FRAMEWORK FOR RANGELAND MONITORING



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Prepared by
Dr. Grace Nangendo
ESIPPS International, Plot 160, Sir Apollo Kagwa Road,
Makerere Kikoni, Kampala Uganda

Submitted by	Submitted to
Dr. Grace Nangendo Plot 160, Sir Apollo Kagwa Road, Makerere Kikoni P. O. Box 600491 KAMPALA (U), Tel: +256782738248, Email: nangendoc@gmail.com Web: https://esipps.org	**The Director** IGAD Centre for Pastoral Areas and Livestock Development (ICPALD), Kabete Vet Lab, Kapenguria Road, P. O. Box 47824-00100, Nairobi, Kenya.

Document Control

Client: IGAD Center for Pastoral Areas and Livestock Development (ICPALD)	**Consultant:** Dr. Grace Nangendo Plot 160, Sir Apollo Kagwa Road, Uganda Microcredit Foundation Building, Makerere Kikoni P. O. Box 33011 KAMPALA (U), Tel: +256782738248, Email: nangendoc@gmail.com Web: https://esipps.org

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EXECUTIVE SUMMARY

Rangeland degradation is a significant problem globally, particularly in the IGAD region. Key drivers include climate change, overgrazing, bush encroachment, and unsustainable land management practices. The consequences include reduced rainfall absorption, increased runoff, soil nutrient loss, and overall poorer vegetation condition. Specific to the IGAD Region, the challenge of Climate Variability is making the rangelands vulnerable to climate change and drought, which are major drivers of rangeland degradation. This report provides an outcome of a consultancy to Develop Tools, Indicators, Data Collection Protocol, and Manual for Rangeland Health Monitoring in the IGAD region. The consultancy was commissioned by the IGAD Centre for Pastoral Areas and Livestock Development (ICPALD) with funding from GIZ under the "Strengthening IGAD's Capacity to Increase Resilience in the Horn of Africa" (SCIDA III). The focus sites were the Karamoja area of Uganda and, the Turkana and West Pokot area of Kenya. The objectives of the study were to (i) map out suitable indicators for rangeland monitoring, (ii) Identify tools to use to monitor the indicators, and (iii) recommend the most suitable frameworks for rangeland monitoring. The study used a multi-disciplinary approach, combining Geospatial analysis, ecological field based rangeland health conditions data collection and participatory appraisal methods. Literature reviews, stakeholder consultations and expert reviews were used to inform the development of Rangeland health indicators and monitoring frameworks.

Effective implementation requires a multi-faceted approach that integrates robust monitoring protocols, clear implementation arrangements, and a strong emphasis on learning and adaptation. This includes defining specific objectives, selecting appropriate indicators and methods, establishing clear roles and responsibilities, and ensuring that data management and analysis are well defined. A well-designed framework that addresses the key elements leads to establishment of effective rangeland health monitoring programs that contribute to the long-term sustainability of these vital ecosystems

The report provides an analysis of frameworks used in rangeland monitoring, presents selected indicators and maps out tools used in rangeland monitoring. It also provides Key lessons learned to approach rangeland health monitoring review, together with gaps and opportunities for strengthening monitoring and evaluation for creating sustainable system for rangeland health monitoring. It systematically identifies suitable sets of indicators that can be monitored using a well-articulated framework, which is rapid yet providing adequate information to guide decision making at regional , national, sub-national and community levels.

The report identified the ecological (vegetation cover and biomass, Soil Quality, Biodiversity, Water Resources) and Socioeconomic Indicators. In general, the experts mainly depended on livestock condition scoring, interviews with the communities, and visible field assessment as the main indicators and tools used to monitor the rangeland health status. The study revealed that the local community had diverse and rich knowledge of rangeland health and monitoring. Integrating this knowledge with modern techniques will result in more accurately predicted weather conditions for better decision-making. Ecological Field-Based tools provide the crucial ground-truth data and local context for understanding rangeland health,

particularly in ecologically diverse and socially complex landscapes. Tools such as the Participatory Grassland and Rangeland Assessment (PRAGA) methodology and the Participatory Rangeland Management (PRM) Toolkit are designed to empower communities through integrating indigenous knowledge with ecological assessments.

The study identified the Earth Observation platforms for spatial data analysis for this enables precise mapping, analysis, and visualization of rangeland condition, improving understanding of rangeland threat trends, and guiding targeted interventions. Soil analysis indicate that soils in both Turkana and Karamoja regions are dominated by sandy soil, but sand content was higher in Turkana. Karamoja had great variability in clay and pH levels. In contrast, Turkana's soil is more uniformly sandy and low in moisture, organic matter, and nutrients across all sites. While both regions exhibit low organic carbon and organic matter, indicating generally poor soil fertility, Karamoja shows slightly more variation in moisture content (M.C %) and soil texture.

Based on the results, it is possible to develop a robust framework for rangeland health monitoring, which is crucial for understanding and managing these valuable ecosystems. A combination of the Land Degradation Surveillance Framework (LDSF) and Land-Potential Knowledge System (LandPKS), plus leveraging the values of the Participatory Grassland and Rangeland Assessment (PRAGA) methodology, was selected for it provides comprehensive coverage of the identified indicators for rangeland monitoring. The associated training manual provides a guidance on how to use these tools.

This framework is a living tool that should be regularly revised to suite the prevailing conditions.

LIST OF ACRONYMS AND ABBREVIATIONS

- AEZ – Agroecological Zones
- AGB – Above-Ground Biomass
- ASALs – Arid and Semi-Arid Lands
- CDI – Combined Drought Index
- CHIRPS – Climate Hazards Group InfraRed Precipitation with Station
- CIAT – International Center for Tropical Agriculture
- DPSIR – Driver-Pressure-State-Impact-Response
- ESD – Ecological Site Description
- FAO – Food and Agriculture Organization
- FPAR – Fraction of Photosynthetically Active Radiation
- GEO – Group on Earth Observations
- GEOGLAM – Group on Earth Observations Global Agricultural Monitoring
- GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit
- GLCC – Global Land Cover Classification
- GLDAS – Global Land Data Assimilation System
- HERD – Holistic Ecosystem Restoration Demonstration
- ICPALD – IGAD Centre for Pastoral Areas and Livestock Development
- ICRAF – International Centre for Research in Agroforestry (World Agroforestry Centre)
- ICRISAT – International Crops Research Institute for the Semi-Arid Tropics
- IDDRSI – IGAD Drought Disaster Resilience and Sustainability Initiative
- IGAD – Intergovernmental Authority on Development
- IIRH – Interpreting Indicators of Rangeland Health
- ILRI – International Livestock Research Institute
- JRC – Joint Research Centre (European Commission)
- LDSF – Land Degradation Surveillance Framework
- LGP – Length of Growing Period
- LST – Land Surface Temperature
- MEA – Millennium Ecosystem Assessment
- MODIS – Moderate Resolution Imaging Spectroradiometer
- NASA – National Aeronautics and Space Administration
- NDVI – Normalized Difference Vegetation Index
- PGIS – Participatory Geographic Information System
- PRAGA – Participatory Grassland and Rangeland Assessment
- PRM – Participatory Rangeland Management
- RARE – Rangeland Assessment and Restoration Effectiveness
- RCMRD – Regional Centre for Mapping of Resources for Development
- RDST – Rangelands Decision Support Tool
- SAVI – Soil Adjusted Vegetation Index
- SMAP – Soil Moisture Active Passive
- SPEI – Standardized Precipitation Evapotranspiration Index
- SPI – Standardized Precipitation Index
- STM – State-and-Transition Models
- SWALIM – Somalia Water and Land Information Management
- SWI – Soil Water Index
- UNEP – United Nations Environment Programme
- USAID – United States Agency for International Development
- VCI – Vegetation Condition Index



Definition of key terms

Above-Ground Biomass (AGB): Refers to the total biomass of living plants above the soil surface, including stems, leaves, and reproductive parts. It is estimated using measurements and calculations from harvested vegetation.

Annual plant: A plant which grows from seed and completes its life cycle, including flowering and seeding, within 1 year or less. Some annuals can live longer than 1 year when growing conditions are favourable.

Arid: A region or climate where lack of sufficient moisture severely limits the growth and production of vegetation. The actual limit of sufficient moisture varies according to temperature in the specific location (FAO, 2011; LandPKS, 2019).

Semi-Arid: A region with low and variable rainfall, typically between 250–500 mm annually, where vegetation is limited and droughts are frequent. These areas support rangelands but are vulnerable to overgrazing and land degradation (FAO, 2011; IPCC, 2007).

Hyper-Arid: Extremely dry climates receiving less than 100 mm of rainfall per year, with negligible vegetation and high evapotranspiration. These zones are often classified as deserts (UNEP, 1992; LandPKS, 2019).

Dry Sub-Humid: Transitional zones with 500–800 mm of annual rainfall, where moisture is generally sufficient for vegetation, but seasonal deficits can affect productivity. These areas are often targeted for sustainable intensification (WRI, 1992; Smith et al., 2007).

Desert: A type of arid environment with minimal precipitation and sparse vegetation, often characterized by extreme temperature fluctuations and poor soil moisture retention (MEA, 2005; FAO/LEAD, 2006).

Seasonally Dry Tropical: Climates with distinct wet and dry seasons, where vegetation growth is concentrated in the rainy period and dormancy occurs during dry spells. These are common in savanna and woodland rangelands (Briske & Heitschmidt, 1991; Rangelands Gateway, 2024).
Drought-Prone: Areas that frequently experience prolonged periods of below-average rainfall, leading to reduced forage availability and increased vulnerability of pastoral systems (Jones & Thornton, 2008; ILRI, 2006).

Available forage: The proportion of forage production that is accessible for use by a specified kind or class of grazing animal.

Basal area (ground cover by perennial grasses): In the rangelands, this term is used for the percentage of ground covered by the base or butts of perennial tussock grasses. Basal area of tussocks is a consistent way of measuring the health of tussock grassland from year to year.
Biennial: Plants that complete their life cycle over 2 years.

Canopy: The aerial portion of vegetation that provides groundcover when viewed from above, usually referring to shrubs or trees and not annuals.

Carrying capacity: The number of livestock units a paddock or management area can carry over the long term while maintaining or improving land condition.
Combined Drought Index (CDI): A drought indicator available by integrating more than one input variable or indicator. It is composed of three warning levels (watch, warning, and alert) by integrating Precipitation Drought index (PDI), Temperature drought index (TDI), and vegetation or soil moisture drought index (VDI).

Desirables or desirable species: Those species in each pasture type that are usually productive, palatable, and perennial.

Driver: An aspect of a system that causes or contributes to a change on another aspect of the system. For instance, climate change is a driver of water availability. In the DPSIR framework, drivers are underlying human activities or natural phenomena that initiate changes in rangeland ecosystems, such as population growth, policy decisions, or climate variability.

Drought: A prolonged period without rain, compared to the norm, leading to a shortage of water for vegetation and animals.

Ecosystem: The biotic and abiotic environment and the ecology in a clearly defined system. An ecosystem equals the environment plus ecology.

Environment: The surroundings in which an organism lives, including biotic (other living organisms) and abiotic (e.g., soil, water, atmosphere) factors.

Earth Observation (EO): Technologies involving satellite and aerial imagery that significantly enhance the capability to monitor rangeland ecosystems over large spatial scales.
Erosion: The process by which soil particles are detached and moved from the land surface by the action of wind (wind erosion) or water (water erosion).

Forage: Browse and herbage which is available as food for grazing animals or for harvesting for feed (i.e., hay or silage).

Land Degradation Surveillance Framework (LDSF): A critical and widely recognized framework developed by the World Agroforestry Centre (ICRAF), providing a systematic and scalable approach for assessing land health at landscape level. It integrates biophysical and ecological indicators and is rooted in principles of adaptive management.
Land- Potential Knowledge System (LandPKS)

Normalized Difference Vegetation Index (NDVI): A remote sensing technique offering consistent, spatially extensive, and cost-effective means to monitor vegetation condition, productivity trends, and drought stress over large landscapes.

Participatory Rangeland Management (PRM): A structured, inclusive, and community-driven approach developed to strengthen local governance and improve the sustainable use of rangelands. It involves a three-stage process encompassing nine key steps.

Rangelands: Extensive ecosystems characterized by natural or semi-natural vegetation, predominantly grasses, shrubs, scattered trees, and herbaceous plants. They are primarily utilized for grazing or browsing by livestock and wildlife.

Rangeland Management Committees (RMCs): Local governance structures that are increasingly central to decentralized rangeland stewardship in the IGAD region. They play a role in community-based rangeland management.
Rangeland Management Plan (RMP): A plan co-created with community leaders and RMCs that outlines grazing rules, seasonal access schedules, restoration strategies, water development, and roles and responsibilities within a Rangeland Management Unit (RMU).

Rangeland Management Unit (RMU): The spatial boundaries of the rangeland that communities collectively determine they will manage under the PRM model.

Savanna: Area of grassland with scattered trees.

Seasonal Carrying Capacity (Seasonal CC): The number of livestock units a paddock or management area can carry in the current season while maintaining land condition. This carrying capacity can markedly fluctuate between seasons.

Standardized Precipitation Evapotranspiration Index (SPEI): A multi-scalar drought index based on climatic data, used to determine the onset, duration, and magnitude of drought conditions for rangeland ecosystems. It has a multi-scale character, providing SPEI timescales between 1 and 48 months.

1. Introduction

1.1. Background

Rangelands are extensive ecosystems characterized by natural or semi-natural vegetation, predominantly grasses, shrubs, scattered trees, and herbaceous plants. They are primarily utilized for grazing or browsing by livestock and wildlife (Food and Agriculture Organization [FAO], 2021). Rangelands ecosystem types include a variety of natural landscapes including; Grasslands, Shrublands, Savannahs, Woodlands and Deserts.

1.2. The Scope of Rangelands and their governance

i. Globally, rangelands cover approximately 54% of the Earth's terrestrial surface, encompassing diverse landscapes such as grasslands, savannahs, shrublands, deserts, and woodlands (UNCCD, 2024). In Africa, rangelands are estimated to cover 66% of the land surface, although there are variations from country to country (Bolo et al. 2019). The scope of rangelands in Africa are vast, covering the majority of Africa's land area and serving as a crucial, yet vulnerable, foundation for the continent's ecological balance and the livelihoods source for a substantial portion of its population. In the Intergovernmental Authority on Development (IGAD) region, which includes Djibouti, Eritrea, Ethiopia, Kenya, Somalia, South Sudan, Sudan, and Uganda, rangelands constitute nearly 70% of the total land area. In Eastern Africa, for example, land surface coverage of rangeland areas varies from 44% in Uganda and 65% in Ethiopia to 74% in Tanzania and over 80% in Kenya ((Bolo. et al. 2019).

ii. According to the UNCCD report of 2009, rangelands support approximately 2 billion people worldwide (Hutchinson et al. 2011; MEA, 2005), 268 to 325 million pastoralists & agro-pastoralists in Africa (UNCCD, 2009). About 69% of the rangelands in developing countries are used for livestock production (Safriel et al., 2005) and contribute 10% to global meat production (Rodriguez, 2008). Livestock production in rangelands accounts for between 50% and 80% of agricultural gross domestic product (GDP) in developing countries (Neely et al., 2009; Mortimore et al., 2009).

iii. In the IGAD region, rangelands are the backbone of the livestock industry that provides various economic opportunities along the value chain, therefore contributing significantly to the member countries' national GDPs. Extensive livestock production, characterized by seasonal herd mobility to track pasture and water over expansive rangelands, is the dominant land use in the ASALs of IGAD employing up to 90% of pastoralist populations in the region. About 53% of the region's cattle (51 million), 71% of the goats (58 million), and 68% of the region's sheep (58 million) are found in the ASALs (FAO, 2008).

iv. Pastoral production is found at all scales of operations, with most being small herds, providing meat, milk, blood, hides, and skins, as well as transport, storage of wealth, means of social security and obligations, security against disasters, obtaining goods and services through barter and generation of cash through local trade or export markets (FAO, 2008). In the Horn of Africa, the livestock sector contributes 10% – 50% of the individual countries' agricultural GDP (Behnke et al., 2011; ICPALD, 2013; ICPALD 2017).

v. Besides livestock production, rangelands are habitats for a diversity of flora and fauna of both socio-cultural, environmental, and economic significance. Rangelands are Biodiversity Hotspots as they contain significant biodiversity, with over 7,500 protected areas covering more than 3 million square kilometers and 1,940 key biodiversity areas across Africa (Briske, 2017). In addition they provide a variety of Ecosystem Services: Beyond food production, rangelands provide essential ecosystem services, including; Water catchments, Carbon sequestration, and Soil stabilization. They are a source of various goods such as timber and non-timber products such as fiber, gum and resins, honey, medicinal and food plants, minerals, oil, and gas, among

others. In addition, the rangeland ecosystems provide, scenic beauty as well as a habitat for wildlife that form the basis of ecotourism in respective countries. Rangelands also host sacred sites that are valued for spiritual and religious purposes. These sites often conserve islands of indigenous biophysical resources, including important biodiversity, as well as being linked to the cultural identity of certain ethnic groups (Wild and McLeod, 2008, Verchurren et al., 2010).

vi. Governance and management of rangelands are often transboundary in nature, meaning they span national borders, which requires cooperation between different countries for effective management. This often presents complex communal land tenure systems resulting in challenges for governance and sustainable management (Maru, 2020). This is especially true in Africa, where rangeland ecosystems are shared across multiple countries and are influenced by diverse management approaches, such as those for pastoralism, conservation, and climate adaptation. For example, nomadic pastoralists frequently cross borders for seasonal grazing, and a breakdown in cross-border management can degrade rangelands and weaken risk management strategies, according to the Legal and policy arrangements for cross-border pastoralism. This often results in issues like land degradation, climate change, and land-use competition from agriculture. This presents the need to promote transboundary natural resources, requiring collaboration between neighboring authorities and diverse management approaches.

1.3. Rangeland degradation

Globally, rangeland degradation is a serious environmental problem, especially in pastoral and semi-pastoral areas that are constantly shrinking (Daba and Mammo 2024). Rangeland degradation is a significant issue globally, particularly in Africa and especially in the Arid and Semi-Arid Lands (ASALs) of the IGAD region. This degradation is driven by a combination of natural factors like climate change and human activities like overgrazing and unsustainable land use practices. The consequences include decreased productivity, biodiversity loss, and increased vulnerability to drought, impacting the livelihoods of millions who depend on these ecosystems. Both natural and human factors contribute to rangeland degradation, which poses a serious threat to grazed areas. There is also a lack of standardization in the concept of land degradation and inadequate monitoring (Abate and Angassa, 2016). Degraded rangelands are marked by reduced biological and economic productivity due to unsustainable human land use, affecting hydrology, soil processes, and vegetation composition (Wily, 2008). There is a deficiency in the current policy framework for agro ecological zones as well as trustworthy evaluations of the effects of grassland degradation on livelihoods. Adoption of sustainable land management is hampered by a lack of knowledge and experience (Nkonya et al., 2015). Natural causes of rangeland degradation include climate change and variability, aridity and desertification, drought, as well as alien species invasion. Anthropogenic rangeland degradation can manifest through agricultural activities and associated developmental practices, overstocking and overgrazing, as well as breakdown of social structures and government policies/by-laws (Bolo et al. 2019).

