University of Nairobi

School of Engineering

Monitoring Land Degradation Neutrality using Geospatial Techniques in Support of Sustainable Land Management:

A Case Study of Narok County.

BY

Owuor George Ogutu

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Declaration

I, (Owuor George Ogutu), hereby declare that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other Institution of Higher Learning.

Owuor George Ogutu ……George………

Name of student 2/9/2021

This project has been submitted for examination with my approval as university supervisor.

Prof. Faith Njoki Karanja ……………………………

Name of supervisor 2/9/2021

Dedication

I dedicate this project to my late Dad, Bishop Domnic Ogutu Saoke.

Acknowledgement

I would like to give my sincere gratitude to the following people, without whom I would have not completed this research project.

My supervisor Prof. Faith N. Karanja whose insights and knowledge in the subject directed me through this research. I would also like to thank the staff at the Department of Geospatial and Space Technology, the School of Engineering at the University of Nairobi for the valued support, critique and guidance during this research project.

I also give thanks to my family, friends and colleagues for the support during this study period, may you all be blessed. Lastly, I would like to give special thanks to God for the grace and energy he granted me to carry out this project.

Abstract

Land degradation is a worldwide phenomenon defined as “a gradual reduction or loss in the biological or economic productive capacity of the land” (UNCCD, 2016). Land degradation is closely linked with major global environmental themes like climate change, food and water security, biodiversity decline and overall loss of ecosystem functions and services (Giuliani, et al., 2020). The main cause of land degradation is the change in land use and land management practices including overgrazing, deforestation and monocultures.

Fortunately, the importance of healthy landscapes as the basis for healthy societies and economies has been recognized by the global community. The land degradation neutral world goal is clearly stated in the Sustainable Development Goals targets.

This project employed Remote Sensing, GIS technologies together with ‘Trends. Earth’ model and Google Earth Engine to monitor land degradation status and trend in Narok County in Kenya. Three sub-indicators; change in Land Cover obtained from Landsat images, change in Land Productivity and change in Soil Organic Carbon were used to analyse the aggregate land degradation status using the principle of one-out-all-out on their overlayed pixels. The study quantified the proportion of land in Narok county that is degraded, stable and the areas with improvements by overlaying change in land cover, change in soil organic carbon and change in land productivity datasets. The results showed that 54.13% of Narok county is stable, 41.48% is degraded and 4.39% of the county is improving.

This study has shown that geospatial technologies have an important role in the realization of the SDGs, especially SDG 15 which deals with life on land. Land degradation is proven through this study to be occurring at the local or pixel level; therefore, the county governments and civil societies should engage the communities in sustainable land management and ecosystem restoration activities.

This study managed to highlight the land degradation status of Narok County. However, there is still an opportunity for further research to demonstrate how these results can change when uniform and high spatial resolution datasets are used.

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List of Abbreviations

1OAO	One Out All Out
AVHRR	Advanced Very High-Resolution Radiometer
CIDP	County Integrated Development Plan
CSP	County Spatial Plan
DIKW	Data Information Knowledge Wisdom pattern
EO	Earth Observation
ESA	European Space Agency
GEE	Google Earth Engine
LDN	Land Degradation Neutrality
MODIS	Moderate Resolution Imaging Sensor
NDMA	National Drought Management Authority (Kenya)
NDVI	Normalized Difference Vegetation Index
PRAIS	Performance Review and Assessment of Implementation System
SDG	Sustainable Development Goal
SLM	Sustainable Land Management
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification

CHAPTER 1: INTRODUCTION

1.1 Background

Land degradation is a worldwide phenomenon defined as, “a gradual reduction or loss in the biological or economic productive capacity of the land” (UNCCD, 2016). Land degradation is closely linked with major global environmental themes like climate change, food and water security, biodiversity decline and overall loss of ecosystem functions and services (Giuliani, et al., 2020). These global environmental challenges influence the ongoing change in human comfort, safety, shortage in food supply and migration. The cause of land degradation is the increased human activities and intensification of natural processes. According to a report published by FAO in 2011, 25% of usable global land is already degraded. The assessments on these degraded areas indicate that they are mainly in Africa, especially in the southern hemisphere.

Change in land use together with poor land management practices including overgrazing, deforestation and monocultures are the leading human activities fuelling the rate of land degradation (Ishtiaque, et. Al, 2020). These poor land management practices normally affect the soil quality which is normally declining in its function of supporting the ecosystems. The decline in ecosystems has led to the loss of biodiversity, increased soil erosion, salination, reduced soil fertility through the depletion of soil nutrients, soil organic matter, soil pollution and desertification (Liu et. al,2019). Poverty and ignorance are usually attributed to poor and unsustainable land management practices. Using local-based monitoring solutions and techniques to identify the degraded areas would provide the solution to these problems and improve sustainable land management practices.

Kenya is not left behind when it comes to facing global land degradation challenges. 80% of Kenya’s land including Narok County is classified as ASAL i.e., arid and semi-arid land (National Drought Management Authority, 2018). The classification of ASAL areas in Kenya uses the amount of annual rainfall being received in these areas which are usually very low compared to other regions in Kenya. These areas are consequently marginalised and have high rates of poverty, ethnic conflicts and migrations. About 30% of Kenya’s total population lives in these ASAL areas (UNDP, 2021). They earn their living through a mix of subsistence farming and pastoralism. These ASAL areas are susceptible to droughts, flooding and with the increase in the impact of climate change, they are at risk of desertification. Additionally, ASAL areas in

Kenya have been degraded from deforestation and overgrazing, this has further reduced the productivity of these lands, threatened food security, livelihoods and biodiversity (Othieno, 2014).

Fortunately, the importance of healthy landscapes has been recognized by the world community. Increased degradation is prominent in the global agenda for sustainable development. Countries of the United Nations pledged to support the 17 sustainable development goals (SDG) which are aimed to be accomplished by 2030 (United Nations, 2021a). Land degradation Neutrality is mentioned in goal 15.3 as one of the targets to be attained.

SDG 15, in particular, is dealing with life on land. It states that "this goal aims to protect, restore and promote sustainable use of the terrestrial ecosystems, sustainably manage forests, combat desertification and hold and reverse land degradation and hold biodiversity loss" (United Nations, 2020). Land degradation neutrality (LDN) is fundamental to this target. LDN is defined as "a state whereby the amount and quality of land resources necessary to support ecosystem functions services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems" (UNCCD, 2018). LDN intends to mitigate the ongoing loss of healthy landscapes through sustainable land management (SLM) practices. Losses should be well-adjusted by improvements. There is a strong connection between LDN and other SDGs like poverty eradication, food security, health, gender, water, energy, cities and climate change (Orr, et al., 2017). The target on land degradation neutrality can therefore be observed as cross-cutting issues that need to be addressed to not only reach a land degradation neutral world but also play a pivotal role in attaining other sustainable development goals as well (Maurice, 2016).

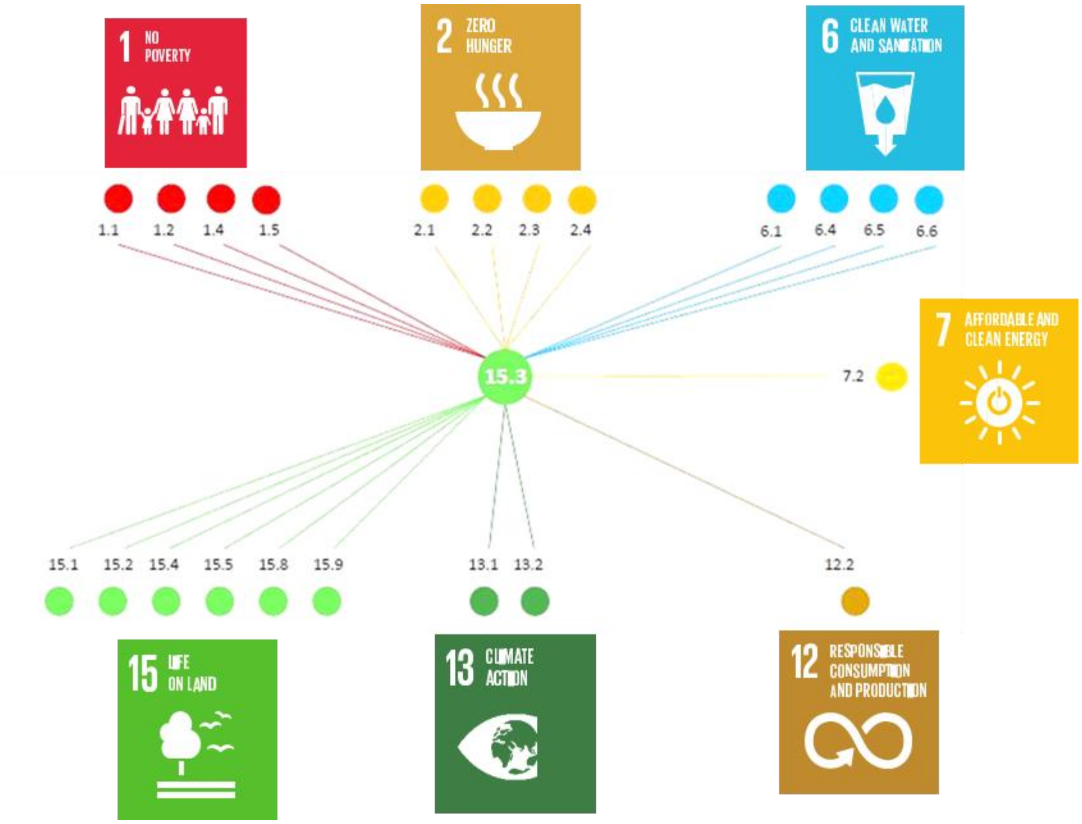


Figure 1.1 List of SDG goals, indicators and targets that can be achieved by having a neutral land degradation status through SDG target 15.3 (LDN target setting report in Kenya, 2011).

The United Nations Convention to Combat Desertification (UNCCD) developed a scientific framework guideline document that has a procedural proposal in defining LDN indicators and actions for their achievements (UNCCD, 2016). The member countries are required to use the proposed LDN framework to inform the percentage of the land that is degraded as a ratio of the entire land area and make periodic reports on the progress towards the set 'zero net loss,' the main objective of SDG 15.3.

Finding the proportions of the land area which has been degraded is further broken down into three sub-indicators which can be measured using the available geospatial techniques both at the global, national and county scales for ease of decision making. The sub-indicators include; the trends in land cover, land productivity and soil carbon stocks (Giuliani, et al., 2020).

1.2 Problem Statement

The dominant community living in Narok County traditionally owned the land communally and practised livestock keeping as a source of livelihood in the rangelands. However, these rangelands have been subdivided into individual ranches limiting the mobility of the livestock. Consequently, it has led to overgrazing as increased pressure is put on ranches to provide pasture for the livestock (Othieno, 2014). The rate of poverty in the county has also prompted the community to cut down indigenous tree species for charcoal production. Additionally, some pastoral and forest lands have been transformed into farmlands. This depletion of land cover and land productivity has made land in Narok County to be vulnerable to soil erosion, low productivity, loss of biodiversity, depletion of soil nutrients and other forms of land degradation (Ngaruiya & Muithui, 2016).

The land degradation in Narok county is consequently driving species to extinction, increasing social and political instabilities, increasing poverty and migration, increasing land-use competition, intensifies climate change, reduction in rural livelihoods, reduced water supplies, threaten wildlife habitat and loss of biodiversity.

To solve these problems, sustainable land management would be needed together with local-based monitoring solutions to identify the degraded areas. This project monitored the land degradation trend and status in Narok county between the years 2001 and 2018. It identified the status of land that is degraded, stable and.

1.3 Study Objectives

1.3.1 General Objective

The main objective of this study was to Monitor Land Degradation Neutrality (LDN) using geospatial techniques in support of Sustainable Land Management (SLM) practices in Narok County.

1.3.2 Specific Objectives

The specific objectives of this study were to;

- Review the causality and monitoring period for land degradation in Narok county.
- Identify geoinformation data for monitoring Land Degradation Neutrality for Narok county.
- Model the Land Degradation Neutrality trend for Narok County.

- Apply Land Degradation Neutrality for sustainable land management for Narok County.

1.4 Justification for the Study

This study aims to provide the needed LDN monitoring support for sustainable land management practices at the county level in Kenya especially in the ASAL regions. The counties will be able to integrate the Geospatial techniques with their traditional statistical data to help them answer the questions about land degradation like when? Where? Why? and how can the increase in land degradation be mitigated? The civil societies will be able to use this information to identify specific areas to channel their sustainable land management campaigns since the aggregation of the amount of degradation is done at the pixel level. Local communities will also be able to see the status of land degradation in their locality hence be able to make decisions on which land management practice to employ to prevent their respective parcels of land from losing productivity. This study also aimed at supporting the process of setting sound land restoration targets on the identified degraded areas by the national government thus improving the well-being of the citizens, biodiversity and ecosystems and climate situation.

The corrective measures taken following the report from this research will not only ensure that the global LDN target is achieved but also other related SDGs, targets and indicators including climate change, biodiversity, adequate food, clean water, end poverty etc benefit from the trickle-down effects.

1.5 Scope of work

This study only focussed on Narok County to determine its Land Degradation status using change in; land cover, land productivity and soil organic carbon over a 17-year monitoring period from 2001 to 2018. The study used the pre-processed Landsat dataset to create land cover sub-indicator datasets for the analysis. Land productivity indicator was obtained from the European Joint Commission on Research Centre. Soil Organic Carbon was obtained from International Soil Reference and Information Centre. Google Earth Engine was deployed to run the time-series datasets from Trends. Earth plugin tool in QGIS. The three indicators were analysed to determine the area of Narok county which has been degraded, stable and finally the areas which have been improving by helping the decision-makers to enforce appropriate sustainable land management (SLM) policies and programs.

1.6 Organization of the report

This research report is organized into five chapters. The first chapter is introductory and it has the background information, the statement about the problem, the set objectives; main and specific objectives, justification of the study, the scope of the study and project organization.

The second chapter delves into reviewing relevant literature on land degradation, its causes and land degradation neutrality monitoring at a global scale, regional scale and national scale. It also looked at arid and semi-arid areas in Kenya. The chapter also looked into the indicators that can be used in monitoring land degradation. The monitoring period is also determined in this chapter based on the recommendation by the United Nations Convention to Combat Desertification (UNCCD). Lastly, the role of geospatial technology in monitoring land degradation neutrality is also discussed.

The third chapter covers the study area, data, materials and processes that helped to achieve the set objectives of this study. The fourth chapter looked into the outputs from chapter three and the discussions on the insights from the results. The fifth chapter gives the conclusion drawn from the discussion about the results and provides the recommendation on what can be done to reverse the trends observed and lastly it identified the areas for further research that this study failed to explore. The reference part provides the list of the literature materials that were reviewed in the study.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Growth in the human population and activities has put direct pressure on land (Liu et. al, 2019). The land is under increased pressure to enhance its productivity potential in delivering the goods and services to support the increased demand for high quality and nutritious food, animal feeds and fibre as noted by United Conventions to Combat desertification (UNCCD,2017). However, due to the fixed quantity of land, the increased competition to control land resources has the potential to cause social and political instabilities, poverty and migration. The competition faced by land also comes from different land uses eg. Urban areas sprawling into food production areas. Climate change, on the other hand, is playing a magnifying role in these tensions as it increases the frequency of extreme weather events that stresses land capacity to supply vital services especially when water availability is reduced (Orr, et al., 2017).

As was noted by FAO in 2011, 25% of all land worldwide is currently highly degraded due to increased human pressure and competition, 36% is slightly or moderately degraded and only 10% is improving. The overall health and productivity of land are declining while the demand for land resources is increasing.

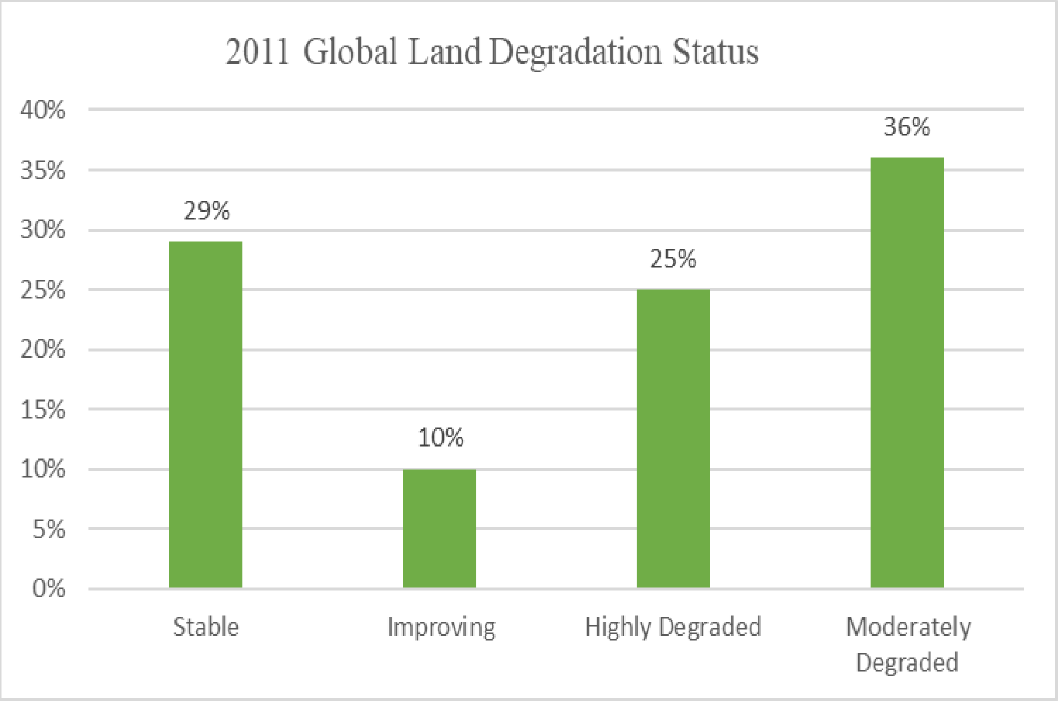


Figure 2.1 Global Land Degradation Status, (FAO, 2011).

Recognising the benefit of halting and reversing land degradation under the concept of “Zero net land degradation, ” a strive to achieve a land degradation neutral (LDN) world was adopted by the United Nations through the SDGs (target 15.3). This target is global and is subject to translation into national and sub-national targets. LDN was conceived to encourage a dual prolonged approach of measure to avoid, reduce and restore degraded land (Gonzalez-Roglich, et al., 2019).

