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Natural resources in the Djenkoa sub-catchment in Burkina Faso: From spatio-temporal dynamics to the need for environmental communication

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Abstract

The aim of the study was to analyse changes in land use in the Djenkoa sub-basin. This was done using secondary data from satellite images taken during the periods 1993-2003, 2013 and 2023. In addition, 252 people living in villages bordering the Djenkoa sub-basin were interviewed. The results of the study showed that tree savannahs, shrub savannahs, rainfed cultivation, gallery forests and orchards are the dominant units over the period 1993-2023. In addition, the units 'water bodies', 'wooded savannah' and 'shrub savannah' are decreasing, while the units 'rainfed cultivation', 'gallery forest' and 'bare soil' are increasing significantly. This reflects a decline in tree and shrub resources in the Djenkoa sub-catchment. The study also revealed that farmers living around the sub-catchment are not adopting environmental practices that are sufficient to cope with this situation. Urgent action is therefore needed to raise awareness and train people to conserve the natural resources of the sub-catchment.

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Introduction

Catchments are fragile ecosystems that provide socio-environmental benefits. In fact, catchment ecosystems provide the most important ecosystem services to urban populations (Bouland and Hunhammar, 1999; Flotemersch *et al.*, 2016). Within a catchment, natural resources in general and water resources in particular can be affected by changes in biophysical factors such as climate and land use/vegetation, as well as socio-economic factors such as population and income (Woyessa *et al.*, 2021). This results in demographic, climatic and socio-economic changes that have negative impacts on local resources (Kupiec *et al.*, 2021). In West Africa, several studies have highlighted changes in land use in catchments. In Ghana, a regressive trend in forest resources was observed in the Barekese catchment between 1973 and 2000 (Boakye *et al.*, 2021). In northern Nigeria, changes in land use had a negative impact on the land component of the Afikpo catchment between 1996 and 2016 (Obiahu and Elias, 2020). In Burkina Faso, watersheds structure the socio-economic life of riparian populations, but they are affected by problems related to anthropogenic and climatic activities in the centre-west of the country (Yaméogo and Sawadogo, 2024). In the Sahel and northern regions, changes in the land surface are affecting the retention capacity of the soil and the flow of the Nakambè River in the Dano catchment (Mahe *et al.*, 2005). In the southwest, the cumulative effects of soil change and climate change are affecting water resources and soil erosion in the Dano catchment (Op de Hipp *et al.*, 2019). However, there are few, if any, sub-basin studies in Burkina Faso. Nevertheless, the study of actual and potential land use change (LU) is essential for land use planning, which is a necessity for proper water resources management (Aduah *et al.*, 2017). This study addresses the spatio-temporal dynamics of the Djenkoa sub-basin in Burkina Faso and the need to consider environmental issues.

Materials and methods

Presentation of the geographical context of the study

The Djenkoa sub-basin is located in the Mouhoun watershed, in the Sudanese zone (Fig. 1). The Djenkoa sub-basin management area belongs to the Southern Sudanese climate, which is characterised by a rainy season lasting 5 months (May-September) and a dry season for the rest of the year (October - April). Rainfall is relatively abundant (averaging 1095 mm/year) but varies from year to year depending on climatic conditions. The average temperature is 27.6°C, with less variation from north to south.

Data

This includes survey data and satellite imagery.

Survey data

This was obtained from surveys carried out in the riparian areas of the Djenkoa sub-catchment. A sample of the population was surveyed in the selected localities using the following sampling technique:

$$n = Deff * \frac{\frac{Z^2 p(1-p)}{\varepsilon^2}}{1-r} \quad (1)$$

Precision is set at 5% (95% confidence level) where z = 1.96 (corresponding quantile of the normal distribution);

The relative error $\boldsymbol{\varepsilon}$ is set at 10%;

Deff is the sampling effect, fixed at 1.25;

r is the non-response rate set at 5%.

The share p is the share of households that have already experienced the phenomenon (share of agricultural migrants, share of seasonal migrants, share of permanent migrants).

In the absence of information on the current level of these indicators, p is set at 50% in order to obtain a maximum (mathematical) size. This results in a sample of 126 households to be interviewed. In order to increase the accuracy of the indicators to be calculated, the sample size was revised to 252 households. The breakdown is shown in the Table 1 below.

Data from satellite images

Planimetric data were used to collect information (Table 2). Monitoring of land cover dynamics in the study area (enter the name of the study area) was carried out using LANDSAT images downloaded from the earthexplorer.usgs.gov site in GEOTIFF format (path 197; and row 052).

