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Monitoring Rangeland Degradation and its Dynamism in Pastoral Areas of Afar Region, Ethiopia by using Earth Observation Data

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***Abstract*— *Rangelands cover a significant portion of the world's land area, particularly in Africa, where they support the livelihoods of communities and contribute to national economies. However, rangeland degradation poses a significant environmental challenge globally, threatening ecosystem services and impacting food security, water availability, and resilience to climate change. In Ethiopia, rangeland degradation is a pressing issue, driven by factors such as overgrazing, deforestation, soil erosion, and climate change, which in turn affect vegetation cover, soil fertility, and biodiversity. This study analyses Rangeland cover changes in Afar pastoralist systems using Landsat satellite images from 2000 to 2020. This was done by downloading and processing Landsat images of 2000, 2010 and 2020. A supervised classification approach identified five land-use/cover classes, and results show significant changes in forest, grassland, bare land, cropland, and wetland areas over the two-decade period. Grassland areas declined drastically. The findings underscore the complexity of land use dynamics in the Afar region and highlight the need for holistic approaches integrating ecological conservation, sustainable land management, and community engagement to mitigate further degradation and preserve vital ecosystems. By addressing the complex drivers of land use change and adopting adaptive management strategies, stakeholders can work towards fostering resilience and promoting the long-term sustainability of the region's landscapes and livelihoods.*

***Keywords*— Rangeland degradation, Land-use/cover, GIS, Remote sensing, Sustainable land management.**

I. INTRODUCTION

Pastoralism, a traditional way of life in many African Savannahs, has been shown to be resilient to variable climates [1].

Pastoral systems support the livelihoods of millions of people living in harsh environments where alternative land use systems are highly risky [2]. About 90% of the national livestock export and 26% of the draught animals, on which almost all the crop production is dependent, come from the pastoral sector. Pastoral rangelands make up about 50 to 70% of the world's land area and 65% of Africa's land mass [3].

East African countries have vast areas of rangeland, among which Ethiopian rangelands cover about 64% of the total area [4].

Rangeland degradation poses a significant environmental challenge globally, particularly in Africa, where it threatens the livelihoods of millions of people dependent on these ecosystems for grazing and other resources. According to the Food and Agriculture Organization (FAO), approximately 70% of the world's rangelands are considered degraded to some extent due to climate change and other factors [5]. Degradation of land and vegetation is mainly a consequence of complex interactions between climate, inappropriate resource management practices, policies and regulations, lack of law enforcement, and unsustainable grazing pressures [6].

This degradation not only impacts ecosystem services but also undermines food security, water availability, and resilience to climate change for local communities [7].

Rangeland degradation in Ethiopia is a significant environmental challenge with far-reaching consequences for both ecosystems and human livelihoods. Multiple factors contribute to this degradation, including overgrazing, deforestation, soil erosion, and climate change. As a result, vegetation cover declines, soil fertility diminishes, and biodiversity decreases, impacting the productivity of livestock and exacerbating food insecurity and poverty among pastoral communities [8,9,10]. Urgent action is required to implement sustainable land management practices, promote community-based conservation initiatives, and strengthen policy frameworks to address rangeland degradation and safeguard the resilience of Ethiopia's ecosystems.

Afar region is one of the largest pastoral and agro-pastoral groups inhabiting the rangelands of north eastern and central parts of the Main East African Rift Valley. Despite this huge resource potential and significant contribution to the livelihoods and national economy, there are persistent challenges, such as continued degradation of rangelands, shrinkage of land available for grazing, and reduced opportunities for mobility.

According to a report by UNICEF [11], three consecutive failed rainy seasons have brought on severe drought in Ethiopia’s lowland regions of Afar, Oromia, the Southern Nations, Nationalities, and Peoples’ (SNNPR) and Somali regions, drying up water wells, killing livestock and crops, and pushing hundreds of thousands of children and their families to the brink.

