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Spatial Analysis of Structural Changes and Floristic Distribution of Forest Landscapes in the Centre-West Region of Burkina Faso

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Abstract

Land use and occupation dynamics impact landscape structure, diversity, richness and balance of vegetation cover. The aim of this study is to describe the process of fragmentation of the forest landscape from 1990 to 2020 and its effects on the degradation of the floristic characteristics of the vegetation in the Central West region of Burkina Faso. To achieve this, satellite data were collected and processed as part of a mapping approach to describing the landscape and the different types of landscape fragmentation. Mapping indices of landscape fragmentation (relative richness, change process, patch zones, Shannon diversity index) were also calculated. These indices were programmed in Idrisi Selva's *Landscape Pattern and change process analysis* module. Spatio-temporal analysis revealed that in 1990, the landscape was dominated by natural vegetation formations, covering 66.33% of the territory. By 2020, these had been degraded to 44.80% by farmlands. The mapping analysis of indices also showed that the study area is characterized by four types of landscape fragmentation, including attrition, aggregation, creation and dissection. We also observed an abundant homogeneity, diversity and richness of conservation areas with legal and land tenure status. However, the structure is heterogeneous in landscapes outside protected areas and in areas under human occupation. This shows the crucial role played by conservation areas in preserving and balancing the diversity of vegetative cover in the study area.

Keywords

Change Process, Fragmentation, Remote Sensing, Landscape, Burkina Faso

1. Introduction

Most landscapes around the world have undergone changes to meet the needs of humanity (Dourma et al., 2019). Globally, no one knows exactly how much tropical forest has been destroyed, but it is clear that these forests are being significantly reduced by agriculture, pastoral activities and urbanization (Chakravarty et al., 2012; Sikuzani et al., 2024). In terms of forest cover, 30% of the earth's surface is covered by forests. The United Nations Convention to Combat Desertification, considers land use patterns and forest resources as key elements for our survival and in the fight against land degradation and desertification (Odum, 2024). However, in general, the degradation of vegetation cover contributes to changing the structure of the landscape (Tente, Oloukoi, & Toko, 2019). Deforestation and loss of diversity are regularly observed worldwide, and the conservation of vegetation cover for better carbon sequestration is a major and new concern for humanity (Odum, 2024; Sikuzani et al., 2023). With this in mind, according to the FAO (2012) in Solly et al. (2020), around 80 countries worldwide, including 03 in Africa, succeeded in slowing the rate of deforestation from 2005 to 2010. Changes in land use and occupation patterns contribute to global-scale interactions, resulting in forest fragmentation and biodiversity loss (Awuh, Officha, Okolie, & Enete, 2018). Landscape dynamics are also known to negatively affect the state of ecosystems, contributing to the degradation of ecosystem services (Huang et al., 2023). But at the same time, landscape can be seen as the product of the relationship between a society and its environment which is subject to change according to historical context (Robert, 2021). Climate factors along with socio-economic factors through human activities underpin the current structure of the Sahelian landscape, particularly in West Africa (Ouoba, 2013; Sadda et al., 2016). In Niger, Senegal and Burkina Faso, the areas covered by forest formations represent respectively 6.6%, 11% and 14% of their respective territories (Triplet, 2009). These areas are constantly subject to degradation, and the FAO (2016) estimated that from 2000 to 2010, 7 million hectares of vegetation formations were lost in tropical Africa due to farmlands every year.

Data processing techniques are constantly being improved for a better understanding of the processes of landscape transformation by fragmentation. Landscape structure analysis is based on the trend towards ecosystem degradation (Sanon et al., 2019) and the fragmentation of large blocks of patches into much smaller patches. It is invaluable for mapping and assessing the heterogeneity of landscapes Lemenkova (2024). This analysis method was developed by Bogaert et al. (2004). It represents a major advance in the study of tropical landscapes and the conservation of forest resources. The authors, Mama, Alassane, Traoré, Sinsin, & Bogaert (2020a) and Mama et al. (2020b) used this statistical approach based on patches to characterize the spatial structure of the landscape. The results of the analyses cover dominance, fragmentation rates, Shannon diversity indices, specific richness and forms of fragmentation by land-use category (Tente, Oloukoi, & Toko, 2019; Tchibozo & Domingo, 2014). The integration of various algorithms, for example, into landscape analysis has recently led to the conclusion that the Random Forest (RF) is the most appropriate for this kind of analysis (Dede et al., 2024). Ribeiro et al. (2016), showed also how to model and integrate Google Earth Engine (GEE) for a better analysis and interpretation of edge effects. In addition, the effects of borders on the structure and functioning of landscapes were analyzed on the basis of parameters considered essential such as tree basal area (TBA), variation in tree diameter at breast height (DBH) and the amount of standing and downed dead-wood (Pöpperl & Seidl, 2021). Authors have also looked at edge dynamics at the periphery of complex networks to analyze controllability of these complex network's peripheries (Pang et al., 2019). Regarding the Simpson's Diversity Index (SDI), Herrera et al. (2023), note the lack of reliable criteria for its selection. For him, another index combining H and HB (Brillouin index) is more appropriate in the context of analyses that take into accounts the links between ecology and thermodynamics. In addition, following inadequacies in diversity measurement techniques, ecologists over the last decade have introduced two parameters including coverage as a method for equalizing samples, and hills diversity including a range of diversity metrics (Roswell, Dushoff, & Winfree, 2021). Regarding the Shannon diversity index, Konopiński (2020), after identifying the biases in the use of this index, proposed the use of Zahl's unbiased estimator for better results. Species richness has significant effects on ecosystem functioning, but the similarities and differences of these effects are still poorly understood. To improve the analysis of the effects of plant diversity on ecosystem functions, Jiang et al. (2021), used different techniques such as, analysis of variance (ANOVA), the Shipley test of d-separation, a model based on theoretical knowledge, and standardized path coefficients used to measure direct or indirect effects of the predictors.

However, Clark Labo has implemented this technique from Bogaert et al., 2004 in its "implication of the Idrisi selva LCM model" module. Thus, this module offers an immense opportunity for the scientific community to spatialize landscape structures, biodiversity and specific wealth for better decision-making in terms of conservation.

In Burkina Faso, from 2002 to 2013, 19% of the territory was degraded, 9% of which is made of forests. In the Central West region, this degradation is the result of high demand for energy wood. According to estimates, 3,154,475 tons of wood equivalent have been exploited, 84% of which is extracted from forests (MEEVCC, 2017). Socio-economic changes, as well as agricultural and pastoral production systems, could explain these deforestation trends (Bensaid, 2007; Solly et al., 2020; N'Guessan, Akpa, Yao, & Dja, 2019). Yet, forests constitute a "cornerstone" for conservation strategies (Guariguata, Cronkleton, Duchelle, & Zuidema 2017) and a heritage to be preserved and passed on to new generations. Certain species that make up the forests are threatened with extinction though they have socio-economic (Diatta et al., 2021), cultural and medicinal (Ouôba et al., 2006) interests. Therefore, they must be conserved and then reproduced in the parks and protected areas identified to perpetuate and conserve them.

In the Central West region, the conservation of vegetation formations is crucial because of their role in sustaining human life, protecting soils against erosion, facilitating the water cycle (infiltration, runoff) and fixing the soil.

This study of the spatial and temporal evolution of land use dynamics will provide a better understanding of the evolution of landscape structure through its various forms of fragmentation in the Central West region, using a mapping approach.

2. Methodology and Materials

2.1. Overview of the Central West Region of Burkina Faso

The Central West region is located between 11˚ and 13˚ north latitude and between 1˚30 and 3˚ west longitude (**Figure 1**). It is bordered to the south by the Republic of Ghana; to the north by the North region; to the east by the Central, Plateau Central and Central South regions; and to the west by the Boucle du Mouhoun and South-West regions. The study area encompasses a diversity of conservation areas. It includes six (6) classified forests and wildlife reserves.

