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Decadal Intensity Analysis and Landscape Fragmentation of Land Use land Cover Change in the Owesse River Basin, Southwest Nigeria

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Abstract

Land use and land cover (LULC) change and landscape fragmentation pose significant threats to ecosystem sustainability in tropical river basins, particularly in rapidly developing regions of sub-Saharan Africa. This study assessed the spatio-temporal dynamics, intensity, and fragmentation of LULC change in the Owesse River Basin, Southwest Nigeria, over a 30-year period (1994–2024). Multi-temporal Landsat imagery (TM, ETM+, and OLI-TIRS) was classified into five LULC categories using supervised maximum likelihood classification, with overall accuracies exceeding 85%. Post-classification change detection was integrated with Intensity Analysis to evaluate interval-, category-, and transition-level changes, while landscape fragmentation was quantified using Morphological Spatial Pattern Analysis (MSPA) and FRAGSTATS metrics. Results revealed significant transformations across all land-cover classes. Forest cover declined markedly, while light vegetation (agriculture) and built-up areas expanded substantially, indicating increasing anthropogenic pressure. Barren land exhibited fluctuating trends associated with land degradation and recovery, whereas water bodies showed slight increases over time. Interval-level analysis identified 2004–2014 as the most active period of change. Category-level results showed forest as a dominant losing class, while light vegetation and built-up areas were active gaining classes. Transition-level analysis revealed systematic conversions primarily from forest to agricultural land and built-up areas, alongside secondary transitions involving other land-cover types. Fragmentation analysis indicated increasing landscape heterogeneity, characterized by reductions in core areas and increases in edge and isolated patches, reflecting declining connectivity. Overall, the findings highlight a transition from natural to human-dominated landscapes driven by agricultural expansion and urbanization. The study demonstrates the value of integrating intensity analysis with landscape ecological metrics and provides critical insights for sustainable land-use planning and ecosystem conservation in tropical river basins.

Keywords: Ecological metrics; Land change; Ecosystem sustainability; river basin; sub-Sahara Africa

Résumé

Les changements d'occupation et d'utilisation des sols (COUS) et la fragmentation des paysages constituent des menaces importantes pour la durabilité des écosystèmes dans les bassins fluviaux tropicaux, en particulier dans les régions en développement rapide d'Afrique subsaharienne. Cette étude a évalué la dynamique spatio-temporelle, l'intensité et la fragmentation des changements de COUS dans le bassin de la rivière Owesse, au sud-ouest du Nigéria, sur une période de 30 ans (1994-2024). Des images Landsat multi-temporelles (TM, ETM+ et OLI-TIRS) ont été classées en cinq catégories par la method de classification supervisée du maximum de vraisemblance, avec une précision globale supérieure à 85 %. La détection des changements post-classification a été intégrée à l'analyse d'intensité pour évaluer les changements aux niveaux d'intervalle, de catégorie et de transition, tandis que la fragmentation des paysages a été quantifiée à l'aide de l'analyse morphologique des structures spatiales (MSPA) et des métriques FRAGSTATS. Les résultats ont révélé des transformations significatives dans toutes les classes d'occupation des sols. Le couvert forestier a fortement diminué, tandis que la végétation claire (agriculture) et les zones bâties se sont considérablement étendues, indiquant une pression anthropique croissante. Les terres arides ont présenté des tendances fluctuantes liées à la dégradation et à la régénération des sols, tandis que les plans d'eau ont légèrement augmenté au fil du temps. L'analyse par intervalles a identifié la période 2004-2014 comme la plus active en termes de changements. Les résultats par catégorie ont montré que la forêt était la principale classe perdante, tandis que la végétation claire et les zones bâties étaient les principales classes gagnantes. L'analyse de transition a révélé des conversions systématiques, principalement de la forêt vers les terres agricoles et les zones bâties, ainsi que des transitions secondaires impliquant d'autres types de couverture terrestre. L'analyse de la fragmentation a indiqué une hétérogénéité croissante du paysage, caractérisée par une réduction des zones centrales et une augmentation des lisières et des parcelles isolées, reflétant une connectivité décroissante. Dans l'ensemble, les résultats mettent en évidence une transition des paysages naturels vers des paysages anthropisés sous l'effet de l'expansion agricole et de l'urbanisation. Cette étude démontre l'intérêt d'intégrer l'analyse d'intensité aux indicateurs d'écologie du paysage et fournit des informations essentielles pour une planification durable de l'utilisation des terres et la conservation des écosystèmes dans les bassins fluviaux tropicaux.

Mots-clés : Indicateurs écologiques ; Changement d'affectation des terres ; Durabilité des écosystèmes ; Bassin versant ; Afrique subsaharienne

1.0 Introduction

Land use and land cover (LULC) change is one of the most serious environmental problems of the world and is related to climate change, loss of biodiversity and land degradation. The rapid transformation of forests into agricultural and urban land use has heavily impacted ecosystem services and environmental resiliency due to population growth and economic development, especially in tropical areas (Geist & Lambin, 2002; Foley et al., 2005; Dias et al., 2023). Landscape fragmentation and ecological instability further increase due to urbanization (Jiang et al., 2022). The processes are closely linked to challenges in global development such as climate action, food security, sustainable urbanisation (SDGs 11, 13, and 15). Increasing agricultural expansion and infrastructural development are continuing to drive forest loss and land degradation at regional level, especially in south-western Nigeria (Adewole et al., 2020).