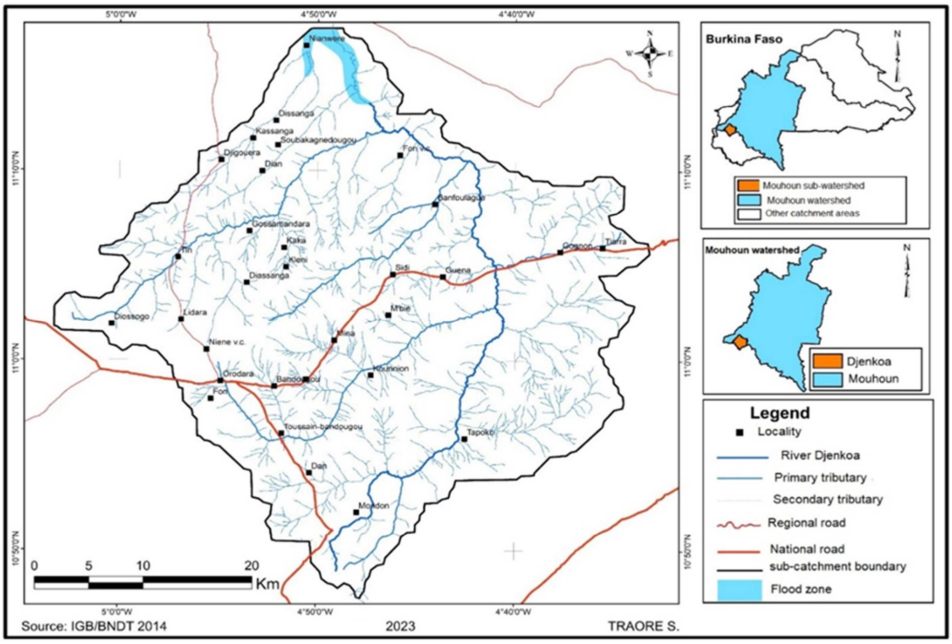

Fig. 1. Geographical location of the Djenkoa sub-basin

Table 1. Breakdown of surveyed households and village

Communes	Number of households (2019)	Frequency (% of households)	Survey village	Number of heads of household questioned
Kourinion	3 056	15.07	Kourinion	40
			Banflagoué	17
			Toussian-Bandougou	15
Orodara	9 641	47.54	Orodara	50
			Diossogo	20
			Tin	20
Djigouéra	3 870	19.08	Djigouéra	40
			Kaka	15
			Dissanga	15
Banzon	3 710	18.29	Niawere	20
Total	20 277	100	10	252

Source: Data INSD 2019 Adapted to the field

Table 2. Characteristics of the satellite imagery used in the study

SL	Acquisition date	Sensors	Satellite	Resolution	Number of bands	Source
1	11/10/1993 23/10/2003	Thematic Mapper (TM)	Satellite optical	30 meters for most TM bands, and 79 meters for MSS.	7 bands	NASA/ USGS
2	04/10/2013	ETM+ (Enhanced Thematic Mapper Plus	Satellite optical	15 meters (panchromatic), 30 meters (multispectral), 60 meters (thermal)	8 bands	USGS
3	07/10/2023	OLI-TIRS OLI (Operational Land Imager) TIRS (Thermal Infrared Sensor)	Satellite optical	15 meters (panchromatic), 30 meters (multispectral), 100 meters (thermal).	11 bands	USGS

Source: Satellite imageries 1993, 2003, 2013, 2023

All these images were acquired in October, which is the optimum period for better perception and discrimination of plant communities and other units in the study area. The images used are LANDSAT images with a resolution of 30 m. Due to their quality, these images were acquired in October. Using images taken during this period means that cloud cover is greatly reduced, thus limiting atmospheric distortion. These images were used to study the process of land use change and land degradation over the medium and long term. Four land use maps were produced using satellite images from 1993, 2003, 2013 and 2023.

Data processing

Methods for processing primary data

Descriptive statistics were used to process the primary data.

Secondary data processing methods

There are two main stages: pre-processing and processing.

Step 1: Satellite image pre-processing using ENVI 4.7 software

The aim of image pre-processing is to improve the readability of the data and make it easier to interpret and extract information. These preliminary operations are carried out by radiometric enhancements and geographic adjustments, which are performed after linear spreading of the histograms of each spectral band to improve contrast. This ensures that overlays and comparisons are correct. All this pre-processing is carried out using ENVI 5.3 software. The following steps were taken to pre-process the images:

Displaying image

Image display is one of the fundamental operations in remote sensing image processing. It can take place either on screens or on devices such as printers and photographic instruments. Display can be monochromatic, achromatic or colour.

Improve and enhance

Pratt and Goulty (1991) defined image enhancement as a set of techniques designed to improve the visual appearance of an image or to convert the image into a form more suitable for human or machine analysis. In image enhancement, the system is not concerned with improving the fidelity of the reproduction of the image in relation to an ideal form of that image, as is the case in restoration.