2.2 Land Degradation Neutrality Monitoring

Land degradation neutrality monitoring aims to achieve no net loss of land-based natural capital when compared with the baseline (Orr, et al., 2017). Monitoring LDN is based on quantifying the baseline and then assessing the balance between the improved areas with areas of significant negative changes relative to the baseline at the end of the LDN monitoring period. Several studies have been conducted to measure and monitor the LDN using different methodologies at different scales and datasets.

2.2.1 Global Scale

Giuliani et al. carried out a study aimed at generating knowledge using earth observations to support sustainable development goals; with a special focus on target 15.3.1 (Giuliani, et al., 2020a). They used a geospatial technology model called ‘trend. earth’ is a free tool available in the QGIS platform designed for monitoring trends in the earth surface. They incorporated the three sub-indicators; land cover, land productivity and carbon stocks from the scientific framework provided by UNCCD to monitor LDN. They managed to achieve their objective of generating knowledge using earth observation to monitor land degradation as illustrated in figure 2.2 below.

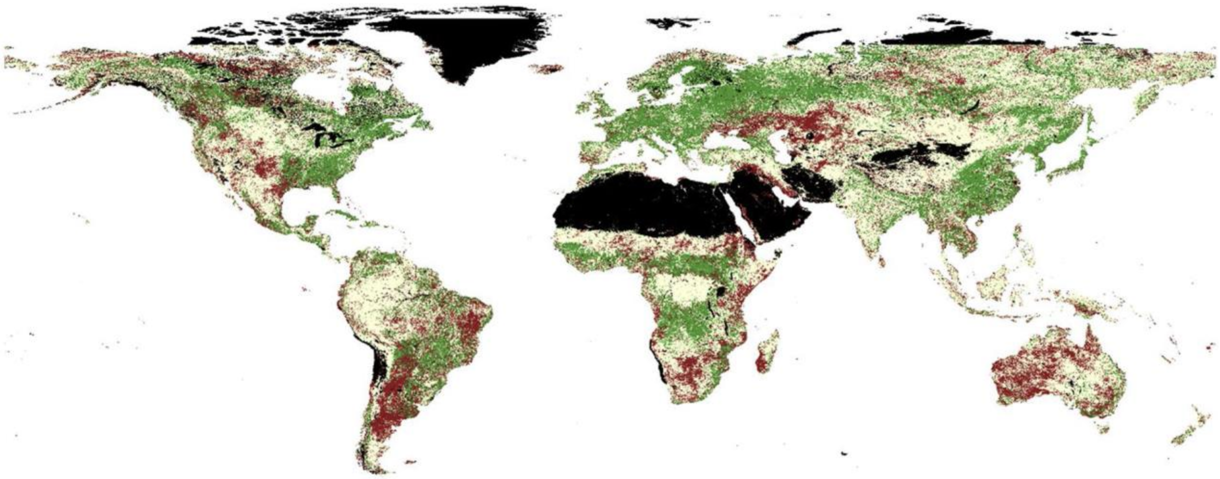


Figure 2.2 Global Land Degradation Model. The improved areas (Green), Stable areas (Yellow), Degraded areas (Red) and No data areas (Black), (Giuliani et al, 2020).

Even though their objective of generating knowledge of monitoring land degradation to support SDG was met. They however noted in the conclusion that the data provided at a global scale are very coarse in terms of spatial resolutions and may give inaccurate figures in the national reports. They recommended using national or regional scales and integration of local indicators at national and regional levels to enable validation of the results from the model.

It is noted that results on LDN status from a global study could not be used to quantify the individual member country reports. It also lacked ownership by the statistical and reporting authorities on SDGs.

2.2.2 Regional Scale

In the same year Giuliani, et al., carried out another study to monitor land degradation at a national level as a proof of concept using satellite earth observation time series data and exploring the potential of the data cube to support SDG 15 (Giuliani, et al., 2020b). They took note of the coarse resolution of the global data provided by MODIS or AVHRR and tried to work with medium to high-resolution satellite EO data ie. Landsat or Sentinel for a small area in Switzerland before generating the indicators at the national scale using python scripts on Jupiter notebook to compute the sub-indicators. The indicators generated showed much finer details providing improved information on the spatial patterns of land productivity, land cover and carbon stocks. They brought out accurate correlation which was proposed for implementation.

However, they observed that annual average NDVI values, a proxy used for monitoring land productivity indicators can vary from time to time thus proposing future studies to utilize the data provided on the cloud which can be analysed by the Google Earth Engine (GEE).

This regional-level monitoring was also applied by Mariathasan et al. in a study of evaluating Earth Observation solutions for Monitoring Namibia’s SDGs (Mariathasan, Bezuidenhoudt, & Olympio, 2019). They used carbon Stocks and land productivity data while 30m Land cover was generated from Landsat 7 dataset on a ‘Trend. Earth’ model is powered by the GEE. The result was as shown in figure 3 below.

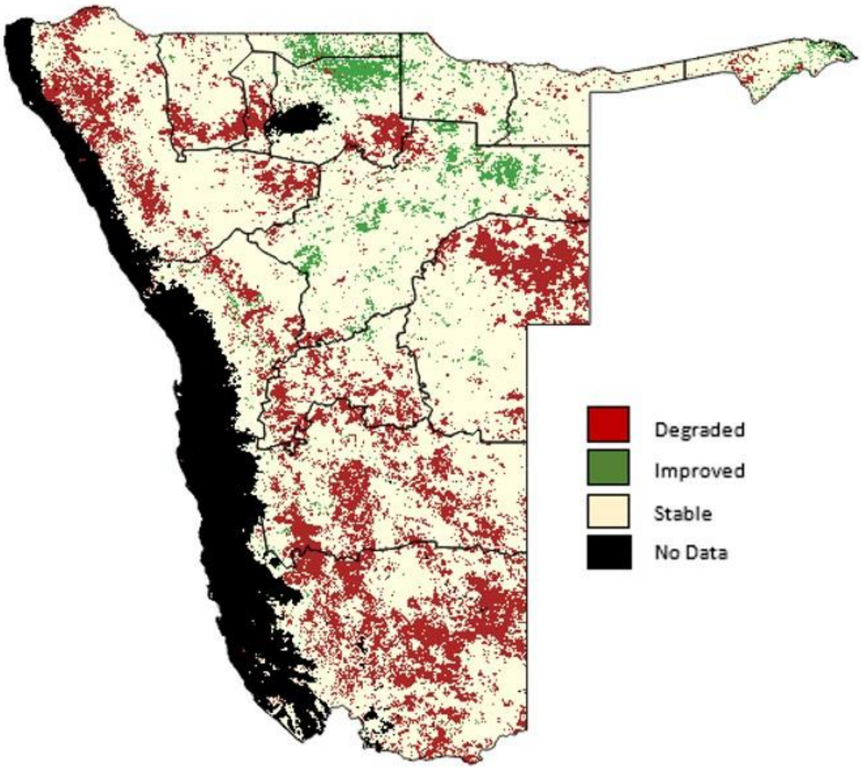


Figure 2.3: Namibia Land Degradation Model, (Mariathasan, Bezuidenhoudt, & Olympio, 2019)

From this regional scale level it is observed that EO data can be a good complement to traditional statistical measures by integrating the indicators at the pixels level thus capturing both spatial (e.g maps) and temporal (eg. Graphs) and publishing the result of the analysis for the decision-makers.

2.2.3 National Scale

Kenya being a signatory of UNCCD has formulated national LDN targets to address land-use management challenges (Republic of Kenya, 2018). The government of Kenya has expressed commitment to the LDN response hierarchy ie. Avoid, reduce and restore the degraded land through sustainable land management practices. The country has completed the target setting exercise and is working towards its achievements including the one on 10% forest cover, protection of wetlands, hilltops and slopes from unsustainable land-use practices. The country is committed to managing soil erosion and other environmental degradation as well (The Kenya Ministry of Environment, 2018).

However, there is still a gap in monitoring and communicating the progress towards the national targets including LDN reporting especially using Geospatial Technology. The use of geospatial technology to monitor SDG indicators have not been adopted in Kenya. This study will therefore use the recommended geospatial datasets by the UNCCD to monitor the LDN, an SDG target 15.3 in Kenya and offer decision making support in terms of the specific areas in which the sustainable land management efforts are needed to avoid, reduce and restore the degraded land with a case study area being Narok county.

2.3 Arid and Semi-arid (ASAL) counties in Kenya

Kenya is facing land degradation challenges at a higher rate compared to the global rate which is at 25%. According to the National Drought Management Authority, 80% of Kenya's land including Narok County is classified as arid and semi-arid land (National Drought Management Authority, 2018). This classification is based on the low amount of annual rainfall being received in these areas. These areas are normally marginalised, and with high rates of poverty, ethnic conflicts and migrations. About 30% of Kenya's total population lives in these ASAL areas (KNBS, 2019). They earn their living through a mix of subsistence farming and pastoralism. These ASAL areas are susceptible to droughts, flooding and with the increase in the impact of climate change, they are at risk of desertification. Additionally, ASAL areas in Kenya have been degraded from deforestation and overgrazing, this has further reduced the productivity of these lands, threatened food security, livelihoods and biodiversity.

Figure 2.4 Arid and Semi-Arid Counties in Kenya, (NDMA, 2021)

2.4 Causes of Land degradation in Narok County

Narok County is part of the ASAL region in Kenya. It has about 2/3 of its land classified as semi-arid (National Drought Management Authority, 2018). Degradation of land in Narok is mainly caused by land-use changes and management practices including overgrazing, deforestation and monocultures. The practices result in the declining functioning of the ecosystems and decreasing soil quality.

2.5 Land Degradation Neutrality Monitoring period and Indicators

United Nations Convention to Combat Desertification (UNCCD), the custodian of the Land degradation neutrality under target 15.3 of the UN SDGs developed a good practise guidance (GPG). The GPG has provided recommendations that LDN monitoring should cover a period of not less than 12 years (UNCCD, 2017). This is to allow the correction on the climatic fluctuations and also the vegetation lifespan to have grown into maturity for most of the vegetation species. It is also recommended by the UNCCD that monitor LDN should use the sub-indicators of land cover, land productivity and soil organic carbon (Gonzalez-Roglich, et al., 2019) due to their availability globally and can be customized by the member countries based on the local standards. To assess the area degraded, the changes in these indicators are combined to give the overall land degradation status.

2.5.1 Change in Land Cover

Change in land cover can be assessed using land cover maps of the study area at the start of the monitoring period and the target year (Gonzalez-Roglich, et al., 2019). There are already default data sets at the global scale for this analysis but local maps can also be used for a high level of accuracy, precision and local acceptance of the result. The land cover change indicator can be computed by reclassifying the land cover maps and then a land cover transition analysis is performed to determine which land cover class has changed over time and which one has remained constant. Using the local knowledge of the condition in a given study area one can determine which change has taken place as; degraded, stable or improved () using -, 0 or + conditions respectively (trends. earth, 2021). The information is then combined to provide information on the land cover change map showing potential degradation or improvement depending on the type of land cover change.

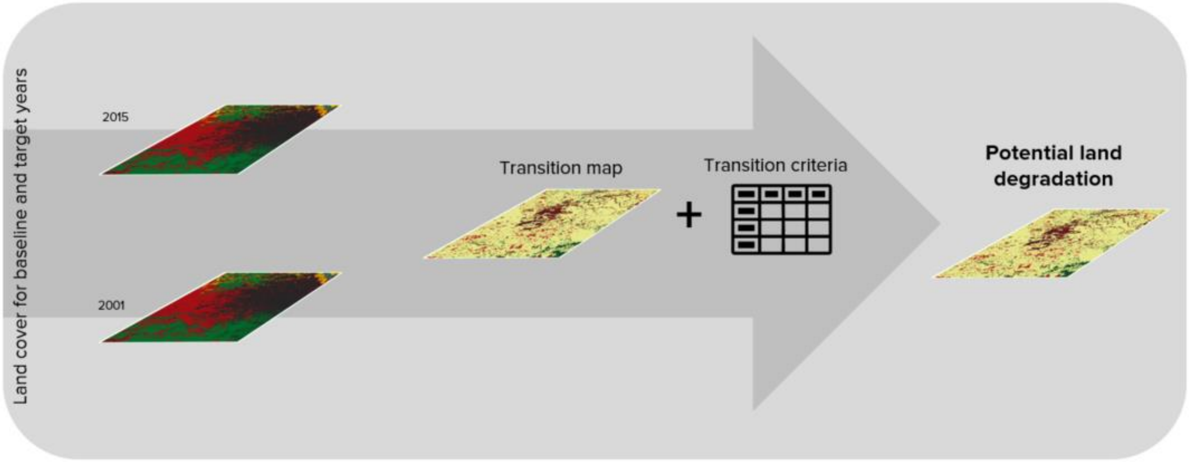


Figure 2.5 Land Cover change indicator calculation, (Trends. Earth, 2021)

2.5.2 Change in Land Productivity

Land productivity is the biological productive capacity of the land (Reddy & Kumar, 2018), the source of all food, fuel and fibre (UN Statistics, 2021). Net primary productivity (NPP) being the amount of carbon assimilated after photosynthesis and autotrophic respiration over a given period (UNCCD, 2017). Measuring land productivity in kg/ha/yr. is time-consuming and expensive to estimate thus remote sensing can be used to derive the NPP using the normalized Difference Vegetation Index (NDVI).

Assessing the change in land productivity can therefore be measured using change indicators from the NDVI time-series data comprising the trajectory, state and performance of the vegetation over the monitoring period (UNCCD, 2021). The results from the three sub-indicators are then combined to inform the type of land degradation occurring in the area.

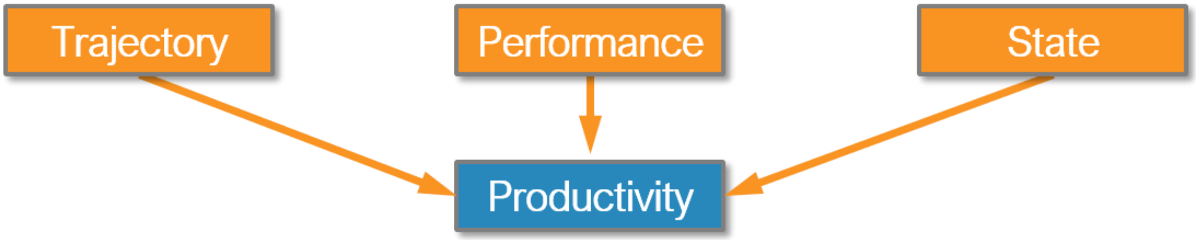


Figure 2.6 Sub indicators of Net Land Productivity, (Trends. Earth, 2021)

Trajectory

A trajectory is the measure of the rate of change in the primary productivity of the vegetation over a given period. A linear regression at the pixel level is established to identify the areas changing primary productivity. A positive trend in NDVI would indicate potential improvement in land conditions while a negative trend would mean potential land degradation (trends. earth, 2021).

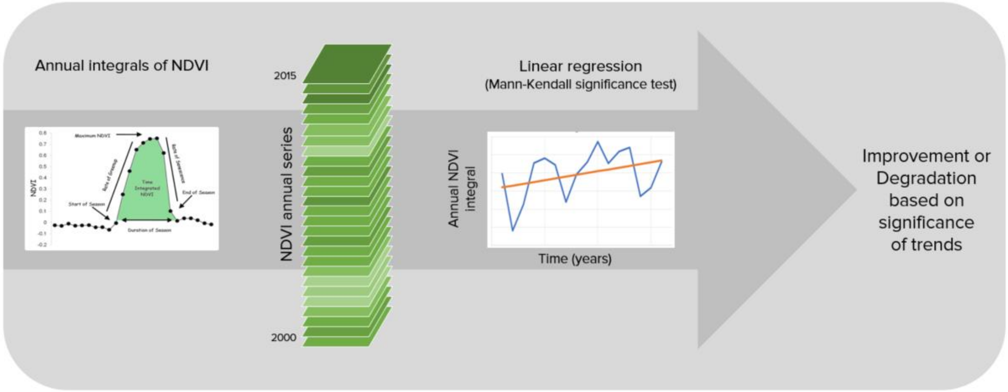


Figure 2.7 The NDVI trajectory over the monitoring period, (Trends. Earth, 2021)

State

The productivity state indicator is used to determine the recent changes in primary productivity in comparison with the set baseline period. It is calculated by definition of the baseline and comparison period for monitoring. Each pixel of the baseline NDVI is then used to compute the frequency distribution. Mean NDVI for the baseline is then computed and assigned the percentile that corresponds to the percentile class with 1 being the lowest and 10 the highest. The same computation is done for the comparison year and the percentile class they belong to. A comparison is done between the pixel values of the baseline and the comparison period. If the value is <2, it would indicate recent improvement however, if it is >2 it would mean degradation (trends.earth, 2021).

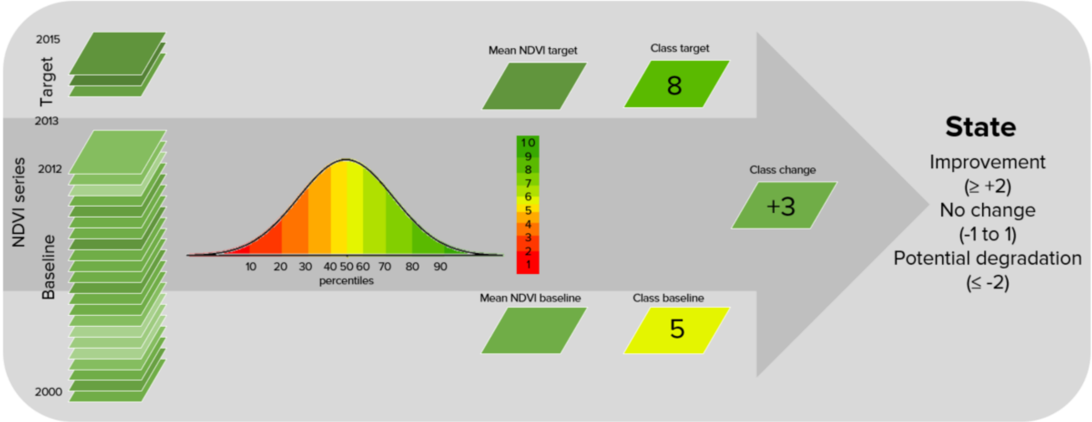


Figure 2.8 The state of NDVI over the monitoring period, (Trends. Earth, 2021)

Performance

The productivity performance indicator is used to measure the relativity of the vegetation under study with other vegetation with similar land cover types or bioclimatic regions throughout the study area (trends. earth, 2021). The productivity indicator is calculated by defining the analysis period and a mean of the time series for the NDVI is computed for each pixel. Similar ecological units with the unique intersection of land cover and soil type are then defined. For each unit, mean NDVI is extracted to calculate the frequency distribution with the values previously calculated. The value representing the 90th percentile will be considered as the highest productivity unit. If the observed mean NDVI is lower than 50% than the maximum productivity, that pixel is considered degraded.

