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CLIMATE INNOVATION AND TECHNOLOGY (JCIT)
Advancing Research in Climate, Sustainability and Emerging Technologies
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LAND USE LAND COVER CHANGE IN TWO AGRICULTURALY IMPORTANT BUT ECOLOGICALLY CONTRASTING ZONES OF THE GAMBIA

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ABSTRACT
This study examines land use land cover change (LULCC) in the Central River Region (CRR) and Upper River Region (URR) of The Gambia from 2002 to 2024 using satellite imagery and supervised classification techniques. The analysis highlights a significant transformation in land cover, with agricultural expansion being the most dominant change. Between 2002 and 2013, croplands increased by 53,698.86 hectares. Settlements also grew significantly, expanding by 12,493.62 hectares. Conversely, natural landscapes such as grasslands and forests experienced severe losses, primarily converted into farmland and settlements. Grassland cover declined by 48,672.36 hectares from 2002 to 2013 and by 43,482.6 hectares. Future projections for 2024-2034 predict a net loss of 37,211.85 hectares of grasslands and a net gain of 32,090.13 hectares in agricultural land in CRR. Similarly, in URR, agriculture is expected to expand by 13,562.91 hectares, while grasslands are projected to shrink by 19,930.95 hectares. These findings highlight the intensification of land use determined by agriculture and rural development, emphasizing the need for sustainable land management practices to mitigate deforestation, habitat loss, and environmental degradation.

Keywords: *LULCC, Agricultural Expansion, Supervised Classification, CRR and URR The Gambia, Environmental Degradation.*

INTRODUCTION

Land cover refers to the physical and biological cover over the land's surface, while land use is the human use of land for different activities (Keller andSoares 2003) Land use and cover change (LULCC) is the term for human modification of the earth's terrestrial surface as a result of different human activities (FAO, 2016).

Recent studies highlight the rapid expansion of cultivated land at the expense of forests, natural grasslands, and woodlands. For instance, (Ramankutty *et al.*, 2008), observed substantial increases in agricultural land use globally, driven by the need to meet food production demands for a growing population. This trend has been accompanied by significant deforestation and habitat conversion, which in turn affects carbon sequestration and accelerates climate change (Crosson *et al.*, 2011).

The impacts of LULC changes are multifaceted. Forest fragmentation leads to the loss of contiguous habitats, which is detrimental to wildlife and plant species that rely on large, unbroken tracts of land. This

ISSN: 2806-4933 | DOI: https://doi.org/10.67303/jcit.v1i1

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fragmentation not only reduces biodiversity but also disrupts ecosystem processes such as pollination and seed dispersal (Chernozhukov *et al.,* 2016). Furthermore, land degradation resulting from intensive agriculture diminishes soil health, leading to reduced agricultural productivity and increased vulnerability to erosion and desertification (Bivand, 2015)

However, LULC change dynamics have not been uniform in all parts of the world because of different driving factors. Population pressure, human activities, and development have influenced LULC changes around the globe,(Liyew, Tsunekawa and Haregeweyn, 2019).

According to reports between 2015 and 2020, Africa experienced a deforestation rate of approximately 4.41 million ha per year. This represents the highest rate of net forest loss globally during that period. Given that Africa's total forest area was about 636 million hectares in 2020, the annual deforestation rate equates to approximately 0.69% of the continent's total forested area (Mekonnen *et al.*, 2018). LULCC can affect regional and global climates through greenhouse gases emission or sequestration and by altering the overall reflectance properties of the earth's surface. (FAO, 2016).

In The Gambia, the major drivers of land use and land cover changes are land clearing for agriculture, tree cutting for firewood and charcoal, and settlement expansions (Bah, 2019). Similarly, (Ceesay et al., 2017) assessed deforestation in The Gambia and concluded that logging contributes to climate change through an increase in temperature of 1^{0}C every 10 years from the 1940s and a reduction in rainfall from 1950 to 2000. National forestry assessments for two periods (2009/2010 and 1981/1982) were compared, and the results showed a 7 % reduction in forest cover from 1981/1982 to 2009/2010 (Nget et al., 2011). This means deforestation-related activities in The Gambia need to be monitored, as well as their linkages to climate change assessment, for a better understanding of the climate change situation in the country. From the year 1984, agricultural extensification has significantly impacted various agroecological zones in The Gambia's Central River Region (CRR). Between 1984 and 2017, cropland areas expanded, while shrub/wood savanna and wooded savanna areas decreased. This shift is largely attributed to land clearing for agriculture, driven by factors such as low soil fertility, which hampers vegetation growth and contributes to increased CO_2 emissions. Farmers have reported that declining soil fertility has led to reduced crop yields, prompting the expansion into new lands to sustain agricultural production. These land-use changes and soil degradation processes are linked to increased CO_2 emissions, exacerbating climate change impacts in the region. (Sanneh, Babana and Yaffa, 2022).

The causes of human-induced climate change mainly through land-use activities have attracted the attention of researchers and stakeholders globally (Goldewijk and Ramankutty, 2004; Song and Deng, 2017; Seddon *et al.*, 2020; Temesgen *et al.*, 2021; Chen *et al.*, 2022). Despite growing concerns over environmental degradation and land resource management in The Gambia, there remains a significant gap in comprehensive, long-term assessments of LULC changes, particularly in the CRR and URR. Existing studies often focus on national or broader regional scales, with limited temporal coverage or outdated datasets that fail to capture recent trends and drivers of land transformation. As these regions are vital for agriculture, biodiversity, and rural livelihoods, understanding how land cover has evolved from 2002 to 2024 is crucial for informing sustainable land management strategies, climate adaptation planning, and policy interventions tailored to local contexts. It is equally important to compare how LULCC driven by agriculture and its related socio-economic development such as settlement expansion manifests in areas with marked ecological differences in climate and vegetation. This is because climate and vegetation characteristics are pull factors in agriculture and influence agricultural practices of farmers as well as the land's ability to regain vegetation cover when a cultivated land is allowed to fallow, a practice common in the Gambia. This paper therefore seeks to compare the dynamics of LULCC in the CRR and URR which are two agriculturally important but ecologically different regions in the Gambia.

2. MATERIALS AND METHODS

2.1. LOCATION OF THE STUDY

The study was conducted along the extensive floodplains of the River Gambia, located within the CRR and the URR). Geographically, the area spans from longitude 15°27'43.905" W and latitude 13°38'19.187"N to longitude 13°47'34.031"W and latitude 13°26'52.939"N. It encompasses two (2) of the country's primary agroecological zones: the Sahel-Grasslands Zone, also known as the Semi-Arid Zone, and the Sudano-Sahelian or Riverine Zone. The Sahel-Grassland Zone, spanning approximately 147,684 hectares in the extreme northern part of CRR, is characterized by its semi-arid climate, characterized by limited surface water availability and erratic rainfall patterns, with an annual average of below 900 mm. These climatic conditions render rainfed crop production particularly challenging and unreliable. According to soil suitability assessments, only 28% of the land is classified as suitable for cultivation, whereas 21% is marginal and 36% is deemed unsuitable for agricultural activities (Neeff von Luepke, H., Schoene, D., 2006). The combination of low and inconsistent precipitation, high evapotranspiration, and minimal water retention capacity of the soils further limits the region's agricultural potential. The Sudano-Sahelian or Riverine Zone, on the other hand, benefits from relatively better water availability due to its proximity to the River Gambia, yet still experiences similar climatic challenges. These environmental constraints significantly influence land-use practices and necessitate innovative agricultural strategies to enhance food security and improve livelihoods in the region (Brown, 1997). See figure 1