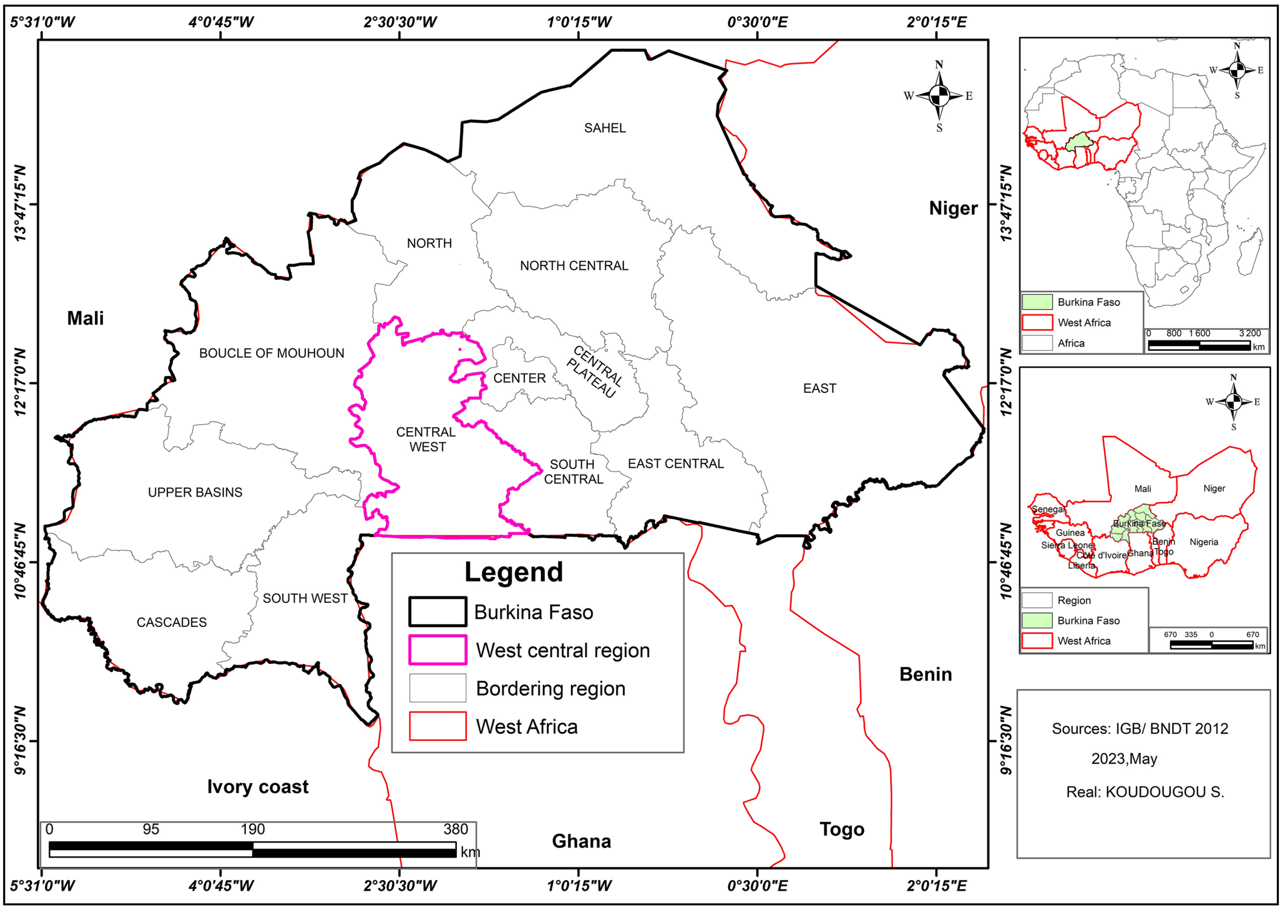

Figure 1. Localization central west region.

The main vegetation formations are shrub savannahs, tree savannahs and gallery forests. The inter-annual average cumulative rainfall is 859.57 mm. The Central West region therefore belongs to the Sudanian phytogeographic domain (Fontes & Guinko, 1995). Its altitudes range from 223 m to 527 m. As for the soils, they are essentially hydromorphic, derived from the association of lithosols on ferruginous cuirasses and tropical ferruginous soils reworked on sandy-clay material at dept.

2.2. Types of Images Used

To establish the land use dynamics, image sensors including Landsat 4 TM (*Thematic Mapper*), Landsat 7 ETM (*Enhanced Thematic Mapper*) and Landsat 8 Olitir (*Operational Land Image - Thermal infraRed Sensor*) from 1990, 2000, 2010 and 2020 were used (**Table 1**). Spatial coverage of the area required a mosaic of four scenes. These images have a resolution of 30 × 30 m and were collected from USGS/NASA sites. The images from October, November and December of each year were selected.

Table 1. Summary of remote sensing data characteristics.

Study area	Type of images	Path/Row	Resolution (m^2)	Composition
Central West Region	Landsat 4 TM 1990	195/051; 195/052 196/051; 196/052	30 × 30	Pir/R/V
	Landsat 7 ETM 2000 et 2010	195/051; 195/052 196/051; 196/052	30 × 30	
	Landsat 8 Olir-tir	195/051; 195/052 196/051; 196/052	30 × 30	

2.3. Supervised Classification of Satellite Images

The classification methodology for mapping consists of three stages: pre-processing, classification and post-processing.

2.3.1. Geometric and Radiometric Correction

Geometric errors can affect the positioning and estimation of surface areas. To compensate for this, a simple georeferencing correction was carried out using a correctly calibrated raster of the study area. The method used for image-to-image georeferencing consisted of using the Map algorithm. The result is a correctly aligned image, with no overflow and in the local coordinate system. The following path *Map/Registration/Select GCPs: Image to Image*.

This radiometric correction consisted of improving the quality of the image before processing. The calibration procedure followed the preprocessing/calibration utilities/Landsat calibration process.

2.3.2. Processing

The second phase of image processing involved color composition (Near

Infrared/Red/Green), image exploration to recognize land use classes, and *ROI* selection. The ENVI software *jump-to-location* algorithm was also used. This algorithm allowed to go back in time and identify the exact nature of the ROI at a given point. This *ROI* recognition process enabled us to better distinguish land use classes, taking us closer to the reality on the ground. The separability of land use classes was subsequently measured. In addition, the *Maximum Likelihood* classification method was used to redistribute pixels into land use classes.

2.4. Post Classification

2.4.1. Confusion Matrix Validation

The class quality was measured using the confusion matrix. Then, the Kappa index was used to assess the accuracy of the classification. According to Cohen (1960), the Kappa coefficient or Kappa index is excellent when it is >0.81; good when it ranges from 0.80 to 0.6; moderate when it ranges from 0.60 to 0.21; bad when it ranges from 0.20 to 0.0; very bad when it is below 0.

2.4.2. Field Validation Using Control Points

The validation of the classification involved comparison among the classified images and the color compositions, use of external sources such as BDOT (Land Use Database), Google Earth, field checking associated with *ND visualizer* analysis. Corrections were thus necessary to improve distinction among the various classes showing poor separability.

