI was calculated using the following formula.

NDVI= (NIR-RED)/NIR+RED……………………………………………Equation (i)

Where NIR and RED are the amounts of near-infrared and red light respectively.

The formula is based on the chlorophyll that is absorbed in RED whereas the mesophyll leaf structure scatters NIR. Normalized Difference Vegetation Index (NDVI) analysis was performed on 3 images of the years 2003, 2010, and year 2017. A high index value indicates high vegetation cover or healthy vegetation while a low index value indicates low vegetation cover or unhealthy vegetation.

4.2.3.2 Supervised classification and change detection

Six classes were used in classification this includes: - Water, Mango plantation, built-up areas, Grassland, Forest, and Built-up areas. MLC algorithm through identification of features and training areas was used in classification. Training samples of between 70 to 150 were used in each land cover class.

Descriptive information was used to show change, and post comparison technique for detection was applied to independently compare the classified land cover maps of the years 2003, 2010, and 2017. Classification and analysis were done using ArcGis 10.7. An accuracy assessment of the images was used to determine the accuracy of the analysis for the three images. The summary is shown in (Figure 4.5).

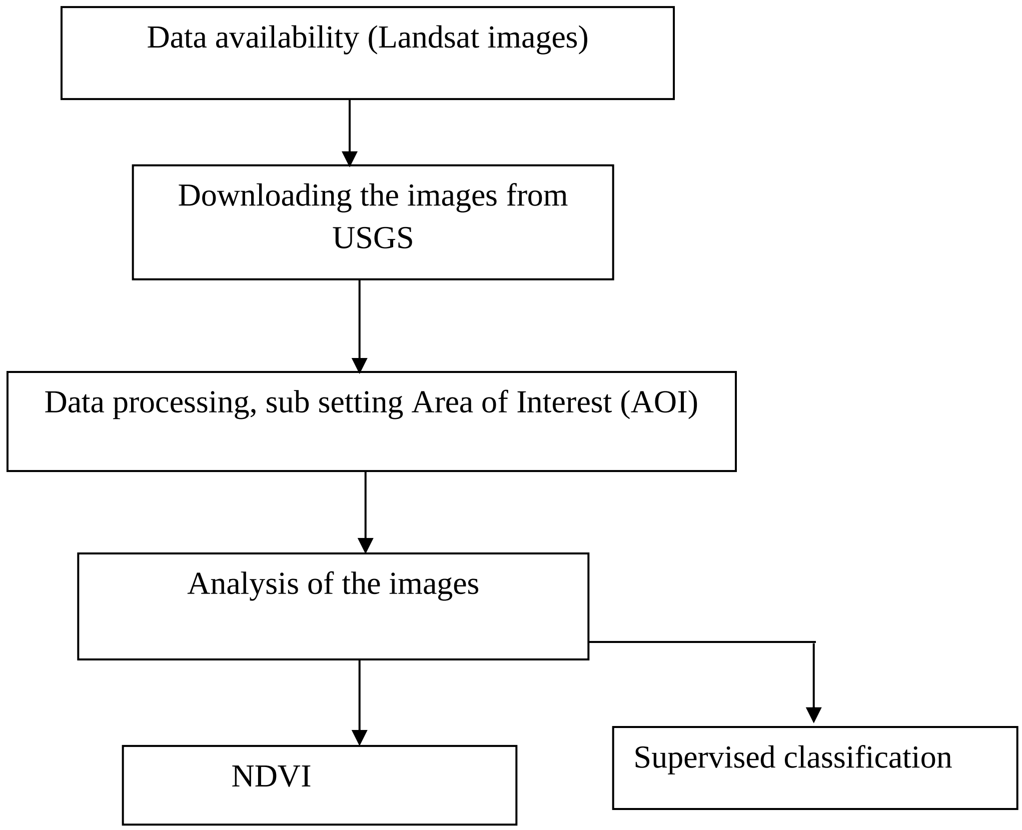

Figure 4.1: Summary of availability and analysis of data

Table 4.2: Land cover classification scheme used in the study area

Land cover type		**Description**
1	Forest Vegetation	River line forest, forest reserve and patch of the forest
2	Water	Dams, rivers and wetlands
3	Grassland	Areas covered with grass and trees
4	Built up areas	Settlement, buildings and livestock bomas
5	Bare Land	Exposed are with no vegetation cover, areas covered by rocks
6	Mango plantation	Mango trees

4.3 Results

The results obtained through the analysis of the images are illustrated in (Figure 4.2, 4.3), and (Table 4.4). It was determined that the period from 2003 to 2017 witnessed a drastic change in land cover. The findings also show water bodies were 481.32 hectares in 2003, which is (2.33%) of the land, in 2010, which has declined to 276.75 hectares accounting for (1.33%) of the land. In the year 2017, and further declined to 219.24 hectares covering (1.06%) of the land. Mango plantation covered 2,076.18 hectares of land. In 2003 accounting for (10.05%) of the land, while in the year 2010 the mango plantation increased to 2112.75 hectares which covered (10.22%) of the land, further increase in the year 2017 to 3284.64 representing (15.88%) of the land.

Bare land in 2003 was 1696.95 hectares covering (8.21%) of the land, in the year 2010 the bare land increased to 1995.75 hectares translating to (9.65%) of the land, and in the year 2017, the bare land had increased drastically to 9090.18 hectares covering (43.95%) of the land. Built-up areas in 2003 were 3760 of the land representing 18.18% of the land, which increased to 4837.23 in 2010 covering (23.39%) further expanding in the year 2017 to 5189.85 covering (25.09%) of the land. The area under grassland in the year 2003 was 8154.18 accounting for (39.43%) of the land, grassland declined in the year 2010 to 6524.73 covering (31.55%) of the land.

In the year 2017 grassland declined drastically to 2341.26 a percent of (11.32%) of the land. Forest vegetation in the year 2003 was 4509.72 hectares representing (21.81%) of the land. In the year 2010, the forest had increased to 4934.25 hectares a percent of (23.86%) while, in the year 2017 the forest had declined to 556.29 translates to (2.69%) of the land cover.