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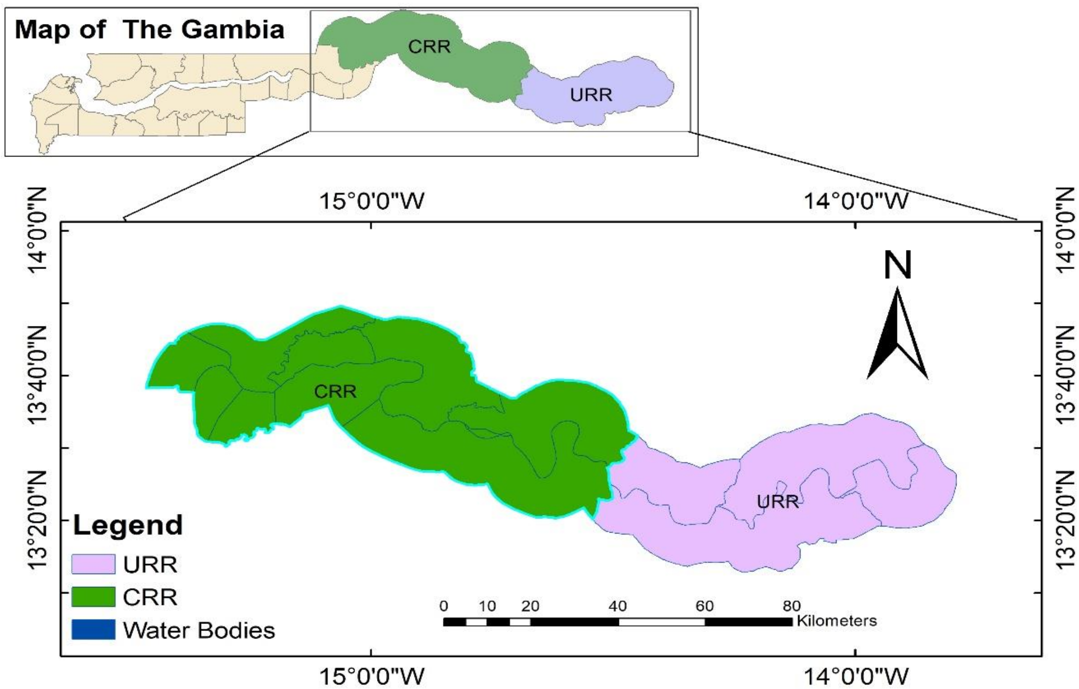

Figure 1: Location of the Study Area URR AND CRR and their communities

2.2. LAND USE LAND COVER CLASSIFICATION AND CHANGE ANALYSIS

Five (5) land use/land cover (LULC) categories were identified through field visits to align with the objectives of this study Congalton and Green (2019). Table 1 shows the classification scheme used. Landsat TM7, Landsat 8, and Landsat 9 (OLI) satellite images for the years 2002, 2013, 2022, and 2024 covering the study area were freely downloaded from the USGS portal (https://www.usgs.gov/). These images, summarized in Table 2, were acquired during the dry season (November to March) to ensure minimal cloud cover and optimal visibility, a common practice in tropical LULC studies. (Roy *et al.*, 2014). A field GPS survey was conducted to collect training and validation points for each of the identified LULC classes in the study area. A total of 225 training data points were collected, with 45 points per class for the five LULC categories: waterbodies, grassland, cropland, forest, and settlement (Foddy, 2002).These training points were used for supervised classification and accuracy assessment. See Figure 2 for the spatial distribution of training sites.

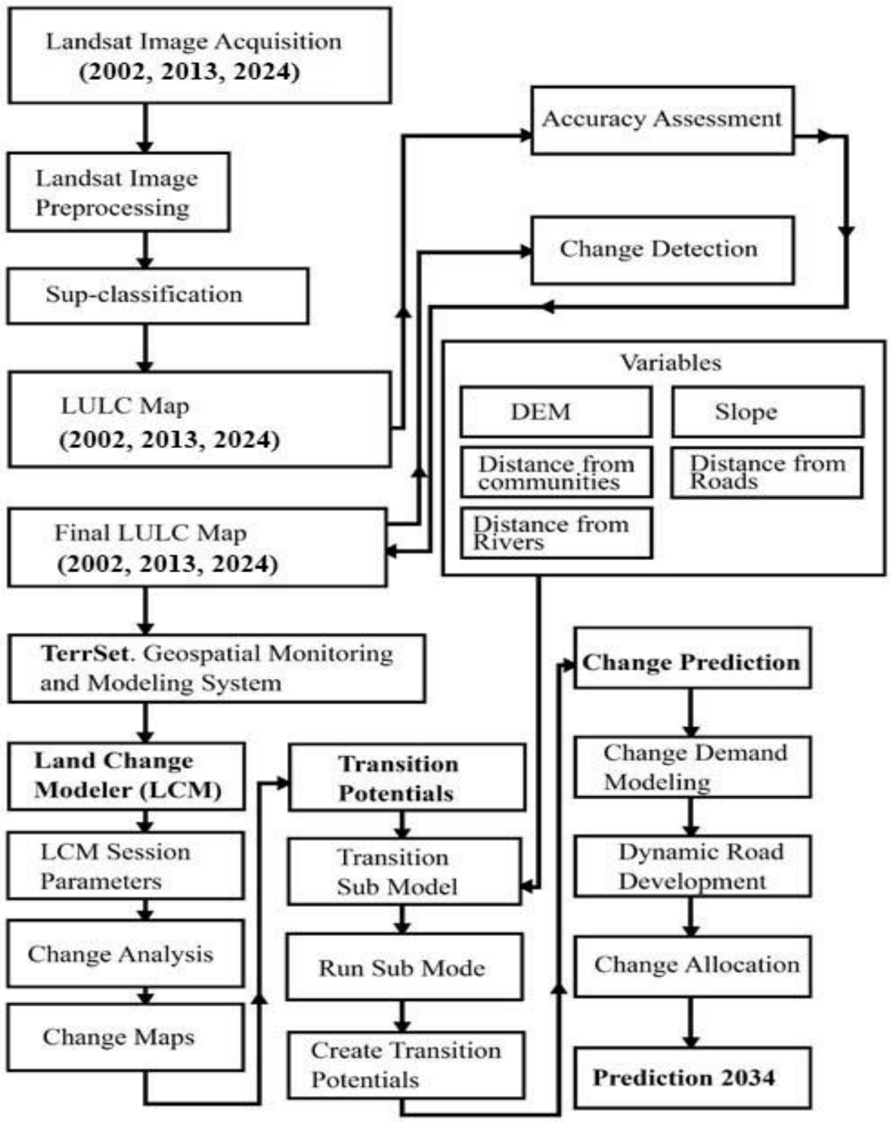

Figure 2. Predicted method Terrset

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Table 1: Description of each class for the study area classification

No.	Classes	Descriptions
1	Waterbody	In the CRR and URR, waterbodies refer to rivers, lakes, reservoirs, or ponds used for both natural and economic activities.
2	Settlements	It includes houses and developed surfaces such as industries. The class Consists of some bare grounds within communities.
3	Cropland	This includes areas used for the production of food crops, e.g., rice, maize, and sorghum.
4	Grassland	Land area that is covered by grasses predominantly *Andropogon gayanus* , *Hyparrhenia spp, Pennisetum pedicellatum (Kyasuwa), Sporobolus pyramidalis*, *Cenchrus biflorus* (FAO, 2010).
5	Forest	Land area with standing trees of a minimum height of 5m with a tree canopy of 15% and above.

