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Analysis of Land Cover Dynamics in Gashaka-Gumti National Park, North-East, Nigeria

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Abstract

Land use change, driven by human population growth, poses significant environmental degradation and challenges in nature conservation planning. This study aimed to assess land use and land cover change patterns in Gashaka-Gumti National Park, focusing on land cover types. Landsat images from 1987, 2003, and 2021 were processed and classified into five classes: high forest, woodland, grassland, barren land, and open land. The intensity of change was determined using three increasing details of land change. The results showed an accuracy of over 85%, indicating acceptable precision. The rate of land change decreased by 2.6% between 1987 and 2003 and further decreased by 2.0% between 2003 and 2021. During the initial period, grassland and barren land expanded and decreased, while open land and grassland increased. During the initial and subsequent epochs, grassland increased across all categories except for high forest and woodland. The transformation of dense forest and woodland into grassland and other land use types indicates the potential impact of human activities, posing a significant challenge to conservation efforts. The study's findings indicate that forest and woodland ecosystems are facing significant risks due to grassland encroachment, primarily attributed to anthropogenic activities. Therefore, intensifying efforts to preserve forests and woodlands is crucial for achieving conservation goals.

Keywords: Land Change; High Forest; Exponential Growth; Gashaka-Gumti National Park;

1. Introduction

Land Use and Land Cover Change (LULCC) reflect human activity's impact on the Earth's surface, driven by rapid population growth, particularly in developing regions such as sub-Saharan Africa, Southeast Asia, and Latin America (Nyamekye et al., 2020; Kourosh et al., 2019). This phenomenon contributes to both global and local environmental changes, including urban expansion and significant deforestation. Since the 1960s, over half of global forests have been lost (IUCN, 2017), with 178 million hectares disappearing between 1990 and 2000 alone (FAO, 2020). Tropical forests, which experienced over 10 million hectares of loss between 2000 and 2020, are particularly affected, with Africa accounting for much of this decline (Venkatappa et al., 2020; World Bank, 2014). This forest loss endangers 80% of terrestrial biodiversity and critical ecosystem services, including air quality, water regulation, and climate stabilization (IUCN, 2017; Petersen et al., 2018). Furthermore, deforestation is the second-largest contributor to global greenhouse gas emissions after fossil fuel combustion ((Mitchell et al., 2017; Stocker, 2014; Engdaw, 2020).

Advancements in remote sensing (RS) and geographic information systems (GIS) have facilitated the integration of multi-source satellite data, enabling precise and cost-effective LULCC analysis. Techniques involving Landsat data are particularly prevalent in developing countries due to their accessibility, medium-resolution observations, and open data

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policy since 2008 (Hirschmugl et al., 2017; Banskota et al., 2014; Herold et al., 2011). Protected areas (PAs), such as Nigeria's national parks, game reserves, wilderness areas and sanctuaries (Oyinloye and Ado, 2019; Ejidike and Ajayi, 2013) aim to conserve biodiversity (Dudley et al., 2010). However, their effectiveness is debatable, with studies indicating higher forest loss within some PAs compared to areas outside them (Leberger et al., 2020).

Gashaka-Gumti National Park (GGNP), established in 1991, is Nigeria's largest protected area and a biodiversity hotspot (Aina et al., 2018; Umar et al., 2019). Despite its status, GGNP faces threats from illegal logging, agricultural expansion, and poaching, driven by population growth and poverty (Ejidike & Ajayi, 2013). Previous studies on GGNP's LULCC have been constrained by data limitations and inadequate methodologies. For instance, Gumnior & Sommer (2011) encountered inadequete cloud-free Landsat coverage, while Aina et al. (2018) used NDVI data that failed to fully capture land cover dynamics. To address these gaps, this study applies intensity analysis (Aldwaik & Pontius, 2012), a proven method for examining LULCC patterns (Sun et al., 2020; Enaruvbe et al., 2019; Enaruvbe & Atafo, 2019; Huang et al., 2018; Yang et al., 2017). The study examines LULCC in GGNP from 1987 to 2021, aiming to inform sustainable management strategies to mitigate ecosystem degradation and preserve biodiversity.