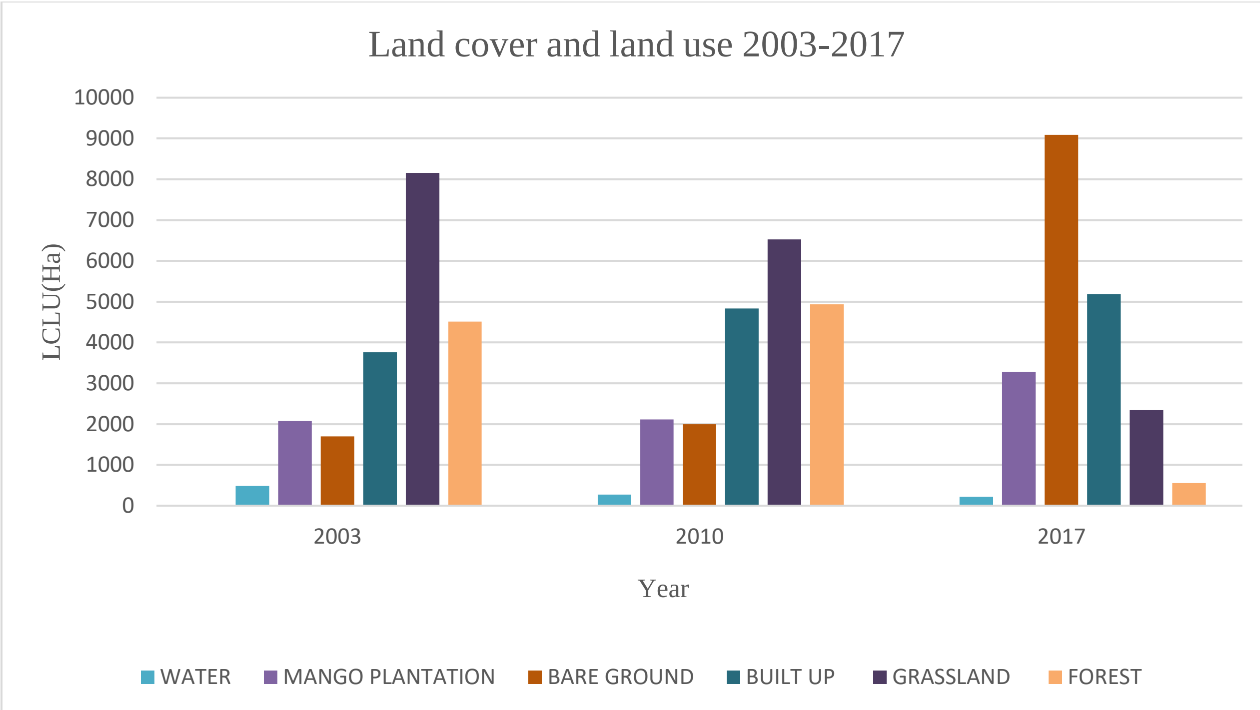

Figure 4.2: Land cover and land use in Ha

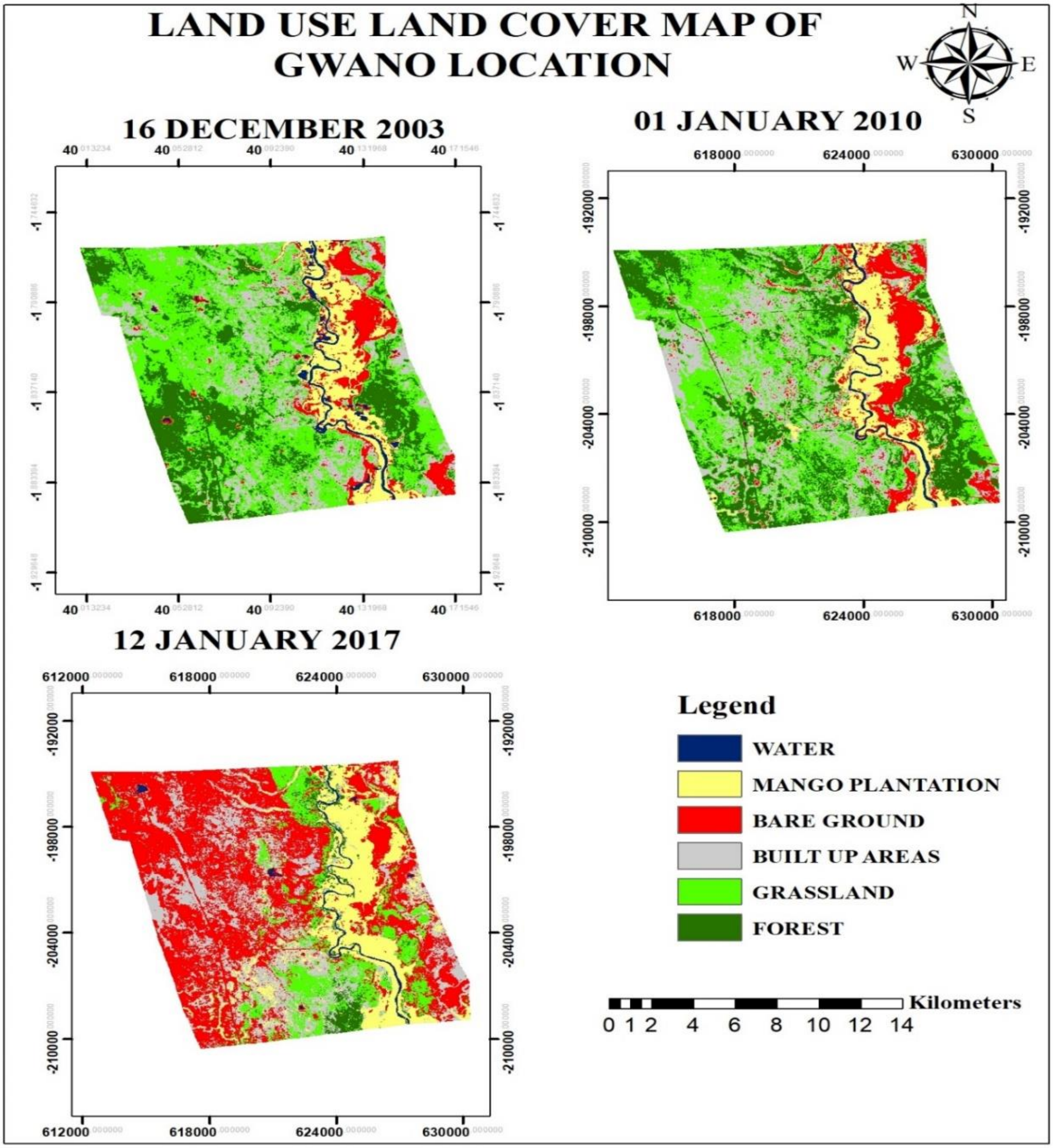

Figure 4.3: Land cover changes for the year 2003, 2010 and 2017

Table 4.3: Area and percentage change of land use land cover in Gwano location

	2003	2003	2010	2010	2017	2017
CLASSES	Area in Ha	% Area	Area in Ha	% Area	Area in Ha	% Area
WATER	481.32	2.33	276.75	1.34	219.24	1.06
MANGO PLANTATION	2,079.18	10.05	2,112.75	10.22	3,284.64	15.88
BARE GROUND	1,696.95	8.21	1,995.75	9.65	9,090.18	43.95
BUILT UP	3,760.11	18.18	4,837.23	23.39	5,189.85	25.09
GRASSLAND	8,154.18	39.43	6,524.73	31.55	2,341.26	11.32
FOREST	4,509.72	21.81	4934.25	23.86	556.29	2.69
TOTAL AREA	20681.46	100	20681.46	100	20681.46	100

4.3.1 NDVI analysis showing how vegetation cover has change over a period of 20 years in Gwano location, Tana River County

According to the NDVI value most of the area had healthy vegetation that is a value of 0.86. There are degraded lands which is represented by low NDVI index value of 0.26.

