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Drivers Of Land Use, Land Cover Change, Climate Change Vulnerability And Adaptation Options In Narok North Sub-County, Kenya

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Abstract
Background: *Narok North Sub-County is experiencing significant changes in land use that are increasing its vulnerability to climate-related hazards, such as floods and droughts. These changes have weakened traditional coping mechanisms, exposing local communities to greater socio-economic and ecological risks. Despite the crucial role of land use in shaping environmental resilience and adaptation, there is limited understanding of its specific impacts on local livelihoods and adaptation options. This study assessed the drivers of land use and land cover change (LULCC), its impact on extreme weather events such as floods and droughts, and available adaptation options.*
Materials and methods: *This study adopted a mixed-methods approach, combining remote sensing analysis of Landsat imagery (1990–2022) with household surveys and key informant interviews. Household surveys and KIIs were used to identify the key drivers of land use and land cover change, while satellite imagery analysis assessed the extent and patterns of these changes. The study also examined the impacts of land use transformations on extreme weather events such as floods and droughts, along with available adaptation options. Landsat 5, Landsat 7, and Landsat 8/9 imagery were utilized to detect and quantify shifts in LULC, focusing on transitions from forests and grasslands to agricultural and urban land uses.*
Results: *The findings reveal the drivers of land use and land cover change as agricultural expansion, population growth, urbanization, and infrastructure development. These transformations are leading to a shift from sustainable land management practices to more intensive agricultural activities, resulting in the fragmentation of land, deforestation, and degradation of natural habitats. Such changes are exacerbating the region's vulnerability to climate-related hazards, including floods and droughts, which are projected to intensify due to climate change. Remote sensing analysis indicated that forest cover loss accelerated after 2010, driven by increasing farmland demand and settlement expansion. While cropland showed fluctuations due to evolving land management practices, built-up areas steadily expanded in line with urban growth. The study also identifies gaps in land use planning, zoning enforcement, and disaster risk reduction, which have contributed to further environmental degradation.*
Conclusion: *The lack of access to real-time climate data and insufficient investment in climate-resilient infrastructure have heightened vulnerability in the region. These findings highlight the need for stronger governance frameworks and sustainable land management strategies to mitigate climate risks and enhance long-term resilience.*
Keywords: *Land Use, Land Cover Change, Climate Change, Vulnerability, Adaptation, Policy, Sustainable Development*

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I. Introduction

In Kenya, rapid population growth has significantly influenced land use and land cover (LULC) changes, transforming natural landscapes into agricultural fields and urban settlements (Shilibwa et al., 2024). Narok County has experienced extensive LULC changes over the past decades, driven by population increase, agricultural expansion, urbanization, and evolving socio-economic factors (Mootian, Seno, & Mabwoga, 2020). These shifts have led to land fragmentation, deforestation—particularly in the Mau Forest—and shrinking grazing lands, exposing the region to climate risks such as prolonged droughts and recurrent floods (KNBS, 2021). The depletion of natural resources, coupled with weak land use planning and policy enforcement, has further exacerbated the vulnerability of local communities, particularly pastoralists who rely on sustainable land and water access (CGIAR, 2019).

Despite evidence linking LULC changes to increased climate vulnerability, there remains a research gap in understanding how these transitions influence climate risks and adaptation strategies at the sub-county level. Existing studies have either focused on general land use changes (Mootian et al., 2020) or climate vulnerabilities in Narok County (CGIAR, 2019), with limited emphasis on their interconnected impacts. This study aims to bridge that gap by assessing the key drivers of LULC changes, evaluating their implications for climate vulnerability, and identifying viable adaptation options tailored to the region's socio-ecological context.

By aligning with sustainable development goals, the research underscores the importance of protecting critical ecosystems like the Mau Forest, promoting stakeholder engagement, and fostering evidence-based policymaking. The findings will contribute to local and national land use planning while informing broader climate adaptation strategies, ensuring more resilient and sustainable land management in Narok North Sub-County.

II. Materials And Methods

This study employed a mixed-methods research design, integrating qualitative and quantitative approaches to comprehensively analyze land use and land cover (LULC) changes in Narok North Sub-County. This methodological framework allowed for a spatial-temporal assessment of land use transformations while incorporating community insights into the drivers and impacts of these changes.

Study Design:

A cross-sectional survey design was adopted, suitable for examining relationships between land use, climate variability, and socio-economic factors at a given point in time. The study leveraged Geographic Information Systems (GIS) and remote sensing techniques to map and analyze LULC trends over multiple decades (1995–2022).