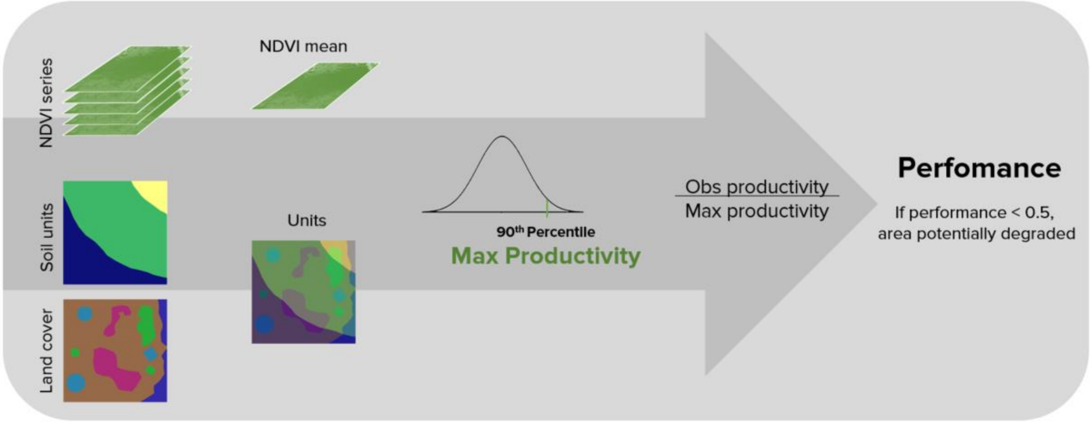


Figure 2.9 The NDVI Performance over the monitoring period, (Trends. Earth, 2021)

2.5.3 Change in Soil Organic Carbon

The final sub-indicator for monitoring LDN is the change in soil organic carbon (SOC) over the monitoring period. This is a difficult indicator to calculate its change due to variability of the soil properties, cost and time taken to conduct representative for soil surveys (Gonzalez-Roglich, et al., 2019). To overcome these challenges land cover methods can be used to estimate changes in SOC and identify degraded areas (trends. earth, 2021). This indicator can be calculated by determining the SOC reference values using soil grids for the first 30cm of the soil profile as the reference values for calculations. The land cover maps for the start and final year for monitoring are then reclassified into 7 land cover classes including grassland, forest, cropland, wetland, artificial areas, bare land and water. To compute the change in carbon stocks for the monitoring period, the coefficient for changes in land use, management and inputs are provided by UNCCD.

The relative difference in SOC between the baseline and the target year is expressed as a loss of 10% of SOC or less. Areas with more than 10% will be interpreted as potentially improved.

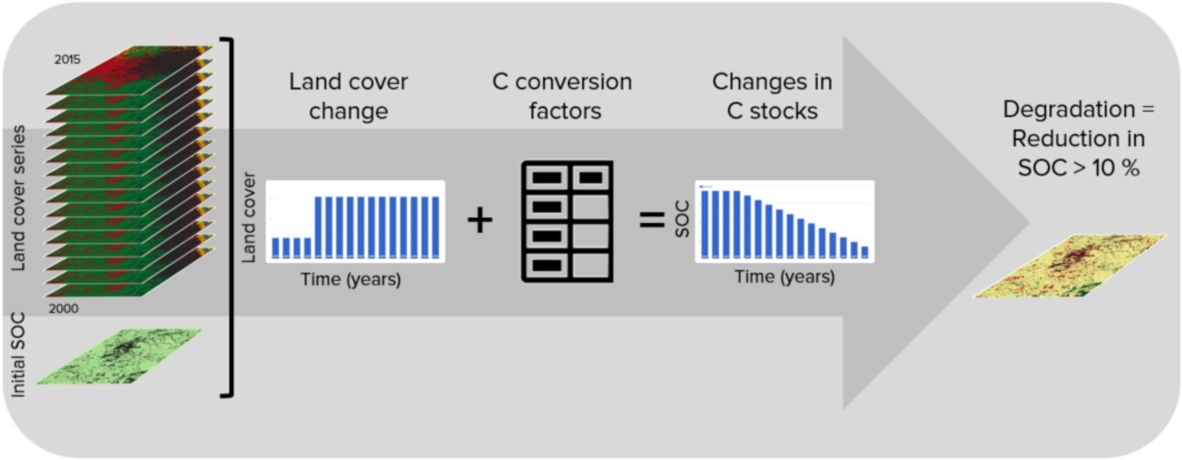


Figure 2.10 The Change in Soil Organic Carbon calculation, (Trends. Earth, 2021)

2.6 Monitoring Period for Land Degradation Neutrality

The monitoring periods for land degradation Neutrality is proposed to be at least 12 years (UNCCD, 2017). This is sufficient time to measure the change in indicators since it allows for a whole generation of most vegetation cover to grow to a level that can be monitored using satellite sensors. This study used the period between 2001 and 2018 to monitor land degradation in Narok.

2.7 The role of Geospatial Technologies in Monitoring Land Degradation

The application of GIS and Remote sensing techniques in monitoring land degradation neutrality estimates the areas that are degraded, improving and stable to be more feasible (Reddy & Kumar, 2018). It provides reasonable costs and high accuracy in large spatial areas.

The use of multispectral satellite data has shown great potential in deriving information on the extent, spatial distribution, nature and magnitude of various kinds of the phenomenon being observed including land degradation. The advantages of monitoring land degradation using remote sensing are magnificent and timely for the achievement of the SDGs. They include having explicit spatial data with near real-time resolution. In this study, the application of remote sensing and GIS in assessing and mapping the land degradation status of Narok county has been carried out and discussed.

Data from three satellite sensors have been explicitly used in this study. Landsat satellite sensor data has been used to extract changes in land cover. Soil Grids from ISRIC sensor has been used to extract change in soil organic carbon and MODIS satellite sensor data to extract the change in NDVI information which is a proxy for net land productivity to monitor land degradation has immense potential for assessment of land degradation at local scales.

2.8 Conceptual Model

The criteria for monitoring land degradation neutrality in Narok was identified to involve using a combination of customized landcover datasets and globally available datasets on land productivity and soil organic carbon as sub-indicators.

These data were to be collected from both the USGS website portal for Landsat data and google earth engine for both land productivity data and soil organic carbon through trend. earth model.

The base year for the monitoring period was to be used as the independent variable since any land degradation change would be measured against it. The annual data for the subsequent years from 2001 to 2018 would be the dependent variables since the change recorded on them would inform the trend on land degradation status which was the gist of this study.

This rate of change on the dependent variable would be analysed through the trends. earth model, GIS and excel to generate the figures and finally present the results.

Figure 2.11 shows the conceptual model that was used to guide the decisions taken regarding the scope of monitoring land degradation neutrality in Narok.

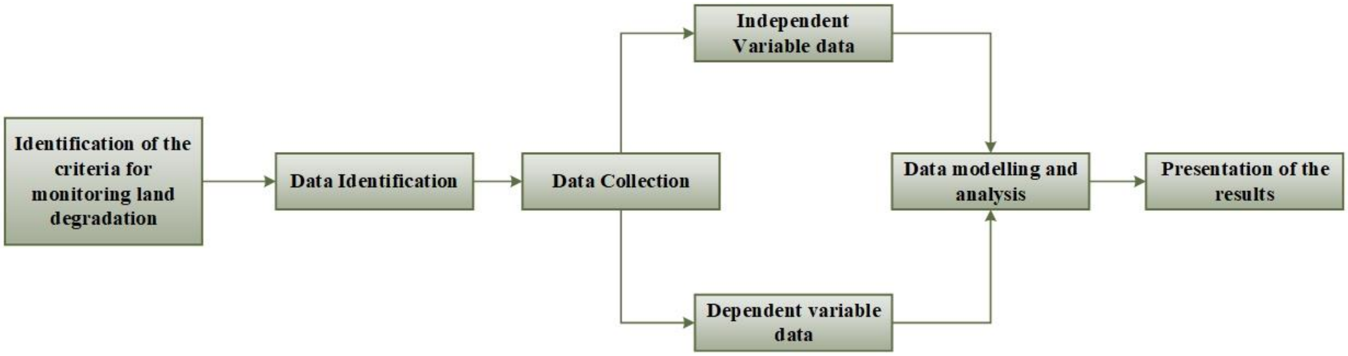


Figure 2.11 The conceptual model (Author,2021)

CHAPTER 3: MATERIALS AND METHODS

3.1 Introduction

This chapter covers the study area, datasets and their sources, cleaning process and analysis methods and techniques that were used to achieve the set objectives of this study.

3.2 Study area

The study area was Narok county, which is located 120 km West of Nairobi, the capital city of Kenya. It is found in the Great Rift Valley and it lies between latitudes 0˚ 50′ and 1˚ 50′ South and longitude 35˚ 28′ and 36˚ 25′ East, as shown in figure 3.1. The county covers an approximate total area of 17921 km^2 and has a total population of 1.158 million people according to the 2019 census. The county borders the Republic of Tanzania to the south and six other counties in Kenya i.e., Nakuru, Bomet, Nyamira, Kisii, Migori and Kajiado.

The county has a rich natural ecological system that the residents depend on for agriculture and water. The main economic activities include wheat farming, pastoralism, tourism, trade and gold mining. Masai Mara National Reserve where the great wildebeest migration, one of the seven wonders of the world is located within its borders in the southern part. Mau forest, a national water tower is also partly within Narok county in the Northern part.

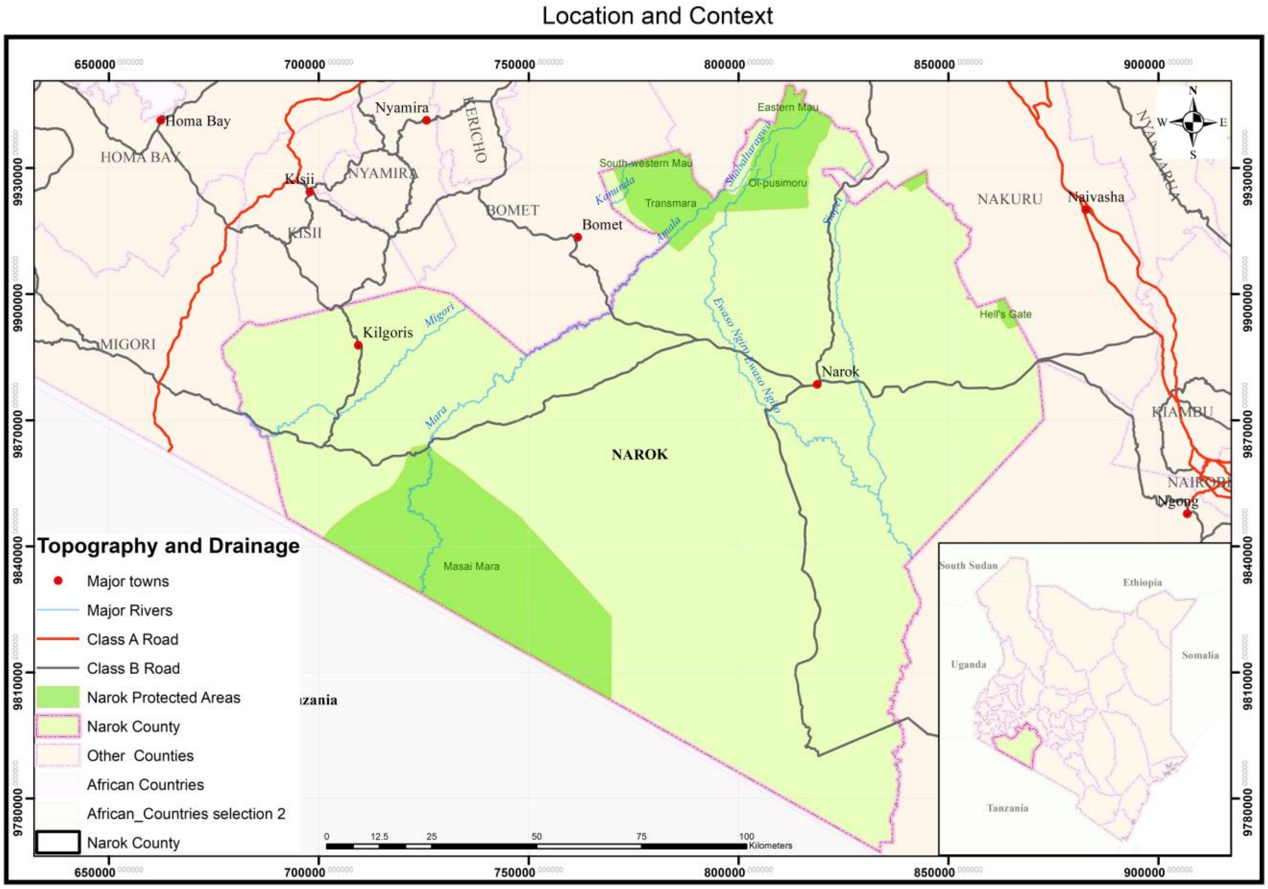


Figure 3.1: Location and Context of the Study Area, (Author,2021)

3.3 Narok Physiography

Narok County is part of the ASAL region in Kenya. It however has two main ecological zones. The highlands of Mau with an altitude of 3100m above sea level is located on the North-western side while the rest of the county comprises lowlands covered by bushlands, shrubs and grasslands.

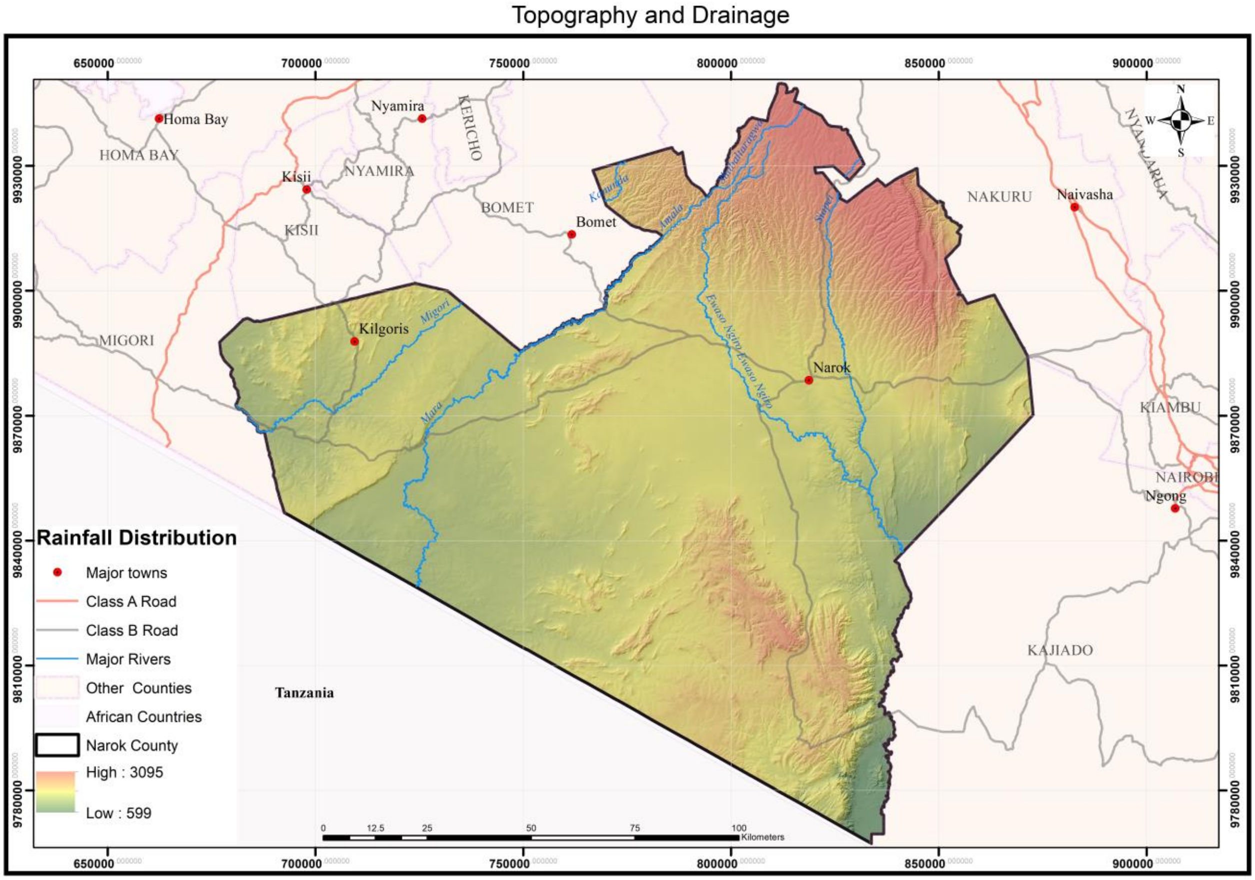


Figure 3.2: Topography and the drainage basins in Narok county, (Author,2021)

The highlands are the source of many rivers e.g., Mara, Mogor, Narok Enkare traversing the county and supporting the ecosystems as they flow to Lake Victoria and Lake Natron. The county's altitude and physical features are the main influence on its climatic conditions (Ngaruiya & Muithui, 2016).

The high temperature in Narok County normally ranges from 20˚C between the months of January to March. The low temperatures are experienced between the months of June-September at 10-20 ˚C.