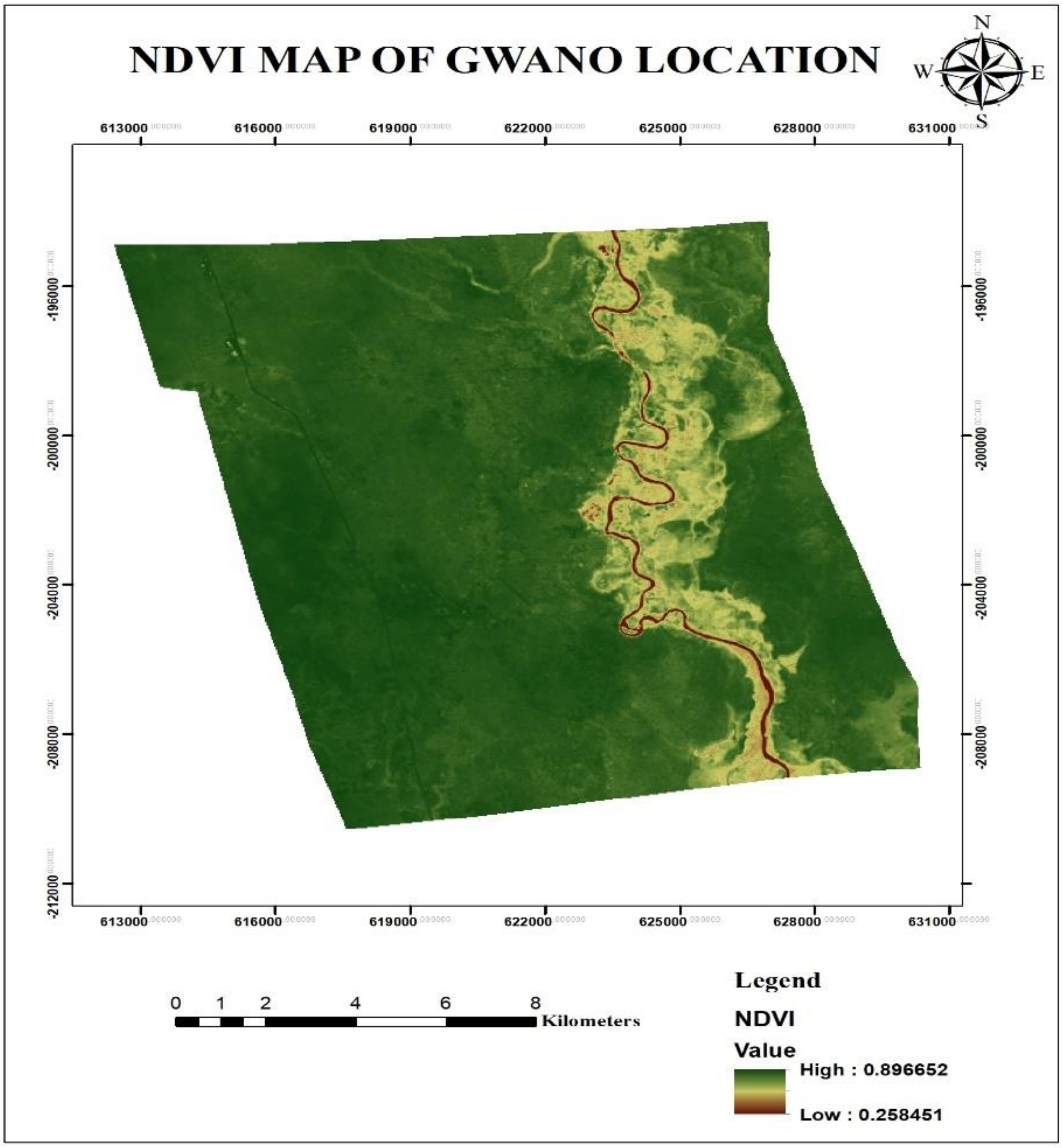

Figure 4.4: NDVI for the year 2003

NDVI value ranges between -0.84 to 1.37. There has been healthy vegetation but there are areas with as low as 0.1, which indicated low vegetation cover. The health vegetation has declined compared to the year 2003.

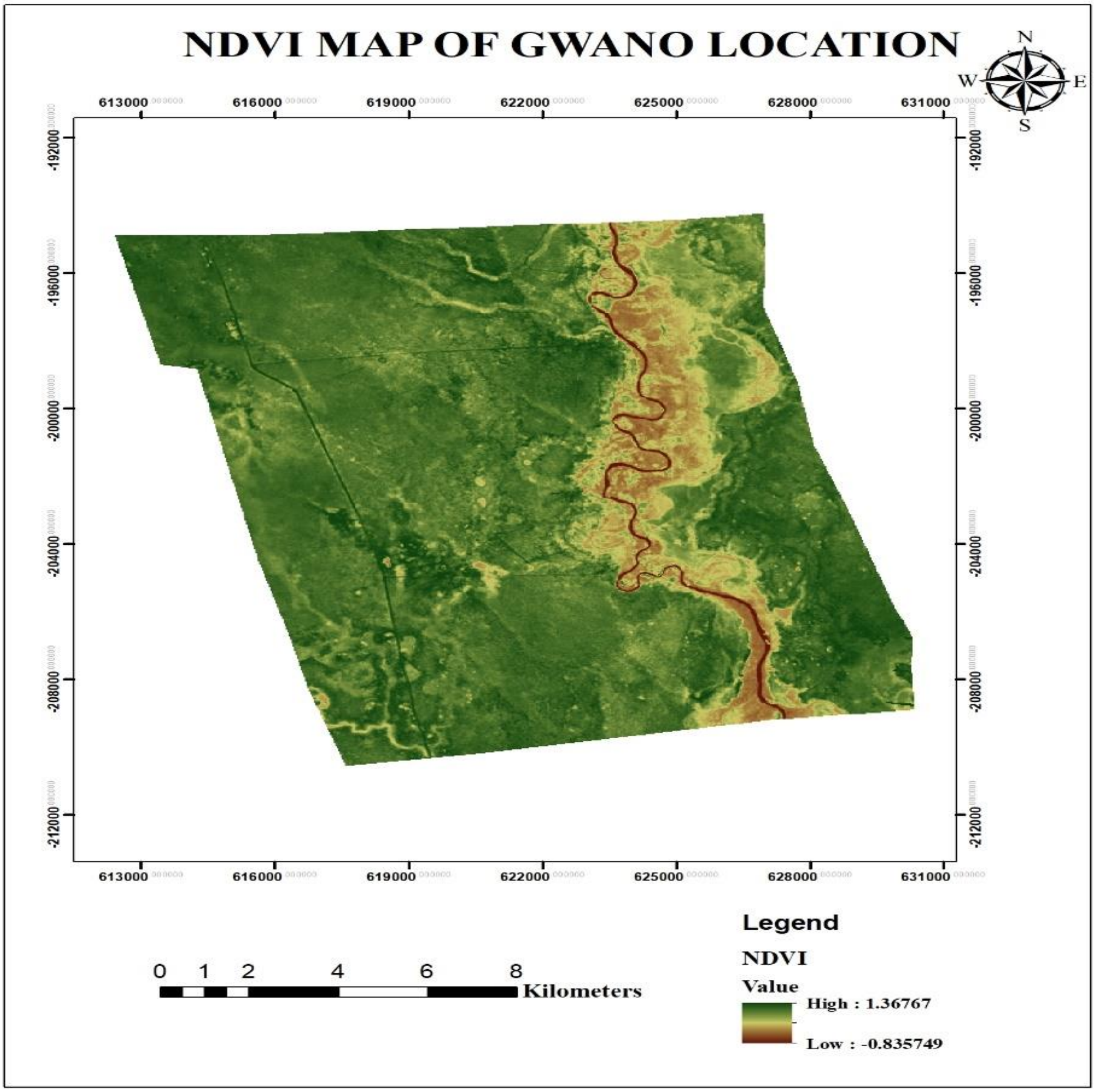

Figure 4.5: NDVI for the year 2010

NDVI at the year this year ranges from -0.14 and 0.82. The vegetation cover in 2017 has decreased compared to the year 2003 and 2010. In the year 2017 land degradation has been witnessed.