Lu et al. (2004) and Weng (2012) have found the remote sensing and Geographic Information Systems (GIS) to be effective tools for monitoring the dynamics of LULC. But traditional methods tend to look at the idea of net change and ignore the speed and mechanisms of transitions, as outlined by Pontius and Millones (2011). Intensity analysis resolves this problem by examining change at the interval, category, and transition levels, which helps distinguish systematic from random processes (Foley et al., 2005). Spatial configuration and fragmentation are measured by complementary landscape metrics: Morphological Spatial Pattern Analysis (MSPA) and FRAGSTATS (McGarigal et al., 2012).

Although integrated intensity fragmentation studies have been used worldwide, they are not widespread in Nigeria (Adegboyega, 2021). This study thus uses multi-temporal Landsat data, intensity analysis, and landscape metrics to quantify LULC dynamics in the Owesse River Basin over 1994-2024 in terms of the magnitude, transition dynamics, and fragmentation patterns of those changes.

The method offers valuable insights into land transformation processes, ecosystem connectivity and ecosystem stability, and it has implications for hydrological processes and environmental sustainability.

Overall, the results contribute to the evidence-based planning and conservation of land and habitat by providing information on priority areas for rapid change and fragmentation. The study also advances the science of land change by providing support for the use of integrated geospatial data systems in data limited tropical settings.

2.0 Materials and Method

2.1 Description of the study area

The study area is the Owesse River Basin in South West of Nigeria (Figure 1). The basin covers the tropical rainforest derived savanna transition zone of parts of Ondo, Osun, Ogun, Ekiti and Edo States. It features a humid tropics climate and well-defined wet and dry seasons, annual rainfall more than 1200 mm and mean temperature range from 24°C to 30°C. The basin is ecologically sensitive and ideal for the evaluation of land use intensity and fragmentation; the basin's land use is diverse and dominated by forest, agriculture and growing settlements (Akinyemi, 2013). The location and spatial extent of the study area is shown in Fig. 1.

2.2 Data Acquisition

Multi-temporal images of Landsat satellites were downloaded for four different periods: 1994, 2004, 2014, and 2024 using the USGS EarthExplorer website. The images included Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS) with a resolution of 30 meters. The images were chosen during the dry season (November to February) to reduce cloudiness and vegetation reflectance variations due to seasonality (Table 1).

A Digital Elevation Model (DEM) with a resolution of 30 meters was sourced from the Shuttle Radar Topography Mission (SRTM) dataset. Other ancillary datasets included the administrative boundaries provided by the Office of the Surveyor General of the Federation (OSGOF) and Google Earth imagery.

