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Spatio Temporal Assessment of Goronyo Dam in Sokoto State

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ABSTRACT

Sedimentation, water quality, and allocation problems persist, with the reservoir at 10% capacity, threatening livelihoods/ecosystems and demanding spatio-temporal monitoring. The research methodology adopted for this study are Landsat7 ETM satellite image of 2003 and the Landsat8 OLI satellite images of 2013 and 2023, captured during the dry and wet seasons to show changes that took place. The results show that In 2003, during the dry season (Figure 2 and Table 6), Water bodies covered 721.32 km^2, Built-up areas accounted for 70.21 km^2 (0.80%), Vegetation spanned 562.09 km^2 (6.42%), Agricultural land covered 717.01 km^2 (8.18%), and Bare land dominated with 6,689.58 km^2 (76.36%). The research concludes that the LULC changes in Goronyo reflect broader environmental and socio-economic challenges, highlighting the need for integrated, adaptive management to ensure the sustainability of the dam and its surrounding landscape. The study recommends that Climate Change Adaptation: Assessing and planning for climate change impacts on rainfall and hydrology will be vital for long-term water resource and land use planning.

Keywords: spatio; temporal; goronyo; dam; Sokoto; monitoring

INTRODUCTION

Dams and reservoirs worldwide, particularly in arid and drought-prone regions, supply water for domestic, industrial, agricultural, transportation, fishing, and hydropower needs (Barbosa, 2022; Połomski & Wiatkowski, 2023; Wendt et al., 2021; Tuncok & Eslamian, 2017). Critical for livelihoods and development, examples span China's and Brazil's hydropower giants, U.S. projects, and Kenya's sand dams, enhancing surface water, food production, energy, and flood control in developing areas. Sustainability, however, is undermined by seasonal variability, climate change, and anthropogenic pressures, causing water body fluctuations in volume and extent (Şen, 2021; Pokhrel et al., 2018; Ho et al., 2017; Hogeboom et al., 2018; Zhang & Shang, 2023). Sahel, Middle Draa Valley, and Mekong Basin regions rely on dams for drought relief yet face erratic rainfall, upstream issues, and disputes; adaptive measures like sand dams and cooperation are essential amid extreme weather (Lazurko et al., 2024; Yifru et al., 2021).

On Nigeria's Rima River in Sokoto State, Goronyo Dam enables irrigation, flood control, and year-round farming by storing wet-season water, transforming agriculture, supporting livestock /fisheries, and curbing floods for food security (Ogilvie et al., 2020; Wulde et al., 2022; Eduvie & Oseke, 2021). Sedimentation, water quality, and allocation problems persist, with the reservoir at 10% capacity, threatening livelihoods/ecosystems and demanding spatio-temporal monitoring (Sogno et al., 2022; Adjovu et al., 2023; Chen et al., 2022; Huang et al., 2018; Raji et al., 2024; Martin & Francis, 2022).

STUDY AREA

The Goronyo Reservoir is located between latitudes 13°30′N and 14°00′N and longitudes 5°30′E and 6°00′E, approximately 5 km east of Goronyo town and 90 km from Sokoto city. It extends 20 km in length and 10 km in width, encompassing nearly 200 km^2, with a storage capacity of 942 million cubic meters and irrigation potential for 81,000 hectares.

