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RESEARCH ARTICLE

FOREST MANAGEMENT AND LAND USE DYNAMICS IN THE WAKOU COMMUNAL FOREST AND DIAPANGOU SYLVOPASTORAL ZONE (BURKINA FASO)

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Abstract

In Burkina Faso, the degradation of forest resources has led to the implementation of strategies to preserve and restore plant formations. To this end, the Wakou communal forest (FC) and the Diapangousylvopastoral zone (ZSP), in the east of the country, have benefited from forest management. This study analyzes the impact of these management on vegetation by mapping the different land-use units. To this end, 08 Landsat images from 1989, 1999, 2009 and 2018 were processed. Field observations and data collection were used to perform a supervised classification using maximum likelihood. The results show that in the FC, the area of wooded savannah has increased significantly, rising from 1.95% in 1989 to 54.53% in 2018. Shrub savannah has decreased from 89.22% in 1989 to 42.14% in 2018. Fields have also declined, respectively from 13.55% in 1989 to 2.22% in 2018. In the ZSP, the results show that wooded savannah increased from 4.40% to 17.92% between 1989 and 2018. Shrub savannah regressed from 72.70% in 1989 to 55.50% in 2018. Fields increased from 16.34% to 22.55% over the same period. The change in land use units shows that in the FC, shrub savannah has regressed in favor of wooded savannah. It has gained 78.21ha and is the largest surface area at 83.76 ha. In the ZSP, shrub savannah decreased by 105.19 ha in favor of wooded savannah and by 69.10 ha in favor of fields. Monitoring of management activities is recommended to ensure sustainable management of the forest resource.

Introduction:-

Forest resources are of vital importance to people's daily lives (Adjonou et al., 2016; FAO, 2015; Thiombiano et al., 2012; PIF, 2011). They play a crucial role in conserving biodiversity, stabilizing climatic and social balances and mitigating conflicts (Pomel and Salomon, 1994). Despite the vital importance of forests, they continue to face enormous difficulties as a result of anthropogenic pressure accentuated by climate change. This has resulted in a reduction in forest area and biodiversity, with the disappearance of certain plant species. This regressive dynamic generally favor's the agricultural front in a context of demographic pressure (Zoungrana, 2010; Kabore and Dipama, 2013; Kaboré and Dipama, 2014, FAO, 2016; Tapsoba, 2016). With this in mind, an awareness of the importance of forests and the dangers associated with their degradation will emerge at both international and local level. Forest management will therefore be undertaken in Africa with the aim of protecting certain forest areas or organizing their exploitation (CILSS, 2005).

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Burkina Faso began to take an interest in forest planning in the 1980s, with the development of a policy for the management of classified forests in 1984 (Segueda, 2010). This led to the implementation of several projects and programs, with the support of international organizations, with the aim of conserving and restoring degraded natural resources as far as possible (CILSS 2005, Ouédraogo B, 2009). In the rest of the country, a number of developments have been undertaken, with 667.600 ha developed and 20.2400 ha under development (Ouédraogo, W.A., 2011). All of these developments, which were intended to improve the dynamics of plant formations, have produced a certain number of results, although these are not always well known (Belemviré et al., 2008).

In the east of Burkina Faso, climatic and human dynamics are having an impact on the degradation of plant formations. Studies by Hahn Hadjali k. and Thiombiano (2000) highlight the disappearance of several plant species in this part of the country. The province of Gourma, where the rural commune of Diapangou is located, has seen a sharp deterioration in its natural resources, particularly forestry. The density of woody species in the commune is 69.21 feet / ha (IFN-2, 2015). This is well below the regional average, which varies between 100 and 150 feet/ha, and the average for Gourma province, which is 110.78 feet/ha (IFN-2, 2015). This has led several projects and programs to take an interest in the commune, in order to preserve its forest resources. With this in mind, the communal forest and the sylvopastoral zone have been managed with the help of technical and financial partners.

In view of the objectives, which are sometimes mixed in the context of developments in general, it seemed important to present, in the context of the Communal Forest (CF) and the Diapangou Sylvopastoral zone (ZSP), the achievements in terms of plant resource conservation. To do this, it is necessary to have data on the evolution of these resources through the proportions occupied by the different land-use classes. The main objective is therefore, to analyze the impact of forest management on plant cover, in terms of dynamics. The assumption is that forest management could help to improve the state of the vegetation cover. Specifically, the aim is to (i) carry out spatio-temporal mapping of land cover in 1989, 1999, 2009 and 2018 and (ii) analyze changes between land cover classes in the study area.

Methodology:-

Presentation of the study area

The communal forest (CF) and the sylvopastoral zone (ZSP) are located in the rural commune of Diapangou, Gourma province, in the eastern region of Burkina Faso (Figure 1). The commune lies between 11°57' and 12°16' north latitude and 0°2' and 0°20' east longitude. The communal forest covers an area of 153.61 ha and the forest-pastoral zone covers 690.17 ha. Climatically, the study area has a North Sudanian climate. It is marked by an alternating dry season from October to April (7 months) and a rainy season from May to September (5 months). The average rainfall between 1988 and 2022 is 846 mm per year. The maximum rainfall, recorded in 1994, is 1366.2 mm and the minimum, recorded in 1990, is 568 mm. The average annual temperature for the same period was 28.9°C. The vegetation consists of natural formations of the shrub savannah to tree savannah type, dominated by utilitarian species such as Vitellaria paradoxa, Parkia biglobosa and Lannea microcarpa. There are also riparian formations along watercourses. These are dominated by species such as Mitragyna inermis, Daniellia oliveri, Ficus capensis, Khaya senegalensis, Diospyros mespiliformis and Ficus iteophylla (Thiombiano and Kampmann, 2010). The population of the rural commune of Diapangou rose from 26510 inhabitants in 2006 to 34087 at the last census in 2019 (INSD, 2022). The population is characterised by its youth (51.49% aged 0-14), with the working population (aged 15-64) estimated at 45.12% of the total population. The population is mainly made up of farmers with an extensive agricultural production system, with small family farms averaging just 04 hectares. After agriculture, livestock farming is the second most important production activity in the municipality, with a traditional, extensive production system.

The communal forest (CF) and the sylvopastoral zone (ZSP) of the Diapangou commune were identified around 1985 and 1987 as part of the 'village wood' project and were created by the decrees of 09 June 2011 (Commune de Diapangou, 2011). The Diapangou communal forest, known as the Wakou communal forest, was once a village forest, created and managed in the traditional way by the people of Wakou. It serves as a traditional place of worship and a burial ground for the first-born of the various families in the village of Wakou, hence the sacred nature of the site and the desire of the people of Wakou to conserve their forest and protect their ancestral burial ground. The sylvopastoral zone was also created thanks to the development of the production and conservation area in the Diapangou commune. This is an area in which wood production (trees) and fodder are combined with extensive livestock farming. It was created with the aim of resolving conflicts between livestock farmers and farmers.