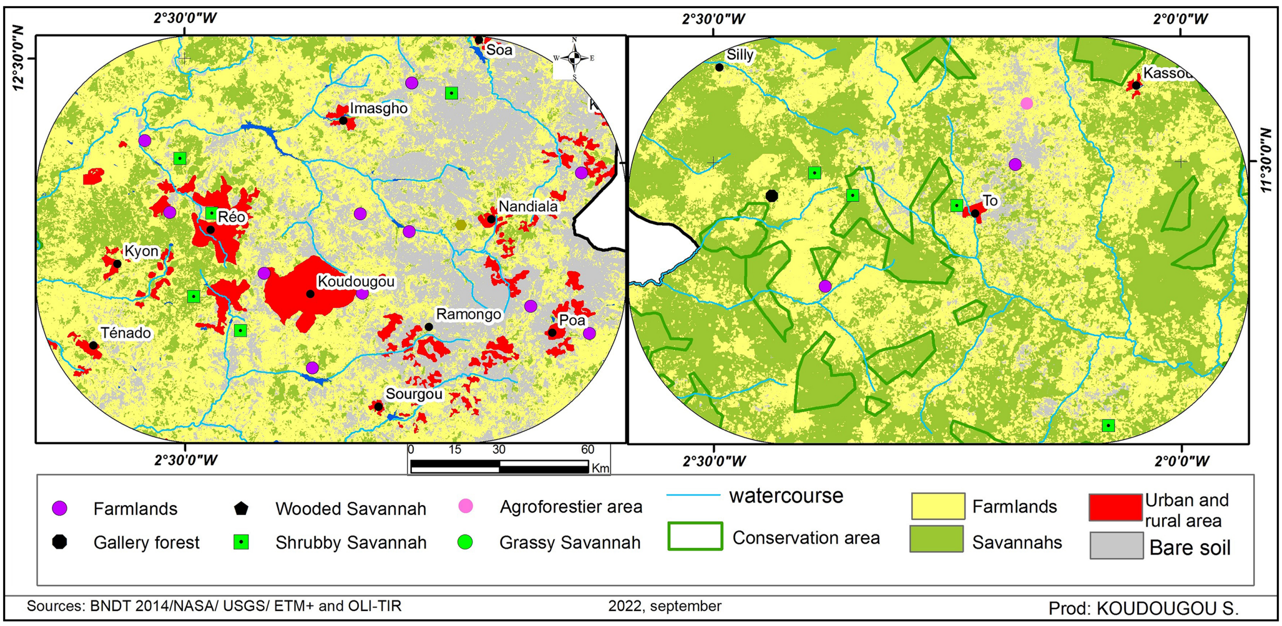

Figure 2. Distribution of control points.

The validation of the classification involved comparison among the classified images and the color compositions, use of external sources such as BDOT (National Land Use Databases), Google earth, field checking associated with ND visualizer analysis. Around fifty control points were defined for field verification. Figure 2 is an extract to illustrate their spatial distribution. Corrections were thus necessary to improve distinction among the various classes showing poor separability.

2.4.3. Correction of Land Use Units

The corrections involved the habitat and gallery forest classes that had not been associated during classification. The aim was to minimize confusion concerning these classes. The correction process consisted in digitizing gallery forests and habitats. These classes were respectively digitized from the color composition and on *Google Earth*. Spatial analysis operators were then used to subtract and insert the layers.

2.5. Landscape Pattern and Change Map

The equations used in this research were described by Bogaert, Ceulemans & Eysenrode (2004), Tente, Oloukoi, & Toko, (2019) to describe the process of landscape fragmentation.

2.5.1. Mapping Analysis of Change Processes

Land use maps were prepared in advance. Landscape pattern and change process analysis were carried out using Idrisi Selva's *Implication/Landscape Pattern and change process analysis* module. This module was used to generate landscape fragmentation patterns and change processes such as standardized entropy, relative richness, patch zones and change processes. Indeed, the *Change process* module compares previous and subsequent land cover maps and measures the nature of the ongoing change within each land cover class. To do this, it uses a decision tree procedure that compares the number of land cover patches present in each class between the two periods, with changes in their zones and perimeters. The result is a map in which each land cover class is assigned the category of change it undergoes: deformation, displacement, perforation, shrinkage, enlargement, attrition, aggregation, creation, dissection and fragmentation.

2.5.2. Standardized Entropy Mapping

It refers to Shannon entropy, standardized by the maximum entropy for the number of land cover classes involved. This measurement system is needed to map biodiversity. It is calculated from the following formula (1):

$$E = -\left(\sum_{i=1}^{k} Pi + \ln\left(Pi\right)\right) \Big/ \ln\left(n\right) \quad (1)$$

where:

n: the number of classes in the image;

Pi: the i-class proportion of all classes in the image;

i: the index of classes within the neighborhood;

k: total number of classes in the neighborhood (block of identical pixels);

ln: natural logarithm.

The result is an index ranging from 0 to 1, where 0 indicates a case of uniform land cover within the neighborhood and 1 indicates maximum possible diversity of land cover within the neighborhood.

2.5.3. Relative Richness Mapping

This is another measurement system of land cover class diversity, measured according to formula (2) below:

$$R = \frac{n}{n\max} * 100 \quad (2)$$

where n refers to the number of different classes in the neighborhood and $n$max refers to the maximum number of possible classes.

2.5.4. Edge Density Mapping

Edge density is a simple system of measuring fragmentation. Edge density is characterized by the number of adjacent pixel pairs in the neighborhood that are different from each other with respect to the maximum number of different pairs possible.

2.5.5. Patch Zone Mapping

The patch zone groups adjacent pixels of a similar land cover category into patches, calculates their surface areas and generates an image in which each pixel expresses the patch zone to which it belongs.

3. Results

3.1. Classification Quality

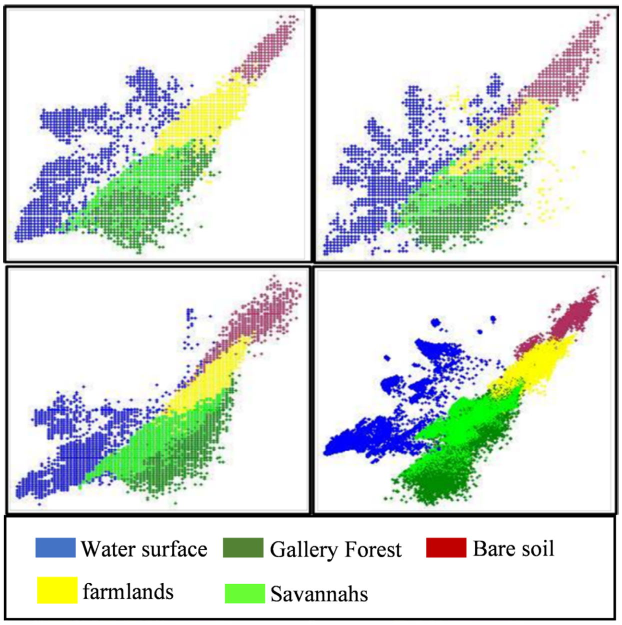

Figure 3. Separability associated with the image classified in 1990, 2000, 2010, 2020. Source: Result of processing with N-D visualizer.

The assessment of the classification quality of Landsat images showed that, overall, 20,377 pixels out of 27,669 were well classified, giving an overall accuracy of 73.65%. For 2010 images, the overall accuracy is 87.30%. However, the confusion matrix associated with the 2020 image shows an overall accuracy of 19,382/27,669 pixels, or 70.05%. Figure 3 shows the levels of separability among classes, balance and/or imbalance among classes. It illustrates good balance between gallery forest, savannah, farmlands and bare soil classes, but low separability between savannahs and gallery forests.