Management of rangelands is crucial and requires taking diverse issues into account. Rangeland management should consider livestock conditions, a major means of livelihood in arid and semi-arid regions [12]. A repeatable monitoring technique for rangeland conditions is essential for developing knowledge of important ecological processes and for conservation purposes [13Monitoring the health of pastoral rangelands using fieldwork techniques is challenging in arid and semi-arid areas due to the large geographical area, rough terrain, and rich diversity over short distances. Many rangeland degradation studies [14, 15,16] in pastoral areas of Ethiopia were performed by traditional methods, such as questionnaires and field surveys, which have lower accuracies than advanced remote sensing approaches.

An efficient and suitable tracing system is required to assist in setting up a drought early warning system [17]. In recent years, the availability of remotely sensed data has provided a long-term and large-scale opportunity because it is strengthened by the ability of the datasets to present vegetation and land surfaces at large spatial and temporal extents [18]. As a result, remote sensing is a well-known and effective method for assessing rangeland [19]. Because of their low cost and constant availability across large and remote areas, time series of remote sensing data are frequently used to estimate the extent and intensity of rangeland degradation.

The objective of this research work is to analyze the patterns and dynamics of land-use/cover changes from 2000 to 2020. Its aim is to establish an integrated early warning system for drought monitoring and management in the dry-land ecosystem of Afar pastoralist systems, amidst the challenge of increasing feed production for sustainable livestock production. Exploring degraded rangeland ecosystems and identifying driving forces using remote sensing data and GIS spatial approaches are deemed necessary at both local and regional levels among Afar pastoralists.

II. MATERIAL AND METHODS

Description of study area

The Afar Region is located in the Northeast of Ethiopia, sharing international borders with Eritrea and Djibouti. The Afar community inhabits about 100,860km^2, of which over 60% is known for extensive range and grassland; thus forming an essential resource base for livestock production in the region. According to Ethiopia relief web Report [20], The Afar region, Eastern Ethiopia is characterized by a harsh climate, temperatures reaching up to 40°C, with highly unpredictable average precipitation between 600 and 5 mm annually.