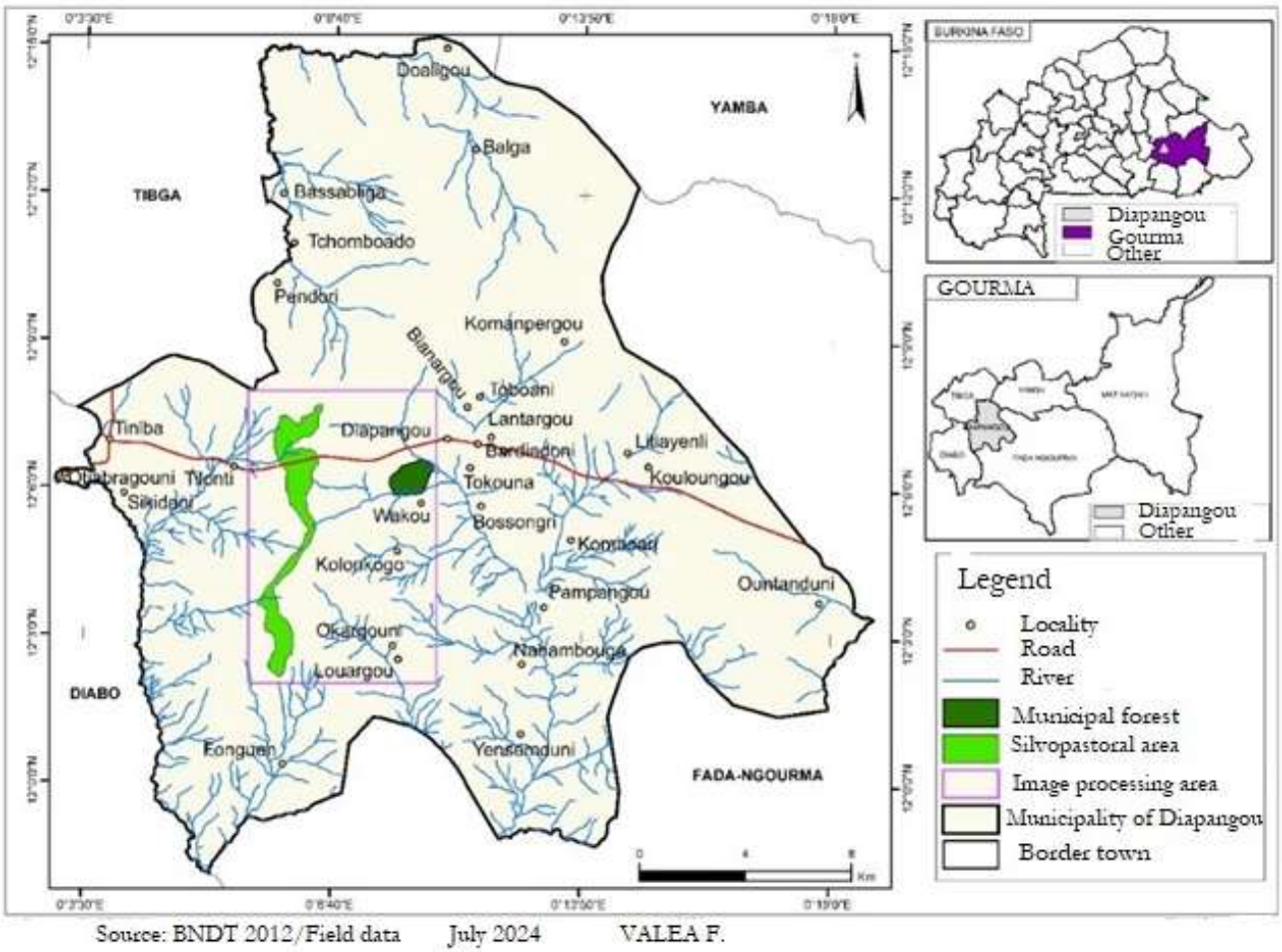


Fig.1:- Location of the study area.

Data and tools

Landsat TM (1989), ETM+ (1999), TM (2009) and OLI-TIR (2018) satellite images with 30 m resolution were selected. Sheets 194/051 and 194/052 were required to cover the study area. These images were downloaded free of charge from the NASA website (ww.earthexplore.us.gov). In total, eight (8) images from the years 1989 (26 October), 1999 (09 December), 2009 (12 December) and 2018 (18 October) were used. This choice was justified by the availability and quality of the images. The time step used is justified by the fact that the overriding concern is to have an observation period spread over 30 years, integrating the pre- and post-development periods, and to have good quality images for all the scenes on the different dates.

Spatially referenced databases, in particular the National Topographic Data Base (NTDB 2012) obtained from Geographies Institute of Burkina (IGB), were used to spatialize the results, as well as Google Earth images, which were used to better discriminate between land use classes.

The surveys covered 114 households in the surrounding localities sampled (Wakou, Diapangou and Titlonti) for the field surveys. In addition, interviews (25) were conducted with resource persons such as communal authorities, customary authorities, Village Development Committee (CVD) chairmen, local management committees, technical service managers and association managers at the two sites.

The data is collected using GPS and transferred using DNR Garmin and Expert GPS software. QGIS 2.14 and ArcGIS 10.3 were used to produce the various maps. ENVI 4.7 remote sensing software was used to process the satellite images. Microsoft Office 2013 Word extension was used for document entry.

Landsat image processing

ENVI 4.7 and ArGIS 10.3 were used for processing and mapping. This was done in several stages:

- The color composition 5, 4, 3 for the 2018 scenes and 4, 3, 2 for the other scenes (1989, 1999, 2009) were used to obtain a false color composition. The color composition 5, 4, 3 was chosen for the 2018 scenes because it shows the vegetation in red, giving a better view of the plant formations. The choice of the 4, 3, 2 color composition for the other scenes is due to the mismatch in bands between the Landsat 8 satellite images and those of the Landsat 7, Landsat 5 and Landsat 4 types.
- The bands were grouped together using layer stacking.
- Mosaicking involved assembling the two consecutive scenes (194/051 and 194/052) covering the study area. It was carried out for the different dates concerned using Envi 4.7 mosaicking.
- Extraction of the treatment area, which is a quadrilateral encompassing the said study sites. The study area itself comprises the FC, the ZSP and the surroundings of these forest areas. The size of the treatment area was chosen to give an overall view of the vegetation in the locality and to facilitate the drawing of ROIs (Region Of Interest). This extraction was carried out using the "spatial subset" tool.
- Supervised classification: regions of interest or ROIs (Region Of Interest) were selected and classified using the "Maximum Likelihood" algorithm. The reliability of the classification in relation to the thematic classes were checked using the "Compute ROI separability" tool because according to Nguena De Kalambak C. (2016),

If 0.0 < class < 1.0 separability is very poor and 0.0 implies total confusion between two classes; if 1.0 < class < 1.9 separability is poor; if 1.9 < class < 2.0 separability is very good and 2.0 reflects perfect separability.