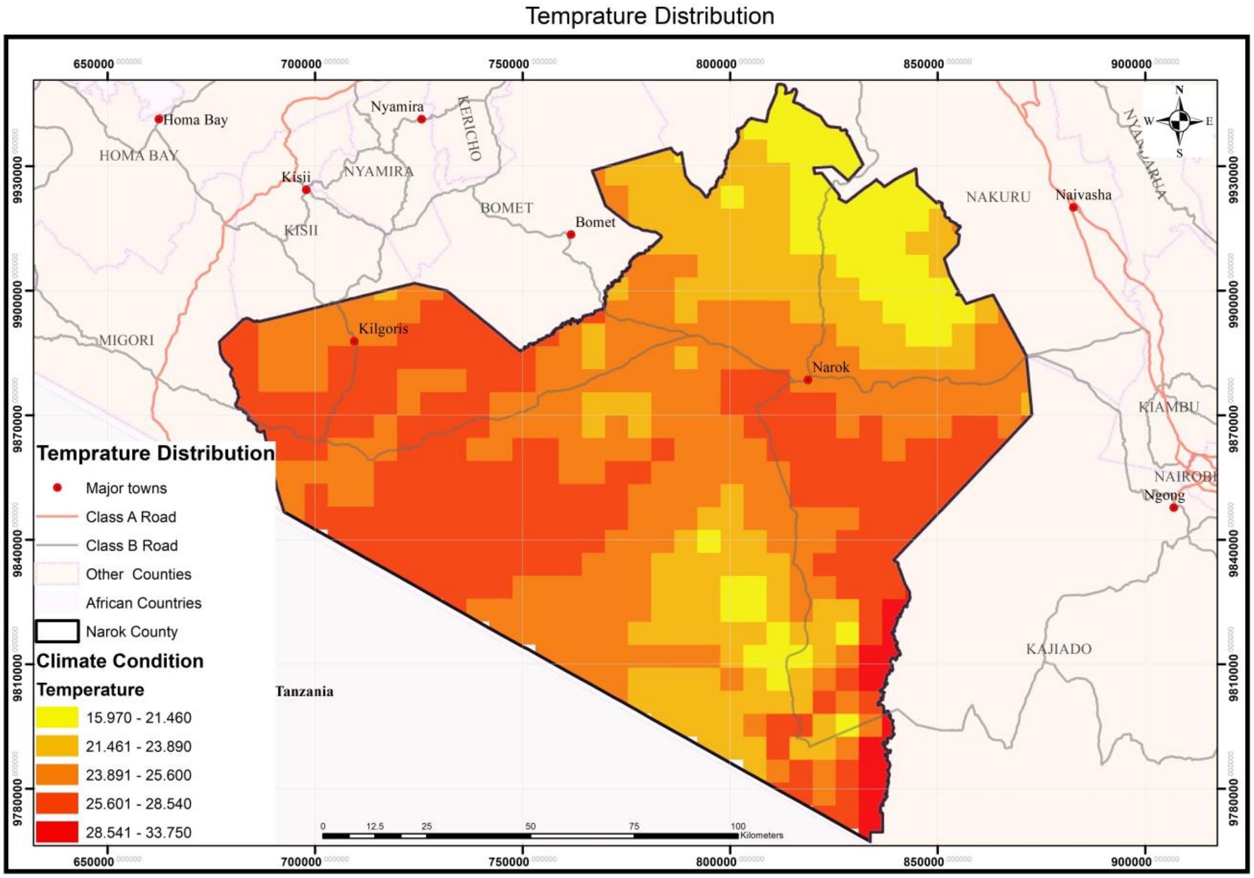


Figure 3.3: Distribution of temperature in Narok county, (Author,2021)

The rainfall experienced in Narok is bimodal with long rainfall occurring between February to June while short rainfall is between August to November with an average of 2,500mm and 450mm respectively and an annual average of 771mm (National Drought Management Authority, 2018).

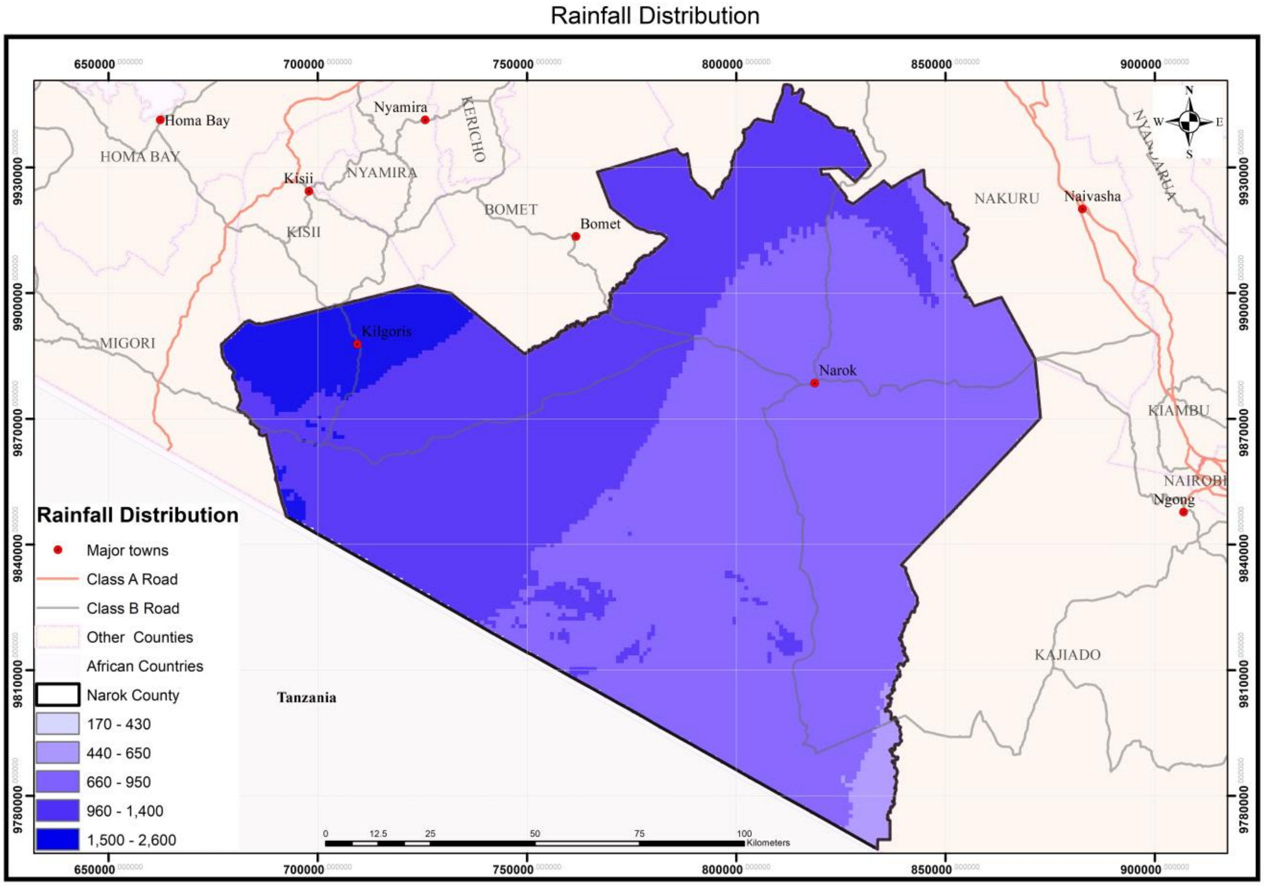


Figure 3.4: Distribution of rainfall in Narok county, (Author,2021)

3.4 Population growth and change in livelihood activities

In 2001, the population of Narok district currently Narok county was 623,123 this then had 85% increased to 1,157,873 in 20018 (KNBS,2021). This change in population shows that the number of people living in Narok almost doubled during the monitoring period of this study from 2001 and 2018. This population growth led to increased pressure on land in Narok to enhance its productivity potential in delivering the goods and services to support the increased demand for high quality and nutritious food, animal feeds and fibre to support the increased population.

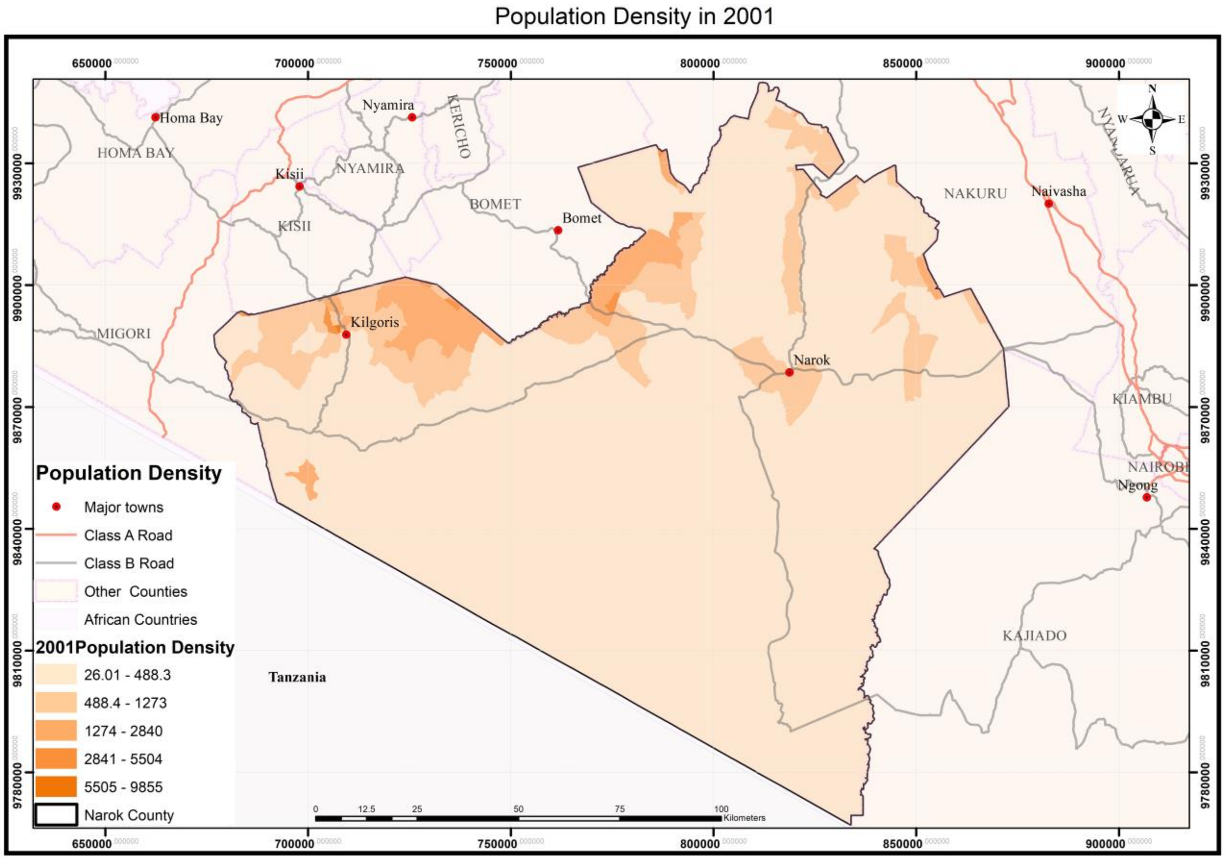


Figure 3.5: Narok County Population Density for the year 2001, (Author,2021)

Additionally, the dominant community living in Narok County traditionally owned the land communally and practised livestock keeping as a source of livelihood in the rangelands. However, these rangelands have been subdivided into individual ranches limiting the mobility of the livestock (UNDP 2021). Consequently, it has led to overgrazing as increased pressure is put on ranches to provide pasture for the livestock.

The rate of poverty in the county has also prompted the community to cut down indigenous tree species for charcoal production (Othieno, 2014). Some pastoral and forest lands have also been transformed into farmlands. This increased extraction of resources from the land in Narok without equivalent restoration activities has made land in Narok County to be vulnerable to soil erosion, low productivity, loss of biodiversity, depletion of soil nutrients and other forms of land degradation.

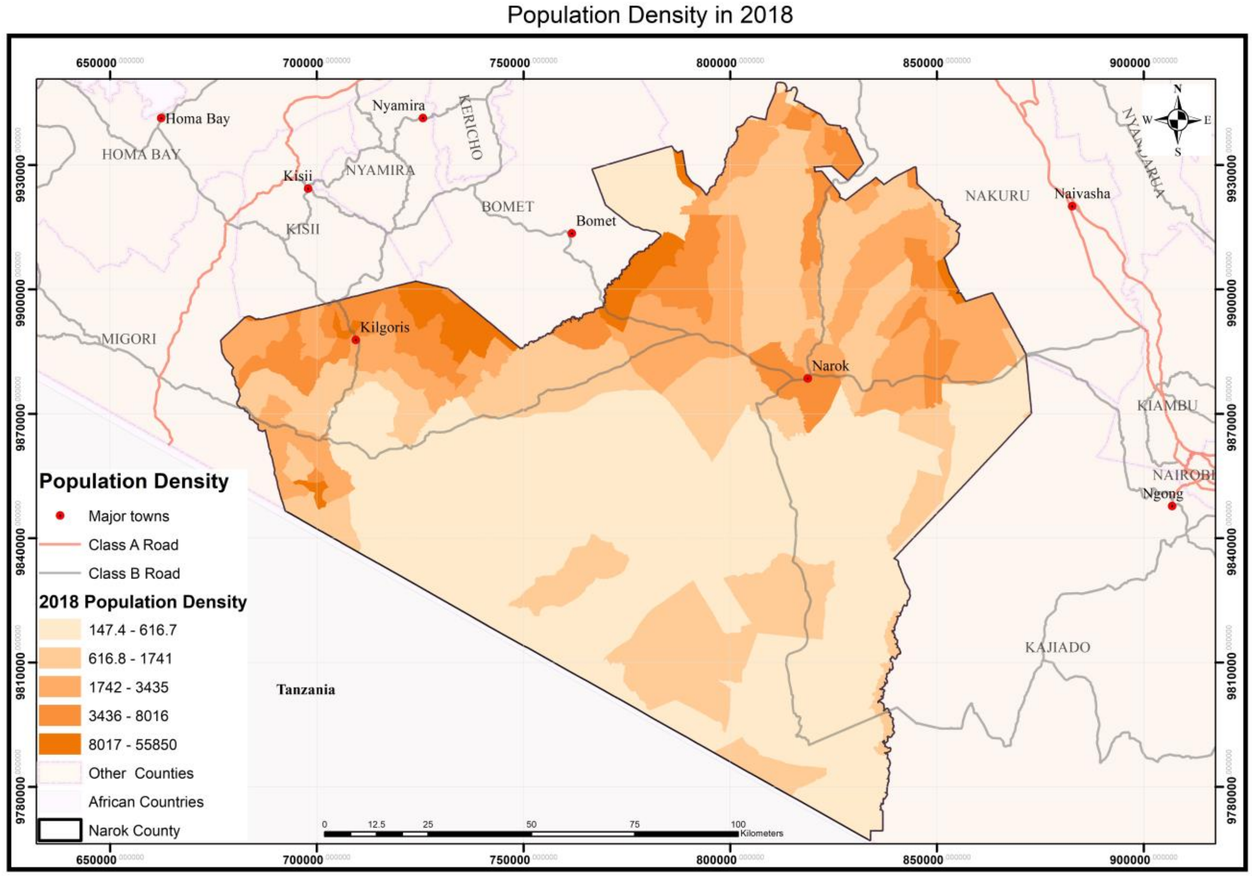


Figure 3.6: Narok County Population Density for the year 2018, (Author,2021)

3.5 Research Instrument

The following software and applications were used to conduct this project

1. ArcMap 10.8: This is software by Esri GIS that is used to manage, analyze, process and visualize spatial data and information.
2. QGIS: This is a free and open-source cross-platform desktop geographic information system application that supports viewing, editing and analysis of geospatial data.
3. Microsoft office word; This is an application by Microsoft that was used to document and compile the report.
4. Microsoft Excel: This is another Microsoft application that was used to carry out the statistical analysis of the land degradation quantities and changes in monitoring indicators.
5. Microsoft Office PowerPoint: This is the final Microsoft application that was used to present the study process and findings to the examination panel.

3.6 Data Sources and Tools

3.6.1 Data Sources

The following were the sources of data that were used in this study.

No.	Data	Data Sources	Data Specifications/Characteristics
1	Landsat Medium Resolution Satellite Imagery Data (2001 and 2018)	USGS portal	**Landsat Image 2001** Acquisition date; April 2001 Sensor name; Landsat-7 Cell size 30,30 Research Area; 17921km

			Landsat Image 2018 Acquisition date; April 2018 Sensor name; Landsat-8 Cell size 30,30 Research Area; 17921km
2	Administrative boundary	Survey of Kenya	Vector (polygon)
3	DEM (SRTM)	USGS portal	SRTM dataset Resolution; 30m horizontal and 10m vertical
4	Kenya Climate Surface Data	Kenya Metrological department and Kenya Agricultural Research Organization (KALRO)	Monthly climate data. 30m grid
5	Net Primary Productivity	European Joint Commission on Research Center	Variable; NDVI Sensor name; MOD13Q1-coll6 Units; Mean annual NDVI Spatial resolution ; 250m
	Soil Organic Carbon	International Soil Reference and	Soil Grid

		Information Center	Spatial resolution; 250m carbon stocks for the 30cm of the soil profile
6.	Narok Population data	Kenya National Bureau of Statistics (KNBS)	Projected census data for the years 1999 and 2009

3.6.2 Tools

The following tools were used to collect data for this research.

1. Trend. Earth: This is a QGIS plugin tool for monitoring land change using earth observation in an innovative desktop and cloud-based system.
2. Google Earth Engine: Is an application platform for scientific analysis and visualization of geospatial datasets, for academic, nonprofit business and government users.

3.7 Mapping of Degraded Land in Narok County

To determine the proportion of land that is degraded in Narok, the Data-Information-Knowledge- Wisdom (DIKW) approach was used in this study. Different components were organized into a workflow that enhanced flexibility (Different data sources), scalability (different scales from County, National to global) to effectively monitor the environment. The study also applied the SDG indicator framework (UNCCD, 2018a) and the implementation of good practice guidance (UNCCD, 2017) by the United Nations Convention to Combat Desertification.

