Using Google Earth Engine and the Normalized Difference Drought Index (2000–2024) to assess the spatiotemporal drought severity in Kenya's arid and semi-arid landscape

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Abstract

Arid and Semi-Arid Lands (ASALs) have seen a surge in extreme climatic events with devastating environmental and livelihood effects. Understanding the dynamics of these extreme events such as drought at the landscape level is essential for anticipatory action among resource-dependent communities in the ASALs. This study utilised Systems Google Earth Engine (GEE) to analyse 24 years of Normalised Difference Drought Index (NDDI) trends in the Narok West landscape of Kenya across six timeframes (2000, 2005, 2010, 2015, 2020 and 2024). Our analysis revealed increasing trends of severe drought conditions (39.7%), moderate drought conditions (1.4%) and decreased drought conditions (2.1%) over the study period. Temporal increase in drought events were observed to be on the rise from 2015 with extreme events most witnessed in 2020. This weather variability, which may primarily be due to climate change, is expected to result in a rise in the frequency and severity of drought and rainfall periods. This could have a detrimental effect on water quality and quantity, public and ecosystem health, mental health and wellness, peace and protection, and rangeland ecology. For future drought scenarios using Earth Observation Systems (EOS) and GEE, mainly NDDI, our study adds to the body of research that could help with methodological and empirical studies as well as corrective actions. In order to adapt to and manage the effects of a changing climate, these scenarios necessitate interdisciplinary community and landscape strategies. There is need for the community to develop a more comprehensive understanding of the impacts of climate change and the need to plan the sustainable management of water resources.

Key words: climate change, earth observation, Google Earth Engine, meteorological drought, remote sensing, Narok

Introduction

Drought, defined as "a prolonged dry period in the natural climate cycle resulting from lack of precipitation," (1), or "abnormally dry weather or an exceptional lack of water compared to normal conditions to constitute a hazard," (2), is one of the natural hazards that has debilitating effects on ecosystem integrity, hydrology, livelihoods, biodiversity and food security. Droughts as the most far-reaching and catastrophic of all-natural hazards (3). When droughts occur, they often spatiotemporally vary in intensity, duration, and progression, as well as return episodes. Reduced rainfalls, depleted soils, reduced or absent surface waters, and poor rangeland and livestock productivity are the symptoms of droughts. Weather variation and climate change aggravate the drought phenomenon globally (4). Droughts affect more than a third of the global land surface and cause more than $6 billion in economic losses annually (5). Droughts are also a national, regional, and global concern as they compromise access to portable water, as envisioned in Kenyan Vision 2030 (6), the African Union [AU] Agenda 2063 (7) and a myriad of UN SDGs (8) including SDG 6: Clean Water and Sanitation and SDG 13: Climate Action are of concern, while others are SDG 1: Poverty-Free, SDG 2: Zero Hunger, SDG 3: Good Health and Well-Being, SDG 4: Quality Education, SDG 5: Gender Equality, SDG 14: Life Below Water, and SDG 15: Life on Land.

Droughts can be classified based on their duration, impact, and recovery rate (9). Broadly, the categorisation includes meteorological drought, hydrological drought, agricultural drought and socio-economic drought (10). Meteorological drought denoted is the degree of dryness or reduction of rain over three months during which monthly precipitation remains well below the long-term average in regions of dry climatic conditions (11–13). Hydrological droughts are marked by lower levels of surface and subsurface water, which can be seen in stream flow, groundwater levels, and lake and reservoir levels (14). Agricultural droughts are cyclic occurrences over time (months or even years) witnessed by reduced moisture supply below normal climatically appropriate moisture levels to produce crops which affects overall yield (15). Socio-economic drought which only affects humans, is manifested through reduced supply, demand, and availability of certain commodities and their relationship with meteorological, hydrological, and agricultural drought (5,16).

It is projected that drought events will rise in frequency, intensity, and duration in many regions across the world (17,18). This can have an impact on the biodiversity and communities that inhabit arid and semi-arid lands (ASALs) and water-scarce areas. Droughts are ranked first among all-natural disasters when quantified based on the number of humans affected (19,20). (4) assert that drought incidents in East Africa have doubled from once every three years to once every six years since 2015.

Due to its eco-climatic conditions, Kenya is designated as a drought-prone country (21). Approximately 80% of its total land mass is classified as ASAL (22). In Kenya and the Horn of Africa, recent research has demonstrated a decrease in rainfall intensity and frequency (23–25). The ecohydrology of landscapes and the scarcity of water resources may be exacerbated by this variation in weather patterns. Kenya has borne the brunt of droughts (26), in as much as they are not classified. Narok, a frontier ASAL and rangeland county in Kenya, continues to witness increased incidents of drought, adverse weather patterns, and a changing climate (27–30).With a changing ecosystem characterized by increased fencing by individual landowners, land division, and rangeland denudation (31,32), the situation is compounded by an increase in the number of livestock, and a concurrent decrease in the number of wildlife species (33), boding poorly for land- resource utilization, and impacting human-animal health and productivity, and livelihoods. The major constraint in policy making for sustainable climate-associated solutions, is the lack of drought monitoring and classification (26).

Studies on drought in Sub-Sahara (SSA) and greater Low-Income and Middle-Income countries (LMICs) are limited to agriculture and food security (34–36), with a paucity of data on their impacts on water resources, especially with population increase and demand for water resources, and hydrological related disaster prevention. It is therefore increasingly prudent that early detection of droughts, primarily meteorological drought using earth observation systems (EOS), in fragile ASALs and water-scarce areas through region-specific assessments, be prioritised. The EOS can complement the limited and poor-quality ground data within these regions (37,38). These EOS assessments utilising various satellite sensors (39,40), can guide timely early warning systems, adaptive and remedial coping interventions, critical in mitigating their negative drought impacts. Despite the importance of EOS and Google Earth Engine (GEE), these innovative systems have been rarely used in SSA and LMICs.

Additionally, the data describing EOS are often sparse and limited, while the current state of weather variability along spatiotemporal scales is poorly understood. SSA countries have not readily embraced EO-data for decision-making (41). Google Earth Engine (GEE) is a free cloud computing platform that is effective in conducting geospatial big data analysis (42–45). Even though GEE has been used a lot and quickly (42,45–48), not many studies have looked at how it can be used to find and map droughts in SSA, LMICs, and the majority world. The primary objective of this study was to assess and determine spatiotemporal meteorological drought dynamics within Narok West Sub-county in southwestern Kenya in the context of weather variation and climate change, between the years 2000 and 2024. This was achieved using the Normalised Difference Drought Index (NDDI), integrated earth observation (EO) systems, and GEE. This region of interest is part of a broader study on scope of weather variation and climate change on above ground water resources in semi-arid Narok West landscape and its effects on community livelihoods and health.

Materials and Methods

Study Area

Narok West Sub-County lies within Narok County (1.3605° S, 35.7407° E), the south-eastern part of Kenya (Figure 1). It has an average altitude of 1,296 meters above sea level. The ambient temperature ranges between 12℃ and 28℃, with a bi-modal annual rainfall ranging from ranging between 500 – 1,800mm. This rainfall pattern is influenced by the Intertropical Convergence Zone (ITCZ) and topographic relief from Lake Victoria (49), with the wet season spanning between November-June and the dry season covering July-October. Currently, the region is experiencing an increase in ambient temperatures (50) and a decrease in annual rainfall (51). Narok West Sub-County is a heterogeneous landscape consisting of tree-grass mosaics, with grassland predominating and being interrupted by trees, rock outcrops, and dispersed wetlands (52). The Greater Maasai Mara Serengeti Ecosystem, which encompasses Narok West Sub-County, is a critical migratory corridor for wildlife (53,54).