The overall separability indices generated ranged from 1.8 to 2.0 for this study. In order to validate the different classifications, confusion matrices were generated to check their quality. The confusion matrix includes the kappa coefficient, which is the ratio between the number of well-classified pixels and the total number of pixels surveyed, and the overall accuracy, which is the proportion of well-classified pixels calculated as a percentage.

- Post classification and vectorization: after classification, classes were combined using the "Combine Classes" tool, isolated pixels were filtered using the "Sieve Classes" tool, classes were homogenized using the « Clump Classes » tool and smoothed using the « Majority/Minority Analysis » tool.

Vectorization of the classifications was carried out using the 'Classification to Vector' post classification tool.

- After vectorization, all the land use units were exported to ARCGIS 10.3, where the areas of interest (the CF, the ZSP and the area comprising the two forest entities) were extracted. This made it possible to assemble the land-use units for each area of interest using the "dissolve" tool. The different areas were generated using the "calculate geometry" tool. The 'union' tool was then used to highlight the changes that had taken place between the various dates and to update the areas. Finally, the areas of the land-use units obtained were exported to Excel 2013, for the construction of the transition matrices, using the pivot table.
- The transition matrix: to analyze the conversion of land-use units over time, the transition matrix approach was used. According to Schlaepfer (2003), the transition matrix provides a condensed description, in the form of a square matrix, of land-use changes and allocations over the time interval under consideration. The cells of the matrix contain the value of an area that has changed from an initial class i to a final class j during the period under consideration (t0, initial date to t1, final date). The values in the columns represent the proportions of areas occupied in the landscape by each land-use class at time j, and those in the rows, at the initial time i.

Results:-

Accuracy of classifications

The image classification results give an overall accuracy of 99.23% for the 1989 image, with a Kappa coefficient of 0.99, and an overall accuracy of 99.18% for the 1999 image, with a Kappa coefficient of 0.99. For the 2009 and 2018 images, the overall accuracy is 98.76% and 98.00% respectively, with a Kappa coefficient of 0.98 and 0.97 respectively (Table 2). For 2009 and 2018, the overall accuracy is 98.76% and 98.00% respectively, with a kappa coefficient of 0.98 and 0.97 respectively (table 2). These values show that more than 95% of the pixels in the four images were correctly classified in accordance with the ground-truth data. Overall, the values of the various supervised classification accuracy indicators obtained for the different images reflect, on the one hand, the good quality of the samples and, on the other hand, the good match between the classification result and the spatial reality contained in the images (Sanou et al. 2022, p8).

Table 1:- Summary of confusion matrix results.

Image Landsat	Kappa Coefficient	Overall accuracy
1989	0.99	99.23 %
1999	0.99	99.18 %
2009	0.98	98.76 %
2018	0.97	98.00 %

Source: statistical data calculated from confusion matrices

Land use dynamics from 1989 to 2018 in the communal forest

The processing of Landsat images from 1989, 1999, 2009 and 2018 reveals 5 land use units out of the 153.61 ha covered by the CF. These are: wooded savannahs, shrub savannahs, fields, bare areas and outcrops of cuirass (Table 2).

In 1989, shrub savannah predominated and extended over the whole of the CF. It occupied 137.05 ha or 89.22% of the total area of the CF. It is followed by fields (8.82%) in the northern part and a tiny part occupied by wooded savannah (1.95%) in the south-west. Bare areas and outcrops of cuirass were almost non-existent in 1989. Vegetation cover is estimated at 91.17%.

In 1999, shrub savannah was still the dominant land use unit in the FC, accounting for 141.31 ha or 91.99% of its surface area. This land use unit has increased by 4.26 ha since 1989. It is followed by wooded savannah in the north-east, which increased from 1.95% of the FC area in 1989 to 6.02% in 1999. In terms of vegetation cover, the total proportion in 1999 was 98.01%. The surface area of fields fell from 8.82% of the surface area of the CF in 1989 to 1.59% in 1999. They are located on the southern edge of the CF. Bare land also appeared to the south, near the fields, covering 0.61 ha, or 0.39% of the surface area of the CF.

In 2009, three land use units saw an increase in surface area. These were fields (to the south), which increased from 1.59% to 4.67%, wooded savannah to the east and center of the CF, which increased from 6.02% to 13.22%, and bare areas, which increased from 0.39% to 1.25% of the surface area of the FC. Shrub savannah remains the most represented land use unit at this date, with 121.87 ha, or 79.34% of the forest area. However, its area declined from 141.31 ha in 1999 to 121.87 ha in 2009. At the same time, outcrops of cuirass appeared in the south-east of the CF, covering 2.34 ha, or 1.52% of the total forest area. Vegetation cover is estimated at 92.56%.

According to the occupancy situation in 2018, wooded savannah increased from 13.22% to 54.53% of the CF area in 2018, becoming the most represented occupancy unit. The other 4 land use units all saw a decrease in area in 2018. Fields (to the south) fell from 4.67% of the area of the FC in 2009 to 2.22% in 2018, shrub savannah from 79.34% in 2009 to 42.14% in 2018, bare areas from 1.25% in 2009 to 0.11% in 2018 and finally cuirass outcrops which fell from 1.52% in 2009 to 1.00% in 2018. The vegetation cover rate is 96.67%.

Table 2:- CF land use units in 1989, 1999, 2009 and 2018.

Units	**1989**		**1999**		**2009**		**2018**	
	Area		**Area**		**Area**		**Area**	
	Ha	**%**	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**
Champ	13,55	8,82	2,44	1,59	7,17	4,67	3,41	2,22
Savane arborée	3,00	1,95	9,25	6,02	20,31	13,22	83,76	54,53
Savane arbustive	137,05	89,22	141,31	91,99	121,87	79,34	64,73	42,14
Zone nue	0,00	0,00	0,61	0,39	1,92	1,25	0,17	0,11
Cuirasse	0,00	0,00	0,00	0,00	2,34	1,52	1,53	1,00
Total	153,61	100,00	153,61	100,00	153,61	100,00	153,61	100,00

Source: processing of Landsat images from 1989, 1999, 2009 and 2018

Land use dynamics from 1989 to 2018 in the sylvopastoral zone

Covering an area of 690.17 ha, the ZSP has 6 land-use units over the study period. These include tree savannah, shrub savannah, fields, outcrops of cuirass, bare areas and burnt area, which vary from one date to the next (Table 3).

In 1989, there were 5 different land-use units in the ZSP. Shrub savannah was the most common land-use unit at that

date, with 501.77 ha, or 72.40% of the area of the ZSP. It is followed by fields in the central and southern part of the ZSP with 16.34%, bare areas in the south with 6.08%, wooded savannah in the north with 4.40% and outcrops of cuirass with 0.48% of the surface area of the ZSP. Vegetation cover is estimated at 76.8%.

In 1999, the area of shrub savannah increased from 501.77 ha to 581.85 ha, or 84.31% of the area of the ZSP. The other land-use units, i.e., fields, outcrops of cuirass, wooded savannah and bare areas, saw their surface areas decrease compared with 1989. The wooded savannah is now only a tiny island in the north; it has fallen from 4.40% to 0.05%, the fields in the north-east and south-west from 16.34% to 11.58%, outcrops of the cuirass from 0.48% to 0.34%, and the bare areas from 6.08% to 3.48%. A new occupancy unit has appeared: burnt area, with 1.65 ha, or 0.24% of the surface area of the ZSP. The vegetation cover rate is 84.42%.