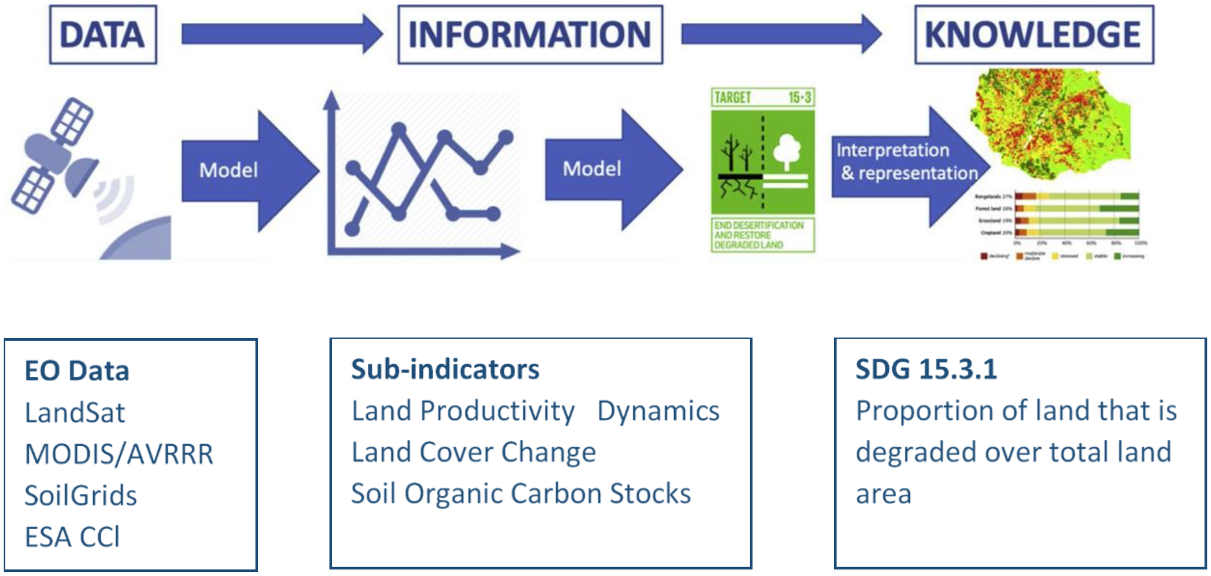


*Figure 3.5: Product and services for the Proposed workflow (*Giuliani, et al., 2020)

3.8 Research methodology flow Chart

The DIKW diagram above was actualized through a research methodology flow chart. The monitoring period was set to be between the years 2001 being the base year recommended for monitoring by the UNCCD and the year 2018 due to the availability of data. 2001 was therefore the base year upon which the amount of change in terms of land cover, land productivity and soil organic carbon was to be monitored. The study used the pre-processed Landsat dataset to create land cover sub-indicator datasets for the analysis. Land productivity indicator was obtained from the European Joint Commission on Research Centre. Soil Organic Carbon was obtained from International Soil Reference and Information Centre. Google Earth Engine was deployed to run the time-series datasets from Trends. Earth plugin tool in QGIS. The three indicators were analyzed to determine the area of Narok county which has been degraded, stable and finally the areas which have been improving to help the decision-makers to enforce appropriate sustainable land management (SLM) policies and programs. Figure 3.6 shows the methodological framework used in this study.

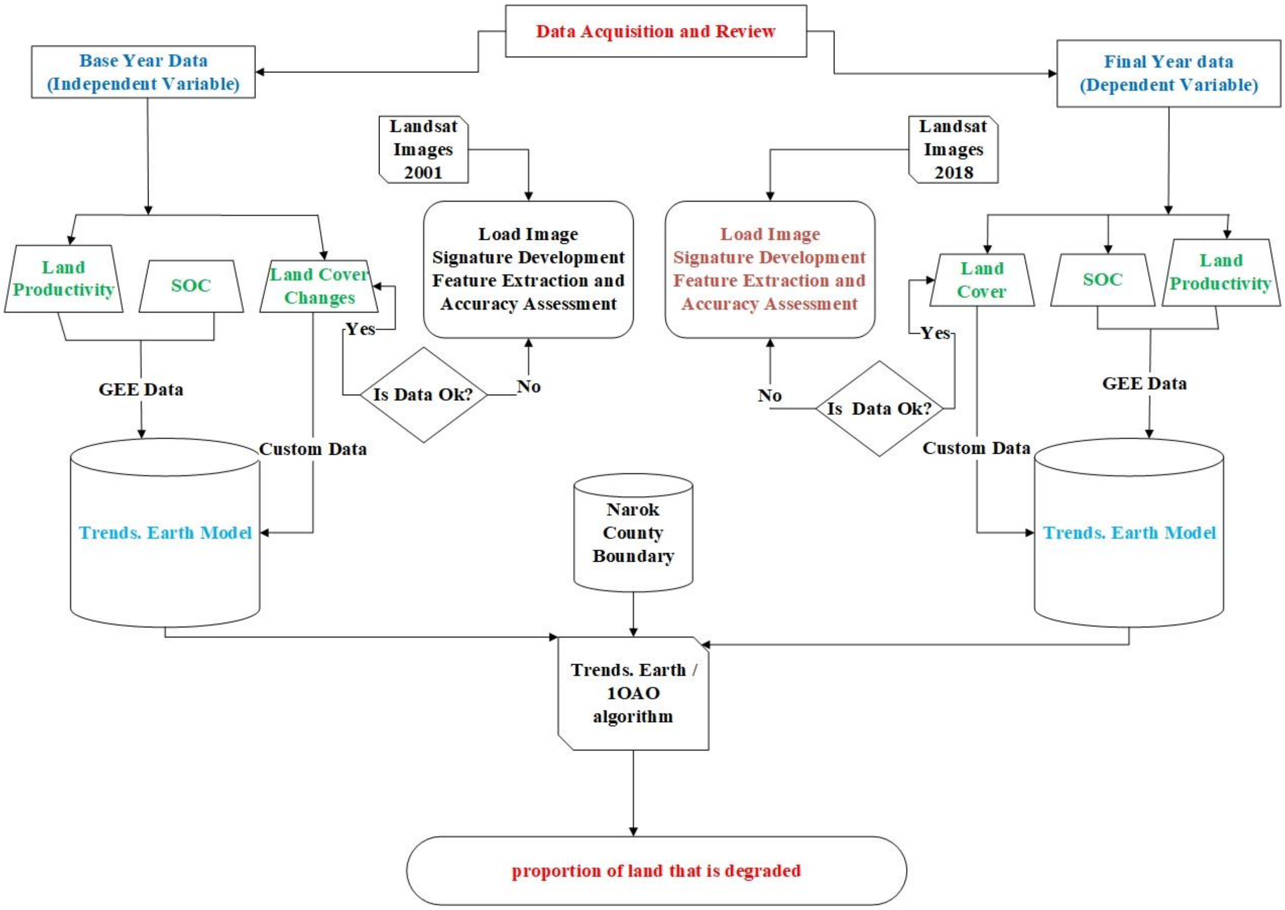


Figure 3.6: Methodology framework, (Author,2021)

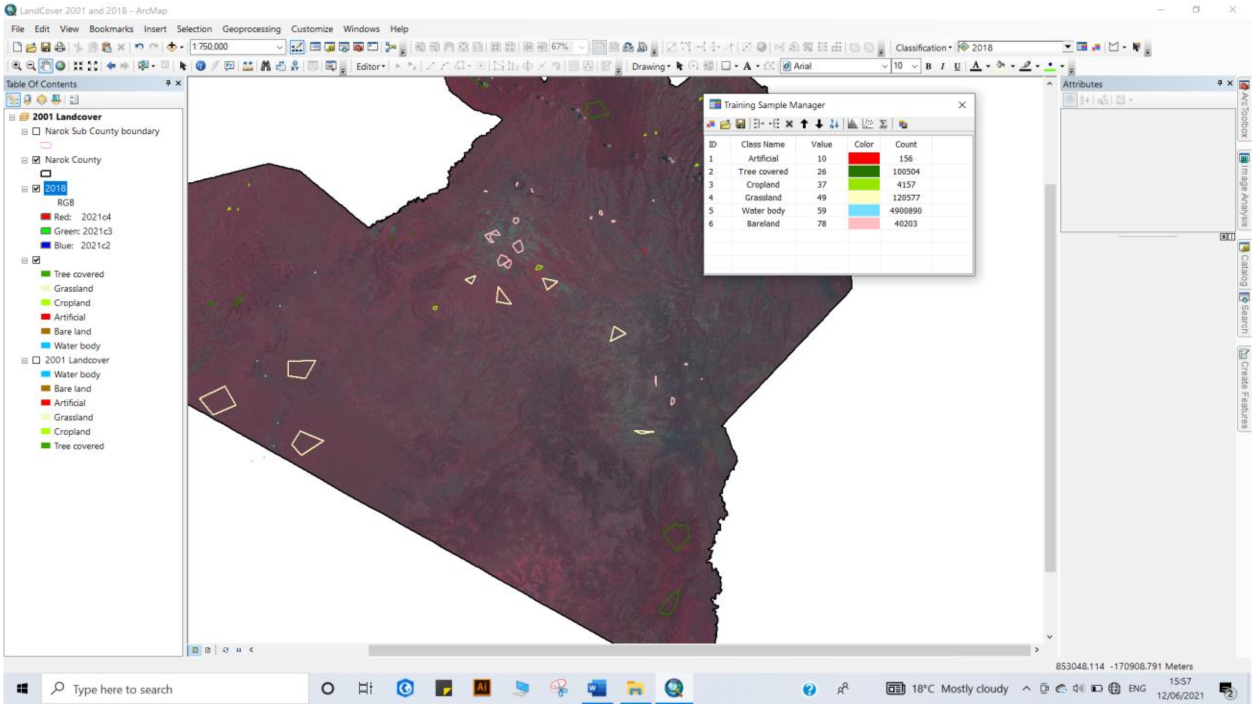
3.9 Geoinformation for Monitoring Land Degradation

The recommended sub-indicators for monitoring land degradation neutrality by the UNCCD are change in land cover, change in land productivity and change in soil organic carbon. All the three sub-indicators are spatial in nature and could be extracted from the existing earth observation datasets.

3.9.1 Change in Land Cover Indicator

3.9.1.1 Supervised Classification

The land cover indicators were extracted from the Landsat7 and Landsat 8 satellite images for the years 2001 and 2018 respectively. A supervised classification method was used to determine which feature is covering which part of the county. Seven classes which are recommended by the good practice guide book by UNCCD were used. These include; 1. Tree-covered areas, 2. Grasslands, 3. Croplands, 4. Wetlands, 5. Artificial areas, 6. Other land and 7. No data. The spectral signatures for the recommended categories were developed and then the GIS software assigned each pixel in the image to the type of cover that is most comparable. The supervised classification method was preferred because it is most frequently used in quantitative remote sensing analysis of the image datasets. A maximum likelihood classification algorithm was applied under this supervised classification after training samples were developed. More than one training sample was developed for each land cover class.



ID	Class Name	Value	Color	Count
1	Artificial	10	🟥	156
2	Tree covered	26	🟩	100504
3	Cropland	37	🟩	4157
4	Grassland	49	🟨	120577
5	Water body	59	🟦	4900890
6	Bareland	78	🟥	40203

Figure 3.7: Land Cover for maps generation process for the base year and the target year of the monitoring period, (Author,2021)

3.9.1.2 Accuracy assessment

A confusion matrix tool was used in ArcMap to confirm the accuracy of the classification before the compilation of the land cover maps. 360 reference points for each land cover classification were picked randomly on the image used for classification. This was then used to calculate the user accuracy, producer accuracy and overall accuracy. This process was repeated severally until a workable accuracy of 87% for the base year and 92% for the final year were achieved.

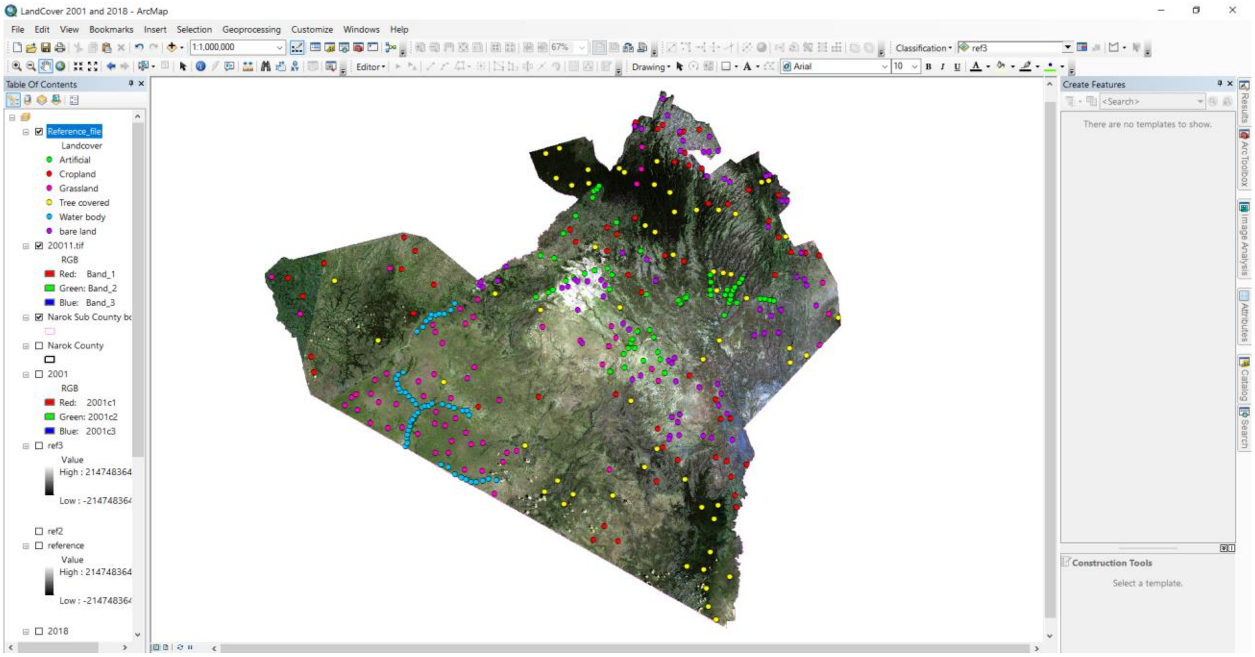
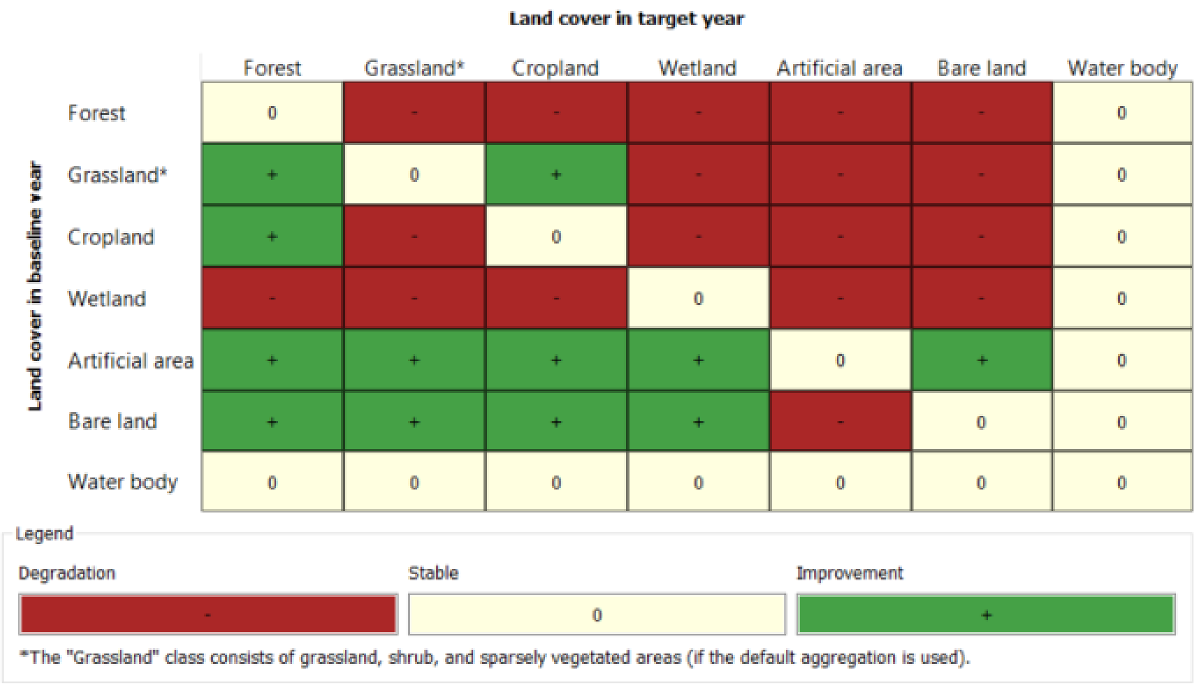


Figure 3.8: Sample reference points for the accuracy Assessment, (Author,2021)

3.9.1.3 Land cover transition matrix

To get the amount of change, the land cover maps loaded in QGIS were the Trends. Earth plugin was used to calculate the change in land cover. A transition matrix provided by the UNCCD in the scientific framework document is part of the plug-in development and was used to determine the change in land cover.

Using the local knowledge of Narok County, it was easy to determine which changes have taken place as; degraded stable or improved () using -, 0 or + conditions respectively. For instance, if the area was forested land in the base year and in the target year the land cover was found to have changed into agriculture then the area was considered to have declined. However, if the area was grassland in the base year but was found to be cropland that was considered to be stable since the area is a wheat-growing zone and wheat have a spectral reflectance that can be similar to grassland under Landsat image.



Land cover in target year

Land cover in baseline year

	Forest	Grassland*	Cropland	Wetland	Artificial area	Bare land	Water body
Forest	0	-	-	-	-	-	0
Grassland*	+	0	+	-	-	-	0
Cropland	+	-	0	-	-	-	0
Wetland	-	-	-	0	-	-	0
Artificial area	+	+	+	+	0	+	0
Bare land	+	+	+	+	-	0	0
Water body	0	0	0	0	0	0	0

Legend

Degradation	Stable	Improvement
-	0	+

*The "Grassland" class consists of grassland, shrub, and sparsely vegetated areas (if the default aggregation is used).

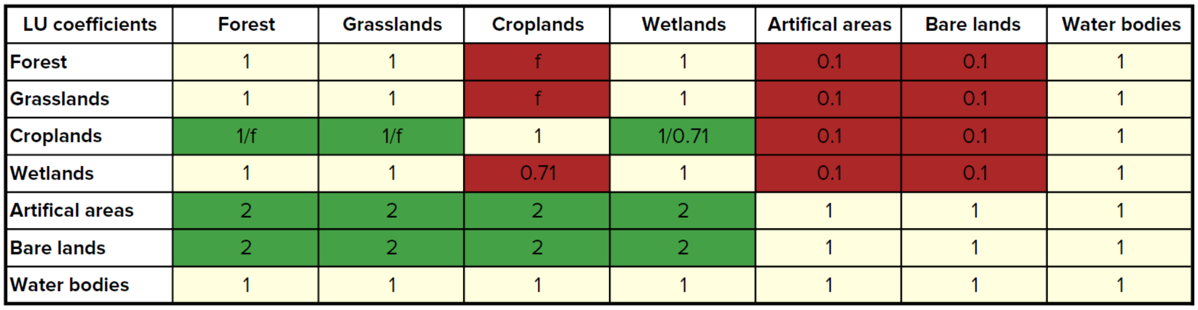
Figure 3.8: Land cover change matrix, (trends. earth, 2021)

3.9.2 Change Land Productivity Indicator

Assessing the change in land productivity was measured using change indicators from the NDVI time-series data comprising the trajectory, state and performance. The results from the three sub-indicators were then combined to inform the type of land degradation occurring in the area. The land productivity dataset was obtained from European Joint Commission on Research Center through GEE and Trends. Earth plugin automatically combined the three sub-indicators of trajectory, performance and state and gave the analysis-ready land productivity change output over the monitoring period.