Fig. 1. Map of Narok West Sub-county. Inset is the map of Kenya showing the location of the study area.

Data Acquisition and Tools

Our study utilised remote sensing data derived from EOS, GEE, and GIS techniques in analysing historical satellite data from Narok West Subcounty during the period between 2000 and 2024. We utilized Landsat 7 and Landsat 8 imagery to give a comprehensive overview of the changes that have occurred over the study area in the past 24 years on Google Earth Engine, ArcGIS 10.8, and R Studio version 3.6.0. Using data filters of administrative maps, Landsat images for the Narok West area spanning from the years 2000 to 2024 were retrieved from the GEE satellite catalogue (https://earthengine.google.com/datasets/). Using GEE's Code Editor (https://code.earthengine.google.com/), we wrote supervised algorithms and executed scripts for NDDI indices based on the required spectral bands. The filtered images of 30 m resolution were generated based on the desired date ranges. The old pictures were also pre-processed with ortho-rectification, geometric and radiometric corrections, and other steps to make sure they were lined up correctly and matched the real geography of the area of interest. For the wet season studies, images of April were used, whereas those of August were used for the dry season studies. We also complemented satellite imagery with rainfall data from the Kenya Meteorological Department of the area. These were used to establish not only the driest and most wet months, but also seasonal rainfall trends (March-May wet season and June-August dry season) based on the study period using linear regression.

NDDI Calculation and Drought Assessment

Since there is no single index that can fully establish drought on a geospatial and temporal scale, we thus combined several indices, including remote sensing data, into a single product. The Normalized Difference Vegetation Index [NDVI] (55), Normalized Difference Water Index [NDWI] (56–58), and Normalized Difference Drought Index [NDDI] (59–61) were obtained from Landsat spectral bands (near infrared, red, and green). NDVI is used to measure the amount of vegetation cover in an area based on its health/vigour and was calculated using equation 1 and ranges from -1 to 1. Negative NDVI values indicate clouds and water, while positive values near zero indicate bare soil, and higher positive NDVI values connote sparse vegetation (0.1 - 0.5) to dense green vegetation (0.6 and above).

Equation 1: $$NDVI = (NIR - Red) / (NIR + Red)$$

NDWI is an index used to establish vegetation humidity, based on the water content of leaves. Like NDVI, its values range from -1.0 to 1.0. Additionally, we use it to identify the presence of open water features. We calculate NDWI from the amount of near-infrared (NIR) and green (G) spectral bands (Equation 2).

Equation 2: $$NDWI = (G - NIR) / (G + NIR)$$

Using NDVI and NDWI values, we calculated NDDI using equation 3 as guided by workflow (Figure 2). We used the values to establish and map drought severity, categorizing it into three classes (Table 1). NDDI has been used in the past to measure drought in rangelands (62–64). This is because NDDI responds more strongly to dry season (summer) drought conditions and is a more sensitive indicator in grasslands and arable lands (60).

Equation 3: $$NDDI = (NVDI - NDWI) / (NDVI + NDWI)$$

Fig. 2. Study Workflow

Table 1. Classification of Drought Levels Based on NDDI Index (61).

NDDI value	**Drought level**	**Legend**
<0.1	Non-drought	Green
0.1 to 0.3	Moderate drought	Yellow
>0.3	Severe drought	Red

It is worth noting that employing NDDI cannot conclusively depict metrological drought, as it can also be influenced by soil type, vegetation type, phenological stage, geo-location, and climate zone (64).

Results

Meteorological Data Characteristics of Narok West

An analysis of the annual rainfall pattern confirmed that Narok West experiences bi-modal annual rainfall cycles. The March-April-May (MAM) season is characterized by a long-wet season, with April experiencing the maximum rainfall amounts. Conversely, the June-July-August (JJA) months are characterized by a long-dry season, with August marking the conclusion of the dry season. The seasonal rainfall trend analysis demonstrated that rainfall patterns increased during the long-wet season (Figure 3), while rainfall quantities decreased during the long dry season (Fig. 3). The trend line was at a significance level of 7.05% [R^2 = 0.0705] and 2.8% [R^2 = 0.0288], respectively (Fig. 3). The JJA dry season experiences a substantial decrease in rainfall quantities over time, in contrast to the MAM wet season, which witnesses an increase. The Narok West landscape's weather variability is corroborated by this rainfall trend.

Fig. 3. Seasonal rainfall trends Narok West (June – August dry season and March – May wet season)

Spatial-temporal distribution of drought conditions over Narok West

The NDDI in the study area varied from -0.489 (lowest in April 2000) to 0.469 (highest in August 2005) with minimum values during the rainy season and maximum values dry season respectively. 12 NDDI map severity composites indicating drought characteristics (table 1) were computed for each pixel class (Figure 4; Figure 5). Results showed that between 2000-2010, there was a declining pattern of drought conditions over Narok West Sub-county during the long rains seasons. This decrease from severe and moderately drought conditions was shifting to no drought conditions. However, by 2010, extreme drought conditions were more pronounced in the south-east section of Narok West while very good conditions intensified in the northern sections of the Narok West landscape. It is important to note, no drought emerged in the south-west, and north-west of Narok West sub-county in 2015 but narrowed towards the central part of the area in 2020. This pattern was interrupted by the re-emergence of drier conditions dominating the central to northeast sections of Narok in 2024. The analysis of the temporal patterns revealed that severe drought incidents have been increasing in Narok West Sub-county during the August dry season since 2000, with 2020 being the most severe event. The sub-country's spatiotemporal distribution of drought has undergone a transformation, transitioning from the north-eastern to the northern and south-eastern regions. April 2005 was the driest in the rainy seasons that were examined, while April 2020 the least dry. The sub-county's southeast region is the driest. Since 2015, the Mara National Reserve has been experiencing an increasing number of dry episodes during the April wet season in relation to the wildlife conservation areas.

Fig 4. Spatiotemporal distribution and intensity of Narok West Subcounty NDDI during the April wet season

Fig 5. Spatiotemporal distribution and intensity of Narok West NDDI during the August dry season

The spatiotemporal intensity of our NDDI findings were computed to establish the relative frequency (%) of landmass experiencing NDDI-derived drought conditions during the study period. This ascertained that lands acreage under severe drought and moderate drought in the

Narok West Sub-cunty have been on the increase, with the converse being witnessed in acreage under good (none – drought) conditions (Figure 6).

Fig. 6. Relative frequency (%) of landmass experiencing NDDI-derived drought conditions between 2000 and 2024

A look at the trend of drought conditions during the MAM wet season showed that the area of Narok West subcounty that is not experiencing drought is decreasing by 18.95% ($R^2 = 0.1895$) over the study period (Fig. 7). Landmass under severe drought and moderate drought trend lines stood at a significance level of 4.87% [$R^2 = 0.0487$] and 19% [$R^2 = 0.1918$], respectively, over the study period (Figure 7). These acreages under no drought conditions and severe drought conditions during the wet seasons are significant and warrant concern.