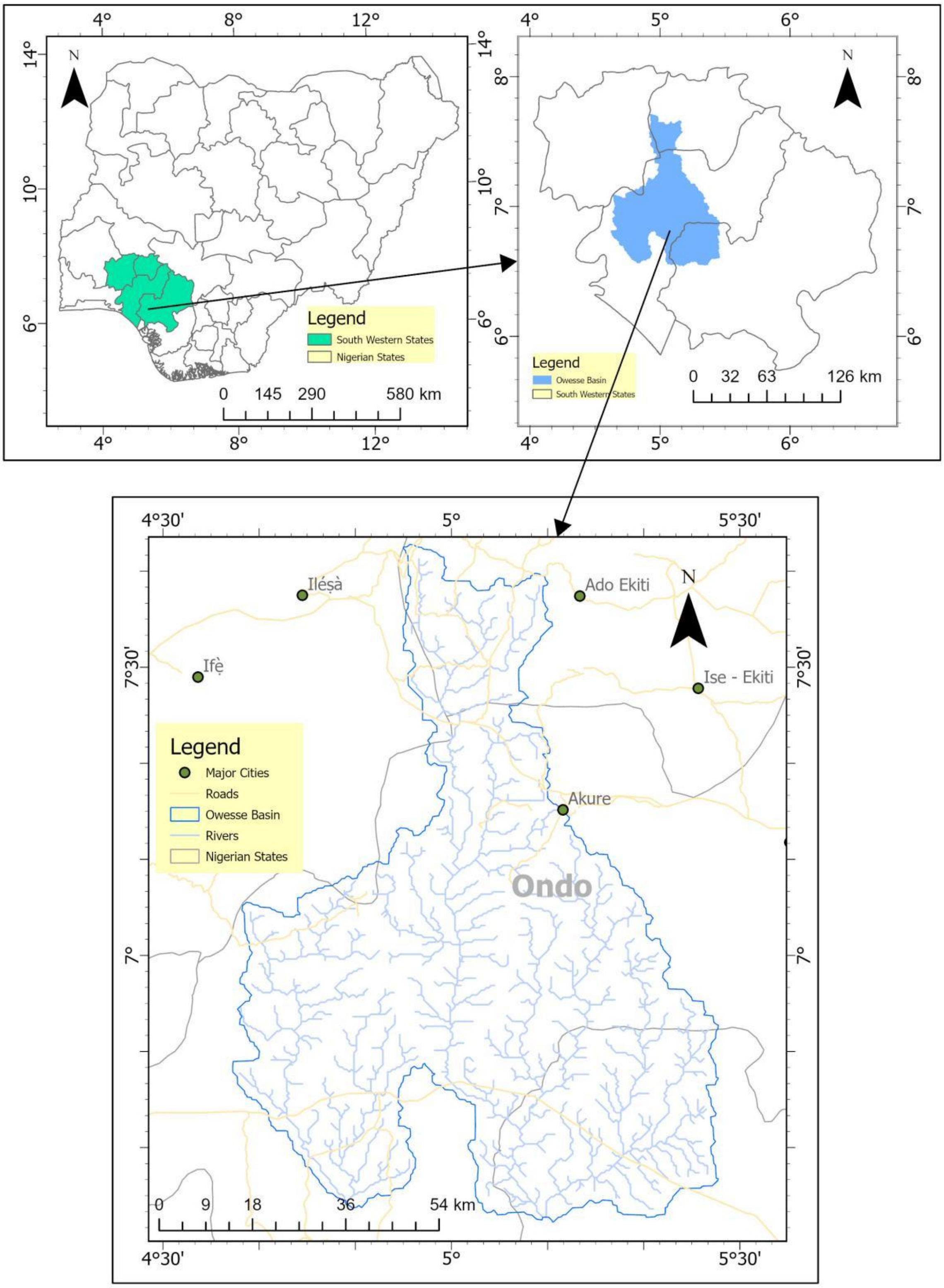

Figure 1: Location and spatial extent of Owesse River basin area.

Table 1: Data types and Details

Data Type	Source	Purpose	Date
Landsat Imageries TM, ETM+ and OLI-TIRS (30m resolution	Earthexplorer	Landuse/land cover	1994,2004,2014,2024
DEM (SRTM) (30m resolution)	USGS/CGIAR-CSI	Watershed analysis	2020
Shapefile of Nigeria, Southwest	OSGOF	To generate boundary and maps	2024

2.3 Data pre-processing

The data was pre-processed to guarantee data quality and consistency throughout the epochs. In order to reduce some of the distortions from the atmosphere and the sensor, Dark Object Subtraction (DOS) method was applied for radiometric calibration and atmospheric correction. All data sets were geometrically corrected and co-registered to the UTM Zone 31N and WGS 84 coordinate system. Quality Assessment (QA) band masking was used to reduce cloud and shadow effects and all images were cropped to the study area boundary. To improve discrimination of land cover, false colour composites were created from bands 4–3–2 (NIR-Red-Green) for Landsat TM/ETM+ and bands 5–4–3 (NIR-Red-Green) for Landsat OLI. The spectral separability was enhanced using image enhancement techniques, such as contrast stretching. To make sure the analyses were consistent, all the data sets were resampled and standardized to a spatial resolution of 30 m (Lu et al., 2004; Jensen, 2015).

2.4 Image Classification

Land use and land cover (LULC) types were classified in the Owesse River Basin for the following years: 1994, 2004, 2014 and 2024 by using a supervised classification approach. The Maximum Likelihood Classification (MLC) algorithm was adopted because it is generally considered to be effective and widely used in remote sensing studies (Jensen, 2015; Lu et al., 2004). This approach uses the most likely class for each pixel, and assumes that the spectral responses for each land-cover class are normally distributed.

The training data were representative samples of forest, light vegetation, built-up areas, water bodies, and barren land, which were selected using field experience, visual interpretation, and information from high-resolution reference imagery. These samples were used to generate the spectral signatures and for guiding the classification process within a GIS. The maps were subjected to post-classification processing to enhance accuracy, such as filtering and correcting misclassified pixels. LULC maps generated were used for change detection, intensity analysis and fragmentation analysis, and were validated by applying the conventional accuracy assessment procedure.

Intensity analysis quantified LULC changes in magnitude, rate and direction for the intervals 1994 to 2004, 2004 to 2014 and 2014 to 2024 as well as the category and transition levels (Foley et al., 2005).

We analyzed fragmentation with FRAGSTATS metrics to quantify landscape composition and configuration (McGarigal et al., 2012). Class Area (CA), Percentage of Landscape (PLAND), Number of Patches (NP), Patch Density (PD), Edge Density (ED), Landscape Shape Index (LSI), and Patch Cohesion Index (COHESION) were used to represent spatial extent, fragmentation, landscape complexity, and connectivity.

Intensity and fragmentation analyses complement each other to gain insights for both temporal dynamics and spatial structure of LULC change in the basin.

3.0 Results and Discussion

Figure 2 shows the Land Use and Land Cover (LULC) distribution within the Owesse River Basin, comprising forest, built-up areas, barren land, water bodies, and light vegetation. The forest class was the dominant land-cover type throughout the study period, covering 5,187.06 km² (82.70%) in 1994, 4,839.78 km² (77.16%) in 2004, 4,455.35 km² (71.03%) in 2014, and 4,163.29 km² (66.38%) in 2024. This indicates a continuous decline in forest cover over the 30-year period.

3.1 Land Use/Land Cover

The Owesse River Basin land-use and land-cover (LULC) changes from 1994 to 2024 show a trend of decreasing natural forest cover, significant growth in degraded vegetation (light forest), and an increase in built-up and barren areas. This path is typical of the landscape changes that have occurred in the southwest of Nigeria as a result of urban sprawl, population growth, and anthropogenic pressures on the landscape. In the mid-sized cities, for instance, Akure, increases in built up areas attributable to urban growth have been reported with vegetated areas being sacrificed during the process (Oyinloye & Kufoniyi, 2013). Similarly, urbanization and land development have been found to significantly affect natural ecosystem in other LULC studies from the southwestern Nigeria setting, with similar trend of vegetation loss and land conversion to built-up and bare lands (Arowolo et al., 2018). The study shows that, at the national and regional level, population growth and urban expansion all the time threaten forest ecosystems, which are already under pressure due to the fragmentation, deforestation, and alteration of ecosystems (Seto et al., 2012). The same regional patterns are observed in continental level studies across Africa, where forest cover change is related to demographic, agricultural and economic factors, seeing the loss and fragmentation of dense vegetational cover in the biodiverse regions (McGarigal et al, 2012).