Study Area

Narok North Sub-County, located in Narok County, Kenya, covers 2,603 km² and consists of five wards: Olposimoru, Melili, Olokurto, Nkareta, and Narok Town. The region experiences bimodal rainfall patterns, with long rains (February–June) and short rains (August–November), averaging 500 mm to 2,500 mm annually.

The economy is primarily agriculture-based, with pastoralism and crop farming as dominant livelihoods. The sub-county includes part of the Mau Forest Complex, a critical water catchment area, making it a vulnerable zone for land degradation and climate risks.

Sample size: The study sampled 100 households

Samples size calculation

Using Yamane's formula (Yamane, 1967), the sample size was calculated as follows:

$$n = \frac{(\mathrm{N} * \mathrm{Cv\^{}2})}{(\mathrm{Cv\^{}2} + (\mathrm{N} - 1) * \mathrm{e\^{}2})}$$

Where:

n = Sample size

N = Population size (59,996 residents)

C_V = Coefficient of variation (0.5)

e = Acceptable error (0.05 at 95% confidence level)

Subject & Selection Methods

Respondents were randomly selected across the five wards to ensure diverse representation from urban, peri-urban, and rural areas.

Primary data collection involved structured household surveys targeting local farmers, pastoralists, and urban dwellers to capture land use practices, environmental perceptions, and adaptation strategies.

Semi-structured interviews were conducted with key stakeholders, including Narok County Government officials responsible for land use planning and policy enforcement, Kenya Forest Service (KFS) and National Environment Management Authority (NEMA) representatives involved in forest management and conservation, as well as community leaders and pastoralist elders with expertise in traditional land tenure systems. These interviews provided critical insights into land governance challenges, conservation efforts, and policy gaps.

To validate remote sensing data, ground-trothing surveys were conducted using GPS points to confirm land cover classifications. Additionally, participatory mapping sessions were held with community members to identify areas of deforestation, flood-prone zones, and contested grazing lands, ensuring local knowledge was integrated into geospatial analysis.

Geospatial analysis was conducted using multispectral Landsat imagery, including Landsat 5 (TM) for 1995–2010 data, Landsat 7 (ETM^+) for 2000–2010 data, and Landsat 8/9 (OLI/TIRS) for 2015–2022 data. Data processing and classification were performed using QGIS and ArcGIS software, applying Maximum Likelihood Classification (MLC) algorithms to map land use transitions. Normalized Difference Vegetation Index (NDVI) analysis was used to assess vegetation changes and forest degradation over time.

A review of relevant government reports and scientific publications supplemented the primary data collection. These included Kenya National Bureau of Statistics (KNBS) reports on population growth trends and urban expansion, the Narok County Integrated Development Plan (CIDP) 2018–2023, 2023-2027 outlining land use policies and county development priorities, and meteorological data from the Kenya Meteorological Department (KMD) spanning 1990–2022, providing insights into rainfall and temperature variability.

Statistical Analysis Techniques

Geospatial Analysis

Time-series analysis assessed the spatial-temporal shifts in forest cover, grasslands, and agricultural land. Supervised classification algorithms categorized LULC changes, using NDVI metrics for vegetation monitoring.

Statistical Analysis

Descriptive statistics (means, frequencies, and percentages) analyzed survey responses on land use perceptions. Inferential statistics (Chi-square tests, correlation, and ANOVA) examined relationships between land use changes and climate vulnerability indicators using SPSS v.23.

Thematic Analysis

Qualitative data from KIIs and field observations was coded into thematic categories (deforestation, land tenure conflicts, climate adaptation strategies).

III. Results And Discussions

The study aimed to analyze the background characteristics of the respondents to determine whether they constituted a representative sample. Data was collected and analyzed based on gender, age group, marital status, duration of residence in the study area, education level, occupation, income level, and sources of income.
The findings indicated that the majority of respondents 62% were male, while 38% were female.

This trend is attributed to cultural norms where men, as household heads, are more likely to participate in surveys. Women reflected a lower engagement due to traditional gender roles. The majority of respondents fell within the 18–28 years and 29–39 years age brackets, representing a youthful population actively involved in economic activities. The lowest representation was from the 60–69 years age. Additionally, 66% of respondents were married, while 34% were single.