Fig. 7. Narok West landmass experiencing drought conditions during the wet season (MAM)

In terms of drought conditions during the JJA dry season, trend analysis showed that the amount of land in Narok West Subcounty that is not experiencing drought is decreasing. This decrease was 31.43% [$R^2 = 0.3143$] over the study period (Fig. 8). The percentage of land that was in severe drought (80.04% [$R^2 = 0.8004$]) and moderate drought (18.749% [$R^2 = 0.1879$]) during the study period (Figure 8). These declines in acreages under no drought conditions and increased acreages witnessing both severe and moderate drought conditions during the dry seasons are significant.

Fig 8. Narok West landmass experiencing drought conditions during dry season (JJA)

Overall, the amount of land in Narok West Subcounty that is not in drought is steadily going down. From 2020 to 2024, it dropped by 21.48% [$R^2 = 0.2148$] (Figure 9), while the amount of land that was in severe drought and moderate drought went up by 39.72% [$R^2 = 0.3972$] and 1.49% [$R^2 = 0.0149$], respectively. These declines in acreages under no drought conditions and increased acreages witnessing severe and moderate drought conditions during the dry seasons are significant.

Fig. 9. Spatiotemporal landmass changes in Narok West based on NDDI

Discussion

The analysis of spatiotemporal trends of the Narok West landscape using GEE revealed the surging intensity and severity of meteorological drought across time and space. witnessed drought conditions during both the rainy seasons and Narok West dry seasons. Our study established that during the long rain (MMA wet season), the landscape's acreage experiencing no drought conditions and drought during the MMA wet season has been declining, while areas experiencing moderate drought and severe drought during the same MMA wet seasons are increasing (Fig. 6).

Regarding drought during the dry season (JJA), the Narok West landscape is experiencing a sharp increase in areas under severe drought conditions. A time series analysis indicated that the sub-county's acreage under moderate drought and no drought conditions has decreased. The increase in acreage under severe drought is of concern as it would plausibly result in increased water scarcity, manifested in decreased quality and quantity. The direct and indirect ramifications of drought are complex, interactive, and diverse. Drought incidents have a bearing on water availability and resources. The fragile wetlands of the Narok West ASAL landscape are predisposed to increased evapotranspiration and reduction of water quality and quantity.

Narok West Sub-county predominantly sources water from above groundwater resources with dotted constructed dams and water pans (65). The domestic, agricultural, livestock, and wildlife sectors use these lentic and lotic water bodies. The shared water points, many of which are open to the public and often have faeces and total coliform bacteria (66–68), should not be consumed directly, especially in communities further downstream (69). Previous studies revealed that surface waters in the Narok landscape have bacterial loads of *Escherichia coli*, *Shigella* spp., *Proteus* spp., *Salmonella* spp., *Enterobacter* spp., *Klebsiella* spp. and *Citrobacter* spp. (69). Pathogens that live in water get into these bodies of water even more because more than half of the people who live in Narok practice open defecation due to unavailability of toilets / latrines and cultural norms (70). These point and non-point contaminants and pollution expose the community to increased incidents of gastrointestinal infection and compromised health, financial drain in a bid to access portable water and remedial medication and an upsurge in zoonotic diseases (71–73) and related antimicrobial resistance (74–77). The results will have a profound impact on human, animal, and ecosystem health (78). Additionally, these virulent strains can be spread across the landscape as the Mara-Serengeti ecosystem is a transboundary migratory corridor. In addition, the health burden can be aggravated by the introduction and dissemination of the strains to new localities by migrant birds that frequent and utilize the landscape. Therefore, the deterioration of public health and the difficulty of treating maladies in LMICs can be exacerbated by changes in the weather and climate, as individuals may not always receive the appropriate diagnosis or adhere to their prescribed medicines (79). It has the potential to impede the completion of numerous UN SDGs, the One Health Approach, and global antimicrobial resistance gains (80–83), as well as other plans for the environment, public health, and development (84,85).

Approximately close to 60% of the Kenyan population lack access to safe and clean portable water (86,87). A meteorological drought, like the one in Narok, is caused by irregular rainfall and changing weather patterns (88–90). This scenario would make water quality and quantity levels unpredictable in Kenya and East Africa (91,92). The Narok landscape is already experiencing an increase in the frequency, intensity, and severity of weather-related calamities and catastrophes, including the loss of human life, livestock and wildlife mortality, and infrastructure damage (28,33,93). This exacerbates the susceptibility of marginalised communities. Surface runoff waters accumulate in dams and dams during the rainy season and are transported into rivers and streams during flooding, which exacerbates the persistence and dispersal of water- and food-borne pathogens in downstream watershed areas (94). This predisposes those communities to an increase in waterborne-related morbidity and mortality incidents, as well as to mental health concerns and the suppression of water recreation activities.

The meteorological drought can also exacerbate challenges associated with the coexistence of communities, livestock, and wildlife due to the difficulty of accessing water (51,93,95,96)**.** The Narok landscape is lacking in water infrastructure (65), and droughts result in the drying of seasonal rivers and water pans. This increases the likelihood that people will be required to travel considerable distances to obtain water, which can have a detrimental impact on their mental well-being. The situation is further exacerbated by the expansion of bare ground, the fragmentation of natural vegetation, the proliferation of nuisance and invasive species such as *Opuntia* spp., *Ipomoea carnea*, *Argemone ochroleuca*, *Parthenium hysterophorus*, *Solanum* spp., *Datura stramonium*, *Xanthium strumarium* and *Psidium guajava*, and the overutilization of water resources, which are the result of increased fencing and land tenure changes (31,97). These changes confine, exclude, and obstruct pastoral communities and wildlife, resulting in overgrazing, ecosystem degradation, and the expansion of bare ground (98). Furthermore, the drought incidents have the potential to worsen the conflicts over water-related natural resources that have already been observed among multiple users (99–103).

The genetic diversity of grasses, forbs, herbaceous legumes, and other plants that grow above ground, as well as the amount of biomass that plants produce due to drying out, can be reduced by frequent and severe weather droughts (104–106). Additionally, the chemicals that plants use can be affected (32). This conclusion is consistent with the findings of previous research. The alteration has significant effects on the spatial ecology of ungulates and pollinators, as well as on their foraging regimes and the capacity to host a variety of species (107,108). Additionally, it compromises the vulnerability of biodiversity (109). Ultimately, the health and resilience of Narok West's ASAL rangeland would be impacted by these changes.

The absence of leguminous forage in Narok West attributed to droughts can detrimentally impact on the productivity and biomass of livestock, as evidenced by decreased meat and milk yields (110,111). This is since there are fewer unprocessed protein minerals available for livestock to forage upon. This predisposes the pastoralism communities to food insecurity and lower market sales (wet and dried meat weight) due to the slow growth and poor body conditions of their livestock. Members of sedentary communities may be compelled to utilize transhumance to maintain their livestock.

The loss of above-ground biomass could alter the migration patterns and habitats of wildlife, even though there are more conflicts between humans and wildlife over resources. The rangeland health, tourism potential, and socio-economic levels of the greater Mara-Serengeti region would continue to be influenced by extreme wildlife population oscillations and dynamics, which are negatively impacted by reduced forage due to variation in weather (50,51,112). This is particularly true in Narok County, which is primarily supported by agriculture, livestock husbandry, and tourism industries. The production of cereals and pulses cultivated in the landscape would be impacted by the emerging reduced and unreliable rainfall, thereby compromising food security interventions. The mortality of perennial flora and the proliferation of nuisance and invasive species can be influenced by increased drought incidents, frequency, and intensity in the Narok landscape (113–115). This is due to the foraging of more palatable herbage species and their replacement by non-palatable ones, which has led to a decrease in productivity, a decline in ecosystem health, and an increase in investment in the management of invasive species. Maasai local indigenous knowledge systems may also be at risk due to changes in the weather and the location of plant growth, as well as the overharvesting of existing plants. This knowledge encompasses ethnomedicine and indigenous vegetables, as the community uses both conventional and complementary medicines (116–119). Despite the potential for the loss of biodiversity in the dry forests, woodlands, and rangelands of the ASAL Narok West landscape, as well as changes to ecosystem services and the social, economic, and environmental benefits that they provide, the threat of invasive species is not given sufficient attention.