The results are consistent with the identified drivers of natural land-cover loss and increasing landscape heterogeneity in tropical and subtropical regions (Lambin et al., 2003; Foley et al., 2005), such as urban expansion and agricultural intensification, which occurred globally. These comparisons collectively validate the fact that land-use change dynamics in the Owesse Basin are similar to the wider LULC change trends observed in West Africa and other regions globally, and reinforce the need to develop sustainable land-use planning and conservation measures that will help to reduce further forest degradation and habitat loss in the basin.

3.2 Change detection

Figure 3 shows considerable and consistent changes in LULC categories during the period from 1994 to 2024 in the study area. The forest category lost 1,023.77 km² (19.74%) of its land surface, with the most extensive reduction recorded from 2004 to 2014, implying increased land use transformation activities. On the other hand, there was an increase in the built-up category by 145.54%, which shows fast-growing urbanization especially after 2014. There was also an extensive increase in the barren category, implying widespread land disturbances. Light vegetation also increased by 83.29%.

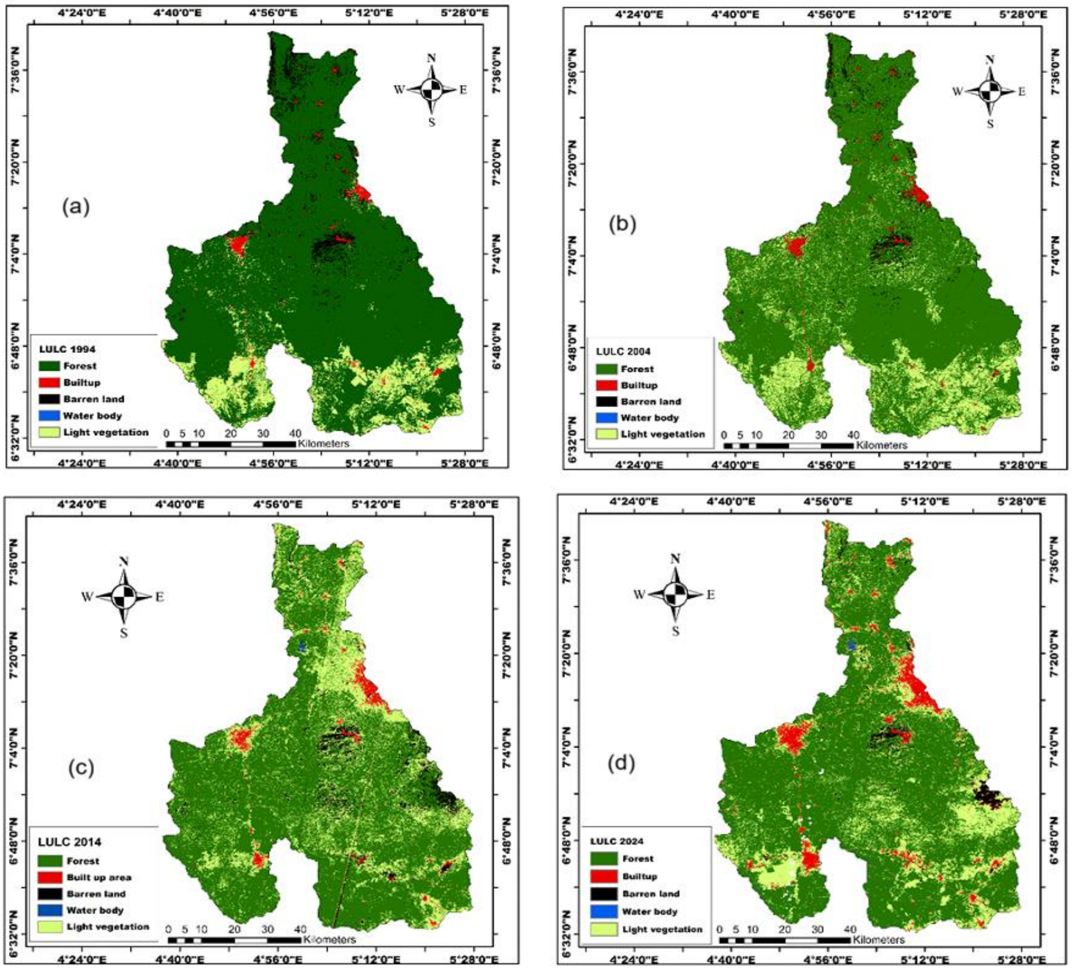

Figure 2: Land use and Land Cover Decadal representation of the Owesse River basin (a) 1994, (b) 2004, (c) 2014, and (d) 2024.