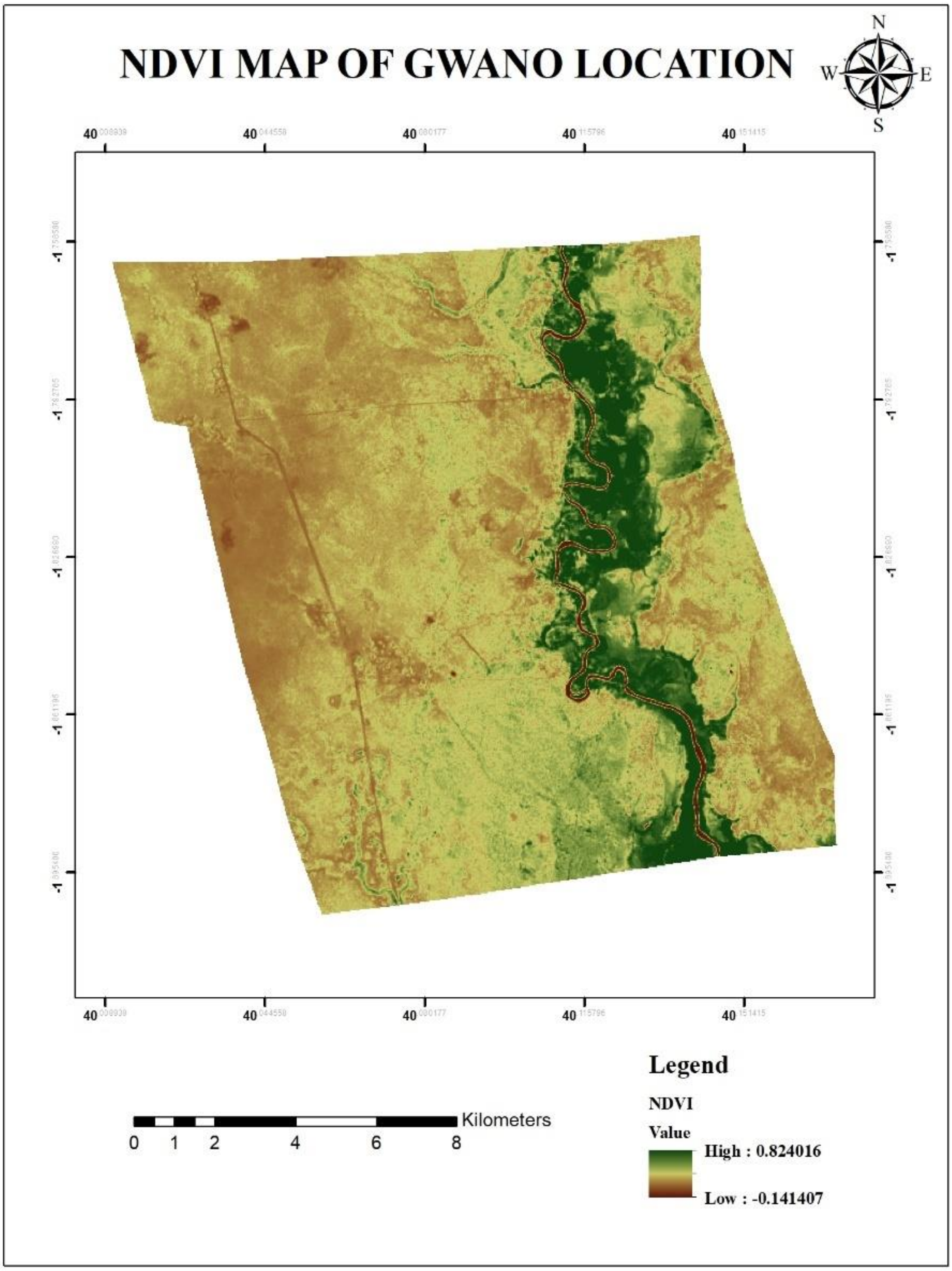

Figure 4.6: NDVI for the year 2017

4.4 Discussion

Grassland is key in livestock production (Lüscher, 2014) although, in the study area it has been converted to built-up areas and bare ground percent change is (8.21%) in 2003 to (43.97%) in 2017. Grassland also can reduce the effects of climate change (Laidlaw, 2013). However, grassland in the study has been declining greatly this has been attributed to overgrazing, increased population, and climate change which manifests itself as drought. Overgrazing that has been witnessed has caused feed shortage and death of animals although, the area has a browse-rich shrub that is edible for goats and camels and grassland which supports the sheep and the cattle. To avoid overgrazing, sustainable land use is desired for improved livestock production in the study area.

The bare ground had increased due to overgrazing and increased drought. Similar studies by (Benoit, 2002; Kipkemboi, 2017) found that overgrazing in the Tana River has led to the destruction of biodiversity and a reduction in vegetation cover. The built-up areas had increased due to the increase in population, marrying more than one wife by the communities in the study area. This has raised further the demand for land for construction, farming, and grazing bare land also had increased. The water level had also declined due to decreased amount of rainfall in the study area and the catchment areas including the Aberdare range (Lagat, 2019), and increased irrigation along the river where crops such as maize, watermelon, onions, rice, vegetables, and tomatoes (Hussain, 2016). While, studies by (Mbora, 2004) found that forests along the river had been fragmented to introduce mango farming and crop farming, this is because there is a big demand for mango fruits and food in Hola town and other towns within the area. Reduced forest vegetation observed in the study is in agreement with trends observed by Langat earlier in studies along Tana River Basin (Langat, 2019).

Forest vegetation has great ecological and economic importance. The forest provides local communities with timber, firewood, medicine, fodder, food (wild fruit), and honey (Krieger, 2001). Forest also has environmental benefit which includes reduction of the concentration of greenhouse gasses in the atmosphere (Hudiburg, 2011) and its habitat for wild animals (Betts, 2019), despite the great contribution of forest in reducing climate change the forest cover has been constantly cleared to pave way for farming, burning of charcoal and to produce timber. There is a need for incentives for the local communities and the county government to restore the forest through afforestation, rehabilitation, and reforestation.

From the image analysis vegetation cover has been declining through logging, increased settlement, increased cultivation, and overgrazing. The land is no longer productive, and quick rehabilitation for degraded land is required.

4.4 Conclusions and recommendations

From the study, it has been identified that multi-temporal satellite imagery plays a vital role on identifying the areas which are highly affected by degradation and also in monitoring vegetation cover. Change detection has been made easy, time is saved, the cost has been reduced and accuracy has been increased in identifying the areas which need quick rehabilitation.

It was found that vegetation cover has been declining, according to NDVI analysis, the health of vegetation has been decreasing. Also, from the findings, the bare land covers a large area an area of about (85%) in the year 2017. This area has little or no vegetation especially reduced grassland which has negative impacts on the land and livestock production. Most livestock has been lost due to lack of forage this has made the pastoralist communities lose their livelihood. Water bodies have decline in the year 2017. Water bodies are important source of water for plants.

Bare lands are prone to soil erosion and reduced productivity caused by land degradation. The highest percentage of the study area is highly degraded in the year 2017, it is expected that land degradation will increase in the future due to increasing climate change and overgrazing. Most of the land cover has been converted to build up areas and mango plantation. The stakeholders and county government should consider rehabilitation of the degraded land by use of indigenous grass species suggested by the communities in chapter six which are well adapted to the area.

Acknowledgement

I am thankful for Tana River Beef Project (TARIBE) for funding the research work. They made the research possible.

CHAPTER FIVE

Analysis of species composition, cover and density for rehabilitation planning in Wenje, Tana River County

Abstract

The natural vegetation in rangelands plays a great role in livestock production in Kenya and the region, however, there has been an increasing loss of important plants due to over-grazing, climate change impacts, and land use changes. This has often left the soils prone to land degradation. To address the vegetation loss, climate change, and degradation challenges, we need to understand the existing vegetation and the threats to their existence for conservation and planning for development. This study was done to assess the vegetation cover and determine the most dominant plant species in the site, using belt- transects, and quadrants. The Shannon Weiner's diversity index (H') was calculated to determine the evenness and diversity of vegetation species in the study area.

The vegetation composition and density were calculated for thirteen (13) sampling points selected in the study area. The points were within the hundred by ten meters (100M×10M) belt transect. Each belt transects had 5 plots placed at 20 meters intervals. Five (5) meters square quadrant was used in collecting data on woody species while, one (1)-meter square quadrant was used to collect data on herbaceous specie vegetation dominancy was estimated using the calculation of vegetation composition.

The five (5) most dominant herbaceous plant species were *Cyprus rotundus* (30.41%), *Cynodon dactylon* (19.38%), *Cucumis pustulatus* (10.65%), *Ruellia patula* (9.55%) *and Corchorus olitorius* (8.78%). While the five (5) most dominant woody species in the study area were *Ricinus communis* (14.05%), *Acacia reficiens* (11.24%), *Cordia goetzii* (10.95%), *Prosopis juliflora* (9.47%) and *Acacia zanzibarica* (8.14%). The values of Shannon Weiner's diversity index (H') were 2.2, 3.0 for herbaceous species and woody species respectively, which indicates high biodiversity. The study area had an average of 20% vegetation cover, which was low. Much of the vegetation had been removed due to over-grazing, leaving the soil prone to land degradation. Most of the dominant species are palatable to livestock, this species is both suitable for livestock feeding and reducing land degradation. Since the study has found out that there is low vegetation cover, land rehabilitation is recommended to improve the ecosystem.

Keywords: Vegetation Composition, Vegetation Cover, Densities, Livestock Production, Communities, Land degradation.

5.1 Introduction

Arid and Semi-arid lands (ASAL) counties, including Tana River County, suffer land degradation because of such natural causes as drought and floods as well as human activities including poor grazing management, vegetation clearing, and over-cultivation (LADA 2016). There is a need for informed planning for rangeland rehabilitation and the use of vegetation types and species that are best suited to specific areas (Maitima *et al.*, 2009). Modern techniques exist to perform such studies (Aly *et al.*, 2016). This study sought to evaluate vegetation species composition, cover, and density in Wenje, Tana River County.

To understand the vegetation attributes, it is important to calculate the density, frequency, and composition of the species. The plots are created and data is collected to represent the entire area (Chytrý, 2003). Vegetation density is the number of individual species per unit area (Launchbaugh, 2009). Vegetation density is known to affect the availability of livestock feed in an area (Poggi, 2004; Monamy, 2004). Vegetation composition is the identity of the plant species comprising the community, vegetation cover is also needed to determine land rehabilitation (Threlfall, 2016).

The study seeks to determine the most dominant species and its contributions to improving livestock production. Also, help in proper land management practices using the results from the study and the condition of the land using land cover. Tana river county encounters challenges of livestock feed scarcity which has led to increased conflicts between the communities for the competition of the scarce resource (Kipkemboi, 2017) with proper grazing management there will be adequate feed and conflicts will be reduced.

There are diverse livestock types found in Tana River County that are kept by the three communities that are Wardei, Orma (pure pastoralists), and the Pokomo (Agro pastoralists). Livestock keeping by these communities is an important source of household food and income. The key livestock products are milk, meat, hides, and skins. The manure is also a source of income. (Givens 2000; Lutta, 2021).

