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Spatial Reconstruction Of Landscape Dynamics In The Grand-Balé Catchment Area Between 1976-2022 (Burkina Faso)

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Abstract: In recent years, Burkina Faso has experienced recurrent flooding on a section of National Road No. 1. This area, which is susceptible to flooding, is located in the Grand Balé basin. L'objectif de cette recherche est donc d'évaluer les modifications du paysage dans le bassin du Grand Balé afin d'éclairer les décideurs. The study is grounded in the national topographic database, utilising Landsat images from the MS, TM, ETM+ and OLI sensors from 1976, 1992, 2007 and 2022, in conjunction with verification outputs. The random forest algorithm was utilised for the classification of the images. The results indicate that wooded savannah covered (13.36%) in 2022, in comparison with (21.92%) in 2007, (39.51%) in 1992 and (42.8%) in 1976. The shrub and grass savannah exhibited relatively stable coverage, with 51.64% in 2022, 53.89% in 2007, 40.3% in 1992, and 49.15% in 1976, respectively. This decline in tree cover is offset by an increase in both 'cultivated area' and 'habitat' cover. The former increased from an occupancy rate of (6.91%), (19.04%), (22.72%) to (32.56%), while the latter increased from (0.13%), (0.25%), (0.63%) to (1.76%) in 2022. The analysis of the landscape dynamics in the catchment area reveals a marked shift during the 1976-2022 observation period. The study finds that the cultivated area has undergone a substantial expansion of 371.35%, while the habitat area has experienced a notable increase of 1297.84%, at the expense of tree formations. These results can be used to inform decision-making processes concerning development projects within the catchment area.

Keywords: Burkina Faso, Change mapping, Land use, Catchment area, Grand-Balé

I. Introduction

Burkina Faso is a Sahelian country with an estimated 39,000 km^2 of forest cover, or 14% of its territory [17]. There are 3905 km^2 of national parks, 25,455 km^2 of wildlife reserves and 8,800 km^2 of classified forests [7]. Most of these landscapes are being increasingly transformed by human activities designed to satisfy basic needs (food, health, equipment, etc.) [11]. Human pressure on the natural environment is also reflected in late and uncontrolled bushfires, slash-and-burn agriculture, high demand for fuelwood, overgrazing and population growth. All this pressure is due in particular to a predominantly rural population [3] dependent on natural resources. According to the Ministry of the Environment and the Living Environment [17], the area of forest is shrinking at a rate of 1,050 km² per year. Even the country's protected areas are not spared from this degradation [24], which is marked by poaching, pastoral pressure, farming, logging and bush fires, not to mention the new phenomenon of chemical pollution linked to industry, mining and the expansion of herbicide spraying in agricultural areas [18] (Figure 1).

The natural resource potential of the Grand-Bâlé watershed is also under pressure from natural factors and human activities. Today, the floristic impoverishment of the gallery forests in this catchment is obvious. Indeed, the vegetation is declining not only because of climatic hazards, but above all because of human activities: settlement of migrants in classified areas, grazing of animals, bush fires [12]. Human settlements in the classified forests of Pâ and Sorobouly [8] and the development of agro-pastoral activities around these areas are responsible for the loss of forest cover [24] and [28].

Figure 1: Antropic pressures on natural formations in the Pâ classified forest

Despite awareness-raising campaigns and reforestation with the support of projects and programmes such as the Forestry Investment Programme (PIF) and the Projet d'appui aux communes de l'Ouest du Burkina (PACOF), the loss of vegetation cover remains visible due to certain unsuitable agro-pastoral practices.

In order to remedy the continuing degradation of the vegetation cover and reduce the risk of flooding, it is important to grasp the rural changes in this catchment area, with a view to improving the sustainable management of natural resources. In the Gran-Balé catchment area, what is the extent of human pressure on landscape degradation? To answer this question, this research postulates that human activities have been the main driving force behind changes to the landscape in the Gran Bâlé catchment. The research is therefore based on a multi-date analysis of Landsat satellite data from 1976, 1992, 2007 and 2022 in order to identify changes in land-use classes attributable to human pressures on the environment in the Grand-Bâlé basin.

II. Materials and methods

1. Grand-Bâlé watershed

The Grand-Balé is a tributary of the right bank of the Mouhoun river, Burkina Faso's main perennial watercourse. It rises in the sedimentary formations in the west of the country, around 16km south-west of Maro. Administratively, the catchment area includes the communes of Houndé, Bagassi, Bana, Békui, Béréba, Bondokui, Boni, Boromo, Founzan, Kona, Koti, Houndé, Lena, Oronkua, Ouarkoye, Pâ, Pompoï, Safane, Satiri and Yaho.

The catchment area lies between 11°20’ and 12°0’ north latitude and 3°50’ and 2°50’ west longitude. It covers an area of approximately 5135 km^2 with a perimeter of 455.5 km. The length of the main talweg is approximately 189.4 km. The relief is slightly uneven, with elevations ranging from 234 to 577 meters. More than 53% of the catchment lies between 290 and 340 meters (Figure 2).

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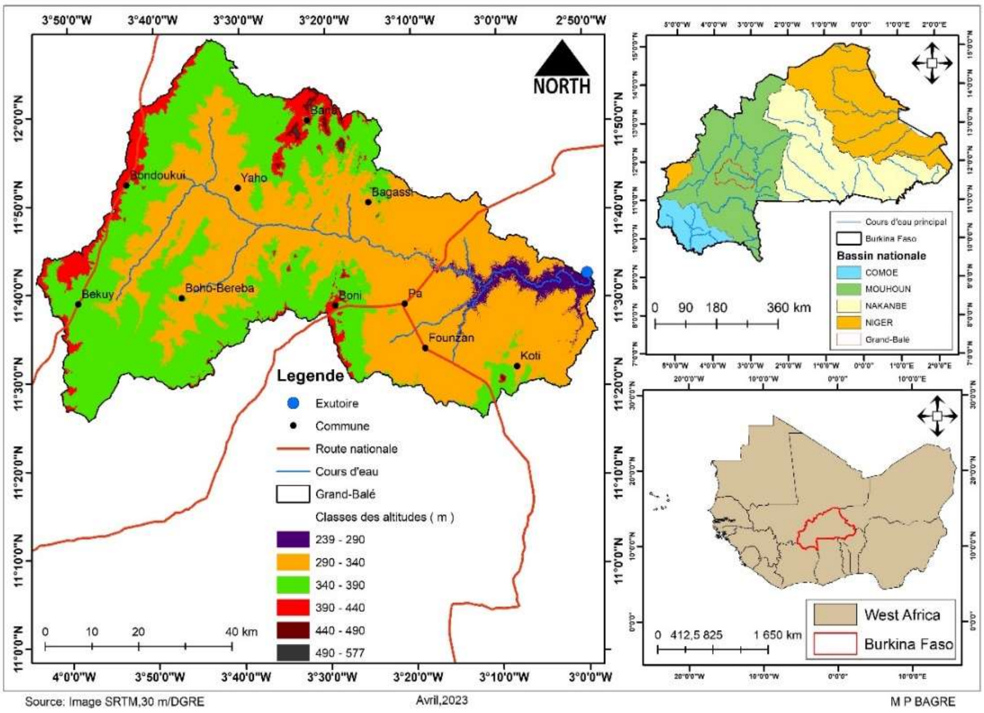