A field GPS survey was undertaken to collect training and validation points of each identified land use/ land cover class in the study area. Forty-five training data points were collected for each LULC class described in Table 2

Table 2 Description of the images used in the study

Landsat name	Sensor	Path	Row	Spatial Resolution	Date
7	EMT+	203	51	30m	2002/04/04
7	EMT+	204	50	30m	2002/04/11
7	EMT+	204	51	30m	2002/04/11
8	OLI/TIRS	203	51	30m	2013/12/06
8	OLI/TIRS	204	51	30m	2013/12/13
9	OLI/TIRS	203	51	30m	2024/01/11
9	OLI/TIRS	204	51	30m	2024/01/18

Data Acquisition

Landsat satellite imagery was acquired for four historical time points -2002, 2013, and 2024-and used to simulate land cover changes and predict the 2034 Land Use and Land Cover (LULC) scenario for the Central River Region (CRR) and Upper River Region (URR) in The Gambia.

All images were downloaded from the USGS Earth Explorer platform and selected for minimal cloud cover and consistent seasonal conditions (dry season).

The satellite images were prepared by stacking the bands to form a multispectral image composite for each epoch. The images were classified using the Random Forest machine learning classifier and the field training datasets. The Random Forest classifier was chosen because it has been shown in the literature to yield higher classification accuracy than other classifiers in mapping highly heterogeneous landscapes. (Nel *et al.*, 2022).

All image processing and classification were performed in the R studio. The classification procedure yielded four (4) LULC maps for the time steps 2002, 2013, and 2024.

The accuracy of the LULC maps was assessed by generating error matrixes for each using the field validation datasets as reference points. Overall, Users', Producers', and Kappa accuracy were calculated from the error matrix to assess the accuracy of the classified maps. A change matrix was analyzed from 2002 to 2024 to assess the transitions.

2. Preprocessing of Satellite Imagery

Image preprocessing was conducted in **Terrset** and **ArcGIS Pro 3.2**, following standard procedures (Arfasa, Owusu-Sekyere, and Doke, 2023). Radiometric Calibration and Atmospheric Correction using DOS (Dark Object Subtraction) method to reduce haze and scattering effects. Geometric Correction to ensure all images are aligned spatially using UTM Zone 28N projection Cloud Masking performed using the Fmask algorithm. Layer stacking for multispectral bands relevant for land cover classification.

3. Supervised Classification

Supervised classification was performed using the Maximum Likelihood Classification (MLC) algorithm, a widely accepted method for remote sensing LULC tasks (Seyam, Haque and Rahman, 2023). Classification was conducted for all four years: 2002, 2013, and 2024. Land Cover Classes: Forest, Grassland, Cropland, Settlements and Water Bodies Training samples were collected using a combination of: Historical Google Earth imagery Ground truth data from recent surveys, Expert knowledge and high-resolution Sentinel-2 validation layers.

4. Accuracy Assessment

Accuracy assessment was conducted using confusion matrices for each classified map with the following metrics (Nel *et al.*, 2022). Overall Accuracy (OA) Kappa Coefficient (K) Producer's and User's Accuracy Validation was performed using stratified random points compared to reference data from Google Earth and field observations.

5. LULC Change Detection (2002–2024)

Change detection was conducted using **post-classification comparison**, calculating area transitions and generating change matrices between: 2002–2013-2013–2024. These change matrices were generated using TerrSet's Land Change Modeler (LCM), (Martín-Arias *et al.*, 2022) Eastman, highlighting patterns and conversion rates among land classes.

6. LULC Prediction for 2034

Terrset Land Change Modeler (LCM) and CA-Markov Chain Model were used for the simulation of 2034 LULC. Transition Potential Maps were generated using Multi-Layer Perceptron (MLP) neural networks, incorporating: Elevation, Distance to roads, Distance to rivers, Distance to settlements Slope Model Calibration used data from 2002, 2013. Prediction Year: 2034 Validation: The 2024 prediction (from 2002–2024 data) was compared against the actual 2024 classified map for model reliability. This hybrid CA-Markov and neural network approach improves simulation accuracy by incorporating both spatial dependence and transition probability (Arfasa, Owusu-Sekyere, and Doke, 2023).

3. Results and Discussions

3.1. LULC maps of the CRR of The Gambia for 2002, 2013, and 2024

A Landsat 7EMT+, 8, and 9 (OLI) satellite data were selected for conducting a LULC classification for the CRR of The Gambia as shown in the interpretation of the Maps and matrix tables below.

The maps illustrate land use changes over time (2002, 2013, and 2024) in the study region, highlighting five land cover classes represented in the legend: water bodies, grassland, settlements, croplands, and forest (see Figure 3a). Grassland remains the dominant cover type, although it has slightly decreased compared to earlier years due to the spread of croplands and settlements, a trend consistent with observations in other West African landscapes (Muller *et al.*, 2015). Forest cover has declined significantly since 2002 and now appears highly fragmented, primarily limited to patches along certain riparian zones and upland areas. .

This fragmentation reflects increased anthropogenic pressure and conversion of forests to other land uses (Hosonuma *et al.,* 2012). Croplands have expanded substantially, especially in the central and southern parts of the region, often replacing grasslands and forests. Such expansion is largely driven by population growth, rural livelihoods, and concerns about food security (Van Vliet *et al.*, 2015). Settlements have also increased noticeably by 2024, particularly in the central and eastern portions of the region, where they now form denser and more clustered patterns, indicative of urban or peri-urban expansion (Seto *et al.,* 2012). Waterbodies have remained relatively stable over the years, consistently following the course of the central river, a prominent and permanent feature in the landscape.