With the increased intensity and spatial scale of droughts in Narok West, access to sufficient portable water for communities, livestock, and wildlife will dwindle. Women, children, and the Maasai culture are currently experiencing this impact. According to the Maa culture, women and girls are tasked with household chores including fetching water and firewood and cooking (120–123). Prolonged droughts will lead to increase in hours spent undertaking these chores and may adversely impact education progression, mental health and further aggravate poverty (124–128).

In the Narok West landscape, intensive pastoralism hinders the natural regrowth of vegetation after droughts and complicates the interaction between wildlife and livestock, particularly during the dry season (129). It is crucial to acknowledge that intensive pastoralism results in the shunting of crop grass to the ground, which exacerbates landscape desiccation during dry periods. This is because the soil quality is diminished because of the rapid increase in temperature of the exposed ground (130). These changes will eventually affect the way local people make a living (131). The changes will also erode the integrity of the range, particularly along riparian areas (98,132,133). Additionally, they will render the ecosystem's surface water resources more susceptible to hydrological extremes, particularly those related to the water, land, food, and energy nexus.

Conclusions

Our study reveals a spatiotemporal synergistic method for meteorological drought assessment and severity in the Narok West ASAL area between 2020 and 2024 using comparative satellite-derived methods using GEE. It not only supports and underscores the significance of RS and GIS emerging technology in appraising drought severity but also their use in establishing trends and intensity in the Narok savanna ecosystem. Our study established that drought conditions have been increasing in Narok West in frequency, severity, and spatiotemporal scale since 2015, with 2020 being the most severe, while the converse is true for good conditions. Additionally, the area of study is increasingly experiencing delayed rainfall in April and witnessing meteorological drought, especially in the August dry seasons. This study underscores the importance of the adoption of EOS and GEE across large spatial scales as this can provide both real-time monitoring of a changing environment over large swaths of land, as well as broader early warning systems, especially in the majority world.

On a microscale level, the sub-county's meteorological drought has the potential to compound the vulnerability of biodiversity by weakening surface wetlands and grasslands. It could also impede food security and nutrition in the ASAL region, worsen the challenges faced by pastoral communities in earning a livelihood, and result in increased disputes regarding the allocation of water among crop farmers, livestock owners, wildlife conservationists, and water users.

Recommendations

ASAL areas in Kenya, the Horn of Africa, and SSA should use GEE and NDDI to detect and predict droughts, especially with the adoption of machine learning (134–138). Based on the study findings, we advocate adoption of the drought-coping strategies through initiatives for conserving water resources and nature-based solutions (139). These include intensive community-led rainwater harvesting and storage, conservation of riparian zones and intensive reafforestation/rehabilitation of degraded landscapes to enhance wetland resilience and dryland landscape integrity. There needs to be a thorough study of how changing weather patterns affect water quality, the timing of waterborne diseases and WASH interventions, and the way people make a living in communities. At the same time, open science should make hydrometeorological data easier to access and use for modelling and decision making. Local indigenous knowledge and practices (LIKP) should be explored and be incorporated in climate change mitigation and adaptation action plan among the communities in the Narok socio ecological system.

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This paper forms part of the wider study on scope of weather variation and climate change on above ground water resources in semi-arid Narok West landscape and its effects on community livelihoods and health. We acknowledge helpful discussions on the ideas and insights presented in this paper by anonymous reviewers.