To enhance images, you need to:

1. Scale the amplitude and modify the contrast;
2. Modify the histogram to subdivide it into non-adaptive and adaptive modifications, then clean up the noise generated by linear and non-linear cleaning;
3. Enhance the contours that include linear enhancement and statistical differentiation;
4. Enhance the colour image including natural colour, pseudo-colour and false colour image enhancement;
5. Multi-spectral image enhancement.

Assembling consists of combining the bands of satellite imagery covering the search area into a single band for easier processing. Once the Landsat images had been downloaded, a zip folder was created. The first thing to do was to unzip it, which revealed several files (strips) with a .TIF extension. In order to process the image, we needed to merge these strips into a single multi-strip image as the output file.

Colour composition

The true colour composition using the combination of bands 4-2-3 for the TM/ETM+ images and 5-4-3 for the OLI TIRS image was used. These compositions were chosen because they better distinguish vegetation from other land cover units. Here, the different shades of green shown on an analysed image correspond to vegetation, but the green may vary according to species or health status (Fig. 2).

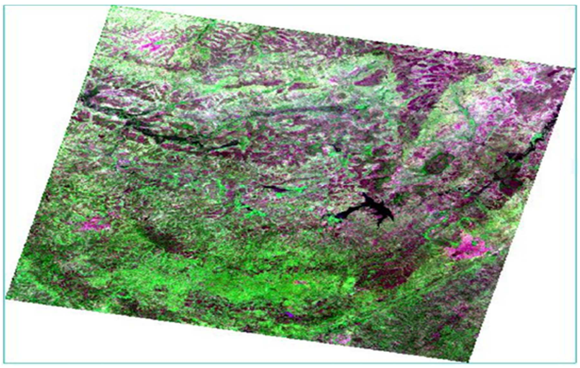

Fig. 2. Landsat 8 image with 5-4-3 colour composition

Extraction from the study area

To gain a better understanding of the land use in the study area, the mosaic image was used to subdivide the area. This was done by overlaying the study area on the image in question using the 'Subset Data via ROIs' tool (Fig. 3).

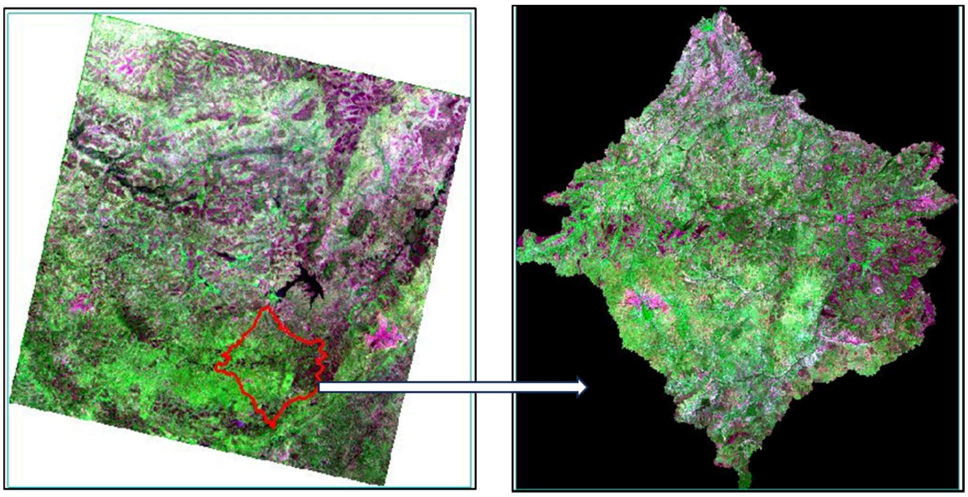

Fig. 3. Extraction of the area of interest

Supervised classification and the Kappa index

This classification is based on the radiometric value of the occupation units to be classified. We classified the sampled units using the maximum likelihood algorithm. Eight (08) land use units were selected: wooded savannahs, shrub savannahs, gallery forests, rainfed crops, orchards, water bodies, discontinuous urban fabric and bare soil. The choice of land-use units depends on our theme and the objectives defined.

Post classification

For this operation, we first had to combine the classes using the 'combine class' tool, then eliminate the isolated pixels using the 'seive' tool. We also used the 'clump class' tool to homogenise the classes, and the 'Majority/Minority analysis' tool to smooth the classes.

Vectorisation

After post-classification, the classified image was vectorised. It was then transferred to ArcGIS 10.8 software for cartographic processing and analysis. Some units, such as orchards, were additionally digitised using the software.