Figure 2: Grands-Balé catchment area and its relief

From a climatic point a view, the catchment is located in the Sudanian climate zone. At the Boromo synoptic weather station, average annual rainfall between 1922 and 2013 was 900 mm [23]. At soil level, the catchment is under the influence of five soil groups. These are eutrophic brown soils, reworked soils, eroded soils, leached and impoverished soils and Pseudogley soils with low humus content. The catchment area is covered by sedimentary rocks, shales, basalts, andesites, sandstones, granites and micaschists. Vegetation is abundant and is dominated by open savannah formations [12].

2. Data and methodology

2.1. Data collection

The data utilised in the present study pertain to geographical data, namely the national database of topographical data [4] produced by the Institut Géographique du Burkina (IGB), and satellite imagery. The latter are principally constituted of Landsat images from the MS, TM, ETM+ and OLI sensors, which belong to the 196/052 scene and were recorded in 1976, 1992, 2007 and 2022, respectively. The data, with a resolution of 30 meters per pixel, was obtained from the internet at the following address: https://earthexplorer.usgs.gov/. Furthermore, an image from the Shuttle Radar Topography Mission (SRTM) with a resolution of 30 meters was utilised for the extraction of the various physiographic parameters from the basin. As previously stated, the aforementioned resources are freely accessible via the internet at the previously specified address. In addition, in a bid to validate the classification results of satellite images, points of control were collected in the basin-versant using a GPS. In conclusion, the empirical observations have facilitated the acquisition of pertinent data, which is instrumental in achieving the desired outcomes.

2.2. Data processing methods and analysis

In the context of the analysis of Landsat satellite images, the QGis 3.34.8 software was utilized for the digital processing of the data. In accordance with the prescribed procedure, it is imperative to execute a sequence of actions, encompassing a preliminary phase, the treatment itself, and a concluding phase of post-treatment. Prior to the initiation of the treatment itself, it was imperative to undertake atmospheric corrections, import the relevant audio tracks, and subsequently assemble them into a coherent whole. The color composition, employing a near-infrared/red/green palette, was developed to facilitate the identification of the plant strata. In the context of the study conducted in the Grand Bâlé basin, the analysis of the collected data enabled the identification of seven distinct classes of soil use. In the context of this study, our focus has been on the forest gallery, the savannahs characterized by trees, shrubs, and grasses, the habitat, the bodies of water, the agricultural area, and the barren soils. The classification of images was facilitated by the implementation of the random forest algorithm. In the context of the research conducted by the "habitat" class, the visual interpretation of the outcomes of the classification process was executed through the utilization of the "merge" function within the ArcGis 10.8 software. The results of the classification were verified through the collection of points of control on site. In the postprocessing stage, the outcomes of the classification process were filtered and polygonized.

2.3. Assessing the accuracy of classification

In the present study, the kappa index was selected as the analytical instrument in order to assess the reliability of the classifications. While the distribution of radiometric values of objects may appear indistinct in reality, it does facilitate the establishment of acceptable intervals for the outcomes of classifications. According to Girard et al. (1999), as cited by [22], an index of Kappa ranging from 0.75 to 1 can be considered adequate. The utilisation of this scale is instrumental in the validation of the outcomes derived from the classification process.

2.4. Quantifying changes

Rates of expansion or change of land use units were calculated using formula (1) and (2) below from Djohy et al. (2016). $\mathbf{TV}(\%) = \left[\frac{S2}{S1} - 1\right] * 100$ (1) et $\mathbf{TCa}\ (\%) = \left[\frac{\mathbf{TV}}{\mathbf{t+1-t0}}\right]$ (2). In these equations, TV is defined as the rate of change; S1 is the area in year t0; S2 is the area in year t+1; and TCa is the annual growth rate. Implementing this methodological approach yielded several results, which are described in the following section.

III.Results

1. Assessment of classification accuracy

In the present study, the accuracy of the classifications was assessed using the Kappa index, as indicated in the methodological approach. This coefficient is indicative of the degree to which the results obtained from the map correspond to the truth in the field. The Kappa indices obtained in this research are of the order of 0.88, 0.8, 0.86 and 0.94, corresponding respectively to the classification of images from 1976, 1992, 2007 and 2022.

2. Surface area in the Grand-Balé basin between 1976, 1992, 2007 and 2022

Figure 3 and table 1 clearly show the spatial and temporal distribution of land cover classes for the years 1976, 1992, 2007 and 2022 in the Grand-Balé basin.