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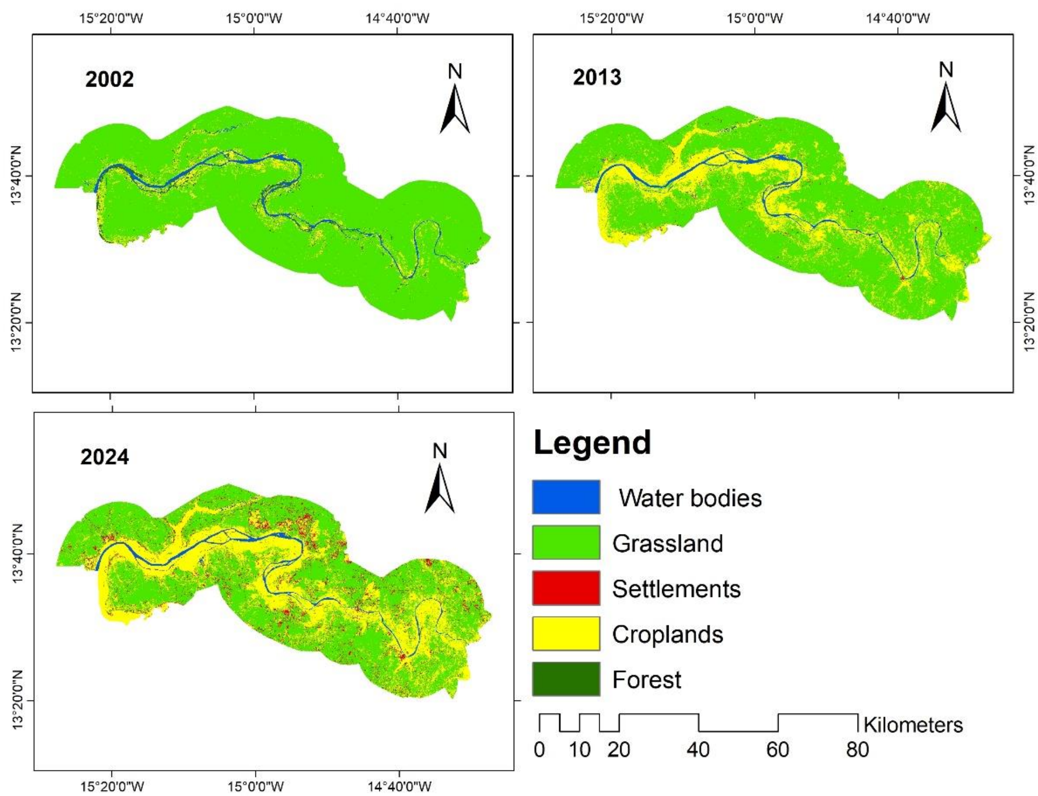

Figure 3a: Land use land cover maps of the CRR for 2002, 2013, and 2024

- **LULCC in the CRR from 2002 to 2013**

Table 3 presents the LULCC matrix for the CRR between 2002 and 2013, and the results revealed significant shifts across the five (5) major LULC classes in the research area. The croplands experienced the largest net gain (+53,698.86 ha), reflecting rapid expansion and encroachment into other land classes, especially grasslands and forest. These findings are similar to the one reported by Tarawally *et al.*, (2019). However, the forest cover saw substantial deforestation, losing (-5,881.77 ha), primarily to agriculture, and the water bodies experienced a net loss (-755.91 ha), which could be attributed to water extraction or natural changes, Similar findings have been obtained by Dampha, (2021a)The settlements expanded with a net gain of 1,611.18 ha, likely due to population growth and urbanization, but the Grasslands suffered a major net loss of 48,672.36 ha, mainly converted into agricultural land. findings are similar to the one reported by Mekonnen *et al.*, (2018).

Table 3: LULCC matrix of CRR showing the overall transition in land use classes directly from 2002 to 2013 (ha)

LULC Class	Water bodies	Grassland	Settlement	Croplands	Forest	Initial total	Gross loss	Net change
				2002-2013 CRR				
Water bodies	6874.2	397.44	12.96	669.69	0.18	7954.47	1080.27	-755.91
Grassland	216.63	212893	1484.73	49650.75	2.16	264247.1	51354.27	-48672.4
Settlements	0	80.1	32.85	20.79	0	133.74	100.89	1611.18
Croplands	97.74	1510.11	213.03	21823.11	128.1	23772.15	1949.04	53698.86
Forest	9.99	694.26	1.35	5306.67	467.1	6479.37	6012.27	-5881.77
Final total	7198.6	215575	1744.92	77471.01	597.6	302586.8		
Gross gain	324.36	2681.91	1712.07	55647.9	130.5			

- **LULCC in the CRR from 2013 to 2024**

Table 4. Land Use and Land Cover (LULC) statistics for the Central River Region (CRR) of The Gambia from 2013 to 2024:

LULC, 2013 and 2024, the CRR experienced significant changes in land use and land cover. Grassland, the dominant land cover in 2013, declined substantially by 49,724 hectares, decreasing from 215,453 ha (71.24%) to 165,729 ha (54.8%), indicating widespread land conversion. In contrast, cropland expanded markedly, increasing by 33,349 ha, from 77,433 ha (25.6%) to 110,783 ha (36.63%), reflecting intensification of agricultural activities in the region. The settlement area also saw a dramatic rise, growing from just 1,745 ha (0.58%) in 2013 to 18,632 ha (6.16%) in 2024, an increase of 16,887 ha, suggesting rapid urbanization and infrastructure development. Similar findings have been reported by (Tarawally *et al.*, (2019).

Water bodies experienced a slight reduction of 226 ha, declining from 7,198 ha (2.38%) to 6,973 ha (2.31%), which may be linked to seasonal variability or changes in hydrological patterns. Meanwhile, forest areas continued to shrink, dropping from 598 ha (0.2%) to 310 ha (0.1%), a net loss of 287 ha, reflecting ongoing deforestation pressures, Similar findings have observed by (Bah, 2019) possibly due to fuelwood harvesting or land clearing for agriculture and settlement expansion.

Overall, the data highlight a clear trend of natural land cover loss (grassland and forest) and conversion into anthropogenic uses (cropland and settlements). This transition raises concerns about biodiversity loss, soil degradation, and the need for sustainable land management in the CRR.

Table 4. Class statistics of LULC of CRR, 2013-2024

Class	**2013 (ha)**	**2024 (ha)**	**Change (ha)**	**2013 %**	**2024 %**	**Change %**
Water bodies	7198	6973	-226	2.38	2.31	-0.075
Grassland	215453	165729	-49724	71.24	54.8	-16.44
Settlement	1745	18632	16887	0.58	6.16	5.58
Cropland	77433	110783	33349	25.6	36.63	11.03
Forest	598	310	-287	0.2	0.1	-0.10

➢ **LULCC in the CRR from 2013 to 2024**

Table 5 presents the Land Use and Land Cover (LULC) transition matrix for CRR from 2013 to 2024. The table shows the proportions of land in each class in 2013 that remained the same or transitioned into other classes by 2024.

The transition matrix indicates significant land cover dynamics in the Central River Region over the 11 years. Waterbodies remained relatively stable, with 88.4% of their 2013 area persisting in 2024, while 9.0% transitioned into cropland, and 2.6% into settlements, suggesting some degree of wetland drainage or land reclamation for agriculture and urban development. Similar Findings have been reported by Dampha, (2021a).

Grassland, which initially occupied a large portion of the landscape, was notably unstable. Only 71.8% of its area remained grassland in 2024, while a substantial 22.2% converted into cropland, and 5.9% became settlements. Similar findings have been reported by Bah, (2019) This demonstrates that grasslands have been a primary source for agricultural expansion and urbanization, reflecting intense land conversion pressure.

Settlement areas were relatively persistent, with 73.5% of the 2013 settlement area still classified as such in 2024. However, 15.8% reverted or transitioned to grassland, and 10.5% to cropland, possibly indicating classification changes or expansion into surrounding vegetated areas. Similar findings have been obtained by (Tarawally *et al.*, 2019).

Cropland was the most stable class, with 79.6% of its 2013 area remaining in the same category. However, 13.8% converted into grassland, and smaller proportions into settlement and waterbodies, suggesting some rotational land use or classification variability. Similar findings have been obtained by Bessah *et al.*, (2019).