Step 2: Validation phase

At this stage, the accuracy of the classification was measured by comparing the classes assigned by the model with the actual classes observed in the field (ground truth). This ensures that the model is reliable and can be used for previous analyses. At this stage, we created validation data (ground truth), which enabled us to construct a confusion matrix and accuracy indicators such as the Kappa index. Supervised classification of our various images enabled us to produce satisfactory confusion matrices and Kappa indices for each year, the formula for which is as follows:

Kappa coefficient (K)

It has been the basis for the assessment of the accuracy of the units. The Kappa coefficient (K) is then calculated using the following equation (Abdelkareem *et al.*, 2018).

$$K = \frac{N\sum_{1=1}^{r} Xii - \sum_{i=1}^{r} X_i + X + i}{N^2 - \sum_{i=1}^{r} X_i + X + i} \quad (2)$$

Where:

r: Number of rows/columns in confusion matrix

Xii: Number of observation in row i and column i

Xi+: Total number of row i

X+i: Total number of column i

N: Number of observations.

A kappa value greater than 0.5 can be considered to be satisfactory for the modelling of land use change (Pontius, 2000). Furthermore, in the study, K is greater than 0.5 as follows:

1993: K: 0.941053

2003 : K: 0.839744

2013 : K: 0.848333

2023 : K: 0.878333

Table 3. The transition matrix mode

		Land use units j at time t1			
		Unit 1 (j=1)	Unit 2 (j=2)	Unit 3 (j=3)	Sum Eito of lines
Land use units i at time to	Unit 1(i=1)	a(1,1)	a(1,2)	a(1,3)	E1to = Σa(1,j)
	Unit 2 (i=2)	a(2,1)	a(2,2)	a(2,3)	E2to = Σa(2,j)
	Unit 3 (i=3)	a(3,1)	a(3,2)	a(3,3)	E3to = Σa(3,j)
	Sum of Ejt1 columns	E1t1 = Σ a(i,1)	E2t1= Σa(i,2)	E3t1= Σa(i,3)	ΣΣ a(i,j)

Source: Yanogo, 2012

Step 3: ArcGIS operations

ArcGIS 10.8 operations included additional digitization, calculation of various statistics (transition matrix, land cover change) and cartographic processing. The statistical calculations were based on the transition matrix and land cover change. The transition matrix is a double-entry table that provides a condensed description of changes in the state of land cover cells between two dates (Schlaepfer, 2002). It is summarized in Table 3 below.

Land Cover Change (LCC) is also used to capture changes between land cover units. Its formula is as follows (Wang *et al.*, 2018):

$$LCC = \left(\frac{\sum_{i=1}^{n} \Delta S_{i-j})}{S_i}\ X\ \frac{1}{T}\ X\ 100\% \qquad (3)$$

Results

State of land use in the Djenkoa sub-catchment between 1993 and 2023

It concerns changes in land use over the periods 1993, 2003, 2013 and 2023.

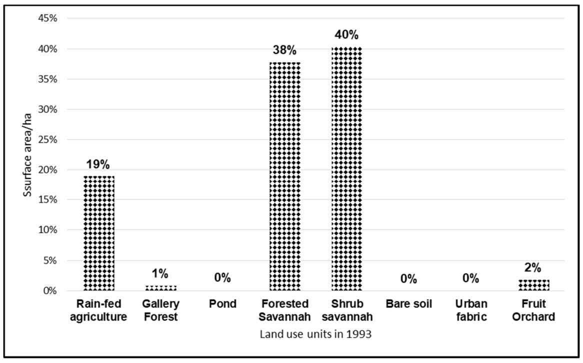

Fig. 4. Land cover in 1993

Land use in the sub-catchment in 1993

Fig. 4 The spatial distribution of land use units in 1993 shows that vegetation formations (shrub savannah and wooded savannah) were very dense in the catchment, covering about 40% and 35% of the area respectively. This indicates that open natural areas were in the majority at that time. Rain-fed crops covered about 20% of the area, indicating the importance of rain-fed agriculture. The other categories (gallery forest, bare ground, urban fabric and orchard) occupied marginal areas, each at a low level. The predominance of vegetation formations (wooded savannah and scrubland) may reflect the predominance of nature.

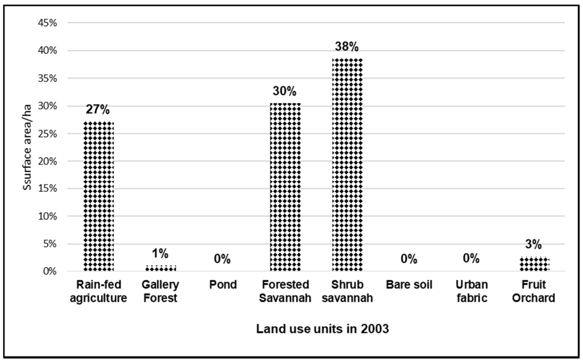

Fig. 5. Land cover in 2003

Land use in the sub-catchment in 2003

Fig. 5 below shows the spatial distribution of land use units in 2003. It shows that the plant formations (shrub savannah and tree savannah), which were very dense in the catchment in 1993, have slightly decreased in area, reaching 35% for shrub savannah and 30% for tree savannah. On the other hand, rainfed vegetation has increased and now covers about 25% of the area. The other categories (gallery forest, bare ground, urban fabric and orchard) still occupy marginal areas, each at a low level**.**

Land use in the sub-catchment in 2013

The spatial distribution of land use units in 2013 shows that vegetation formations (shrub savannah and wooded savannah) still account for a large proportion of the catchment area, with areas of over 25% for wooded savannah and over 35% for shrub savannah (Fig. 6). There has also been an increase in rainfed crops, which account for about 30% of the area, with orchards increasing by about 5%. The other categories (gallery forest, bare ground, urban fabric) still occupy marginal areas, each at a low level.