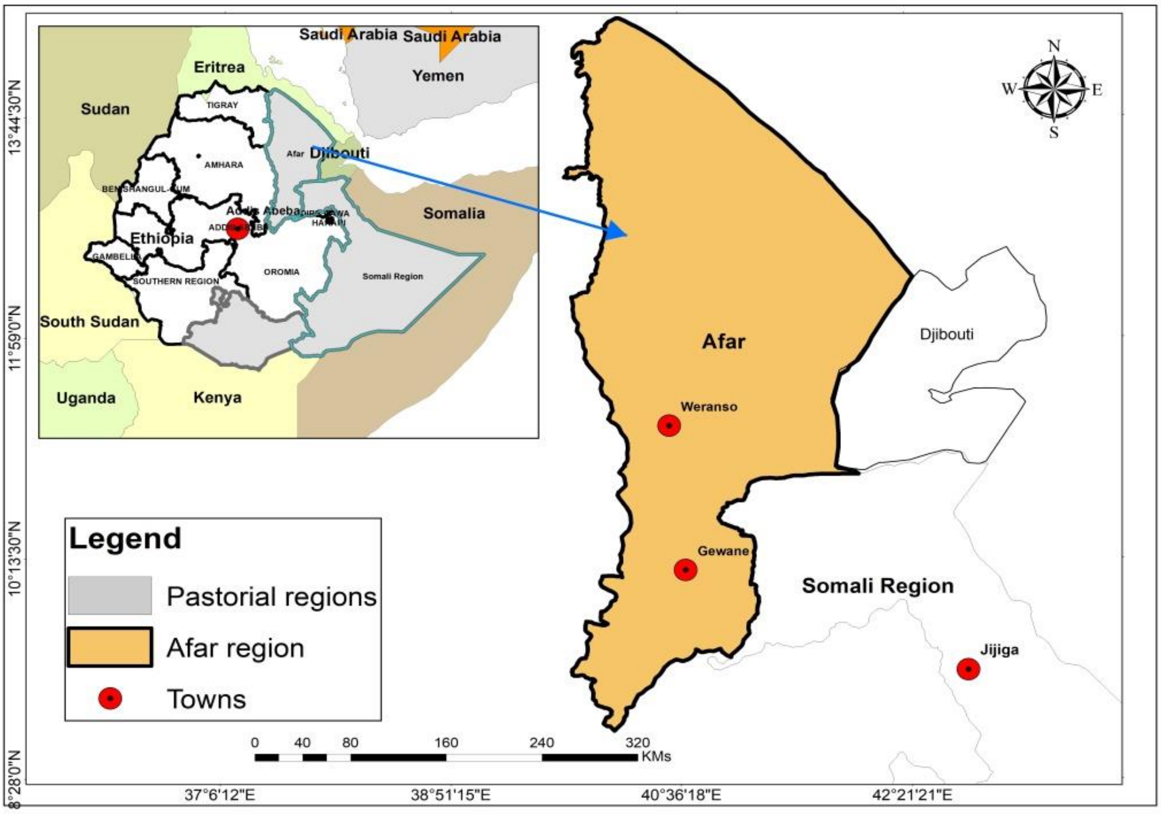

Fig.1. Study area map

Data Sources

Landsat satellite images Landsat 5 and 8 Operational Land Imager (OLI) sensors of three acquisition years (2000, 2010 and 2020) with less than 10% cloud cover were obtained from the United States Geological Survey (USGS) Earth explorer website (https://earthexplorer.usgs.gov/) on dry season. Once pre-processing and mosaicking of the images were completed, the area of interest was Subset with the aid of vector boundary layer of the study area. The spatial resolution of the images was 30 meter. After gathering satellite data pre-processed and processed using ERDAS 9.2 and Arc map10.5 software,

Table 1: Data source

Data	Year	Band	Resolution (M)
Land sat 5	2000	TM	30
Land sat 5	2010	TM	30
Land sat 8	2020	OLI	30

III. METHODOLOGY

Data Collection and Pre-processing

Ground Control Points (GCPs) were identified and collected to facilitate accurate geometric correction of the images. Radiometric correction techniques were applied to normalize pixel values, and image enhancement methods, including histogram equalization and sharpening, were employed to improve visual quality.

The pre-processed imagery was segmented into homogeneous regions, and spectral, textural, and contextual features were extracted for classification. A supervised classification was done by using Maximum likelihood classification Algorithm through ERDAS imagine 9.2 software were utilized to classify land-use/cover types. In this approach, training samples were selected for all the five classes. The samples were equally distributed and scattered over the study area. The land use type for each sample was identified according to colour, size, shape, texture and its spatial relationships with neighbours. Classification accuracy was assessed using ground truth data and validation techniques. GIS spatial analysis tools were used to analyze the spatial distribution and patterns of land-use/cover changes.

Table 2. Land use and land cover (LULC) classes and their descriptions

LULC class	Description
Forest	an area naturally covered by closed stands of large trees
Grassland	an area dominated by local or introduced grasses and forbs species
Cropland	refers to agricultural lands that are seasonally cultivated by the local people for the production of mainly grains like wheat, sorghum, maize and teff
wetland	refers to a land occupied by water permanently throughout the year.
Bare land	Barren rocky land, salt affected land

Post-classification refinement was applied using additional contextual information gathered from supplementary datasets, such as land cover maps, land use databases, and environmental variables, along with expert opinions, to enhance the accuracy of the classification. Change detection accuracy was evaluated using ground truth data and validation techniques.