2. Materials and Methods

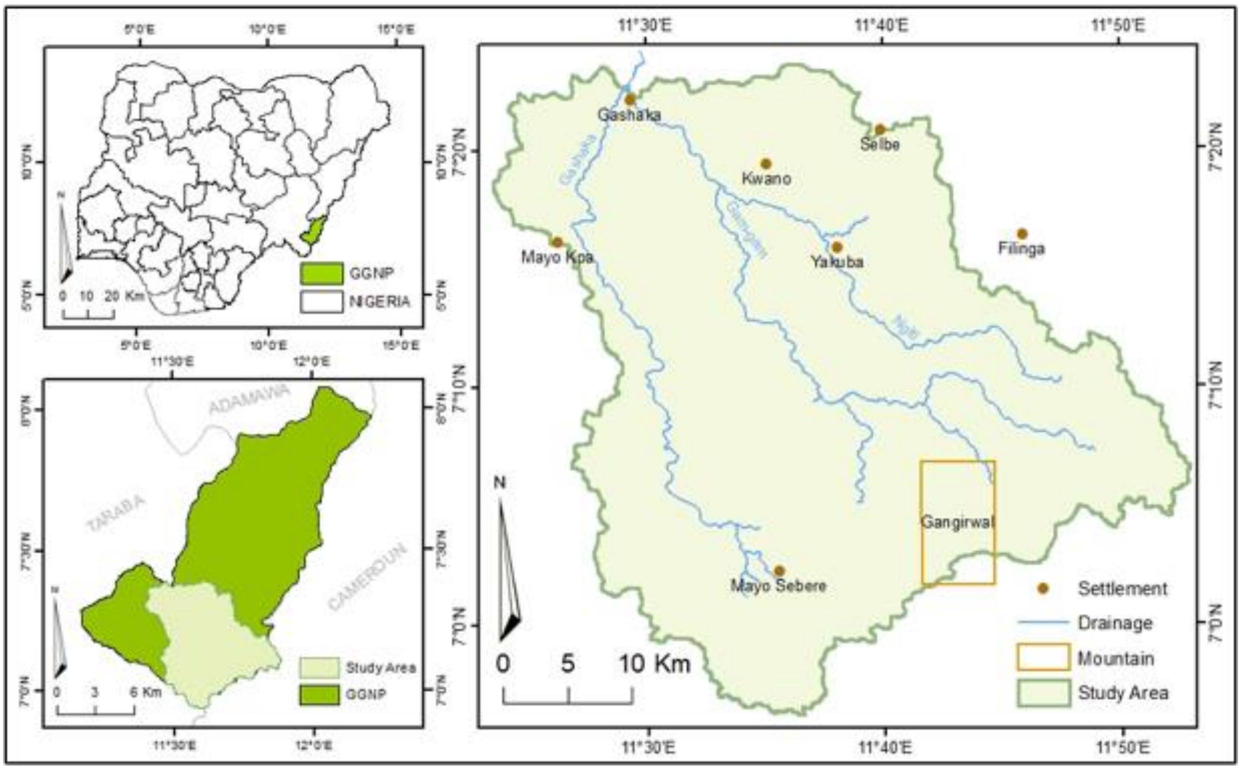

Figure 1 River Gashaka Catchment in Gashaka-Gumti National Park, Nigeria.

The River Gashaka Catchment, covering an area of 1531 square kilometers, is located between latitudes 6^0 94′ N to 7^0 39′ N and longitudes 11^0 39′ E to 11^0 88′ E within the southern sector of the Gashaka-Gumti National Park (GGNP), as depicted in Figure 1. This region provides suitable habitats for various important species, including the rare Nigerian-Cameroonian chimpanzee, black-and-white colobus, Putty-nosed monkey, Tantalus monkey, Olive baboon, and others. Additionally, it encompasses significant park facilities such as the research center, the Gashaka Primate Project site, and popular tourist destinations like the Gangirwal or Chappal Wade (known as the mountain of death), which is the highest peak in West Africa, as well as the Selbe/Hendu highlands. Gumnior and Sommern (2012) reported these details.

The area is characterized by undulating high lands, mountains, and riparian plains, with leptosols, ferrasols and acresols soils (Mubi & Tukur, 2012). Its elevation ranges from 240 m/asl. in Gashaka plains to 2,419 m/asl on Gangirwal (Gumnior & Sommern, 2012; Mubi &Tukur, 2012). The area is drained by three main streams: Mayo (River) Ngetti, Gam-gam, Gashaka and their tributaries into Mayo Kam, which empties into River Taraba, a major tributary to River Benue (Gumnior & Sommern, 2012). The river valleys are characterized by gallery forest surrounded by grass savanna mixed with herbs and shrubs (Adeonipekun *et al.,* 2018). The mean annual rainfall in the area is about 2033 mm. the wet season lasts between April and September. The temperature ranges from a mean annual minimum of 20^0 C to a mean annual maximum of 31.7˚C, but the higher altitudes may sometimes drop below 5°C around December, while daytime temperatures may also rise to 40°C in March (Oruonye *et al.,* 2018). There are many enclaves of human settlements comprising various ethnic groups within the GGNP. The population in the area mostly engages in subsistence farming, animal husbandry, vocational jobs, among other occupations (Oruonye *et al.,* 2018). The Hausa-Fulani Jihad of the 19th century has also led to the expansion of grazing enclaves in the area, with the consequences of a growing human populations within the park, which pose an increasing threat to the ecosystem (Gumnior & Sommern, 2012).

2.1. Sources of data

Table 1 Data collection and their sources

Landsat(30m)	Acquisition date	Path/Raw
Landsat 5 TM	22/01/1987	186/55
Landsat 7 ETM+	10/01/2003	186/55
Landsat 8 OLI	19/01/2021	186/55

Table 1 shows the datasets used in this study and their sources. The shape file of Gashaka-Gumti National Park, which cuts across Path//Row 186/055, 186/054 and 185/055, was downloaded from the World Database on Protected Areas (WDPA)'s website, www.protectedplanet.net, from which River Gashaka catchment area was delimited for this study. Cloud-free, dry season Landsat images of January 22, 1987, January 10, 2003, and January 19, 2021 were acquired from the archives of the United States Geological Survey (USGS). The choice of all the images was to avoid phenological differences in land cover. GPS coordinates for various land covers were randomly collected across the study area. Some locations were, however, inaccessible because of the complex nature of the terrain in the area. Ground information for these inaccessible areas was collected using high resolution Google Earth and Planet images, complemented by existing topographical maps of the study area. The research and ICT unit of Gashaka-Gumti National Park also provided relevant base maps and other referenced materials.

2.2. Data analysis

The shape file for the River Gashaka Catchment was extracted from the Gashaka-Gumti National Park through hydrological modelling of the area. This was overlaid to extract the study area from the image stacks (bands 4, 3 & 2 for TM 1987 & ETM+ 2003 and 5, 4 & 3 for OLI 2021). The field reference data, local knowledge of the study area, and Google Earth were used together to identify 5 land cover classes described in Table 2, following the classification scheme of Anderson *et al.,* (1976). Training Signatures were sampled to represent the 5 land cover classes for each of the Landsat images, and then the Maximum likelihood algorithm was applied to classify each image into high forest, woodland, grassland, barren land, and open land. The accuracy of classification was validated by comparing the features classified on the maps with the ground-referenced data and Google Earth historical images in ERDAS Imaging 2014 then, the LULC maps were smoothened using the generalization extensions of the spatial analyst tools in ArcGIS 10.7.