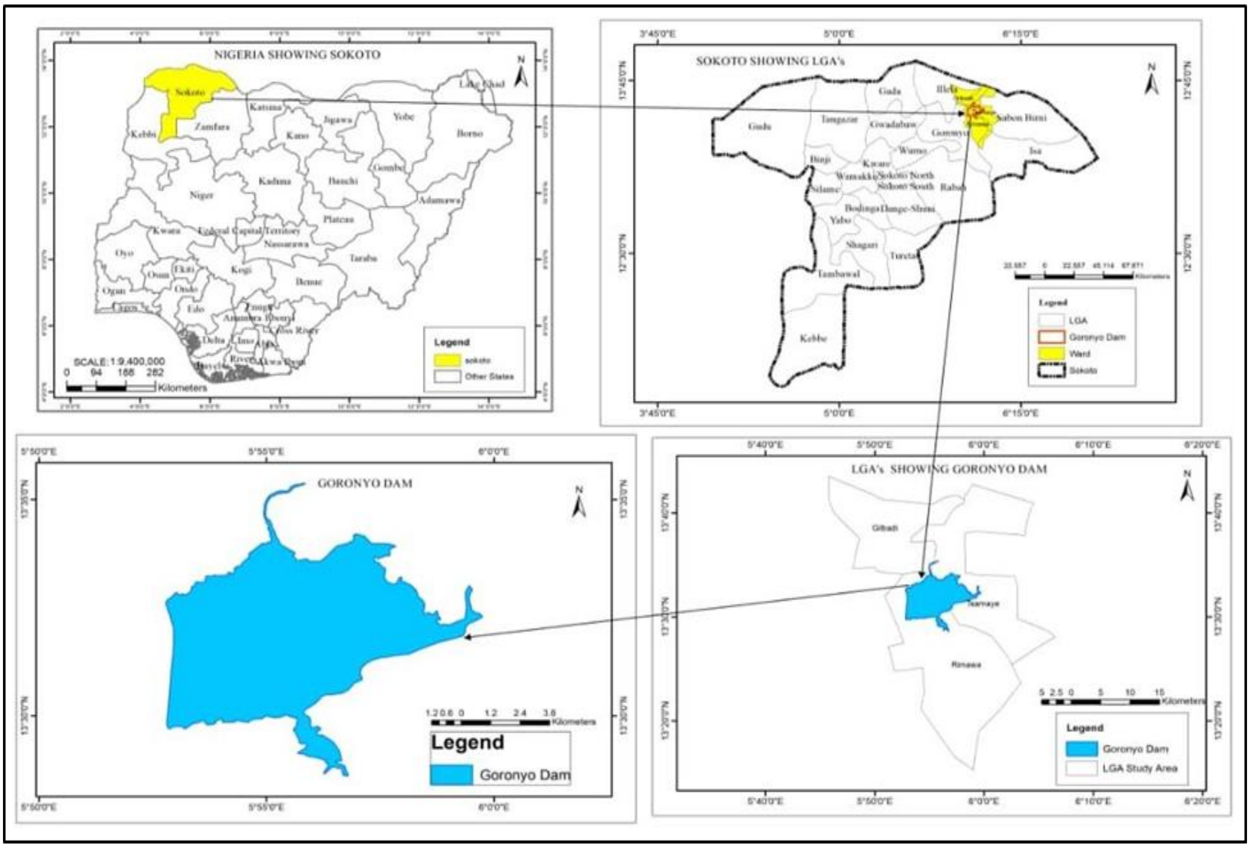

FIGURE 1: Study Area Map.

TABLE 1: Features of Main Dam.

Parameter	Value
Length	5,285m
Crest elevation	294.00m
Crest width	8.50m
Maximum height above ground	20.00m
Total fill	$4.45\times10^6 m^3$

Source: Author's Analysis, 2024.

TABLE 2: Features of Secondary Dam.

Parameter	Value
Length	1,792m
Crest elevation	294.00m
Crest width	8.50m
Maximum Height above ground	12.00m
Total fill	$0.5\times10^6 m^3$

Source: Author's Analysis, 2024.

TABLE 3: Features of the Saddle Dyke.

Parameter	Value
Length	5,385m
Safety spillway length	2,000m
Crest elevation(non-overflow section)	290.50m
Overflow section	9.00m
Maximum Height above ground	9.00m
Total fill	$0.35\times10^6 m^3$

Source: Author's Analysis, 2024.

RESEARCH METHODOLOGY

Data types and sources

The data used for this research work are Landsat7 ETM satellite image of 2003 and Landsat8 OLI satellite images of 2013 and 2023, captured during the dry and wet seasons to show changes that took place.

TABLE 4: Satellite imageries downloaded from the United States Geological Survey (USGS).

Landsat 7 ETM+	Wavelength (M)	Resolution (M)	Landsat 8 (OLI)	Wavelength (M)	Resolution (M)
Band 2	0.52-0.60	30	Band 3 (Green)	0.53 - 0.59	30
Band 5	1.55-1.75	30	Band 6 (SWIR)	1.57 - 1.65	30

Source: Author's Analysis, 2024.

Data Processing

- ***Image Pre-processing***

This study utilizes Landsat 7 ETM+ imagery from 2003 and Landsat 8 OLI images from 2013 and 2023. All satellite images were pre-processed by the U.S. Geological Survey (USGS) to Level 1G, ensuring correction for radiometric and geometric distortions. Each image incorporates all available spectral bands at a spatial resolution of 30 meters. These bands were layer-stacked to create composite images of the study area, facilitating land use/land cover classification and image analysis for 2023. For surface water extraction across the study periods, the green (bands 2 and 3) and shortwave infrared (SWIR; bands 5 and 6) bands from both Landsat 7 ETM+ and Landsat 8 OLI were employed.

- ***Supervised image classification***

To accurately determine the land use and land cover (LULC) in the study area for 2003, 2013 and 2023, a land cover classification was performed. Following the selection of representative training sites, supervised classification was conducted using the Maximum Likelihood algorithm on the Landsat imagery, specifically utilizing bands 2 and 3 (green) alongside bands 5 and 6 (shortwave infrared, SWIR). Additionally, visual image interpretation was carried out, supported by field observations and cross-referenced with high-resolution imagery from Google Earth to enhance classification accuracy.

- ***Modified Normalized Difference Water Index (MNDWI)***

The surface water extraction will be computed using the modified normalized difference water index (MNDWI), which uses the GREEN and SWIR for the enhancement of open water features. MNDWI = (GREEN − SWIR)/ (GREEN + SWIR) Where: GREEN = pixel values from the green band SWIR = Pixel values from the short-wave infrared band

- ***The Magnitude of Change from (2003 to 2023)***

The rate of change that took place over the study period will be achieved using the formula C = B – A

Where:

C = The magnitude of change B = Base year

A = Reference year

Percentage of changes (E)

$$= \frac{C}{Base\ year * 100}$$

Annual rate of change (D)

$$= \frac{C}{Number\ of\ years\ between\ the\ period}$$

Where:

C = magnitude of change of each urban land use divided by the number of years between the periods, i.e., 3 years for 2003 and 2013, and 3 years for 2013 and 2023, 2003-2023 for 6 years.

To detect the changes in the land use/cover at different years, post-classification comparison of the change detection techniques was used.

Data Analysis

- ***The LULC Distribution of the Area within the Period of 2003, 2013, 2023***

Landsat imagery for both the dry and wet seasons of each study year was classified using the supervised Maximum Likelihood classification technique. The resulting land cover maps were categorized into five classes: Water, Built-up, Vegetation, Agricultural Land, and Bare Land. The area and percentage of each class were calculated, and seasonal changes in land cover were systematically analyzed to assess temporal dynamics within the study area.

- ***The Areal Extent of the Dam in 2003, 2013, 2023***

The surface water dynamics of the Goronyo Dam reservoir were analysed for dry and wet seasons in 2003, 2013, and 2024 using the Modified Normalized Difference Water Index (MNDWI) applied to Landsat imagery. The spatial extent of surface water for each seasonal interval was quantified using the geometry calculation tool within the field calculator. Areal fluctuations between seasons and years were computed, and percentage changes were derived from these spatial metrics using the methodological framework outlined in Section 3.2.4 to evaluate temporal variations in reservoir extent. Results were synthesized through comparative tabular summaries and visualized via time-series line graphs to illustrate interannual and seasonal patterns in water surface dynamics.