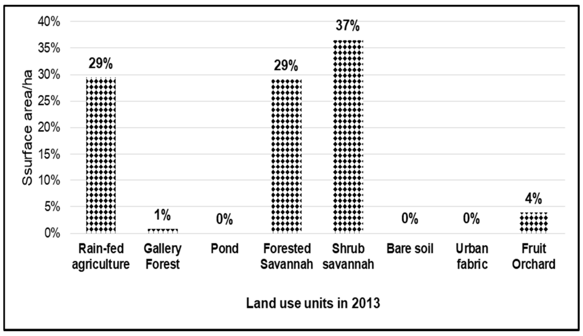

Fig. 6. Land cover in 2013

Land use in the sub-catchment in 2023

The spatial distribution of land-use units in 2023 reveals that plant formations (shrub savannah and wooded savannah) still account for a significant proportion of the catchment area, with areas of over 25% for wooded savannah and 35% for shrub savannah (Fig. 7).

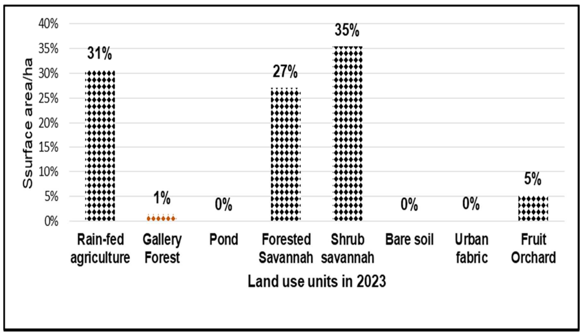

Fig. 7. Land cover in 2013

There has also been an increase in rainfed crops, which now cover around 30% of the area, with orchards increasing by 5%. The other categories (gallery forest, bare ground, urban fabric) still occupy marginal areas, each at low levels.

Dynamics of land use units in the sub-basin between 19993 and 2023

Land use units in the sub-basin fluctuate between progression and regression over the period 1993-2023 (Fig. 8).

In order to understand the evolutionary dynamics of the land-use units, we calculated the average annual rate of change of the different land-use units. This operation allowed us to obtain two situations, namely progression and regression. Table 4 below summarizes the evolutionary dynamics of the land-use units in the study area between 1993 and 2023.

The table shows that between 1993 and 2023, land-use units such as rainfed crops, bare soil, urban fabric and orchards increased, while water bodies, wooded savannah and shrub savannah decreased. Gallery forest is the only land use unit that showed progressive change between 1993-2003; 1993-2023; 2003-2023; 2013-2023 and regressive change between 2003-2013. The increase of the above land-use units can be explained by demographic pressure, climatic migrations and many other factors. On the other hand, the decrease in land-use units is due to climate change, pressure on natural resources, bush fires, agriculture and many other factors.

Land use change in the subcatchment between 1993 and 2023

Table 4 shows the land use transition matrix between 1993 and 2023. The land-use dynamics show a conversion of areas from wooded savannah to other types of ecological units. In particular, wooded savannahs are the units that have lost a significant proportion of their area to shrub savannahs (21 785, 92 ha) and orchards (3 153, 81 ha).

Table 5 shows the transition from tree savannah to shrub savannah. This could be explained by a number of factors, including climate change, land degradation and human pressure.

Climatic variability, characterised by a reduction in rainfall, induces hydric stress, which is unfavourable for the survival of trees, which have greater hydric requirements than shrubs. In addition, practices such as overgrazing and deforestation can lead to soil degradation, affecting the establishment of tree species. In addition, selective felling of trees for timber or charcoal reduces their density, making it easier for shrubs to dominate.