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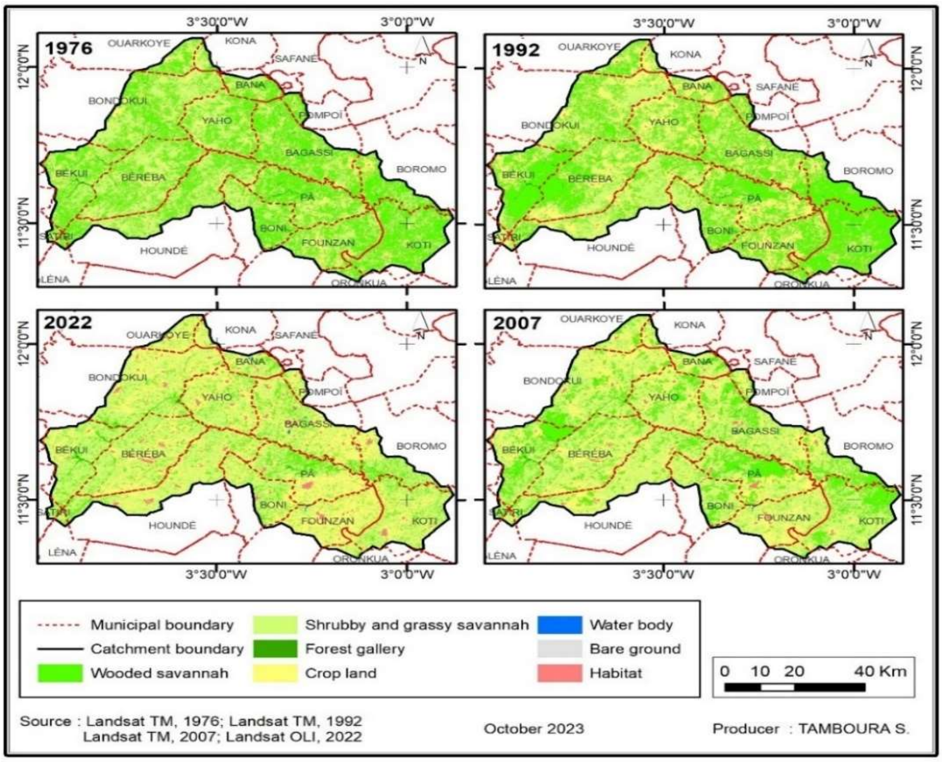

Figure 3: Map of surface conditions in Grand-Balé between 1976, 1992, 2007 and 2022

Table 1: Area and rate of land cover units between 1976, 1992, 2007 and 2022

LULC	1976		1992		2007		2022	
	Km^2	(%)	Km^2	(%)	Km^2	(%)	Km^2	(%)
Cu	354.77	6.91	977.88	19.04	1167.09	22.72	1672.24	32.56
Fg	50.24	0.98	43.90	0.85	33.50	0.65	26.14	0.51
Ha	6.48	0.13	12.95	0.25	32.19	0.63	90.58	1.76
Sa	2197.96	42.8	2029.07	39.51	1125.51	21.92	686.07	13.36
Sah	2524.01	49.15	2069.62	40.3	2767.71	53.89	2652.28	51.64
Sn	1.93	0.04	2.02	0.04	6.61	0.13	3.67	0.07
Pe	0.41	0.01	0.36	0.01	3.17	0.06	4.81	0.09
Total	5135.79	**100**	5135.79	**100**	5135.789	**100**	5135.79	**100**

Source: *Processing of Landsat images from 1976, 1992, 2007 and 2022*

Legend*: Fg: Forest gallery, Sa: Wooded savannah, Sah: Shrubby and grassy savannah; Cu: Crop, Ha: Habitat, Sn: Bare ground, Pe: Water body*

As illustrated in Table 1, in 1976, the Grand-Balé catchment area was predominantly characterised by shrub and grass savannahs, along with wooded savannahs, which collectively spanned an area of 2,524.01 km^2 and 2,197.96 km^2, constituting 49.15% and 42.80% of the total catchment area, respectively. The remaining surface area is comprised of the following: the cultivated zone (354.77 km^2, 6.91%), gallery forest (50.24 km^2, 0.98%), habitat (6.48 km^2, 0.13%), bare soil (1.93 km^2, 0.04%), and water bodies (0.41 km^2, 0.01%).

With regard to the surface conditions observed in 2007, shrub and grassland savannahs constituted 53.89% of the land cover within the catchment area, encompassing an area of 2,767.71 km². The cultivated area was 1,167.09 km² (22.72%), while wooded savannahs occupied 1,125.51 km² (21.92%). The remaining area of the catchment is distributed as follows: gallery forest (33.50 km²; 0.65%), habitat (32.19 km², 0.63%), bare land (0.66 km², 0.13%), and water bodies (3.17 km², 0.06%).

In 2022, analysis of the results showed that the Grand-Balé catchment area was dominated by shrub and grassland savannahs and farmland, with areas of 2,652.28 km^2 and 1,672.24 km^2 respectively, representing an occupancy rate of 51.64% and 32.56%. For the remaining land-use units, 'wooded savannah' occupies 686.07 km^2 (13.36%), 'habitat' holds 90.58 km^2 (1.76%), 'gallery forest' occupies 26.14 km^2 (0.51%), 'water bodies' cover 4.81 km^2 (0.09%) and 'bare ground' controls 3.67 km^2 (0.07%).

3. Changes in surface status in the Gran-Balé basin between 1976 and 1992

3.1. Changes in land use between 1976 and 1992

Table 2 below shows the dynamics of surface conditions in the Grand-Balé catchment (1976-1992).

Table 2: Dynamics of surface conditions in the Grand-Balé basin between 1976 and 1992

LULC	Sup_1976		Sup_1992		S_2/S_1-1*100
	Km^2	(%)	Km^2	(%)	TEG (%)
Cu	354.77	6.91	977.88	19.04	+175.64
Fg	50.24	0.98	43.89	0.85	-12.62
Ha	6.47	0.13	12.95	0.25	+99.99
Sa	2197.96	42.80	2029.06	39.51	-7.68
Sah	2524.01	49.15	2069.62	40.30	-18
Su	1.93	0.038	2.02	0.039	+4.44
Pe	0.41	0.008	0.36	0.007	-11.66

Source: *Processing of Landsat images from 1976 and 1992*

Legend: TGE =Total change rate

According to this table, between 1976 and 1992, agricultural land in the catchment area increased from 354.78 km^2 (6.91%) to 977.88 km^2 (19.04%), representing an overall increase of 175.64%. This progressive dynamic is justified by the weight of demographic pressure on the catchment area. From 6.47 km^2 (0.12%) in 1976, settlement had increased to 12.95 km^2 (0.25%) by 1992, representing an overall increase of 99.99%. On the other hand, an insignificant progressive trend can be observed in the 'bare soil' occupation item, which rose from 1.93 km^2 (0.038%) in 1976 to 2.02 km^2 (0.039%), i.e. an overall rate of increase of +4.44%.