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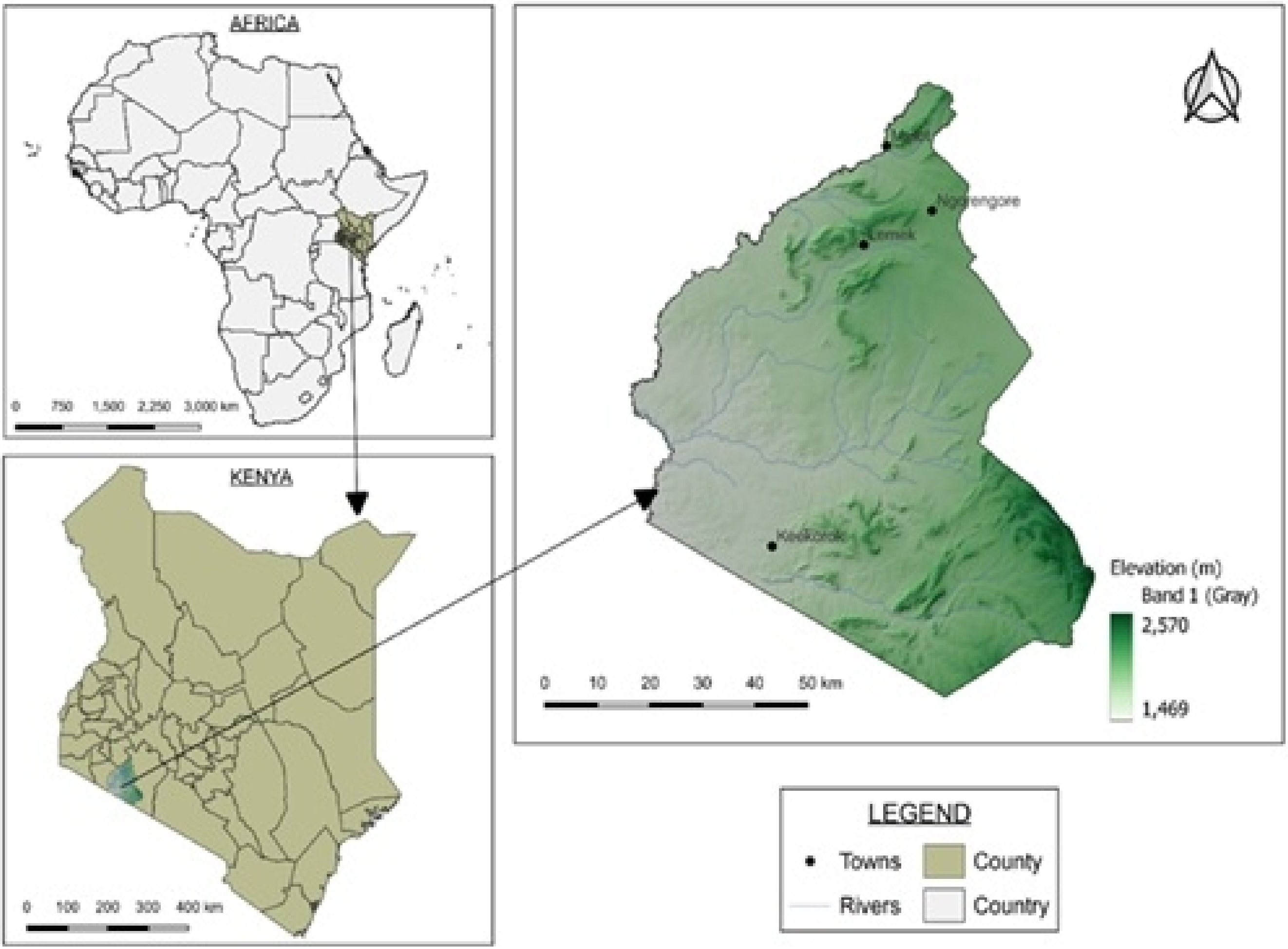
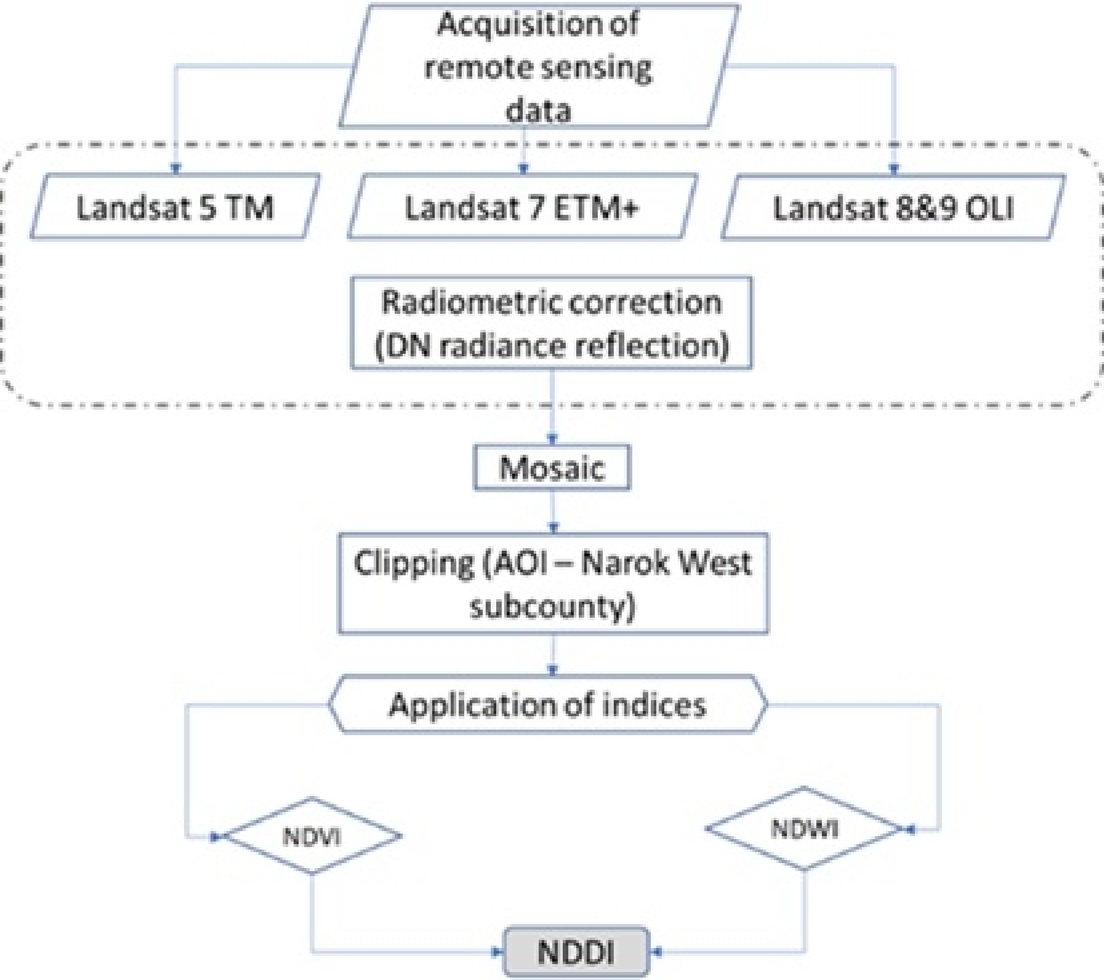
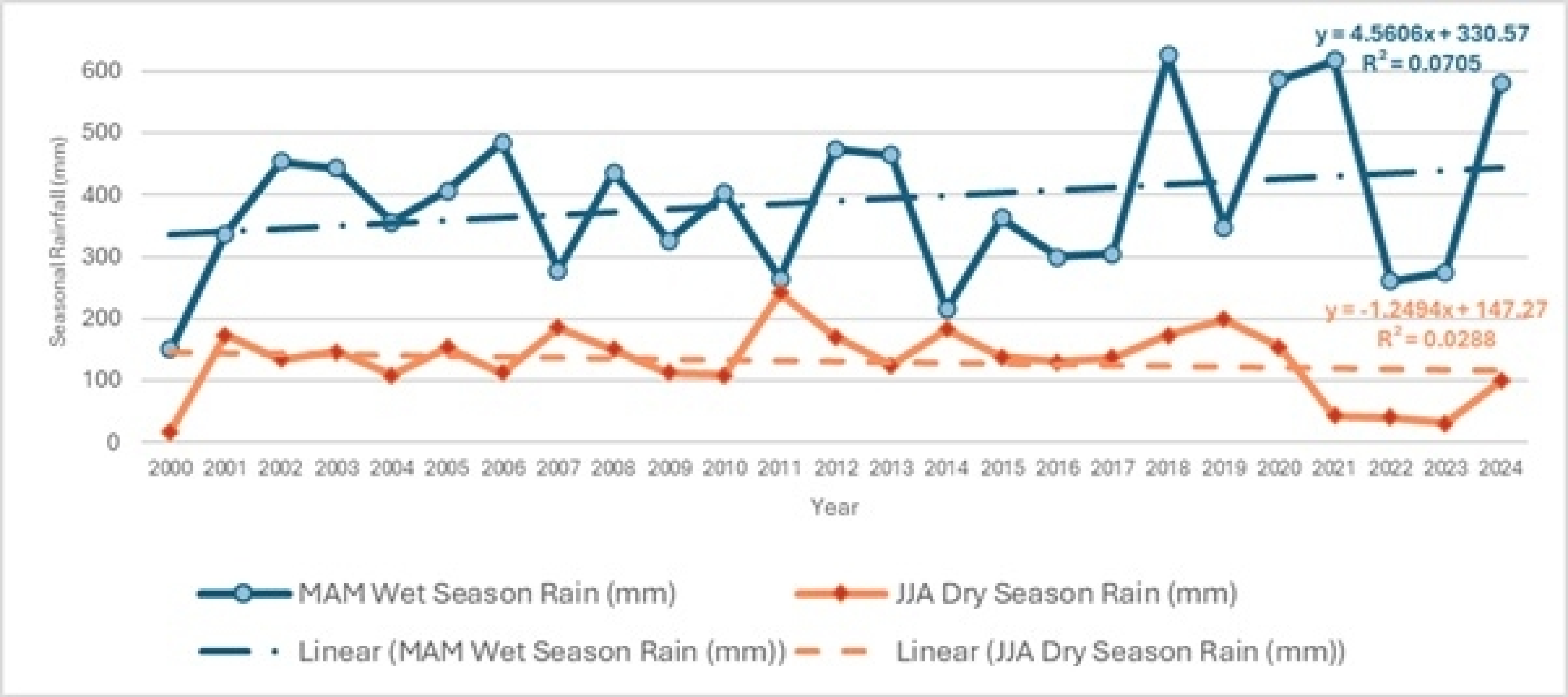

AFRICA
0 750 1,500 2,250 3,000 km
KENYA
0 100 200 300 400 km
0 10 20 30 40 50 km
Elevation (m)
Band 1 (Gray)
2,570
1,469
LEGEND
Towns
County
Rivers
Country