Table 3. Assessment of classification accuracy

Accuracy (%)							
Classified Image	Classes	2000		2010		2020	
		Producer's	User's	Producer's	User's	Producer's	User's
	Forest	93.52	90.27	87.17	90.58	92.75	98.2
	Grassland	84.30	80.45	75.25	85.24	80.74	83
	Cropland	80.5	88.56	90.01	75.54	82.87	82.4
	Bare land	100.0	95.19	78.50	85.24	77.58	90
	Wetland	78.00	85.21	93.01	89.24	90.15	79.52
	Overall accuracy (%)	88.81		90.92		85.25	
	Kappa Statistics	0.86		0.89		0.82	

Assessing classification accuracy in land use image classification is crucial for ensuring the reliability of remote sensing analysis. Key metrics include producer's accuracy, which measures the likelihood of correctly classifying features on the ground, and user's accuracy, which evaluates the probability of accurately identifying classified pixels.

Overall accuracy provides a straightforward assessment of classification performance by calculating the proportion of correctly classified pixels, while Kappa statistics offer a more robust measure by considering agreement beyond chance alone. Proper assessment of classification accuracy is essential for informing decision-making in various applications, such as urban planning and environmental monitoring, and ensuring the credibility of remote sensing analysis results.

IV. RESULT

Land Use and Land Cover Changes

The land use/cover maps spanning three periods (2000, 2010, and 2020) depicted in Figure 2, demonstrated a commendable overall map accuracy of 89% for all images, achieved through the application of an error/confusion matrix. This method, as commonly acknowledged in the field, serves as a standard approach for evaluating per-pixel classification accuracy [21].

Moreover, Kappa statistics were computed for each classified map to provide further insight into the accuracy of the results. With a resulting Kappa statistics of 0.89 for each time period, the classification performance is deemed robust and reliable. This aligns with the findings of recent research [22], who emphasize the acceptability of such high levels of accuracy for subsequent analysis and change detection.