On the other hand, over the same analysis period, regressive dynamics were observed for certain land use classes. The 'shrub and grass savannah', 'gallery forest', 'water body' and 'tree savannah' land cover classes lost surface area of around (-454.39 km^2), (-6.34 km^2), (-0.05 km^2) and (-168.89 km^2) respectively. The overall rate of loss of area of 'shrubby and grassy savannahs' was (-18%) as this class fell from 2,524.01 km^2 (49.15%) to 2,069.62 km^2 (40.30%) and reached (-12.62%) for gallery forest, which fell from 50.24 km^2 to 43.89 km^2. On the water bodies and wooded savannah, surface area losses were of the order of (-11.66%) and (-7.68%). The former fell from 0.41 km^2 (0.008%) to 0.36 km^2 (0.007%) and the latter from 2197.96 km^2 (42.80%) to 2029.06 km^2 (40.30%).

3.2. Changes between land use units from 1976 to 1992

The period spanning from 1976 to 1992 was distinguished by a succession of transitions among diverse land use categories. Tables 3, 4 and 5 provide a synoptic overview of the changes that occurred between the different classes over this period. It is observed that, within the specified timeframe, the surface areas of the designated land use units remain constant. As illustrated in Table 3 below, these unchanged areas are designated by the colour green.

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Table 3: Matrix of land cover changes between 1976 and 1992 in square kilometers

Unité	Cu	Fg	Ha	Sa	Sah	Sn	Pe	T1-1976
Cu	249.67	0.51	2.32	13.30	88.56	0.39	0.003	354.77
Fg	0.55	25.28		20.98	3.40	0.001	0.007	50.23
Ha	0.02		6.43	0.001	0.02			6.47
Sa	72.46	10.86	0.63	1525.27	588.62	0.06	0.04	2197.95
Sah	654.86	7.23	3.54	469.41	1388.93	0.02		2524.01
Sn	0.3		0.01	0.005	0.06	1.54		1.93
Pe		0.001		0.07	0.01		0.007	0.40
T2-1992	977.87	43.89	12.95	2029.06	2069.62	2.01	0.05	5135.78

Source: *Processing of Landsat images from 1976 and 1992*

Table 4: Percentage loss of surface area at the expense of other land use units

Units	Cu	Fg	Ha	Sa	Sah	Sn	Pe	
Cu	70.37	0.14	0.65	3.75	24.96	0.11	0.001	100
Fg	1.107	50.33	0	41.78	6.77	0.002	0.014	100
Ha	0.31	0	99.36	0.007	0.31	0	0	100
Sa	3.3	0.49	0.03	69.39	26.78	0.003	0.002	100
Sah	25.94	0.29	0.14	18.6	55.03	0.001	0	100
Sn	15.6	0	1.005	0.25	3.06	80.08	0	100
Pe	0	2.332	0	18.88	3.05	0	75.73	100

Source: *Processing of Landsat images from 1976 and 1992*

As demonstrated in table 4 above, between 1976 and 1992, a variety of conversions were observed between different land cover classes. Gallery forest experienced a significant loss of 20.98 km^2, equivalent to 41.78% of its surface area, to wooded savannah. Furthermore, approximately 13.31 km^2 of the wooded savannah underwent transformation into shrub and grass savannah, contributing to a total loss of 26.78% of its surface area. In addition, 654.86 km^2, representing 25.94% of the shrub and grass savannah area, was cleared for cultivation, along with 72.47 km^2 of wooded savannah (3.3%). Additionally, bare soil experienced a loss of 0.30 km^2, equivalent to 15.6% of its surface area, due to cultivation. This demonstrates the impact of human pressures on the natural formations of the Grand-Balé catchment.

Table 5: Percentage gain in area at the expense of other land use units

Units	Cu	Fg	Ha	Sa	Sah	Sn	Pe
Cu	25.53	1.16	17.93	0.65	4.28	19.28	1.01
Fg	0.06	57.59	0	1.034	0.16	0.04	1.95
Ha	0.002	0	49.68	0	0.001	0	0
Sa	7.41	24.74	4.9	75.17	28.44	2.85	11.31
Sah	66.96	16.48	27.33	23.13	67.11	1.15	0
Sn	0.031	0	0.15	0	0.003	76.68	0
Pe	0	0.022	0	0.004	0.001	0	85.73
	100	100	100	100	100	100	100

Source: *Processing of Landsat images from 1976 and 1992*

As shown in Table 5, there were instances of enhancements in vegetation cover. The gallery forest benefited from 10.86 km^2, representing 24.74% of the wooded savannah and approximately 7.23 km^2, or 16.48% of the shrub and grass savannah. The wooded savannah was reinforced by 469.41 km^2 of shrub and grass savannah, representing 23.13%. In addition, the area of unbuilt land has seen an increase of 0.39 km^2, representing a 19.27% rise. Figure 4 presents the distribution of changes observed in the land cover and land use categories, in addition to those that demonstrated stability between 1976 and 1992.