Rangelands deteriorate in productivity, ecological integrity, and resilience due to both anthropogenic and natural factors. Globally, rangeland ecosystems are increasingly threatened by overgrazing, land conversion, deforestation, climate change, and unsustainable land management practices (ILRI, IUCN, FAO, WWF, UNEP & ILC, 2021). This is illustrated in Figure

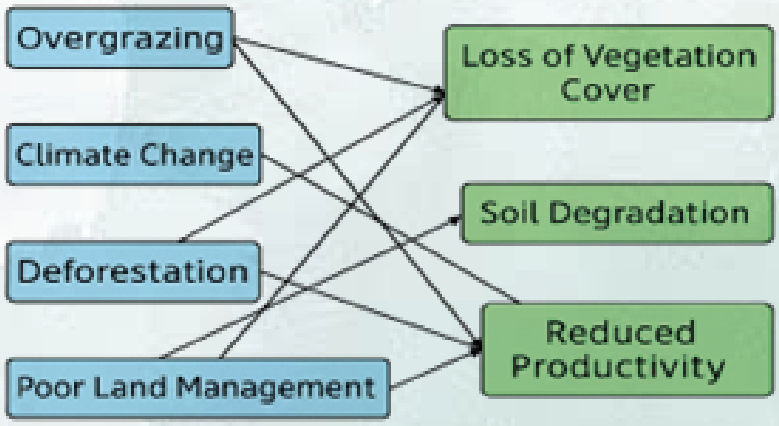


Figure 1: Threats to rangelands

Overgrazing occurs when livestock stocking exceeds the land's carrying capacity, resulting in diminished vegetation cover, soil compaction, and reduced productivity. In regions such as the IGAD area, persistent high livestock densities coupled with poor grazing management practices exacerbate these impacts, significantly impairing ecosystem functions and resilience (FAO, 2021; IGAD, 2020).

Land conversion is another significant driver of rangeland degradation, particularly evident through the transformation of rangelands into agricultural or urban areas (Figure 2). Such conversions often lead to habitat fragmentation, loss of biodiversity, and disruption of traditional pastoral livelihoods. In East Africa, extensive areas of pastoral land have been converted to crop production, settlement expansion, or industrial uses, markedly reducing the available grazing lands for pastoralist communities (Herrick et al., 2019; IGAD, 2020).

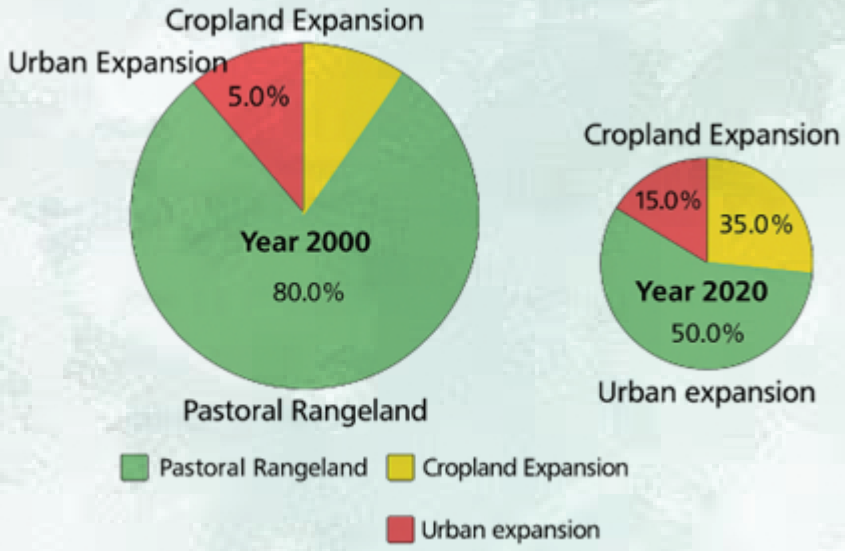


Figure 2: Change of rangelands to other land uses in eastern Africa between 2000 and 2020 (FAO/ESRI, 2020)

Climate change further compounds these pressures, manifesting as increased frequency and severity of droughts, unpredictable rainfall patterns, and rising temperatures, as shown in Figure 3. for IGAD regions (Reference source). For instance, climate projections indicate significant changes in rainfall variability and growing season lengths, intensifying the vulnerability of pastoralists whose livelihoods heavily depend on stable climatic conditions (ILRI et al., 2021).

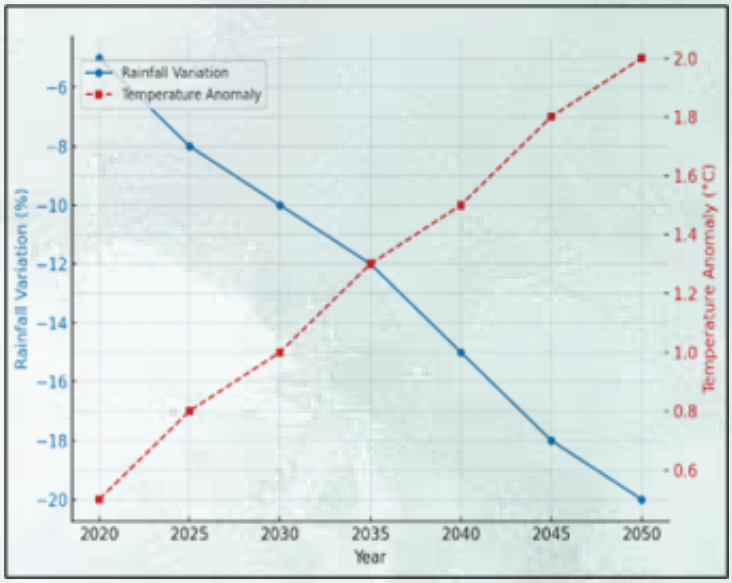


Figure 3: Predicted temperature and rainfall variation between 2020 and 2050

1.4. Management Strategies

Effective restoration and sustainable management of degraded rangelands depend heavily on systematic monitoring and evaluation. These practices are essential for detecting changes in landscape features, shifts in vegetation patterns, and overall rangeland health (Bolo PO et al, 2019). By implementing regular monitoring, managers can identify negative trends that may require restoration efforts, recognize ecological disturbances such as invasive species outbreaks or transformations in plant communities, and take timely corrective measures. Monitoring typically involves assessing various indicators, including plant species composition, forage biomass, utilization rates, and vegetation cover. Below is a range of monitoring methods, ranging from traditional field-based approaches to modern technological tools available to support the evaluation of rangeland conditions and guide restoration efforts.

Sustainable Grazing Systems

Sustainable grazing systems are essential for maintaining the ecological balance and productivity of rangelands. Strategies such as rotational grazing involve systematically moving livestock between pastures to allow vegetation recovery, thus preventing overgrazing, promoting biodiversity, and enhancing pasture productivity (Teague et al., 2013). Improved pasture management practices, including reseeding with drought-resistant and nutritious forage species, can significantly enhance vegetation cover and resilience against climatic stresses, particularly important for arid and semi-arid regions like the IGAD area (FAO, 2021; IGAD, 2020). Incorporating indigenous knowledge, such as traditional seasonal grazing calendars, can further optimize the sustainability and ecological integrity of grazing practices (Oba, 2012).

I. Erosion Control and Soil Restoration Techniques

Effective erosion control and soil restoration are crucial to rehabilitating degraded rangelands. Techniques such as establishing vegetation barriers, contour ploughing, and terracing can significantly reduce soil erosion, conserve soil moisture, and enhance soil fertility (FAO, 2021). Additionally, reforestation and agroforestry initiatives can stabilize soils, improve nutrient cycling, and enhance carbon sequestration. Soil restoration practices, including reseeding degraded areas with indigenous grasses and legumes have been proven effective in restoring ecosystem functions and productivity in degraded pastoral regions (Herrick et al., 2019; ILRI et al., 2021). In the IGAD region, combining such techniques with community-based participatory approaches ensures greater adoption and sustained benefits (IGAD, 2020).

II. Water Resource Management

Sustainable management of water resources is critical in supporting livestock and human livelihoods in dryland rangelands. Effective water management strategies encompass the establishment and maintenance of water harvesting structures, such as small-scale dams, water pans, and boreholes, that provide reliable water sources throughout dry periods (ILRI et al., 2021). Integrating rainwater harvesting techniques, such as roof catchment systems and micro-catchments, enhances water availability for livestock, reduces stress on existing water resources, and improves resilience to climate variability (FAO, 2021). Water resource management should incorporate community-based management committees to ensure fair distribution and maintenance, thereby minimizing conflicts over water access and promoting collective stewardship (IGAD, 2020).

III. Policy Frameworks Supporting Sustainable Rangeland Use

Robust policy frameworks are fundamental to ensuring sustainable rangeland use and management. Effective policies should support secure land tenure, enabling pastoral communities to manage grazing areas, sustainably without fear of displacement or encroachment by other land uses (Davies et al., 2016). Additionally, frameworks that facilitate cross-sectoral collaboration, integrating agricultural, environmental, and socio-economic policies, can more effectively address the complex challenges facing rangelands (FAO, 2021). Regionally, there are several initiatives at the IGAD level, such as the Regional Strategic Framework (Rangeland Management for Arid and Semi-Arid Lands of the IGAD Region). The IGAD Protocol on Transhumance, and The Eastern Africa Livestock Feed and Feeding Strategy 2023-2037. At the national level, we have Medium-term National Development Plans and the 10-year National Country Programming Papers for implementation of the IGAD Drought Disaster Resilience and Sustainability Initiative (IDDRSI), and Country Specific Rangeland Management Policies. These are examples of policy-driven interventions promoting rangeland restoration, capacity building, and resilience among pastoralist communities (IGAD, 2020). Strengthening legal provisions and community rights over natural resources enhances governance and fosters collective responsibility for sustainable management (ILRI et al., 2021).

State of rangelands and why the monitoring Framework State of rangelands

I. Reasons for monitoring rangelands

Rangelands have environmental, social and economic benefits, including support to national economies through tourism and employment. Despite their benefits, rangelands are under threat of continued degradation driven by anthropogenic and natural causes. The consequences of rangeland degradation are profound and multifaceted, encompassing ecological, economic, and social dimensions. Ecologically, degraded rangelands exhibit significant soil erosion, reduced

vegetation productivity, and biodiversity loss, undermining critical ecosystem services such as carbon sequestration, water regulation, and habitat provision (FAO, 2021). Economically, degradation reduces productivity and resilience of pastoral systems, negatively affecting livestock health and production. This translates directly into diminished incomes and heightened poverty among pastoral communities, further exacerbating vulnerability to climatic shocks and socio-economic stressors (Davies et al., 2016) (Figure 4.).

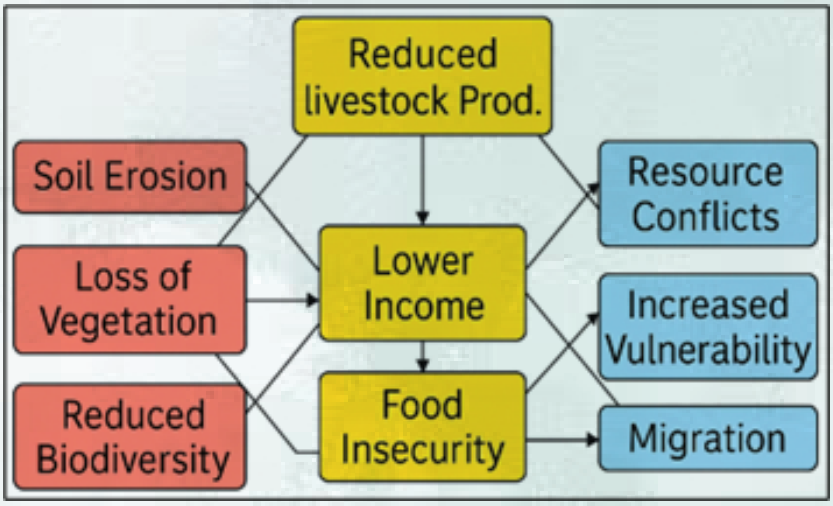


Figure 4: Drivers and impacts of rangeland degradation

Socially, degradation intensifies competition for scarce resources, contributing to increased conflicts among pastoralist communities, particularly evident in the IGAD region, where resource-related conflicts have become increasingly common (ILRI et al., 2021; IGAD, 2020). It is, therefore, important that the rangelands are regularly monitored to identify impacts before they become severe and establish intervention mechanisms before negative impacts of identified threats occur.

1.2 Objectives and Expected outcomes

Objectives

1. To map out suitable indicators for rangeland monitoring
2. Identify tools to use to monitor the indicators
3. Recommend the most suitable frameworks for rangeland monitoring

Expected outcomes

1. Well-articulated indicators for rangeland monitoring
2. A framework combining both conventional and ITK indicators to inform rangeland monitoring

Guiding Principles for identifying the most appropriate framework

1. Should be rapid (timeliness, actionable)
2. Should allow for equal participation (including gender inclusion)
3. Should be user-oriented/centred
4. Should allow for multi-temporal (monthly, seasonal and annual) assessment and visualization
5. Should be integrated (have ecological and indigenous variables)
6. Should be pictorial/visual and allow for immediate interpretation and validation
7. Should be a living tool (allow for flexibility, updatable, compatible with ---, cost-effective and multi-functional (can be customizable))

2. Review of existing frameworks/methods for Rangeland monitoring

A well-structured monitoring framework is critical for systematically assessing rangeland health, guiding sustainable management, and promoting resilience among pastoral communities. Beyond the overarching objectives of this manual, such as standardizing assessments and enhancing community involvement, clear monitoring objectives should specifically encompass drought resilience, grazing management, biodiversity conservation, and sustainable land use planning. Establishing clear objectives ensures the collection of relevant and actionable data, facilitating informed decision-making for adaptive management (Lepak et al., 2024; Pellant et al., 2020). In the IGAD region and broader sub-Saharan Africa, several rangeland monitoring frameworks have been successfully implemented, each with distinct methodologies, advantages, disadvantages, and practical applications. An analysis of frameworks using the SWOT (Table 1). Satellite-based approaches, notably the Normalized Difference Vegetation Index (NDVI) monitoring, leverage remote sensing to provide continuous, spatially extensive assessments of vegetation health and biomass production (FAO, 2021). The primary advantages of NDVI include cost-effectiveness, wide coverage, and the capability for consistent temporal monitoring, essential for tracking drought dynamics and vegetation responses over long periods. However, limitations arise from reduced accuracy in differentiating vegetation types and sensitivity to cloud cover. NDVI monitoring has extensively informed drought early warning systems and pasture management across the Sahel, notably improving grazing strategies and drought resilience (ILRI et al., 2021; FAO, 2021).

2.1. SWOT analysis of Frameworks

Table 1 presents a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis of four commonly used rangeland and land degradation assessment frameworks: the Land Degradation Surveillance Framework (LDSF), Interpreting Indicators of Rangeland Health (IIRH), Participatory Rangeland Management (PRM), and the Land-Potential Knowledge System (LandPKS). Each framework is evaluated based on its key features, highlighting its ability to monitor ecological conditions, engage communities, and inform land management decisions.

Table 1: Evaluation of the Frameworks using SWOT

No	Framework	Strength	Weakness	Opportunities	Threats
1	**Land Degradation Surveillance Framework (LDSF)**	- Covers several indicators (soil health, biodiversity, and vegetation cover) - Has a structured protocol ensures consistency across spatial and temporal scales, - Enables regular interval monitoring to ensure early detection of subtle changes - combines ground-based data with Earth observation (EO) datasets to improve spatial and temporal coverage - Has a robust sampling design that ensures unbiased data collection across heterogeneous landscapes - The indicators used form the basis for evaluating restoration outcomes and planning further interventions	- complex - It is costly to implement - needs technical expertise, which limits its widespread adoption in resource-constrained contexts need for further research into effective land management practices and the potential for high variability in data collection	Its flexibility, low cost, and ability to be used by various stakeholders. It provides a standardized approach for monitoring land degradation trends and impacts of interventions.	-Lack of technical capacity building and training for local communities and other stakeholders s a threat to use by the communities
2	**Interpreting Indicators of Rangeland Health (IIRH) framework**	- Covers several indicators (soil stability, hydrologic function, and biotic integrity) - comprehensively captures ecosystem health - fosters community engagement	- It is subjective due to the qualitative assessments - Its dependency on skilled assessors	-It provides a valuable tool for assessing and managing rangeland health,	its potential limitations which is threat the limitation to use it in conjunction with other relevant information and perspectives
4	**Participatory Rangeland Management (PRM)** framework	- increased community ownership - improved management practices - conflict reduction - enhanced biodiversity conservation	- demands substantial time investment in community capacity-building and participatory processes	- Once participants learn, they can train others. -Offers opportunity for increased community involvement and more sustainable resource management	-It faces challenges like the need for strong local governance, potential conflicts, and the time and resources required for successful implementation.
5	Land- Potential Knowledge System (LandPKS	- Covers several indicators (soil, hydrologic function, human-induced impacts, and topography) - Is participatory - Allows for quick visualization of results	- It is qualitative, and so results consistency is dependent on the assessor	to improve land management through accessible, site-specific data collection and analysis	Threats include the challenge of integrating diverse knowledge sources and ensuring long-term sustainability

2.2 Selected Frameworks for consolidation to develop the ICPALD rangeland monitoring framework

These are frameworks that will be used to develop the framework for rangeland monitoring in the IGAD region. They are informed by the study, combined with experts' guidance at the validation meeting. A combination of the LDSF and LandPKS, also leveraging the values of the Participatory Grassland and Rangeland Assessment (PRAGA) methodology tool, provides comprehensive coverage of the identified indicators for rangeland monitoring. Whereas LDSF provides good baseline spatial layers, LandPKS and PRAGA allow for participation of community members and quick visualization of field results. Components of these frameworks will be combined to develop the appropriate rangeland monitoring framework for ICPALD.

2.2.1 LDSFs-Based Indicators of Rangeland Health Monitoring

The Land Degradation Surveillance Framework (LDSF) applies a standardized set of biophysical indicators to assess and monitor rangeland health at the landscape level. These indicators (Figure 5.) are designed to capture the key ecological dimensions of rangeland condition and include vegetation cover (assessing the abundance and diversity of herbaceous and woody species), soil properties (such as soil organic carbon, infiltration capacity, and texture), and visible signs of land degradation (including sheet, rill, and gully erosion).