Interestingly, forest showed the least stability, with only 25.4% remaining as forest by 2024. A significant 73.7% of forested land transitioned into cropland, indicating severe deforestation, likely due to agricultural encroachment. A small portion also changed into settlement (0.8%) and grassland, highlighting the vulnerability of forest ecosystems in the region. Similar findings have been obtained by Tarawally *et al.*, (2019).

Overall, the matrix reveals a dominant trend of land transformation into cropland and settlements, with grassland and forest experiencing the highest rates of conversion. These patterns emphasize the need for targeted conservation and land management policies to protect ecologically valuable and carbon-rich land cover types like

Table 5. Transition matrix CRR from 2013-2024 in hectares (ha)

Classes	Waterbodies	Grassland	Settlement	Cropland	Forest
Waterbodies	0.883924	0.000025	0.025743	0.090308	0.000000
Grassland	0.000773	0.718164	0.058855	0.222184	0.000023
Settlement	0.002012	0.158017	0.734988	0.104674	0.000310
Cropland	0.005677	0.138475	0.057843	0.796030	0.001976
Forest	0.000452	0.000000	0.008283	0.737349	0.253916

- **Summary Statistics of LULC maps of the CRR of The Gambia for 2002, 2013,and 2024**

Water Bodies PA declined from 82.4% (2002) to 78.6% (2024). UA trend was maintained a perfect 100% across all years. While the user's accuracy indicates that all identified water bodies were correctly classified, the declining producer's accuracy suggests the underestimation or misclassification of some water bodies, especially in 2013 and 2024. The fluctuations may reflect dynamic water levels or difficulties in distinguishing water bodies during certain years. Similar results have been obtained by Dampha, (2021a).

The Grassland PA trend remained high throughout, fluctuating slightly from 99.8% (2002) to 98.4% (2024). User Accuracy trend: Improved over time, rising from 96.6% (2013) to 98.1% (2024). The Grassland was consistently well-identified, with only minor classification errors. The improvement in UA reflects fewer cases of other land covers (like croplands) being misidentified as grasslands. The Settlements PA trend: Recovered from 84.9% (2013) to 100%, and 2024). Similar findings have been reported by (Bah, 2019). UA trend: Also improved, achieving 100% since 2013. Settlements initially faced some under classification in 2013, but subsequent maps corrected these issues, onward.

This suggests better detection and mapping of urban areas, possibly due to improved satellite imagery or classification methods. Croplands PA trend declined slightly from 100% (2002) and improved to 97.4% (2024). User Accuracy trend improved steadily from 94.4% (2002), before stabilizing at 95.5% (2024). Similar results have been obtained by Bah, (2019).

The classification of croplands has become more reliable, despite minor fluctuations. The Forest Producer Accuracy trend: Maintained perfect 100% accuracy across all years. UA trend: Dropped from 88.2% (2002) to 77.8% (2013 and 2024) recovered to 100%. Similar findings have been reported by Tarawally *et al.*, (2019)

The Forest areas were correctly identified (high PA), but earlier years (2013,) saw misclassification errors, with non-forest areas being labeled as forest (low UA). The 2024 recovery in UA suggests improved methods in distinguishing forests from other land covers, likely due to better spectral resolution or refined classification algorithms. Overall Accuracy and Kappa Statistics Overall accuracy: 2002: 99.3% 2013: 97.9% 2024: 97.5% Kappa statistics: 2002: 0.96 2013: 0.95 2024: 0.94 Similar results have been reported by Dampha, (2021b), who reported his kappa statistics were 0.63 and bush grassland was 86%, respectively. Its producer accuracy was from 1985 to 2020, where it had the highest Producer's Accuracy (91%). Therefore, he was confident about the reliability of his classified map in terms of its ability to distinguish urban settlements from areas with green spaces.

Table 6: Summary of the classification accuracy for the CRR LULC maps

LULC Class	2002		2013		2024	
(%)	PA	UA	PA	UA	PA	UA
Water bodies	82.4	100	74.7	100	78.6	100
Grassland	99.8	100	99.8	96.6	98.4	98.1
Settlements	100	95.4	84.9	100	100	100
Croplands	100	94.4	93.1	98.4	97.4	95.5
Forest	100	88.2	100	77.8	100	100
Overall accuracy	99.3		97.1		97.5	
Kappa	0.96		0.93		0.94	

3.2. LULC maps of the URR of The Gambia for 2002, 2013, and 2024

Description

In 2024, the region displayed significant landscape transformation (see Figure 4b). Croplands emerged as the dominant land use, expanding extensively across the central and eastern parts. This substantial growth compared to 2002 and 2013 indicates large-scale agricultural development, driven by population growth and the need for increased food production (Van Vliet *et al.*, 2015; FAO, 2021). Grasslands were still present, especially in areas less suited to cultivation, but have declined significantly from their original dominance in 2002. In many locations, grasslands have transitioned into croplands or settlements, a trend also documented in similar semi-arid regions (Gibbs *et al.*, 2010).

Settlements became widespread in 2024, often concentrated near water bodies and along major routes such as rivers and roads. Their expansion since 2002 reflects rapid urban growth and demographic shifts (Seto *et al.*, 2012). Forests**,** once part of the landscape in 2002, had almost completely disappeared by 2013 and were not visibly present in 2024. This points to severe deforestation, likely due to land conversion for agriculture and settlement, a pattern seen in many developing countries (Hosonuma *et al.*, 2012). Water bodies**,** primarily rivers, remained relatively consistent in extent across all years. Although limited in spatial coverage, they continue to play a crucial role in guiding settlement patterns and agricultural activities. From 2002 to 2024, the landscape has undergone a profound transition from natural vegetation, grasslands and forests, to human-dominated land uses such as croplands and settlements. Urbanization and agricultural intensification have been the primary drivers of this change, contributing to environmental degradation, including deforestation, habitat loss, and biodiversity decline (Foley *et al.*, 2005; IPCC, 2022).