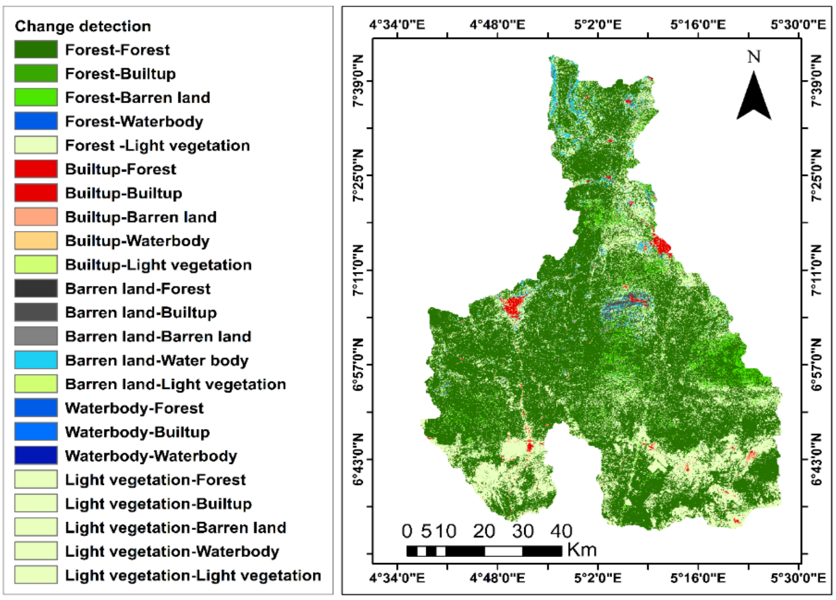

Figure 3: Land-use/land-cover change detection map (1994–2024).

3.2 Analysis of Forest loss

It can be observed that there is a consistent reduction in forest cover in the Owesse Basin from 1994 to 2024 (Figure 4). While forest was the predominant land use in the basin in 1994, accounting for 82.70% of the land area, the share reduced gradually to 66.38% in 2024. The initial decrease from 1994 to 2004 was slow due to agriculture development and peri-urban growth. This period saw the sharpest decrease in forest cover from 2004 to 2014 as a result of increased deforestation from urbanization and agriculture. Forest cover also reduced slowly during the years from 2014 to 2024.

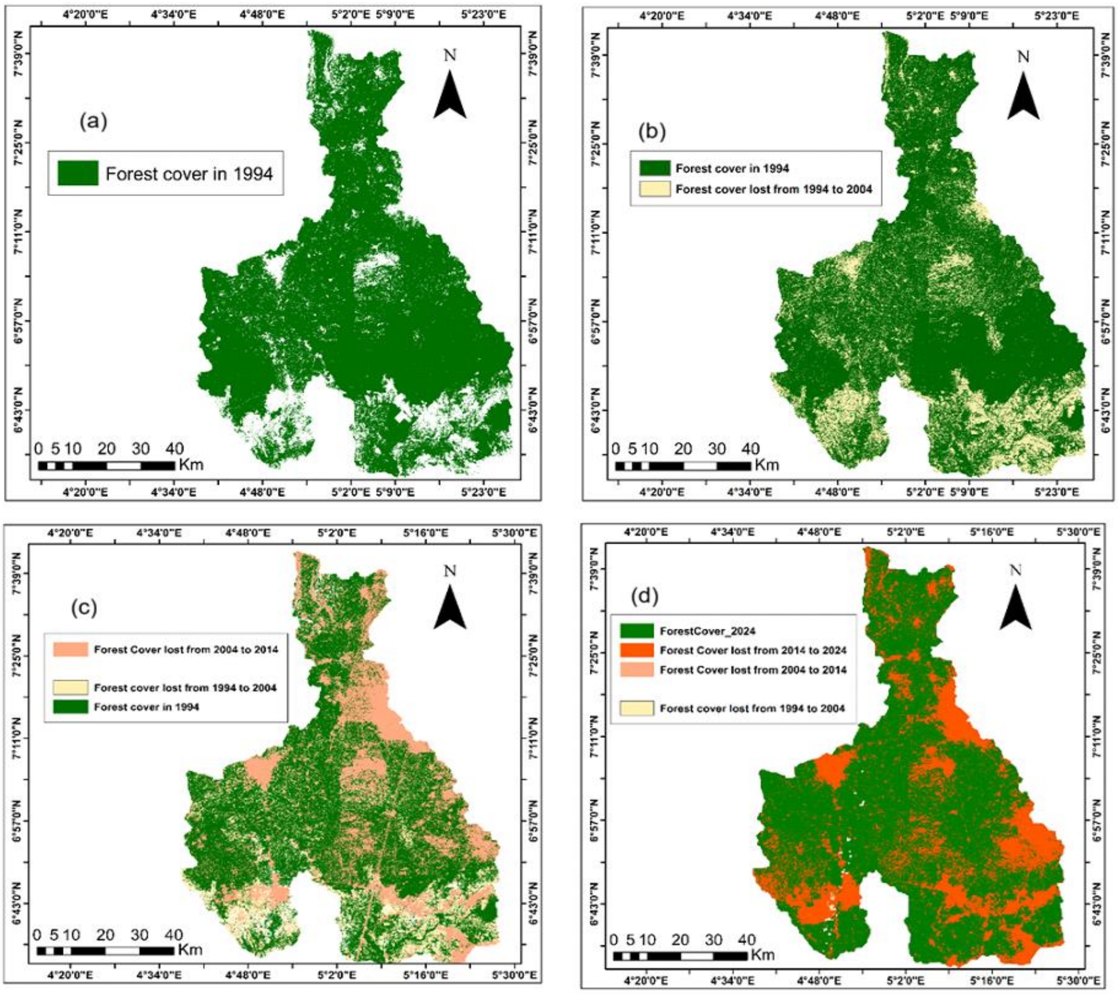

Figure 4: Decadal cover loss in of the Owesse River basin (a) 1994 (b) 2004 (c) 2014 and (d) 2024.