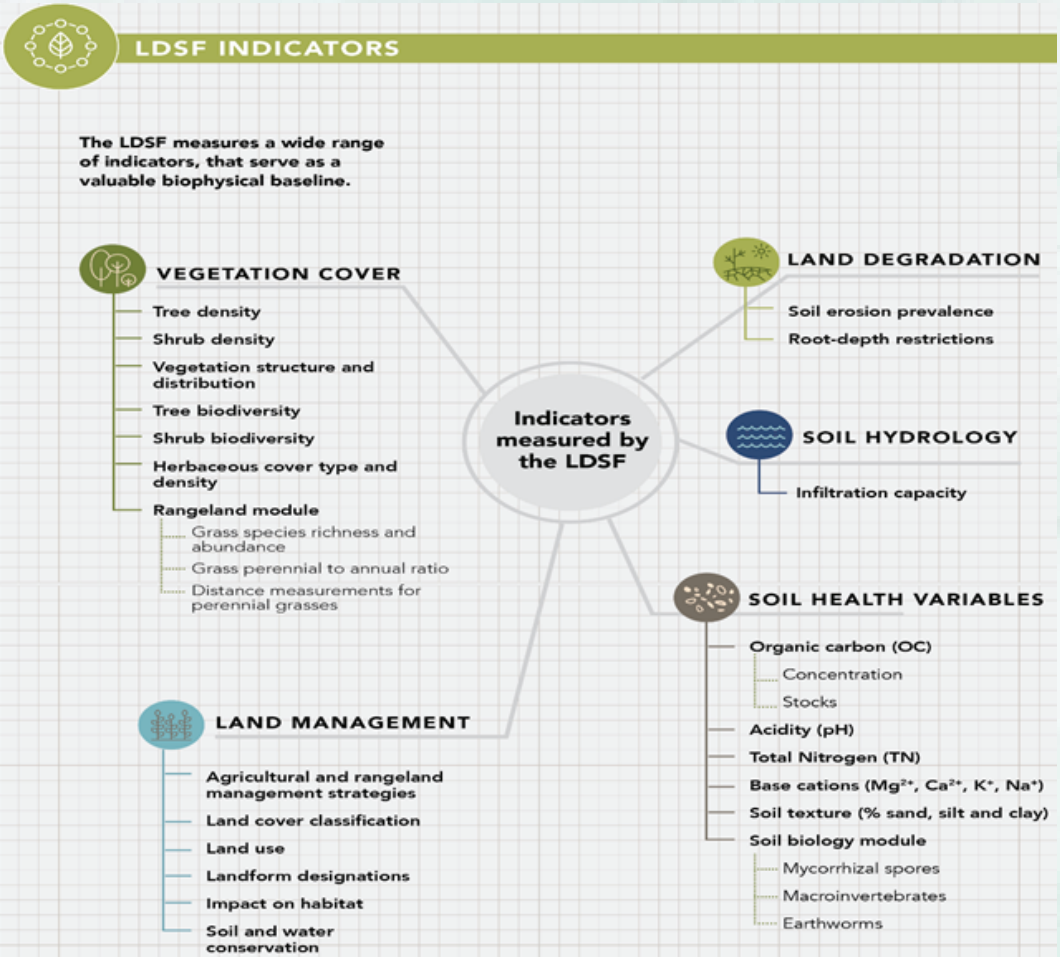


Figure 5: Land degradation surveillance framework (LDSF) indicators for rangeland health monitoring (Adapted from Vegen and Winowiecki, 2023)

In addition, the LDSF integrates information on land management practices such as burning, grazing intensity, and conservation measures, offering insights into human impacts on ecosystem functioning. Together, these indicators provide a holistic view of rangeland status and form the foundation for long-term monitoring, restoration planning, and adaptive land management in dryland and pastoral environments.

2.2.2 Rangeland health monitoring using Earth Observation data in Cloud-based platforms, E.g. Google Earth Engine (GEE)

The use of Earth Observation (EO) technologies has significantly advanced rangeland health and condition monitoring by providing consistent, large-scale, and temporally rich datasets. Satellite-derived indicators such as vegetation indices (e.g., NDVI, EVI), land surface temperature, and soil moisture are increasingly used to assess trends in rangeland productivity, degradation, and seasonal variability. These datasets enable researchers and land managers to detect early signs of overgrazing, drought stress, and land cover change across broad spatial extents. When combined with ground-based observations and traditional ecological knowledge, EO data supports more robust and evidence-based rangeland management strategies (Boone et al., 2018; Bastin et al., 2017) Figure 6

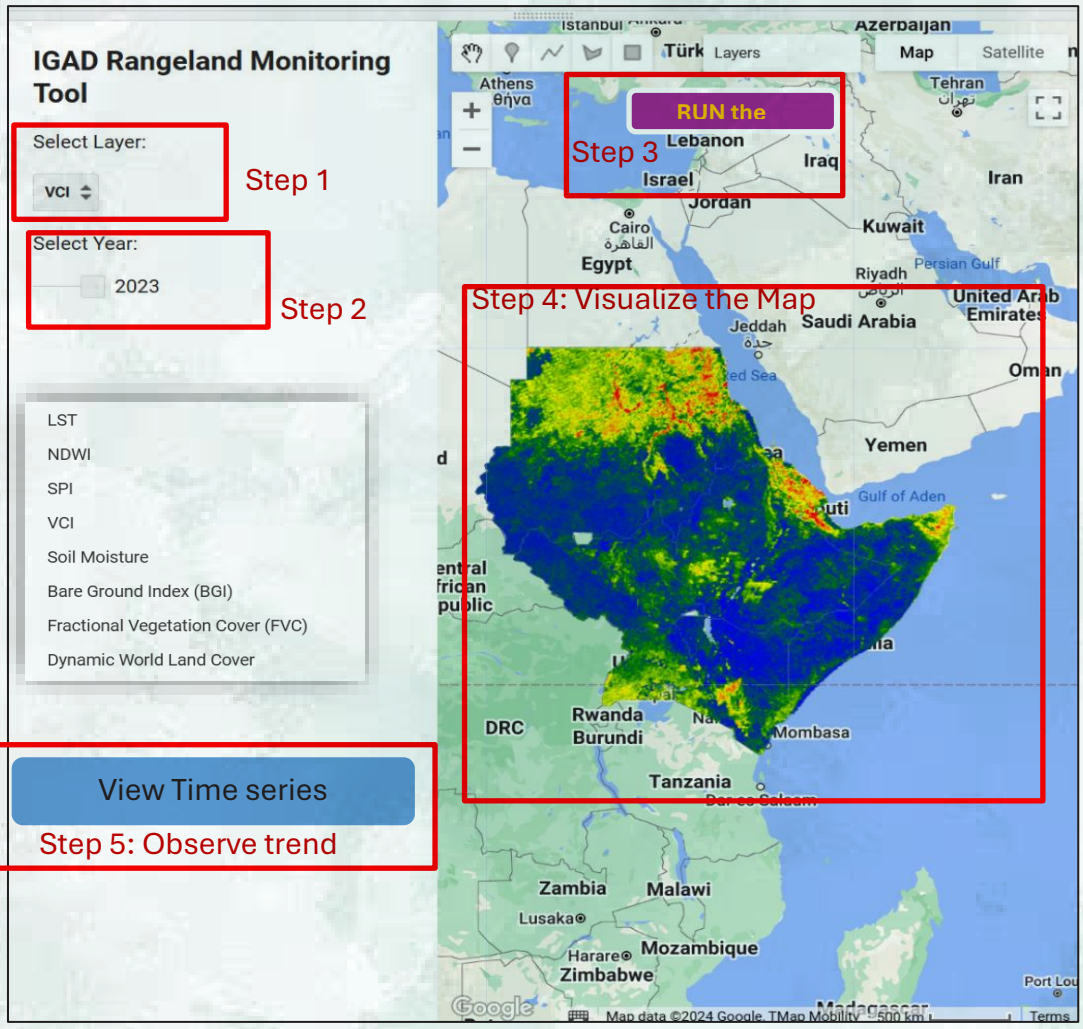


Figure 5: Graphical User Interface of the Rangeland monitoring Tool ((Adopted from IGAD, 2024)

Cloud-based platforms like Google Earth Engine (GEE) facilitate near real-time analysis and visualization of rangeland dynamics, enabling users to monitor vegetation conditions, assess biomass variability, and map land degradation hotspots over time (Gorelick et al., 2017). Moreover, GEE's capacity for integrating multi-source datasets, including Landsat, MODIS, Sentinel, and climate reanalysis products—enhances its application in multi-temporal and multi-scalar monitoring of rangeland ecosystems. Figure 7. shows the screenshot of the developed IGAD Rangeland Health Monitoring Tool using GEE Technology and EO data

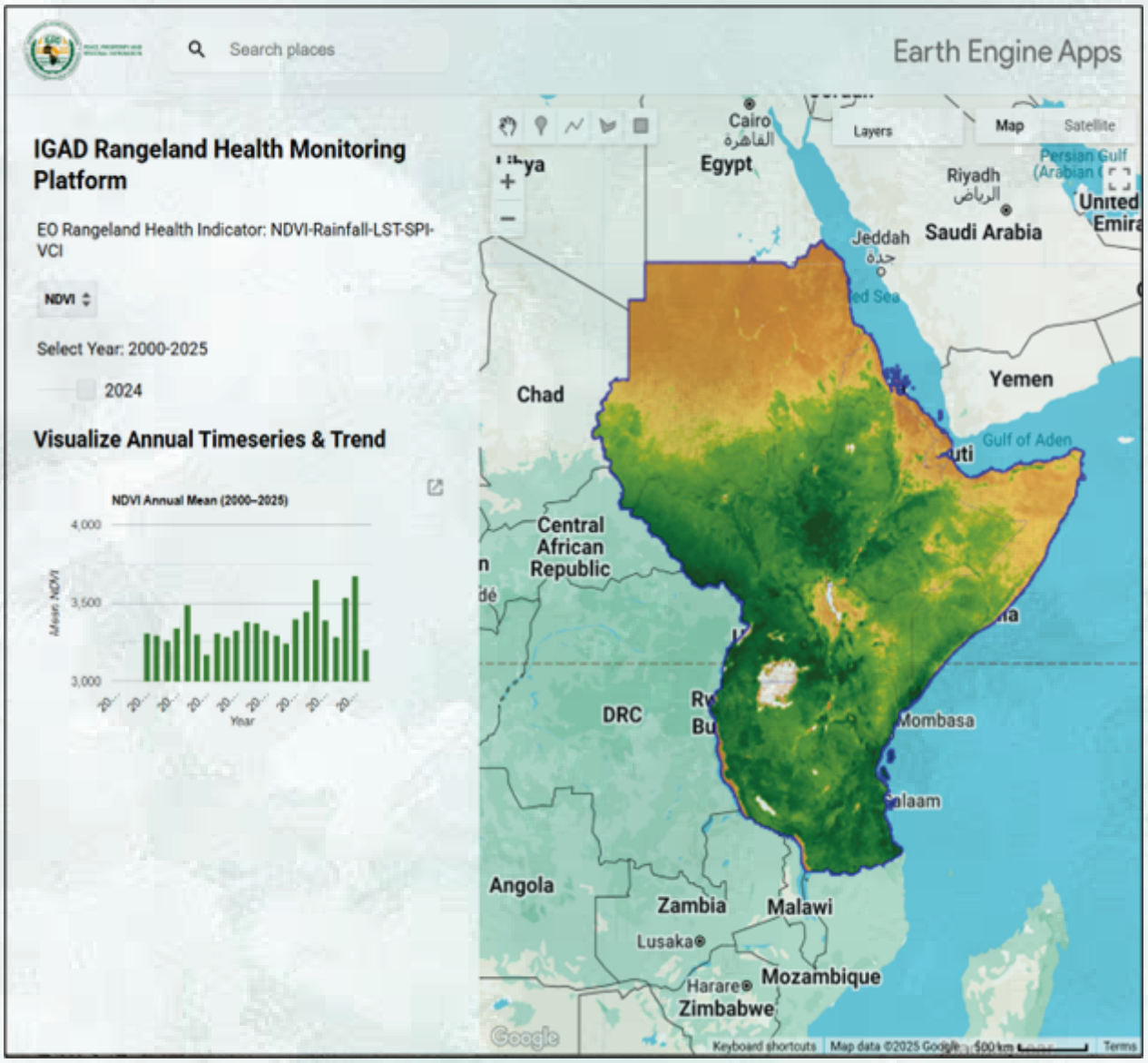


Figure 7: IGAD Rangeland Health Monitoring Tool using GEE Technology and EO data

3 Indicator identification and selection

Indicators have been identified in a participatory way using a team of rangeland experts from the IGAD region. Below, we provide the high-level categorization and a table of indicators in each category (Table 2).

3.1. Indicator categories

3.1.1. Vegetation Cover and Biomass

Vegetation cover and biomass are central indicators for assessing rangeland productivity, forage availability, and resilience. Remote sensing techniques, particularly the Normalized Difference Vegetation Index (NDVI), offer consistent, spatially extensive, and cost-effective means to monitor vegetation condition, productivity trends, and drought stress over large landscapes (FAO, 2021). However, NDVI analysis should be complemented by ground surveys to accurately assess plant species composition, density, and biomass (Lepak et al., 2024). Ground surveys, including line-intercept methods, biomass sampling, and photographic documentation, provide detailed insights into vegetation dynamics, community structure, and health at specific sites, informing targeted management actions (Louhaichi et al., 2022).

3.1.2 Soil Quality

3.1.3 Biodiversity

Biodiversity indicators reflect the complexity and resilience of rangeland ecosystems. Species richness, habitat conditions, and functional group diversity are widely used biodiversity metrics. Species richness—the total number of different species present—is fundamental for ecosystem resilience and productivity. Assessing the relative abundance of functional groups such as perennial grasses, shrubs, and legumes further informs the ecological balance and stability of rangeland communities (Louhaichi et al., 2022). Regular biodiversity monitoring through field surveys, coupled with remote sensing to map habitats, enables managers to detect early changes and degradation trends, facilitating proactive conservation actions (Herrick et al., 2019).

3.1.4 Water Resources

Water availability, accessibility, and seasonal variability significantly influence the sustainability of pastoral livelihoods. Indicators for water resources include the presence and condition of natural water sources (springs, rivers, seasonal water pans), the adequacy of artificial water structures (boreholes, dams), and seasonal fluctuations in water availability. Effective water management encompasses water harvesting techniques, such as micro-catchments and contour bunds, which are crucial for enhancing water retention and availability during drought periods (Louhaichi et al., 2022). Regular monitoring of these indicators helps ensure water resource sustainability, prevents resource conflicts, and informs adaptive water management strategies, especially important in water-scarce rangeland environments (FAO, 2021).

3.1.5 Socioeconomic Indicators

Socioeconomic indicators offer insights into human-environment interactions and community resilience. Essential indicators include land tenure security, livelihood resilience, household income diversification, and vulnerability to environmental or economic shocks. Secure land

tenure fosters sustainable land management by offering communities long-term incentives for resource conservation and investment in land restoration practices (Louhaichi et al., 2022). Livelihood resilience, assessed through indicators like income diversity, adaptive capacity to drought, and food security, helps gauge the effectiveness of rangeland management strategies and policies (Davies et al., 2016). Socioeconomic assessments must be participatory, integrating community perspectives to ensure relevance and effectiveness of interventions in promoting sustainable rangeland use and enhancing community wellbeing (FAO, 2021).

3.2. Selected Indicators

Table 2: Indicators for rangeland assessment (Allowing for Rapid at Geospatial and Community Level).

Broad category	Sub-category	Characteristics	What is measured		Limitation	Proposed Earth Observation datasets
			Conventional	Indigenous and Traditional Knowledge (ITK)		
Ecological	Vegetation - Annual - Perennial	-Vegetation structure -Vegetation type -Woody vegetation (shrubs, sub-shrubs, trees) -Herbaceous vegetation	Type cover Density Distribution Biodiversity	- vegetation structure - forage/species preference score - Grazing potential - Milk quantity and quality (increasing or decreasing) - fattening cows (cow health) - Ecosystem services Indicator of water logged areas	-Seasonality -Invasive plants - causing diseases/death to animals	Vegetation indicators e.g. Vegetation Condition Index (VCI) Normalized Difference Vegetation Index (NDVI)
	Soil - physical - chemical - biological	Soil Health	- infiltration capacity - soil pH - Soil fertility - Soil texture - Cumulative mass - SOC Soil litter/Organic matter	- flooding prone - level of stoniness - soil compaction - soil cracking - soil preferences		Soil Moisture Active Passive (SMAP)
		Surface stoniness	- Observing surface stoniness	- signs of erosion - rock outgrowth - surface stoniness		
	Hydrology	Water quality and quantity	- Depth - area/length - pH, - salinity - turbidity	- water preferences by the livestock - distance to the water source - water level - length (time taken) of watering the animals - water life (observation of insects, amphibians, reptiles etc) - water table (plants, soils etc.)		- Standardized Precipitation Evaporation Index (SPEI) - Combined Drought Index (CDI) Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS)
		Water seasonality/availability/accessibility	- Distance to water source - permanent or seasonal			
		Water sources	- boreholes - Dams - Streams/rivers - Lakes - Seas/ocean			

Socio-economic	Land tenure systems	Land ownership/ security	- tenure system - right of ownership, using and access/transiting through the land - management decision	- Secure or insecure, why? - land use changes - conflicts	-The challenge of engaging local communities in decision-making promotes ownership and responsibility. - Challenge of raising awareness of the benefits of sustainable practices	The level of Community engagement and educator on proper grazing techniques an land management
	Livestock products	Livestock productivity (milk, meat) Herds structure (livestock categories) Animal body condition Trend in change of herds/species		- Milk quantity and quality (increasing or decreasing) - fattening cows (cow health) - Number of different species		
	Rangeland Management practices	Land use practices	- Prescribed Fire (frequency and intensity) - Grazing (frequency and intensity)	- whether they regulate burning - movement patterns - distance to the grazing land - planned seasonal grazing - availability of grazing reserves	•-Limitation of establishing clear regulations and land tenure rights to incentivize sustainable management.	Documenting of case studies on son on implementation of successful regulations and enforcement of restrictions on
				- herds splitting - Purpose of burning (e.g. clearing the bush Killing ticks) - Ability to supplement with crop residues	-Without proper legal structures, sustainable management practices are difficult to enforce, and resources may be exploited unsustainably - Enforcing restrictions on overgrazing and uncontrolled access to rangelands.	overgrazing cases.

4. Measurements/datasets (data collection protocol)

4.1 Guiding Principles

Effective rangeland health monitoring necessitates the implementation of clear, well-structured data collection protocols that are both scientifically rigorous and participatory. These protocols should be adaptable to the diverse ecological zones and sociocultural contexts within the IGAD region, accommodating changing environmental conditions such as climate variability and

land-use pressures. Emphasizing inclusivity by integrating local communities, particularly pastoralists and Agro-pastoralists, as key contributors in the design, implementation, and evaluation of monitoring activities ensures relevance, builds local capacity, and fosters ownership and sustainability (IGAD Center for Pastoral Areas and Livestock Development [ICPALD], 2024). Moreover, adopting a multi-scale and multi-temporal approach—spanning plot to landscape levels and covering seasonal to long-term trends—is essential to capturing the dynamic nature of rangelands (Pellant et al., 2020).