For 2009, two land-use units showed a progressive dynamic compared with the 1999 land-use units. These were wooded savannah and fields. Wooded savannah increased slightly from 0.36 ha, or 0.05% of the area of the ZSP in 1999, to 0.54 ha, or 0.08% of the surface area of the ZSP in 2009. Fields increased more significantly from 11.58% to 17.91%. They occupy the entire central, north-eastern and eastern parts of the ZSP. The land-use units that have experienced a downward trend are cuirass outcrops, shrub savannah and bare areas. Shrub savannah fell from 84.31% of the area of the ZSP in 1999 to 78.90% in 2009. However, it was still the most common land-use unit in 2009. Cuirass outcrops and bare areas fell from 0.34% and 3.48% respectively of the surface area of the ZSP in 1999 to 0.25% and 2.86% in 2009. Vegetation cover is estimated at 78.98%.

The 2018 situation shows that 05 land use units are present in the ZSP, three of which are increasing while two are decreasing. The areas that have increased are fields, cuirass outcrops and wooded savannah in the north, north-west and south. Fields in the center and south increased from 123.63 ha, or 17.93% of the surface area of the ZSP in 2009, to 155.64 ha, or 22.55% of the same surface area in 2018. Cuirass outcrops have increased from 0.25% to 3.13% and wooded savannah from 0.08% to 17.92%. The land-use units that have declined are shrub savannah, which fell from 78.90% of the surface area of the SPA in 2009 to 55.50% in 2018, and bare areas, which fell from 2.86% to 0.91%. In terms of vegetation, the total proportion in 2018 is 73.42%.

Table 3:- Land use units in the ZSP in 1989, 1999, 2009 and 2018.

Units	**1989**		**1999**		**2009**		**2018**	
	Area		**Area**		**Area**		**Area**	
	Ha	**%**	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**
Field	112.76	16.34	79.91	11.58	123.63	17.91	155.64	22.55
Cuirass	3.30	0.48	2.36	0.34	1.72	0.25	21.59	3.13
Wooded savannah	30.36	4.40	0.36	0.05	0.54	0.08	123.68	17.92
Shrubby savannah	501.77	72.70	581.85	84.31	544.54	78.90	383.01	55.50
Bare area	41.98	6.08	24.03	3.48	19.74	2.86	6.25	0.91
Burnt area	0.00	0.00	1.65	0.24	0.00	0.00	0.00	0.00
Total	690.17	100.00	690.17	100.00	690.17	100.00	690.17	100.00

Source: processing of Landsat images from 1989, 1999, 2009 and 2018

Changes in CF land use units between 1989 and 2018

The changes between 1989 and 2018 are shown in the transition matrices. They show the conversion of each occupancy unit in the CF and between 1989 and 2018.

Between 1989 and 1999, the transition matrix shows that 0.79 ha of fields, 1.28 ha of wooded savannah and 126.98 ha of shrub savannah underwent no change. In terms of area lost, 0.15 ha of wooded savannah and 1.50 ha of shrub savannah were transformed into fields, i.e., 1.65 ha of plant cover transformed into fields. Still in terms of losses, 7.96 ha of shrub savannah were converted to tree savannah. Of the units that recorded an increase in area, shrub savannah gained 12.75ha and 1.57ha at the expense of fields and shrub savannah respectively. Bare areas also appeared during this period at the expense of shrub savannah, with a surface area of 0.61 ha. Table 4 shows the conversions carried out in the FC between 1989 and 1999.

Table 4:- Transition matrix of CF units between 1989 and 1999.

1989 1999	Field	Wooded savannah	Shrubby savannah	Bare area	Total
Field	0.79	0.01	12.75	0.00	13.55
Wooded savannah	0.15	1.28	1.57	0.00	3.00
Shrubby savannah	1.50	7.96	126.98	0.61	137.05
Bare area	-	-	-	-	-
Total	2.44	9.25	141.31	0.61	153.61

Source: Landsat images processed in 1989 and 1999.

Fig. 2:- Land use in 1989, 1999, 2009 and 2018 in the study area.

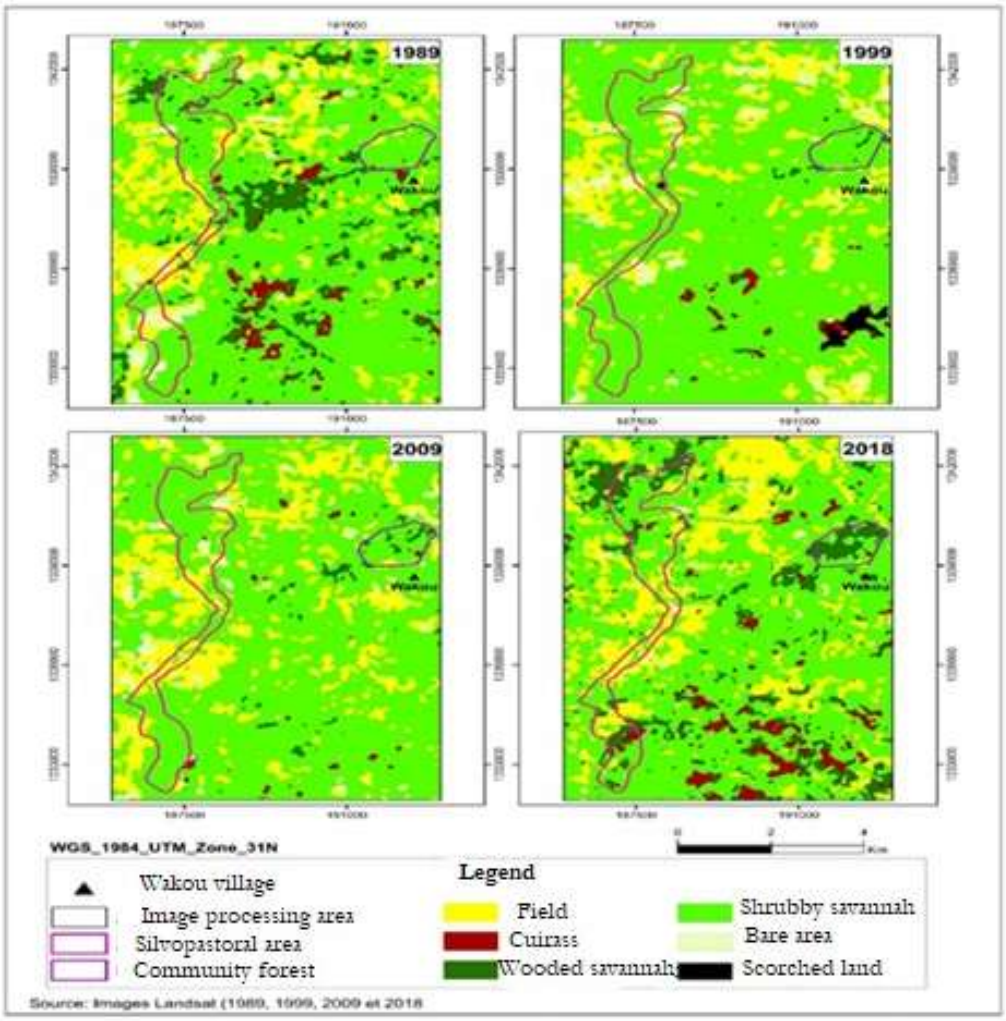


Figure 2 below shows the land use over the entire study area. It includes the area covering the CF and the ZSP.