Trees, grass, or forbs are the most important vegetation in rangelands as a source of forage to livestock accessed through direct grazing, or through cutting and carrying (Barnes and Baylor, 1995. In addition, bees also rely on the same plants for the collection of nectar while providing an important ecosystem. The pollination of flowers is an essential process for quality seed development that support regeneration and soil gene bank development (Dukku, 2013).

5.2 Materials and methods

5.2.1 Description of the study area

The study was carried out in Wenje, which is situated in Tana River County. The image of the study area is shown in chapter three (Figure 3.1). Tana River County is one of the coastal counties of Kenya. It borders 5 counties, Isiolo to the north, Garissa to the north, Kitui to the west, Lamu to the south east, and Kilifi and the Indian Ocean to the south, the ocean only extends for 76 KM (GOK, 2018). Tana River County is located 02°30’S, 40°20’E. (SMART T.R.C, 2016).

5.2.1.1 Climate

Tana River County is one of the ASAL counties in the country with a hot climate. The annual temperature is 30ºC with the highest from January to March and the lowest being 20ºC from June to July. The rainfall is low and erratic the annual rainfall ranges from 280 mm and 900 mm with long rains in April and May, and short rains from October to December. November is the wettest month of the year. The dry climate supports pastoralism (ROK, 2018).

5.2.1.2 Soil

Most soils are shallow depth of 40- 140 cm. there is sandy levees deposited in riverbeds during the rainy season. The soils that are found in the riverside forest are neither saline nor alkaline and they have good permeability and high-water retention capacity (Maingi, 1998).

5.2.1.3 Vegetation

Grassland is a most dominant habitat with different types of grass including *Echinochloa haploclada* with River *Bothriochloa glabra* and *Setaria splendid* being the most common type of grass. These grasses are used majorly by Wardei and the Orma for grazing their livestock. Bushlands have both grass and woody tree species mostly dominated by species such as *Acacia sp*. The bushlands support both wildlife and livestock. Goats and camels browse on both trees and shrubs. Orma and the Warden use the bush lands as browse for their livestock. Bushlands provides also firewood for the communities.

5.2.1.4 People and livelihoods

There are diverse livestock types found in Tana River County that are kept by the three communities that are Wardei, Orma (pure pastoralists), and the Pokomo (Agro pastoralists). Livestock keeping by these communities is an important source of household food and income. The key livestock products are milk, meat, hides, and skins. The manure is also a source of income. (Lutta, 2021; Givens 2000).

The people who are deriving their livelihood from pastoralism are 40%. The remaining 60% derive their livelihood from farming, formal employment, and business, communities are Pokomo (Tana North District KIRA Report, 2013).

5.2.2 Data collection

5.2.2.1 Sampling design

Before vegetation field data collection, satellite image was downloaded from google earth for the year 2020 (row 166 and path 61). The image was analyzed to allow for stratified vegetation delineation since the area is quite expansive. Transects were laid systematically in seven villages in the study area, this includes: - Vukoni (B1 and B2), Wenje (B3 and B4), Kipendi (B5 and B6), Maroni (B7 and B8), Makere (B9), Hara (B10 and B11) and Bulla (B12 and B13) as shown in Table 5.5. These plots were within ten by hundred meters (10M×100M) belt transects which were established along plant communities in different ecotypes including river lines, farmlands, and grazing areas. Each belt transects had five (5) plots placed at twenty (20) meters intervals. Five (5) meters square quadrant was used in collecting data for woody species while one (1)-meter square quadrant was used to collect data on herbaceous species. A total of (13) points were selected (Figure 5.1). The parameters measured were density, composition, and cover. Ocular estimates were used to measure the cover in the quadrants along the transects during sampling. This was used because the method is versatile and best suited for measuring both grasses and forbs. It's also a rapid method, faster and reliable. Vegetation is not disturbed during estimation to ensure proper ground cover is recorded. Vegetation species were counted and recorded in a data sheet with unique numbers for each plant species. A plant that could not be identified in the field was collected and preserved using a plant press for further identification at the University of Nairobi herbarium.

Both herbaceous and woody vegetation density, composition, and cover were calculated to determine the most dominant species Shannon Weiner's diversity index (H') was calculate to determine the evenness of species and distribution of the species.

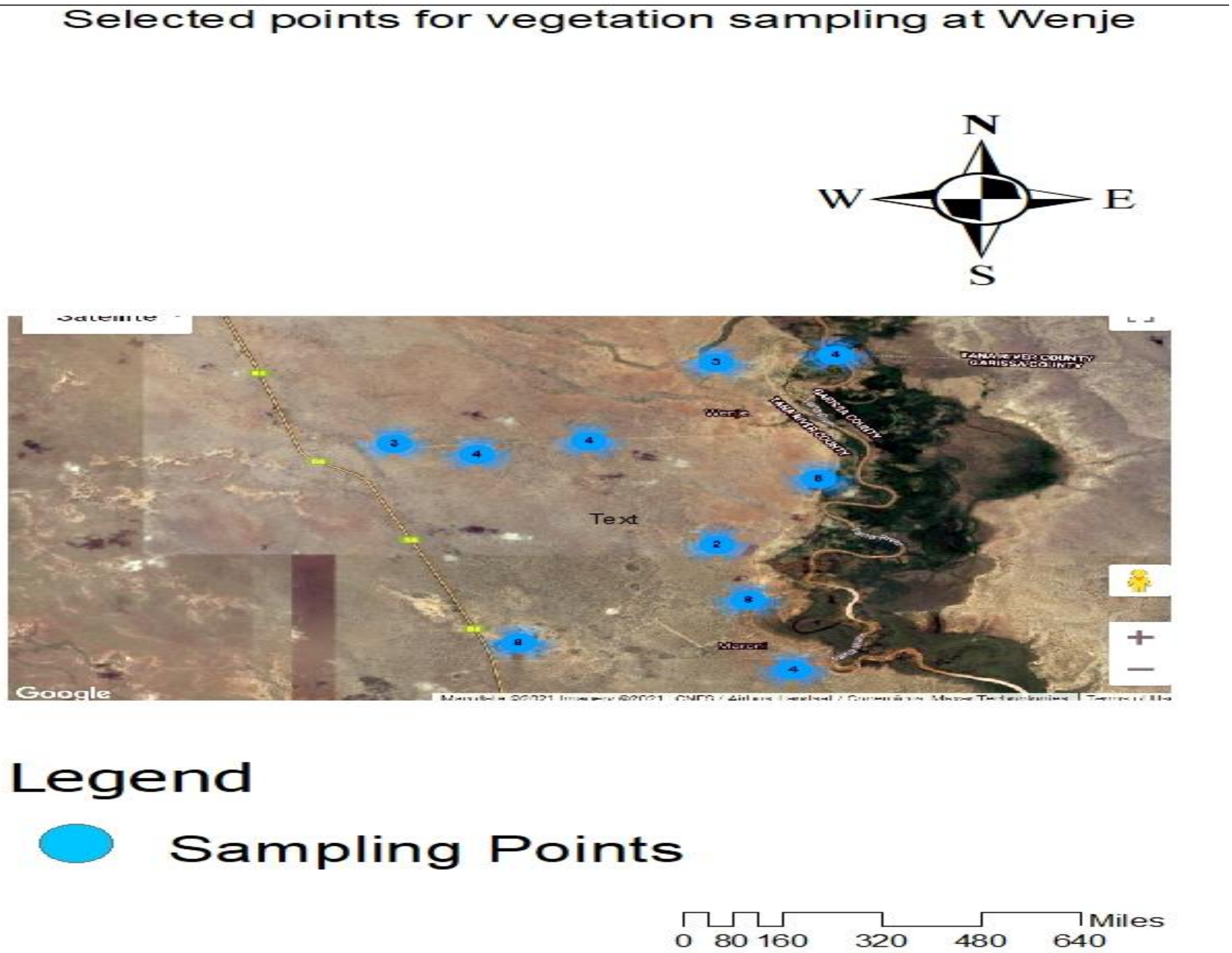

Figure 5.1: Selected points where the data was collected

5.2.3 Data analysis

The ecological data collected was entered into Microsoft excel where analysis was done by calculation of density, cover, composition, and Shannon Weiner's diversity index(H') the formulas were computed to excel. Vegetation cover was analyzed to show descriptive statistics and presented in graphs and mean. The following formulas were used in the analysis: -

Vegetation indices computations

Species composition refers to the contribution of each plant species to the vegetation. Percent composition of the species was determined by calculation of relative density as described by (Krebs, 1989). Using the following formula: -

$$\frac{ni}{N} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots \textbf{Equation (i)}$$

Where *ni* is the number of individual species

N is the total number of individuals.