Regarding residency, most participants had lived in the study area for 20–50 years, with many being either born or raised there. This long-term residence indicates a strong attachment to the land and significant local knowledge. In terms of education, 60% of participants completed secondary education, 20% attaining college or university qualifications, and the remaining 20% reporting no formal education. Cultural factors such as early marriages and polygamy were cited as barriers to higher educational attainment, particularly for women. Occupationally, 69% of respondents were businesspeople, 16% were social workers, 7% were farmers, 5% were administrators, and 3% were health workers. This suggests that small and medium enterprises, such as kiosks and grocery shops, play a significant role in land use changes, as business expansion often leads to land clearance along major roads. Income levels varied, with most respondents earning less than Ksh 10,000 per month, 26% earning between Ksh 10,000 and 20,000, and only 7% earning between Ksh 21,000 and 30,000. This low income drives individuals to engage in additional income-generating activities, many of which impact land use and contribute to land degradation. Income sources were evenly split, with 44% earning from off-farm activities, another 44% from on-farm activities, and the remainder earning from both. Regarding the impact of income on land use, 55% of respondents indicated a moderate effect, 35% reported a significant effect, 6% saw a very significant effect, while only 1% and 3% reported no effect or little effect, respectively. Overall, over 86.4% of respondents acknowledged that income levels influenced land use and changes in the study area.

Finally, perceptions of rainfall pattern changes since the 1990s varied. Nearly half (47%) of respondents were unsure, while 33% reported decreased rainfall frequency, 14% observed frequent rainfall, and 6% noted very frequent rainfall. This suggests that most respondents were unable to accurately recall changes in rainfall patterns over time.

Key Drivers of Land Use and Land Cover Change in Narok North Sub-County

Land use and land cover (LULC) changes in Narok North Sub-County are shaped by dominant land use practices, which simultaneously serve as drivers of change. These practices include agriculture, pastoralism, urban development, deforestation, and settlement expansion. While these activities sustain livelihoods, they also contribute to environmental degradation and landscape transformation.

Agricultural Expansion and Commercial Farming

Agriculture is a primary land use practice, with large areas of forest and savannah grasslands converted into cropland for wheat, barley, maize, potatoes, and other crops. Cropland cover increased from 2,174.56 hectares in 1995 to 2,336.76 hectares in 2000 but declined to 1,126.50 hectares in 2005 due to economic constraints such as fluctuating crop prices, limited access to financing, and high input costs. However, agricultural land has since expanded, reaching 2,123.22 hectares by 2022, driven by increased food demand, commercial farming, and supportive government policies.

Pastoralism and Overgrazing

Pastoralism remains a significant land use practice, deeply embedded in cultural traditions that value large livestock herds. Overgrazing, however, has led to grassland degradation, soil erosion, and reduced pasture productivity. Grassland cover initially declined from 872.25 hectares in 1995 to 834.99 hectares in 2000 due to excessive grazing pressure and land conversion. However, community-led initiatives to plant grass for hay production led to an increase, peaking at 1,899.09 hectares in 2015. By 2022, grassland cover slightly declined to 1,574.15 hectares, likely due to soil degradation and overuse.

Urbanization and Infrastructure Development

The shift from communal group ranches to individual land tenure has facilitated land fragmentation and increased land exploitation for settlements, schools, hospitals, and infrastructure. Built-up areas expanded significantly from 6.74 hectares in 1995 to 54.18 hectares in 2022, indicating the growing demand for housing and services in Narok North, which hosts the county headquarters. This trend highlights the challenge of balancing urban expansion with sustainable land management.

Deforestation and Logging for Fuelwood and Charcoal

Deforestation, particularly in the Maasai Mau Forest and river catchment areas, is driven by logging for timber, fuelwood, and charcoal production. Approximately 72% of Narok County's population relies on firewood for cooking (KNBS, 2019c), increasing the demand for wood resources. Traditional cooking methods, such as the three-stone fireplace, continue to exacerbate deforestation. The loss of tree cover threatens biodiversity, disrupts ecosystems, and affects water resources.

Population Growth and Land Subdivision

Rapid population growth has increased land pressure, leading to the conversion of forests, grasslands, and wetlands into farms and settlements. Between 1995 and 2005, forest cover remained relatively stable, but from 2010 onwards, a sharp decline occurred, with forest cover dropping to 950.20 hectares by 2022 due to expanding agriculture and settlement. Weak conservation measures and inadequate enforcement of environmental policies have accelerated these changes.

Climate Variability and Land Degradation

Climate change has amplified LULC changes by intensifying land degradation through erratic rainfall patterns, prolonged droughts, and rising temperatures. These climatic stressors have worsened soil erosion, reduced pasture productivity, and increased the frequency of extreme weather events such as droughts and floods. Although human activities remain the primary drivers of LULC changes, climate variability exacerbates existing vulnerabilities, making land use practices more unsustainable.