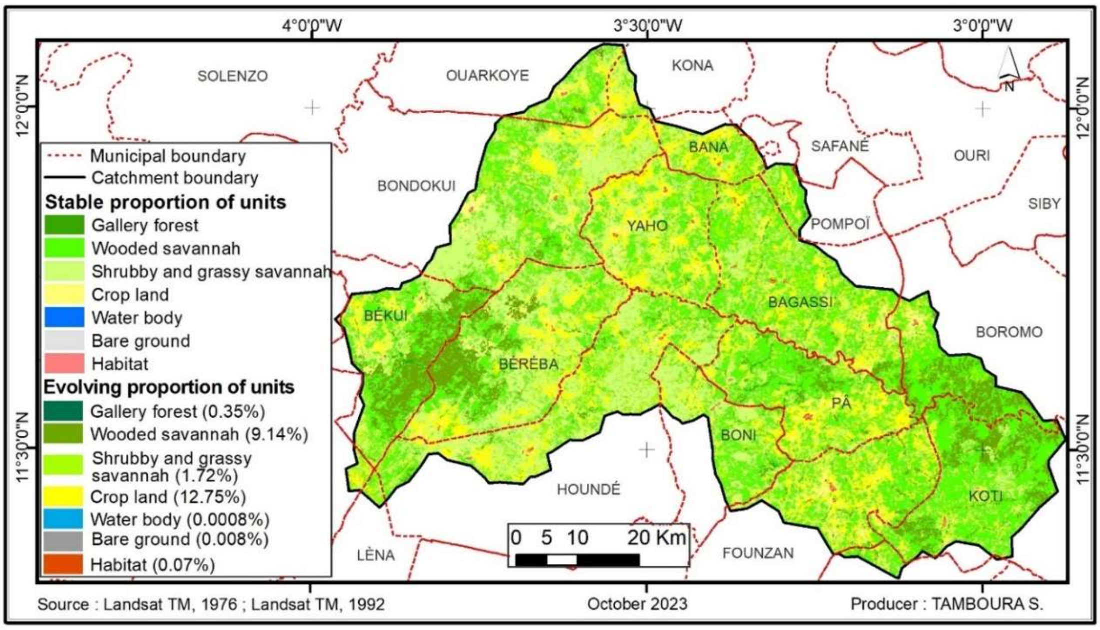

Figure 4: Conversion map of land use units between 1976 and 1992

4. Changes in surface status in the Gran-Balé basin between 1992 and 2007

4.1. Changes in land use between 1992 and 2007

Land-use units in the Grand Balé catchment continued to change over the period 1992-2007. The woody layer became very degraded and dominated by savannah shrubs and grass. Farming areas are progressing over the vegetation conservation zones. Bare soil and habitat are changing at considerable rates. Progressive dynamics were observed during this period. Water bodies increased from 0.36 km^2 (0.007%) to 3.17 km^2 (0.06%), an overall increase of 785.23%. Bare ground rose from 2.02 km^2 (0.04%) to 6.61 km^2 (0.13%), an increase of 227.52%. Habitat increased overall by 148.59%, from 12.95 km^2 (0.25%) in 1992 to 32.19 km^2 (0.63%) in 2007. The shrub and grass savannah increased from 2069.62 km^2 to 2767.71 km^2, an increase of 33.73%. Agricultural land rose from 977.88 km^2 (19.04%) to 1167.09 km^2, representing an overall increase of 19.35%. The analysis period was also marked by a decline in two land cover classes. These were savannah, which fell from 2029.06 km^2 to 1125.51 km^2, i.e. a 44.53% decrease in surface area, and gallery forest, which declined by 23.67% in surface area, having fallen from 43.89 km^2 (0.85%) to 33.50 km^2 (0.65%) (Table 6).

Table 6: Dynamics of surface conditions in the Grand-Balé basin between 1992 and 2007

Units	Sup_1992		Sup_2007		S_2/S_1-1*100
	Km^2	(%)	Km^2	(%)	TEG (%)
Cu	977.88	19.04	1167.089	22.72	+19.35
Fg	43.89	0.85	33.50	0.65	-23.67
Ha	12.95	0.25	32.19	0.63	+148.59
Sa	2029.06	39.51	1125.51	21.92	-44.53
Sah	2069.62	40.30	2767.71	53.89	+33.73
Sn	2.02	0.039	6.61	0.13	+227.52
Pe	0.36	0.007	3.17	0.06	+785.23

Source: *Processing of Landsat images from 1992 and 2007*

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4.2. Changes between land use units from 1992 to 2007

During the analysis period, transitions between land cover classes were observed. The area of land cover units that remained stable is indicated in green (Tables 7). Shrub and grass savannas have been transformed into wooded savannas. In certain areas, the landscape has undergone a transformation, becoming characterised by shrubbery and grass savannah. The transition from savannah to cultivated area, and the degradation from wooded savannah to shrub and grass savannah, is primarily located at the eastern and western extremities of the basin (Figure 5).

During the specified analysis period, gallery forests experienced a loss of 15.83 km^2 (36.06%) of surface area to wooded savannah and 13.16 km^2 (29.98%) to shrub and grass savannah. The wooded savannah has experienced a substantial loss of approximately 1,144.49 km^2, equivalent to 56.40%, to the shrub and grass savannah. This finding is indicative of a substantial and precipitous decline in vegetation cover within the catchment area. Furthermore, a substantial area of shrub and grass savannah (414.96 km^2 or 20.05%), 219.33 km^2 (10.81%) of wooded savannah and 0.47 km^2 (23.38%) of bare soil have been converted into fields. Concurrently, gallery forest, wooded savannah and shrub and grass savannah were reinforced. In fact, 408.54 km^2, corresponding to 36.29% of the shrub and grass savannah, were converted into wooded savannah, and 19.65 km^2, equivalent to 58.66% of the latter, were converted into gallery forest. As illustrated in Figure 4, the distribution of changes observed in the Grand-Balé catchment between 1992 and 2007 is demonstrated (Table 7, 8 and 9).

Over the analysis period, the gallery forest underwent a net loss of 15.83 km^2 of surface area, corresponding to 36.06% of its initial area. This reduction is attributable to the expansion of treed savannah, which absorbed 13.16 km^2, or 29.98% of the gallery forest, while shrub and grass savannah increased by 13.16 km^2, representing 29.98% of its total area. An in-depth analysis of the changes in the extent of the various biotopes reveals a significant transformation of the original habitat, with a net loss of 1,144.5 km^2 of wooded savannah, corresponding to 56.40% of its original area. This change is attributable to a transition towards shrub and grass savannah zones, which increased by 56.40%. It should also be noted that the shrub and grass savannah area has been significantly reduced. This reduction represents an area of 414.96 km^2, or 20.05% of its initial area, 219.33 km^2 of wooded savannah, or 10.81%, and 0.47 km^2 of bare soil, or 23.38%. In addition, 3.41 km^2 of gallery forest (7.79%) were cleared for farming. At the same time, the gallery forest, wooded savannah and shrub and grass savannah were reinforced. The shrub and grass savannah and the gallery forest increased in area by 408 km^2 respectively.