- ***Effect of LULC changes on the areal extent of the Dam***

To examine the impact of land use/land cover (LULC) classes on the spatial extent of the dam, GIS-based overlay analysis and spatial intersection techniques were employed. For each study year, seasonal LULC raster datasets were systematically overlaid using the raster calculator tool to identify areas of intersection between the dam's extent and adjacent LULC classes.

This process generated new raster outputs highlighting zones where LULC changes encroached upon or influenced the dam's boundaries. The analysis was repeated across all temporal intervals, culminating in a series of time-series maps that visually delineated the evolving spatial relationships between LULC dynamics and the dam's footprint.

RESULTS PRESENTATION AND DISCUSSIONS

- ***Land Use Land Cover Distribution of Goronyo in 2003, 2013, and 2023***

The land use and land cover (LULC) classification of Goronyo for the years 2003, 2013, and 2023 was categorized into five major classes: Water bodies, Built-up areas, Vegetation, Agricultural land, and Bare land. Classification was performed separately for the two main seasons-dry and wet-of each year using the Maximum Likelihood method in QGIS 3.32. The area of each class was calculated in square kilometers, and the results were visualized. Additionally, the rate of LULC change over time.

Land Use Land Cover (LULC) Distribution of Goronyo in 2003

TABLE 5: LULC in Goronyo 2003.

CLASS	2003 - dry		2003 - wet		Area Change (km²)	Percentage Change (%)
	Area (km²)	%	Area (km²)	%		
Water-Body	721.32	8.23%	1,055.49	12.05%	334.17	46.3%
Built-Up	70.21	0.80%	71.08	0.81%	0.87	1.2%
Agric land	562.09	6.42%	1,106.13	12.63%	544.04	96.8%
Vegetation	717.01	8.18%	1,395.06	15.93%	678.06	94.6%
Bare Land	6,689.58	76.36%	5,132.44	58.59%	-1,557.14	-23.3%
TOTAL	8760.2	100%	8760.2	100%		

Source: Author's Analysis (2024).

In 2003, during the dry season (Figure 2 and Table 5), Water bodies covered 721.32 km^2, Built-up areas accounted for 70.21 km^2 (0.80%), Vegetation spanned 562.09 km^2 (6.42%), Agricultural land covered 717.01 km^2 (8.18%), and Bare land dominated with 6,689.58 km^2 (76.36%). In the wet season of the same year (Figure 3 and Table 5), Water bodies expanded to 1,055.49 km^2 (12.05%), Built-up areas slightly increased to 71.08 km^2 (0.81%), Agricultural land grew to 1,106.13 km^2 (12.63%), Vegetation increased to 1,395.06 km^2 (15.93%), while Bare land decreased to 5,132.44 km^2 (58.59%).

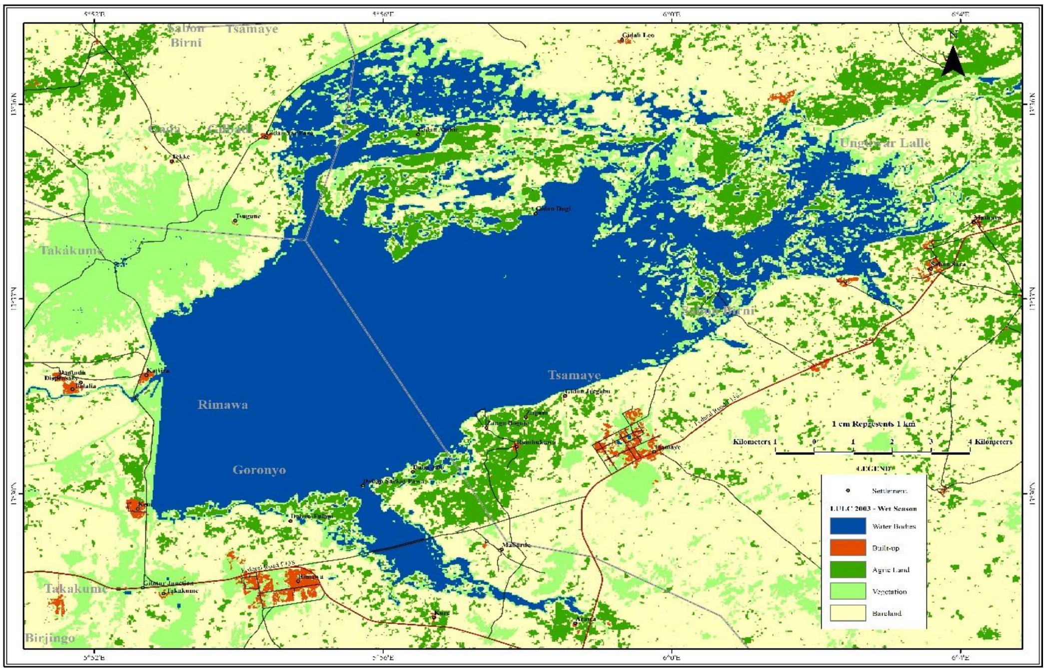

FIGURE 2: LULC Wet Season, 2003.
Source: Author's Work, 2024.