Table 2. LULC categories and their descriptions

LULC class	Description
High forest	Rain forest mixed with dense woodland, montane & sub-montane forest (>75 trees per ha, a minimum height of 5 m at maturity)
Woodland	Woodland (<75 trees per ha) with a mixture of shrub and scattered grasslands
Grassland	Treeless open canopy shrub savanna & grasslands
Barren land	Rocks, unexposed bare land/fire scars
Open land	Exposed soils/rocks, with active human interferences such as Settlements, roads, crop lands & fallows lands

2.3. Intensity Analysis

Intensity analysis is a quantitative method for examining the interactions between categorical variables from a general to a more detailed level (Kourosh *et al.,* 2019l). Change in the study area was analyzed in terms of size and intensity using the transition matrices generated from the cross-tabulation of the time intervals, 1987-2003 and 2003-2021. The analysis revealed three levels of information, i.e., time interval, category, and transition levels.

interval level reveals how size and the overall annual rate of change vary across the time intervals. It shows which time interval is relatively faster or slower when compared with the hypothesized uniform rate of change (represented by a uniform line). The rate of change is faster when it rises above the uniform intensity line and slower when it falls below it. The pattern of change is considered stationary when it remains either above the uniform line across the time interval or below it throughout the different time intervals (Aldwaik & Pontius, 2012).

The category level revealed how the size and intensity of annual gross gains and losses vary across the space for each category. Annual gross gains and losses were examined and compared with the uniform intensity of change to see which category is relatively dormant or active in a given time interval. When the category's gross gain or gross loss is either greater or less than the uniform intensity at all the different intervals then, the pattern of change is considered to be stationary (John *et al.,* 2013; Aldwaik & Pontius, 2012).

The transition level reveals the variation in size and intensity of the transition among the categories available for that transition. It shows which categories are intensively avoided or targeted when compared with the annual uniform intensity. When a gain in category *m,* for example, either targets category *n* at all intervals or avoids it at all intervals, then the transition from *n* to *m* is considered stationary, giving the gain of *m.* Similarly, when a loss in category *m* is either targeted at or avoided by *n* at all intervals, then the transition from *m* to *n* is considered to be stationary given the loss of *m* (Fuwen *et al.,* 2019; John *et al.,* 2013; Aldwaik & Pontius, 2012).

3. Results

3.1. Accuracy assessment of land use and land cover

The accuracy of maps derived from remote sensing satellite image data processing is an important consideration when such maps need to be used as input for decision-making. The level of accuracy depends on a number of factors, including the quality of the data, the level of processing and the expertise of the analyst (Enaruvbe *et al.,* 2019; Shao & Wu, 2008). The overall classification accuracy of the maps in this study is: 88% for 1987, 89% for 2003 and 88% for 2021 (Table 3). Both the producer's and user's accuracies were generally high.

Table 3 Accuracy of land cover classification

	1987		**2003**		**2021**	
	Producer's Accuracy (%)	User's Accuracy (%)	Producer's Accuracy (%)	User's Accuracy (%)	Producer's Accuracy (%)	User's Accuracy (%)
High forest	100.00	100.00	100.00	93.30	96.40	96.40
Woodland	100.00	66.70	77.80	80.80	63.60	77.80
Grassland	58.30	100.00	100.00	88.90	40.00	100.00
Barren land	72.70	88.90	61.50	88.90	100.00	75.00
Open land	100.00	61.60	100.00	100.0	100.00	71.40

Overall accuracy: 1987 = 88%, 2003 = 89%, 2021 = 88%

3.2. Pattern of land cover change over River Gashaka catchment

The pattern of land use and land cover change is shown in Figure 3. The figure shows that the River Gashaka catchment is dominated by high forest. Table 4 indicates an overall increase in high forest, grassland and barren lands area during the period of this study. In contrast, however, woodland and open land recorded declines during the period of this study.

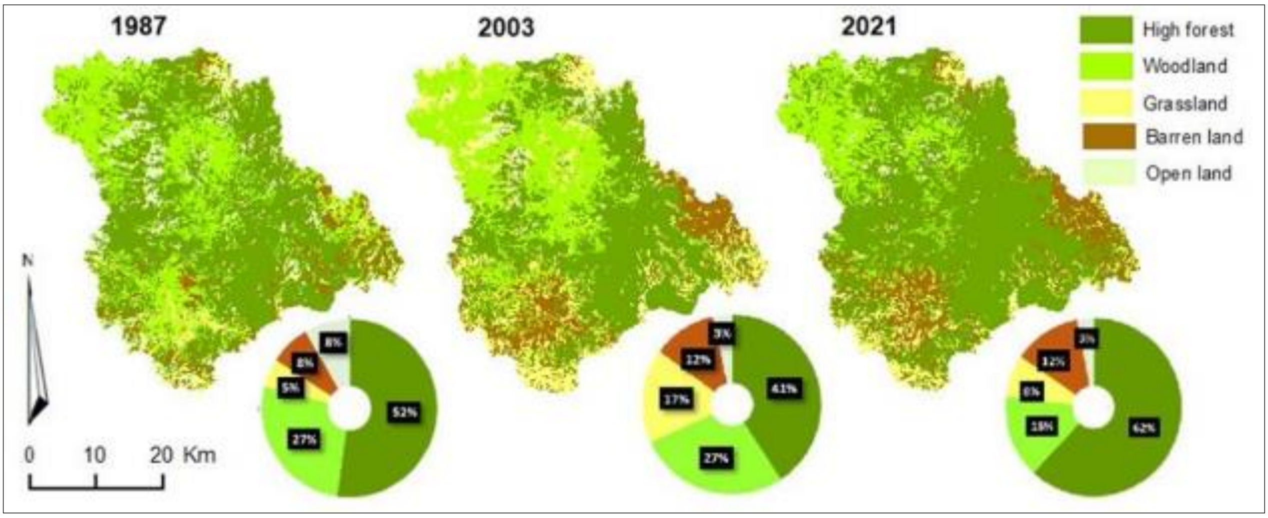

Figure 2 Patterns of land cover change over River Gashaka catchment

Table 4 Land cover distribution over RGC, in square kilometers (km^2) and percentage (%)

Category	1987		2003		2021	
	km^2	(%)	km^2	(%)	km^2	(%)
High forest	797	52	621	41	943	67
Woodland	406	27	418	27	230	15
Grassland	80	5	257	17	115	8
Barren land	114	8	176	12	190	12
Open land	128	8	52	3	45	3

3.3. Intensity of land use and land cover change

The transition matrices in Table 5 show the changes that occurred among the land cover classes in the two time intervals. The values in the diagonal cells remain unchanged during the time intervals, which signifies persistence, while the values that appear off-diagonal show the amount of changes from the earlier to the later year for each category (John *et al.,* 2013).