4.2. Field Methodology

The methods used in this study integrated indigenous knowledge, expert knowledge, and field ecological observations for developing indicators and tools for long-term monitoring of rangeland health. Traditional or indigenous knowledge plays a crucial role in how pastoralist communities manage their pastures and livestock in the face of climate change. They use this deep understanding of their local environment to adapt e.g. of seasonal variations in pasture availability, water sources, and animal behavior, to make informed decisions regarding grazing patterns and livestock selection, thus enhancing their resilience to climate fluctuations (Singh et all., 2020). Actions often include practices like rotational grazing, monitoring key plant indicators, weather conditions, astrology or examination of planetary bodies (stars, moon, etc.), and monitoring occurrence and behavior of other animal species.

In general, pastoralists have always lived with environmental uncertainty and have developed a diverse range of strategies, institutions, and networks to exploit this unpredictability and risk to their advantage. The local community have long-term indigenous knowledge which is tried and tested (Hill et al., 2015). Thus, learning from community experience can provide an important opportunity and knowledge base that can be integrated into the modern knowledge system for use by the community. Expert knowledge from the practitioners and managers of rangeland resources was collected using a key informant interview guide. The collaborative rangeland monitoring framework is illustrated in Figure 27.

4.2.1. Community Engagement and Indigenous Knowledge Documentation

A core component of effective rangeland data collection is the integration of indigenous knowledge systems. Pastoral communities possess a deep-rooted, context-specific understanding of vegetation dynamics, grazing patterns, seasonal mobility, and ecological indicators of rangeland health. Participatory methods—such as focus group discussions (FGDs), seasonal calendars, resource mapping, and oral histories—should be systematically employed to document and incorporate this traditional ecological knowledge (TEK). Doing so enhances both the relevance and accuracy of data, while promoting culturally appropriate and socially acceptable interventions (Oba, 2012). Moreover, community-based monitoring systems offer valuable early warning mechanisms for drought, land degradation, and resource-based conflicts (UNCCD, 2024).

In this study, we sought to capture both expert and indigenous knowledge on livestock and natural resource management, the drivers influencing livestock productivity, and the concurrent transformations within Agro-pastoral systems. A mixed-methods research design was adopted, involving key informant interviews (KIIs), FGDs, and direct observations to ensure robust and triangulated data collection.

We explored the Community knowledge of the existing tools and protocols for rangeland health monitoring, and the gaps in the effective monitoring of rangelands in the Karamoja region (Ugan-

da), West Pokot, East Pokot, and Turkana (Kenya). Twelve (12) FGD sessions were conducted using a tool (Annex 8.4) and each group consisted of between 6 to 11 community members (Figure 12).

The study was conducted across rangeland areas in the Karamoja region of Uganda (Kaabong, Kotido, Moroto, Nakapiriprit, and Amudat Districts) and the neighboring counties of Kenya (West Pokot, East Pokot, and Turkana). Twelve FGDs were carried out using a structured tool (see Appendix 1), specifically developed to explore the TEK that pastoral communities rely on to adapt to environmental stressors and socio-economic changes (Singh et al., 2020). Each FGD comprises 6 to 11 participants, with sites selected to capture geographical and ecological variation. The locations included:

- Uganda: Moruita Subcounty (Nakapiripirit), Loroo Subcounty (Amudat), Lokosilei Subcounty (Moroto), Labongea Subcounty (Kotido)
- Kenya: North Pokot Subcounty and Lokitonyala Subcounty (West Pokot), Lioma Lerenkippi Village and Lokiriama Subcounty (Turkana), Lobe Subcounty and Kapenguria Subcounty (Pokot North), and Kawabata-Amakuriat Parish (West Pokot



Figure 12: Focus group discussions in the Karamoja region

Key informant interviews (KIIs) targeted a diverse set of experts, including district officials, county chiefs, rangeland committee members, and respected community elders (see Figure 6). From a curated list of over 40 potential interviewees, 20 individuals were selected based on their experience and institutional representation to provide a holistic view of rangeland health assessment. The KII questionnaire (Appendix 2) covered topics such as vegetation attributes (species composition, cover, biomass, palatability), soil characteristics (texture, degradation, organic matter, moisture), and broader ecosystem health indicators (above-ground biomass, invasive species presence, water availability, and disturbances).

All interviewees remained anonymous in the final report, identified only by their institutional roles. Interviews were conducted using a combination of methods: (i) in-person interviews, (ii) emailed questionnaires for those unreachable in person, and (iii) phone interviews where necessary. Each session lasted 15–25 minutes, and all 20 interviews were recorded with the informed consent of the participants. The data collection period was December 2024.

4.2.2. Indigenous knowledge-based tools

This section presents both the data collection tools and the results of applying these tools in the field during the implementation of this project. The study found that the targeted pastoral communities had rich Indigenous knowledge, which they used in decision-making regarding the utilization of rangelands and seasonal access to pastures and water resources over a long period. The Indigenous Knowledge of tools and indicators currently used by the local community to monitor rangeland health were highly similar from both Ugandan and Kenyan sites. The key indicators /tools used by the local communities to monitor the health of rangelands are categorized into various themes as indicated in Table 3. When the changes in the indicators are observed this triggers the migration process in search of better locations with better quality rangeland resources (especially green pastures and water resources) for livestock.

Table 3: The type of indicators /tools used by the local communities to monitor the health of rangelands and to act in search of better conditions

Indicator/tool used	Details and explanations in the use of the indicator
Vegetation /biomass cover-related indicators.	• Grass quality changes, - Good and healthy grass availability as an indicator. When the grass is healthy it is green. The color of the grass when it changes from green to yellow is used as an indicator of grass quality. • Grass cover of the ground/soil. The level of grass cover indicated the level weather – sparse and dense on the ground. This is related to soil erosion. • Presence of invasive plant species that are not palatable to the livestock. E.g. Some Acacia plants species which smell bad to the livestock. • The quantity and quality of milk produced by the animals are used to show the status of the grass, i.e. if it is exhausted or not. • Grazing pressure, observation of the quality of grass/pasture. The presence of plants that are poisonous and avoided by the animals.
Weather condition indicators	• High heat or hot temperatures which lead to heat waves make the animals die of heat stress. • The performance of rituals to appease the god to give rain promptly is done when there is a delayed rainfall.
Soil conditions	• Soil status exhibited using erosion, deep gullies, good water retention capacity, etc. Soil erosion was associated with land degradation
Water resources availability	• Sufficient water availability for livestock. • Water levels in the ponds, valley dams, and rivers. • Water levels in the constructed boreholes -when it takes longer for water to yield when pumped manually- time taken for water to start coming out is an indicator that there is a reduced water level in the below-ground water table level. • Color of open surface water. Green color indicates bad water source which may poison the animals.

Health conditions of livestock	• When cows /female animals start getting abortions, the sudden death of animals also triggers the signs of bad omen and rangeland conditions. • Presence of some parasites in the area which leads to sudden death of the animals, especially the foot and mouth diseases. • When the liver of the animal expands and becomes swollen. The intestines of the animals may also be affected. • Observations of animal body conditions can be used to check the rangeland conditions. • Where there are more parasite ticks, which bring diseases the herders keep moving to avoid infestation and disease outbreaks. • Presence of some parasites carrying vectors in the area. For example, the presence of ticks and tsetse flies in an area. • Animal body conditions and shape can be used to check the rangeland conditions. • • Wild animal interaction with livestock can result in disease outbreaks.
Quality of biodiversity	• The variety of wild plants and animals in the area constitute biodiversity. The high population of biodiversity consisting of wild animals and plants in an area is a good indicator of good quality rangeland. • The presence of termites in which they are active is also an indicator of the near future weather conditions. Some termites destroy plants around the area. • The population of wild animals in an area e.g. rats in the bush, if many means the rain will come early in the next season.

4.2.3. Existing monitoring systems and gaps

The current common practices for rangeland management and monitoring in the region used by the communities included, among others, (i) rotational grazing, (ii) fire management, and (iii) water point protection. The traditional leaders play a big role in the monitoring of rangelands through giving directives on where to graze. The roles played by traditional leaders were still strong within the communities. To the communities, their approach was more effective in maintaining rangeland health despite government system intervention, which was formed in parallel to their in the names of production and environment committees/ units within the villages. The traditional approaches were trusted because the practices address key rangeland issues like overgrazing, soil erosion, livestock health, and water scarcity, which are the main concerns of the pastoralists.

- The local community members were not privy to the new technologies that are dependent on ICT such as remote sensing (RS) technology and geographical information systems (GIS). The communities strongly believe that the above traditional indicators and tools used to predict a range of land conditions were very effective in assessing the health of rangelands because they are simple and observable, and they were developed and used consistently over a long time. They also inher-

ited these from their ancestors who similarly depended on these for years for their survival. These tools were easy to use and had observable signs that were easy to apply by a common person or the herders.

- To the communities the current traditional monitoring protocols aligned very well with the specific needs of their area and region because the protocols were contextually relevant to their cultural practices, climate, or ecological conditions. The current indigenous methods used involve the local community members and this formed part of the community's daily routine in terms of the data collection process.

- The gaps or challenges identified in the monitoring methods include no systematic data collection approach by the community as the observations were made when it had already happened or when the problem was realized e.g. livestock animal health condition deteriorating, leading to death. The observations were locally and spatially relevant but did not cover large spatial areas since groups were independent of each other in the region.

- The respondents were interested and willing to integrate their indigenous knowledge with the modern technology-based data collection (e.g., drones, mobile apps) approaches and tools as this would enhance monitoring efforts for effective prediction and improve monitoring of rangeland health conditions. They expressed interest and willingness to incorporate adapting the traditional knowledge for the long-term monitoring of rangeland health conditions.

- Unfortunately, these traditional methods of rangeland health monitoring are not formalized or integrated within the local government system and there are thus no formal data collection practices at the community level or lower government levels at the moment. And this was the main gap that exists in these current practices.

- Contribution of expert knowledge on existing tools, indicators, and protocols, key variable indicators for long-term monitoring, field assessment to establish current practices and identify gaps, and long-term monitoring using earth observation and field data. Also grazing by different teams or groups that have aggregated near water sources.

The experts mainly depended on livestock condition scoring, interviews with the communities, and visible field assessment as the main indicators and tools used to monitor the rangeland health status (Figure 1.). Other uses to a lesser extent included vegetation sampling, soil health assessment, and remote sensing images. Many responses were in agreement that the tools were moderately to very effective in assessing and monitoring rangeland health.

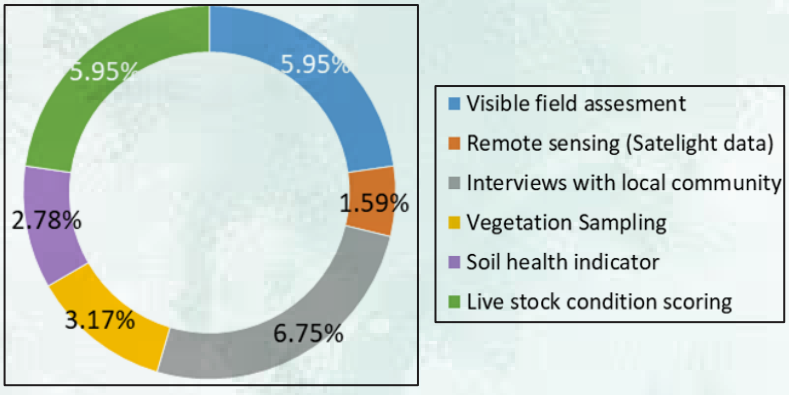


Figure 1: The various indicators and tools currently used by key rangeland workers in the region to assess rangeland health status

The responses to the key challenges faced while using the health monitoring tools are shown in Figure 38. The main challenges included inadequate resources, lack of trained personnel, poor data management, insufficient data coverage or gaps, limited access to remote sensing data, and lack of community participation. Of the existing indicators, the most useful for monitoring rangeland health were mentioned to be vegetation cover and diversity, livestock health and conditions, grazing pressure, soil erosion rates, soil fertility, and water availability (Figure 33). Others included invasive species and fire occurrence.

The field experts suggested that the variables that are considered very crucial for long-term monitoring of rangeland health in decreasing levels included vegetation growth rate and seasonal patterns, biodiversity index, water table levels, climate variability, traditional knowledge, and rangeland management (Figure 2). Others were soil compaction, livestock grazing pattern, soil organic matter, and ground cover.

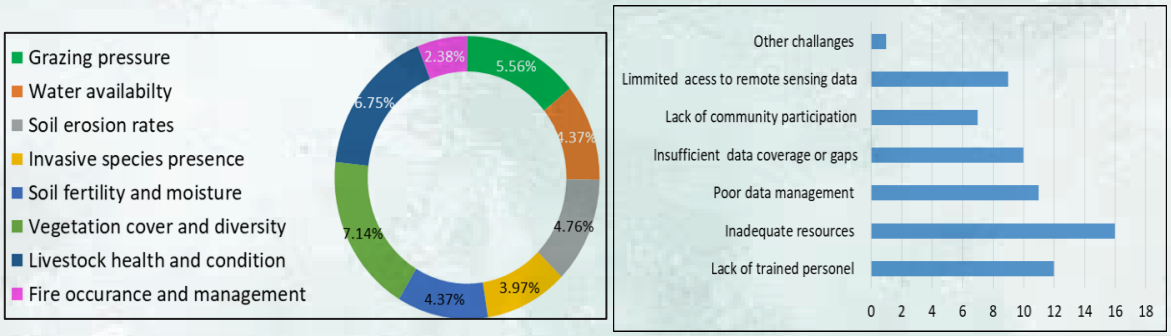


Figure 2: Key challenges faced while using the various tools for monitoring rangeland health

For effective monitoring of these variables for long-term rangeland health management, many of the experts suggested that the monitoring be done quarterly, followed by biannually, and then seasonally. Accordingly, the best methods of measuring effective indicators are field surveys focusing on vegetation and soil sampling, and local community surveys (Figure 3). Other approaches suggested included participatory monitoring approaches, and remote sensing (Figure 4).

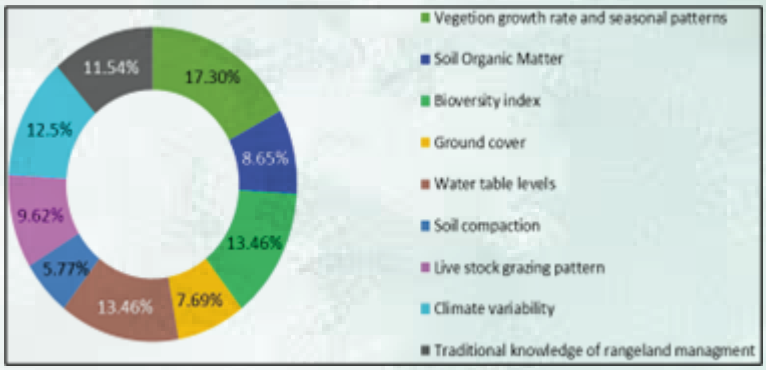


Figure 3: The variables considered crucial for long-term monitoring of rangeland health

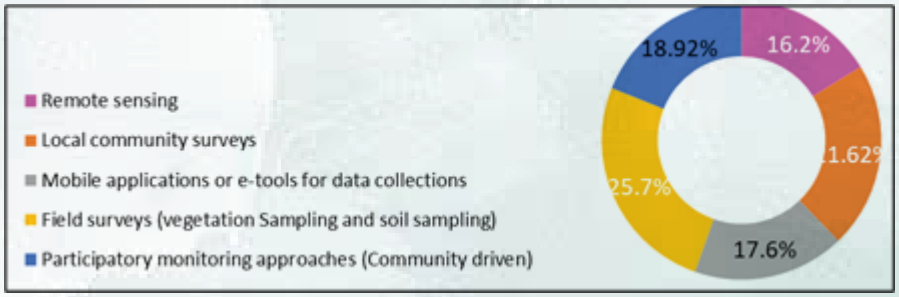


Figure 4: The tools used for long-term monitoring of rangeland health

Common practices being used in the community to monitor or manage rangeland health included livestock management based on pasture availability and community grazing management (Figure 5). Others included vegetation restoration practices, water point management, and fire management. The majority reported that these approaches were either moderately effective or effective. This suggests a high potential for the use of these approaches in the current approaches in monitoring the rangeland health within the communities.

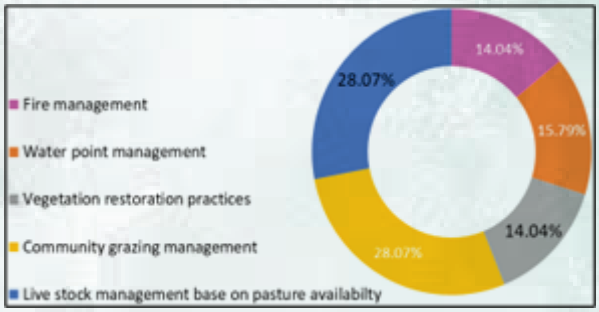


Figure 5: Common practices being used in the community to monitor or manage rangeland health

The type of earth observation data (e.g. satellite images, drone data) which are currently used or available for monitoring range-land health in the region include climate and weather data, vegetation indices, and land cover change detection (Figure 6). Other uses included fire occurrence data and soil moisture data. The frequency at which the Earth observation data is used to inform a range of land management decisions is monthly or weekly/quarterly, and is rarely used annually. The main barriers to utilizing Earth observation data effectively in rangeland management were mainly the high cost of obtaining satellite data, followed closely by lack of integration between remote sensing data and ground truthing and lack of technical skills or experts in the field (Figure 7).

Other barriers listed were limited infrastructure and a lack of data accessibility or coverage. The type of indicators from Earth observation data recommended for long-term monitoring of rangeland health were vegetation health/cover, soil degradation detection, erosion pattern, grazing pressure indices, and fire risk maps. The experts at the district level suggested the key factors that would ensure the success of Rangeland health monitoring programs in the region to be capacity building and training of the local community, active involvement of local stakeholders, clear communication and reporting mechanism of policy support and government system, regular monitoring and data collection and adequate funding for the monitoring activities.

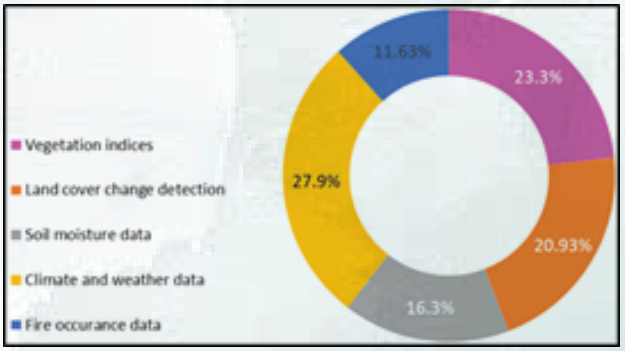


Figure 6: Earth observation data currently used or available for monitoring rangeland health

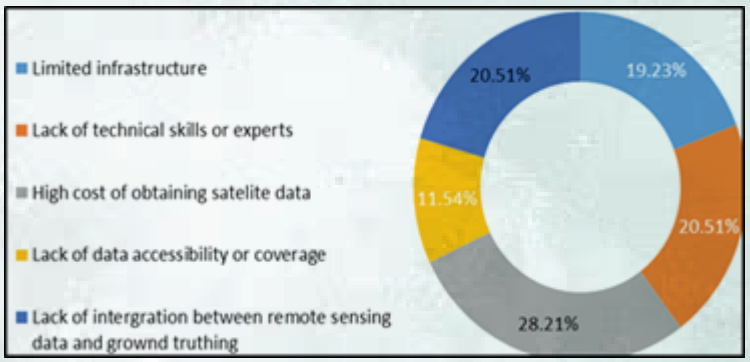


Figure 7: The main barriers to utilizing Earth observation data effectively in range land management

In conclusion, the study revealed that the local community had a diverse and rich knowledge of rangeland health and monitoring, which can be harvested and integrated with modern techniques. Integrating local knowledge with the government monitoring system to improve the prediction of future weather conditions more accurately for better decision-making is recommended. This will help the community adapt to the unpredictable climate conditions and prevent the potential loss of the livestock herds, which are the main source of their livelihood and improve ecosystem services provision.