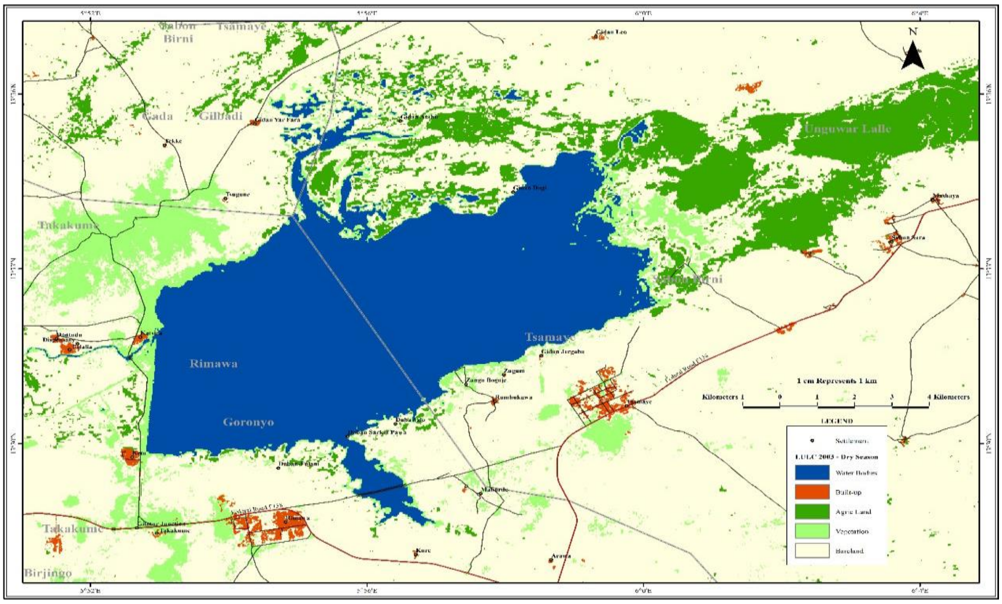

FIGURE 3: LULC Dry Season, 2003.
Source: Author's Work, 2024.

Land Use Land Cover (LULC) Distribution of Goronyo in 2013

The LULC classification of Goronyo during the dry period of 2013 (as depicted in Figure 4 and Table 7) yielded the following land cover percentages. Water bodies covered an area of 547.32 square kilometers. Built-up areas accounted for a certain percentage, occupying 71.10 square kilometers. Vegetation represented a specific percentage, covering 781.82 square kilometers. Agriculture land comprised a certain percentage, occupying 771.47 square kilometers. Bare land constituted a specific percentage, covering 6,588.49 square kilometers.

TABLE 6: LULC in Goronyo 2013.

CLASS	2013 - dry		2013 - wet		Area Change (km²)	Percentage Change (%)
	Area (km²)	%	Area (km²)	%		
Water-Body	547.32	6.25%	1,054.76	12.04%	507.44	92.7%
Built-Up	71.10	0.81%	81.00	0.92%	9.90	13.9%
Agric land	781.82	8.92%	2,926.60	33.41%	2,144.78	274.3%
Vegetation	771.47	8.81%	1,315.21	15.01%	543.74	70.5%
Bare Land	6,588.49	75.21%	3,382.63	38.61%	-3205.85	-48.7%
TOTAL	8760.2	100%	8760.2	100%		

Source: Author's Analysis (2024).

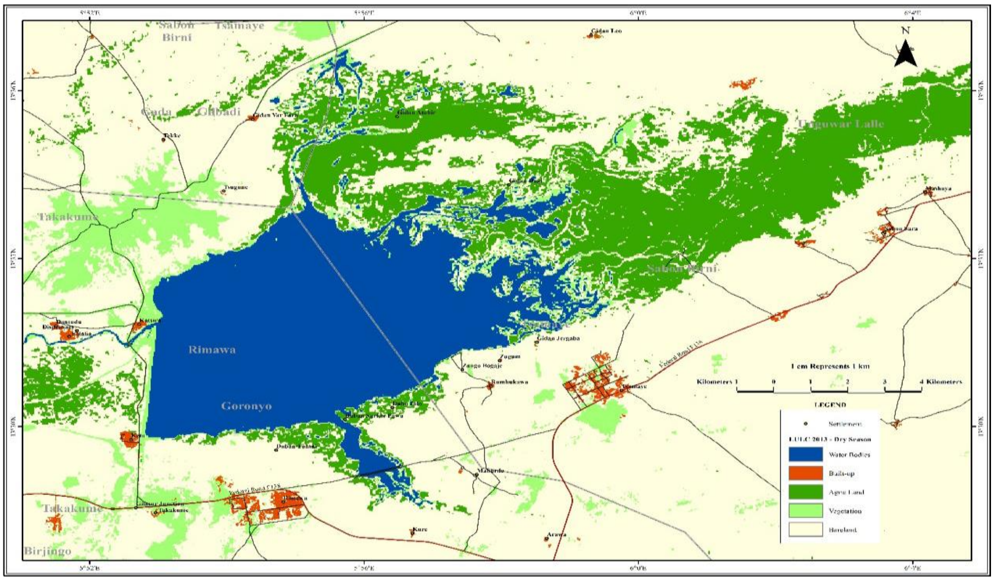

FIGURE 4: LULC Dry Season, 2013.
Source: Author's Work, 2024.

For the wet period of 2013, the LULC classification result in Goronyo (as indicated in Figure 5 and Table 7) revealed the following land cover percentages. Water bodies covered an area of 1,054.76 square kilometres. Built-up areas accounted for a specific percentage, occupying 81.00 square kilometres. Vegetation represented a higher percentage, covering 2,926 square kilometres. Agriculture land occupied a specific percentage, encompassing 1,315.21 square kilometres. Bare land covered 3,382.63 square kilometres.