3.3.1. Interval Level Intensity

The observed rates of annual change for each time interval are shown in Figure 4 and compared with the hypothesized uniform annual change of 2.32%, represented by the red dashed line. The intensity of land cover change during the first epoch (1987-2003) was above the uniform annual change while the intensity of change for the second epoch (2003-2021) was below the uniform annual change. This implies that although the rate of annual land use change was fast in the first epoch, it slowed down during the second epoch.

Table 5 Transition matrix for the LULC classes (sq. km.)

	2003					
1987		High forest	Woodland	Grassland	Barren land	Open land
	High forest	16790.7	4698.3	1716.0	511.8	193.4
	Woodland	478.8	6998	2274.4	2184.4	194.1
	Grassland	26.8	117.5	1031.0	2184.4	137.8
	Barren land	568.3	485.1	1109.0	1224.6	26.4
	Open land	741.4	242.8	1549.3	269.2	1006.6
2003	2021	High forest	Woodland	Grassland	Barren land	Open land
	High forest	6546.7	4860.5	181.5	735.9	218.6
	Woodland	2515.8	1440.8	1813.7	1364.3	553.2
	Grassland	701.7	214.8	1071.0	3251.0	210.0
	Barren land	397.4	288.4	186.4	187.0	4910.0
	Open land	6546.6	4860.5	181.5	735.9	218.6

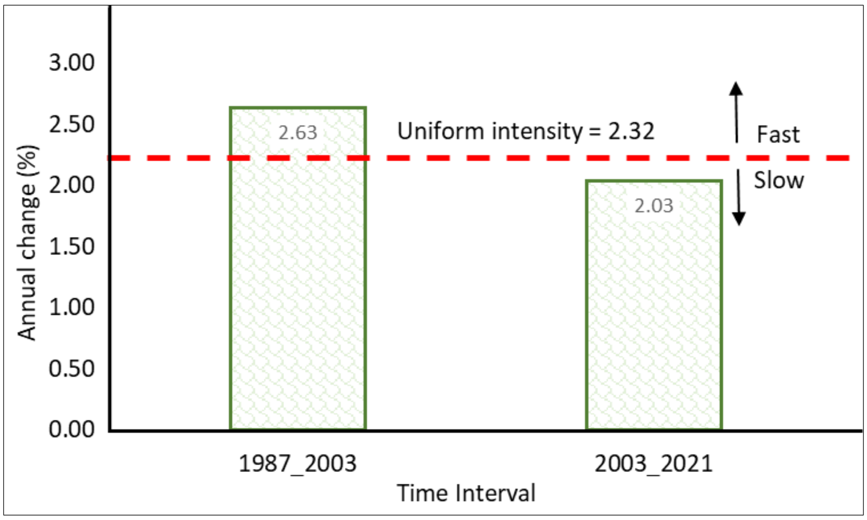

Figure 3 The interval intensity of land use and land cover change in RGC

3.3.2. Category Level Intensity

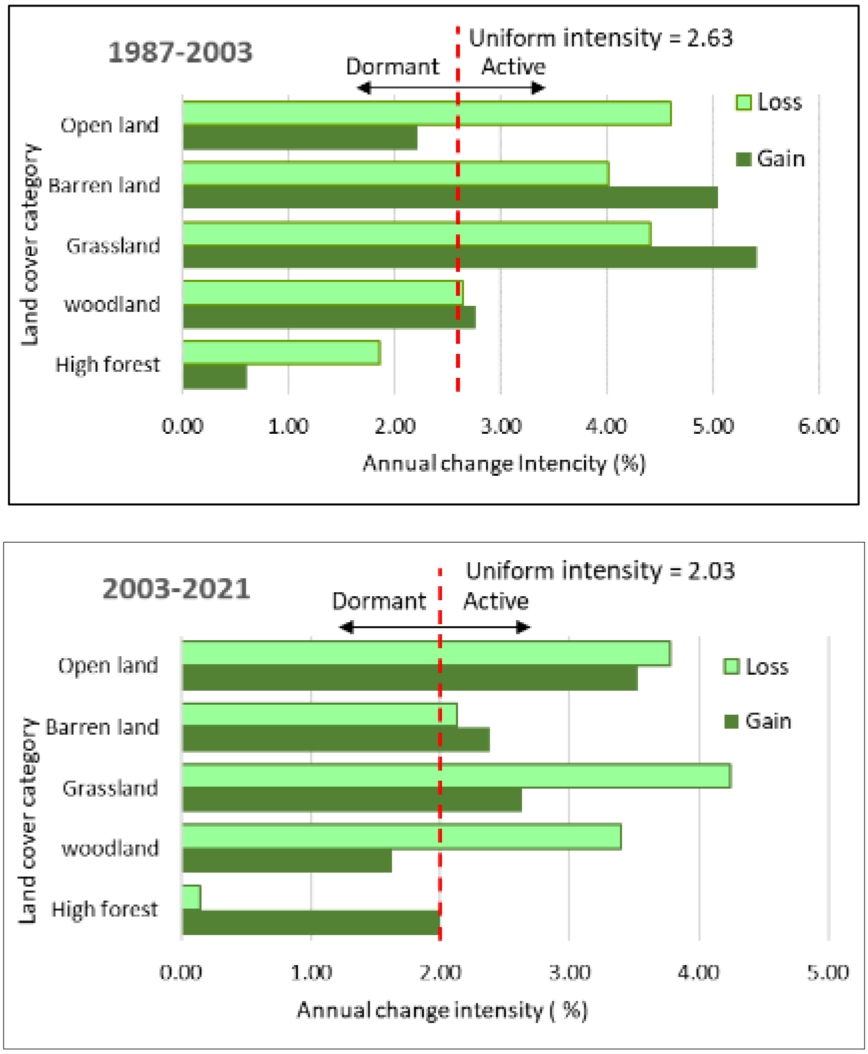

Figure 4 Categorical Intensity of LULC change in RGC

Figure 5 shows the category level intensity; grassland and barren land were the most active gaining and losing categories during the first epoch. The rate of land use change during the 1987-2003 epoch was 2.63%. The annual uniform intensity of land use change, however, declined slightly to 2.03% during the second epoch. We observe that open land, barren land, grassland, and woodland have been actively losing land since 1987. In contrast, barren land and grassland have been actively gaining since 1987, but while open land was dormant in the first epoch, it became active in the 2002-2021 epoch, and woodland, which was active during the first epoch, was dormant in the second (Figure 5).