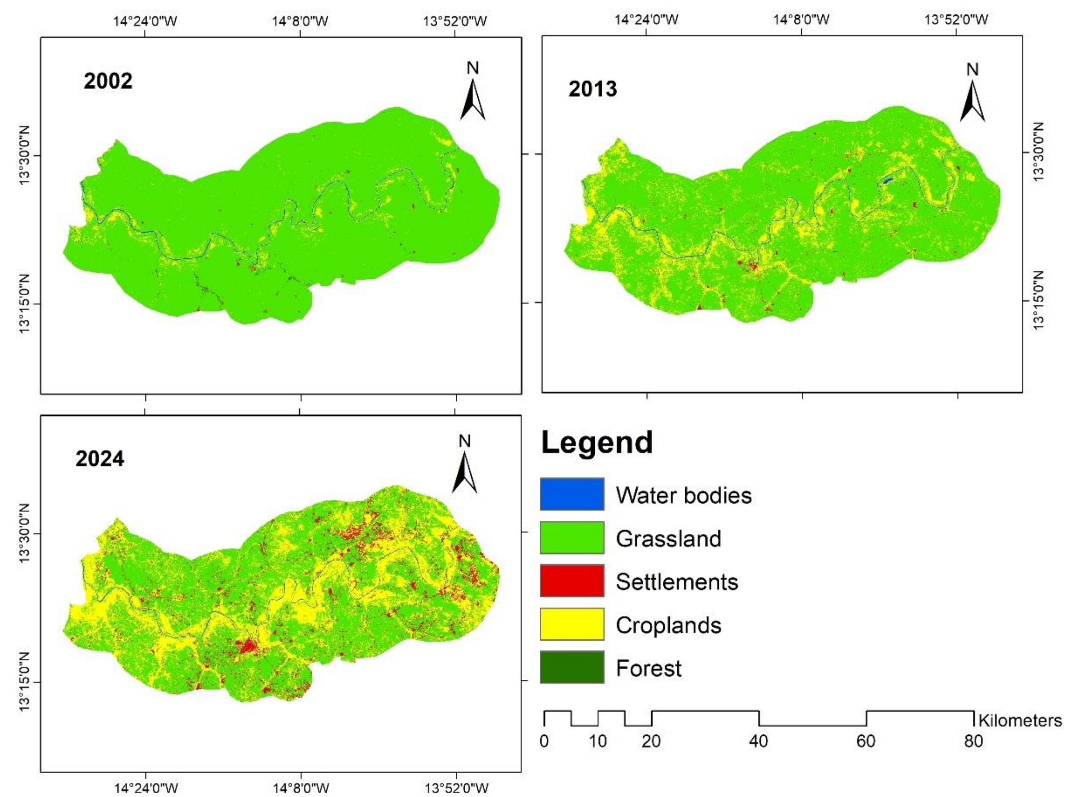

Figure 4b: LULC maps of the URR for 2002, 2013, and 2024

3.3 LULCC in the URR from 2002 to 2013

Table 6 shows that Grassland and forests experienced the largest losses, with much of the grassland converted to cropland with settlements. Croplands saw the most significant increase, a net gain of 29,048.13 ha, reflecting the growing importance of farming in the region. Similar results have been obtained by Dampha, (2021a).

The Settlements expanded by 1,447.29 ha, signifying increased urbanization and human presence. A similar finding has been obtained by Water bodies that underwent a moderate decline of 97.92 ha, possibly due to encroachment and climatic factors affecting water availability.

From 2002 to 2013, the URR experienced major land use transformations, with grassland and forests converted primarily into croplands and settlements. The loss of grassland (29,895.93 ha) highlights the growing pressure on natural ecosystems due to agricultural expansion. Similar results have been obtained by (Tarawally *et al.*, 2019). Additionally, the decline in forest cover raises concerns about environmental sustainability. These changes reflect the region's shifting focus toward crop and development, underscoring the need for land-use planning to balance growth with ecosystem conservation. (See figure 4).

Table 7: LULCC matrix of the URR showing the overall transition in LULC classes directly from 2002 to 2013 (ha)

LULC Class	Water bodies	Grassland	Settlements	Croplands	Forest	Initial total	Gross loss	Net change
				2002-2013 URR				
Water bodies	1431.9	151.74	0	83.7	0	1667.34	235.44	-97.92
Grassland	54.36	165952.44	1374.03	29214.54	90.45	196685.82	30733.38	-29895.9
Settlements	0	47.79	363.42	26.1	0.09	437.4	73.98	1447.29
Croplands	82.17	572.94	145.35	7166.07	161.64	8128.17	962.1	29048.13
Forest	0.99	64.98	1.89	685.89	99	852.75	753.75	-501.57
Final total	1569.42	166789.89	1884.69	37176.3	351.18	207771.48		
Gross gain	137.52	837.45	1521.27	30010.23	252.18			

3.4 LULCC in the URR from 2013- 2024

Between 2013 and 2024, the Upper River Region (URR) underwent significant land use changes, primarily characterized by the reduction of natural vegetation and the expansion of anthropogenic land uses. Grassland, which was the dominant land cover in 2013 at 166,596.75 hectares (80.27%), experienced a substantial decline of 49,833.81 hectares, reducing to 116,762.94 hectares (56.26%) in 2024. Similar results have been obtained by (Tarawally *et al.*, 2019). This represents a significant 24.01% decrease, highlighting the scale of land conversion.

In contrast, cropland expanded dramatically over the same period, increasing by 37,638.72 hectares, from 37,155.96 hectares (17.90%) in 2013 to 74,794.68 hectares (36.04%) in 2024. This sharp increase of 18.13 percentage points reflects intensifying agricultural activity, likely driven by growing food demands and rural livelihood pressures. Similar findings have been recorded by Bah, (2019)

Settlement areas also grew substantially, rising from 1,882.35 hectares (0.91%) in 2013 to 14,526.36 hectares (7.00%) in 2024, an increase of 12,644.01 hectares. This 6.09% increase indicates rapid urbanization and infrastructure development in URR over the period. Similar findings have been recorded by Thenkabail, (2015).

Meanwhile, water bodies decreased slightly by 225.54 hectares, falling from 1,569.24 ha (0.76%) to 1,343.70 ha (0.65%), likely due to hydrological shifts or encroachment. The most concerning change is observed in forest areas, which dropped from 351.18 hectares (0.17%) to 127.80 hectares (0.06%), a loss of 223.38 hectares. This 0.11% decrease, though minuscule in percentage terms, indicates continued pressure on already limited forest resources. Similar Results have been obtained by Dampha, (2021a)

The LULC trends in URR reveal a strong shift from natural vegetation, especially grassland and forest, toward cropland and settlements. These changes suggest increasing land use intensity, potentially at the expense of ecosystem services, biodiversity, and carbon storage. The findings underscore the urgent need for integrated land management strategies to balance development with ecological sustainability. (see table 7).

Table 8. Class statistics of LULC of URR 2013 to 2024

Class Statistics		URR				
Class	2013 (ha)	2024 (ha)	Change (ha)	2013 (%)	2024 (%)	Change (%)
Water bodies	1569.24	1343.7	-225.54	0.76	0.65	-0.11
Grassland	166596.75	116762.94	-49833.81	80.27	56.26	-24.01
Settlement	1882.35	14526.36	12644.01	0.91	7.00	6.09
Cropland	37155.96	74794.68	37638.72	17.90	36.04	18.13
Forest	351.18	127.8	-223.38	0.17	0.06	-0.11

Water bodies remained relatively stable, with 72.2% of their 2013 area (about 1,133.6 ha) remaining unchanged. However, 27.4% (about 429.1 ha) shifted to cropland, and a small fraction (0.4% or 6.2 ha) became settlement, suggesting water areas were converted primarily for agricultural use. Similar results have been obtained by (Bessah *et al.*, 2019)

Grassland, which had the largest area in 2013, showed considerable transition. While 65.6% (about 109,359.9 ha) remained grassland in 2024, 27.9% (roughly 46,462.2 ha) converted into cropland—a major transformation. About 10,653.6 ha transitioned into settlement, indicating grasslands are the primary source for both agriculture and urban expansion. Similar results have been obtained by Bah, (2019)

Settlements were quite stable, with 77.5% (about 1,459.3 ha) persisting, while 12.3% (about 230.9 ha) reverted to grassland and 10.3% (approximately 193.3 ha) transitioned to cropland. This may indicate some reclassification or expansion into adjacent land types. Similar results obtained by Tarawally *et al.*, (2019)

Cropland was also stable, with 73.7% (about 27,390.4 ha) remaining cropland. Notably, 19.3% (approximately 7,169.7 ha) of cropland in 2013 transitioned to grassland, and about 2,383 ha were lost to settlement. Interestingly, 2.3% (835.0 ha) turned into forest, suggesting some reforestation or classification change. Similar findings have been observed by Dampha, (2021a)

Forest had the highest instability: only 10.6% (about 37.1 ha) remained forest in 2024. A dominant 88.1% (around 309.4 ha) of forest transitioned to cropland, indicating extensive deforestation. Small proportions also changed to grassland (4.2 ha) and settlement (0.4 ha). Similar findings have been observed by Ummah, (2019).