4.2.4. Ecological Field Data Collection and GIS Integration

Field data collection should adhere to standardized and replicable protocols, tailored to local conditions while maintaining consistency for comparison over time and space. Integration with Geographic Information Systems (GIS) and remote sensing allows for spatial mapping and validation of field observations, providing a robust geospatial framework for rangeland monitoring (Pellant et al., 2020). GPS-referenced field data enhances spatial analysis and ensures that observations are traceable and scalable.

The field GIS-based data collection focused on (i) vegetation characteristics, species composition, vegetation cover, biomass, palatability, (ii) soil properties (soil degradation/erosion, soil texture, soil organic matter, and soil moisture), health indicators (AGB, invasive species, water availability, disturbance) were undertaken (Figure 13). Figure 14 shows sites where data were collected. Ecological field data was integrated with satellite imagery and spatial datasets, GIS enabled the mapping and analysis of vegetation cover, species distribution, soil characteristics, and hydrological patterns, i.e. rangeland condition, and extraction of sample site information.

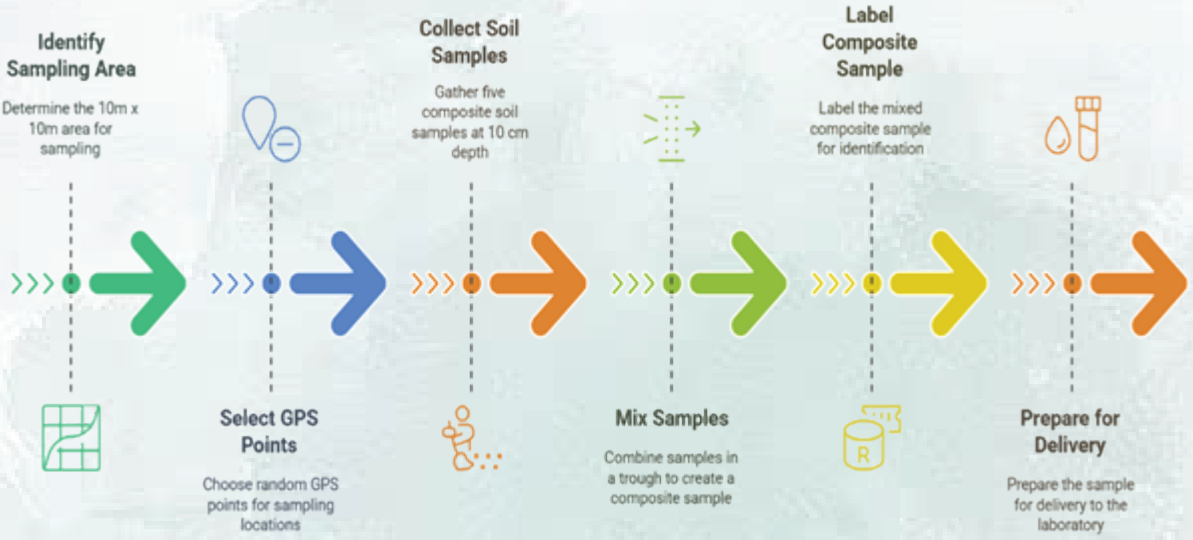


Figure 13: Field GIS-based data collection procedure

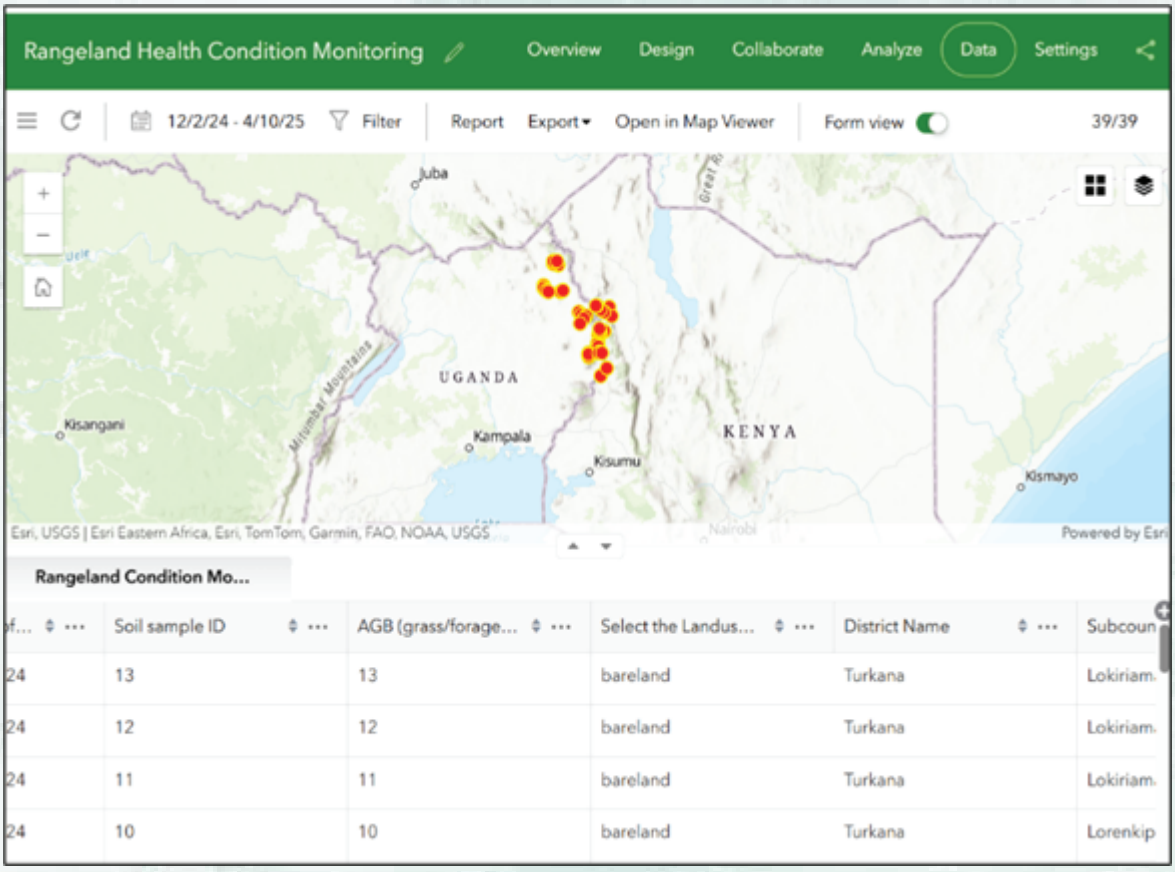


Figure 14: GIS Data collection Tool that was setup

For determination of above-ground biomass (AGB) of grass and herbaceous vegetation, the harvest-and-weigh technique was adopted. This method is straightforward and reliable, providing direct measurements of biomass that can also be used for calibration and validation of remote sensing estimates (Scurlock, Johnson, & Olson, 2002; Tessema et al., 2011). This method involved selecting representative plots within a rangeland site, clipping all above-ground herbaceous vegetation (including grasses and forbs) at ground level within a known area—typically 0.5 m × 0.5 m or 1 m × 1 m quadrats (Figure 15). The collected biomass was then oven-dried at 65°C–70°C for 48–72 hours to a constant weight and weighed to determine the dry mass.

4.2.5 Indigenous practice-based indicators/tools for predicting rangeland climatic patterns

Traditional practices included the observation of the intestine of a slaughtered animal such as goat, lamb, or bull. At slaughter, the expert observes the color appearance of the fresh intestine to predict the near future
weather conditions. The reddish color shows a likelihood of rain, while whitish suggest an indication of no rain/drought to be soon in the area.

- Traditionalists also dream of upcoming season weather patterns as well as likely impact of the weather conditions on the community.
- Smoked Tobacco was also used to predict weather conditions whereby an expert looks at the dry tobacco leaves conditions to predict the start of the dry/ wet season. When hardened shows dry conditions are expected while the softened suggests favorable weather conditions shortly.
- The movement patterns of honeybees and butterflies are utilized, especially the direction of their flight during the swarming period, to predict the weather conditions that will follow.
- Weather patterns, especially when cold and windy conditions, result in no rain while warm and calm conditions lead to heavy rains.
- The strong circling wind which goes with rubbish and dust into the sky during hot days is an indication of no rain soon.
- The presence of some bird species in the area is used as an indicator of rain within the near future and time. For example, cattle egrets and other migratory bird species when plenty suggest the rain will be starting soon.
- The use of ground-dwelling insects. For example, the red ant species. When they are very active in an area, making small holes in the ground, this indicates that the weather situation will be good.
- Astrological knowledge consisted of predicting weather conditions using observations of the celestial bodies i.e. stars and moon at night or in the evenings. The presence of a group of stars in the clear sky was used to predict the weather conditions soon. When a certain group of numerous stars appears in the sky it means a good harvest is expected in the next upcoming rainy season. When the big star rises in the sky and tingles, the next year's season will bring very good harvests since there will be plenty of rain. When the moon appears reddish, rain is expected soon but when white little or no rain is expected. When the moon makes a small circle, the rain is little, but when the big circle a higher amount of rain is expected. White lines in the sky (due to the vast clear line of stars) pass at night between 9 to 11 pm and dividing the sky into two parts is an indication of unfavorable weather conditions.

In general, the above techniques suggest are an indirect indication of temporal spatial weather humidity conditions of both the sols and above atmosphere a particular area. This suggests the level of the traditional methods in relating to the physical weather conditions of an area.

- Phenological (leafing and fruiting) pattern or events of trees/plants. When Tamarind trees start flowering early and the flowers are in abundance, that means rain will come early and a good season is expected and consequently resulting good harvest. The phenology of a local tree species called "topojo". Once it flowers, this means the year will be good and people plan to bring animals back from the wilderness early to prepare for crop cultivation on a large scale. When there is a locust outbreak in the area this indicates intense drought and looming hunger within the community which would occur very soon.

4.3. Rangeland Health Monitoring Tools and Platforms

4.3.1. Ecological Field-Based Tools for Rangeland Monitoring

Ecological Field-Based tools provide crucial ground-truth data and local context for understanding rangeland health, particularly in ecologically diverse and socially complex landscapes like those in Africa. Tools such as the Participatory Grassland and Rangeland Assessment (PRAGA) methodology and the Participatory Rangeland Management (PRM) Toolkit are designed to empower communities by integrating indigenous knowledge with ecological assessments (FAO & UNEP, 2020; Flintan et al., 2019).

Additionally, methods like the Rapid Assessment of Rangeland Condition (HERD) and Ecological Site Descriptions (ESDs), often used alongside State-and-Transition Models (STMs), provide structured approaches for evaluating ecological dynamics and degradation-recovery cycles (Teague et al., 2016; Bestelmeyer et al., 2017). The Rangeland Assessment and Restoration Effectiveness (RARE) tool bridges field observations with geospatial data, enabling practitioners to evaluate restoration impact at scale (Bonnet et al., 2023). Ecological Field-based approaches are invaluable for context-specific decision-making, capacity building, and community engagement in rangeland governance and restoration.

4.3.2 Earth Observation (EO) based Tools and Platforms

Remote sensing technologies complement field-based tools by offering synoptic, scalable, and repeatable observations of rangeland condition across vast and sometimes inaccessible areas.

A) Remote Sensing and GIS

Remote sensing technologies, involving satellite and aerial imagery from sensors such as Sentinel-2, Landsat, MODIS, and SPOT, significantly enhance the capability to monitor rangeland ecosystems over large spatial scales. Remote sensing data, combined with GIS analysis, allows for precise mapping, analysis, and visualization of rangeland conditions, improving understanding of degradation trends and guiding targeted interventions (Herrick et al., 2019).

GIS integrates spatial datasets—including satellite imagery, elevation models, climate data, and field survey data—into comprehensive spatial decision-support systems. Furthermore, GIS facilitates participatory monitoring by allowing integration of indigenous knowledge and field-collected data with remote sensing analyses, significantly enhancing local relevance and management effectiveness (Pellant et al., 2020; Lepak et al., 2024).

B) Tools and Platforms

Platforms such as Earth Map (FAO, 2021) and the Africa Rangelands Atlas (ILRI, UNEP & FAO, 2021) provide users with access to high-resolution satellite data on vegetation dynamics, land use, and climate trends (FAO, 2021; Louhaichi et al., 2022). Systems like the GEOGLAM Rangeland and Pasture Productivity (RAPP) Map and SERVIR's Rangelands Decision Support Tool (RDST) offer real-time tracking of biomass and greenness indices, supporting drought early warning and sustainable grazing planning (GEOGLAM, 2021; SERVIR, 2023).

Regionally tailored tools such as East Africa Drought Watch and ICPAC's Earth Observation for Productive Rangelands focus on key indicators like NDVI, soil moisture, and precipitation anomalies to support adaptive management in climate-vulnerable drylands (ICPAC, 2022). These EO tools enhance early warning systems, land degradation monitoring, and policy formulation for sustainable rangeland use (Table 4).

Table 4: Selected Field-Based Monitoring Tools

Monitoring Tools	Description
Participatory Grassland and Rangeland Assessment (PRAGA) methodology	The Participatory Grassland and Rangeland Assessment (PRAGA) methodology is a global initiative developed by the Food and Agriculture Organization (FAO) and the United Nations Environment Programme (UNEP). PRAGA is a participatory, community-driven approach designed to integrate local knowledge with scientific assessments in evaluating the condition and use of rangelands. The methodology emphasizes land users' involvement in data collection, classification of rangeland types, assessment of land degradation, and identification of management practices. It uses both field observations and participatory tools such as focus groups, resource mapping, and transect walks to gather data on ecosystem health, productivity, and socio-economic values. Given the increasing pressures from climate change, overgrazing, and land use changes, IGAD member states have adopted PRAGA to build a shared understanding of rangeland degradation and sustainable land management (SLM) options. The methodology was piloted in selected dryland areas, engaging local pastoralist communities to map land degradation hotspots, identify trends in vegetation cover, and suggest appropriate interventions such as rotational grazing or enclosure systems. PRAGA's participatory approach has not only improved the accuracy of rangeland assessments but has also enhanced local ownership of rangeland restoration initiatives and policy dialogue.
Ecological Site Description (ESD) and State-and-Transition Models (STM)	The Ecological Site Description (ESD) framework, originally developed in the United States, has been adapted for rangeland monitoring and management in several African contexts. ESDs provide detailed descriptions of land units based on soil, climate, vegetation, and ecological processes.State-and-Transition Models (STMs) are used in conjunction with ESDs to depict the dynamic nature of rangeland ecosystems, illustrating how different states (e.g., healthy, degraded, recovering) can shift due to factors such as grazing pressure, fire, drought, or restoration interventions. These models offer a conceptual tool for understanding rangeland degradation and recovery pathways, and for guiding land management decisions tailored to local ecological conditions. In Kenya and Ethiopia, STMs have helped frame community-based rangeland management by making land degradation processes more visible and manageable at the local level. The integration of local ecological knowledge with ESD/STM frameworks has proven essential for their success, enabling pastoralists and extension workers to co-develop strategies for sustainable use and restoration of rangelands.

Rapid Assessment of Rangeland Condition (e.g., HERD – Holistic Ecosystem Restoration Demonstration)	The Rapid Assessment of Rangeland Condition approach provides a fast, cost-effective method for evaluating the ecological health of rangelands using a simplified set of indicators. One notable example is the HERD (Holistic Ecosystem Restoration Demonstration) methodology, which integrates principles of holistic land management with rapid field assessments. HERD emphasizes visual, semi-quantitative scoring of indicators such as ground cover, plant species composition, bare soil exposure, erosion signs, and evidence of overgrazing. The method is designed to be practical and accessible to local land users, field technicians, and development practitioners, offering a baseline for restoration planning and monitoring progress over time. In Africa, HERD and similar rapid assessment tools have been piloted and applied in Kenya, Tanzania, Uganda, and Ethiopia to support both restoration and sustainable grazing initiatives. These assessments are often conducted alongside community training and land use planning processes, helping to build awareness about ecosystem degradation and practical restoration techniques. For instance, in Northern Kenya, HERD has been used by local conservancies and NGOs to assess the impact of rotational grazing systems and identify priority areas for reseeding and erosion control.
RARE (Rangeland Assessment and Restoration Effectiveness Tool)	The Rangeland Assessment and Restoration Effectiveness (RARE) Tool is a specialized instrument designed to evaluate the condition of Rangelands and measure the success of restoration efforts. It integrates field-based assessments with remote sensing data to provide a comprehensive analysis of rangeland health, focusing on indicators such as vegetation cover, species composition, soil stability, and erosion patterns. The tool is structured to be user-friendly, enabling land managers, restoration practitioners, and policymakers to make informed decisions regarding rangeland management and restoration strategies. In African contexts, tools like RARE have been instrumental in guiding rangeland restoration initiatives. For instance, in Tunisia, the implementation of sustainable rangeland management toolkits has transformed restoration processes by integrating indigenous knowledge with scientific methodologies. Similarly, in South Africa's Namaqualand region, participatory restoration trials have been conducted to evaluate the efficiency and effectiveness of rangeland restoration, addressing challenges such as overgrazing and land degradation.

Participatory Rangeland Management (PRM) Toolkit	The Participatory Rangeland Management (PRM) Toolkit is a structured, community-led approach developed to strengthen local governance and improve the sustainable use of rangelands. It was created through collaborations involving ILRI, RECONCILE, CARE International, and the Rangelands Initiative of the International Land Coalition. The toolkit provides step-by-step guidance for communities and facilitators to engage in inclusive rangeland planning, mapping, resource assessment, and the establishment of grazing agreements. At the heart of PRM is the principle of empowering pastoralist communities to take charge of their rangeland resources. The process builds local capacity to negotiate land use, resolve conflicts, and implement agreed-upon grazing practices. It fosters accountability by encouraging joint monitoring and documentation of rangeland conditions over time. In the IGAD region—particularly in Ethiopia, Kenya, and Uganda—the PRM Toolkit has been instrumental in improving rangeland governance. It has led to formal recognition of communal land rights and improved coordination among stakeholders, including local governments, NGOs, and pastoral associations.
Pastoralist Mapping Tools (e.g., PGIS – Participatory GIS)	Participatory GIS (PGIS) is a powerful tool that enables pastoralist communities to map and document their indigenous knowledge of rangeland resources, land use patterns, and seasonal mobility routes. Pastoralist mapping tools are especially effective for identifying critical grazing areas, migration corridors, watering points, and zones of conflict or degradation. GIS maps often serve as the foundation for negotiating access rights, planning resource use, and preventing conflicts in land use. PGIS combines geospatial technologies (like GPS and satellite imagery) with community-based mapping processes, ensuring that local knowledge is captured, visualized, and integrated into formal planning and decision-making systems. In regions like Northern Kenya, Ethiopia's Afar and Somali regions, Niger, and Chad, PGIS has been widely applied to support community-based natural resource management. For example, in Kenya's Marsabit and Isiolo counties, PGIS has been used by pastoralists to delineate grazing zones and secure recognition of customary land use under county-level planning frameworks.