3.3.3. Transition Level Intensity

Figure 6-10 presents the transition level intensities. During the first epoch, there was a significant loss of high forest, mainly targeted by woodland, whose change rate was above the annual uniform intensity of 1.58% meaning that woodland was actually taking over land from high forest. But during the second epoch, the annual uniform loss for high forest became as low as 0.15% targeted by grassland and open land, while woodland dropped drastically below the uniform line. On the other hand, high forest gained from open land and barren land at a low annual uniform gain of 0.50% during the first epoch, while in the second epoch, woodland became the main target as high forest picked up to 2.05% annual uniform gains.

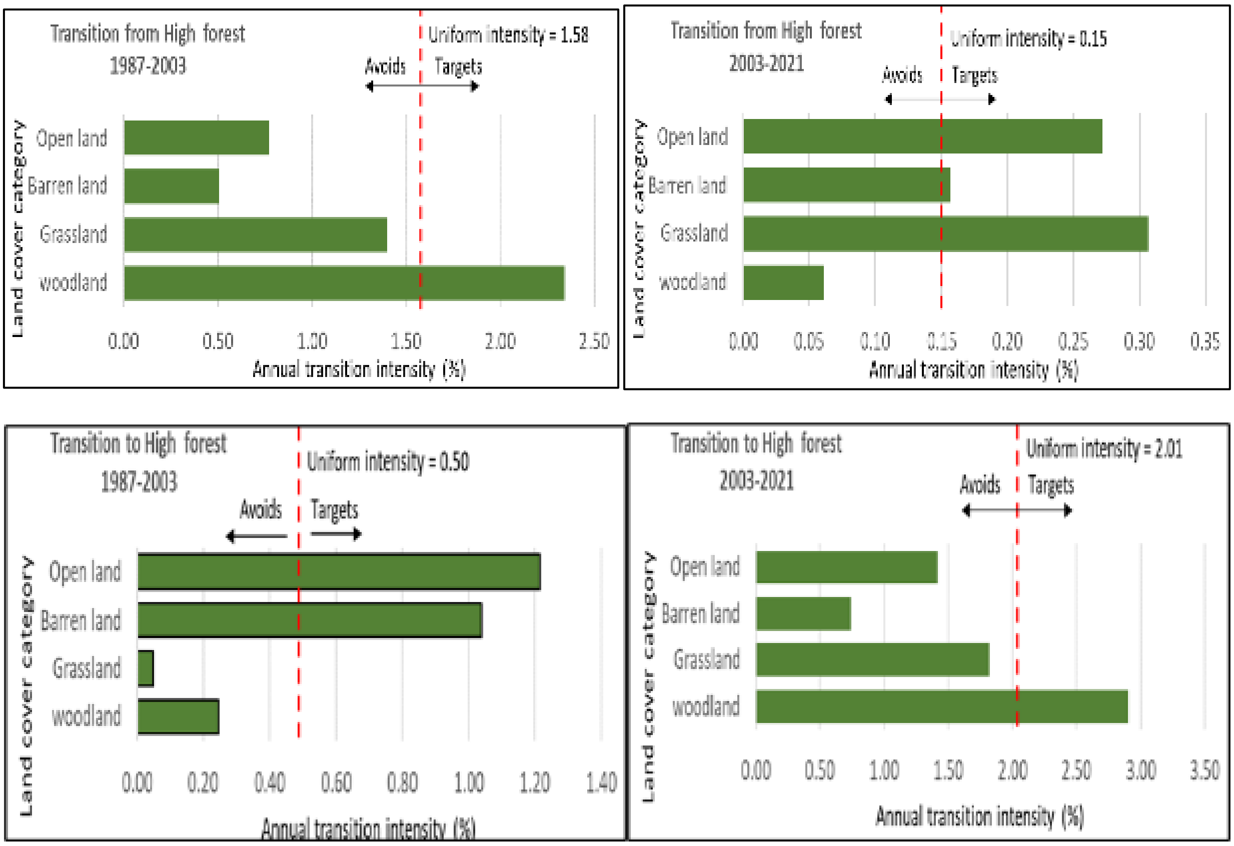

Figure 5 Transition intensity of high forest

During the first epoch, woodland loss was mainly targeted by barren and grassland, whose intensity bars surpassed the annual uniform rate of 1.94%. Meanwhile, woodland also made active gains from high forest at an annual uniform rate of 1.00%. In the second epoch, woodland was losing at a uniform rate of 1.07% mainly to high forest, but was slowly recovering from grassland and open land at an annual uniform rate of 0.33%.