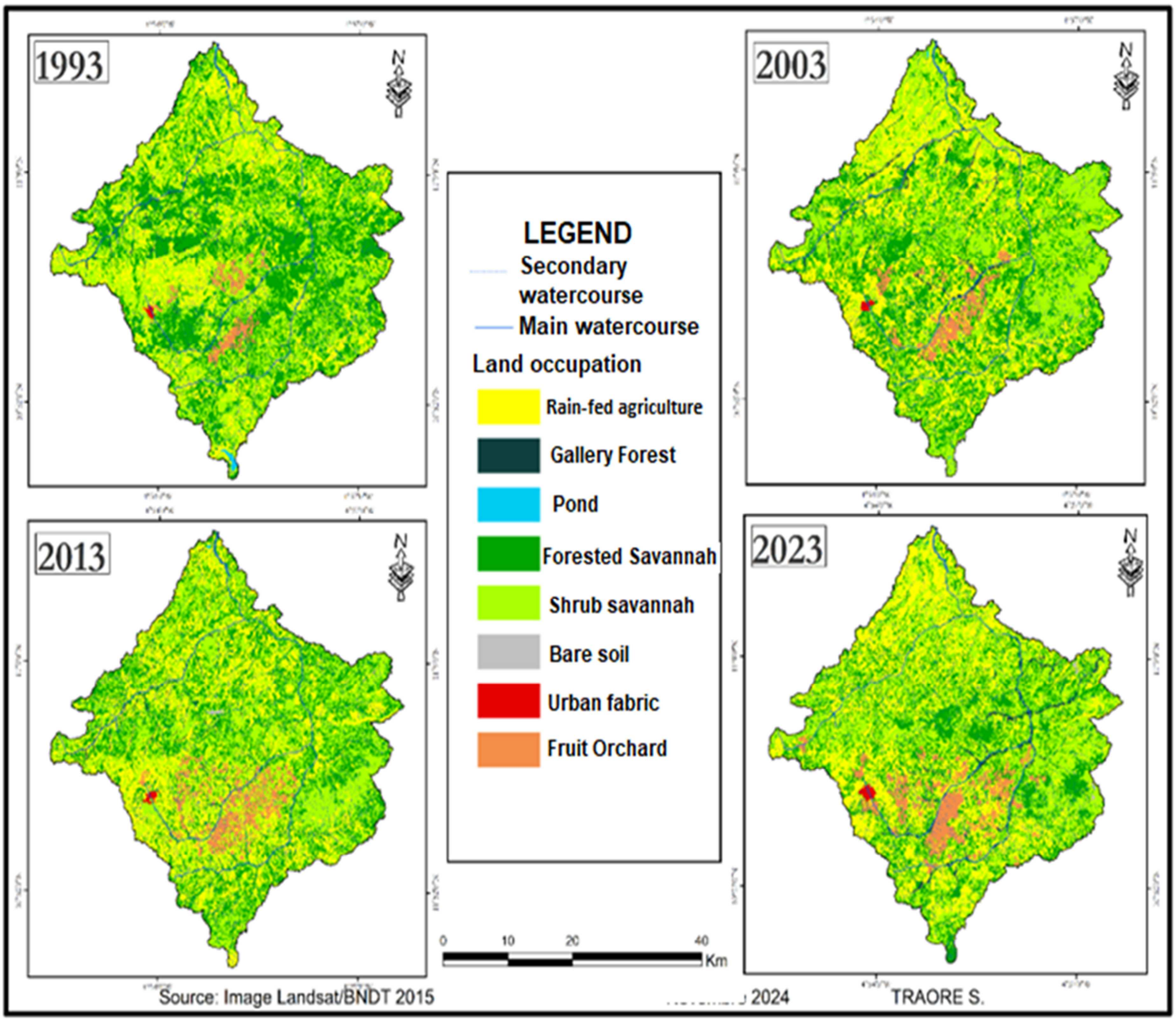

Fig. 8. Spatio-temporal dynamics of the Djenkoa sub-basin between 1993 and 2023

Table 4. Dynamics of the land use units in the study area between the years 1993 and 2023

Land use units	Proportion %											
	1993-2003	Trend	1993-2013	Trend	1993-2023	Trend	2003-2013	Trend	2003-2023	Trend	2013-2023	Trend
Rain-fed agriculture	0.082	+	0.105	+	0.118	+	0.023	+	0.035	+	0.012	+
Gallery forest	0.002	+	0.000	+	0.006	+	-0.002	-	0.004	+	0.006	+
Pond	-0.001	-	-0.001	-	-0.001	-	-0.000	-	-0.000	-	-0.000	-
Forested savannah	-0.074	-	-0.087	-	-0.107	-	-0.014	-	-0.034	-	-0.020	-
Shrub savannah	-0.018	-	-0.038	-	-0.050	-	-0.019	-	-0.031	-	-0.012	-
Bare soil	0.000	+	0.001	+	0.001	+	0.001	+	0.001	+	0.000	+
Urban fabric	0.000	+	0.000	+	0.001	+	0.000	+	0.001	+	0.001	+
Fruit orchard	0.009	+	0.021	+	0.033	+	0.012	+	0.024	+	0.012	+

+ = progression, - = decline

The conversion of savanna trees into orchards is the result of deliberate human intervention, often motivated by the introduction and development of adapted fruit species. This conversion generally requires the partial or total removal of certain trees indigenous to tree savannas, although some are sometimes retained to provide shade or ecosystem services. Trees deemed unprofitable or in the way of fruit crops are systematically removed to allow the establishment of controlled plantations. Finally, socio-economic factors such as increased market demand, agricultural development programmes and land pressure play a key role in farmers' decisions to convert savanna trees into orchards.