Shannon Weiner's diversity index (1963) as described by Krebs (1989). The Shannon diversity index tells you how diverse the species in a given community are. This method was used because it can easily be used to determine the equitability (evenness) of species.

Shannon-Weiner's index (H') was determined using the following formula: -

$$H' = -\sum\left[\left(\frac{n_1}{N}\right) \times \ln\left(\frac{n_1}{N}\right)\right] \ldots\ldots\ldots\ldots \textbf{Equation (ii)}$$

Where;

n_1 = number of individuals of each species

N = Total number of individuals (or amount) for the site

Ln = the natural log of the number

In vegetation surveys, richness is expressed as the number of species and is usually called species richness. Evenness of the vegetation was calculated using the following formula: -

$$E = {}^{H'}/_{Hmax} \ldots\ldots\ldots\ldots\ldots\ldots \textbf{Equation (iii)}$$

Where: -

E= Pileous evenness

H= Shannon-Weiner's index

Hmax= ln(s) species diversity under maximum equitability conditions.

Density of the species was determined by the following formula: -

$$\boldsymbol{Density} = \frac{\boldsymbol{Total\ number\ of\ species}}{\boldsymbol{Total\ number\ of\ plots}} \text{...} \textbf{ Equation (iv)}$$

5.3 Results

5.3.1 Species composition and density

5.3.1.1 Herbaceous species

A total of 5971 herbaceous species was recorded. The five (5) most dominant herbaceous plant species were *Cyprus rotundus* (30.41%), *Cynodon dactylon* (19.38%), *Cucumis pustulatus* (10.65%), *Ruellia patula* (9.55%) *and Corchorus olitorius* (8.78%). Which, together account to 78.76% of all herbaceous species as shown in (Table 5.1). The densities for five most dominant species were as follow: - *Cyprus rotundus* (27.93), *Cynodon dactylon* (17.08), *Cucumis pustulatus* (9.78), *Ruellia patula* (8.77) *and Corchorus olitorius* (8.06) per one meter square. The value of Shannon Weiner's diversity index (H') is 2.2 indicating a high biodiversity. There were diverse herbaceous species in the area.

Table 5.1: Vegetation attributes of herbaceous species in the study area

S/N	Species	Total Number	Composition (%)	Densities ($1m^2$)
1	*Cyprus rotundus*	1816	30.41%	27.9385
2	*Cynodon dactylon*	1157	19.38%	17.8000
3	*Cucumis pustulatus*	636	10.65%	9.7846
4	*Ruellia patula*	570	9.55%	8.7692
5	*Corchorus olitorius*	524	8.78%	8.0615
6	*Hibiscus micranthus*	355	5.95%	5.4615
7	*Indigofera arrecta*	213	3.57%	3.2769
8	*Comdina bagualensis*	146	2.45%	2.2461
9	*Indicofera schimperiana*	116	1.94%	1.7846
10	*Zornia glochidata*	106	1.78%	1.6307
11	*Sulla carnosa*	88	1.47%	1.3538
12	*Sesbania leptocarpa*	34	0.57%	0.5230

13	*Echinochloa haploclada*	25	0.42%	0.3846
14	*Desmodium uncinatum*	22	0.37%	0.3384
15	*Gymnocarrpos deconder*	17	0.28%	0.2615
16	*Cencrus biflorus*	14	0.23%	0.2153
17	*Panicum maximum*	11	0.18%	0.1692
18	*Cyperus pauper*	11	0.18%	0.1692
19	*Vigna unguiculata*	10	0.17%	0.1538
20	*Cyprus distans*	10	0.17%	0.1538
21	*Solunum incanum*	9	0.15%	0.1384
22	*Commelina africana*	9	0.15%	0.1384
23	*Ethulia gracilis*	8	0.13%	0.1230
24	*Cencrus ciliaris*	6	0.10%	0.0923
25	*Tragia furialis*	5	0.08%	0.0769
26	*Lactuca taraxacifolia*	5	0.08%	0.0769
27	*Dichondra repens*	5	0.08%	0.0769
28	*Sporobolus pyramidalis*	5	0.08%	0.0769
29	*Apium leptophyllum*	5	0.08%	0.0769
30	*Lappecea panacea*	5	0.08%	0.0769
31	*Achrayrantes aspera*	4	0.07%	0.0615
32	*Senna obtusififolia*	4	0.07%	0.0615
33	*Striga hermonthica*	4	0.07%	0.0615
34	*Phyllanthus guineensis*	3	0.05%	0.0461
35	*Lotus creticus*	3	0.05%	0.0461
36	*Helianthemum reficomum*	3	0.05%	0.0461
37	*Vicia sativa*	2	0.03%	0.0307
38	*Chloris roxburghiana*	2	0.03%	0.0307
39	*Sida alba*	1	0.02%	0.0153
40	*Crotalaria padocarpa*	1	0.02%	0.0153
41	*Hibiscus asper*	1	0.02%	0.0153
	Total	5971	100.0%	

5.3.1.2 Woody species

A total of 676 woody species were recorded in the study area. The five (5) most dominant woody species in the study area were *Ricinus communis* (14.05%), *Acacia reficiens* (11.24%), *Cordia goetzii* (10.95%), *Prosopis juliflora* (9.47%) and *Acacia zanzibarica* (8.14%). Which, together translates to (53.85%) of the all-woody species as shown in (Table 5.2). The densities of the five most dominant species were as follow: *Ricinus communis* (1.46), *Acacia reficiens* (1.17), *Cordia goetzii* (1.14), *Prosopis juliflora* (0.98), and *Acacia zanzibarica* (0.85) per five-meter square. The value of Shannon Weiner's diversity index (H') is 3.0 for the woody species indicating high biodiversity, this is because the area is dominated by diverse vegetation species across all the ecological ecotypes.

Table 5.2: Vegetation attributes of woody species in the study area

S/N	Species	Total Number	Composition (%)	Densities ($5M^2$)
1	*Ricinus communis*	95	14.05%	1.4614
2	*Acacia reficiens*	76	11.24%	1.1692
3	*Cordia goetzii*	74	10.95%	1.1384
4	*Prosopis juliflora*	64	9.47%	0.9846
5	*Acacia zanzibarica*	55	8.14%	0.8461
6	*Musa sp.*	39	5.77%	0.6000
7	*Boscia coriasea*	33	4.88%	0.5076
8	*Raphia farinifera*	26	3.85%	0.4000
9	*Dobera glabra*	25	3.70%	0.3846
10	*Acacia mellifera*	21	3.11%	0.3230
11	*Commiphora africana*	20	2.96%	0.3076
12	*Indicofera schimperiana*	20	2.96%	0.3076
13	*Grewia vilosa*	15	2.22%	0.2307
14	*Albizia glaberrima*	12	1.78%	0.1846
15	*Salvadora persica*	10	1.48%	0.1538
16	*Diospyros mespiliformis*	9	1.33%	0.1384
17	*Lawsonia inermis*	8	1.18%	0.1230
18	*Azadirecta indica*	8	1.18%	0.1230

19	*Combretum herorense*	8	1.18%	0.1230
20	*Acacia seyal*	6	0.89%	0.0923
21	*Grewia densa*	5	0.74%	0.0769
22	*Combretum nigricans*	5	0.74%	0.0769
23	*Ficus sycomorus*	4	0.59%	0.0615
24	*Garcinia livingstonei*	4	0.59%	0.0615
25	*Grewia tenax*	4	0.59%	0.0615
26	*Sorindeae madagascariensis*	3	0.44%	0.0461
27	*Acacia drepanolobium*	3	0.44%	0.0461
28	*Croton menyhatii*	3	0.44%	0.0461
29	*Acacia tortilis*	3	0.44%	0.0461
30	*Adansonia digitata*	2	0.30%	0.0307
31	*Thespesia danis*	2	0.30%	0.0307
32	*Mangifera indica*	2	0.30%	0.0307
33	*Comdina bagualensis*	2	0.30%	0.0307
34	*Hibiscus micranthus*	2	0.30%	0.0307
35	*Rinorea elliptica*	2	0.30%	0.0307
36	*Terminalia brevipes*	1	0.15%	0.0153
37	*Flauggea virosa*	1	0.15%	0.0153
38	*Rinorea illicifolia*	1	0.15%	0.0153
39	*Ziziphus mauritana*	1	0.15%	0.0153
40	*Comdina bagualensis*	1	0.15%	0.0153
41	*Cordia sinesis*	1	0.15%	0.0153
	Total	676	100.00%	

5.3.2 Attribute of vegetation per village

5.3.2.1 Herbaceous species

Evenness is the richness is expressed as the number of species in the entire area and is usually called species richness. While, vegetation density is the number of species in a sampled area. Considering herbaceous vegetation species distribution among the villages Bulla, Hara, Maroni, Vukoni, Wenje, Kipendi, and Makere. Wenje village had the highest herbaceous vegetation density of (167.9) followed by Maroni village with a value of (151.6), others were Kipendi (143.2), Vukoni (81.3), Makere (78.1), Bula (43.2), Hara (3.7) per meter square. All the villages except Hara had fairly dense vegetation.