3.3 Intensity analysis of Owesse basin (1994–2024)

From the intensity assessment for the interval level, there is evidence of temporal variability in terms of changes in land use and land cover in the Owesse Basin between 1994 and 2024 (Figure 5). The first interval of 1994–2004 had the lowest rate of annual change (1.63%) that was lower than the benchmark value (2.61%), thus reflecting slower landscape changes in this period. On the other hand, the second interval of 2004-2014 recorded the highest value (3.48%) that was higher than the benchmark level and reflected the most intense period of land use and land cover change.

3.4 Interval- and Category-Level Land Change Dynamics

Figure 6 shows the Intensity assessment of the LULC changes in the Owesse Basin using interval data reveals that the process changed from low intensity (1.63% per annum, 1994–2004) to high intensity (3.48%, 2004–2014) and finally became moderate at (2.71%, 2014–2024), implying continued pressure from the humans in the basin albeit declining. The forest was among the active categories in the loss with the greatest net loss of (−0.89%) in 2004–2014 period but gained slightly with 0.65% in the recent past decade, which is indicative of partial recovery. On the other hand, the built-up areas were continuously increasing with the highest percentage increment of 1.69% per annum in 2014–2024. Similarly, the barren land and the light vegetation exhibited fluctuating changes, suggesting alternation between degradation and forest conversion processes. Water bodies, which had increased during 1994-2004, may be linked to hydrological activities following deforestation.

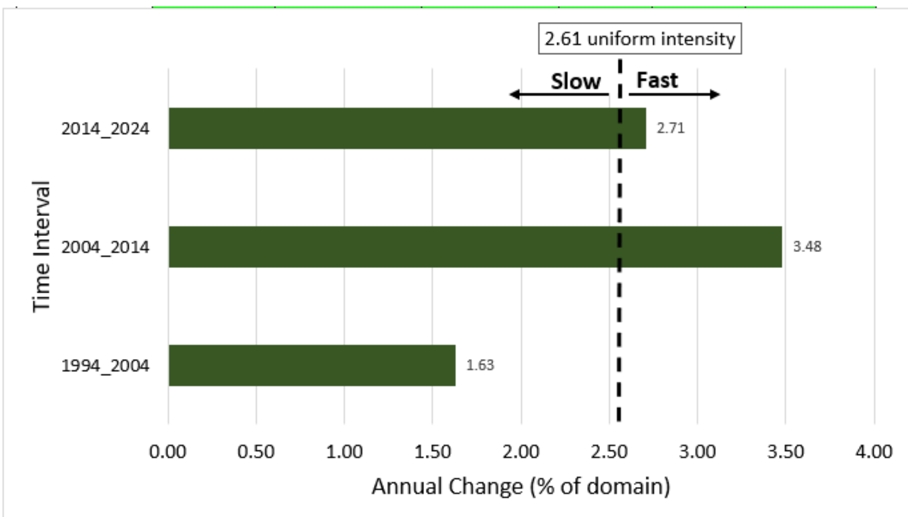

Figure 5: Interval-level intensity analysis of land use/land cover dynamics in Owesse basin (1994-2024).