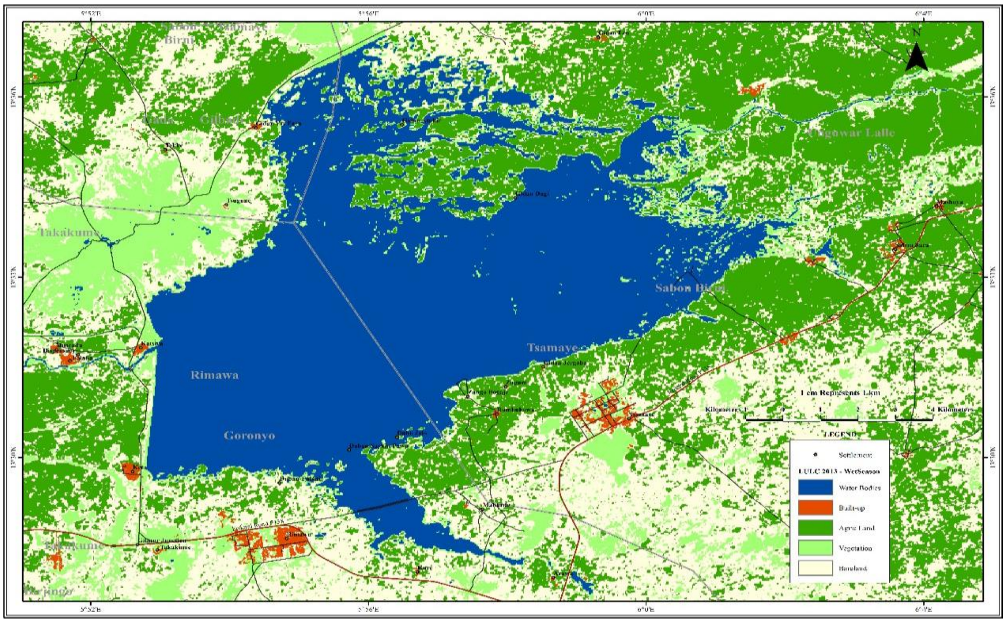

FIGURE 5: LULC Wet Season, 2013.
Source: Author's Work, 2024.

Land Use Land Cover (LULC) Distribution of Goronyo in 2023

TABLE 7: LULC Distribution of Goronyo 2023.

CLASS	2023 - dry		2023 - wet		Area Change (km^2)	Percentage Change (%)
	Area (km^2)	%	Area (km^2)	%		
Water-Body	690.58	7.88%	607.93	6.94%	-82.65	-11.9%
Built-Up	85.95	0.98%	86.40	0.99%	0.45	0.5%
Agric land	1,582.48	18.06%	6,606.45	75.41%	5,023.96	317.5%
Vegetation	176.40	2.01%	240.41	2.74%	64.02	36.3%
Bare Land	6,224.79	71.06%	1,219.01	13.92%	-5,005.78	-80.4%
TOTAL	8760.2	100%	8760.2	100%		

Source: Author's Analysis (2024).

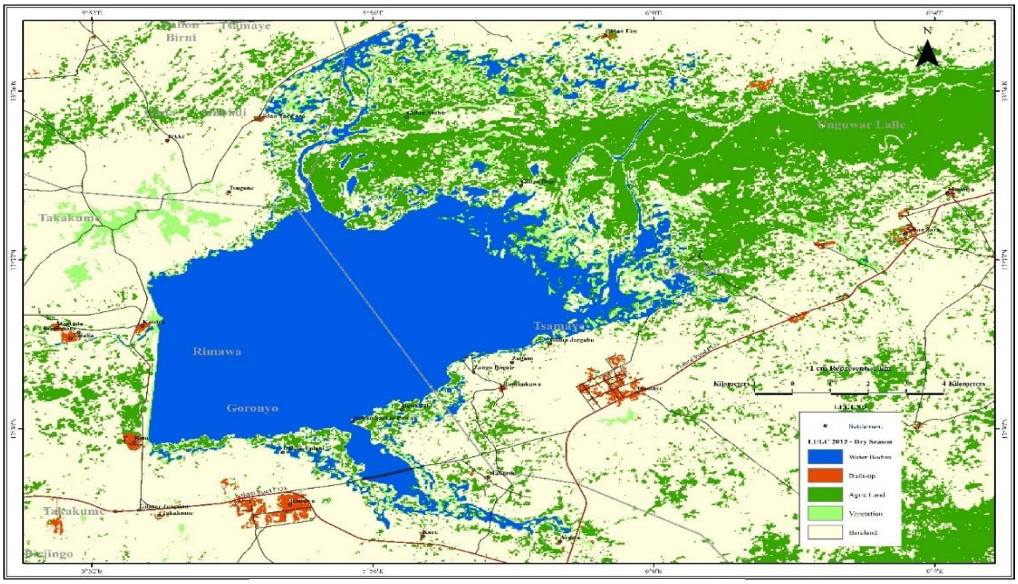

FIGURE 6: LULC Dry Season, 2023.
Source: Author's Work, 2024.

During the dry period of 2023, the LULC classification of Goronyo (as seen in Figure 6 and Table 8) revealed the following land cover percentages. Water bodies accounted for 10% of the area, covering 690.58 square kilometers. Built-up areas represented 0.98% of the region, occupying 85.95 square kilometers. Vegetation covered 18.06% of the land, spanning 1,582.48 square kilometers. Agriculture land comprised 2.01% of the area, with a coverage of 176.40 square kilometers. Bare land constituted the largest portion at 71.06%, encompassing 6,224.79 square kilometres.

For the wet period of 2023, the LULC classification result in Goronyo (as shown in Figure 7 and Table 8) indicated the following land cover percentages. Water bodies covered an area of 607.93 square kilometers. Built-up areas accounted for a certain percentage, occupying 86.40 square kilometers. Vegetation covered a larger percentage, representing an extent of about 6,606.45. Agriculture land encompassed 240.41 square kilometers. Bare land covered 1,219.01 square kilometres.