The transition matrix clearly shows that the dominant trend in URR is the conversion of grassland and forest into cropland and settlements. The largest single transition is grassland to cropland, contributing over 46,000 hectares to cropland expansion. Similar findings have been reported by (Bah, 2019). Forest areas were almost entirely lost to agriculture, with only 10.6% remaining. These patterns raise serious concerns about ecological degradation, loss of biodiversity, and diminishing carbon sinks and point to the need for sustainable land use policies. (see table 9)

Table 9. Transition matrix LULC 2013 to 2024 for URR in hectares (ha)

Class	2013-2024 Water bodies	Transition Matrix Grassland	Settlement	Cropland	Forest
Water bodies	0.722299	0	0.003957	0.273572	0.000172
Grassland	0.00057	0.656405	0.063989	0.278995	0.000041
Settlement	0	0.122639	0.774803	0.102558	0
Cropland	0.0031	0.193049	0.06462	0.736981	0.0225
Forest	0	0.012045	0.001025	0.881343	0.105587

3.5 Summary Statistics of LULC maps of the URR of The Gambia for 2002, 2013, 2022, and 2024

Table 9 show that the classification accuracy for water bodies was initially inconsistent in 2013 but improved significantly, achieving perfect classification by 2024. This suggests better identification of water features in recent years, possibly due to advancements in data resolution or improved mapping techniques. Grasslands Producer Accuracy: Slight fluctuations, peaking at 99.9% in 2013 and dropping to 98.4% in 2024. User Accuracy: Improved steadily from 96.6% (2013) to 99.1% (2024). The Grassland was generally well-classified, although the producer's accuracy slightly declined by 2024. However, improvements in user accuracy indicate greater reliability of grasslands classification in recent years, minimizing misclassification with other land cover types. Settlements Producer Accuracy and User Accuracy: Consistently 100% across all years. Similar findings have been obtained by Dampha, (2021a)

The classification of settlements remained perfect throughout the entire period, reflecting the precise mapping of built-up areas. This suggests that settlements are easily distinguishable from other land cover types, likely due to clear visual contrasts. Croplands PA: Varied across the years, improving from 93.2% (2013) to 97.4% (2024). UA: Increased from 94.7% (2002) to 99.1% (2022) but decreased slightly to 95.5% (2024). Similar results have been observed by (Tarawally *et al.*, 2019). Although croplands were consistently well-classified, some minor fluctuations in accuracy reflect the challenge of differentiating these areas from similar land cover types, such as forest or grassland. The Forest PA: Remained 100% throughout all years, reflecting perfect detection of forested areas. UA: Experienced fluctuations, declining to 77.8% in 2013 but recovering to 100% by 2024. Similar results have been observed by Bah, (2019) While the user's accuracy for forests declined in 2013 and 2022, improvements by 2024 indicate a more reliable classification. This fluctuation suggests possible confusion between forested areas and croplands during certain periods. The Overall Accuracy and Kappa Coefficient Overall accuracy: Peaked at 99.5% in 2002 but decreased slightly to 98.2% by 2024. Kappa coefficient: Remained high, ranging from 0.94 to 0.98, indicating a strong agreement between the classification and ground truth data across all years. Similar results have been obtained by (Martín-Arias *et al.*, 2022)

The overall accuracy shows minor variations across the years, maintaining high values above 97%, reflecting the classification process's general reliability. The Kappa coefficient demonstrates that the land cover classifications were highly consistent, with only minimal misclassifications over time.

The classification of land cover types in the URR has been consistently accurate, with overall accuracy above 97% and Kappa values near 1 across all years. While water bodies, settlements, and forests have achieved near-perfect classification by 2024, similar results have been reported by Mekonnen *et al.* (2018) croplands and grasslands experienced some variations in accuracy, reflecting the inherent challenges of distinguishing between natural and human-influenced landscapes. The improvements in classification accuracy over time suggest enhancements in mapping techniques and data quality, contributing to better land cover monitoring and management.

Table 10: Summary of the classification accuracy for the URR LULC maps

LULC Class	2002		2013		2024	
Unit (%)	PA	UA	PA	UA	PA	UA
Water bodies	92.7	100	74.8	100	100	100
Grassland	99.7	100	99.9	96.6	98.4	99.1
Settlements	100	100	100	100	100	100
Croplands	100	94.7	93.2	98.8	97.4	95.5
Forest	100	100	100	77.8	100	100
Overall accuracy	99.5		97.3		98.2	
Kappa	0.98		0.94		0.96	

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3.6 LULCC matrix of the Prediction CRR and URR showing the overall transition in land use classes directly from 2024 to 2034 (Hectares)

3.7 LULCC in the CRR from 2024 to 2034

Water bodies and forest areas will experience further decline, though water bodies will shrink more slowly than in previous years. Grasslands will see the largest net loss (37,211.85 ha), continuing its transformation into agriculture and settlements. The Settlements will expand substantially, with a forecasted increase of 5,379.57 ha, driven primarily by the conversion of grasslands. Cropland is projected to increase by 32,090.13 ha, reinforcing agriculture as a dominant land use in the region. Forest cover will face significant losses, with over 50% of the existing forest expected to disappear by 2034. (Martín-Arias *et al.*, 2022)

The predicted LULCC from 2024 to 2034 indicate a continuation of urbanization and agricultural expansion at the expense of natural ecosystems such as grasslands and forests. Agriculture will remain the primary driver of land transformation, with grasslands areas being the most affected. The decline in forest cover raises concerns about environmental sustainability and biodiversity loss, while the shrinking of water bodies highlights potential water resource challenges. These trends suggest a need for integrated land-use planning to balance development and conservation efforts in the coming decade. (see table 10).