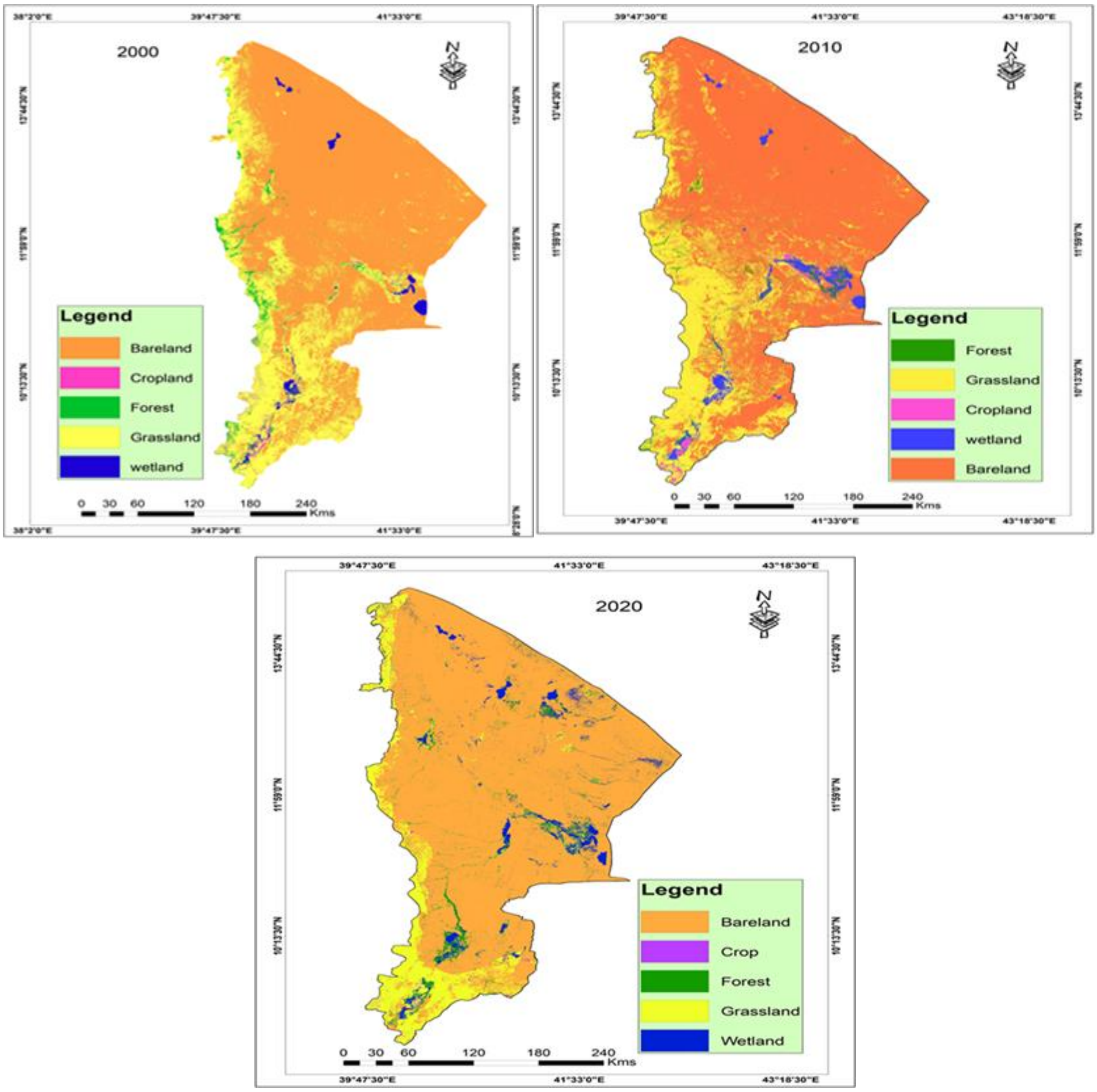

Fig.2. Land use and land cover types in Afar rangelands between 2000 and 2020.

The image classification results revealed that the total land area of Afar pastoral areas amounted to 97,190.69 km². Detailed breakdowns of individual class areas and change statistics for the years 2000, 2010, and 2020 are provided in Table 4.

Table 4. Areas and percentages of LU/LC classes for the years 2000, 2010, and 2020

Classes	2000		2010		2020	
	Area (Sq.km)	Percent (%)	Area (Sq.km)	Percent (%)	Area (Sq.km)	Percent (%)
Forest	1843.18	1.89	1374.68	1.41	2911.97	2.99
Grassland	24617.40	25.32	23428.31	24.1	10105.4	10.39
Cropland	569.22	0.58	689.02	0.7	723.97	0.74
Bare land	69000.53	70.99	69349.43	71.35	80275.37	82.59
Wetland	1160.36	1.19	2270.47	2.33	3188.36	3.28
Total	97190.69	100	97190.69	100	97190.69	100

Based on the statistical data provided for land cover changes in the Afar region over the years 2000, 2010, and 2020, several notable trends can be observed. Firstly, there is a significant decrease in the coverage of Forest areas over the three periods. In 2000, Forest coverage was 1.89%, which decreased to 1.41% in 2010, and then increased slightly to 2.99% by 2020. This indicates a fluctuating pattern, but overall, there seems to be a trend towards increased forest coverage over the years. Secondly, Grassland coverage also shows a notable decrease from 25.32% in 2000 to 10.39% in 2020. This indicates a substantial reduction in grassland areas over the two-decade period.

On the contrary, bare land exhibits a consistent increase in coverage over the years. It was 70.99% in 2000, slightly increased to 71.35% in 2010, and significantly rose to 82.59% in 2020. This suggests a clear trend of expansion in bare land areas over time. Cropland coverage remains relatively stable, with minor fluctuations. It was 0.58% in 2000, increased slightly to 0.7% in 2010, and remained nearly constant at 0.74% in 2020.