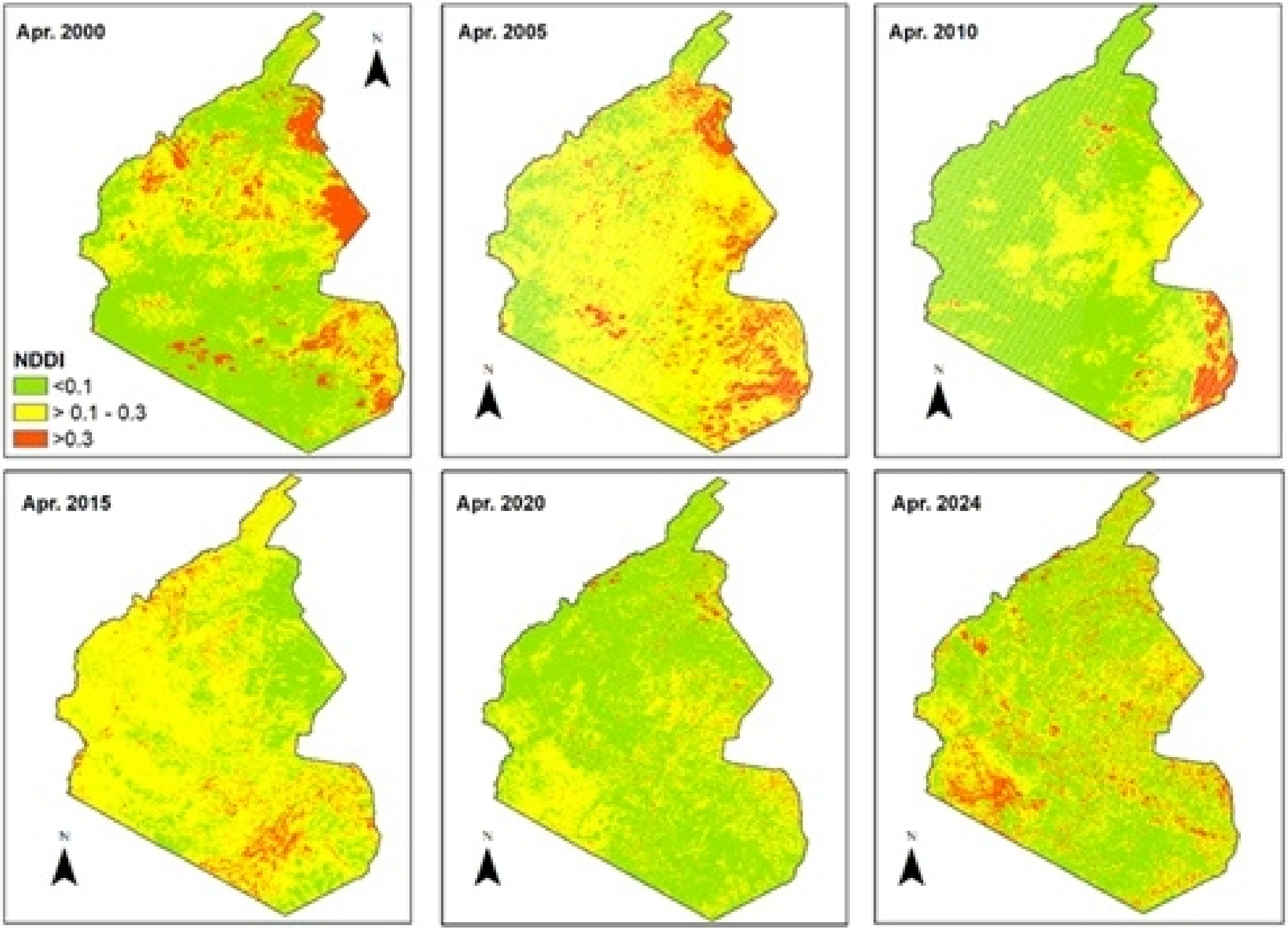
Figure


Acquisition of remote sensing data
Landsat 5 TM
Landsat 7 ETM+
Landsat 8&9 OLI
Radiometric correction (DN radiance reflection)
Mosaic
Clipping (AOI – Narok West subcounty)
Application of indices
NDVI
NDWI
NDDI

Figure


y = 4.5606x + 330.57
R² = 0.0705
y = -1.2494x + 147.27
R² = 0.0288
Seasonal Rainfall (mm)
600
500
400
300
200
100
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024
Year
MAM Wet Season Rain (mm)
JJA Dry Season Rain (mm)
Linear (MAM Wet Season Rain (mm))
Linear (JJA Dry Season Rain (mm))