3.9.3 Change in Soil Organic Carbon Indicator

The final sub-indicator for monitoring LDN is the change in soil organic carbon (SOC) over the monitoring period. This indicator was calculated by determining the SOC reference values using soil grids from International Soil Reference and Information Center through Google Earth Engine (GEE) and Trend. Earth. The first 30cm of the soil profile were used as the reference values for calculations. The land cover maps for the start and final year for the monitoring period were then reclassified into 7 land cover classes including grassland, forest, cropland, wetland, artificial areas, bare land and water. The provided coefficient for SOC changes by the UNCCD was used to determine the change in SOC. The relative difference in SOC between the baseline and the target year is expressed as a loss of 10% of SOC or less. Areas with more than 10% were interpreted as potentially improved. Below is the SOC change calculation matrix with the coefficients.



LU coefficients	Forest	Grasslands	Croplands	Wetlands	Artifical areas	Bare lands	Water bodies
Forest	1	1	f	1	0.1	0.1	1
Grasslands	1	1	f	1	0.1	0.1	1
Croplands	1/f	1/f	1	1/0.71	0.1	0.1	1
Wetlands	1	1	0.71	1	0.1	0.1	1
Artifical areas	2	2	2	2	1	1	1
Bare lands	2	2	2	2	1	1	1
Water bodies	1	1	1	1	1	1	1

Figure 3.9: The Soil Organic Carbon transition matrix, (Trends. Earth, 2021)

3.10 Modelling of the Land Degradation Neutrality status in Narok County

To Quantify the land degradation status of Narok County, the change in land cover, land productivity and soil organic carbon indicators obtained in the above processes were run in the Trends. Earth model in QGIS.The examination of the changes and trends of each sub-indicators were key in determining the final output for the status of land degradation in Narok. The three sub-indicators were responsive to different elements of degradation. This was to determine whether a given area of land is degraded, stable or improving.

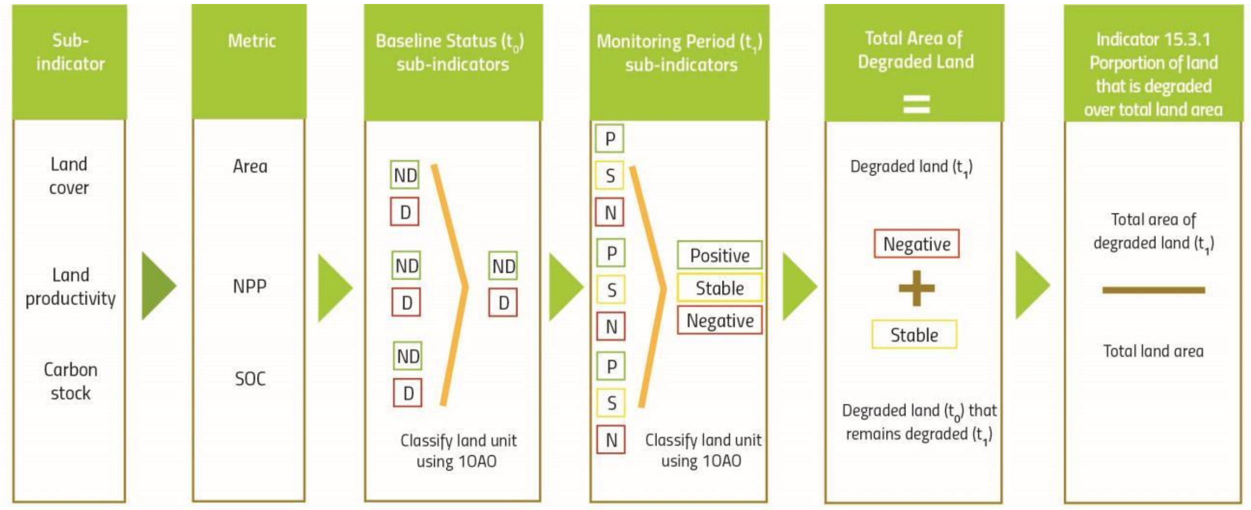


Figure 3.10: LDN indicators overlay analysis matrix using 1OAO principle, *(UNCCD, 2017)*

The principle of One Out, All Out **(1OAO)** was applied (trends. earth, 2021). This meant that when the value of one sub-indicator in a pixel is negative, then the unit pixel is considered degraded. This was applied as a precautionary condition because a positive result from the other two sub-indicators for that particular cell may not have counterbalanced the degradation effect in the negative indicator

CHAPTER 4: RESULTS AND DISCUSSIONS

This chapter consists of the results obtained. And how they contributed towards achieving the main objective of this study.

4.1 Land Cover

Land cover is the physical material on the surface of the earth that was observed by the earth observation satellites whose data were used in this study in the years 2001 and 2018. The land cover for Narok was extracted from the Landsat 7 and 8 satellite imagery through the maximum likelihood classification method. Figures 4.1 and 4.2 show the results for the years 2001 and 2018 respectively.

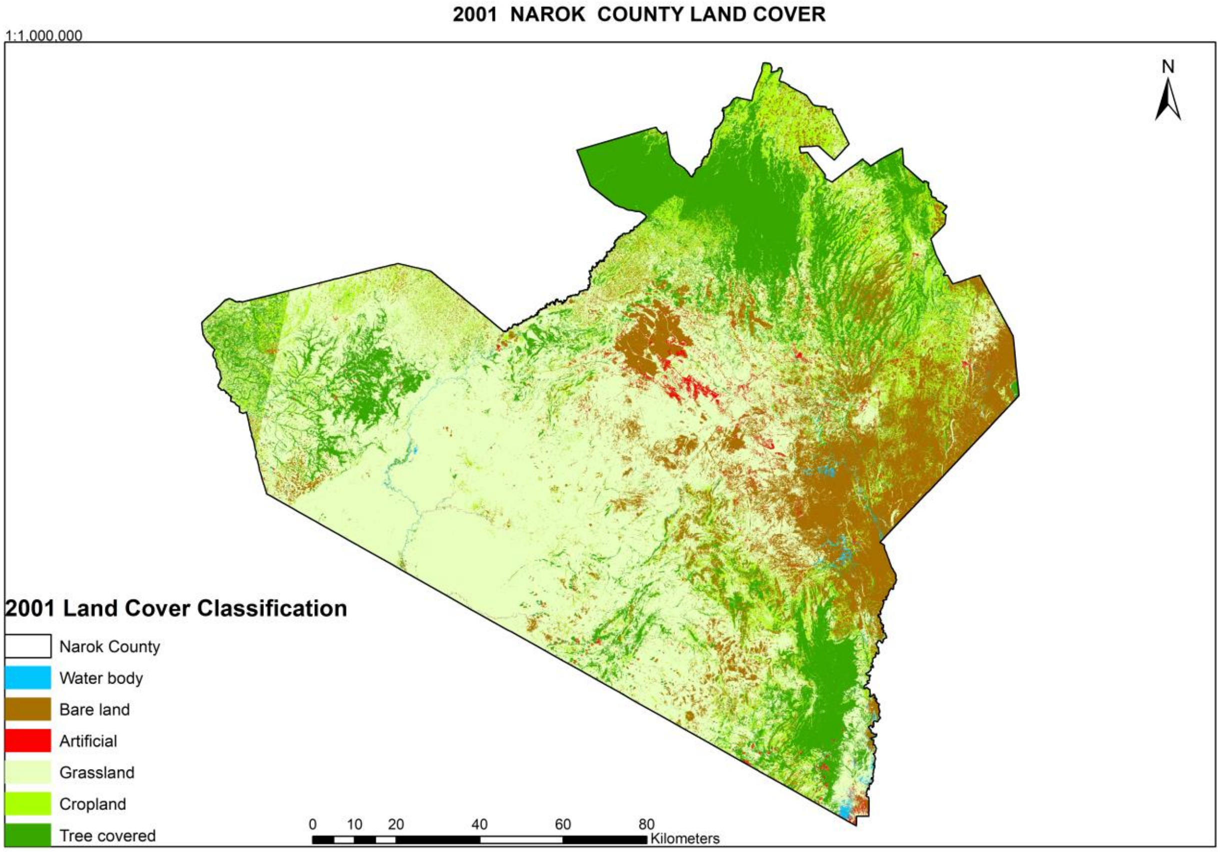


Figure 4.1: A land Cover map for Narok County for the base year of the monitoring period, (Author, 2021)

Figure 4.1 shows that tree cover dominates to the north, south and western areas whereas the central part is covered by grassland and cropland. Bare land is dominant on the east. The water body and artificial development are along the river lines and major urban centres respectively.

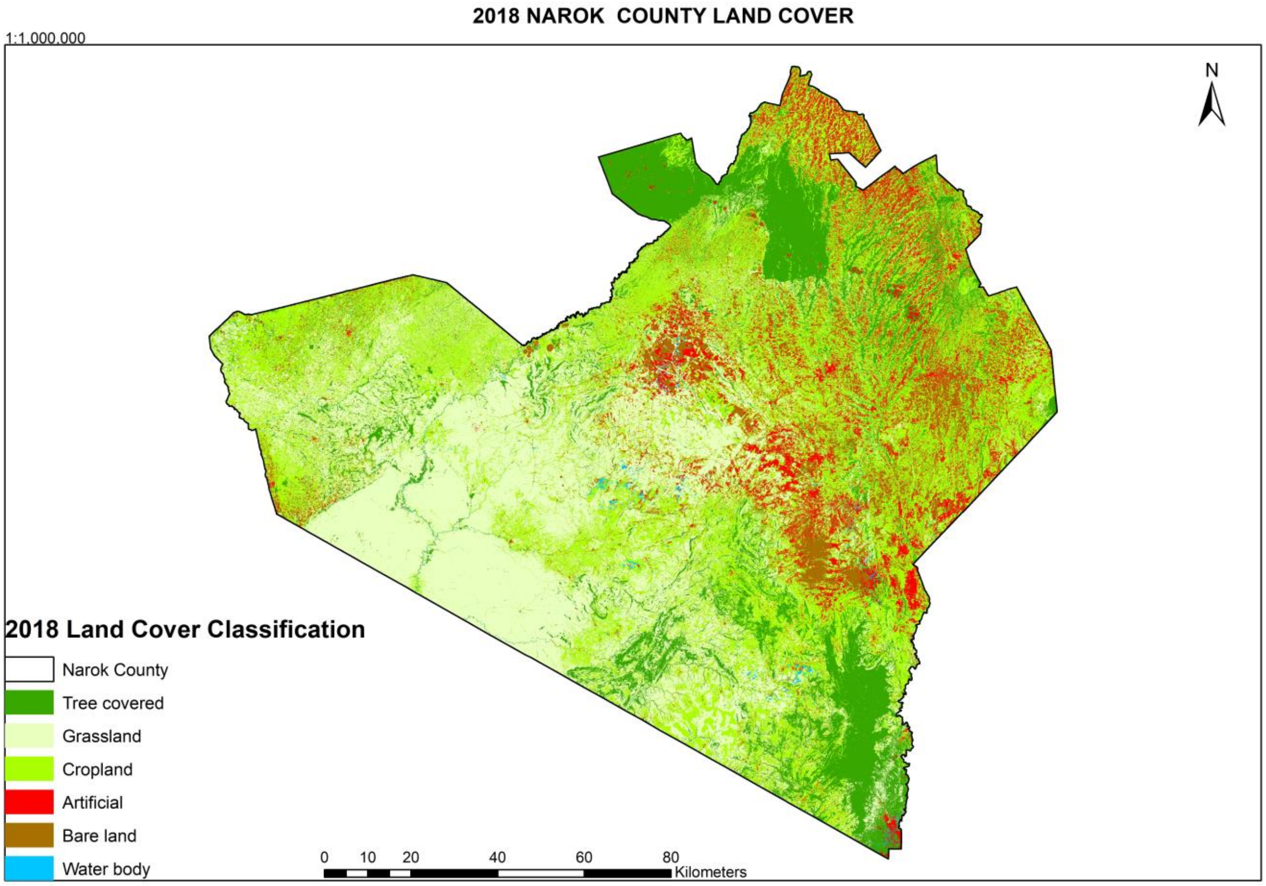


Figure 4.2: A land Cover map for Narok County for the target year of the monitoring period, (Author, 2021)

Figure 4.2 shows that tree cover dominates to the north, south and small areas to the west and east. The central part is covered by grassland and cropland which has replaced most tree-covered areas which were noted in figure 4.1. Bare land has also been reduced and only have little patches. The water body and artificial development are along the river lines and major urban centres respectively. It is also noted that the area under artificial development has also increased significantly due to the increase in human population and activities. The impact of increased human activity was earlier identified as the main cause of land degradation in Narok.

4.1.1 Change in Land Cover

The two land cover layers were put through the land cover change matrix as explained in the methodology chapter to determine the amount of change. Figure 4.3 was the summary of the changes observed.

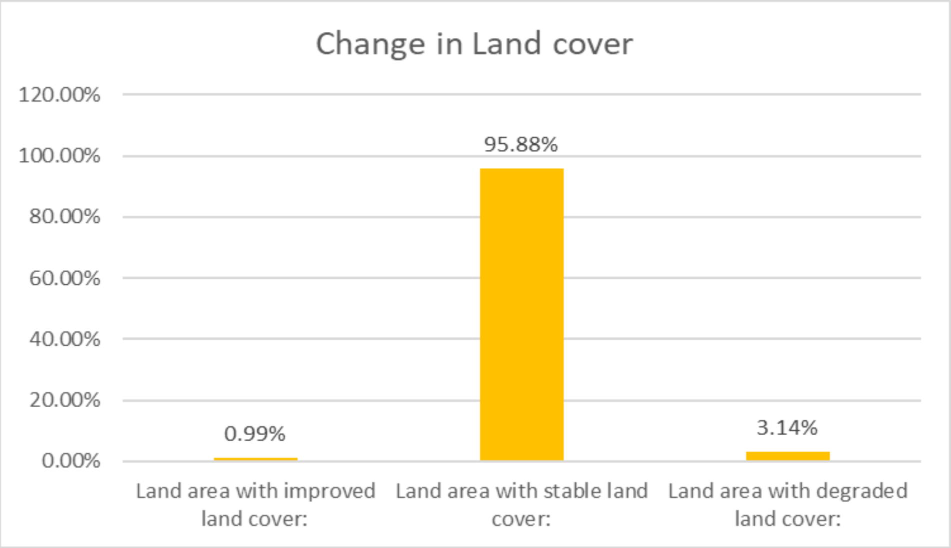


Figure 4.3: A bar graph showing the degradation status from the land cover indicator, (Author, 2021)

It is evident that the county is generally stable with 95.88% of the county have not changed into a land cover that can be termed as improved or degraded. The county also has 3.14% of the total area as degraded and less than 1% has been improved over the 17 years of the monitoring period.

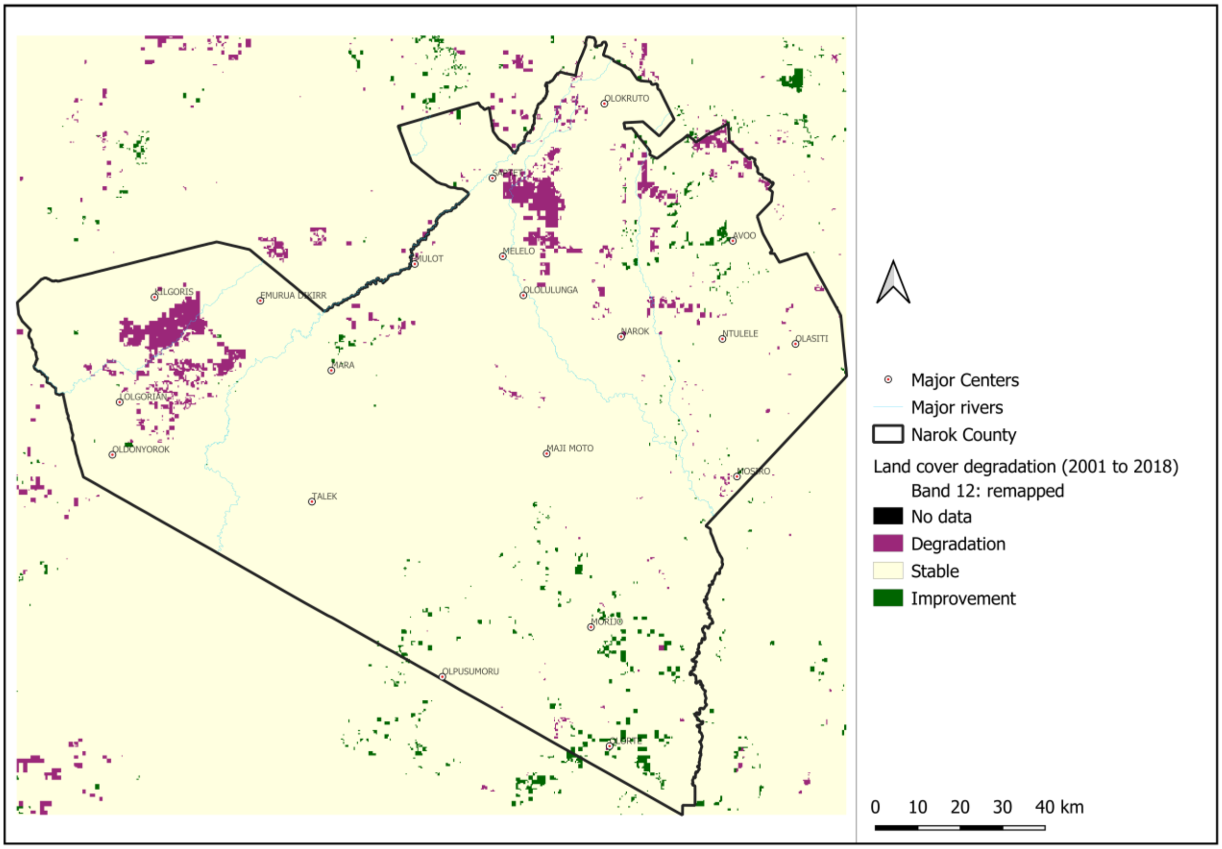


Figure 4.4: A map showing the degradation status from land cover change indicator during the monitoring period, (Author, 2021)

Figure 4.4 showed the spatial location of these changes. It was noted that the negative changes which can eventually result in degraded areas were recorded near the Mau Forest to the north and around the Kilgoris area to the west of the county. This directly relates with the increase in the population density in the two regions while the southern part of the county where the population was not noted to have increased reported stability and improvements.