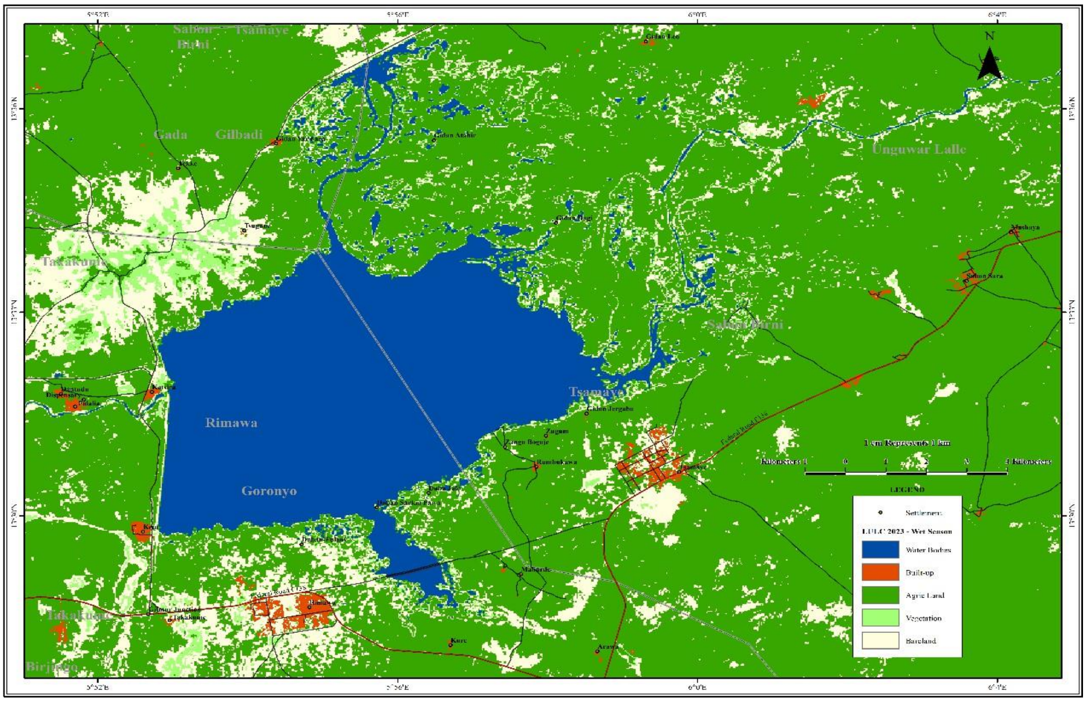

FIGURE 7: LULC Wet Season, 2023.
Source: Author's Work, 2024.

LULC Change Rate in Goronyo

According to the data presented in Table 6, the land cover in Goronyo underwent significant changes between the dry and wet seasons of 2003. During this period, there was an increase in water bodies, with a gain of approximately 32% (334.17 km^2). Additionally, the vegetation cover experienced a substantial growth of 49% (544.04 km^2) owing to the favourable conditions brought by the rainy season. Same as the agricultural land, with a gain of 49% (678.06 km^2). The changes in land cover were also noticeable in the bare land category, which decreased by 30% (1,557.14 km^2) due to the environmental impact of the rainy season.

Shifting the focus to the year 2013, the land cover changes in Goronyo between the dry and wet seasons revealed both similarities and differences compared to 2003. Water bodies continued to expand, recording a gain of approximately 48% (507.44 km^2). Agricultural land experienced a similar gain of 41% (543.74 km^2). The built-up areas remained relatively stable, with a marginal increase of 12% (9.99 km^2) attributed to development activities. The most notable change was observed in the vegetation cover, which exhibited a growth of 73% (2,144.78 km^2) due to the favourable conditions provided by the rainy season. Similarly, the bare land experienced a decline of -95% (3205.85 km^2) as a consequence of the environmental impact of increased rainfall.

Fast-forwarding to the year 2023, the land cover dynamics in Goronyo between the dry and wet seasons presented a different scenario compared to both 2003 and 2013. Water bodies underwent a significant loss, declining by approximately 14% (82.65 km^2). Agriculture land experienced a gain of 27% (64.02 km^2). The built-up areas witnessed a marginal increase of 0.45% (0.24 km^2) due to ongoing developmental activities. As in previous years, the vegetation cover demonstrated robust growth, expanding by 76% as a result of the favourable conditions provided by the rainy season. Additionally, the bare land exhibited a substantial decline of 411% (5,005.78 km^2), indicating the environmental impact of increased rainfall on land cover except for the water bodies.

Areal Extent of Goronyo Dam in 2003, 2013, and 2023

The Dam layers in each of the seasons of the three years were overlaid to analyse the spatial extent of the Dam during this period, as shown in Table 8.

TABLE 8: Dam Extent and its change in 2003, 2013, and 2023.

Year	Season	Area (km²)	Area Change (km²)	Percentage change (%)
2003	Dry	721.32	334.17	46%
	Wet	1,055.49		
2013	Dry	547.32	507.44	93%
	Wet	1,054.76		
2023	Dry	690.58	-82.65	-12%
	Wet	607.93		

Source: Author's Analysis (2024).

According to the data provided in Table 8, the area extent of the dam in Goronyo witnessed significant changes between the years 2003, 2013, and 2023. In 2003, the dam's area increased by 334.17 km2 between the dry and wet seasons, representing a substantial expansion of 46% in water extent. This increase is likely attributed to factors such as increased rainfall and water inflow, contributing to the dam's capacity and overall water storage.

Shifting the focus to 2013, the area extent of the dam in Goronyo experienced a similar pattern compared to 2002. According to Table 9, there was an increase of 507.32 km^2 between the dry and wet seasons, accounting for a significant expansion of 93% in water extent. This expansion suggests that the dam maintained its capacity and continued to play a crucial role in water storage and management during that period.