Figure



Apr. 2000
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Figure

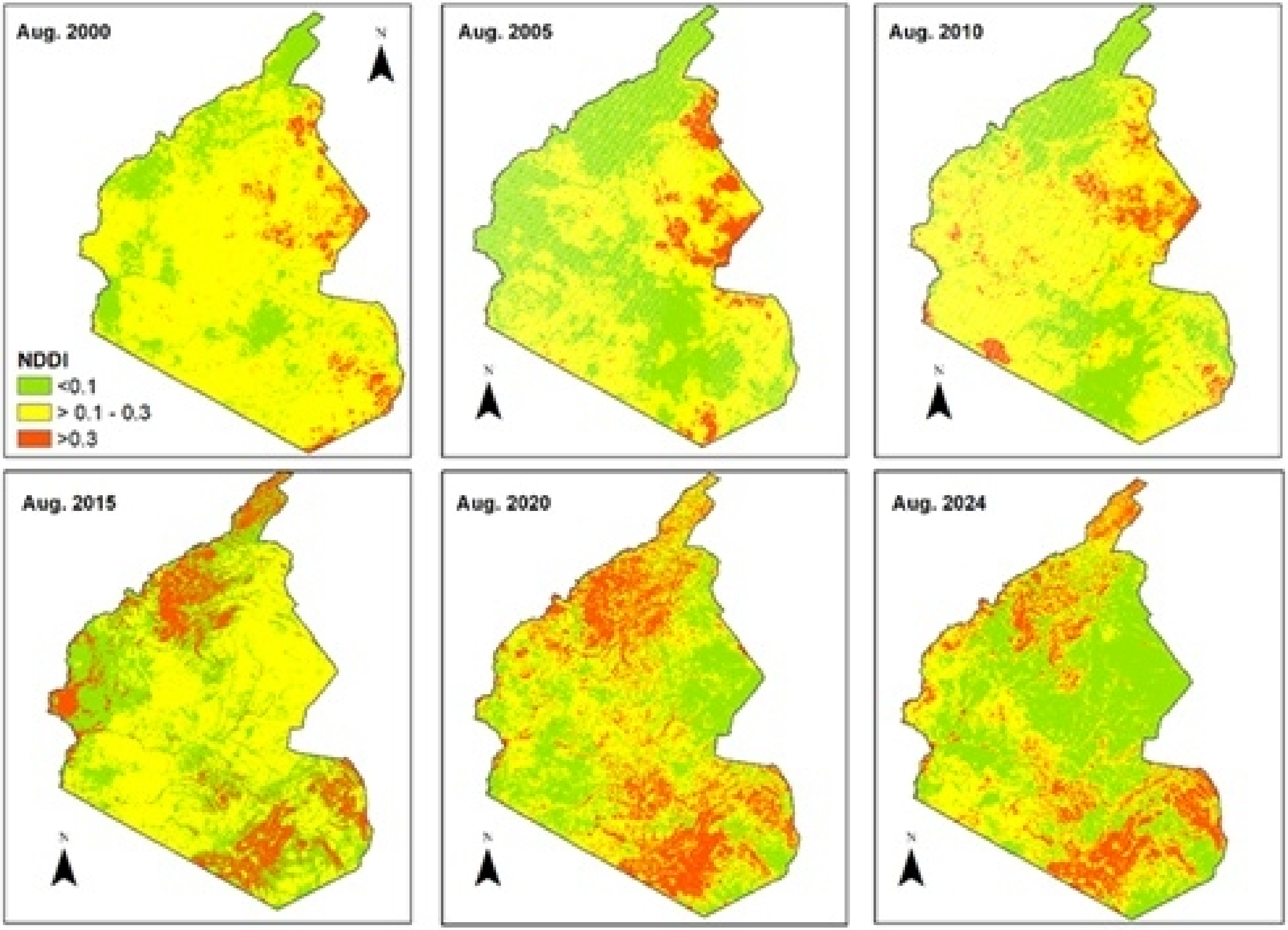

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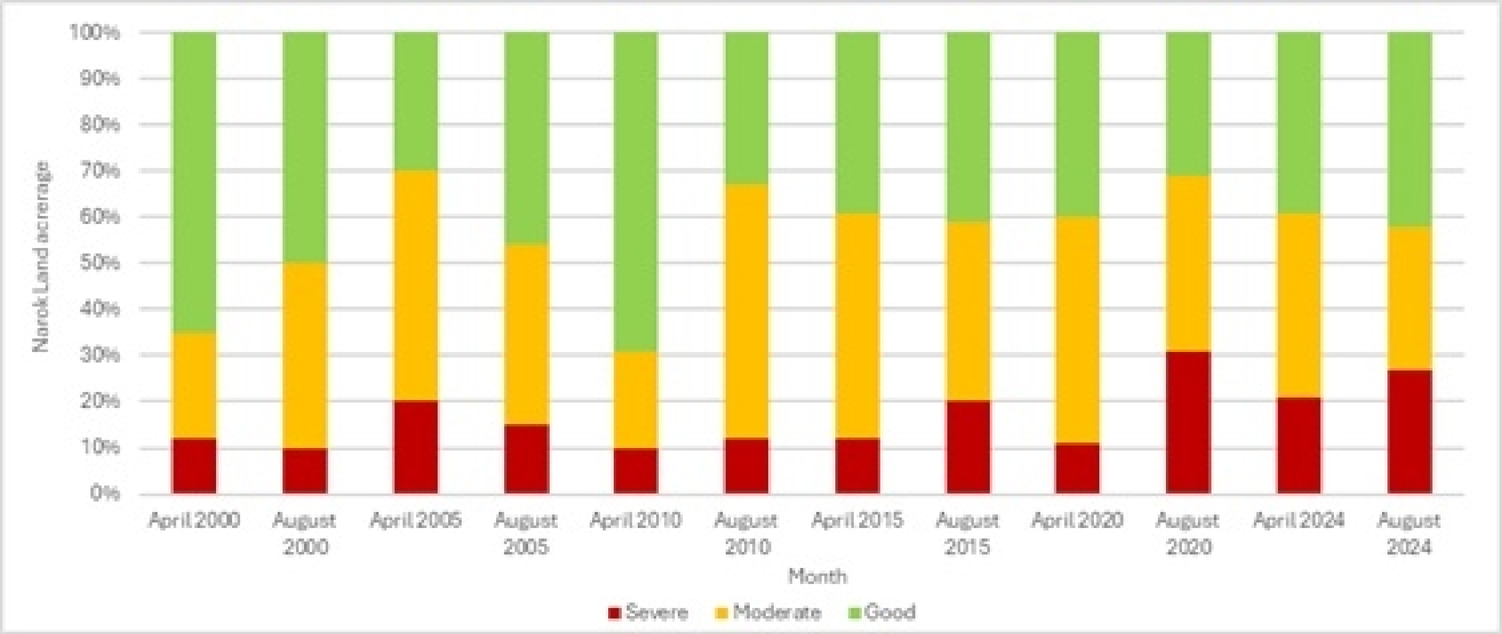
Figure


100%
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0%
Narok Land acreage
April 2000
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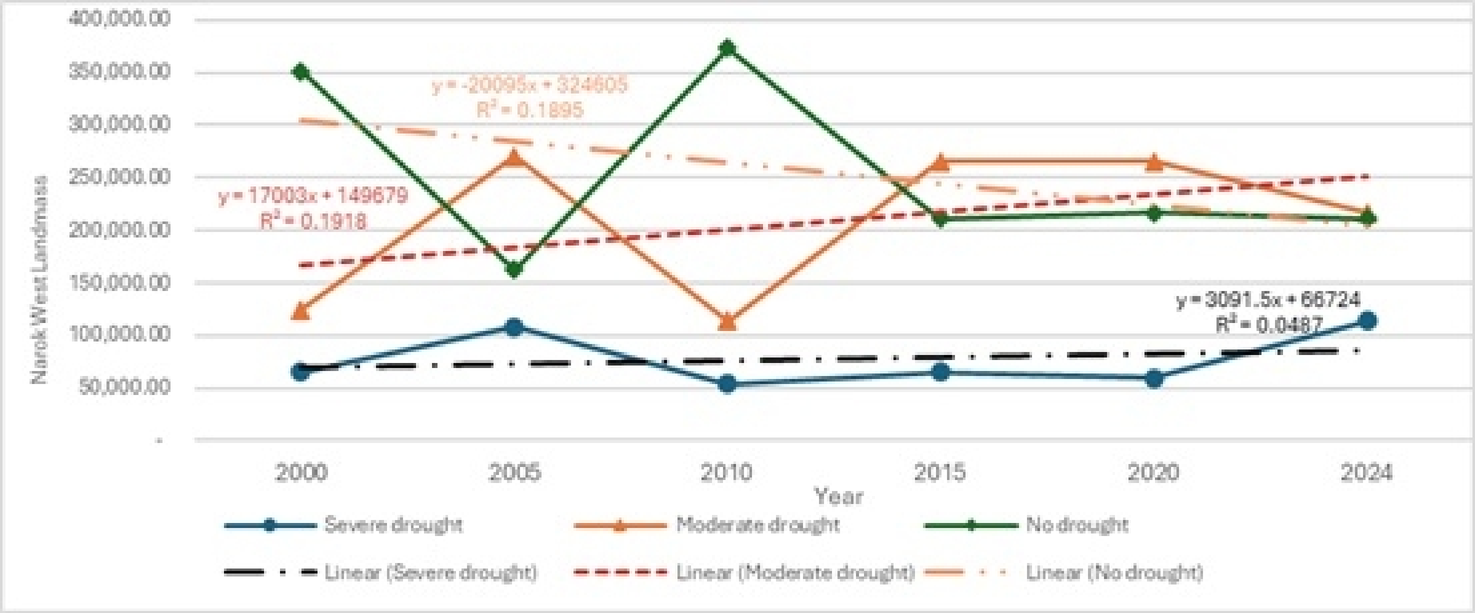
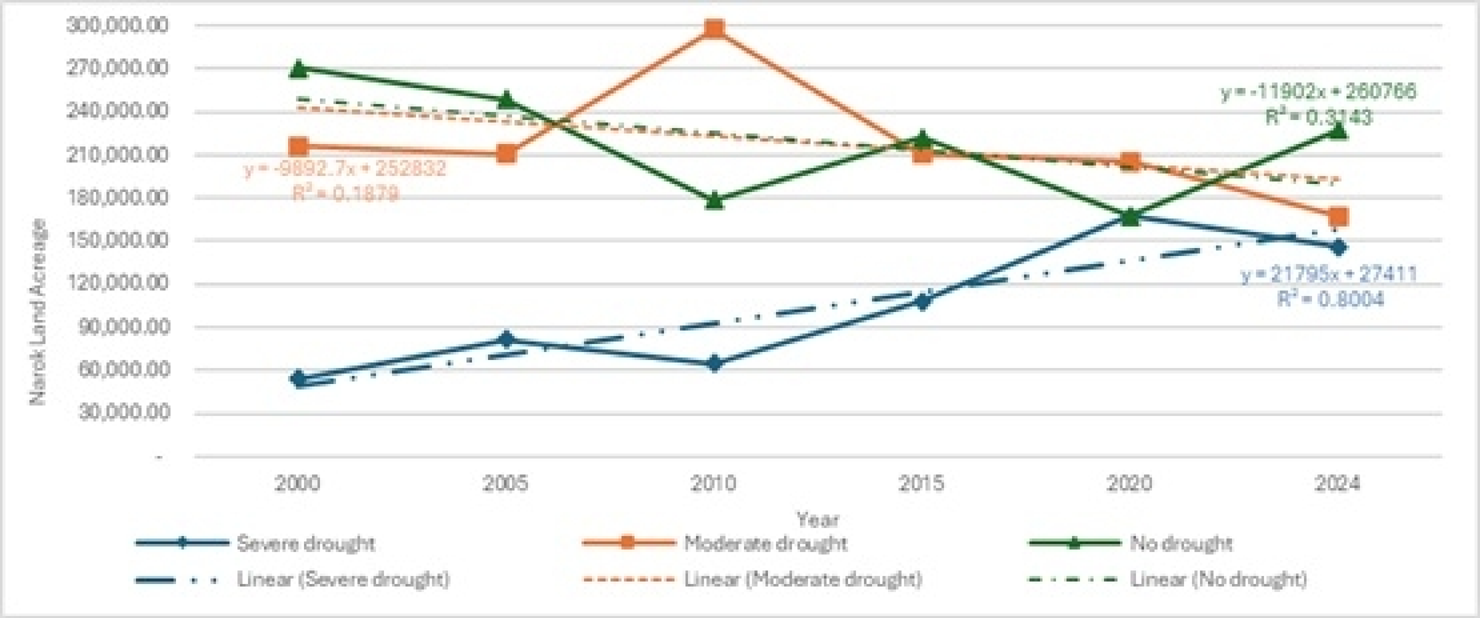
April 2005
August 2005
April 2010
August 2010
April 2015
August 2015
April 2020
August 2020
April 2024
August 2024
Month
Severe
Moderate
Good