3.2. Spatio-Temporal Landscape Dynamics in the Study Area

3.2.1. Trends in Land Use from 1990 to 2020

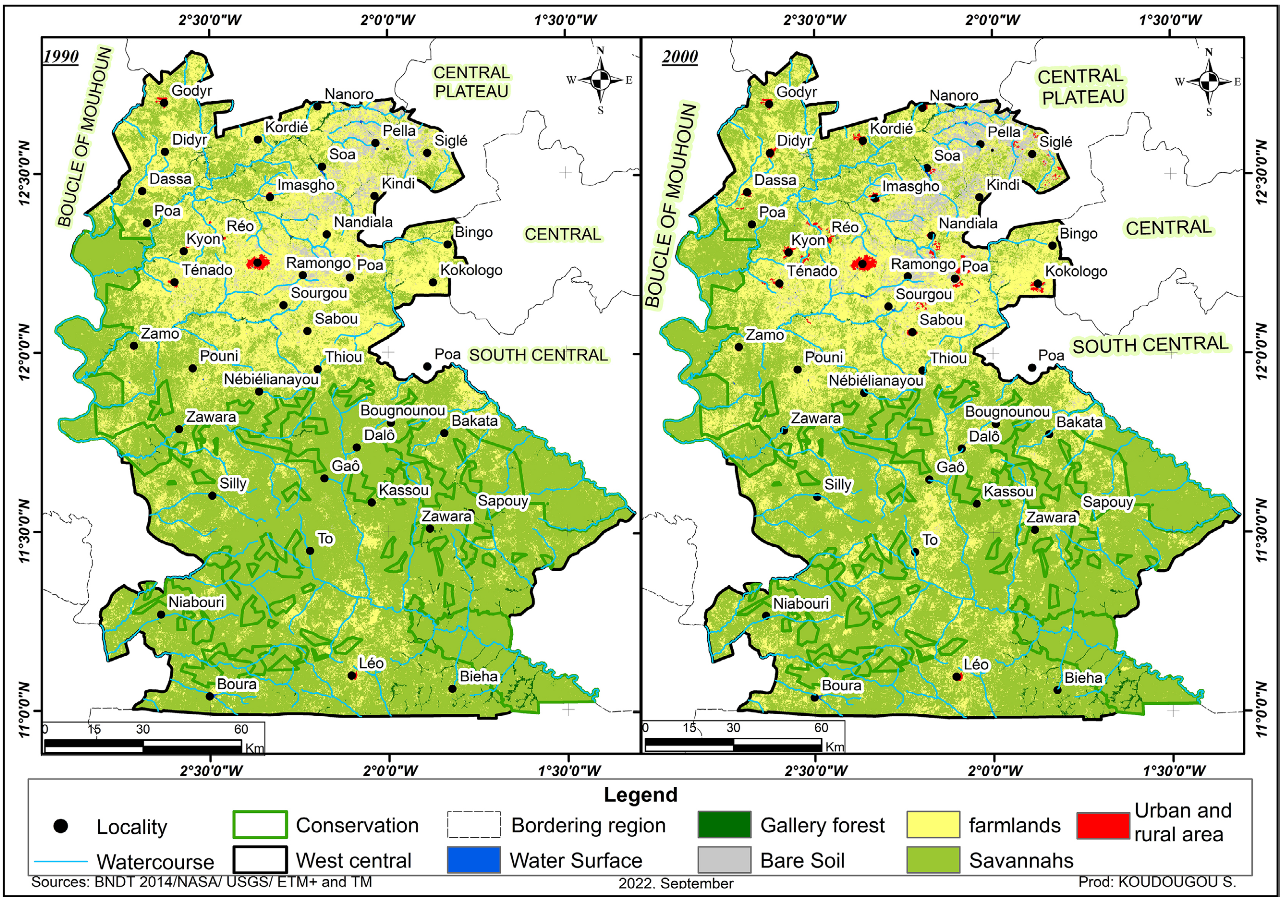

Figure 4. Land use dynamics from 1990 to 2000.

The trends in land use units show changes in 1990, 2000, 2010 and 2020 (Figure 4 and Figure 5). In 1990, the study area was dominated by natural vegetation formations, occupying 66.39% of the spatial extent. This was followed by cropland, which covered 24.52%. Crops were located around urban and rural agglomerations, which accounted for 0.23% of the spatial extent. Bare soil accounted for 2.07%, and was more prevalent along the north-west diagonal running through the Boulkiemdé province. At that time, surface water retention was very minimal

(0.14%). In 2000, the trend in vegetation formations was downwards (**Figure 4**), but they still dominated, occupying 62.56% of the total surface area of the study area. This was followed by cropland, which increased in area (25.52%). The same applies to bare soils (2.07%), which increased in area compared with 1990, to the detriment of vegetation formations. The gradual increase in the surface area of urban and rural areas has undoubtedly led to the loss of vegetation formations and an increase in the surface area of farmlands, as well as bare and eroded soils in the north-western part of the study area. This situation has led to a rush of people into the vegetation formations in search of fertile land and grazing.

The construction of water retention basins in the study area during this period led to an increase in surface area (1.73%). In fact, the impoundment of the Soum dam in the department of Nanoro in 2010 increased the surface area of water from 0.14% to 0.30%. It is the largest water retention infrastructure in the region and the fourth largest dam in Burkina Faso. Urban and rural areas continue to expand, resulting, in the same time, in an increase in peri-urban agricultural land. Vegetation formations, which accounted for 66.39% of the study area in 1990, covered only 51.44% in 2010. By 2010, the boundaries of conservation and forest management areas were already becoming more distinct under the threat of agricultural areas. Some units under forest management since 1990, like those in the northern part of the Nazinon forest management project, had already been downgraded, as they were heavily occupied by humans. The gallery forest and bare, eroded soil formations have experienced a decline in area. By 2020, threats to conservation areas were persistent. The Cassou-Bakata, Taré and Niabouri forest management projects in the department of Niabouri were occupied by farmlands. The south-western limits of the Nazinga game range, the Nazinon classified forest and the southern limits of the Thiogo classified forest have been encroached upon by the expansion of cultivated areas. In 2020, this led to a decrease in the spatial extent of vegetation formations (44.80%) in favor of agricultural areas (42.75%). The proportion of urban and rural areas continued to grow, reaching 1.68%. Water areas remained more or less stable. In contrast, there was a resumption of degradation of sown lands, leading to the appearance of eroded and bare soils (**Figure 5**, **Figure 6**).

3.2.2. Transitions in Land Use Evolution from 1990 to 2000

The transition matrix from 1990 to 2000 reveals that 19.85% of farmlands remained stable, and over 12.34% of the area of vegetation formation was converted to farmlands (**Table 2**). At the same time, they gained 0.97% and 0.02% of their surface area at the expense of bare soils and gallery forests respectively. Urban and rural habitats were built on agricultural lands, bare soils and vegetation formations. The area of bare soils remained more or less stable, at 2.07% in 1990 and 3.05% in 2000. Only 52.82% of vegetation formations and 1.06% of gallery forests remained stable. Indeed, with regards to the changes observed, vegetation formations have gradually evolved into farmlands, and have favored continued degradation towards bare, eroded and stripped soils.