Rangeland Monitoring Toolkit (developed by ILRI)	The Rangeland Monitoring Toolkit is a practical and adaptable resource designed to support the regular monitoring of Rangeland's condition and use. It combines simple, field-based ecological indicators with socio-economic data to provide a holistic view of rangeland health and management. The toolkit is particularly suited for use in low-resource settings and is structured to be accessible to both technical staff and community members. The toolkit allows users to monitor key indicators such as vegetation cover, species diversity, bare ground, and signs of degradation, alongside livelihood metrics like livestock productivity and resource access. It emphasizes repeatable, standardized data collection to support both short-term decision-making and long-term trend analysis. In practice, the Rangeland Monitoring Toolkit has been applied in various African drylands, including in Kenya, Ethiopia, and Tanzania, where it supports both local community planning and regional policy processes.

4.4. Earth Observation platforms that provide base information

4.4.1. GEOGLAM Rangeland and Pasture Productivity (RAPP): https://map.-geo-rapp.org/

Termed GEOGLAM Rangeland and Pasture Productivity (RAPP), this GEO initiative provides the global community with the means to regularly monitor the condition of the world's rangelands and pasture lands on a routine basis and assess their capacity to sustainably produce animal protein in real-time, at global, regional and national levels.

Therefore, the Group on Earth Observations (GEO) and its Global Agricultural Monitoring (GEOGLAM) initiative are bringing together space agencies, existing associated institutional frameworks, in-situ networks,

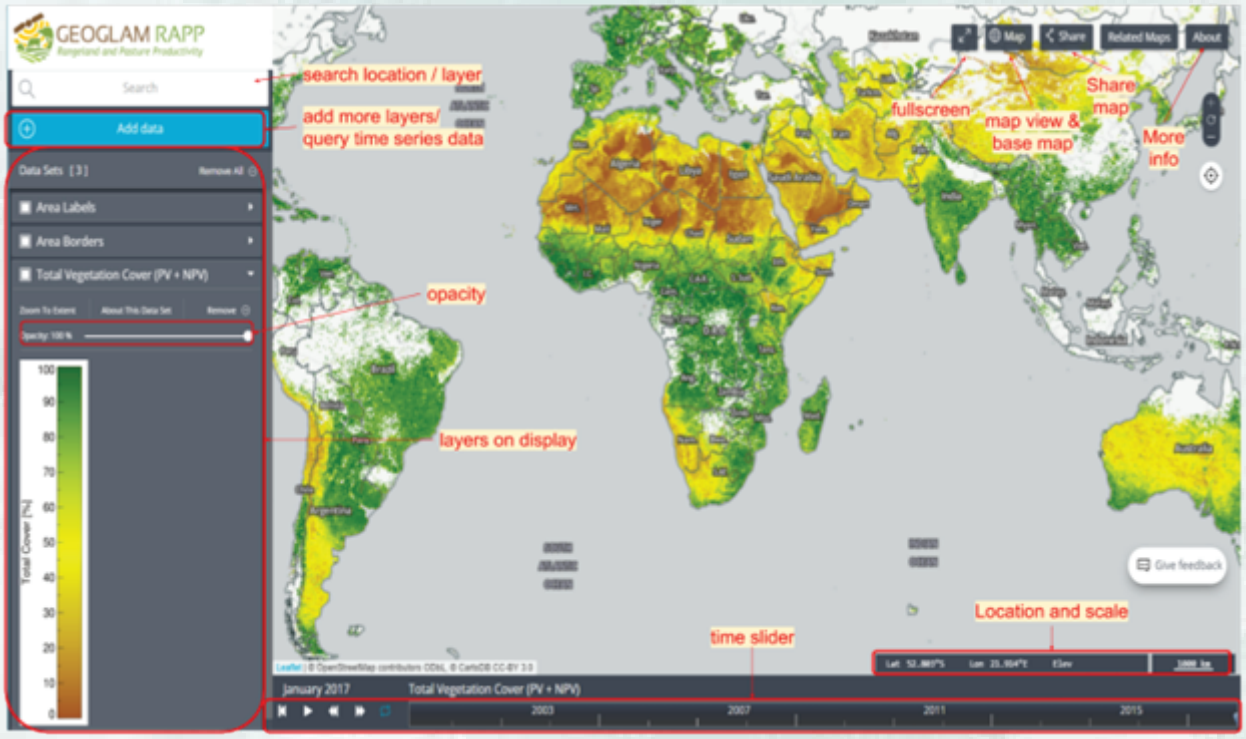
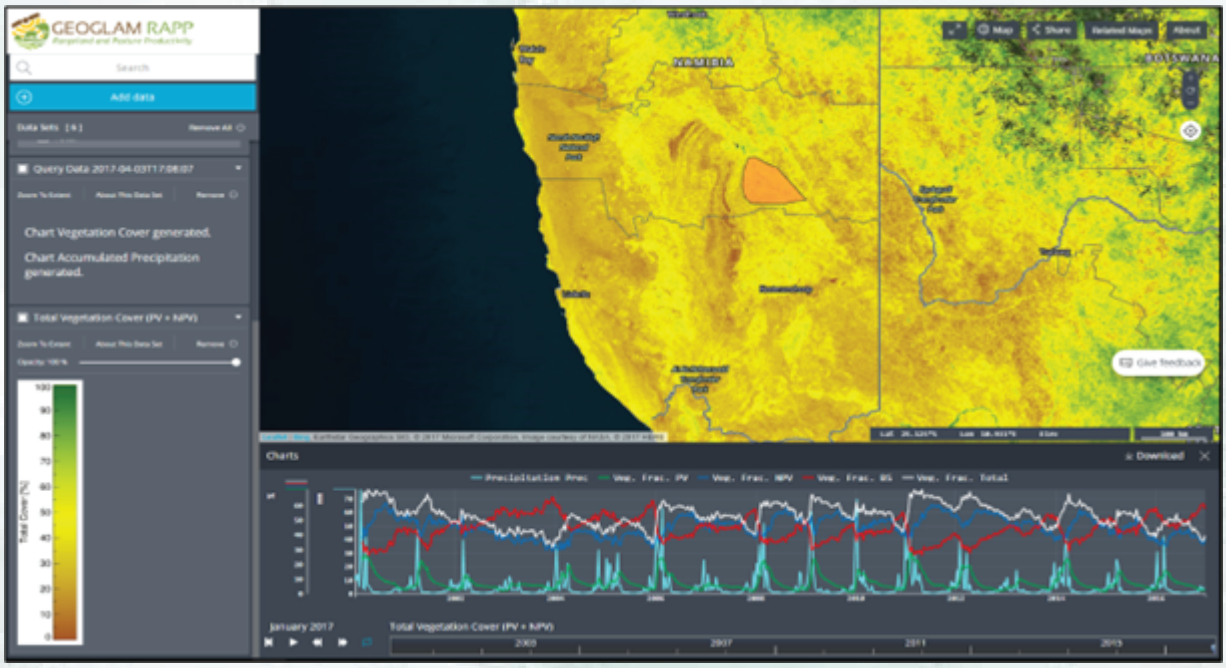


Figure 17: GEOGLAM platform for rangeland condition monitoring

rangeland ecologists, and the pasture productivity modelling community, to establish a dedicated global system for observing the condition of pastures and rangeland status, and ultimately to also estimate biomass dynamics and productivity (Figure 16). RaPP Map can be used to track the status of vegetation cover and the condition of these land systems. Available data includes measures of vegetation cover, monthly rainfall, monthly soil moisture, global land use, and livestock density. Weekly time-series datasets have been available for the past several decades; data for specific weeks can be selected or the entire dataset can be queried to visualize changes over time (e.g. Figure 17).



4.4.2 The Rangelands Decision Support Tool (RDST): https://rdst.servirglobal.net/

The Rangelands Decision Support Tool (RDST) is a product of the SERVIR program, a collaborative effort between NASA (National Aeronautics and Space Administration) and USAID (US Agency for International Development). Initially developed between 2016 and 2023 by the SERVIR Eastern and Southern Africa (SERVIR E&SA) hub at the Regional Center for Mapping of Resources for Development (RCMRD) (Fgure 19).. The current iteration of RDST represents a refined version, spearheaded by the SERVIR Science Coordination Office at NASA and the International Centre for Tropical Agriculture (CIAT) in Kenya, with support from the Bill & Melinda Gates Foundation. Despite the abundance of online data pertaining to vegetation conditions, the RDST serves a unique purpose: offering users a centralized platform for aggregating and synthesizing information to generate maps crucial for decision-making within rangeland ecosystems at sub-regional levels. Leveraging indicators such as the Normalized Difference Vegetation Index (NDVI) at dekadal, monthly, and seasonal intervals, the tool provides current values, anomalies, and deviations from long-term averages. Users can delineate boundaries at county or conservancy levels, selecting a greenness index and integrating it with baseline data on vegetation productivity, including degradation indices. These maps can then be layered with ancillary datasets such as invasive species distributions, surface water maps, rivers, roads, and administrative boundaries.

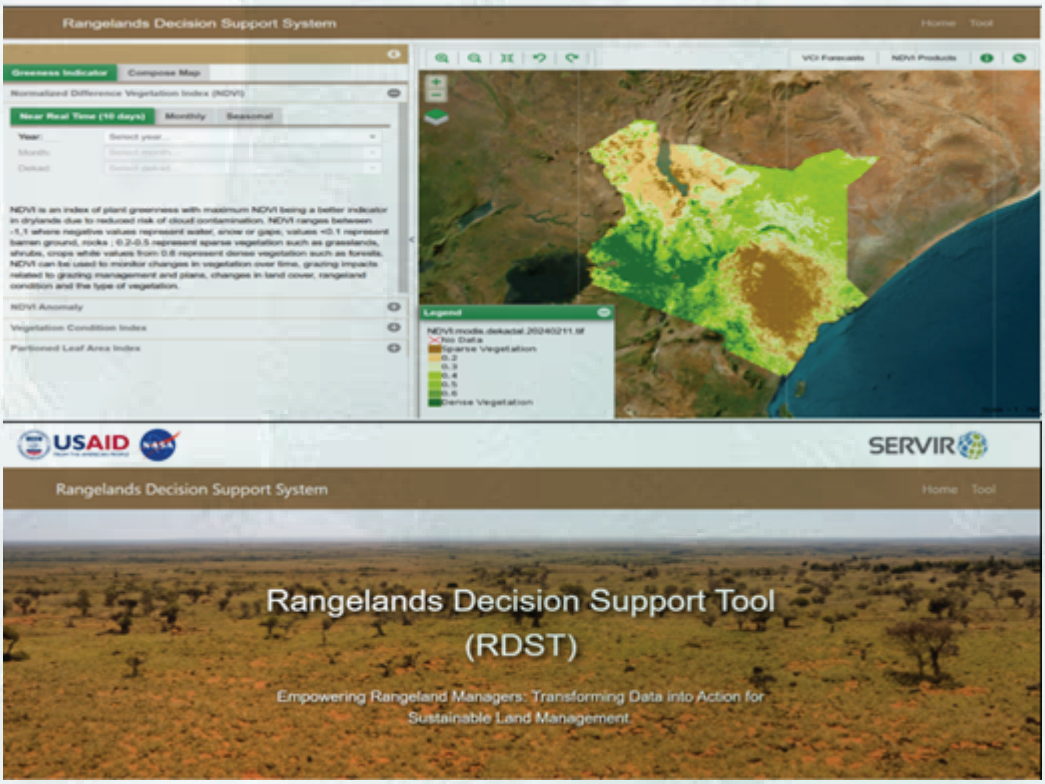


Figure 19. RCMRD platform for rangeland condition montoring

4.4.2. Africa Rangeland ATLAS: https://www.rangelandsdata.org/atlas/

The Rangelands Atlas is a comprehensive, data-rich resource developed to support sustainable rangeland management and policymaking across the globe, with a strong focus on Africa (fgure 20). Launched through a collaboration between organizations such as the International Livestock Research Institute (ILRI), the UN Environment Programme (UNEP), and the Food and Agriculture Organization (FAO), the Atlas compiles and visualizes spatial data on the extent, condition, and use of rangelands. It offers detailed maps and datasets on key indicators such as land cover, livestock distribution, population density, and protected areas, helping to highlight the ecological and socio-economic importance of rangelands. This Rangelands Atlas has been developed to raise awareness on the importance of Rangelands and highlight the changes taking place which are having significant impacts on Rangelands, demanding their protection and restoration.

4.4.3. FAO Earth Map:

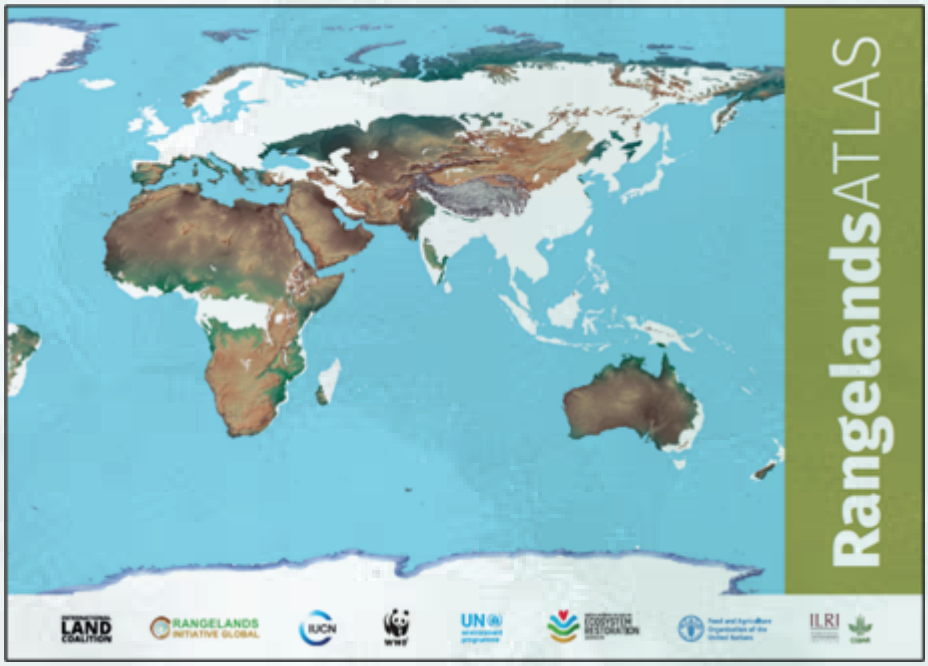
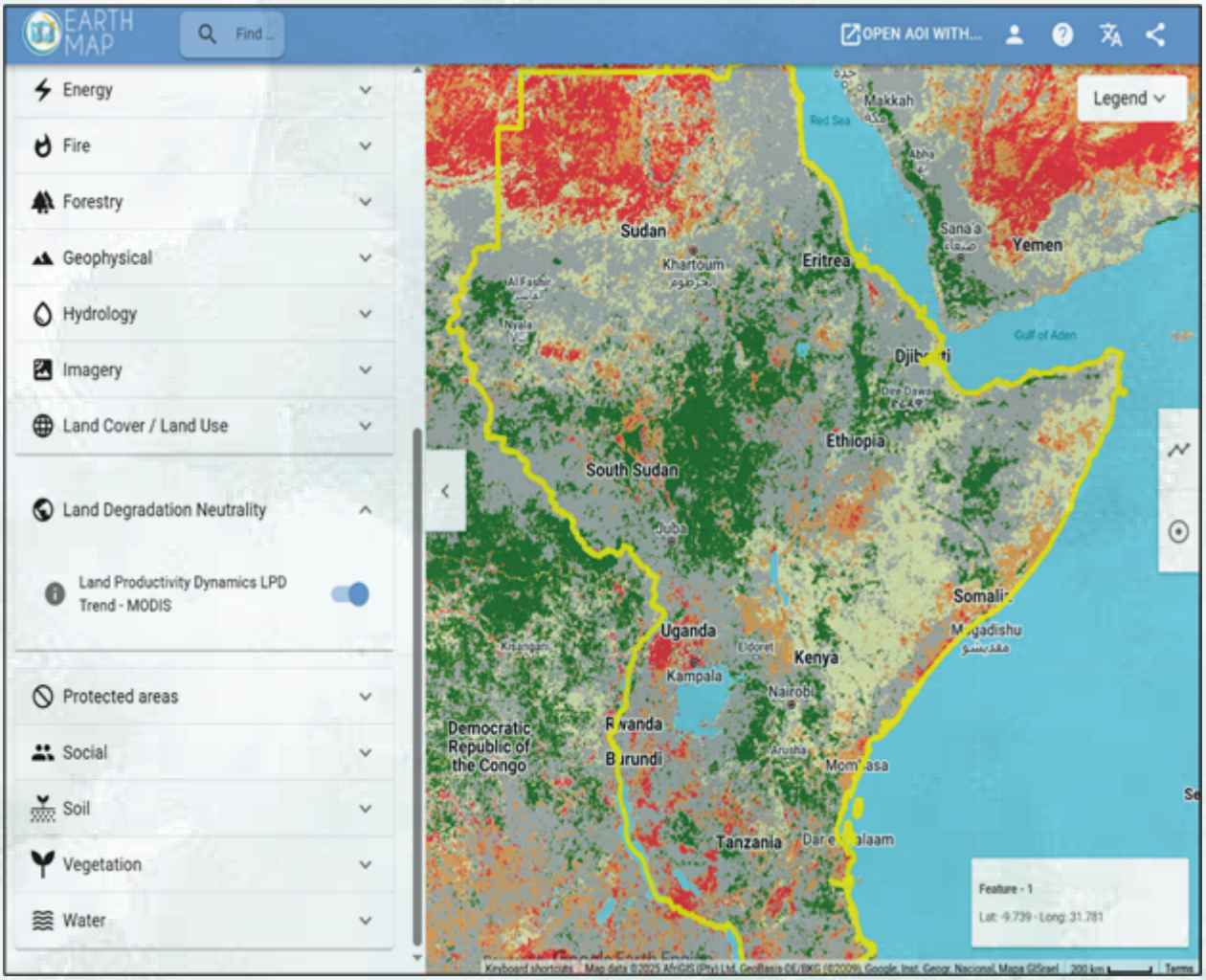