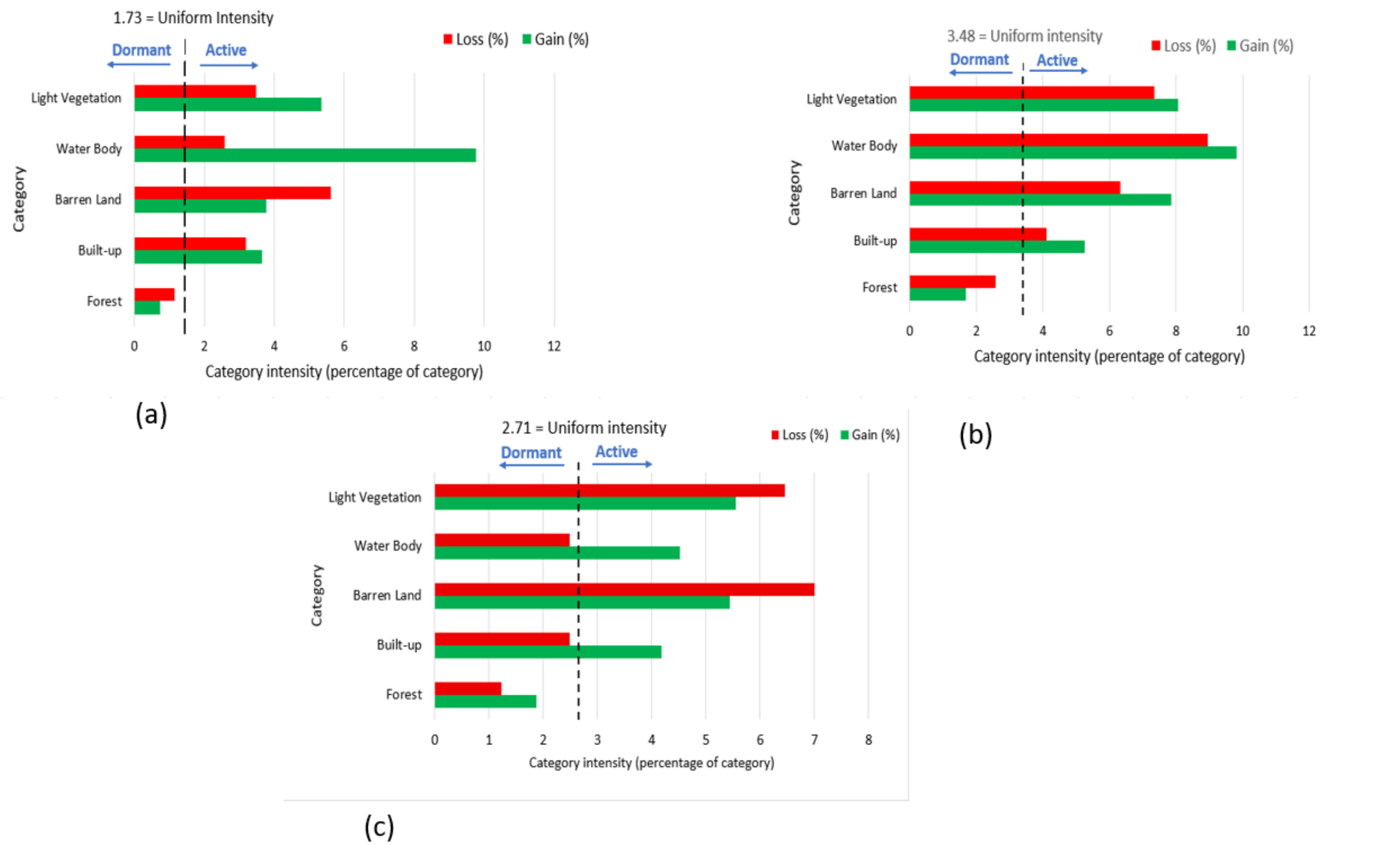

Figure 6: Decadel category-level gain and loss intensity of LULC classes (a) 1994 - 2004, (b) 2004-2014 and (c) 2014 - 2024.

3.5 Transition level of Forest loss in Owesse Basin

The transition analysis for the Owesse basin between 1994 and 2004 and again between 2004 and 2014 indicates that the forest clearance was primarily focused on water and light vegetation, and the degree of intensity was higher than the uniform reference standard, meaning that there was significant land transformation involving productivity and vegetation. Barren land and built-up land were mostly avoided, which suggests that the forest clearance primarily involved the transformation of natural land (Figure 7). The year 2014 to 2024 indicates that light vegetation was the primary target of transformation, while others were avoided. Overall, these patterns highlight that forest loss was systematically directed toward agricultural and transitional lands, with reduced pressure on urbanized and degraded areas in recent years.

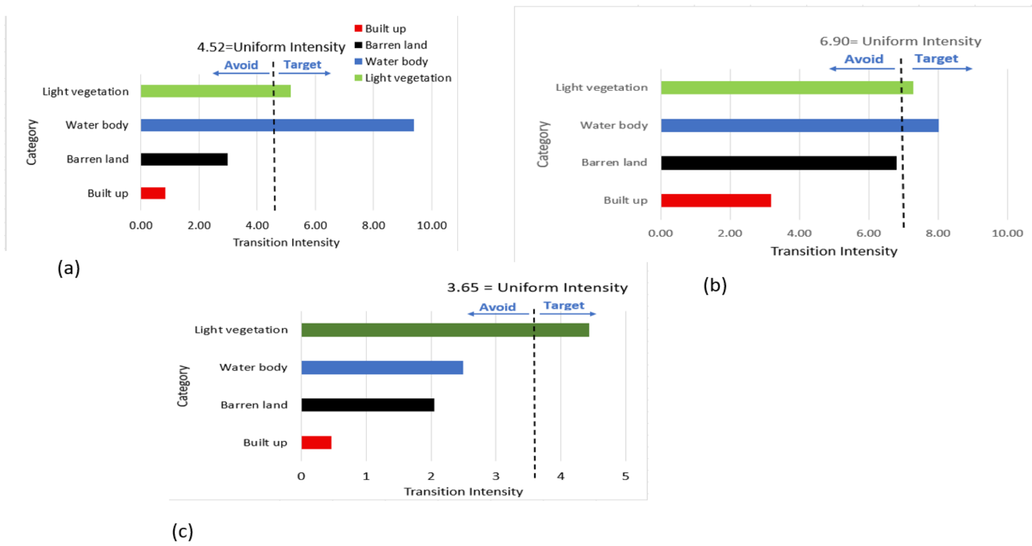

Figure 7: Transition intensity from forest to other land-use categories (a) 1994-2004, (b) 2004–2014 and (c) 2014-2024

3.6 Spatial and Temporal Patterns of Landscape Fragmentation in the Owesse Basin

The Owesse Basin's (1994-2024) fragmentation analysis has shown considerable change in its structure owing to the loss of forest cover, growth of light vegetation and human intervention. Forest cover declined from 518,706 ha (82.7%) to 402,722 ha

(57.1%), while patch number and density increased until 2004 after which patches consolidated into larger fragments; however, high cohesion was maintained (over 99%). The extent of light vegetation grew from 11.6% to 30.3%, with its peak in fragmentation characteristics recorded in 2004-2014, while the growth of built-up land is continuous due to urbanization. Changes in barren land and water bodies show that there is conversion of land and partial recovery of ecosystems (Table 2).