Table 7: Matrix of land cover changes between 1992 and 2007 in square kilometers

Unité	Cu	Fg	Ha	Sa	Sah	Sn	Pe	T1_1992
Cu	528.81	0.36	13.32	58.09	372.33	4.15	0.81	977.88
Fg	3.41	11.29		15.83	13.16	0.00	0.19	43.90
Ha	0.07	0.00	12.72	0.02	0.13	0.00	0.00	12.95
Sa	219.33	19.65	1.19	642.82	1144.5	0.26	1.31	2029.07
Sah	414.96	2.18	4.93	408.54	1237.38	0.86	0.76	2069.62
Sn	0.47	0.00	0.02	0.03	0.16	1.33	0.00	2.02
Pe	0.02	0.01	0.00	0.17	0.04	0.01	0.10	0.36
T2_2007	1167.08	33.50	32.19	1125.51	2767.71	6.61	3.17	5135.79

Table 8: Percentage loss of surface area at the expense of other land use units

Units	Cu	Fg	Ha	Sa	Sah	Sn	Pe	
Cu	54.08	0.04	1.36	5.94	38.07	0.42	0.08	100
Fg	7.79	25.72	0	36.06	29.98	0.01	0.44	100
Ha	0.58	0	98.22	0.16	1.03	0	0	100
Sa	10.81	0.97	0.06	31.68	56.41	0.01	0.06	100
Sah	20.05	0.11	0.24	19.74	59.79	0.04	0.04	100
Sn	23.38	0	1.07	1.72	8.17	65.66	0	100
Pe	5.78	3.9	0	47.14	11.82	2.51	28.85	100

Source: *Processing of Landsat images from 1992 and 2007*

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Table 9: Percentage gain in area at the expense of other land use units

Units	Cu	Fg	Ha	Sa	Sah	Sn	Pe
Cu	45.31	1.08	41.39	5.16	13.45	62.85	25.46
Fg	0.29	33.7	0	1.41	0.48	0.04	6.05
Ha	0.01	0	39.51	0	0	0	0
Sa	18.79	58.66	3.71	57.11	41.35	3.95	41.2
Sah	35.56	6.51	15.32	36.3	44.71	12.98	24.03
Sn	0.04	0	0.07	0	0.01	20.05	0
Pe	0	0.04	0	0.01	0	0.14	3.26
	100	100	100	100	100	100	100

Source: *Processing of Landsat images from 1992 and 2007*

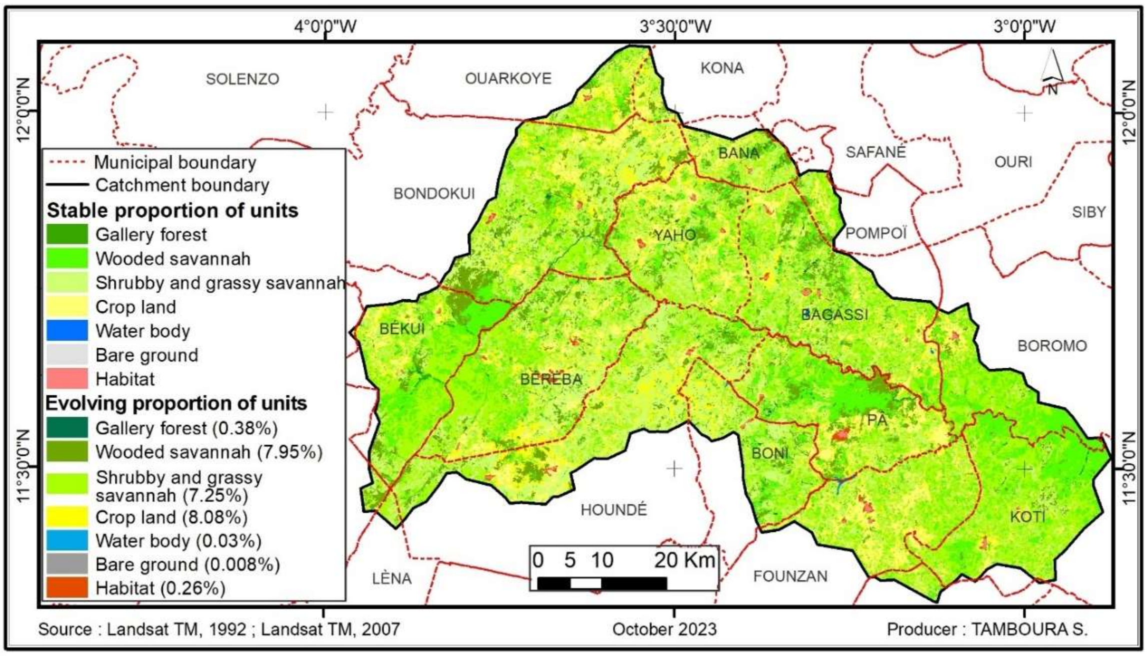

Figure 5: Conversion map of land use units between 1992 and 2007

5. Changes in surface status in the Gran-Balé basin between 2007 and 2022

5.1. Changes in land use between 2007 and 2022

From 2007 to 2022, the rate of loss of vegetation cover decreased. Degradation had a detrimental effect on both savannah and gallery forest. As demonstrated in Table 10, there has been substantial expansion in both agricultural and residential areas. Observations of progressive dynamics have been made in a variety of environments, including habitats, water bodies, and cultivated areas. The habitat zone occupation class exhibited an increase from 32.19 km^2 (0.63%) to 90.58 km^2 (1.76%), signifying an overall augmentation of 181.38%. Water areas exhibited an increase from 3.17 km^2 (0.06%) to 4.81 km^2 (0.09%), representing a 51.86% rise. In the cultivated zone, the overall increase was 43.28%, from 1,167.08 km^2 (22.72%) to 1,672.24 km^2 (32.56%). Conversely, the remaining land cover classes exhibited a decline in surface area. The area of bare soil decreased by 44.55%, from 6.61 km^2 (0.13%) to 3.66 km^2 (0.07%). The wooded savannah experienced a significant decline, with a decrease of 112.51 km^2 (21.92%) to 68.606 km^2 (13.36%), representing a 39.04% reduction in area. Gallery forest experienced a significant decrease in area, from 33.50 km^2 (0.65%) to 26.13 km^2 (0.51%), representing an overall decline of 21.99%. The shrub and grass savannah exhibited a negligible decline, from 2767.71 km^2 (53.89%) to 2652.28 km^2 (51.64%), representing a decrease of 4.17%.