Lastly, Wetland coverage also shows an increasing trend, with values of 1.19%, 2.33%, and 3.28% in 2000, 2010, and 2020 respectively. This indicates a gradual expansion of wetland areas over the years. Generally, the Afar region has experienced notable changes in land cover over the past two decades, including a decrease in forest and grassland areas, and an increase in bareland and wetland areas. These changes reflect various environmental and human factors influencing land use dynamics in the region.

V. DISCUSSION

There is drastic decrease in grassland area in the Afar pastoral region from 2000 to 2020, as evidenced it decline from 24,617.40 km^2 to 10,105.4 km^2. This significant decrease in grassland can be attributed to several interconnected factors, each contributing to the overall decline.

Firstly, livestock grazing pressure, intensified by population growth and traditional pastoralist livelihoods, has led to overgrazing and subsequent grassland degradation [23]. As the population increases, so does the demand for grazing land, resulting in the conversion of grasslands into agricultural or settlement areas [24].

Secondly, the region's susceptibility to climate change-induced phenomena, such as increased temperatures, erratic rainfall patterns, and recurrent droughts, has exacerbated land degradation and desertification, further diminishing grassland ecosystems [25].

Thirdly, expansion of agricultural activities driven by population pressures has led to the conversion of grasslands into croplands or utilized for other agricultural purposes, fragmenting habitats and accelerating biodiversity loss [26].

Additionally, government policies promoting infrastructure development, coupled with inadequate conservation measures and ineffective enforcement of land-use regulations, have further compromised grassland integrity [27].

Lastly, invasive species and pest infestations pose on going threats to native vegetation, altering ecosystem dynamics and exacerbating grassland decline [28,29,30]. These interconnected factors underscore the complexity of land use change in the Afar region, highlighting the need for holistic approaches integrating ecological conservation, sustainable land management, and community engagement to mitigate further degradation and preserve vital grassland ecosystems.

The increase in forest land use from 1843.18 km^2 to 2911.97 km^2 between 2000 and 2020 represents a significant expansion of forested areas in the region. However, it's essential to note that this increase might not solely reflect natural forest regeneration or afforestation efforts. The inclusion of invasive species as part of the forest class in remote sensing data presents a potential complication. While these invasive species may contribute to the overall increase in forested areas observed, their presence could have adverse ecological impacts.

Given the potential ecological and socio-economic implications of invasive species in forested areas, further research is warranted to understand their distribution, impacts, and management strategies. Future studies could employ advanced remote sensing techniques, coupled with field surveys and ecological modeling, to accurately identify and monitor invasive species' spread and assess their ecological impacts on forest ecosystems. Additionally, interdisciplinary approaches integrating ecological, socio-economic, and policy perspectives are needed to develop effective strategies for invasive species management and conservation.

VI. CONCLUSION

The analysis of land use and land cover changes in the Afar pastoral region spanning from 2000 to 2020 reveals significant transformations in the landscape, driven by a complex interplay of environmental and human factors. Through robust image classification methods and statistical analysis, it becomes evident that the region has undergone substantial shifts in land cover composition, with notable trends observed in forest, grassland, bare land, cropland, and wetland areas.

Over the two-decade period, there has been a consistent decrease in forest and grassland coverage, accompanied by a notable increase in bare land and wetland areas. These changes reflect the cumulative impacts of factors such as population growth, livestock grazing pressure, climate change-induced phenomena, expansion of agricultural activities, ineffective land-use regulations, and invasive species infestations.

The drastic decline in grassland area highlights the urgent need for holistic approaches to address overgrazing, land degradation, and desertification, while also emphasizing the importance of sustainable land management practices and community engagement. Additionally, the expansion of forested areas presents both opportunities and challenges, necessitating further research to understand the role of invasive species and their ecological impacts.

Moving forward, interdisciplinary efforts integrating ecological conservation, sustainable land management, and policy interventions are crucial for mitigating further degradation and preserving vital ecosystems in the Afar region. By addressing the complex drivers of land use change and adopting adaptive management strategies, stakeholders can work towards fostering resilience and promoting the long-term sustainability of the region's landscapes and livelihoods.

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