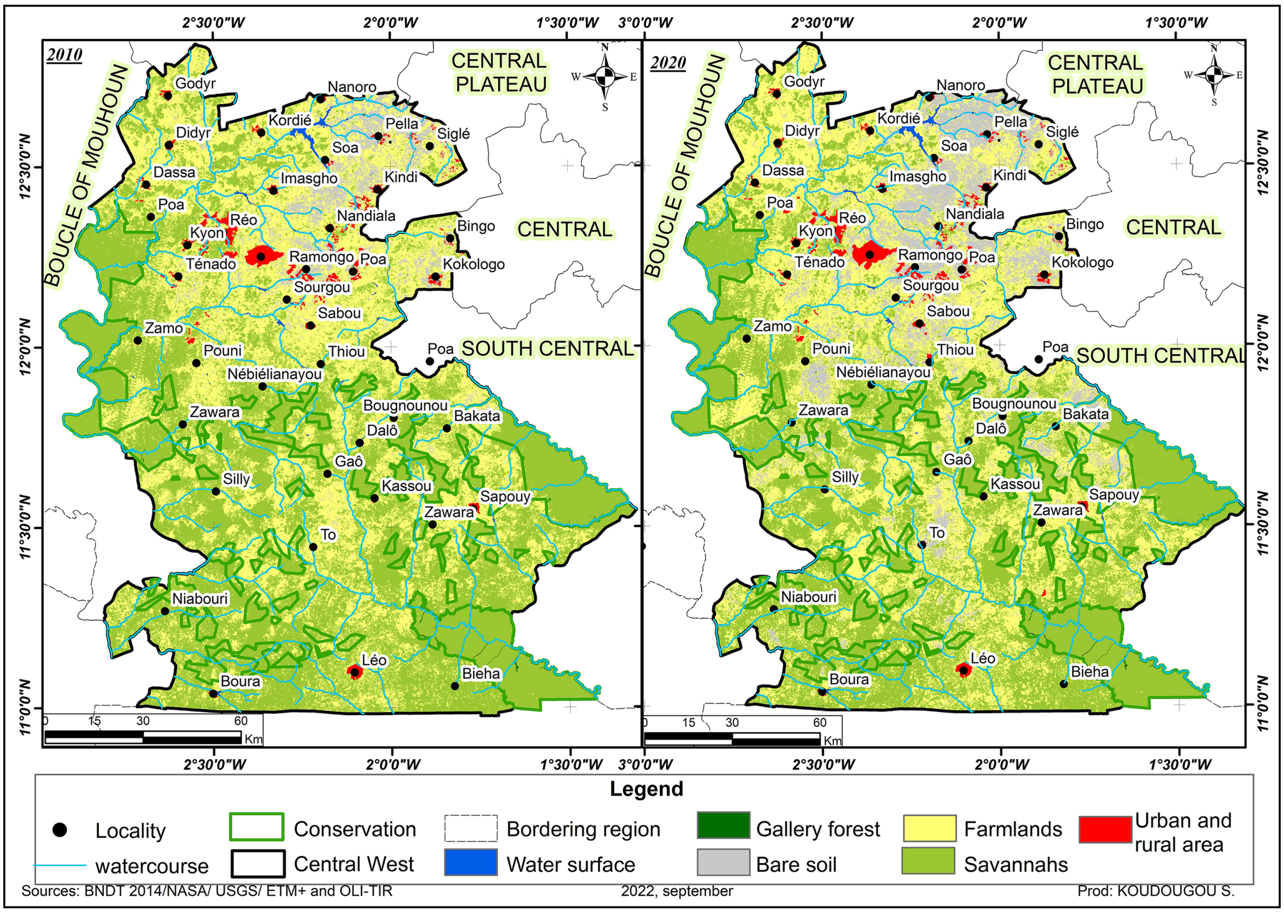

Figure 5. Land use surface areas from 2010 to 2020.

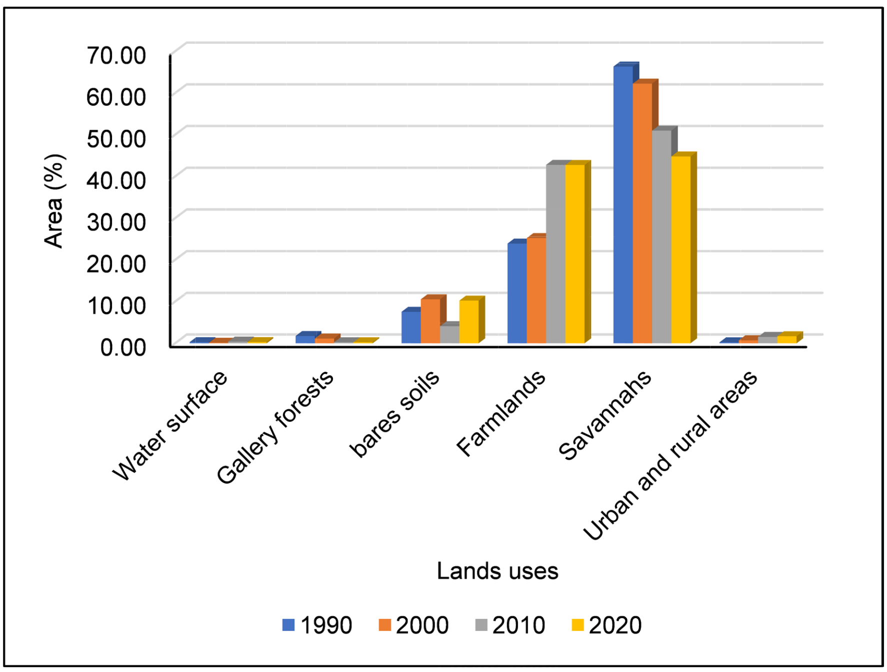

Figure 6. Spatial and temporal evolution of land use units in 1990, 2000, 2010 and 2020. Source: Landsat image processing in 1990, 2000, 2010 and 2020.

Table 2. Transition matrix from 1990 to 2000.

		Area in 1990						Total 2000
		Water surface	Gallery forests	Bare soils	Farmlands	Savannahs	Urban and rural areas	
Area in 2000	Water surface	**0.05**	0.02	0.00	0.04	0.03	0.00	0.14
	Gallery forests	0.00	**1.06**	0.00	0.02	0.06	-	1.14
	Bare soils	0.00	0.01	**1.99**	0.97	0.09	0.00	3.05
	Farmlands	0.01	0.13	0.07	**19.85**	12.34	0.00	32.40
	Savannahs	0.00	0.52	0.01	8.21	**53.82**	0.00	62.56
	Urban and rural areas	0.00	0.00	0.00	0.43	0.04	**0.23**	0.71
Total 1990		0.06	1.73	2.07	29.52	66.39	0.23	**100.00**

Source: Statistical processing of Landsat TM, ETM and OLITIR images.

3.2.3. Transitions in Land Use Evolution from 2000 to 2010

Over the period 2000 to 2010, farmlands accounted for 17.43% of the area of vegetation formations (Table 3). In addition to this, there was also a gradual transformation of water surfaces, gallery forests and bare soils into farmlands. The transformation of water surfaces into farmlands is due to non-compliance with the rules or the non-respect for the easement strips around dam lakes and water retention basins. This is also the case with the exploitation of river banks within gallery forests. As for the bare soils that have become farmlands, improved techniques for recovering and conserving water and soil could be at the origin of this transition. The construction and impoundment of the large Soum dam in 2010 of the Nanoro department, in the extreme north-west of the study area, led to an increase in the surface area under water from 0.14% to 0.30%. However, the degradation of river banks may be responsible for the decline in gallery forests from 1.14% to 0.25%.

Table 3. Transition matrix from 2000 to 2010.

		Area in 2000						Total 2010
		Water surface	Gallery forests	Bare soils	Farmlands	Savannahs	Urban and rural areas	
Area in 2010	Water surface	**0.08**	0.04	0.00	0.09	0.09	0.00	0.30
	Gallery forests	-	**0.24**	0.00	0.00	0.01	-	0.25
	Bare soils	0.00	0.02	**2.99**	0.88	0.11	0.00	4.00
	Farmlands	0.02	0.25	0.06	**24.71**	17.43	0.00	42.48
	Savannahs	0.03	0.58	0.00	6.05	**44.78**	0.00	51.44
	Urban and rural areas	0.01	0.00	0.00	0.68	0.14	**0.70**	1.53
Total 2000		0.14	1.14	3.05	32.40	62.56	0.71	**100.00**

Source: Statistical processing of Landsat TM, ETM and OLITIR images.