Figure 20: EO-Based Rangeland Atlas
https://earthmap.org/

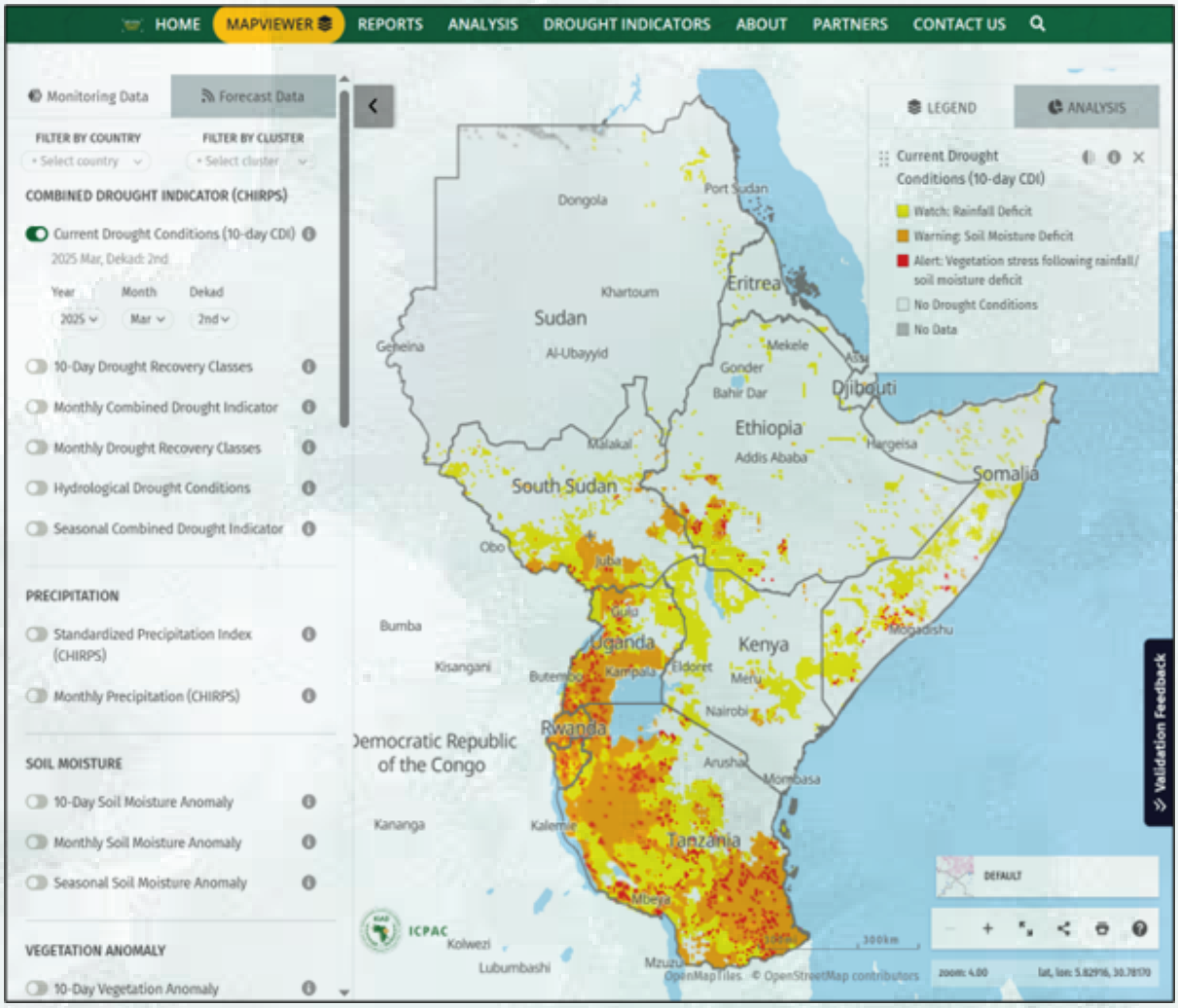
Earth Map is an innovative, free, and open-source tool developed by the Food and Agriculture Organization (FAO) in collaboration with Google. Launched in 2020, this cloud-based platform leverages the computational power of Google Earth Engine to provide users with access to a vast array of satellite imagery and geospatial datasets.

Designed with an intuitive, point-and-click interface, Earth Map enables users—including researchers, policymakers, and local communities—to visualize, analyze, and monitor environmental and climatic changes without the need for prior coding or remote sensing expertise. The platform offers insights into various parameters such as land cover, vegetation health, water resources, and climate trends, facilitating informed decision-making for sustainable land management and climate resilience initiatives.



4.4.4. East Africa Drought Watch: https://droughtwatch.icpac.net/

The East Africa Drought Watch is a near-real-time monitoring system developed by the IGAD Climate Prediction & Applications Centre (ICPAC) to track drought conditions across the East African region. Leveraging Earth observation and weather data, it provides critical information through various drought indicators, including the Standardized Precipitation Index (SPI), Soil Moisture Anomaly (SMA), and the Combined Drought Indicator (CDI)



These tools enable the detection and analysis of precipitation deficits, soil moisture levels, and vegetation stress, facilitating comprehensive drought assessment. The platform offers interactive features such as map viewers, analytical tools, and drought reports, supporting decision-makers, researchers, and local communities in implementing timely and effective drought mitigation strategies. Developed in collaboration with the European Commission's Joint Research Centre, the system is tailored to address the specific climatic challenges of East Africa, aiming to enhance resilience against drought-related impacts.

4.4.5. Earth Observation for Productive Rangelands: https://agriculture-hotspots.icpac.net/

The Earth Observation for Productive Cropland and Rangelands platform is an advanced decision support system developed by the IGAD Climate Prediction and Applications Centre (ICPAC) in collaboration with the European Commission's Joint Research Centre (JRC). This open-access, web-based tool leverages Earth observation data to monitor and analyze agricultural conditions across Eastern Africa, with a particular emphasis on rangeland health. It offers a suite of indicators, including the Fraction of Photosynthetically Active Radiation (FPAR), Standardized Precipitation Index (SPI), and Soil Water Index (SWI), enabling users to assess vegetation productivity, precipitation anomalies, and soil moisture levels.

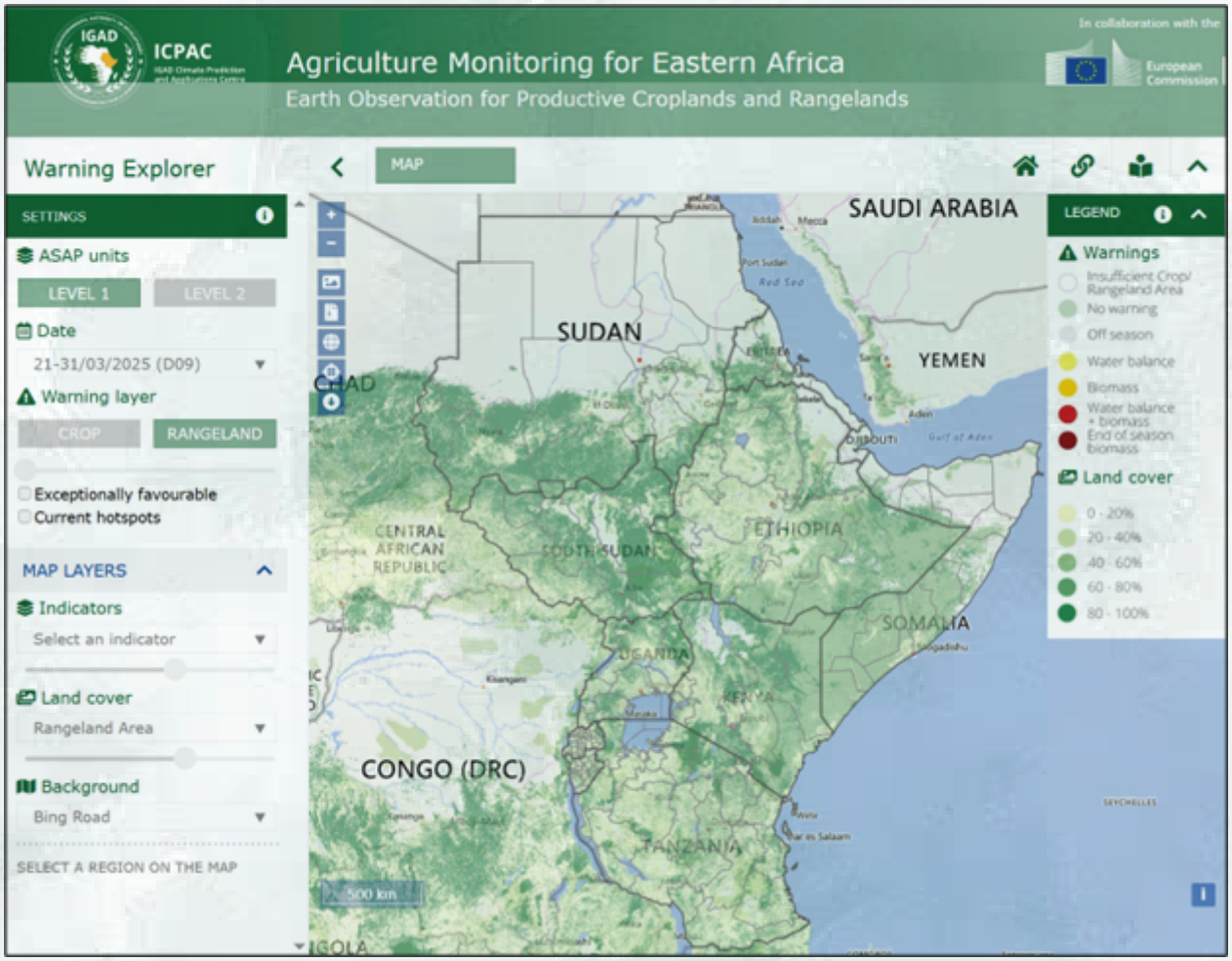


Figure 23: ICPAC Platform for Rangeland Condition Monitoring

The platform's interactive map interface allows for the identification of current agricultural hotspots, facilitating timely interventions and resource allocation. By providing near-real-time data and analytical tools, this system supports policymakers, researchers, and local communities in making informed decisions to enhance food security and promote sustainable rangeland management in the region. Productivity deficits aid in early warning and response planning for food security crises.

4.4.6. JRC eStation: https://estation.jrc.ec.europa.eu/eStation3/

The eStation platform, developed by the European Commission's Joint Research Centre (JRC), is a cloud-based system designed for the reception, processing, and dissemination of environmental data, with a particular emphasis on Earth Observation (EO) products. It offers users access to a suite of EO datasets and analytical tools, facilitating the monitoring of environmental parameters across various regions. The platform's capabilities are especially pertinent for applications such as Rangeland Health Monitoring, where timely and accurate data are crucial for effective management and decision-making.

By leveraging eStation, researchers and land managers can access and analyze satellite-derived indicators relevant to rangeland ecosystems, including vegetation

indices, land surface temperature, and precipitation patterns. The platform's cloud-based architecture enables efficient data handling and processing, eliminating the need for extensive local computational resources. This accessibility enhances the capacity for continuous monitoring and assessment of rangeland conditions, supporting the development of informed strategies to address challenges such as overgrazing, drought, and land degradation. Furthermore, eStation's integration with other tools, like Google Earth Engine, allows for the combination of multiple data sources, enriching the analysis and interpretation of rangeland dynamics.

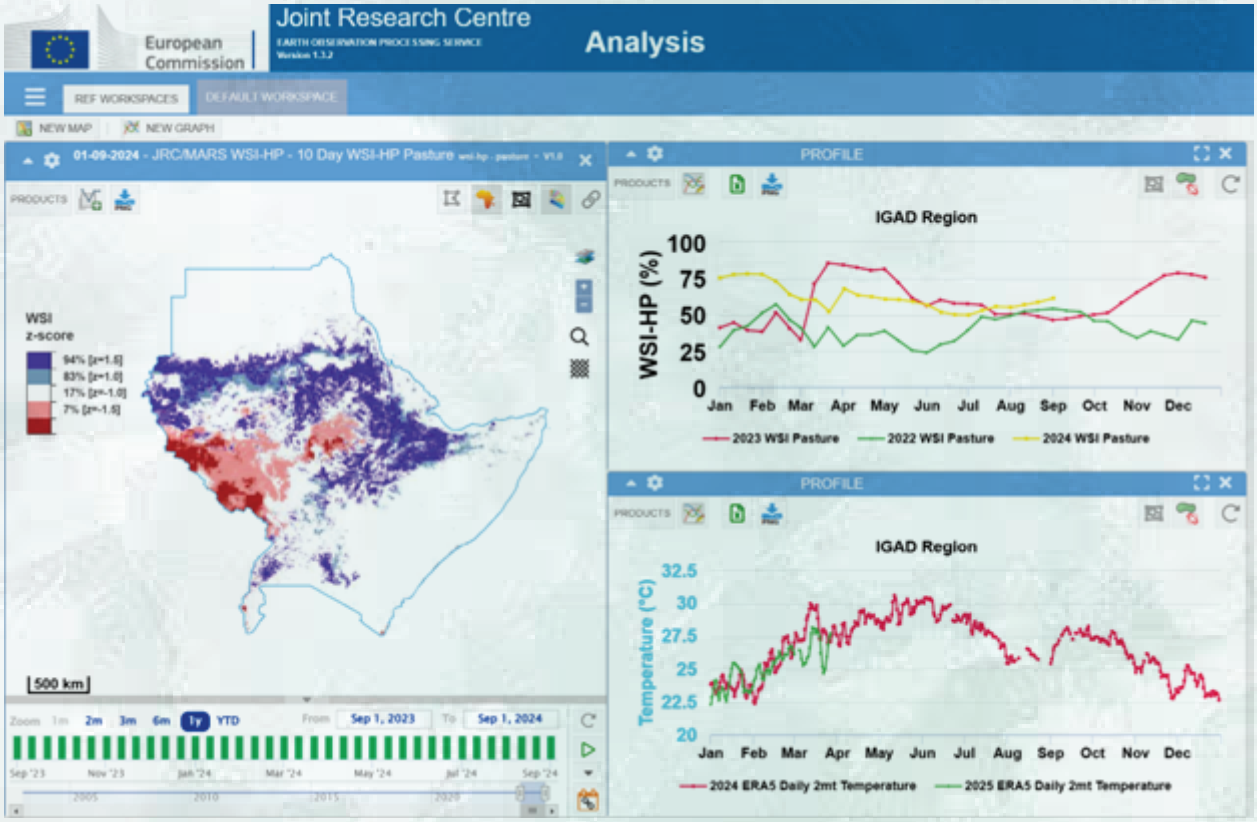


Figure 24: JRC eStation for Rangeland EO data analysis platform

4.5. Protocols and manuals for the Measurements used in the assessment

A standalone training of trainers' manual has been developed as part of this assignment. Here, we provide protocols used for collecting data for input into the framework.

4.5.1. Soil data and biomass processing

The collected biomass was then oven-dried at 65°C–70°C for 48–72 hours to a constant weight and weighed to determine the dry mass (Figure 25).



Figure 25: Laboratory Technician processing field samples

We calculated AGB using the formula below:

$$AGB\left(kg\,ha\right) = \frac{Dry\,weight\,(g)}{Quadrate\,(m)}$$

This formula converts grams per square meter to kilograms per hectare. Multiple quadrats were sampled across the site to account for spatial variability, and the results were averaged to estimate the site-level AGB.

4..5.1.1Soil samples handling in the Laboratory and analysis methods

The samples were air dried at room temperatures (25oC) for 3 days to eliminate the moisture. They were then ground using a porcelain pestle and mortar and then sieved through a 2mm sieve to remove debris and other non-soil materials including stones and roots. The sieved soil samples were repackaged, clearly labeled and analyzed from the Soil, Plant and Water analytical Laboratory at the Department of Agricultural and Environmental Sciences, School of Agricultural Sciences, College of Agricultural and Environmental Sciences - Makerere University (Figure 26).

On the sieved soils samples, a broad spectrum of agronomy related soil properties were analyzed and these included; soil pH, soil organic matter and carbon, total nitrogen, available phosphorus; exchangeable Calcium (Ca2+), Magnesium (Mg2+), sodium (Na+), Potassium (K+), soil texture (the percentage proportions of sand, clay and silt), Cation Exchange Capacity (CEC), Soil colour, moisture content and trace elements. Each soil property was specifically analyzed by analytical methods and procedures as described below.

- Magnesium was analyzed using the atomic absorption spectrophotometer (AAS) on a mehlich-1/mehlich-3, or ammonium acetate extracts while exchangeable Potassium, Calcium and Sodium were analyzed using the Flame photometer on the same mehlich-1 extract.
- Available phosphorus content was determined using a spectrophotometer at 880 nm wavelength after the mehlich 1 extracts reaction with ammonium molybdate in the presence of ascorbic acid (Murphy and Riley, 1962).



Figure 26: Laboratory Soil sample handling and determination of Soil Properties

- Soil pH was measured in a soil-water solution at a ratio of 1:2.5 by the help of a pH meter and the Electrical Conductivity (E.C) was measured on this same soil water solution using the E.C Meter.
- Total Nitrogen (N) was determined calorimetrically at a wavelength of 650 nm on the complexed digestions mixtures using N1 and N2 reagents. Reagents in N1 included sodium salicylate, sodium citrate, sodium tartrate and sodium nitroprusside, while N2 reagents included sodium hydroxide and sodium hypochlorite (JIK) mixed in the stipulated proportions by Okalebo et al., (2002).
- Organic matter (O.M) and Organic carbon (O.C) were determined using the Walkley and Black method following wet oxidation using concentrated Sulphuric acid and Potassium Dichromate.

- Soil texture was analyzed using the hydrometer method (Bouyoucous method) while the trace elements (Zinc, Manganese, copper and iron) were analyzed using the atomic absorption spectrophotometer (AAS) on the DTPA (diethylene Triamine Penta acetic acid) + TEA (Triethanolamine) cheating agent extracts.
- Moisture content was determined on oven dried soil samples at 105o C for 24 hours, while the cation exchange capacity (CEC) was determined using the flame photometer on the second leachate of ammonium acetate following excess saturation with sodium acetate after the soil active sites were freed with ammonium acetate mixed with ethanol.
- Bulk density (B.D) was determined on the oven dried core samples at 105o C for 24 hours and the dry weight divided by the volume of the cores used.
- Saturated hydraulic conductivity (Ksat) was determined on the core samples that were collected. The cores were first covered with a piece of cloth at the base, placed in water to circulation (water oozing out at the top of the core). Using cell tape, an empty core was inserted on top of the circulated core tightly and the pair clumped on a stand.
- With the help of a siphon placed above the empty core, a constant supply of water was maintained and the water that percolates through the system is determined or collected at various intervals, for example at 60min intervals. This procedure was repeated three times and an average cultivated to minimize errors. All analyses were performed using the routine procedures outlined by Okalebo et al., (2002) and other standard operating procedures (SOPs) that are internationally recommended.

4.5.2. Results of Distribution, patterns of soil properties per district

Figure 27 presents soil properties across five districts in the Karamoja region—Nakapiripirit, Moroto, Kotido, Kabong, and Amudat. The soil properties measured include organic matter (O.M %), organic carbon (O.C %), clay (%), pH, sandy soil (%), silt (%), and moisture content (M.C %). Notably, Nakapiripirit exhibits the highest percentage of sandy soil (approximately 80%) and pH, while Kotido shows the highest clay and moisture content.