Governance and Policy Gaps in Land Management

Weak land tenure systems, poor enforcement of environmental regulations, and inconsistent land use policies have enabled unsustainable land practices. The lack of clear policies on land subdivision and resource conservation has led to uncontrolled grazing, deforestation, and land degradation. Strengthening land governance is crucial for ensuring sustainable agricultural practices, urban development, and environmental conservation.

Post-Visual Classification Analysis of Land Use and Land Cover Change Trends in Narok North Sub-County (1990–2022) Using Satellite Imagery

The land use data for Narok North Sub-County from 1990 to 2022 reveals significant changes in the region's landscape. These changes highlight evolving environmental pressures and socio-economic trends, including agricultural expansion, urbanization, and land degradation. A detailed analysis of these land use classes—forest, cropland, grassland, built-up areas, and bare land—provides valuable insights into the region's development trajectory and its implications.

The satellite images displayed below provide a visual representation of the LULC changes in Narok North Sub-County from 1990 to 2022. The images are color-coded for clarity, with each land use class (Forest, Cropland, Grassland, Built-up Areas, and Bare Land) identified in the legend. The maps highlight the dramatic transitions in land cover, particularly the expansion of cropland and built-up areas, as well as the decline in forest cover and grasslands.

Forest Cover Decline: The forested area in Narok North Sub-County decreased from 2566.02 km² in 1990 to 2236.56 km² in 2022, reflecting a decline of 12.8%. This significant reduction suggests ongoing deforestation, likely driven by agricultural expansion, logging, and urbanization. The loss of forest cover is concerning as it could undermine the region's biodiversity, water retention capacities, and overall resilience to climate change.

Expansion of Cropland: Cropland in the region grew substantially from 668.89 km² in 1990 to 914.38 km² in 2022, marking a 36.7% increase. This rise in agricultural land suggests a shift towards more intensive farming, driven by population growth and increasing food production demands. While the expansion of cropland can contribute to economic development and food security, it also raises concerns about soil depletion, water scarcity, and the potential for unsustainable agricultural practices.

Grassland Fluctuations: Grassland areas showed some fluctuations over the period, initially increasing to a peak of 1618.95 km² in 2010, before slightly declining to 1525.39 km² by 2022. This change represents a 4.7% increase overall, but the decline in recent years may be indicative of pressures such as overgrazing, land conversion for agriculture, and the impacts of climate variability. Grasslands are critical for livestock farming, a key livelihood in the region, and their decline may have negative implications for pastoral communities.

Urbanization and Built-Up Areas: The most striking change observed was in the expansion of built-up areas, which grew from a mere 2.05 km² in 1990 to 16.55 km² in 2022, reflecting an extraordinary 707.3% increase. This sharp rise in urban areas corresponds to increasing human settlement and infrastructure development, likely driven by population growth and greater demand for housing, services, and commercial spaces. While urbanization offers economic opportunities, it also highlights the need for strategic land use planning to prevent environmental degradation, such as the loss of agricultural land and the destruction of natural habitats.

Bare Land Increase: Bare land, though still relatively small in total area, increased by 58.6%, from 1.86 km² in 1990 to 2.95 km² in 2022. This increase may be linked to land degradation, soil erosion, or abandonment of land that is no longer suitable for farming. Although the change in bare land is not as dramatic as in other classes, it signals potential challenges in land management and the sustainability of current land use practices.