Table 5. Transition matrix between 1993 and 2023

	Rain-fed agriculture	Gallery Forest	Pond	Forested Savannah	Shrub savannah	Bare soil	Urban fabric	Fruit Orchard	Total 1993
Rain-fed agriculture	10302.45	285.09	2.79	7746.91	10521.01	0.90	79.15	990.99	29929.29
Gallery forest	251.70	266.07	00	139.21	559.00	0.12	00	91.25	1307.37
Pond	10.62	00	00	177.66	53.01	00	00	00	241.29
Forested savannah	16962.54	948.85	1.62	16746.37	21785.92	75.74	0.72	3153.81	59675.56
Shrub savannah	20161.93	690.63	1.71	17266.36	22538.19	43.48	117.71	2891.47	63711.48
Bare soil	00	00	00	1.26	12.69	00	00	00	13.95
Urban fabric	10.17	00	00	1.26	1.84	00	146.18	11.05	170.51
Fruit orchard	823.32	5.90	00	640.88	409.50	00	24.43	957.69	2861.73
Total 2023	48522.73	2196.54	6.12	42719.91	55881.16	120.24	368.20	8096.26	157911.17

Over the same period (1993-2023), rainfed crops are the land use units that have gained the most area at the expense of shrub savannah (20161.93 ha) and tree savannah (16962.54 ha).

The conversion of shrub and tree savannah to rainfed cultivation could be explained by a combination of several factors, namely demographic pressure, economic pressure and land tenure policies. Population growth requires more land for food production. In addition, formerly savannah land is being converted to meet the housing and agricultural needs of growing communities. The development of cash crops, such as cotton, could be a key factor in the conversion of savannah into agricultural land to meet demand. Furthermore, land tenure policies, often characterised by a lack of sustainable management of natural resources, have led to an increase in agricultural production, resulting in the conversion of plant formations.

Shrub savannahs are the land use units that have remained stable (22538.19 hectares), which could be explained by the climatic conditions to which they are best adapted. Shrub savannahs are ecosystems that are able to maintain themselves in the face of disturbances such as bush fires, drought cycles and grazing.

Farmers' perceptions of environmental awareness and need for action in the context of sub-watershed resource dynamics

Raising farmers' awareness of environmental issues is a key element of sustainable natural resource management policies. It enables farmers to adopt environmentally friendly practices and play an active role in protecting their immediate environment.

Types of awareness-raising activities carried out in the sub-basin

Raising awareness of good practice in riverbank protection

One of the major challenges in environmental protection is the maintenance of river banks, which is essential to prevent erosion and maintain water quality. Of the 252 producers surveyed, 167 (66%) said they had received training in good riparian protection practices, while 87 (34%) had not.

This relatively high proportion of producers who have been made aware of the issue shows that local authorities and NGOs have made significant efforts to inform the rural population of the importance of protecting river banks. However, the fact that 34% of farmers had not been made aware may reflect certain limitations in the coverage of awareness campaigns. This could be due to the geographical distance of remote rural areas, logistical problems in organising awareness-raising events or unequal access to information.

Raising awareness of good cotton practices

With regard to cotton production, which remains an important agricultural activity in the study area, 150 producers (60%) were made aware of good cotton production practices, while 102 (40%) received no information on the subject. This result can be explained by the specific nature of the cotton sector in the region: cotton producers are generally made aware by Cotton Technical Agents

(CTAs), who play a central role in disseminating good agricultural practices within Cotton Producer Groups (CPGs). This specialised approach explains why a large proportion of cotton growers are made aware, but also why a certain percentage of growers are not reached, particularly those who are not members of these groups. The structure of the intervention and the organisation of awareness-raising by sector may therefore be a limiting factor.

Raising awareness of good arboricultural practices

Finally, the results show a different situation for arboriculture, which includes agricultural practices related to fruit trees and other tree crops. Only 50 farmers (21%) had been made aware of good tree farming practices, while 201 (79%) had not received any such information.

This low proportion can be explained by several factors. Firstly, tree crops are a relatively new crop in the region, developed mainly by imitation rather than organised awareness programmes. The arrival of agri-food companies such as Dafani SA, COOPAKE and Afridia Industries marked a turning point in the promotion of agricultural practices related to tree cultivation. They have begun to provide technical information, particularly on the use of agricultural inputs (chemical fertilisers, pesticides and fungicides). However, these initiatives only reach a minority of farmers, limiting the spread of good tree farming practices to a small section of the population.