4.1.2 Trends in Land Cover

Trend analysis report of the areas that have recorded change shows that there has been a significant increase in the croplands area while tree-covered areas have reported a decline. Grassland, artificial areas, wetlands, water bodies and other lands have remained relatively stable.

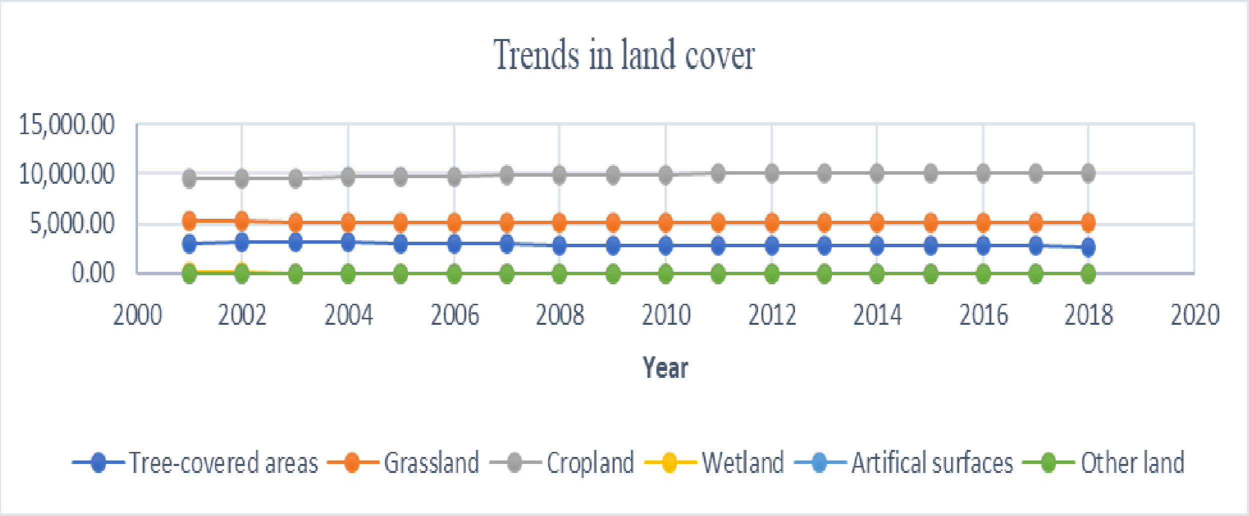


Figure 4.5: A time-series graph showing the change in land cover type over the monitoring period, (Author, 2021)

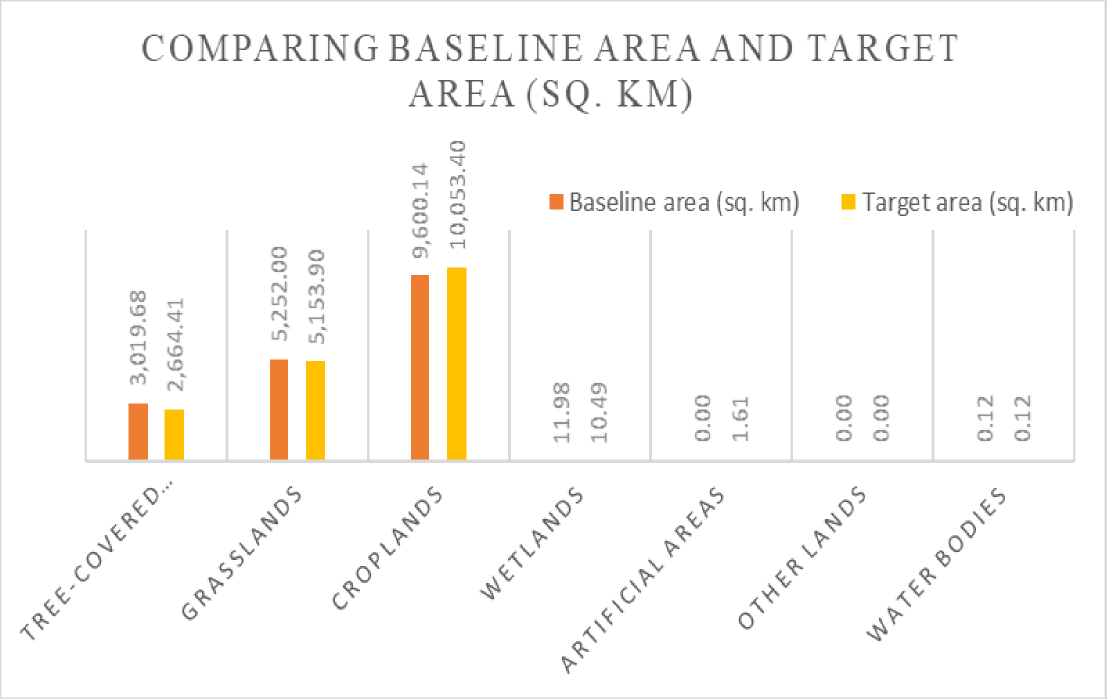


Figure 4.6: A bar graph showing the amount of change in land cover type over the monitoring period, (Author, 2021)

4.2 Land Productivity

Unlike the land cover maps which are discrete, land productivity represents land cover using vegetation density and robustness as a continuous variable indicator. Land productivity indicator shows the ability of a given pixel of land within the study area to support and sustain life thus making it suitable for land degradation monitoring in this study. Land productivity was measured by obtaining data from the time series of the NDVI as explained in the methodology chapter. The result obtained from the time series analysis gave the output for change and trend analysis for the indicator.

4.2.1 Change in Land Productivity

For the Land Productivity indicator, it was noted that significant changes have taken place since 2001. 45.57% of the county have recorded degradation, 3.88% have improved while 55.55% of the county remained stable during the study period.

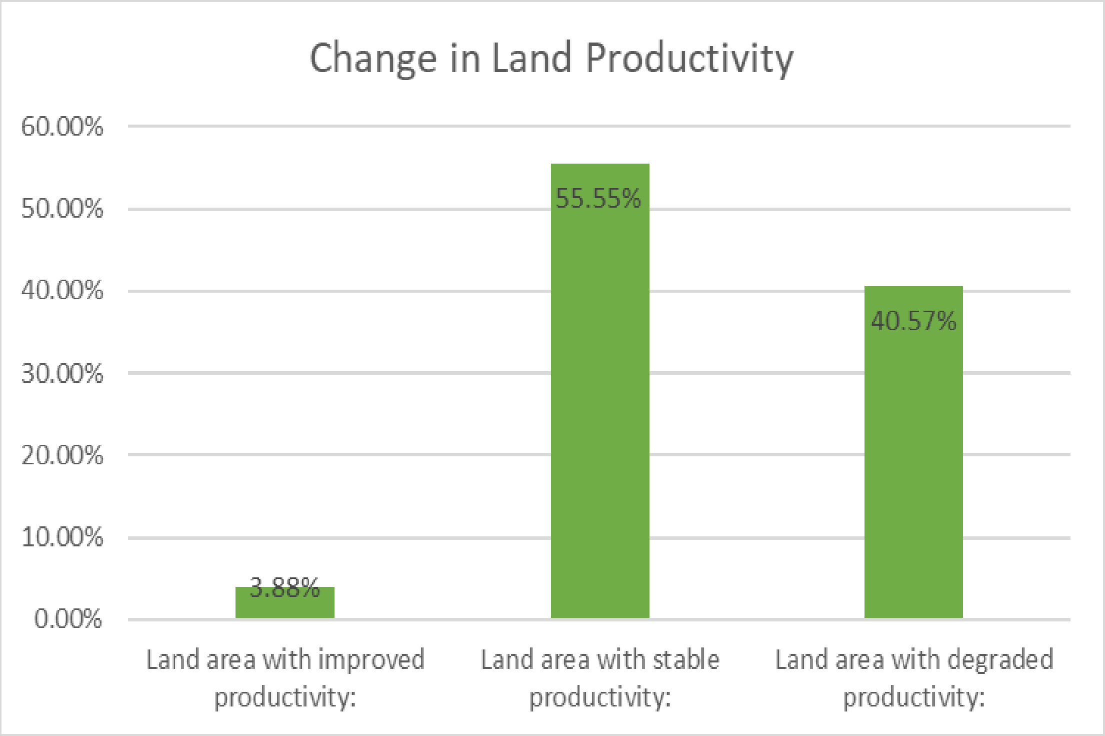


Figure 4.7: *A bar graph showing the degradation status from land productivity indicator, (Author, 2021)*

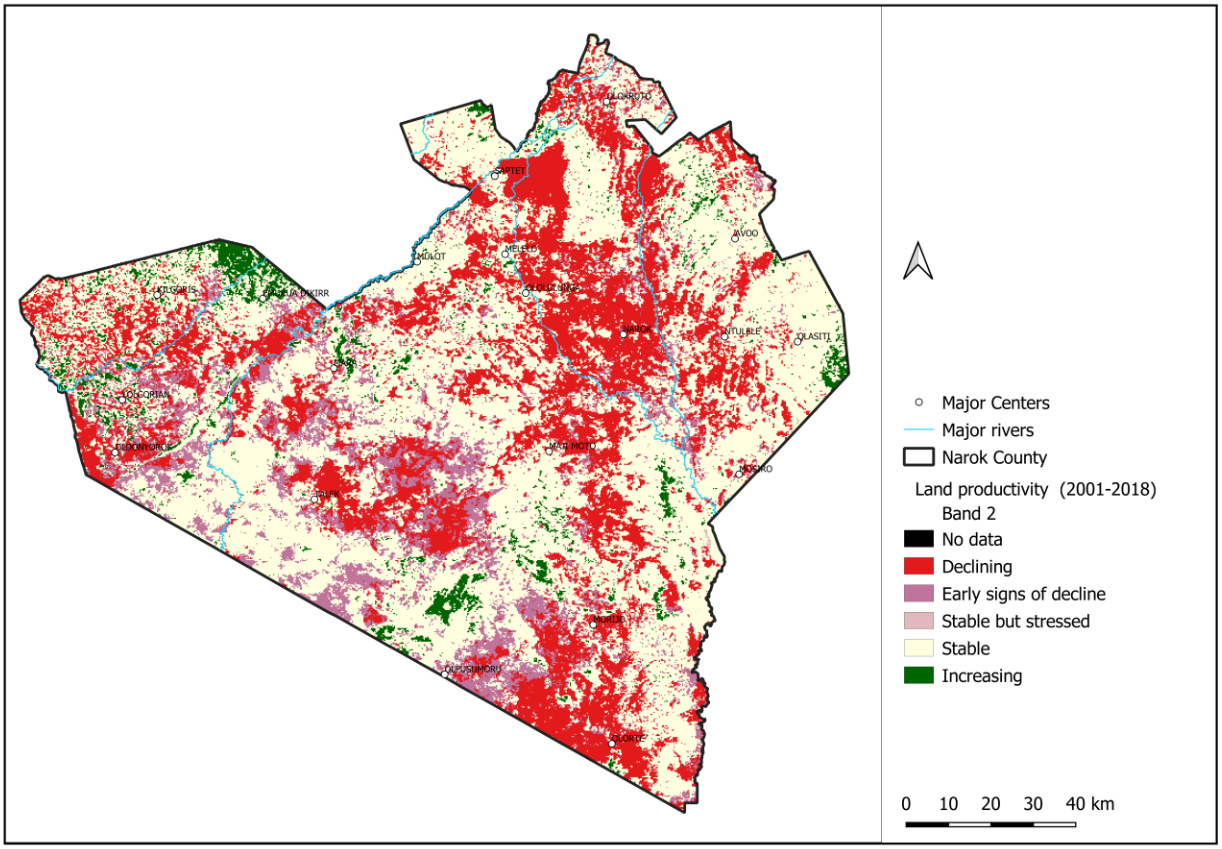


Figure 4.8: A map showing the degradation status from land productivity change indicator during the monitoring period, (Author, 2021)

A map of this change was generated to give the spatial depiction of these areas of the county with different amounts of change. The map in figure 4.8 showed that land productivity has declined towards the Mau forest to the north (areas where forested land is being converted to farmlands), areas around Narok town in the central region (areas where the land cover is changed to urban development areas) and towards the Mau national reserve to the South (areas where overgrazing is taking place).

4.2.3 Trends in Land Productivity

In terms of the trend in land productivity, the result followed the overall land productivity change output. The stable areas are dominating the especially in the areas under agriculture, grassland and forest-covered areas respectively. The stable areas are followed closely by declining areas which are equally present in the agricultural areas, grassland and forest-covered areas. The areas covered by wetlands, artificial and water bodies are stable with no significant change reported.

The land cover types in the graph below are 1. Tree-covered areas, 2. Grasslands, 3. Croplands, 4. Wetlands, 5. Artificial areas, 6. Other lands respectively.

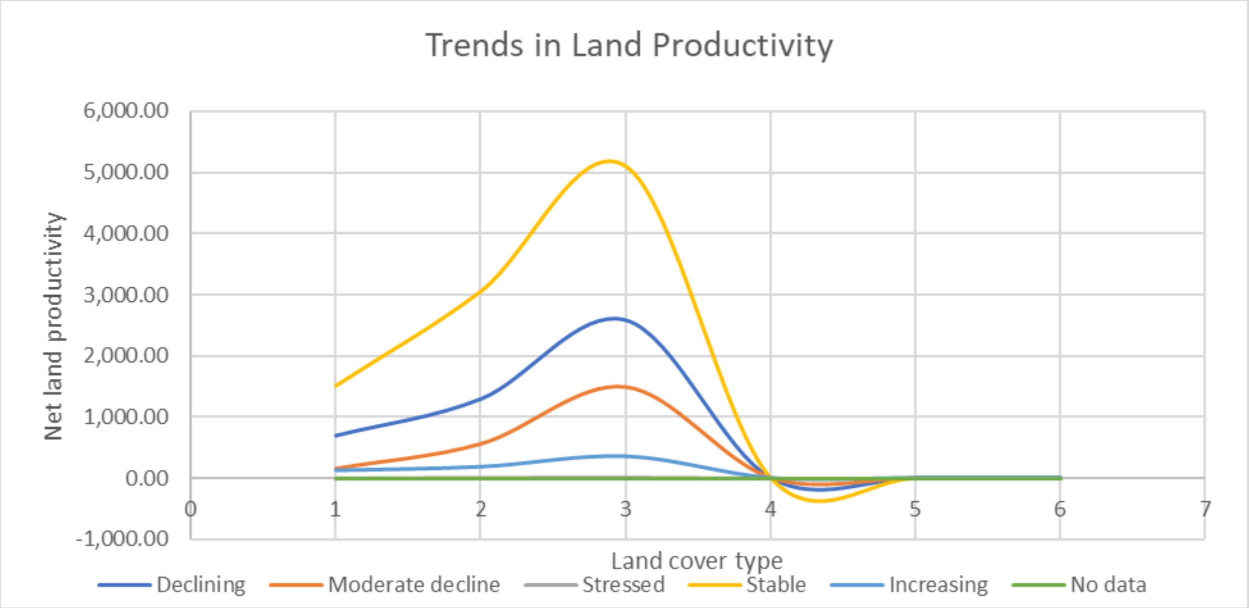


Figure 4.9: A graph showing the net land productivity for each land cover type, (Author, 2021)

4.3 Soil Organic Carbon stock

Soil organic carbon (SOC) is described as the amount of carbon that remains in the soil after the decomposition of the organic material. Loss of SOC not only affects the health of the soil and food production but also increases climate change. Unsustainable land use and management practices may cause SOC loss. Soil Organic Carbon stock information in Narok was measured by obtaining data from the land cover maps for the base year and target year of the monitoring period and then put through a change matrix using the coefficient values provided by the UNCCD in the scientific framework handbook as explained in the methodology chapter. The result obtained from the change matrix gave the output for change and trend analysis for the SOC indicator.

4.3.1 Change in Land Productivity

For the change in soil organic carbon, 98.90% of the county has stable soil organic carbon. 1.04% was found to be degraded while 0.06% was improving.