In contrast to the previous years, 2023 presented a different scenario for the area extent of the dam in Goronyo. According to Table 9, there was a substantial decrease of 82.65km2 between the dry and wet seasons, resulting in a decrease of 12% in water extent. This decline indicates a significant reduction in the dam's water storage capacity during that year. The reasons for this decrease could be attributed to factors such as drought, increased water demand, or changes in hydrological patterns, all of which can impact the water availability and extent within the dam.

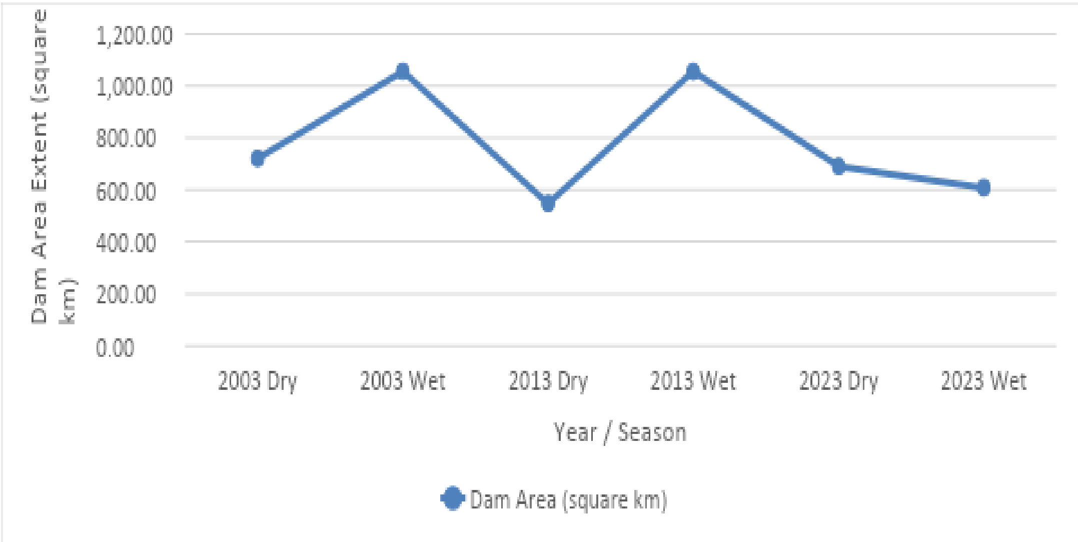

FIGURE 8: Variation in the Seasonal Area Extent of the Dam.
Source: Author's Work, 2024.

From Figure 8, it can also be seen that the largest seasonal Dam area value from 2003 to 2023 was observed in the dry season of 2003, while the smallest area coverage occurred in the wet season of 2023. While there was a notable increase in water extent between the dry and wet seasons in 2003 and 2013, there was however a significant decrease in 2023.

Effect of Land Use Land Cover Change on the Dam Extent

The analysis aimed to understand the impact of land use and land cover (LULC) changes on the extent of the Goronyo Dam. Findings reveal significant alterations in LULC patterns over time, directly affecting the dam's surrounding environment.

The conversion of water bodies into different land cover types was observed over multiple time periods, and notable substantial areas of water were transformed into vegetation, agricultural land, and bare land. As seen in Figure 9, from the dry to wet season of 2003, there was a relatively small increase in vegetation (depicted in light green) and agricultural land cover (depicted in dark green) around the Goronyo Dam. No change was observed in built-up areas, and there was a relatively smaller increase in bare land (see Figure 9). This resulted in a very small encroachment of the Dam by the various land cover classes.