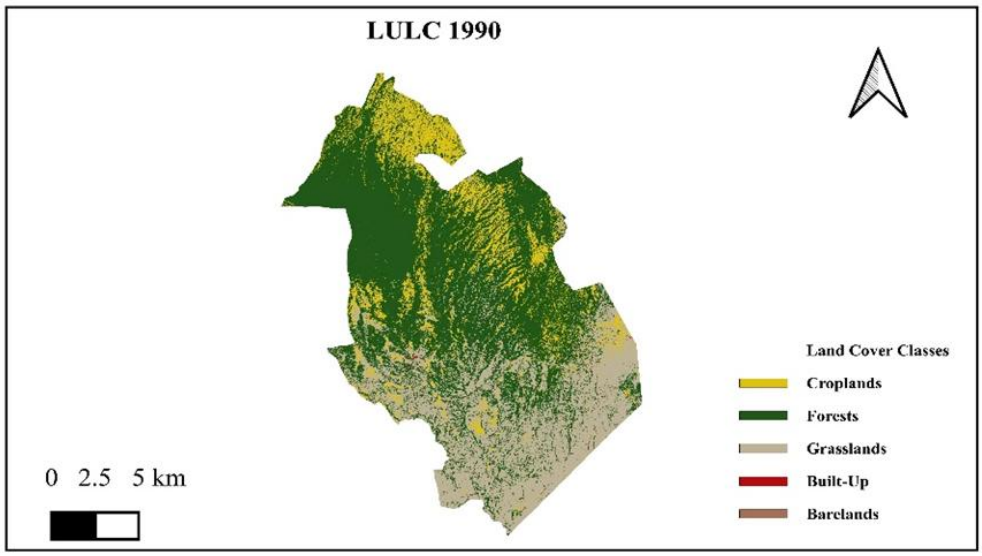

Figure 1 LULC 1990

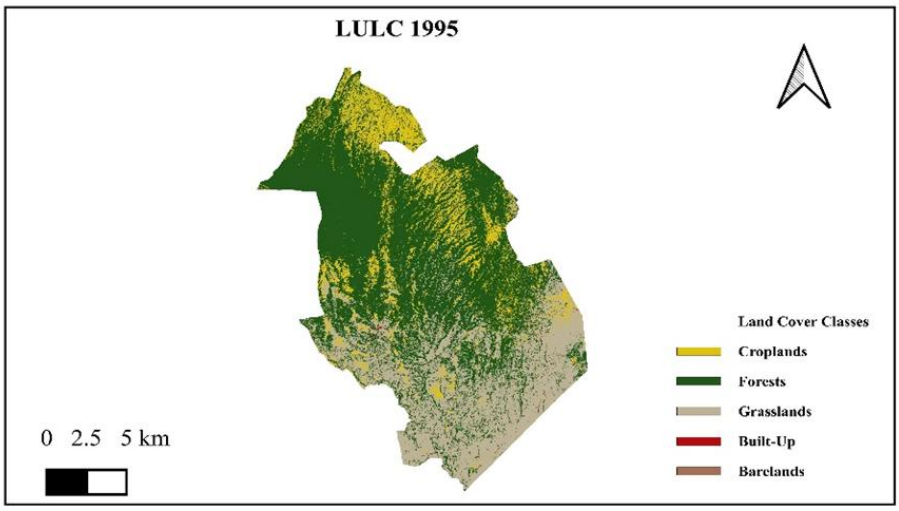

Figure 2 LULC 1995

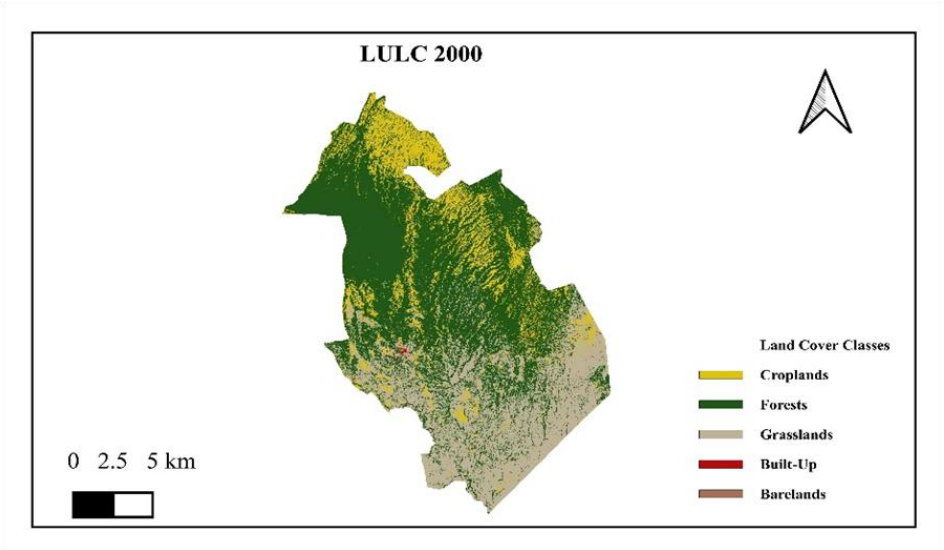

Figure 3 LULC 2000

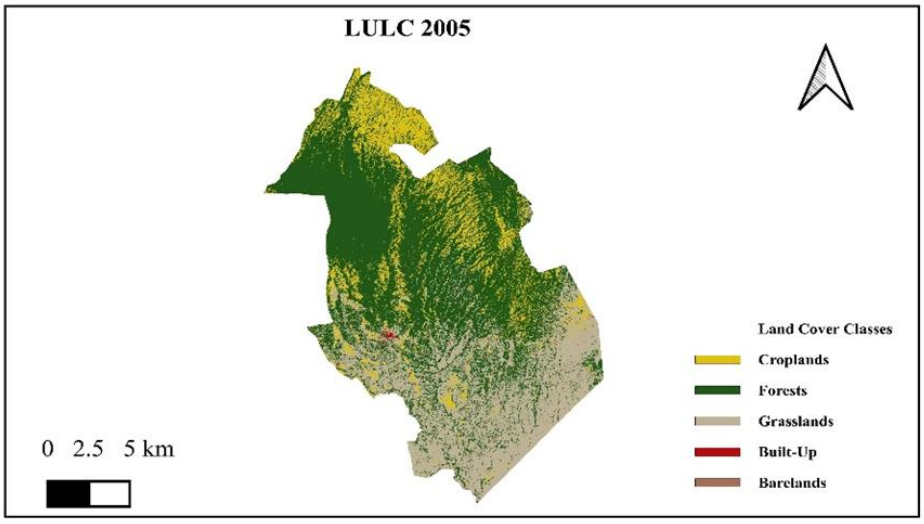

Figure 4 LULC 2005

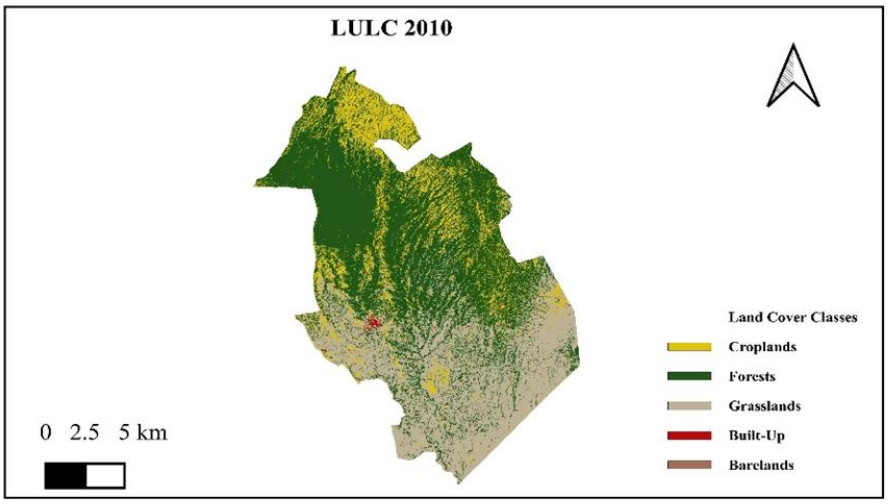

Figure 5 LULC 2010

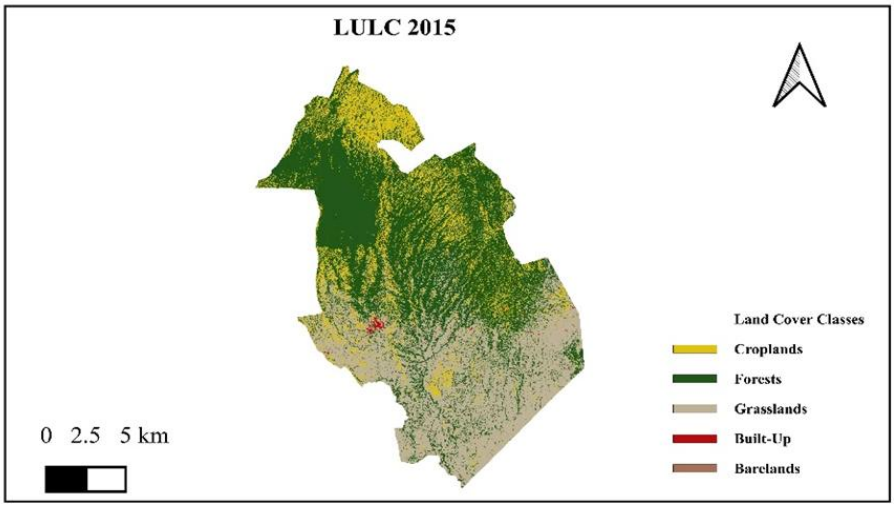

Figure 6 LULC 2015

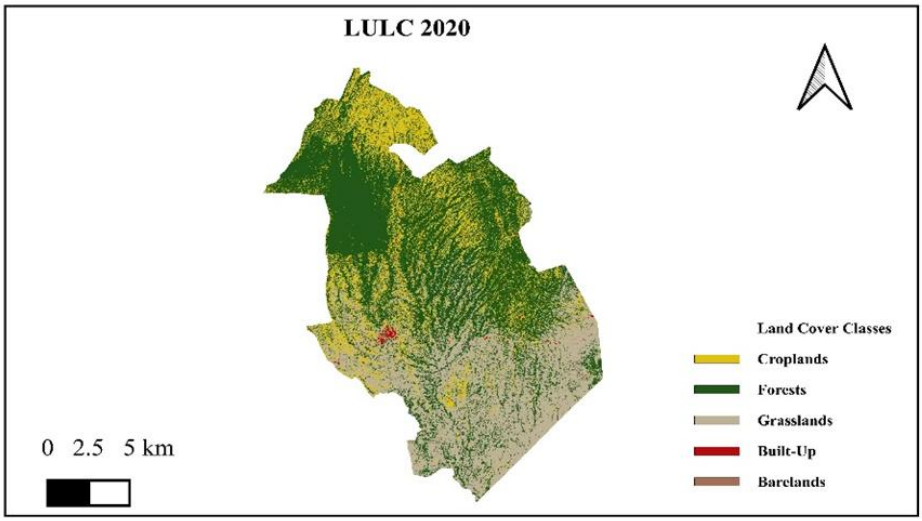

Figure 7 LULC 2020

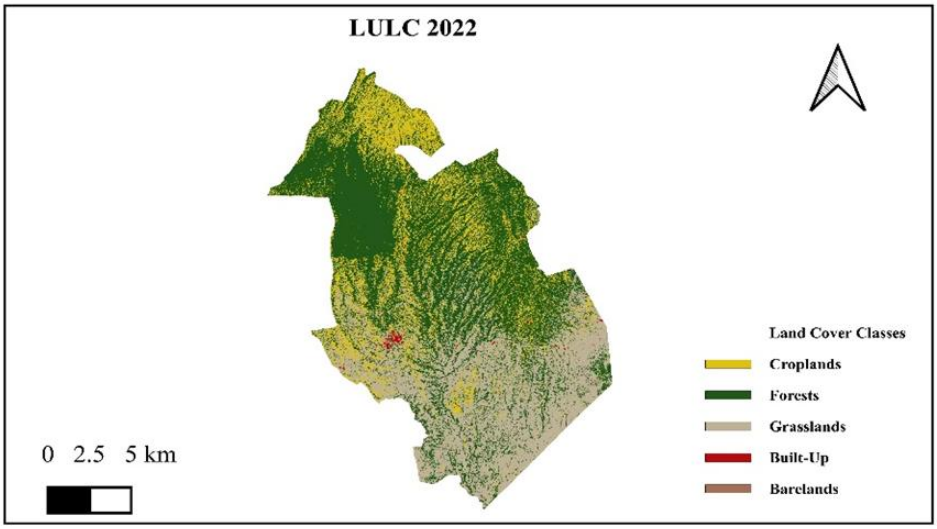

Figure 8 LULC 2022

Climate variability

Climate variability, marked by erratic rainfall patterns, prolonged droughts, and rising temperatures, has become a significant challenge for Narok North Sub-County. These climatic changes have impacted land use, agriculture, and livelihoods, creating both immediate and long-term pressures on the regions environmental and socio-economic systems. Understanding these impacts and identifying practical adaptation strategies is crucial for enhancing the region's resilience.