The evenness in the study area as per village was as follows; Hara (0.74), Wenje (0.66), Maroni (0.62), Makere (0.53), Vukoni (0.45), Kipendi (0.30), and Bulla (0.14). In Bula, Vukoni and Kipendi there was little vegetation evenness while the rest of the villages had good vegetation evenness.

The Shannon Weiner's diversity index (H') per village was as follows, Wenje had a value of (1.86) while Hara had a value of (1.70) then Maroni (1.43), Makere (1.22), Vukoni (1.21), Kipendi (0.86), Bulla (0.27) for herbaceous species as shown in Table 5.3. The biodiversity of herbaceous species was low in all the villages due to overgrazing and the effects of drought.

Table 5.3: Herbaceous vegetation density, Evenness and Shannon Weiner's diversity index (H') **in the study area as per village**

	Vukoni	Bulla	Wenje	Kipendi	Maroni	Makere	Hara
Density(1M²)	81.30	43.20	167.90	143.20	151.60	78.10	3.70
Evenness	0.45	0.14	0.66	0.30	0.62	0.53	0.74
(H')	1.21	0.27	1.86	0.83	1.43	1.22	1.70

5.3.2.2 Woody species

Considering woody vegetation density among the villages Bulla, Hara, Maroni, Vukoni, Wenje, Kipendi and Makere. Vukoni had the highest woody vegetation density of (21.4), other villages include Hara (11.8), Maroni (11.1), Wenje (10.7), Bulla (8.2), Makere (7.4), Kipendi (0.4) per five-meter square. All the villages had fairly dense vegetation except Kipendi.

The evenness is as follows in descending order Kipendi had (0.85), Bulla (0.82), Maroni (0.81), Wenje (0.77), Makere (0.74), Vukoni (0.66), and Hara (0.65) as shown in Table 5.4. The values were close to one, there was vegetation evenness across all the villages.

The Shannon Weiner's diversity index (H') per village was as follows, Maroni had (2.27) followed by Bulla (2.21) then Wenje with a value of (2.02) others were Vukoni (1.97), Makere (1.62), Hara (1.43) and Kipendi (1.26) as shown in Table 5.4 In the study area there was high biodiversity in Maroni, Bulla, Wenje and Vukoni but low biodiversity in Makere, Hara and Kipendi. There is low biodiversity in the three villages due to increased land degradation, especially in the grazing area.

Table 5.4: Woody vegetation Density, Evenness and Shannon Weiner's diversity index (H') as per village

	Vukoni	Bulla	Wenje	Kipendi	Maroni	Makere	Hara
Density(5M^2)	21.4	8.2	10.7	0.4	11.4	7.4	11.8
Evenness	0.66	0.82	0.77	0.85	0.81	0.74	0.65
(H')	1.97	2.21	2.02	1.26	2.27	1.62	1.43

5.3.3 Vegetation cover in percent and mean

From the analysis of the results from the study, the average vegetation cover is 20%. Between 0% to 10% cover was recorded in many plots. The highest recorded value of cover was 90%, while the least value was 0%. According to (Table 5.5), Hara village had low vegetation cover. The vegetation cover and vegetation type varied along the river high vegetation cover and high vegetation diversity compared to the grazing area which had low vegetation cover and low vegetation diversity a result of experienced high overgrazing

Table 5.5: Vegetation cover estimation per village in percent

	Vukoni		Wenje		Kipendi		Maroni		Makere	Hara		Bulla	
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13
Q1	60	10	2	6	10	50	3	15	5	5	0	40	32
Q2	10	70	15	65	8	70	0	25	18	2	0	2	15
Q3	20	65	5	1	10	90	2	55	5	0	0	1	3
Q4	15	10	5	30	0	87	7	8	10	5	2	45	2
Q5	35	85	3	15	15	3	30	3	1	3	10	10	18

Q- Quadrants B- Belt transect

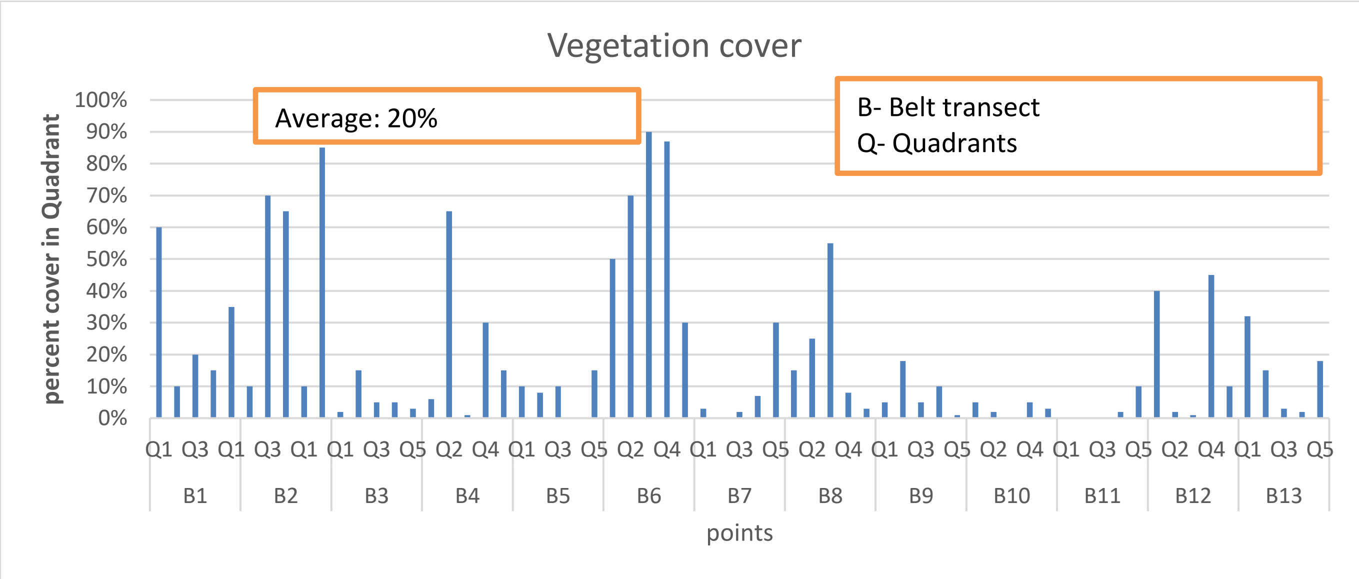

Figure 5.2: Vegetation cover estimation in the study

5.4 Discussion

Vegetation sampling and ecological studies are key to livestock production, this is because the composition, density, and cover can affect the availability of livestock feeds. Also, to determine the condition and the productivity of the land, species cover, diversity, and evenness are critical parameters to measure. According to the study it was found that the majority of the dominant plant species were palatable for livestock. However, the vegetation cover was low due to overgrazing and increasing drought. The study aimed to determine the most dominant vegetation species, cover and acknowledge how the vegetation species would be used by the pastoral communities to increase livestock production, and address the loss of livestock which occur frequently as a result of the reduction or the depletion of livestock feeds caused by land degradation.

The dominant vegetation identified were *Cyprus rotundus* and Cynodon *dactylon* which are good sources of livestock feed for grazers such as cattle and donkeys. It's also essential for reducing land degradation by the provision of soil cover and reducing the carbon (iv) oxide which is a greenhouse gas. The two dominant grass species play a greater role in reducing soil erosion thus there will be less siltation in the Tana River. This agrees with the studies done by Sunita in Mexico which found that grass species play an important role in reducing water run-off and controlling soil erosion (Sunita, 2017).