Table 11. Prediction LULCC matrix of CRR showing the overall transition in land use classes directly from 2024 to 2034 (Hectares)

LULC Class	Water bodies	Grassland	Settlements	Croplands	Forest	Initial total	Gross loss	Net change
			2024-2034 CRR					
Water bodies	6662.43	0.27	0	315.18	0	6977.88	315.45	-90.72

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Grassland	0.72	128310.66	5407.83	32067.18	0	165786.4	37475.7	-37211.8
Settlements	0	24.48	18597.96	16.47	0	18638.91	40.95	5379.57
Croplands	224.01	239.13	12.69	110368.17	28.89	110872.89	504.72	32090.13
Forest	0	0	0	196.02	114.75	310.77	196.02	-167.13
Final total	6887.16	128574.54	24018.48	142963.02	143.64	302586.84		
Gross gain	224.73	263.88	5420.52	32594.85	28.89			

3.8 LULCC in the URR from 2024 to 2034

This table provides a forecast of LULCC in the URR between 2024 and 2034, showing the transitions between five (5) LULC classes: water bodies, grasslands, settlements, cropland, and forest. It details the initial total area of each class, the amount of gross loss, and the net change over the prediction period. Water bodies are predicted to grow slightly, adding 219 ha, despite some minor conversions (2.43 ha) to cropland. This suggests an expansion of water features, potentially from increased rainfall, improved water management, or flooding. Grassland will experience significant losses, primarily to settlements (6,247.26 ha) and croplands (14,176.53 ha). Shows changes in land use and land cover distribution. Similar results have been obtained by (Martín-Arias *et al.*, 2022)

Settlements are projected to expand substantially, gaining 6,266 ha, primarily from grasslands and croplands. This reflects ongoing urbanization and population growth. The minimal loss of 17 ha indicates that once areas are developed, they are unlikely to revert to other land cover types.

Croplands will expand significantly, gaining over 14,286 ha, mostly from grassland areas. This highlights the growing pressure for agricultural production, likely due to increased food demands or agricultural intensification. However, small areas are expected to transition to other land covers, including water bodies (221 ha), suggesting land-use diversification. Forest cover will continue to decline, with almost 80% of the existing forest area projected to be converted into agricultural land.

Only 2.88 ha are expected to regenerate as forest, underscoring the challenge of forest conservation amid agricultural expansion.

Highest Gains: Croplands (+14,286 ha) and settlements (+6,266 ha). Highest Losses: Grassland (-19,931 ha) and forest (-100 ha). The data suggests that cropland expansion and urbanization will dominate land-use trends over the next decade. While some minor gains are predicted for water bodies, forest cover continues to shrink, highlighting the region's vulnerability to deforestation. The loss of the grassland also reflects a shift towards more intensive land use. Similar findings have been obtained by (Martín-Arias *et al.*, 2022).

The URR is predicted to undergo significant land cover transformation between 2024 and 2034, driven primarily by agricultural expansion and urban development. While settlements and croplands are expected to grow, this comes at the cost of grassland ecosystems and forest areas, potentially leading to ecological degradation. If these trends continue, sustainable land management practices will be necessary to balance development with environmental conservation. (See figure 5 and table 12)

Table 12: Prediction LULCC matrix of URR showing the overall transition in land use classes directly from 2024 to 2034 (Hectares)

LULC Class	Water bodies	Grassland	Settlement	Croplands	Forest	Initial total	Gross loss	Net change
				2024-2034 URR				
Water bodies	1343.07	0	0	2.43	0	1345.5	2.43	218.97
Grassland	0.18	96491.97	6247.26	14176.53	0	116915.9	20423.97	-19930.9
Settlements	0	12.33	14514.48	4.68	0	14531.49	17.01	6249.15
Croplands	221.22	480.69	18.9	74127.06	2.88	74850.75	723.69	13562.91
Forest	0	0	0	102.96	24.84	127.8	102.96	-100.08
Final total	1564.47	96984.99	20780.64	88413.66	27.72	207771.4		
Gross gain	221.4	493.02	6266.16	14286.6	2.88			

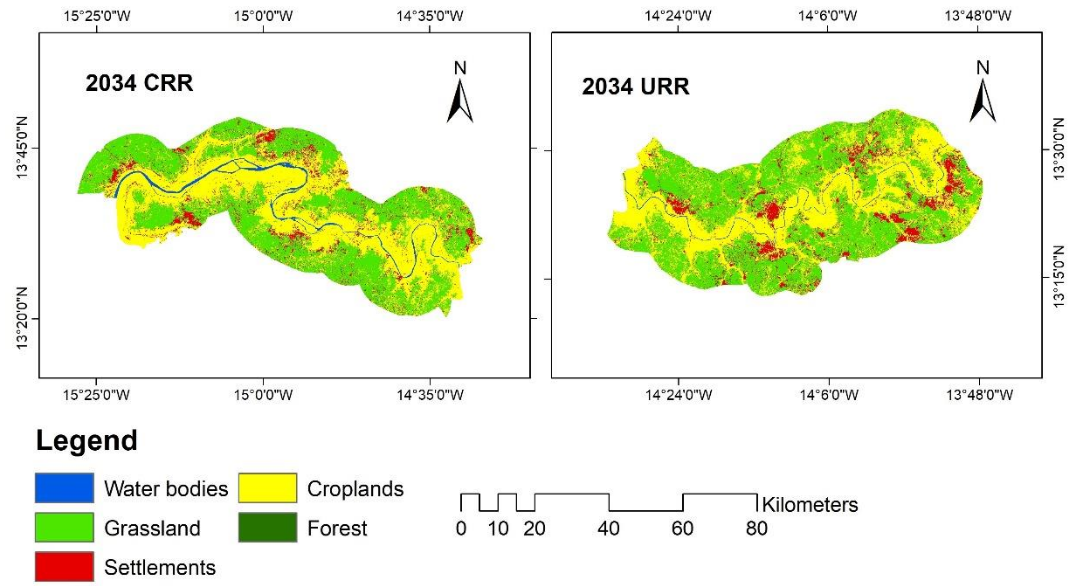

Figure 5c: Predicted Land use land cover maps of the CRR and URR

3.9 Conclusion

The land use and land cover (LULC) change matrix for the CRR between 2024 and 2034 reveals significant shifts in land classes. Croplands experienced the highest net gain of 32,090.13 hectares, primarily from conversions from grasslands and other land use types. Settlements also expanded, gaining 5,379.57 hectares. Conversely, grasslands saw the largest net loss of 37,211.85 hectares, indicating substantial transformation into agricultural land and settlements. Water bodies and forests both experienced slight reductions, with net losses of 90.72 and 167.13 hectares, respectively. These trends highlight increased human activities, particularly agricultural expansion and urbanization, leading to notable landscape transitions over the decade.

The LULCC matrix for the URR from 2024 to 2034 highlights significant land-use transformations. Croplands show the largest net gain of 13,562.91 hectares, driven by conversions from grasslands and other land classes. Settlements also expanded, with a net increase of 6,249.15 hectares. In contrast, the grasslands experienced the most substantial net loss, decreasing by 19,930.95 hectares, reflecting encroachment by agriculture and settlements. Water bodies saw a slight gain of 218.97 hectares, while forests declined marginally, losing 100.08 hectares. These trends indicate growing agricultural activities and urbanization at the expense of natural landscapes.

ACKNOWLEDGEMENTS

This study is supported by a grant from the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) Programme on Climate Change and Land Use, funded by the German Federal Ministry for Education and Research (BMBF). I owe a lot of gratitude to all who have contributed to this Research.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author, Baba Drammeh, upon reasonable request. The Land Use Land Cover (LULC) datasets analyzed in this article were derived from satellite imagery and secondary sources, including Landsat archives and national geospatial datasets. Processed classification outputs and maps generated during the study are available from the author and can be shared for academic and non-commercial purposes.

Declaration of Competing Interests

The author, Baba Drammeh, states that there are no known financial or personal interests that could have influenced the work reported in this article.

Funding Declaration

The author, Baba Drammeh, states that no funding was received for the research, authorship, or publication of this article.

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