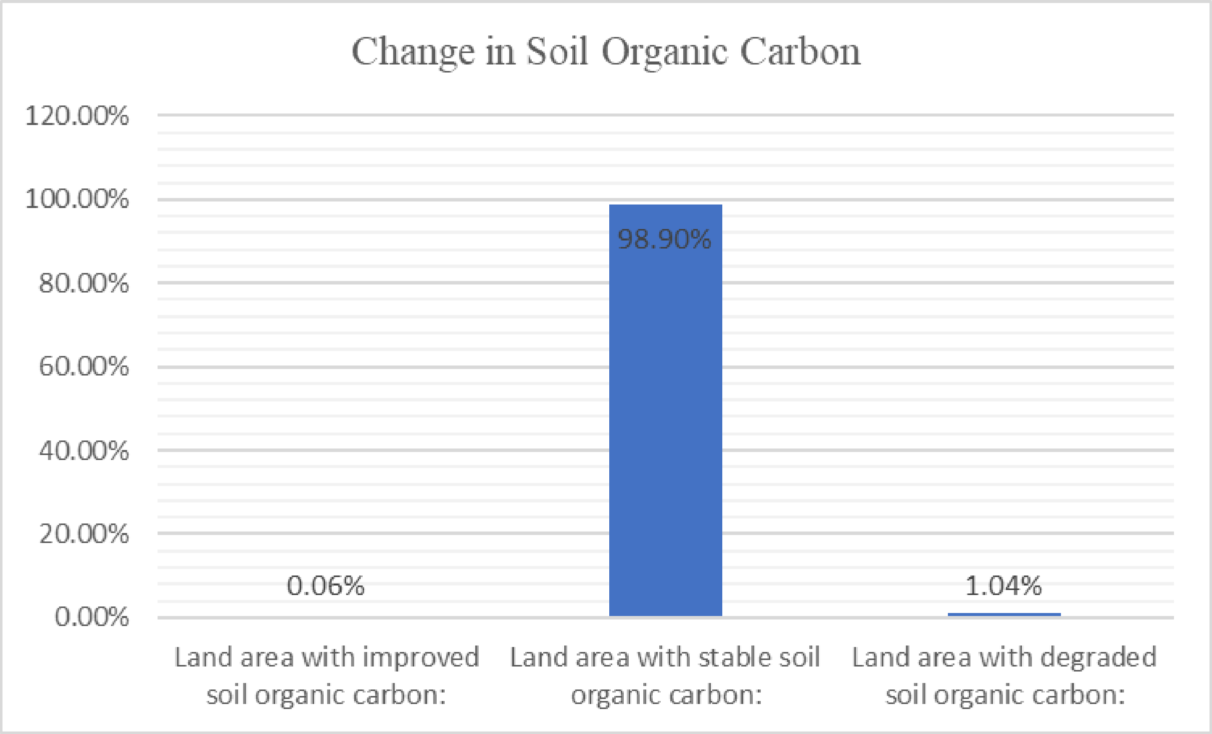


Figure 4.10: A bar graph showing the degradation status from land productivity indicator, (Author, 2021)

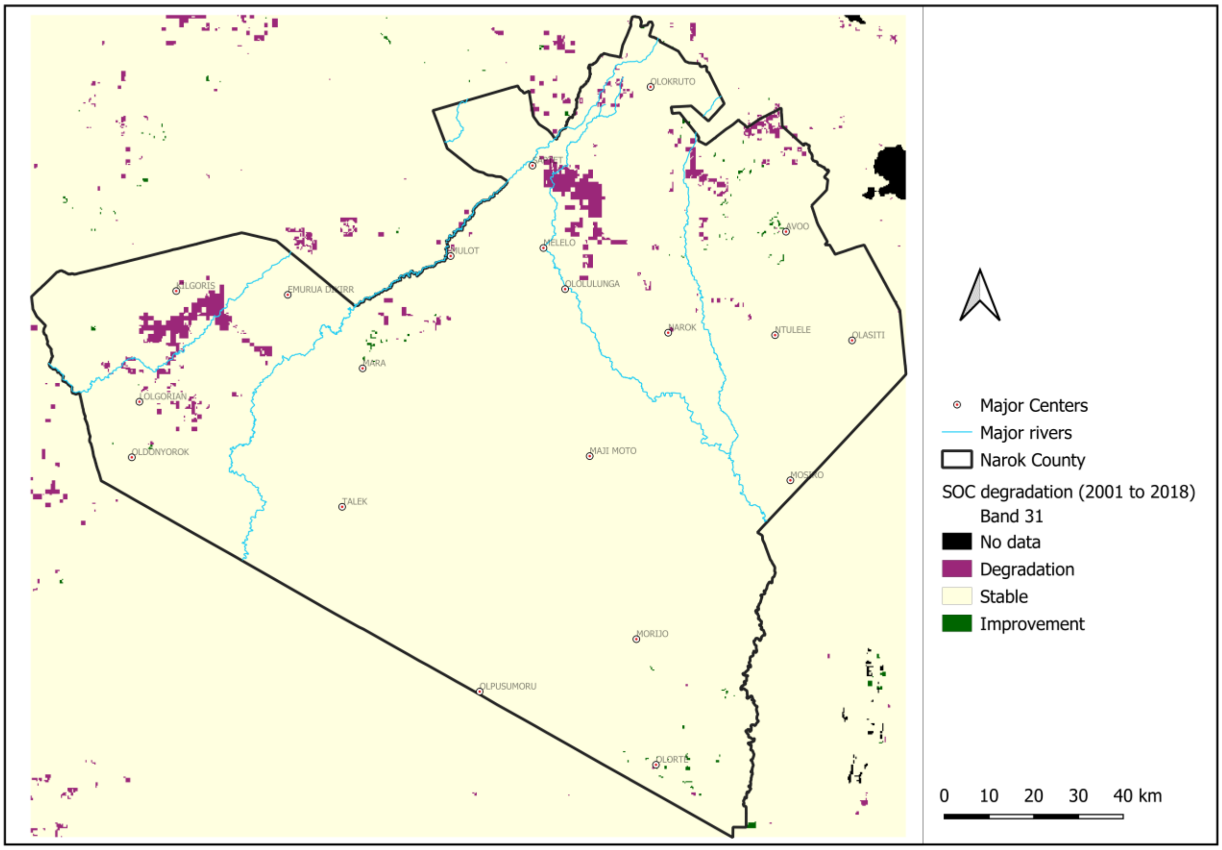


Figure 4.11: A map showing the degradation status from the Soil Organic Carbon change indicator during the monitoring period, (Author, 2021)

Figure 4.11 shows the SOC change indicator which was done to show its spatial distribution. The map showed that most parts of the county were stable during the monitoring period. However, there are patches of degradation around the Mau forest to the north and Kilgoris areas to the west. This result coincides with the change noted in land cover where deforestation, population increase and increase in agricultural activities had affected the land cover of these regions.

4.3.2 Trends in Soil Organic Carbon

The trend for soil organic carbon showed that there is a lot of soil organic carbon in the wetland land covered areas while the artificial land cover areas have the least soil organic carbon since the artificial areas are mostly the built-up areas.

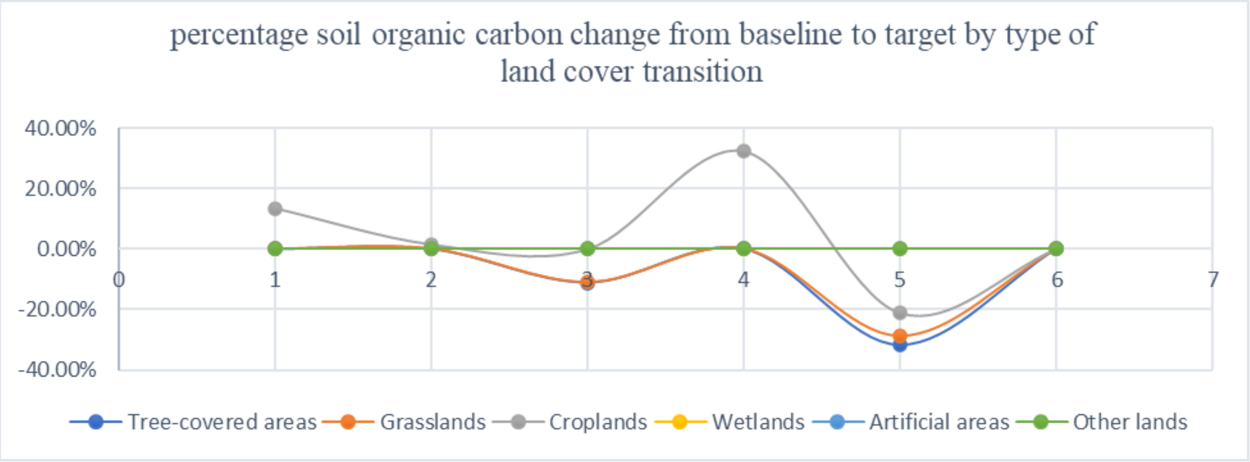


Figure 4.12: A graph showing the change in SOC per land cover type, (Author, 2021)

4.4 Narok Land Degradation Status

The main objective of this study was to Monitor Land Degradation Neutrality (LDN) to support sustainable land management (SLM) practices in Narok County. This was to be achieved by looking at the changes and the trends which have taken place in the monitoring indicators for land degradation. Monitoring the changes on individual indicators alone was not explicitly enough to tell the aggregate level of land degradation due to some inaccuracy that could be present in one indicator. This can be explained further by comparing the changes observed in SOC and that of land productivity. According to the finding based on the SOC indicator, the county is 98% stable and relying on this alone can be misleading because, in terms of land productivity indicator, 40% of the county is already degraded. The study then combined the raster datasets for each indicator using one out all out (1OAO) principle to find the aggregate land degradation status in Narok. The results, therefore, showed that 54.13% of the county is stable, 41.48% of the county is degraded and 4.39% of the county is improving.

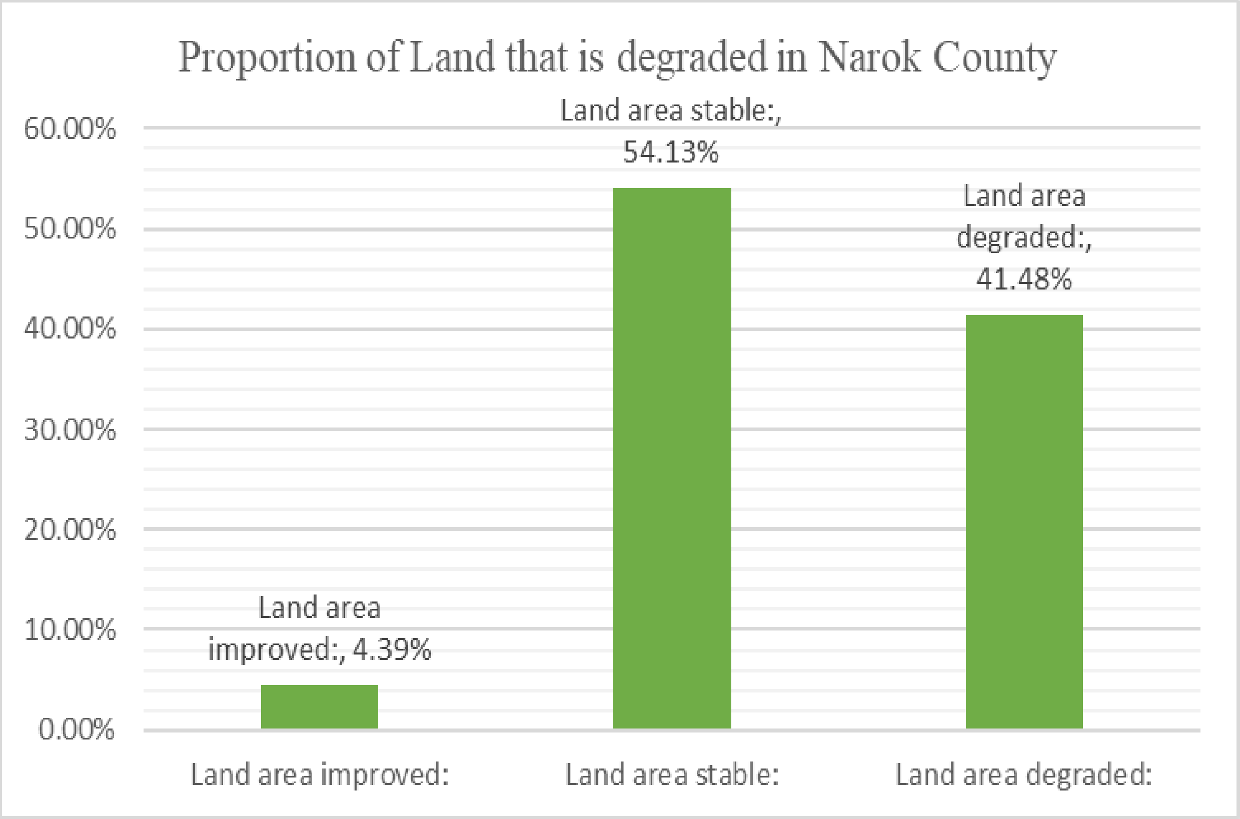


Figure 4.13: A bar graph showing the proportion of land degradation status in Narok County from the combined three sub-indicators, (Author, 2021)

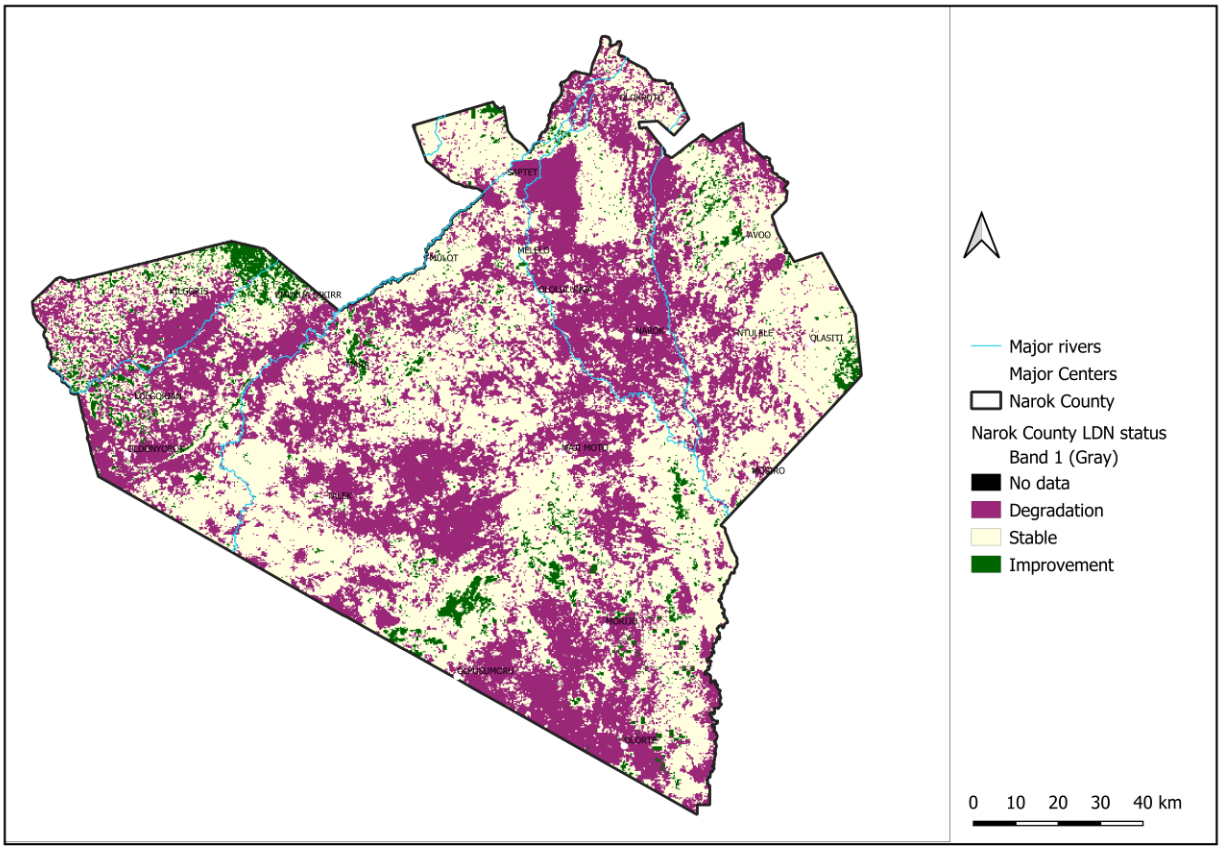


Figure 4.14: A map showing the proportion of land degradation status in Narok County from the combined three sub-indicators, (Author, 2021)

Figure 4.14 shows the spatial distribution of the proportion of land in Narok county that is degraded. The areas of the land cover that were covered by forest were found to be stable or improving. This is because they have high NDVI which provided information on land productivity. They also have a high amount of soil organic carbon from the organic matter present in these areas. The areas which were found to be degraded were observed to have been the areas that were under agriculture, grassland, artificial and bare land covers. These can also be directly linked with the unsustainable land management practices which were identified in the problem statement as the main cause of land degradation in Narok county.

This output can therefore be used by the national government, county government, civil societies and local communities to channel their land rehabilitation and restoration processes in the identified degraded areas by employing sustainable land management practices and techniques.

4.5 Discussion of the Result

The used approach in this project provided a flexible framework for monitoring land degradation neutrality at diverse geographical extents using Geospatial Technologies. The implementation of the methodology was successful and demonstrated the benefits of using trends. earth model including scalability, flexibility, reproducibility and exhaustiveness since the model output is aggregated at the pixel level.

The implementation of the methodology also demonstrated that it can support decision-makers to obtain the required knowledge about land degradation. This is vital to efficiently embed Geospatial Technology in the sustainable land management decision making process.

Finally, having the aggregated results at the pixel level, good support is given to the traditional national statistical data since it helps the users to answer the questions such as how many? Where? and When did the land degradation take place in the study area? These benefits have also demonstrated that EO data can play a very significant function in achieving the SDGs.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study has shown that Geospatial Technologies have a special role in the realization of the SGD goals, especially SDG 15 which deals with life on land. The geospatial technologies have been used to monitored the trends in land degradation in Narok county and identified the areas that are adversely degraded, the stable areas and the areas with improvements.

From the review of the causality of land degradation, it was confirmed that the main cause of land degradation is human activities on land and is intensified by the natural processes. The assessment of these degradations indicated that they are mainly in Africa especially in the southern hemisphere. A region where Narok County is located. Land-use changes and poor land management practices including overgrazing, deforestation and monocultures are the leading human activities in Narok that are fuelling land degradation. The monitoring period to determine the trend in land degradation in Narok was therefore set to be from 2001 to 2018 as recommended by the UNCCD who proposed at least 12 year monitoring period with 2001 being the universal base year.

The geoinformation data for monitoring land degradation were found to be based on three sub-indicators recommended by the UNCCD according to the scientific framework for monitoring land degradation neutrality. The sub-indicators are; change in land cover, change in land productivity and change in soil organic carbon. Remote Sensing was key in data collection and analysis in this study. Land cover data which informed the land cover and soil organic carbon change indicators for Narok county were generated through the maximum likelihood classification method of the Landsat 7 and 8 imageries. Net land productivity was also obtained through the observation of the State, Trajectory and Performance of the NDVI.

The land degradation status and trend analysis model conducted indicate that Narok county has undergone a significant amount of degradation especially on its land cover and land productivity while soil organic carbon stock is quite stable over the monitoring period.

The result has also shown that the identified degraded areas can be mapped out and the information can help the decision-makers and civil societies in channelling the restoration activities in these specific degraded areas.

5.2 Recommendations

The findings of this study proved that sustainable land management, a direct mitigant of land degradation is a county, national and global concern. Priority should be given by the county governments to improve food security and poverty reduction. The national and global organizations should make it a priority to alleviate hunger, reduce poverty, safeguard natural resources, biodiversity and ecosystems, protect the world’s climate situation and preserve the cultural heritage.

Land degradation is proven through this study to be occurring at the local or pixel-level; therefore, the county governments and civil societies should engage the communities in sustainable land management and ecosystem restoration activities including; including prevention of land-use conversions, controlling soil erosion, improving soil water storage, managing soil organic carbon, promoting integrated soil-crop-water management and integrated agroforestry, managing soil salinity in the agricultural land that is under irrigations, and finally rehabilitating and restoring the identified degraded lands.

This study was done in only one county in Kenya. However, the findings have proven to be useful when the national reporting on SDGs are being carried out and it is recommended that it be repeated for the entire country to inform the proportion of the country that is degraded over the total area.

With the population, demand for food and other land-based resources likely to continue over the next decades, these sustainable land management practices will enable the achievement of land degradation neutrality (LDN) and the other related sustainable development goals including zero hunger, poverty, clean water and climate mitigation.

5.3 Areas for Further Research

Even though this study managed to highlight the proportion of land in Narok county that is degraded over the total land area using 30m Landsat image for land cover, 250m MODIS image for NDVI monitoring and 250m ISRIC soil grid, it did not demonstrate how same spatial resolution land degradation monitoring indicator datasets can affect the output results. Further research can be carried out using the same high spatial resolution dataset. This, therefore, provides an opportunity for further research on the same subject.

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