Other grass species were found in the study area, the species are essential in livestock production, for grazing of sheep and cattle this grass species include *Cencrus biflorus, Panicum maximum, Cencrus ciliaris* and *Chloris roxburghiana. Chloris roxburghiana* is an important grass species in most rangelands but the species was declining due to land degradation and overgrazing. Despite being the grass species are tolerant to drought but not resistant to heavy grazing (Mnene, 2005).

The study confirms that since the composition of the species in the study area is (0.03%) the grass species is near depletion. It was only found in enclosures where grazing pressure was minimal, there was less degradation. *Cencrus ciliaris* is an important forage in rangelands around the world, the species is drought resistant and have high biomass though, and the species can dominate other grass species (Sunita, 2017). *Panicum maximum* (guinea grass) is animal forage in almost all the tropic counties and they grow in well-drained, fertile soils. They are also good at stopping and controlling of soil erosion because of their deep and intensive root system (Aganga, 2004).

The grass species were found in plenty the grass species accounts for 0.8% of the *Panicum maximum* and was found mostly along the river bed. The grass species were being cut and carried to be fed on animals by the Pokomos who are agropastoralists. The *Cencrus biflorus* is a grass species found in the tropics it is highly tolerant to disturbances such as grazing which makes it more competitive than other grasses. The grass is a very good livestock forage in the study area (Makhabu, 2012).

The trees and shrubs identified in the study area including, *Acacia rificiens*, *Cordia goetzii*, *Prosopis juliflora*, and *Acacia zanzibarica,* which were reported to be critical feed for browsers such as goats and camels also it's good forage for bees. *Salvadora persica* is a good browse for camels because it is a deciduous plant (Akram, 2011; Seid *et al.,* 2020). It's predicted that *Prosopis juliflora* will be more dominant than the other species since *Prosopis juliflora* is an invasive species that spread very fast, seeds are spread by livestock when ingested and passed out as dung also *Prosopis juliflora* is hard to eradicate, first spreading tree (pasiecznik *et al.,* 2001). *Prosopis juliflora* is faster spreading due to its superiority adaptations characteristics to climate variability, deep tap root, tolerant to aridity, and massive seed production *prosopis juliflora* is taking over the grazing land and farmlands (Saravanakumar, 2013; Mathur & Mathur, 2022).

Tana River County virtually stays for a long period without rainfall. This affects the vegetation cover, composition, and density. The trees are always in a dominant condition most times of the year, the majority have thorns and shed leaves during the dry season. The area is dominated by trees of *Acacia spp,* grasses including *Cynodon dactylon* which most times of the year is dry but replenish faster after rains begin. *Acacia spp* are known to be tolerant to drought and salinity (Akram, 2011) this has enabled the species to grow well in the area. There is an abundance of *Acacia spp* trees in the area including *Acacia reficiens, Acacia zanzibarica,* *Acacia mellifera* and *Acacia seyal* plays a critical role in livestock production, the acacia leaves and pods are rich in protein (Dynes, 2002).

Pastoral communities recognize vegetation as important for their livestock. They depend on vegetation to improve the condition of their livestock and increase livestock productivity. An increase in population, overgrazing and the spread of *Prosopis juliflora* is the main cause of change in vegetation type and cover in the area.

5.5 Conclusion and recommendations

Cyprus rotundus, Cynodon *dactylon, Acacia reficiens, Cordia goetzii,* and *Acacia zanzibarica* are good sources of livestock forage species. There is a need to protect these vegetation species for improved livestock production, improved vegetation cover, reduced land degradation and reduced climate change. The vegetation cover is very low in the main land and high along the river. Overgrazing has led to a great decline in vegetation cover and increased land degradation in the grazing area and the availability of water in the flood plains and controlled grazing along the river encourage the growth of vegetation. *Prosopis juliflora* is an invasive species which alters the vegetation composition due to its ability to dominate, hard to eradicate and spread quickly.

Sustainable land practices and vegetation use is recommended. Woody species are mostly fed by browsers such as goats and camels, while herbaceous species are mostly fed by grazers such as cattle. Sustainable grazing management is important to protect the vegetation cover and curb land degradation. Rehabilitation of the land where the cover falls below 20% will not only increase livestock production but also protect the environment against climate change. This is because trees are known to be high carbon sequesters under their biomass stock. Thus, trees have a critical role in reducing carbon (iv) oxide, which is a greenhouse gas. Trees are known to mitigate the effect of climate change (Jibrin, 2018).

Most vegetation in the study area has socioeconomic benefits such as the source of food, shade, fodder, medicine, firewood, timber, and making products such as timber. The study recommends sustainable use of vegetation for more economic opportunities. For future proper management of the vegetation, customary institutions must be formed for effective management of the natural resources.

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CHAPTER SIX

General conclusions and recommendations

6.1 General conclusions

It is necessary to understand the extent and nature of land degradation because it is a challenge facing the entire world, especially the drylands. This has a negative impact on livelihood. The majority of the people depend on degraded land for crop production and livestock production, this has not been sustainable.

Livestock production in Kenya is an important sector which contributes more than 4.54 billion dollars to the economy. However, livestock production has been affected by declining livestock feed, which has greatly affected the livelihood of the communities. An ecological study was done to assess the most dominant vegetation species and determine the average vegetation cover. Belt transect quadrats were used in data collection and Microsoft Excel was used in data analysis. The results showed that the most dominant herbaceous species were the *Cyprus rotundus*, *Cynodon dactylon, and Cucumis pustulatus*, while the most dominant woody species in the study were the *Ricinus communis*, *Acacia reficiens*, *Cordia goetzii*, *Prosopis juliflora* and *Acacia zanzibarica* in that order. Most of the plants recorded have many ecological and socio-economic benefits such as fodder and forage for livestock, firewood, timber, and fruits.

Multi-temporal satellite images were used to show the major land use and land cover changes in Wenje, Gwano Tana River County, Kenya. Six classes were used in classification 1. Water 2. Mango plantation 3. Built-up areas 4. Grassland 5. Forest. MLC algorithm through identification of features and training areas. Classification and analysis were done using ArcGis 10.7. The results from the analysis indicated following changes, bare land had increased, the forest had declined, grassland had declined, mango plantation had increased, built-up areas had increased and water bodies had declined. The great decline in grassland and increase in bare land has affected livestock production and livelihood for the communities in Wenje.

Finally, Community knowledge and perception of land cover changes, land degradation, and land rehabilitation were studied. The community are aware of climate change and land degradation. The survey was conducted to determine the best four range grasses species which are suitable for rangeland rehabilitation and to determine the spread of spread and the use of *Prosopis juliflora*. *Cynodon dactylon, E haploclada, Panicum maximum* and *Cyprus rotundus*. *Cynodon dactylon* were identified by the communities as the best suitable grasses for land rehabilitation. The community also indicated their understanding of vegetation cover changes and invasive species distribution.

It is very clear from the study that the communities were much affected by climate change which manifests itself as drought and flooding. This has really affected the livelihood of the communities who depend on livestock keeping as a source of livelihood. Most pastoralists have lost their livestock due to a decline in feed. Long droughts in the area have been witnessed, and livestock feed and food security have been undermined.

6.2 General recommendations

1. Sustainable vegetation use is recommended; vegetation is an important source of feed for livestock also Vegetation helps in reducing greenhouse gas in the atmosphere thus mitigating climate change. Woody species were mostly fed by browsers such as goats and camels, while herbaceous species were mostly fed by grazers such as cattle. Most vegetation in the study area has socioeconomic benefits, such as the source of food, shade, fodder, medicine, firewood, timber, and making products such as timber. The study recommends sustainable use of vegetation.
2. The highest percentage of the study area is highly degraded especially during the year 2017, it is expected that land degradation will increase in the future due to increasing

climate change. The study recommends land rehabilitation, this will help in reducing soil particle detachments, conserve the water physical structures and improve livestock production. The grass can be irrigated for increased production. The grass can be harvested and stored to be used in feeding livestock during the dry season. Seeds production will help in furthering land rehabilitation and the sale of the seeds will increase the household income. Future studies are also recommended to determine the impact of rehabilitation on land cover, extend land degradation and identify other areas which require quick rehabilitation.

3. Communities play a greater role in mitigating land degradation. Their involvement in solving land degradation should be prioritized. They have the knowledge and skills in identifying the indigenous grass species which is suitable for rehabilitating the degraded rangelands.

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