Between 1999 and 2009, 0.43 ha of fields, 4.78 ha of wooded savannah, 116.02 ha of shrub savannah and 0.21 ha of bare areas remained stable. During the same period, 6.41 ha of shrub savannah and 0.33 ha of bare areas were transformed into fields. In addition, 15.51 ha of shrub savannah and 0.06 ha of bare areas were transformed into tree savannah and shrub savannah respectively. In terms of gains, shrub savannah increased in area at the expense of wooded savannah (4.47 ha) and fields (1.31 ha). There was also an increase in the surface area of bare areas, at the expense of 1.03 ha of shrub savannah and 0.68 ha of fields. Cuirass outcrops, which were non-existent in 1999, appeared in 2009 with an area of 2.34 ha at the expense of shrub savannah. Table 5 shows the changes in land use between 1999 and 2009.

Table 5:- Transition matrix of CF units between 1999 and 2009.

1999 2009	Field	Wooded savannah	Shrubby savannah	Bare area	Cuirass	Total
Fields	0.43	0.02	1.31	0.68	0.00	2.44
Wooded savannah	0.00	4.78	4.47	0.00	0.00	9.25
Shrubby savannah	6.41	15.51	116.02	1.03	2.34	141.31
Bare area	0.33	0.00	0.06	0.21	0.00	0.61
Cuirass	-	-	-	-	-	-
Total	7.17	20.31	121.87	1.92	2.34	153.61

Source: Landsat images processed in 1999 and 2009

The transition matrix of land-use units between 2009 and 2018 shows stability for 0.55 ha of fields, 17.27 ha of wooded savannah, 52.60 ha of shrub savannah and 1.24 ha of cuirass outcrop. In terms of losses, shrub savannah lost 2.51 ha and 66.46 ha to fields and shrub savannah respectively. Bare areas lost 0.35 ha to fields and 1.56 ha to shrub savannah. The cuirasses lost 1.09 ha to shrub savannah. In terms of gains, shrub savannah gained 0.02 ha at the expense of fields. Shrub savannah gained 6.60 ha and 3.04 ha at the expense of fields and shrub savannah respectively. Cuirass outcrops increased by 0.29 ha at the expense of shrub savannah. Bare areas disappeared completely in 2018. Table 6 shows the transition matrix between 2009 and 2018.

Table 6:- Transition matrix of CF units between 2009 and 2018.

2009 2018	Field	Wooded savannah	Shrubby savannah	Bare area	Cuirass	Total
Fields	0.55	0.02	6.60	-	0.00	7.17
Wooded savannah	0.00	17.27	3.04	-	0.00	20.31
Shrubby savannah	2.51	66.46	52.60	-	0.29	121.87
Bare area	0.35	0.00	1.56	-	0.00	1.92
Cuirass	0.00	0.01	1.09	-	1.24	2.34
Total	3.41	83.76	64.90	-	1.53	153.61

Source: processing of Landsat images from 2009 and 2018

The transition matrix of land-use units in the FC between 1989 and 2018 presents three situations, namely a situation of stability showing that the area of certain land-use units is stable over the period 1989-2018. Indeed, 1.12 ha of field, 0.89 ha of wooded savannah and 55.17 ha of shrub savannah remained unchanged. Analysis of Table 7 also shows a situation of loss, where some land-use units have lost part of their area to others. This is the case for tree savannah and shrub savannah, which have lost 0.15 ha and 2.14 ha respectively to fields. The shrub savannah also lost 78.21 ha of its area to the tree savannah. Finally, there is a situation of gain, where certain land-use units have increased their area at the expense of other land-use units. This is the case for shrub savannah, which has increased in area at the expense of 7.78 ha of fields and 1.96 ha of shrub savannah. Wooded savannah also recorded a gain of 4.66 ha at the expense of fields. Analysis of this table also shows that bare areas were non- existent on both dates, and that the cuirass outcrops present in 2018, with a surface area of 1.53 ha, were non-existent in 1989.

Table 7:- Transition matrix of CF units between 1989 and 2018.

1989 2018	Field	Wooded savannah	Shrubby savannah	Bare area	Cuirass	Total
Field	1.12	4.66	7.78	-	0.00	13.55
Wooded savannah	0.15	0.89	1.96	-	0.00	3.00
Shrubby savannah	2.14	78.21	55.17	-	1.53	137.05
Bare area	-	-	-	-	-	-
Cuirass	-	-	-	-	-	-
Total	3.41	83.76	64.90	-	1.53	153.61

Source: processing of Landsat images from 1989 and 2018

Changes in land use units in the ZSP between 1989 and 2018

The transition matrix of land use units between 1989 and 1999 in the ZSP shows that 21.87 ha of field, 0.19 ha of wooded savannah, 437.99 ha of shrub savannah and 1.67 ha of bare areas remained unchanged between the two dates (Table 8). However, changes were observed for wooded savannah, shrub savannah and bare areas, which lost 0.90 ha, 48.13 ha and 9.02 ha respectively to fields. In addition, 0.39 ha of wooded savannah and 1.98 ha of shrub savannah were transformed into cuirass outcrops. Over the same period, 0.17 ha of shrub savannah and 31.29 ha of bare areas were transformed into tree savannah and shrub savannah respectively. Shrub savannah increased in size at the expense of 81.97 ha of fields, 3.30 ha of cuirass outcrops and 27.29 ha of shrub savannah. Bare areas also increased in size, at the expense of 8.92 ha of fields, 1.46 ha of wooded savannah and 11.98 ha of shrub savannah. Burnt land, present in the ZSP in 1999 with a surface area of 1.65 ha, was non-existent in 1989.

Table 8:- Transition matrix of units in the ZSP between 1989 and 1999.