Kabong also has a high sandy soil percentage, close to that of Nakapiripirit, but with slightly higher moisture content than Amudat. All districts show low values for organic matter and organic carbon, indicating generally poor soil fertility. The variation in pH values suggests differing levels of soil acidity or alkalinity across the region, with Kotido having the highest pH level.

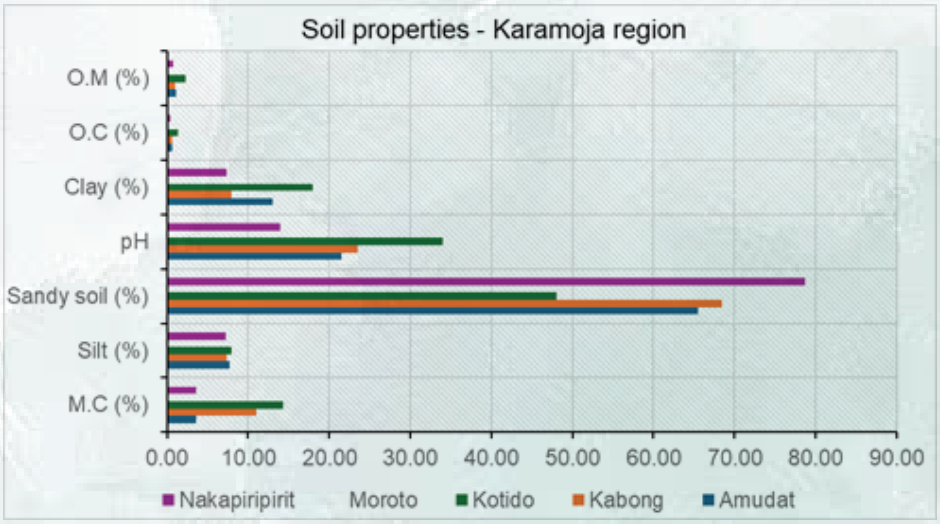


Figure 27: Soil properties across five districts in the Karamoja region (Nakapiripirit, Moroto, Kotido, Kabong, and Amudat)

Figure 28 shows a bar chart comparing key soil properties across three areas in the Turkana region: Western Pokot, Turkana, and Northern Pokot. The dominant soil texture in all three locations is sandy, with Turkana having the highest sand content (around 90%), followed by Western Pokot and Northern Pokot, both slightly above 80%. Clay and silt content are relatively low across the region, with Western Pokot showing slightly higher clay levels.

All areas exhibit low organic matter (O.M %) and organic carbon (O.C %), indicating poor soil fertility. Moisture content (M.C %) is also low across the board, with minor variation between locations. In terms of pH, all sites fall within a narrow range, suggesting moderately neutral to slightly acidic soils, with Western Pokot having the highest pH. Overall, the figure highlights the predominance of sandy, nutrient-poor soils with limited water retention capacity across the Turkana region.

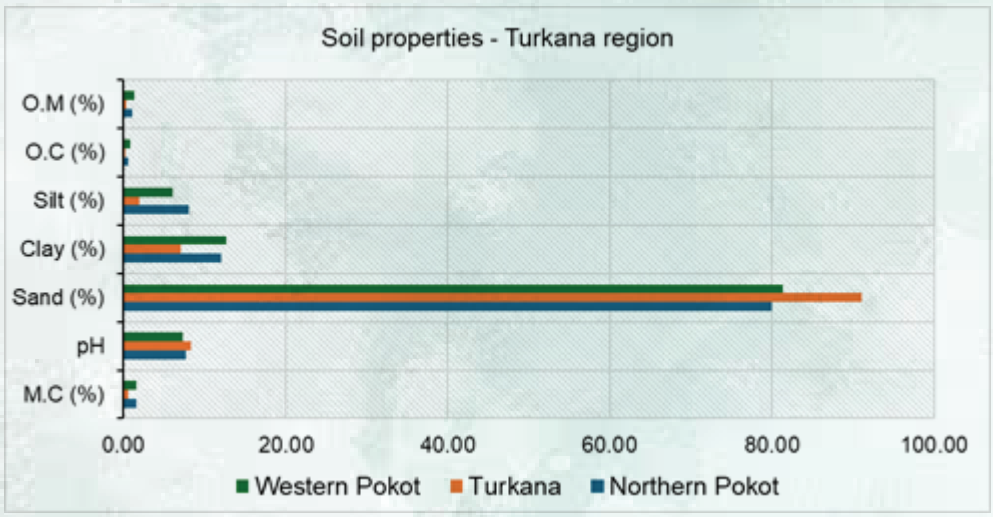


Figure 28: Soil properties across three areas in the Turkana region (Western Pokot, Turkana, and Northern Pokot)

5. Institution and Implementation arrangements (Institutional framework)

Through establishing clear institutional arrangements and implementing effective participatory processes, a rangeland health monitoring framework can contribute better to sustainable rangeland management and improve the livelihoods of rangeland-dependent communities. These arrangements involve establishing a multi-level structure, defining roles and responsibilities, and outlining participatory processes for data collection, analysis, and decision-making. They ultimately foster coordinated buy-in, co-ownership and sustainability.

Institutional arrangements span from a national-level body, potentially a ministry or department, for overall policy guidance, coordination, and oversight of rangeland health monitoring. This body should also ensure alignment with national policies and strategies. The second layer is at sub-regional or district-level institutions. This layer plays a crucial role in ensuring implementation of the monitoring framework at the Local Government level. For example, Subcounties are the basic Government planning administration units in Uganda and are most appropriate for service delivery regarding ecological stewardship and community development. The level could involve sub-regional natural resource management offices or specialized teams. The third level involves households and community- based organizations, including local groups and user associations, which are essential for participatory monitoring. They have over time mastered local and indigenous practices, knowledge and skills that contribute substantially to the understanding, monitoring and management of rangelands. They, however, should be empowered to collect data, participate in assessments, and contribute to management decisions through targeted capacity building initiatives.

Beyond national level, there is the overarching regional level that ensures establishment of synergies and cross learning amongst different countries. It should be noted that at all levels, an effective rangeland health monitoring system requires collaboration across different sectors, such as agriculture, livestock, environment, and water resources. Mechanisms for inter-agency coordination are needed to ensure a holistic approach.

5.1. Integration with Local Governance and planning

The flow down should start right from the IGAD secretariat to the community through the relevant administrative structures in the different IGAD countries. These are outlined below.

1. Regional Institutions (e.g. IGAD, EAC) – the Secretariat
2. National institutions (countries – MDAs) – the Focal point
3. Sub National (Districts/counties/States/Werders/Regional) – the Focal point

4. Community level structures (sub county/Payams/Bomas/RMCs, Traditional institutions etc.)
5. Donor funding or development agencies
6. Research institutions and NGOS e.g. Northern rangeland trust

5.2. Roles and responsibilities of the institutions

Institutions play distinct but interconnected roles in the framework for implementing a rangeland health monitoring system. These roles include establishing monitoring protocols, conducting assessments, analyzing data, and facilitating community engagement. Key institutions include government agencies (e.g., natural resources departments), research institutions, local communities, and potentially NGOs or international organizations among others. The Government Agencies play key role in developing and enforcing policy and legislation related to rangeland management and health monitoring. They oversee the implementation of monitoring programs, allocate resources for monitoring activities, and ensure data collection and analysis are conducted effectively. They coordinate efforts across different sectors (e.g., agriculture, livestock, wildlife) to ensure a holistic approach to rangeland health monitoring. Research Institutions play a crucial role in developing and refining monitoring methodologies, including indicators, sampling techniques, and data analysis methods. They provide technical expertise and training to other institutions and communities involved in monitoring. They analyze monitoring data, identify trends and potential problems, and provide recommendations for management actions. The Local Communities are essential partners in rangeland health monitoring, particularly in participatory approaches. They may be involved in collecting data on vegetation, grazing patterns, and other indicators. They contribute local knowledge and insights to the monitoring process and participate in decision-making based on the monitoring results. While other Stakeholders (e.g., NGOs, International Organizations) often play a role in building the capacity of local communities and other institutions to participate in monitoring. They may facilitate communication and coordination among different stakeholders and can also help mobilize resources for monitoring activities.

5.3. Capacity building and training - knowledge dissemination

Sustaining capacity building initiatives and ensuring adequate financial arrangements for rangeland health monitoring requires a multi-faceted approach that integrates community participation, strong institutions' commitment to funding and monitoring the initiatives, and using adaptive management practices. This includes building local capacity for monitoring, securing diverse funding sources, and fostering strong governance structures that support long-term sustainability. This can involve training community members as rangeland monitors, involving them in data collection and analysis, and fostering a sense of ownership over the monitoring process. Institutional Strengthening includes enhancing their financial management, procurement, and implementation capacities. It also involves diversified funding through a combination of government funding, donor support, private sector investment, and community contributions. Community-Based Financial Mechanisms such

as pastoral savings and credit cooperatives can link livelihood development with access to finance and improve financial sustainability. Lastly establishing strong Governance Structures such as clear and transparent governance structures for rangeland management is crucial for ensuring accountability and effective decision-making. This includes;

- Defining roles and responsibilities,
- Establishing dispute resolution mechanisms, and
- Promoting community participation in decision-making processes

5.4. Financial sustainability of capacity building initiatives

Sustaining capacity building initiatives and ensuring adequate financial arrangements for rangeland health monitoring requires a multi-faceted approach that integrates community participation, strong institutions, and adaptive management practices. This includes building local capacity for monitoring, securing diverse funding sources, and fostering strong governance structures that support long-term sustainability. The main components include;

Institutional Strengthening

Capacity building should extend beyond individual training to strengthen local institutions responsible for rangeland management. This includes enhancing their financial management, procurement, and implementation capacities.

Integrating Traditional Knowledge

Recognizing and integrating traditional ecological knowledge into monitoring and management practices can enhance the effectiveness and relevance of initiatives, ensuring they align with local contexts and cultural practices.

Continuous Learning

Establishing monitoring, evaluation, and learning (MEL) systems is vital for adapting management strategies based on data collected and feedback received. This includes using tools like satellite remote sensing data and geographic information systems (GIS) to track progress and identify areas for improvement

Long-Term Funding

Securing long-term funding commitments is essential for supporting ongoing monitoring and capacity building efforts. This can involve establishing endowment funds or developing sustainable financing models for rangeland management. This however, requires in-depth consultations to explore the most appropriate options.

6. Data management, storage and sharing plan

A well-defined data management, storage, and sharing plan to ensure data quality, accessibility, and usability is required. The plan should include clear objectives, standardized protocols, robust data storage solutions, and mechanisms for secure

data sharing among stakeholders. Clearly state the goals of rangeland monitoring, including what aspects of rangeland health are being assessed and how the data will be used for management decisions.

Establish Monitoring Protocols

This involves developing standardized methods for data collection, including the selection of appropriate indicators, sampling techniques, and data recording procedures. Therefore, the methods outlined in this framework and associated training manual should be used by all IGAD countries to ensure data compatibility and ease of data analysis and results comparison between the countries.

Choose Data Storage Solutions

Select appropriate data storage systems, such as databases, cloud storage, or file systems, ensuring data integrity, security, and accessibility.

Implement Metadata Standards

Create and maintain comprehensive metadata for all datasets, including information on data sources, collection methods, quality control, and spatial and temporal context.

Develop Data Sharing Mechanisms

Establish protocols for data sharing among stakeholders, including secure data access, appropriate data transfer methods, and data use agreements

6.1. Types of data and data formats

Data Formats

Qualitative Data

- Narratives: Written descriptions of rangeland conditions, observations, and management practices.
- Photographs and Videos: Visual documentation of rangeland health, vegetation, and grazing patterns.
- Community Knowledge and Perceptions: Information gathered through interviews, focus groups, and participatory mapping.

Quantitative Data

- Remote Sensing Data: Satellite imagery and aerial photography used to assess vegetation cover, land degradation, and other parameters.
- GIS Data: Geographic Information System data collected in the field e.g. coordinates, derived spatial data e.g. through modeling, and secondary spatial data.
- Field Measurements: Data collected through direct measurements of vegetation, soil, and hydrological characteristics.
- Statistical Data: Numerical data derived from surveys, experiments, and monitoring efforts.

Data Collection Methods

The methods outlined in this rangeland monitoring framework include;

- Literature Review: Gathering information from existing reports, studies, and publications.
- Field Surveys: Systematic collection of data on vegetation, soil, and other parameters.
- Remote Sensing: Using satellite imagery and aerial photography to assess rangeland conditions.
- Participatory Approaches: Involving local communities in data collection, mapping, and monitoring.
- Interviews and Surveys: Collecting qualitative and quantitative data from stakeholders. This could also be carried out in a participatory manner
- Grazing Records: Tracking livestock grazing patterns and utilization of forage.
- Data Storage and Management
- Databases: Organizing and storing data in a structured format for easy access and analysis.
- GIS Systems: These are used for spatial data organization into projects to evidence relations between datasets, analysis and display.
- Data Sharing Platforms: Facilitating data exchange and collaboration among stakeholders.
- Data Governance Frameworks: Establishing guidelines for data collection, management, and sharing.
- It is important to ensure that the selected/designed system has adequate capacity for data hosting

6.2. Data analysis (data analysis tools)

Data analysis involves using various tools and techniques to interpret collected data and inform management decisions. This includes both conventional and participatory approaches, with an emphasis on using data to understand rangeland health attributes like soil stability, hydrologic function, and biotic integrity. The analysis ranges from simple descriptive statistics to more complex models fitting to the needs of the stakeholders. The Data Analysis Tools and Software that are relevant include:

- Specialized Monitoring Apps e.g., LandPKS: For streamlined data collection and analysis using mobile devices.
- Spreadsheet Software e.g., Excel: For basic data entry, organization, and descriptive statistics.
- Statistical Software e.g., R, SPSS, SAS: For more advanced statistical analysis, modeling, and visualization.
- Remote Sensing Software: For analyzing satellite imagery and other remotely sensed data

- Geographic Information Systems (GIS) tools e.g., ArcGIS, QGIS: For spatial data display, analysis, integration with other spatial data and presentation.

6.3. .Dissemination

There is need to prioritize efficient and effective dissemination of information to various stakeholders, including land managers, researchers, and policymakers. This involves establishing clear communication channels, utilizing appropriate technologies, and tailoring information to the specific needs of different target audiences.
The developed online tool will have components for data storage and data access. The tool also has a visualization window where anyone who accesses it can customize/generate a desired output and save it in an easily accessible format.

6.4. Data access and sharing

To ensure orderly data access and sharing it is important to incorporate clear guidelines for data access and sharing to facilitate effective management and decision-making. This includes establishing protocols for data collection, storage, access, and sharing among stakeholders, ensuring data quality, and addressing potential legal and ethical considerations. The Key aspects of data access and sharing within a rangeland health monitoring framework include;

I. Data Collection and Standardization through establishing standardized methods for data collection to ensure consistency and comparability across different monitoring sites and time periods.

II. To develop protocols for data management, including data entry, storage, and quality control.

III. Data Access and Sharing Protocols by clearly defining who has access to the data (e.g., researchers, land managers, local communities) and under what conditions e.g. for further analysis or for only visualization.

IV. Developing a formal process for data requests, including submission of a data request form and a review process.

V. Data Security and Confidentiality. This is very crucial as it supports implementing measures to protect sensitive data from unauthorized access, modification, or disclosure.

VI. Addressing potential legal and ethical considerations related to data ownership, privacy, and intellectual property.

VII. Data Sharing Platforms and Tools that facilitate data sharing and visualization, such as online databases, interactive maps, and dashboards and use of tools that enable local communities to contribute to data collection and analysis.

VIII. Regularly evaluating the effectiveness of management practices based on monitoring data and making adjustments as needed

IX. Involving the local communities in the design, implementation, and interpretation of rangeland health monitoring outputs, which will ensure that the monitoring framework is relevant to local needs and priorities

7. Monitoring, Evaluation, and Reporting Mechanisms

The mechanisms for monitoring, evaluation and reporting on rangelands health may be categorized as follows:

1. Evaluation by external entities
2. Internal monitoring by rangeland users and managers
3. Joint participatory monitoring involving both the external and internal monitoring entities
4. Establishing Monitoring tools and Methods

A robust monitoring, evaluation, and reporting mechanism is essential to track progress, assess effectiveness, and ensure accountability. Such a mechanism helps in understanding how rangelands are changing, making informed management decisions, and adapting strategies as needed. When monitoring, specific measurable, achievable, relevant, and time-bound (SMART) indicators related to rangeland health, such as vegetation cover, soil erosion, and biodiversity must be established. This is accompanied by implementing a system for collecting data on these indicators through various methods, including field surveys, remote sensing, and participatory monitoring with local communities. The developed online tools indicated in Section 4 will be used to generate consistent and comparable outputs that can be used in the evaluation.

Evaluation involves periodic reviews by conducting regular assessments of the progress towards achieving objectives and identify areas where adjustments are needed. The IGAD Regional office should ensure regular reporting and availability of the reports to all relevant stakeholders, including local communities, government agencies, and researchers. This in turn will provide channels for feedback from stakeholders to inform future monitoring and evaluation efforts.

7.1. M&E plan

A comprehensive Monitoring and Evaluation (M&E) plan, which ensures that rangeland health monitoring is effective, efficient, and contributes to sustainable rangeland management should be developed (This was beyond the scope of this assignment).

A detailed plan outlining the monitoring objectives should include a checklist of activities, outputs, indicators, means of verification and define clear roles and responsibilities for different stakeholders. This is ensures consistency and thoroughness in the M&E process. The specific data collection guidance should include; means of location of data collection, methods for measuring indicators, frequency of data collection and data analysis methods.

7.2. Feedback Loops and Learning

Rangeland degradation often creates feedback loops that accelerate further degradation. For example, overgrazing reduces plant cover, leading to increased soil erosion and reduced water infiltration, which in turn weakens plant growth and makes the land more vulnerable to further grazing pressure. Triggers for adaptive management should be identified to avoid any area reaching a tipping point where implementation of reversal mechanisms/interventions would be either very costly or hard to implement.

8. Concluding remarks

A robust framework for rangeland health monitoring is crucial for understanding and managing these valuable ecosystems. Effective implementation requires a multi-faceted approach that integrates robust monitoring protocols, clear implementation arrangements, and a strong emphasis on learning and adaptation. This includes defining specific objectives, selecting appropriate indicators and methods, establishing clear roles and responsibilities, and ensuring data management and analysis are well-defined. This framework is aimed at empowering stakeholders to make informed decisions and promote sustainable rangeland management practices. This framework will contribute to the long-term sustainability of these vital ecosystems.

It is important to note that the framework presented here is a living document. It will continuously be updated based on the prevailing environment in rangeland management and technological advancement in the IGAD region.

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ICPALD

IGAD Centre for Pastoral Areas and Livestock Development (ICPALD)
Kabete Vet Lab, Kapenguria Road,
P. O. Box 47824-00100, Nairobi, Kenya.
Emails: dereje.wakjira@igad.int
Telephone: +254 202573743 (office)