3.2.4. Transitions in Land Use Change from 2010 to 2020

The transition matrix from 2010 to 2020 shows that gallery forests evolved by gaining areas from savannahs (Table 4). Bare soils evolved by gaining a share of the surface area of agricultural areas and vegetation formations. Rural and urban areas gained 0.01% of the surface area of farmlands and 0.1% of the surface area of bare soils. If the dynamics has been gradual in the farmland class, it is undoubtedly because it has gained 6.68% of the surface area of vegetation formations and 6.03% of the surface area of bare soils. These dynamics occurred at the expense of the area of vegetation formations. In the same trend, 0.28% of water surfaces, 0.24% of gallery forests, 3.86% of bare soils, 35.93% of farmlands and 1.51% of urban and rural areas remained stable from 2010 to 2020.

Table 4. Transition matrix from 2010 to 2020.

		Area in 2010						Total 2020
		Water surface	Gallery forests	Bare soils	Farmlands	Savannahs	Urban and rural areas	
Area in 2020	Water surface	**0.28**	0.00	0.00	0.01	0.00	0.00	0.29
	Gallery forests	0.00	**0.24**	0.00	0.00	0.01	-	0.25
	Bare soils	0.01	0.00	**3.86**	6.03	0.32	0.01	10.23
	Farmlands	0.01	0.00	0.12	**35.93**	6.68	0.01	42.75
	Savannahs	0.00	0.01	0.00	0.38	**44.40**	0.00	44.80
	Urban and rural areas	0.00	-	0.01	0.13	0.03	**1.51**	1.68
Total 2010		0.30	0.25	4.00	42.47	51.44	1.53	**100.00**

Source: Statistical processing of Landsat TM, ETM and OLITIR images.

3.3. Landscape Fragmentation and Structure in the Study Area

The analysis of landscape fragmentation focuses on indices (edge density and change process).

3.3.1. Landscape Change Process

From 1990 to 2000, landscape fragmentation was characterized by the dissection (62.57%) and creation (33.24%) of new landscape units. The decade from 2000 to 2010 was characterized by attrition (51.70%) and aggregation (42.47%). From 2010 to 2010, the phenomena of aggregation, attrition and creation of new landscape units increased in the study area (Table 5).

The consequences of this landscape change process include a reduction in connectivity among habitats, an increase in forest edge density and the isolation of the remaining habitat patches.

3.3.2. Forest Edge Density Index

Forest edge density is characterized by values ranging from 0 to 0.600. In 1990, values ranged from 0 to 0.653. In 2000, the extreme values for land isolation were

0.619. Edge values in 2010 and 2020 are identical to those in 1990 and 2000 respectively, but the areas occupied by the 0.072 and 0.196 values are larger and are spread across the entire study area. The low values are found in vegetated areas and in classified areas. This could be explained by the fact that vegetated areas display a homogeneous agrarian landscape, whereas in agricultural areas, edge density is more characterized due to the heterogeneity of the landscape and the significant human activity in these areas (Figure 7).

Table 5. Spatial transformation processes observed in the study area.

Type de fragmentation	Landscape transformation rate (%)		
	1990-2000	2000-2010	2010-2020
Agrégation	3.05	42.47	42.77
Attrition	1.14	51.70	44.92
Creation	33.24	5.83	12.01
Dissection	62.57	-	0.29

Source: Fragmentation modelling based on Idrisi Selva's process.

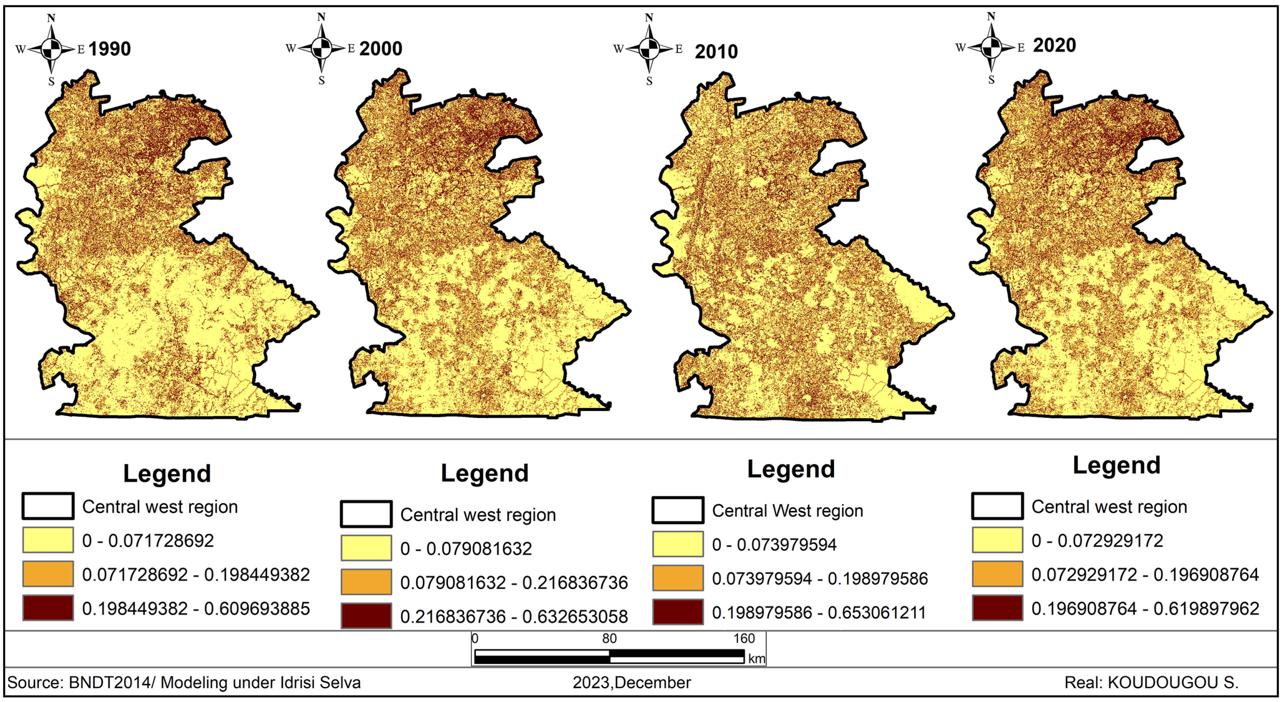

Figure 7. Edge density dynamics in the study area from 1990 to 2020.

3.3.3. Evolution of Patch Zones in the Study Area

Observation of patch zone dynamics from 1990 to 2020 reveals a highly fragmented agrarian landscape characterized by heterogeneity of landscape pixels based on temporal evolution (Figure 8).

The patch structure is very homogeneous in conservation areas with legal status, i.e., game ranges and the classified forests of Nazinon, Thiogo and Labas.

Neighborhoods are more or less homogeneous in forest management areas and widely scattered in agricultural production zones. Surface areas vary from 0.09 ha (minimum value) to 1494882.25 ha (maximum value). The average is 737786.44 ha, with a mean standard deviation of 631587.82 ha.