Figure

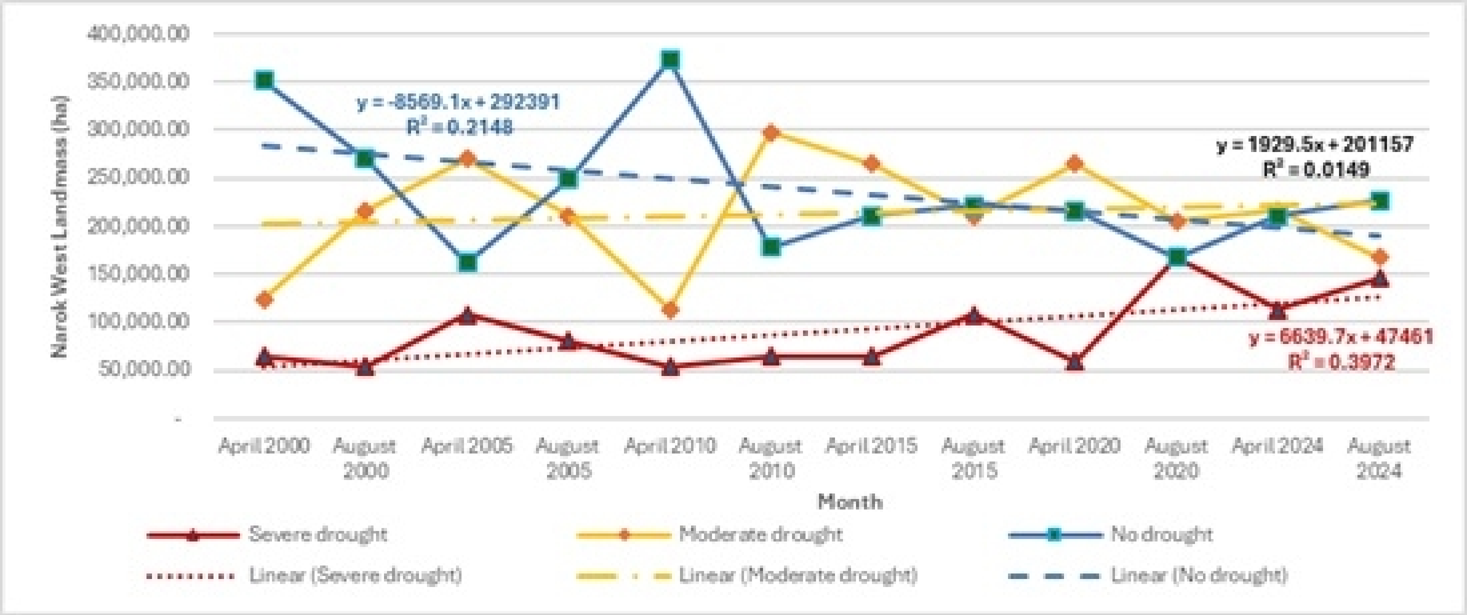


400,000.00
350,000.00
300,000.00
250,000.00
200,000.00
150,000.00
100,000.00
50,000.00
-
Narok West Landmass
y = -20095x + 324605
R² = 0.1895
y = 17003x + 149679
R² = 0.1918
y = 3091.5x + 66724
R² = 0.0487
2000
2005
2010
2015
2020
2024
Year
Severe drought
Moderate drought
No drought
Linear (Severe drought)
Linear (Moderate drought)
Linear (No drought)

Figure


300,000.00
270,000.00
240,000.00
210,000.00
180,000.00
150,000.00
120,000.00
90,000.00
60,000.00
30,000.00
-
Narok Land Acreage
2000
2005
2010
2015
2020
2024
Year
y = -11902x + 260766
R² = 0.3143
y = -9892.7x + 252832
R² = 0.1879
y = 21795x + 27411
R² = 0.8004
Severe drought
Moderate drought
No drought
Linear (Severe drought)
Linear (Moderate drought)
Linear (No drought)

Figure



Narok West Landmass (ha)
400,000.00
350,000.00
300,000.00
250,000.00
200,000.00
150,000.00
100,000.00
50,000.00
-
y = -8569.1x + 292391
R² = 0.2148
y = 1929.5x + 201157
R² = 0.0149
y = 6639.7x + 47461
R² = 0.3972
April 2000
August 2000
April 2005
August 2005
April 2010
August 2010
April 2015
August 2015
April 2020
August 2020
April 2024
August 2024
Month
Severe drought
Moderate drought
No drought
Linear (Severe drought)
Linear (Moderate drought)
Linear (No drought)

Figure