Impact of Climate Variability on Agriculture and Land Use

Narok North faces erratic rainfall, with frequent droughts and irregular distributions that affect agricultural productivity. Crops like maize, barley, and wheat, which depend heavily on consistent rainfall, have suffered due to these unpredictable patterns, leading to reduced yields and food insecurity. Prolonged dry periods further exacerbate soil degradation and increase the risk of crop failure.

In addition to erratic rainfall, rising temperatures have increased evaporation rates, stressing water resources and reducing agricultural potential. Livestock, a key livelihood in the region, are also under threat, as higher temperatures and reduced grazing areas hinder their productivity.

Furthermore, the region's ecosystems, including forests and grasslands, are vulnerable to climate change. These areas provide vital ecosystem services such as water retention, carbon sequestration, and biodiversity. However, changes in temperature and rainfall are weakening these ecosystems, contributing to soil erosion, water scarcity, and loss of biodiversity.

Climate Vulnerability and Its Impacts on Floods

Narok North Sub-County faces increasing climate vulnerability, with extreme weather events such as floods becoming more frequent and severe. These changes, driven by rising temperatures and erratic rainfall patterns, have significantly affected the region's socio-economic and environmental stability.

The study revealed that flooding is a major climate-related hazard affecting Narok North Sub-County, with Narok town identified as the most flood-prone area. Respondents overwhelmingly reported that business people are the most vulnerable group (100%), primarily due to the location of business premises in low-lying urban areas. Frequent flood events were said to disrupt business operations, damage buildings, and result in the loss of goods and income.