1989 1999	Field	Cuirass	Wooded savannah	Shrubby savannah	Bare area	Burnt area	Total
Fields	21.87	0.00	0.00	81.97	8.92	0.00	112.76
Cuirass	0.00	0.00	0.00	3.30	0.00	0.00	3.30
Wooded savannah	0.90	0.39	0.19	27.29	1.46	0.12	30.36
Shrubby savannah	48.13	1.98	0.17	437.99	11.98	1.53	501.77
Bare area	9.02	0.00	0.00	31.29	1.67	0.00	41.98
Burnt area	-	-	-	-	-	-	-
Total	79.91	2.36	0.36	581.85	24.03	1.65	690.17

Source: Landsat images processed in 1989 and 1999

Between 1999 and 2009, 40.50 ha of fields, 502.71 ha of shrub savannah and 3.82 ha of bare areas remained unchanged over the decade (Table 9). During this period, 67.89 ha of shrub savannah and 15.09 ha of bare areas were transformed into fields. In addition, 1.72 ha of shrub savannah, 0.54 ha of shrub savannah and 5.11 ha of bare areas were transformed into cuirass outcrops, tree savannah and shrub savannah respectively, and 1.65 ha of burnt land was transformed into shrub savannah. The area of shrub savannah increased at the expense of 32.49 ha of fields, 2.21 ha of cuirass outcrop and 0.36 ha of shrub savannah. Bare areas also increased in size, at the expense of 6.92 ha of fields and 8.99 ha of shrub savannah. The burnt land occupation unit, which appeared in 1999 with 1.65 ha, was non-existent in 2009.

Table 9:- Transition matrix of units in the ZSP between 1999 and 2009.

1999 2009	Field	Cuirass	Wooded savannah	Shrubby savannah	Bare area	Burnt area	Total
Fields	40,50	0,00	0,00	32,49	6,92	-	79,91
Cuirass	0,15	0,00	0,00	2,21	0,00	-	2,36
Wooded savannah	0,00	0,00	0,00	0,36	0,00	-	0,36
Shrubby savannah	67,89	1,72	0,54	502,71	8,99	-	581,85
Bare area	15,09	0,00	0,00	5,11	3,82	-	24,03
Burnt area	0,00	0,00	0,00	1,65	0,00	-	1,65
Total	123,63	1,72	0,54	544,54	19,74	-	690,17

Source: Landsat images processed in 1999 and 2009

Between 2009 and 2018, 67.16 ha of field, 0.37 ha of wooded savannah, 313.14 ha of shrub savannah and 1.58 ha of bare areas remained unchanged (Table 10). During the same period, 86.56 ha of shrub savannah and 1.92 ha of bare areas were transformed into fields. In addition, 21.59 ha and 122.41 ha of shrub savannah were transformed into cuirass outcrops and tree savannah respectively. During these two decades, 16.24 ha of bare areas were also transformed into shrub savannah. During the same period, the surface area of some land-use units increased. This is particularly true of wooded savannah, which increased in size by 0.91 ha at the expense of fields. The shrub savannah saw its area of occupation increase at the expense of 51.73 ha of fields, 1.72 ha of cuirass outcrops and 0.17 ha of shrub savannah. Bare areas also increased in size, at the expense of 3.84 ha of fields and 0.83 ha of shrub savannah.

Table 10:- Transition matrix of units in the ZSP between 2009 and 2018.

2009 2018	Field	Cuirass	Wooded savannah	Shrubby savannah	Bare area	Total
Field	67.16	0.00	0.91	51.73	3.84	123.63
Cuirass	0.00	0.00	0.00	1.72	0.00	1.72
Wooded savannah	0.00	0.00	0.37	0.17	0.00	0.54
Shrubby savannah	86.56	21.59	122.41	313.14	0.83	544.54
Bare area	1.92	0.00	0.00	16.24	1.58	19.74
Total	155.64	21.59	123.68	383.01	6.25	690.17

Source: processing of Landsat images from 2009 and 2018

The transition matrix of land-use units between 1989 and 2018 shows situations of stability, loss and gain (Table 11). Fields, cuirass outcrops, wooded savannah, shrub savannah and bare areas retained respectively 55.59 ha, 1.26 ha, 6.76 ha, 302.03 ha and 0.31 ha of their surface areas between these two dates. It also shows a situation of loss where part of the area occupied by certain land-use units has been transformed into other land-use units. This is the case for 8.16 ha of wooded savannah, 69.10 ha of shrub savannah and 22.5 ha of bare areas that have been transformed into fields.

We also note the conversion of 20.16 ha of shrub savannah into cuirass outcrops, as well as the conversion of 105.19 ha of shrub savannah and 3.83 ha of bare areas into shrub savannah. During these three decades, 15.31 ha of bare areas were also transformed into shrub savannah. This transition matrix also shows a situation of gain in which the surface area of certain land-use units has increased to the detriment of other land-use units. This is the case for wooded savannah, where the area has increased at the expense of 7.02 ha of fields, shrub savannah, where the area has increased at the expense of 49.51 ha of fields, 0.87 ha of cuirass outcrop and 15.30 ha of wooded savannah. Bare areas also increased in size, at the expense of 0.65 ha of fields and 5.29 ha of shrub savannah.

Table 11:- Transition matrix of units in the ZSP between 1989 and 2018.

1989 2018	Field	Cuirass	Wooded savannah	Shrubby savannah	Bare area	Total
Field	55.59	0.00	7.02	49.51	0.65	112.76
Cuirass	0.30	1.26	0.87	0.87	0.00	3.30
Wooded savannah	8.16	0.13	6.76	15.30	0.01	30.36
Shrubby savannah	69.10	20.16	105.19	302.03	5.29	501,77
Bare area	22.50	0.03	3.83	15.31	0.31	41.98
Total	155.64	21.59	123.68	383.01	6.25	690.17

Source: processing of Landsat images from 1989 and 2018

Discussion:-

The land use maps for the FC and the ZSP show an increase in vegetation cover, although there are differences between the two sites.

Analysis of land use in the FC shows reforestation. Wooded savannah increased from 3ha (1.95%) in 1989 to 83.76 ha (54.53%) in 2018. This makes it the most represented land-use unit in the FC. Shrub savannah, for its part, has lost more than half of its initial area in 1989; from 137.05 ha in 1989, it has fallen to 64.73 ha in 2018, i.e., 42.14% of the study area. Bare land is almost non-existent (0.11% in 2018). Fields have decreased considerably. They have fallen from 13.55 ha in 1989 to 3.41 ha in 2018. The dynamics of change between 1989 and 2018 show that wooded savannahs recorded the greatest gain with 82.87 ha, while fields, and especially shrub savannahs, suffered a loss. This increase in tree cover in Wakou FC could be explained by several factors.