Table 10: Dynamics of surface conditions in the Grand-Balé basin between 2007 and 2022

Units	Sup_2007		Sup_2022		S2/S1-1*100
	Km²	(%)	Km²	(%)	TEG (%)
Cu	1167.08	22.72	1672.24	32.56	+43.28
Fg	33.50	0.65	26.13	0.51	-21.99
Ha	32.19	0.63	90.58	1.76	+181.38
Sa	1125.51	21.92	686.06	13.36	-39.04
Sah	2767.71	53.89	2652.28	51.64	-4.17
Sn	6.61	0.13	3.66	0.07	-44.55
Pe	3.17	0.06	4.81	0.09	+51.86

Source: *Processing of Landsat images from 2007 and 2022*

5.2. Changes between land use units from 2007 to 2022

During this period, forest areas underwent profound transformation. On the one hand, there have been changes indicating deterioration; on the other hand, there have also been improvements. The latter refers to shrub and grass savannahs, which have become wooded savannahs. Additionally, in certain regions, bare soils have been transformed into savannahs characterised by an abundance of trees, bushes and herbaceous plants. These improvement areas are located in the northern part of the catchment area, as shown in figure 6.

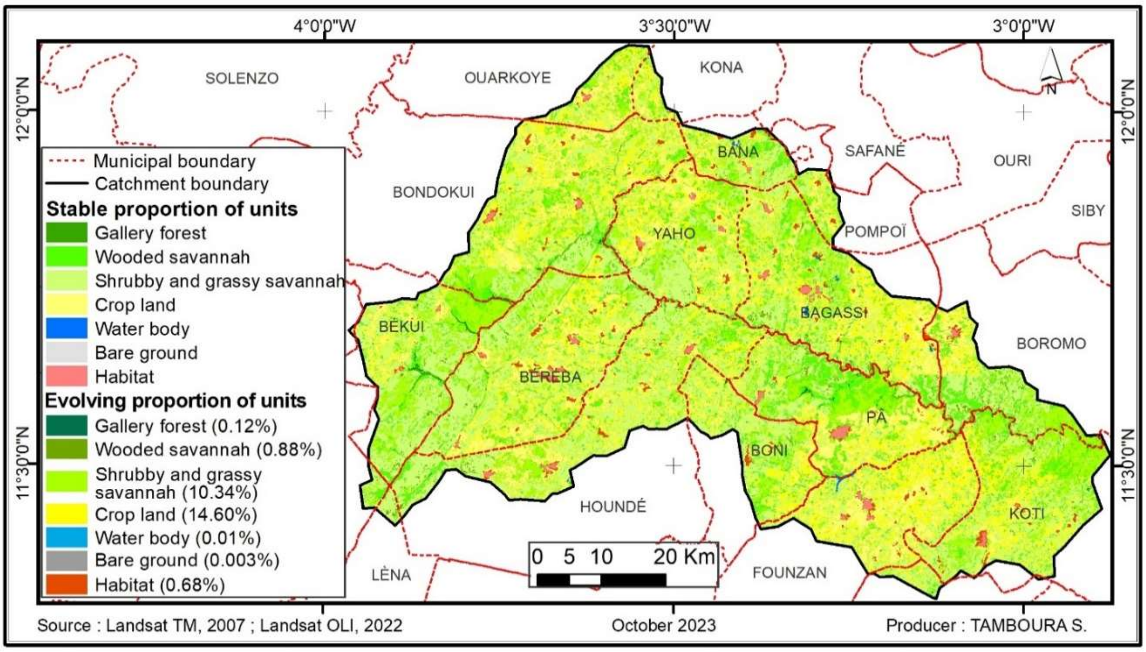

Figure 6: Conversion map of land use units between 2007 and 2022

Tables 11, 12 and 13 show the changes in land cover between the two dates in question. The green boxes in Table 11 show the proportions of land cover classes that remained unchanged during the analysis period. Analysis of the data in the tables shows that gallery forest experienced a net loss of 10.87 km² (32.45%), with 4.99 km² (14.91%) transforming into wooded and shrub/grass savannah. Meanwhile, a surface area of 515.63 km² of wooded savannah, equivalent to 45.81% of the total area, was transformed into shrub and grass savannah. These observations suggest significant alterations to the woody vegetation in the catchment area. It should also be noted that an estimated 739.82 km² of shrub and grass savannah (26.73% of the total surface area) has been converted

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into fields, as have 2.52 km² of bare soil (38.20%) and 72.55 km² of savannah (6.45%). Additionally, the gallery forest increased in size by 7.07 km², representing a 27.08% increase in surface area, at the expense of the wooded savannah. Conversely, the wooded savannah increased in size by 145.78 km², representing a 21.24% increase, at the expense of the shrub and grass savannah. In the same period, approximately 739.82 km² of shrub and grass savannah was cultivated, representing 26.73% of the total area, while 2.52 km² of bare soil was added. The habitat gained approximately 22.39 km² (24.73%) from the shrub and grass savannah.

Table 11: Matrix of land cover changes between 1992 and 2007 in square kilometers

Units	Cu	Fg	Ha	Sa	Sah	Sn	Pe	T_2007
Cu	856.50	0.16	34.85	1.68	273.01	0.20	0.65	1167.08
Fg	0.36	1717.65	0.0004	10.87	4.99	0.00	0.09	33.50
Ha	0.46	0.00	30.87	0.011	0.85	0.00	0.00	32.19
Sa	72.55	7.07	2.31	527.39	515.63	0.008	0.52	1125.51
Sah	739.82	1.47	22.39	145.78	1857.27	0.08	0.88	2767.71
Sn	2.52	0.001	0.14	0.07	0.50	3.37	0.00	6.61
Pe	0.01	0.24	0.00	0.25	0.009	0.00	2.64	3.17
T_2022	1672.24	26.13	90.58	686.06	2652.28	3.66	4.81	5135.78

Table 12: Statistics on the percentage loss of surface area at the expense of other land use units