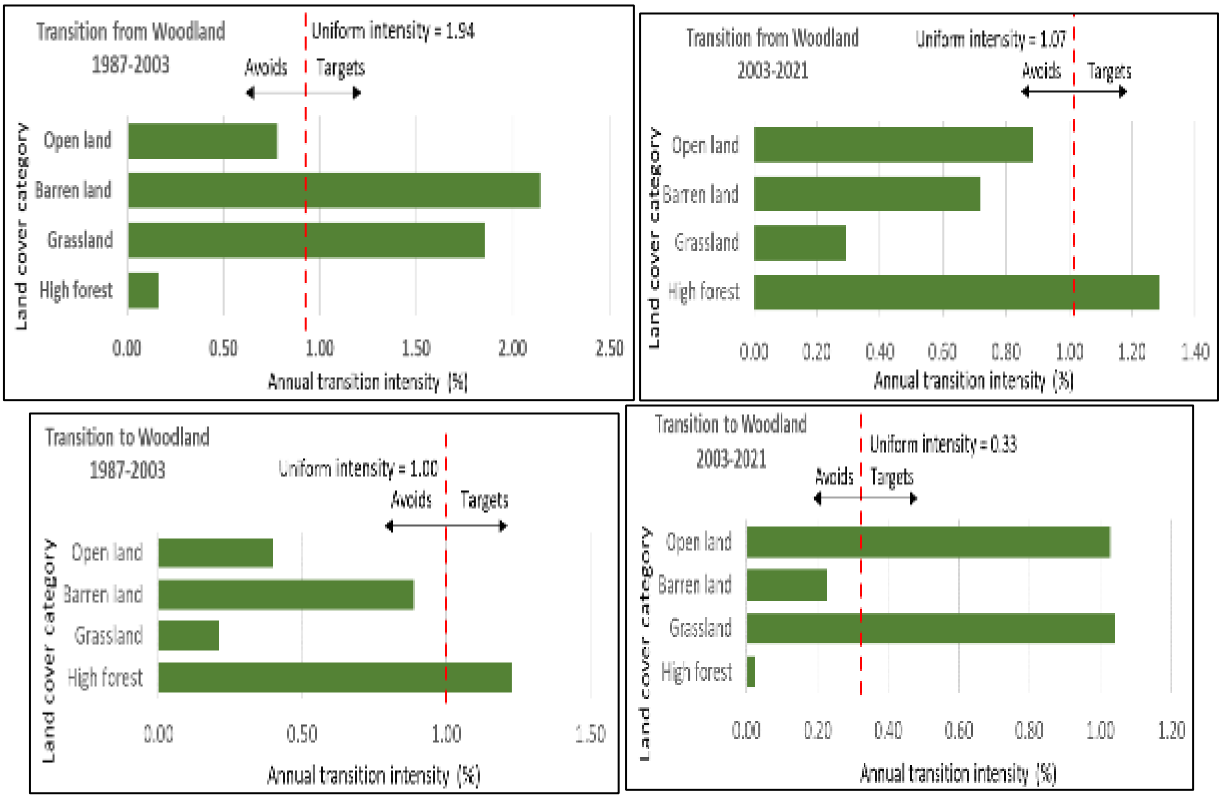

Figure 6 Transition intensity of woodland

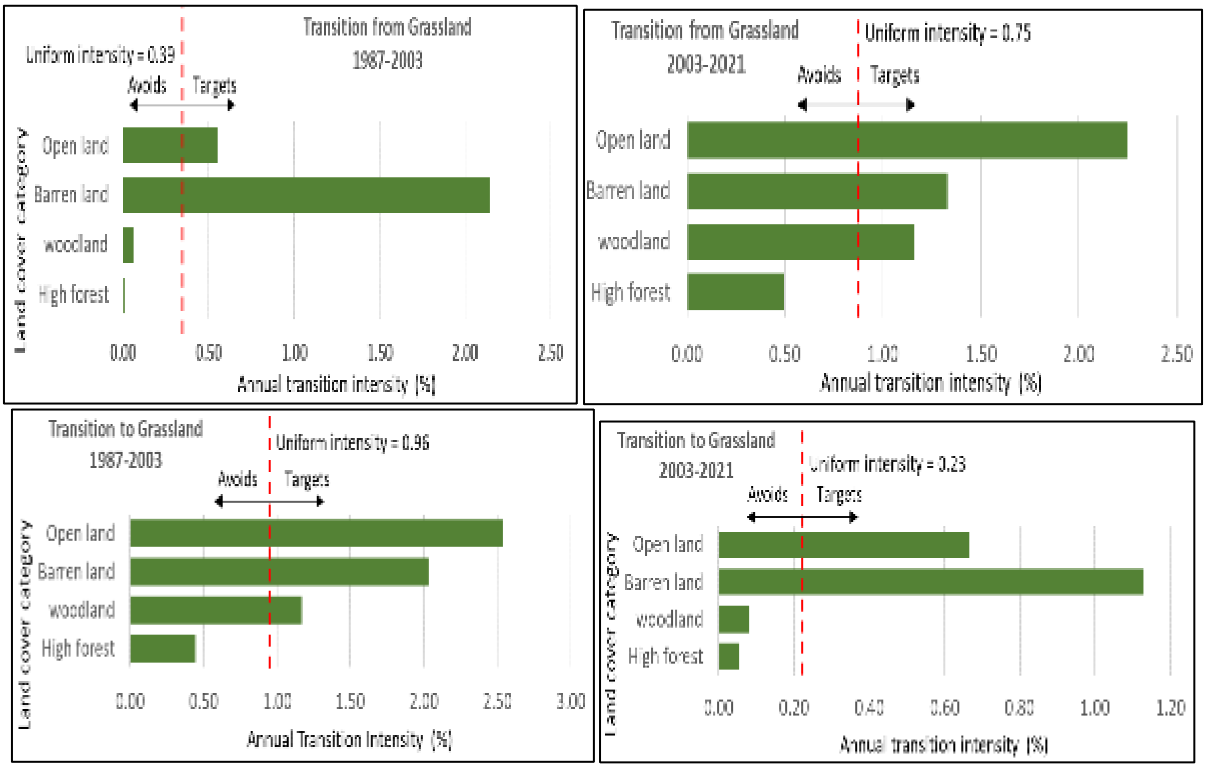

Figure 7 Transition intensity of grassland

During the first epoch, grassland was losing mainly to barren land and slightly to open land but was highly gaining from open land, barren and woodland, with an annual uniform gain of 0.96%. In the second epoch, the annual uniform loss for grass land rose to 0.75% but was mainly targeted by open land, barren land, and woodland, while the increase in grassland was mainly targeted by barren and open land, and the annual uniform change was 0.23%. The annual rates of transition for both barren land and open land were very low for both epochs, and grassland was their main target of transition for both gross gains and losses, while woodland and high forest were avoided.