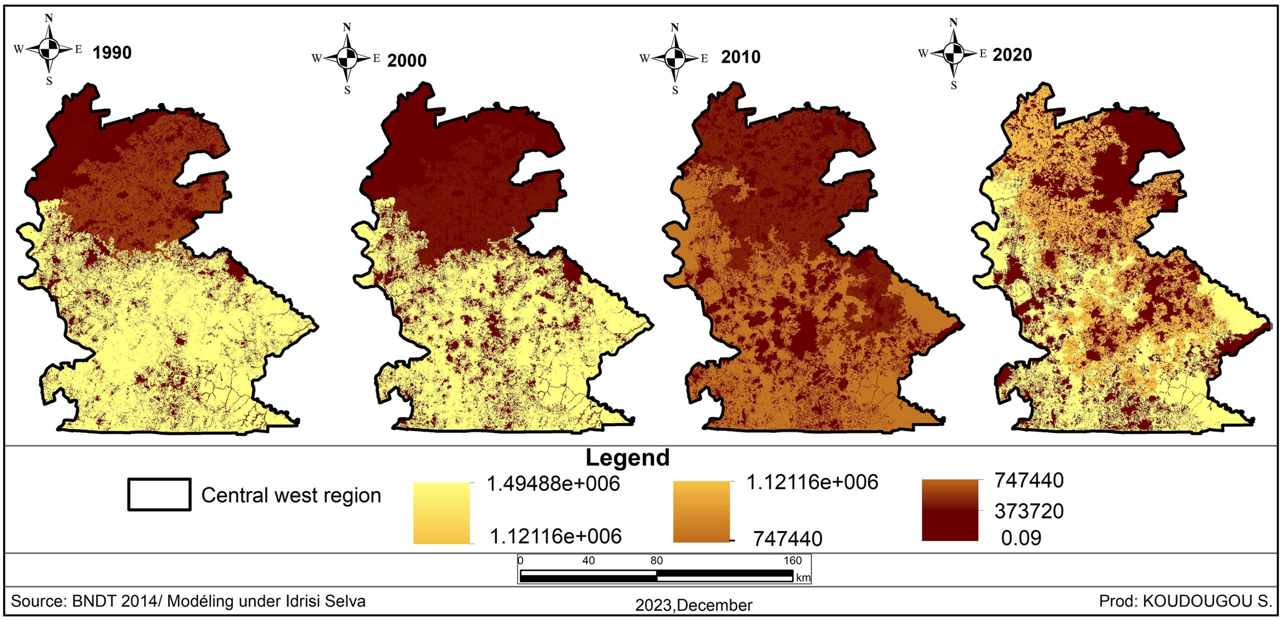

Figure 8. Patch zone dynamics from 1990 to 2020.

3.4. Biodiversity and Forest Landscape Richness Analysis

3.4.1. Standardized Entropy Index or Shannon Biodiversity

In general, mapping analysis of the standardized entropy index shows that habitat diversity was progressively reduced from 1990 to 2020. In fact, in 1990, diversity was abundant in the central part of the study area, as well as in the conservation areas. By 2000, this diversity was gradually reduced at the limits of forest management and conservation areas. In 2010, this diversity of vegetation cover in the Central West region had been limited within the boundaries of forest management and conservation areas. In 2020, only the conservation areas had a good diversity of vegetation cover. The forest management in the central part of the study area, which also served as biodiversity pools, has undergone a gradual decline and showed, in 2020, a heterogeneous diversity in their structure (Figure 9).

3.4.2. Relative Landscape Richness in the Study Area

Relative richness values range from 16 to 100. The lowest pixel values indicate an abundance of richness. The highest values represent low land cover richness. The analysis of this index has enabled us to observe changes in the richness of vegetation cover in the study area. The mapping analysis shows that in 1990, there was a homogeneous distribution of richness in the study area. But the fragmentation that enabled the creation and dissection of the landscape from 1990 to 2000 led to a decline in this richness in 2000 (**Figure 10**). The same applied in 2010, when landscape fragmentation characterized by aggregation and attrition gradually emphasized these dynamics. Finally, the decade from 2010 to 2020 (**Figure 10**) saw a number of fragmentations (aggregation, creation, attrition) which largely led to a decline in the richness of vegetation cover in the study area.

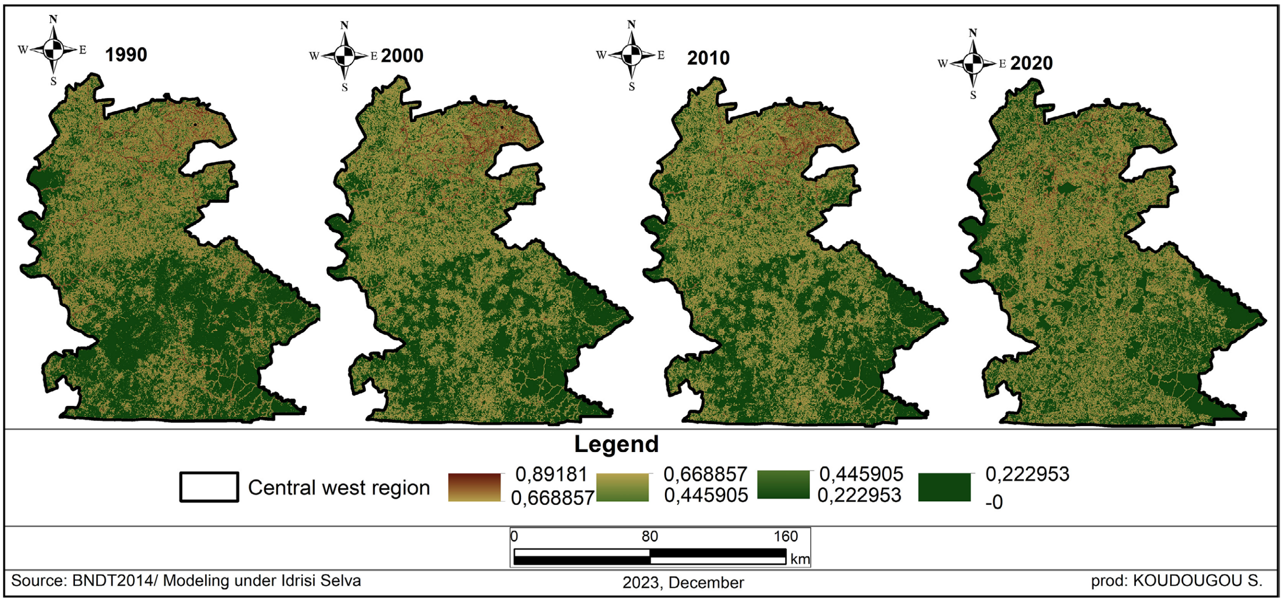

Figure 9. Dynamics of Shannon index evolution from 1990 to 2020.

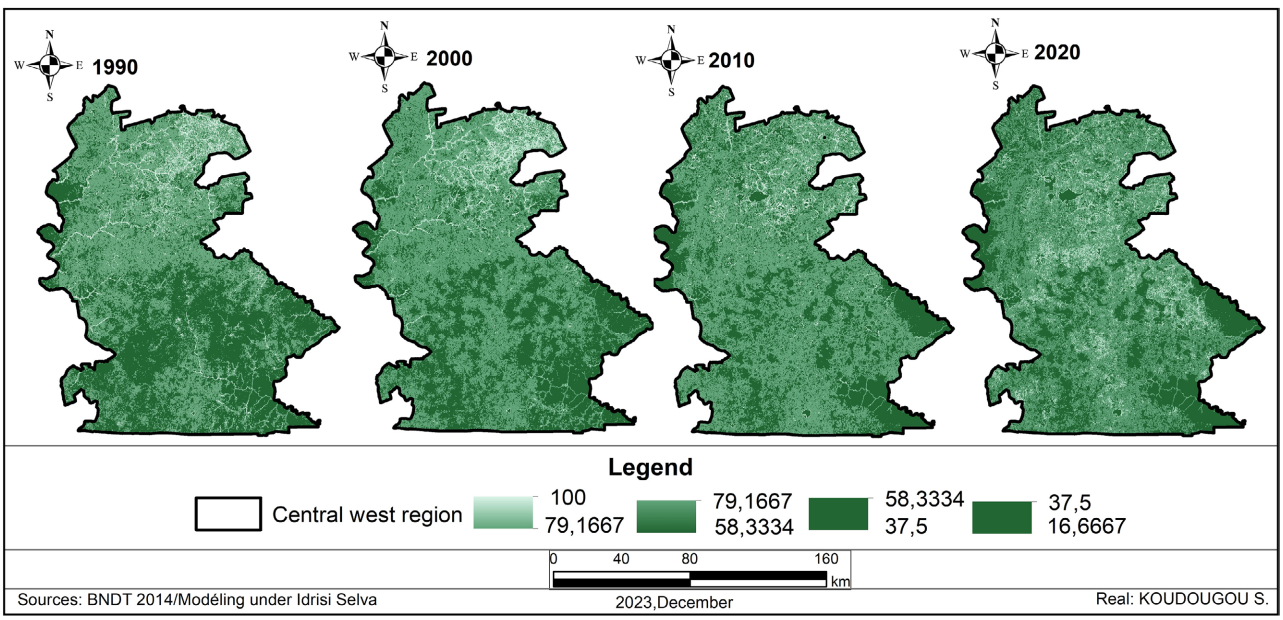

Figure 10. Dynamics of relative richness evolutions from 1990 to 2020.