The first element relates to the relationship between the people of Wakou and their forest ecosystem. The Wakou Communal Forest or Wakou Sacred Forest was once a village forest, created and managed in the traditional way by the people of Wakou. The site of the forest is an old village settlement, which today serves as a traditional place of worship and a cemetery for the first-born children of the various families in the village of Wakou. According to the people of Wakou, this forest is the village's landed property, having been created by their ancestors. The communal forest as we know it today is the result of a long process. It is the result of the determination of the people of Wakou to preserve their forest and ancestral burial ground, and the support of the State through phase 1 of the national land management programs (PNGT I). At Wakou, the sacred nature of the forest means that it receives special

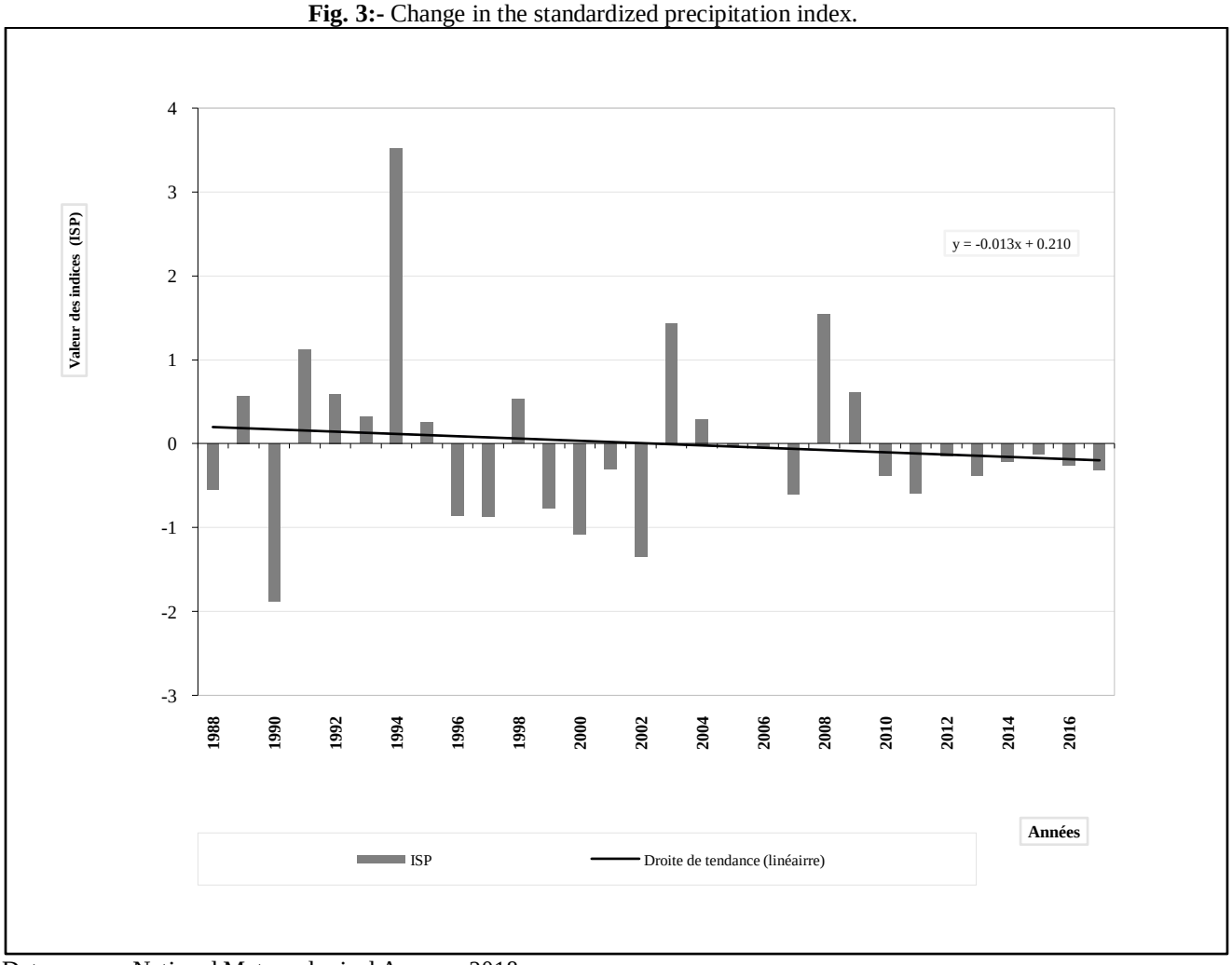
attention from the entire village community. Valéa. F (2010) has shown that in certain societies, parts of the geographical space are culturally valued with a system of representation that is strongly imbued with religious concepts and sociological concerns. The 'natural' space that is the CF therefore has a symbolic and cultural value with which the wakou population identifies. Like any sacred space, the site is governed by a number of prohibitions which, for ritual reasons, prevent it from being used for some of the ordinary activities (farming, hunting, livestock rearing, etc.) that people are used to carrying out on their land. They also associate it with supernatural entities (genies) that have to be dealt with. Managing relations with these genies requires strict preservation of the sites they have taken over (Dugast, 2008).

The second explanatory factor is the management process. The sacred nature of the forest certainly protects it from various forms of anarchic exploitation, but it is also the various interventions and actions in terms of management that have favored the revival of the vegetation. The FC has benefited from the work of NGOs (Tree Aid and Iles de Paix), projects and programs (PROGEREF, PNGT I, II), local authorities, government technical bodies and associations (Base Fadima association). The classification of the forest in 2011 has enabled a number of conservation and restoration actions to be strengthened, as it has established a legal basis for the forest. However, before this classification phase, the communal forest, like the ZSP, was subject to management as part of the Local Governance of Forest Resources (PGLRF) project initiated in Burkina Faso in 2007. There are a number of components to this development, including the drafting of development and management plans (PAG), the demarcation of the areas concerned, forest inventories, the creation of management committees, reforestation campaigns, training in techniques for fighting uncontrolled fires and raising awareness among local populations of the need to conserve forest resources. With the PAG, a certain number of commitments have been made by the local populations of the FC. Various forms of human pressure have been banned in order to preserve and regenerate the plant cover. All these initiatives have gradually led to an increase in vegetation cover and a reduction in the surface area of bare land. These results are similar to those obtained by Kientega R., (2016), in the Gonsé classified forest, where the author shows that there was a slight regreening between 1986 and 2002, following the developments that took place in early 1992. They also corroborate those of Tiamiyu K et al (2023) in the rural commune of Siglé in central western Burkina Faso, where the implementation of management activities has led to a remarkable increase in the area of vegetation cover in the Nafourgou and Dassissé community forests. However, they differ from those obtained by Gadiaga A., (2016), in the Centre-West Forest management sites and those obtained by Nguena de kalambak c., (2016), in the Nazinon classified forest. These authors report a decline in vegetation in these forest management sites (CAF) and attribute this regression in vegetation cover to various anthropogenic pressures.

The third, and no less important, factor determining the dynamics of plant cover is rainfall, in the sense that climatic variations influence the dynamics of plant cover. Indeed, the resumption of rainfall after the major droughts of the 1970s could be a factor in the increase in plant cover in the study area. Indeed, Dipama (2009) confirms the recovery in rainfall in Burkina Faso and shows that there is a slight increase in rainfall for the decade (1991-2000) compared with the decades (1971-1991). Although the trend in the Standardized Precipitation Index (SPI) for the study area from 1988 to 2017 shows a slight downward trend, there are no years of severe and extreme drought (Figure 3). In fact, over the entire series, 16 years have PSI values between -1 and 0. These are considered to be years of moderate drought. These are the years 1988, 1996, 1997, 1999, 2001, 2005, 2006, 2007, and the years from 2010 to 2017. As for the years of moderate humidity, there are seven of them. These are the years with PSI values between 0 and 1: 1989, 1992, 1993, 1995, 1998, 2004 and 2009, with PSI values of 0.57, 0.59, 0.32,0.25, 0.53, 0.29 and 0.62 respectively. There were three years of high humidity: 1991, 2003 and 2008. These years have PSI values greater than 1. The PSI values are 1.12, 1.44 and 1.53 respectively. According to Sinaré et al (2015), the resumption of rainfall in sub-Sahelian Africa and changes in behavior have increased the resilience of ecosystems and encouraged the regreening of certain Sahelian areas in Niger and Burkina Faso.