3.6 Landscape diversity and configuration changes

Landscape structure temporal analysis in Owesse Basin (1994-2024) as shown in Table 3 indicates a trend of fragmentation and partial consolidation. NP values rose from 67,447 in 1994 to 135,569 in 2014 but dropped to 98,244 in 2024, with PD experiencing a similar trend, showing maximum fragmentation in 2014. In a similar trend, LSI values increased to 183.55 in 2014 and reduced to 101.89 in 2024, signifying a change in the edge complexity of the landscape. CONTAG values fell from 73.38% in 1994 to 60.86% in 2014 but increased slightly to 63.94% in 2024, whereas the aggregation index (AI) declined significantly during peak fragmentation and recovery in 2024. Conversely, SHDI and SIDI values increased gradually, suggesting a rise in landscape heterogeneity.

The pattern results from the fragmentation process that took place in the period of 2004 and 2014 due to various activities such as expansion in agriculture, settlement, and infrastructural changes, commonly documented in the southwestern part of Nigeria (Oyinloye et al., 2021; Olorunfemi et al., 2023). As the fragmentation increased, there was a rise in the human disturbance, which declined later as fragmentation processes stabilized in the landscape (Olayiwola & Lawal, 2019). Other parts of West Africa have experienced the same process in the recent past.

In conclusion, the findings suggest a shift in a landscape that was initially homogenous towards one which is increasingly heterogeneous due to human interventions. There are implications for habitat connectivity, ecosystem services, and watershed stability, suggesting the importance of sustainable land use planning in the basin.

Table 2: Class Level Matrices for the Owesse River basin for 1994, 2004, 2014 and 2024

Year	LID	CA (ha)	PLAND (%)	NP	PD (per 100 ha)	ED	LSI	COHESION
1994	Forest	518706.45	82.7037	10675	1.702	37.74	83.7459	99.98
	Builtup area	9840.24	1.5689	7806	1.2446	5.08	80.8474	96.23
	Barren land	25820.1	4.1168	24910	3.9717	16.95	165.9879	95.46
	Water body	2.43	0.0004	21	0.0033	0.0048	4.5455	14.22
	Light vegetation	72817.38	11.6102	24035	3.8322	27.04	158.4503	99.28
2004	Forest	495977.76	76.0798	25618	4.0846	79.4051	178.4012	99.9858
	Builtup area	10537.92	1.6802	7709	1.2291	5.6846	87.2745	96.5753
	Barren land	18181.98	5.899	27678	4.413	15.7074	183.168	89.6525
	Water body	73.44	0.0117	352	0.0561	0.1195	21.5345	46.6702
	Light vegetation	102415.5	16.3294	70140	11.1833	65.2029	320.5333	98.4045
2014	Forest	442713.06	68.585	17432	2.7793	70.946	168.7419	99.9474
	Builtup area	13039.56	2.074	6382	1.0175	6.301	87.0525	98.3791
	Barren land	30995.37	6.9418	39776	6.3418	24.741	220.7743	95.509
	Water body	427.77	0.0682	255	0.0407	0.1541	11.6739	96.9404
	Light vegetation	140029.56	22.326	71724	11.4355	81.1629	341.2942	99.0037
2024	Forest	402722.41	57.072	11173	0.9149	28.5507	129.5366	99.9744
	Builtup area	29016.09	3.376	12789	1.0472	6.082	108.9683	98.5545
	Barren land	14063.04	8.1516	9628	0.7884	3.6993	95.1884	95.8108
	Water body	759.87	1.0622	884	0.0724	0.285	31.5217	92.726
	Light vegetation	178855.61	30.34	63711	5.2171	33.7643	287.0576	98.241

Table 3: Changes in Landscape Diversity and Configuration (1994, 2004, 2014, and 2024)

YEAR	NP	PD	LSI	CONTAG	SHDI	SIDI	AI
1994	67447	10.75	88.04	73.38	0.60	0.22	93.46
2004	131497	20.97	166.53	67.52	0.65	0.36	87.51
2014	135569	21.61	183.55	60.86	0.81	0.45	86.23
2024	98244	8.04	101.89	63.94	1.10	0.61	94.54

4.0 Conclusion

Land Use and Land Cover Changes in the Owesse River Basin have been marked by significant changes since 1994 to 2024. In this regard, forests have significantly declined from being the major land cover type within the region. This decline can be attributed to the continued deforestation and environmental degradation within the Owesse river basin. Major changes took place between 2004 and 2014 during the period of intense infrastructure developments, urbanization, and agricultural practices.

The increase in light vegetation within the basin signifies environmental degradation, while the steady growth in the proportion of bare land and built-up area indicates increased land use changes and surface disturbance. Furthermore, transition analysis highlights that there has been constant pressure on the natural forest ecosystem to undergo land use changes in light vegetation, bare land, and built-up areas.

Moreover, landscape fragmentation analysis also reveals that there is a notable change in the nature of the spatial configuration from relatively intact forest landscape systems to a more fragmented landscape system. This change has been shown through the rise in patch abundance, edge effects, and patch complexity, and the fall in core forests. Despite the slight spatial reorganization of the landscape during recent years, the trend has brought about greater landscape instability and vulnerability.

In summary, the trends noted point to a more fragmented and anthropogenic landscape system with significant consequences for biodiversity conservation and environmental sustainability.

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