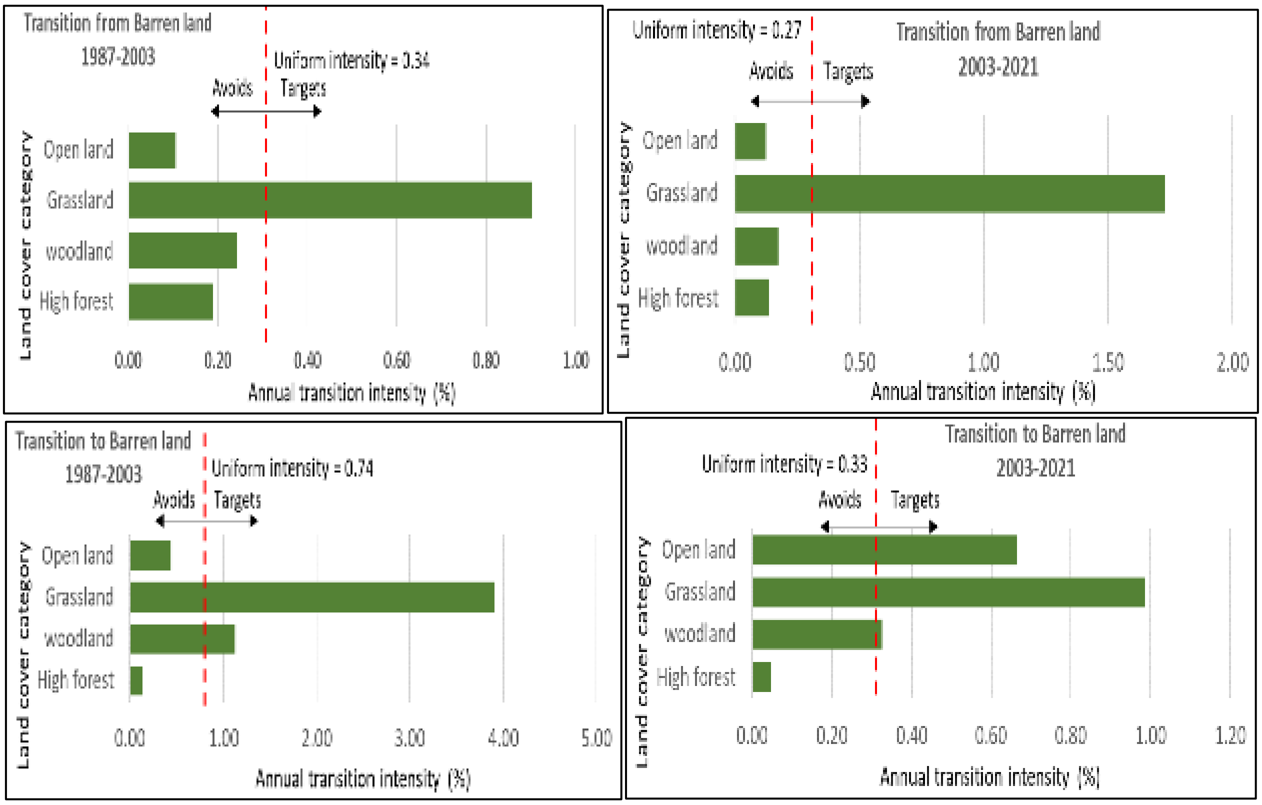

Figure 8 Transition intensity of barren land

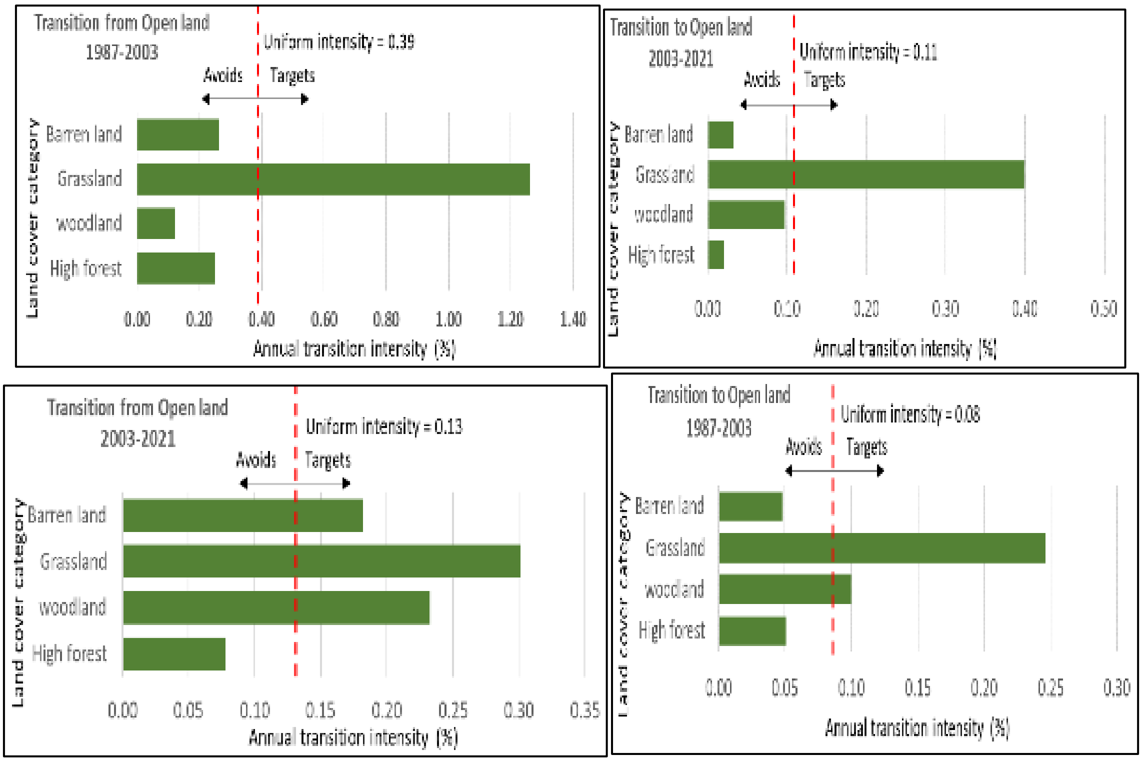

Figure 9 Transition intensity of open land

4. Discussion

The present study examined changes in the land cover of the Gashaka catchment for a period of 34 years (1987-2021), using multi-temporal Landsat data and intensity analysis techniques. Landsat data has been widely used to characterize changes in the tropical environment over the years (Banskota *et al.,* 2014; Hirschmugl *et al.,* 2017). Rwanga & Ndambuki, (2017) have however, noted that the effectiveness of its use mostly depends on the availability and quality of datasets, the researcher's experience with the classification procedures, and the accuracy of the classification outcome. Therefore, in this study, we selected cloud-free data acquired during the same season. The overall accuracy of the supervised classification were all above the acceptable threshold of 85% (Enaruvbe *et al.,* 2019; Anderson *et al.,* 1976).

4.1. Spatio-temporal pattern of land cover change over RGC

The research region exhibited a consistent presence of extensive forest and woodland over the duration of the study, as evidenced by Figure 1 and Table 3. This phenomenon might potentially be attributed to the proactive conservation initiatives undertaken inside Gashaka National Park. The transformation of forest and woodland into grassland in the study region can be linked to the progressive impact of human activities. In the majority of instances, around 15% of the research region was categorized as non-vegetated, specifically referring to barren and open ground. This observation implies a prolonged history of human intervention in the forest ecosystem, posing a substantial risk to the preservation of biodiversity.

This observation was further supported by the identification of numerous settlements and camps across the study area, revealed through Google Earth visualization of high-resolution satellite imagery (Gumnior & Sommer, 2012) also conclude that allowing legal enclaves in the park is a significant threat to its sustainable conservation. In addition, the existence of settlements in a protected area is contrary to the IUCN's definition of protected areas (Dudley et al., 2010).

4.2. The intensity of the land cover transition

Although the methods of intensity analysis have been widely used by scientists (e.g., Ekumah *et al.,* 2020; Kourosh *et al.,* 2019; Enaruvbe & Atafo 2019; Yang *et al.,* 2017; John *et al.,* 2013), there is no evidence that this method has been used in Gashaka National Park. The method has been noted to help in providing a better understanding of LULC change patterns in a landscape.

At the interval level, the annual rate of land cover change was observed in Figure 4 to be faster in the first epoch than the second. This shows that the forest was more stable during the second epoch, which is further proof of conservation influence. Awareness and the enforcement of park protection must have become stronger with the establishment of the area as a national park in 1991 and an Important Bird Area (IBA) in 2001 (Aina *et al.,* 2018), which emphasizes both local and international protection. Similar outcomes have been obtained by other studies; for example, Kourosh *et al.* (2019) analyzed the transitions among land categories during three-time intervals in Qeshm Island, Iran, and found that, overall land-use change was faster in the first and third epochs than the second.