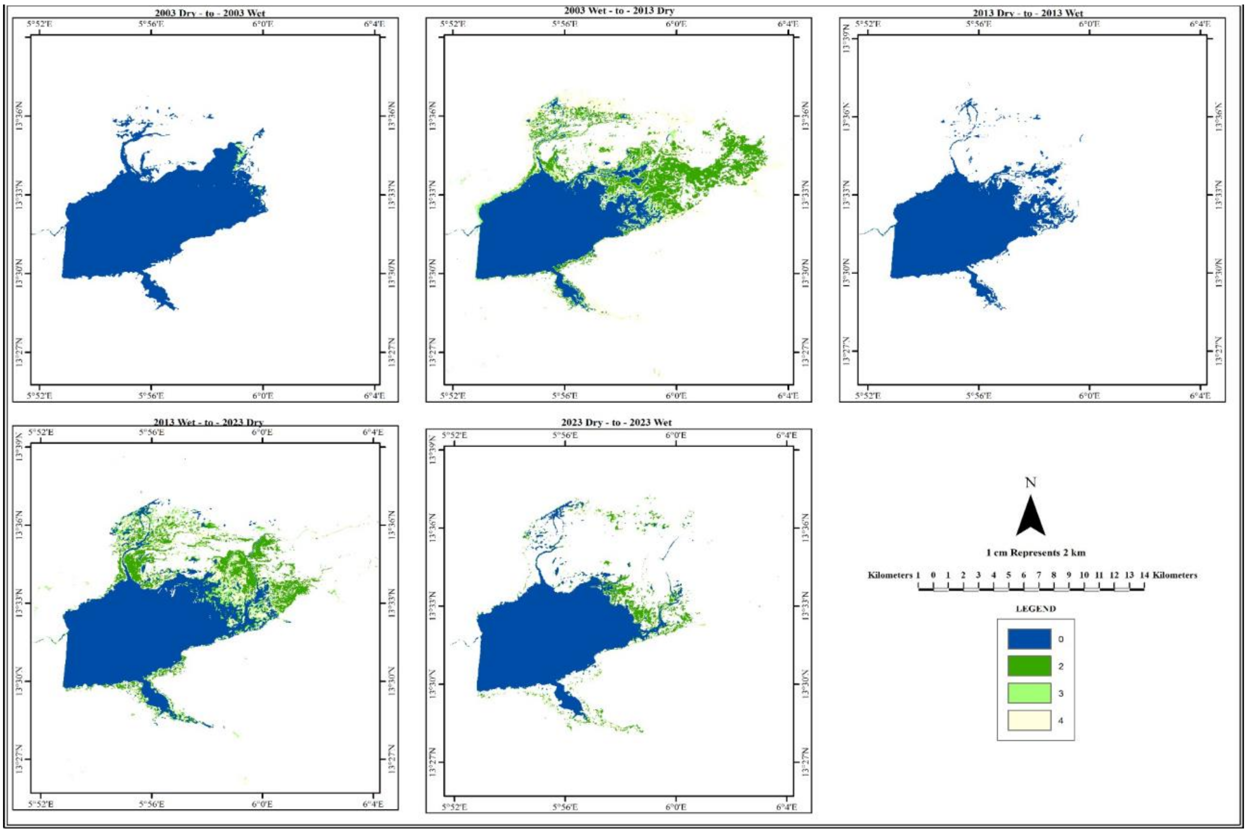

FIGURE 9: Effects of LULC on the Extent of Goronyo Dam from the wet period of 2003 to the Dry period of 2023.
Source: Author's Work, 2023.

From the wet season of 2003 to the dry season of 2013, as depicted in Figure 9, there was a significant increase/encroachment of vegetation and bare land cover into the Dam reservoir's extent. In order words a great portion of the Dam's water was converted into vegetation land cover and bare land cover.

Looking at Figure 9, it can be seen that from the dry to wet season of 2013, there was a small increase in vegetation and agricultural land cover, but no change in built-up areas around the dam extent. During this period a very minut portion of water was encroached.

However, from the wet season of 2013 to the dry season of 2023, as seen in Figure 9, there was a substantial increase in vegetation cover, agricultural land, and bare land cover. However, no influence of built-up area on the dam extent was observed. This led to a very large encroachment into the water body being observed within that time frame, but as much as that observed during the 2003 wet to 2013 dry seasons.

Finally, in the dry to wet season of 2023, as seen in Figure 9, there was a notable increase in vegetation cover, a smaller increase in agricultural land and bareland cover, and still no influence of built-up areas on the dam extent.

The conversion of water bodies to vegetation signifies naturalization processes occurring around the dam. The expansion of vegetation cover, especially during wet seasons, suggests either ecological restoration efforts or encroachment into previously water-dominated areas. This conversion may contribute to biodiversity enhancement and ecological stability within the dam's catchment area. The transition from water bodies to agricultural land reflects human-induced changes, likely driven by agricultural expansion or irrigation projects. The increase in agricultural land area may alter hydrological dynamics and water quality within the dam's vicinity. These changes could impact sedimentation rates and nutrient loading, affecting the overall health of the dam ecosystem.

Conversion of water bodies to bare land may result from natural processes such as erosion or sedimentation, as well as human activities like urbanization or infrastructure development. The expansion of bare land could lead to increased surface runoff and sedimentation in the dam, potentially affecting water quality and sedimentation rates over time.

The observed LULC changes underscore the complex interplay between natural processes and human activities, influencing the extent and health of Goronyo Dam. These alterations may have far-reaching implications for water availability, sedimentation rates, and ecosystem dynamics within the dam's catchment area.

CONCLUSION AND RECOMMENDATION

The Land Use Land Cover (LULC) analysis of the Goronyo Dam area from 2003 to 2023, across dry and wet seasons, reveals dramatic landscape shifts. Maximum likelihood classification in QGIS identified five key classes: water bodies, built-up areas, vegetation, agricultural land, and bare land.

In 2003, bare land prevailed in the dry season at 6,689.58 km^2, with wet-season rainfall boosting water bodies, vegetation, and agriculture. By 2013, all classes contracted water bodies and bare land most severely during the wet season, likely due to environmental stress, data issues, or management changes. This persisted into 2023: water bodies dwindled to 20 km^2 (dry) and 35 km^2 (wet), agriculture continued declining, built-up areas stayed low and stable, and vegetation/agriculture saw minor wet-season upticks. Bare land, while reduced from 2003, remained dominant, flagging productivity and sustainability risks.

Goronyo's land cover proves highly dynamic, shaped by rainfall variability, climate change, dam siltation, urbanization, agricultural expansion, and management practices. Persistent bare land and vegetation/agriculture losses signal degradation, threatening livelihoods in farming and fishing, amplifying flood risks, and curtailing dam functions for water supply and ecosystems.

Urgent measures include ongoing monitoring, sustainable land practices, integrated water management, restoration efforts, and climate adaptation for enduring resilience.

Based on these findings, the study recommends several strategies to enhance resilience and sustainability in the Goronyo Dam area:

(1) Monitoring and Management: Continuous monitoring of land cover and dam extent is essential for informed management and adaptation to both natural and anthropogenic changes.

(2) Sustainable Land Use Practices: Promoting responsible agricultural practices and land conservation can help mitigate soil erosion, sedimentation, and nutrient runoff, supporting the dam's ecological health.

(3) Integrated Water Resource Management: Coordinated water use and allocation, considering land cover impacts on water availability and quality, are critical for sustaining the dam's functions.

(4) Ecological Restoration: Initiatives such as reforestation, wetland preservation, and habitat restoration can enhance biodiversity and ecological stability.

(5) Climate Change Adaptation: Assessing and planning for climate change impacts on rainfall and hydrology will be vital for long-term water resource and land use planning.

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