Units	Cu	Fg	Ha	Sa	Sah	Sn	Pe	
Cu	73.39	0.01	2.99	0.14	23.39	0.02	0.06	100
Fg	1.08	51.27	0	32.45	14.91	0	0.28	100
Ha	1.42	0	95.89	0.03	2.65	0	0	100
Sa	6.45	0.63	0.21	46.86	45.81	0	0.05	100
Sah	26.73	0.05	0.81	5.27	67.11	0	0.03	100
Sn	38.2	0.01	2.19	1.04	7.57	50.99	0	100
Pe	0.37	7.73	0	8.09	0.28	0	83.53	100

Table 13: Calculation of percentage gain in area at the expense of other land use units

Unités	Cu	Fg	Ha	Sa	Sah	Sn	Pe
Cu	51.22	0.63	38.48	0.25	10.29	5.57	13.69
Fg	0.02	65.72	0	1.58	0.19	0	1.98
Ha	0.03	0	34.08	0	0.03	0	0
Sa	4.34	27.09	2.56	76.87	19.44	0.22	10.92
Sah	44.24	5.62	24.73	21.25	70.03	2.25	18.4
Sn	0.15	0	0.16	0.01	0.02	91.96	0
Pe	0	0.94	0	0.04	0	0	55
	100	100	100	100	100	100	100

Source: *Processing of Landsat images from 2007 and 2022*

Discussion

The utilisation of remote sensing techniques and geographic information systems is imperative in the monitoring of landscape units. Forest resources have been shown to be characteristic entities in the evolution of landscapes. Consequently, remote sensing is imperative in the monitoring of these dynamics, as it facilitates the periodic monitoring of forest resources [26], [5] and [16]. The approach employed in this research is predicated on the utilisation of Landsat satellite images from 1976, 1992, 2007 and 2022. The maximum likelihood method has been adopted by several authors [13], [10], [2] and [20]. The classification demonstrates Kappa indices ranging from 0.84 to 0.94. These results are analogous to those of [8] in their study of the anthropisation and sustainable management of the Sorobouly and Pâ classified forests in the province of Balé. The validation of the processing of Landsat images was achieved by these authors with Kappa indices ranging from 0.83 to 0.88.

The findings reveal a decline in the vegetation cover of the Grand-Balé catchment, albeit at varying rates during the periods 1976 to 1992 and 2007 to 2022. It is evident that the deterioration in vegetation cover has not been confined to non-classified areas. Nevertheless, they have long been regarded as an efficacious approach to preserving nature, particularly in sub-Saharan Africa, given the substantial pressures on natural resources [26] and [9]. The evolution of the landscape in Grand-Balé is characterised by the regression of woodland formations. This regression can be attributed to the increase in the number of occupations within the 'cultivated area' sector. These results are consistent with those of [27], [1], [8], [21], [25], [24] and [11]. For these authors, agriculture is identified as a primary contributing factor to the regression of natural formations in the environment. It is asserted by some that action must be taken in order to address the factors that are causing this degradation. Prospective scenarios favourable to the development of natural formations have been formulated [1] and [11]. For these authors, agriculture is identified as a primary contributing factor to the regression of natural formations in the environment. In order to address the issue of degradation, it is imperative that action is taken to address the underlying factors contributing to this phenomenon. Prospective scenarios favourable to the development of natural formations have been formulated [2] and [11]. The study demonstrated that the observed decline in vegetation cover can be attributed to the growth of the population, which is increasingly dependent on natural resources. The marked differences in degradation observed between the classified areas can be attributed to the presence of migrants and the development of gold panning. This demographic pressure is attributable to the increase in 'habitat' occupancy. However, it must be noted that immigration has been demonstrated to exacerbate agricultural pressure and lead to land saturation [15]. As [8] asserts, it is a contributing factor to the degradation of the Sorobouly and Baporo classified forests. The observed decline in plant cover could also be explained by the droughts that afflicted the entire Sahelian strip of Africa during the 1970s and 1980s. Rainfall in Burkina Faso has exhibited significant variability, with a downward trend being observed [14] and [19]. This phenomenon is exerting a deleterious effect on the productivity of the land, thereby impeding the yield of crops and the development of vegetation.

Conclusion

This research enabled the characterisation of the primary land use classes in the Grand-Balé catchment area between 1976, 1992, 2007 and 2022 through the utilisation of remote sensing tools and techniques. A thorough examination of the land-use maps reveals that substantial alterations in land-use categories were documented during the specified analysis period. The increase in agro-pastoral activities and the spread of residential areas are the primary factors elucidating the landscape dynamics in the Gran-Balé basin. The study reveals that progressive and regressive dynamics have been observed in the catchment. The cultivated area has increased significantly, rising from 354.77 km^2 (6.91%) in 1976 to 1672.24 km^2 (32.56%), an increase of 371.36% in 47 years. This dynamic has been at the expense of the wooded savannah, which has lost a significant 1,511.89 km^2 in area, falling from 2,197.96 km^2 (42.8%) in 1976 to 686 km^2 (13.36%) in 1976. Significant area losses were also observed in the gallery forest, which lost 24.1 km^2 of its reference area of 50.24 km^2. Another factor in the dynamics of land use is the increase in the 'habitat' occupation unit. This land-use unit has increased from 6.48 km^2 in 1976, 12.95 km^2 in 1992, 32.19 km2 in 2007 to 90.58 km^2 in 2022. In the Grand-Balé area, there is an expansion of agricultural land around housing estates and along communication routes, whilst at the same time, areas of bare soil and riparian vegetation are developing in proximity to watercourses. A general decline in the quality of plant resources has been indicated by the available data. This phenomenon can be attributed to a number of anthropogenic factors. This degradation has far-reaching consequences, including the exposure of soils to erosion, an increased risk of flooding, and the exacerbation of the vulnerability of local populations. A complementary study on the physical characteristics of the catchment and changes in rainfall could provide a database for decision-makers in the preservation of natural formations and the development of the catchment.

Authors' contributions

This article was written by M. Soumaila Tamboura. He collected the data, processed the Landsat satellite images, and analysed the results. M. Mathias Philippe Bagré and M. Zéphirin P. Kagaméba contributed to the analysis of the results, the methodological aspects, and the language level.

Conflicts of interest

The authors declare that the study was conducted without any conflicts of interest.

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