At the category level in Figure 5, all categories except high forest experienced active gross losses during the first and second epochs but grassland and barren land made the topmost gains, relatively followed by woodland during the first epoch but all began to drop drastically during the second epoch. The high forest was dormant with fewer gains than losses in the first epoch, but the gains began to rise considerably during the second epoch. The forest class was also found to be dormant when intensity analysis was applied by Nyamekye *et al.,* (2020) to investigate the transitions among the major LULC categories in an urban municipality in Ghana.

Figure 6-10 presents the transition level intensity analysis. During the first epoch, high forest was avoided by all categories except woodland, but in the second epoch, woodland became the main target of high forest for transition. Grassland made the most gains from open land, barren land, and woodland but avoided high forest in the first epoch, whereas in the second epoch, woodland was also avoided by grassland. Finally, most of the gross gains and losses for barren and open land targeted grassland and avoided high forest and woodland throughout the study period.

5. Conclusion

This study assessed land cover changes in the Gashaka catchment from 1987 to 2021, leveraging multi-temporal Landsat data and intensity analysis to uncover patterns of transformation. The findings provide significant insights into the implications of human activities and conservation efforts on the park's ecosystem over 34 years.

The spatio-temporal analysis revealed that while extensive forest and woodland persisted due to proactive conservation measures, areas of grassland and barren land expanded, highlighting ongoing human intervention in the ecosystem. Settlements and camps observed through satellite imagery further emphasize the encroachment into protected areas, posing a substantial threat to biodiversity preservation. The existence of legal enclaves within the park is particularly concerning, contradicting the IUCN's guidelines for protected area management, which call for eliminating exploitation and maintaining ecological integrity (Dudley et al., 2010, Eze et al., 2025).

The intensity analysis demonstrated that the rate of land cover change slowed during the second epoch, coinciding with increased awareness and enforcement of conservation policies following the park's designation as a national park in 1991 and its recognition as an Important Bird Area in 2001. This stability suggests that conservation strategies, though imperfect, have had a measurable impact. However, the continued gains in barren land and losses in forested areas during the first epoch underscore the lingering challenges of enforcement and the need for adaptive management strategies.

These findings imply that while conservation efforts in Gashaka-Gumti National Park have mitigated some threats, they have not fully halted land degradation. Strengthening enforcement, limiting human encroachments, and fostering community involvement in sustainable practices are vital for reversing adverse trends. The application of advanced tools like intensity analysis in this study provides a replicable framework for monitoring land cover changes, essential for informed decision-making and policy formulation in protected areas. In conclusion, achieving sustainable conservation of the Gashaka ecosystem requires a multifaceted approach that integrates ecological preservation with human development. Efforts to address the root causes of encroachment such as poverty and population pressure will be critical in ensuring the park's long-term resilience and the biodiversity it supports.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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