The results of this survey show that there is a marked difference in access to awareness raising depending on the type of crop. Cotton growers, due to their organisation into specialised groups, benefit from a greater coverage of awareness of good practices, while tree growers, whose crop is still marginal and relatively new, are less well informed. In addition, awareness campaigns do not seem to reach a significant proportion of farmers, especially those who are not members of cooperatives or directly involved in cotton production.

Discussion

The natural resources of the sub-catchment are fully dynamic over the period 1993-2023. The units of rainfed crops, gallery forests, NI soils, urban fabric and orchards increase.

Conversely, tree and shrub savannahs have been in sharp decline since 1993. This situation reflects the strong influence of human activities on the resources of the Djenkoa sub-catchment. The same trend can be observed in other basins and sub-basins in Burkina Faso. In the Bankandi-Loffing basin in south-western Burkina Faso, a gradual conversion of savannah into farmland and housing has been observed (Idrissou *et al.*, 2022). Similar results were found in the Dano catchment by Okafor *et al.* (2019). Residential areas and cultivated land are clearly increasing at the expense of forest resources and surface water in the Dano catchment.

Projections for 2050 show a worsening of the downward trend in forest resources (Okafor *et al.*, 2019). The work of Yira *et al.* (2016) also indicates that the Dano basin is affected by water availability and soil erosion. In the Nakambè catchment area, woodland and shrubland decreased by 45% and 68% respectively, while water bodies, cultivated land and bare/built-up land increased by 233%, 51% and 75% between 1990 and 2020 (Yangouliba *et al.*, 2023).

The situation is similar in West Africa. West African watersheds such as Sassandra, located in Côte d'Ivoire, the Mono watershed, extending over Togo and Benin, or the Volta watershed, shared by Burkina Faso, Mali, Benin, Togo, Côte d'Ivoire and Ghana, show an increase in built-up land and water bodies, while vegetation groups such as forest, savannah and herbaceous savannah have decreased over the three periods considered (1988, 2002 and 2016) (Obahoundje *et al.*, 2018). In Ghana, in the catchment areas of dams in the north of the country, land-use changes appeared to be significant to the detriment of forest resources (Umukiza *et al.*, 2024).

Conclusion

The spatio-temporal dynamics of land use in the sub-catchment were determined for the period 1993 to 2023. Satellite images were used. The confusion matrix and the rate of land change show that the Djenkoa sub-catchment has a variety of landscape units: rainfed cropping, bare soil, orchards, wooded and shrubby savannahs, water bodies and gallery forest.

Rain-fed cropping, wooded and shrub savannahs and orchards are the dominant units during this period. However, tree and shrub savannahs have declined, while bare soil, rain-fed cultivation and gallery forest have shown positive trends. This situation is the result of advanced land occupation in the sub-basin.

Recommendations

The effective implementation of environmental practices is essential to ensure the sustainable management of natural resources and to address local environmental challenges. While raising awareness is an important first step, it is concrete action on the ground that allows the real impact of environmental initiatives to be measured. As part of this study, producers were asked to identify the concrete actions they were seeing in their immediate environment to protect the environment. These actions can take a variety of forms, ranging from direct measures to protect river banks, to broader actions related to soil and water management.

Penalties imposed by environmental authorities

One of the actions observed by producers is the application of penalties by the environmental protection services. Although this action is not systematic, some producers (70%) reported that they had seen penalties imposed on operators who did not comply with environmental standards, particularly those relating to water and soil management. These sanctions can take the form of fines or operating restrictions.

The use of sanctions is an important deterrent mechanism to ensure compliance with environmental regulations, but it is also important to ensure that the system is perceived as fair and transparent. In the context of this study, the presence of sanctions indicates that controls are in place, but their effectiveness needs to be assessed in terms of the frequency of non-compliance and the extent of the measures taken.

Gully treatment to reduce siltation of watercourses

Gully treatment is another important measure observed in the field. The silting up of watercourses is a major problem in areas where soil erosion is a recurrent phenomenon. Some regions have therefore taken measures to reduce siltation, in particular through gully treatment, a practice that involves stabilising eroded soil and restoring riparian areas. This includes the planting of vegetative cover and the use of plant or stone barriers to slow down the erosion process.

Riparian reforestation

Riparian reforestation is another concrete measure observed by producers. Reforestation is an anti-erosion measure that involves planting trees along the banks of watercourses to stabilise the soil and prevent erosion. It also helps to restore biodiversity in riparian ecosystems. A number of growers reported seeing reforestation initiatives on the banks of rivers or lakes in their area.

Reforestation is particularly beneficial to the environment as it helps reduce greenhouse gases, improves water quality and provides habitat for wildlife.

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