4. Effect of Degradation on Species Distribution

According to local perceptions, the endangered species in the local Morée language are *Compagnadega (acacia goumaensis), Pegenenga (Accacia nilotica), Zamenega (Acccia macrostachya), Kâkalga (Afzelia africana), Toega (Andasonia digitata), Kieghaligha (Balanites aegyptiaca), Voaaga (Bombax costatum), Puturpuga (Calotropis procera), Kombrisaka (Cassia siberiana) Securidata longepedunculata*. This perception corroborates those of the floristic inventory, which shows that these same species have an importance value index of less than 7, as shown in Table 6. We note that most of these species are important in the savannahs and their extinction seems imminent in the agroforestry territory and the fields and gallery forests. Consequently, the savannahs appear to be the only shelters of diversity in the region.

Table 6. Value index for some endangered species.

Species name	Importance value indexes (IVI)						
	(IVI)	shrubby savannah	grassy savannah	wooded savannah	agroforestry area	farmland	forest gallery
Acacia macrostachya	6.82	***10.70***	***17.18***	-	1.12	4.57	3.31
Acacia nilotica	0.87	-	-	-	-	0.57	-
Adansonia digitata	0.34	-	-	-	-	0.57	-
Afzelia africana	0.34	-	-	-	-	0.57	-
Balanites aegyptiaca	4.88	***11.86***	***14.15***	-	-	1.71	-
Bombax costatum	2.93	0.63	0.93	***11.12***	5.06	0.57	6.77
Cassia sieberiana	5.49	4.55	***14.50***	-	-	1.14	-
Securidaga longepedunculata	0.74	-	-	-	-	0.57	3.31

Source: 2022, floristic inventory.

In addition to these, several other species are suffering the effects of ecosystem degradation and are threatened with extinction as a result of the advance of the agricultural front. These are the species of: *Kankansinsalaa (Cassia singueana), Kuenga (Combretum glutinosum), Koumbroanga (Crossopteryx febrifuga), Zoanga (Faidherbia albida), Jolga (Grewia bicolor), Wilinwiiga (Guiera senegalensis), Kinkiryobga (Holarrhena floribunda), Kauli (Mitragyna inermis), Ninnoré (Ozoroa insignis), Roaaga (Parkia biglobasa), Noèga (Pterocarpus erinaceus), Wedga (Saba senegalensis), Pelega (Securidata longepedunculata), Taâga (Vitelaria paradoxa), Adhga (Vitex doniana), Lenga (Ximenia africana).*

5. Socio-Economic and Natural Impact on Landscape Structure

There are three main economic activities in the Central West region. These are the production or exploitation of ligneous species, agriculture and livestock farming. The primary needs of the populations (health, economic and food), hunting and livestock rearing have made it possible to understand that there is a close link between the species of bark, pruning's, burns and holes observed on ligneous species. In fact, 99% of the woody species used for firewood production are also species that are pruned and barked. Of the debarked species, 90% are burnt and 85% have holes in their trunks. For example, pastoralists prune trees to feed their livestock during the lean season; farmers prune the trunks of certain species and prune or cut them down to feed and heal themselves. Hunting and the exploitation of non-wood forest products (wood (22.48%) and charcoal (77.18%)) encourage the burning of trees.

In addition, analysis of the observation data shows that the woody species attacked by termites corroborate those showing parasitic attack. The correlation between the variables shows that 62.2% of the species surveyed show traces of termite attack and 75.1% of those are attacked by parasites. Of the 55.7% of woody plants that had been uprooted by erosion, 88.6% were attacked by termites and suffered more damage from the wind.

We can therefore state without hesitation that the combination of man's actions and those of natural impacts is favoring landscape changes in the central west region.

6. Discussion

6.1. Classification Quality Assessment and Land Use Dynamics Analysis

The validation of classification errors was analyzed on the basis of the confusion matrix and field checking. The classification results show that the overall accuracy in 2000 (73.65%) is good, excellent (87.30%) in 2010 and good in 2020 (70.05%) according to Cohen (1960) scale of classification quality. This is a validation approach adopted by several authors (Agbanou et al., 2018; De Wispelaere, 2023; Aboubacar et al., 2023; Adjonou et al., 2019; Sama et al., 2023). The visual interpretation of the *ND visualizer* in this study also helped to visualize in 3D the classes where confusions are more or less strong. The confusion between certain classes is due to the period chosen for this study. In fact, it corresponds to the periods after early forest management fires. The early fire period in the study area extends from October to November. Early fires are seen as a strategy for preserving woody forest resources. This situation therefore increased the confusion between savannahs and gallery forests, which appear on the Near Infrared/Red/Green color composition in a dark tone for savannahs and a mixture of dark tone (turbid water) and green or dark green for gallery forests. The description of land use dynamics focused on the transition matrix analysis. The transition matrix enables the evaluation of discrete transitions and the quantitative diachronic analysis of the landscape (Badiane, Sané, & Thior 2019, Agbanou et al., 2018). This study illustrated the different forms of change observed in the study area from 1990 to 2020. The matrices show a general trend towards the extension of farmlands, bare soils and habitats rather than savannahs and gallery forests. These results support those of Dourma, Atakpama, Folega & al., (2019) and Zoungrana, Visser, De Cannière & al., (2023), who stated that the dynamic is marked by a decline of natural formations in favor of agricultural land formations.

6.2. Structure and Fragmentation of the Agrarian Landscape in the Study Area

The fragmentation analysis showed that the landscape of the Central West region was characterized by very significant fragmentation from 1990 to 2020. The description of landscape structure through indices of relative richness, edge density and patch zone were addressed by Vogt et al., (2007) and showed the impact of landscape fragmentation on its structure in the study area. Thus, these indices in this research revealed the effectiveness and important role of conservation spaces in landscape dynamics. This description also revealed that the legal status granted to a space or habitat helps to protect it effectively against any human pressures that may contribute to the loss and/or isolation of habitats and the decline in biodiversity in the study area. The forms of fragmentation observed include attrition, aggregation, creation and dissection. These results are similar to those of Zoungrana et al., (2023), Sanon et al (2019), Sama et al., (2023), Shafie et al., (2023) who used spots to illustrate levels of landscape fragmentation. By using spots, they showed that landscape dynamics are characterized by landscape enlargement, creation, attrition, dissection and aggregation. This study suggests a more visual and mapping approach that illustrates the different forms of landscape fragmentation. It also identifies areas where landscape richness and biodiversity are abundant or insufficient to help make decisions.

7. Conclusion

Landsat images were used to analyze spatial and temporal dynamics from 1990 to 2020. Remote sensing was therefore used to map and assess land use areas. It also enabled us to establish the change process, represent biodiversity indices (Shannon and species richness) and determine the level of landscape fragmentation. In general, the forest landscape is characterized by creation, attrition and aggregation. These types of landscape fragmentation are at the root of the conversion of vegetation formations into farmlands. There is also landscape homogeneity in protected forest ecosystems and landscape heterogeneity in farmland formations. Finally, to ensure sustainable conservation of the landscape, efforts must be made to legally protect all natural areas that do not have land tenure status.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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