In the sylvopastoral zone, the most striking feature is the increase in the area of fields, although they are not the most important unit. The area of fields increased from 112.76 ha (16.34%) in 1989 to 155.64 ha (22.55%) in 2018. The area of wooded savannah has also increased. It increased from 30.36 ha (4.40%) in 1989 to 123.68 ha (17.92%) in 2018. Cuirass outcrops have increased from 3.30 ha to 21.59 ha. Shrub savannah remained the dominant formation in 1989, covering 501.77 ha of the 607 ha of the area. This area has shrunk to 383.01 ha in 2018. The area of bare soil has also decreased, from 41.98 ha in 1989 to 6.25 ha in 2018. The change in land use units between 1989 and 2018 shows that fields have increased in favor of 69.10 ha of shrub savannah, 8.16 ha of tree savannah and 22.50 ha of bare soil. Several factors could explain this.

Fig. 3:- Change in the standardized precipitation index.



Data source: National Meteorological Agency, 2018

One factor is the status of the ZSP. It should be remembered that in the ZSP, the management objective is quite different from that of the FC. The purpose of the ZSP is to enable the development of pastoral activity, in conjunction with forestry. To achieve this, it encourages extensive livestock farming, which consists of grazing livestock in order to exploit the spontaneous forage resources located beneath the trees. It also associates wood production with this livestock farming. It is therefore essential to maintain an open space so that the animals can benefit from the fodder, although forestry is associated with it for exploitation purposes. The major problem in the ZSP remains its establishment and management. According to local people, the Diapangou ZSP was set up to resolve the many conflicts between farmers and livestock farmers. Although the area had been identified as a potential pastoral zone since 1985-1987, until 2018 it was occupied by fields and fallow land. The surrounding populations of Diapangou, Okarguni, Kolonkogo, Louargou, Fonguen, Tilonti, Tantiaka and Otiabragouni (the farming hamlet of Wakou), having signed up to the project to create the sylvopastoral zone, agreed to cede part of their land and its creation. It was thus created by municipal decree N°. 2011-0021/MATDS/REST/PGRM/CMR-DPG of 9 June 2011 (Diapangou's commune). However, the population (65% of the village of wakou) say they were not involved in its demarcation and are claiming their land. Some respondents criticized the mayor's office for not having sufficiently involved the landowners and farmers in the ZSP zone, even though they are the main stakeholders. During the questionnaire, 43% of respondents who were dissatisfied with the developments mentioned the lack of involvement of local people, the lack of transparency (30%) and the monopolization of fields and fallow land (20%). This situation has led to continued land clearance and the refusal of the people of Otiabragouni and some of those of Boaka to give up the land earmarked for the ZSP. As a result of this land conflict, the ZSP is home to fields that are not supposed to be used for farming. In addition, the shrub savannah has declined as a result of the

increase in fields between 1989 and 2018. In the field, we noted new clearings after the SPZ was demarcated. These results are consistent with those of Savadogo (2009), Sanon (2019), and Zerbo (2021), who made the same enthronization findings in the Kabore Tambi National Park (PNKT), the Koulbi classified forest in the south-west, and the Guiaro pastoral zone in the center-south, respectively. Bouko et al (2007) have also pointed out that land clearing to increase the area under cultivation is partly responsible for the decline in the vegetation cover of open forests and savannahs in Benin.

The ZSP has benefited from improvements, as has the FC, as a result of the many projects in which local people have been involved. The improvements involve marking the boundaries of the ZSP with paint and erecting signs at the edges prohibiting hunting, bush fires and excessive logging. However, these measures are deemed insufficient because the boundaries of the ZSP are difficult to recognize these days. This encourages the encroachment of fields on the periphery, as the zone has no fixed boundaries marked by boundary stones.

The increase in wooded savannah from 30.36 ha to 123.68 ha can be explained by management actions. These include support for reforestation, protection, the placing of warning signs, the installation of firebreaks, surveillance and involvement in management committees. Certain areas of the ZSP have been withdrawn or closed to various forms of human pressure, with the aim of preserving and regenerating the plant cover.

In the study area, 80% of households surveyed acknowledged that they had been involved in the development of the SZP. In addition, 75.40% of those surveyed were satisfied with the development that had taken place. The main reasons for satisfaction cited by respondents were the gain of a grazing area (49%), the reduction in conflicts between farmers and herders (37%) and the protection of the forest (7%). This is contrary to the studies carried out by Yaméogo (2010). He argues that the participatory management sought in the Gonsé classified forest has only been a showcase for donors.

The transformation of bare areas into savannah can be explained by the regaining of vegetation cover in these areas following the resumption of rainfall after the years of severe drought and the various development actions carried out as previously stated. As far as the role of climate in land use dynamics is concerned, it could be said that, in the case of the ZSP, the climatic factor cannot be a cause of the shrub savannah's regression, given that the ZSP and the FC face the same climatic realities. However, the FC is experiencing an increase in its vegetation cover. The management rules of the ZSP are therefore a key element in the dynamics. This was pointed out by Tiamiyu et al (2022) as one of the explanatory factors for the regressive dynamics of the Siglé village forest, where the authors claim that it is linked more to a management and organizational problem.

Conclusion:-

This study assessed the dynamics of land use in a development context on the CF sites and the ZSP from 1988 to 2018.

A multi-date analysis of Landsat images from 1989, 1999, 2009 and 2018 shows that land use dynamics in the CF show an increase in the area of wooded savannah over the entire study period. This dynamic also shows an increase in the area of shrub savannah between 1989 and 1999, followed by a gradual decline over the rest of the study period in favor of shrub savannah. In addition, fields, although initially minimal, have declined considerably. Bare soil is almost non-existent in 2018. Over the 30 years of the study, there has been a trend towards afforestation, with an increase in wooded savannah. This clearly demonstrates the low human pressure on this CF, one of the consequences of forest management.

The dynamics of land use in the ZSP show a considerable decline in the area of wooded savannah between 1989 and 2009, followed by a significant increase in its area between 2009 and 2018. The area of shrub savannah increased between 1989 and 1999, and then fell steadily between 1999 and 2018.

Bare areas have seen a steady decline in area over the same period, while fields, after declining in area between 1989 and 1999, have seen a steady increase in area between 1999 and 2018, to the detriment of shrub savannah. The creation and management of the Diapangou ZSP is facing land tenure problems, as are several other pastoral zones in Gourma province and the Eastern region. These results should draw the attention of the authorities to the need to develop concerted and inclusive management initiatives in order to optimize development in the context of pastoral activity.

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