Farmers were identified as the second most vulnerable group (71%), while pastoralists were ranked third (43%). According to respondents, floods negatively impact agricultural livelihoods by washing away crops and displacing or killing livestock. This leads to reduced household income and increased food insecurity.

Young children were also noted as highly vulnerable, with several participants highlighting the risk of children being swept away during floods due to their limited ability to respond in emergencies. In contrast, adult men and women were considered the least vulnerable groups (29%), possibly due to better mobility, decision-making ability, and access to information and resources.

Participants identified two main categories of flood risk factors: climatic and human-induced. Climatic factors include erratic and intense rainfall patterns that exceed the absorption capacity of soils and existing

drainage infrastructure. Human-induced factors were more prominently emphasized by respondents and include poor drainage systems, unregulated settlement in flood-prone areas, and insufficient enforcement of land-use planning regulations. In particular, the expansion of urban development into wetlands, riverbanks, and formerly designated open spaces—without proper land-use controls—was cited as a major contributor to increased flood exposure. The conversion of natural vegetation cover into impervious surfaces such as roads and buildings has reduced natural infiltration and increased surface runoff. The combination of these climatic and land-use dynamics has significantly exacerbated the frequency and severity of flood impacts, particularly in urban centers such as Narok town, where vulnerable populations are most concentrated.

These findings demonstrate the differentiated vulnerabilities faced by different groups in the sub-county and highlight the urgent need for targeted flood mitigation and preparedness strategies.

IV. Conclusion And Recommendations

This study assessed the drivers of land use and land cover (LULC) change, climate change vulnerability, and adaptation strategies in Narok North Sub-County. The findings indicate that population growth, agricultural expansion, urbanization, and weak governance structures are key factors influencing land transformations in the region. The significant reduction in forest cover, coupled with the steady increase in cropland and built-up areas, has heightened environmental risks, including soil degradation, loss of biodiversity, and increased climate vulnerability. Socioeconomic factors such as land tenure insecurity, lack of enforcement of land use policies, and unsustainable agricultural practices have further exacerbated these challenges. Addressing these issues requires a multi-dimensional approach integrating policy reforms, sustainable land management, and community-driven adaptation strategies to enhance resilience and environmental sustainability. The recommendations are for both the county government of Narok County and the community members.

For the County Government

To enhance climate resilience and sustainable development, the county should prioritize enforcing land use policies through strengthened zoning regulations that protect ecologically sensitive areas. A collaborative approach is essential; forming multi-stakeholder task forces will facilitate coordination among government agencies, community leaders, and the private sector, ensuring well-defined mandates for land use and climate adaptation strategies. Adequate financial and logistical support must be allocated to effectively implement disaster risk reduction policies, ensuring that adaptation strategies are well-resourced and actionable.

Effective climate adaptation relies on accurate and accessible data. The county must prioritize updating risk maps, integrating GIS into land-use planning, and ensuring hazard-exposure data is publicly available. These measures will empower decision-makers and communities with real-time information. Additionally, strengthening early warning systems, adopting research-driven policies, and introducing climate risk insurance will provide financial security and enhance preparedness against climate-related threats.

Capacity-building programs should train government officials and local administrators on sustainable land management and disaster risk reduction. Additionally, investing in climate-resilient infrastructure, including schools, hospitals, and roads, will enhance community preparedness. Afforestation and reforestation programs should be promoted, with a focus on indigenous tree species that support biodiversity and provide economic benefits. Soil conservation techniques such as terracing, mulching, and agroforestry should also be widely adopted to prevent erosion and improve agricultural productivity.

Sustainable urban planning should be prioritized, incorporating flood-resistant housing and green infrastructure to reduce climate vulnerabilities. To support large-scale adaptation efforts, the county should seek international climate financing from sources like the Green Climate Fund and Global Environment Facility.

For Community Members

Community-driven initiatives should focus on participatory land-use planning and disaster risk reduction. Strengthening conservation efforts such as afforestation, sustainable grazing management, and climate-smart agriculture will improve ecosystem resilience. Rainwater harvesting and drought-resistant crop cultivation should be promoted to enhance agricultural sustainability.

Local knowledge-sharing initiatives through farmer field schools and cooperative networks will improve climate adaptation at the grassroots level. Collaboration with NGOs and private sector stakeholders will provide financial and technical support for resilience-building efforts. Expanding community awareness campaigns through schools, social media, and local forums will further educate residents on sustainable land management.

Practical training programs should emphasize sustainable farming techniques, including intercropping, crop rotation, and fodder-based agroforestry, to reduce soil erosion and improve livestock farming. Establishing community resource management committees will ensure adaptation initiatives are effectively implemented and sustained.

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