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Research Article

SPATIO-TEMPORAL DYNAMIC OF LAND USE/OCCUPATION IN THE COMMUNES OF KOUMBIA AND DEDOUGOU (BURKINA FASO)

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Abstract

The western cotton zone of Burkina Faso has relatively favorable agro-climatic conditions compared to other regions. It is a preferred destination for agricultural migrants, with land saturation as result in some localities. Remote sensing plays an important role in natural resources management, particularly crops land. The objective of this study is to show land use/occupation dynamics in order to propose tracks for their sustainable management. In order to better understand this dynamic, the commune was chosen as the observation scale. Mono-temporal Landsat images covering the communes of Koumbia and Dédougou were used. A total of six scenes from October 1990, 2002 and 2016 were acquired via the United States Geological Survey's (USGS) GLOVIS website. Their processing required several phases : pre-processing, field control, supervised classification with the maximum likelihood algorithm and change detection. ENVI 4.7 was used for images processing and Arc GIS 10.2 for vectorization and mapping. The results show an increase of the surface area of farming areas to the detriment of natural vegetation between 1990 and 2016. At Koumbia, farming area was multiplied by 3.5 and At Dédougou, it increased by 149%, at average annual expansion rates of 4.87 and 3.5% respectively. According to surveys, field expansion as a solution to low land productivity has reached its limits. It is therefore necessary to adopt new sustainable land management techniques. Biochar amendment might contribute to this sustainable land management.

Keywords: Land use/occupation, Spatio-temporaldynamic, Burkina Faso, Koumbia, Dédougou.

INTRODUCTION

Since United Nations Conference on Environment and Development held in Stockholm in 1972, environmental changes have become a major concern worldwide, leading to a collective awareness of environmental degradation (Dimobé, 2017). Land use/occupation is an important variable whose study contributes to a better understanding of biophysical environment and to good management of natural resources (Foody, 2002; Aspinall and Hill, 2007). Burkina Faso is a Sahelian country where more than 80% of the population lives from agriculture which produces 25% of the Gross Domestic Product (GDP) (Bognini, 2011). In this country of 274,000 km2, mining exploitation of natural resources has led to unprecedented deforestation and fertility declining of cropland. Thus, from 1975 to 2013 ; 6,576,000 ha of natural vegetation were converted into cropland, an average of 173,052.63 ha/year (CILSS, 2016). The western and southern areas of the country, once spared, are now affected by this phenomenon with the massive arrival of rural migrants. The communes of Koumbia and Dédougou are no exception. Land use/ occupation change studies are very important for understanding dynamics of certain phenomena such as deforestation, land degradation, desertification and biodiversity loss (Lambin *et al.,* 2001). Land use/occupation mapping is in full development especially in the fields of land use planning and natural resource management. Remote sensing plays an important role in this management by providing spatio-temporal information on land use/occupation (Makak *et al.,* 2018).

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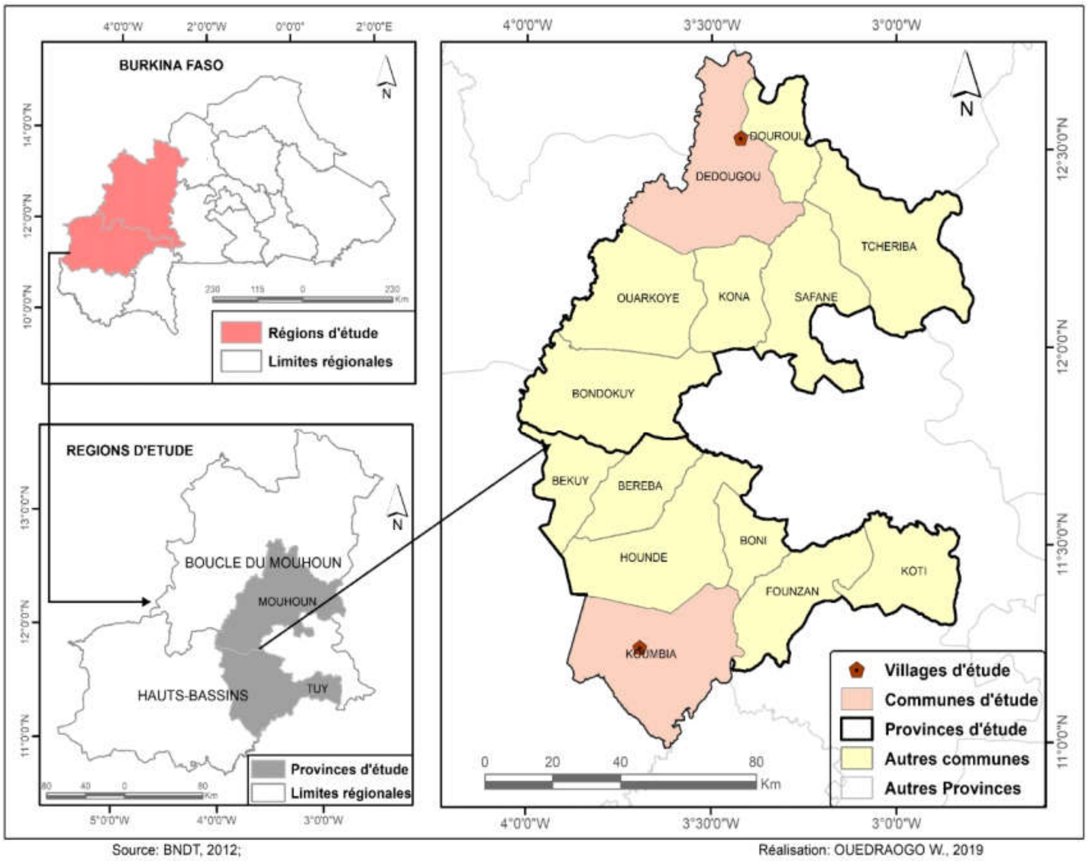
In the savannah areas of West Africa, Landsat images have demonstrated their effectiveness in previous research (Dimobé, 2017; CILSS, 2016; Zoungrana *et al.,* 2015). What are the land use/occupation dynamics in Koumbia and Dédougou's communes with Landsat images? What is the environmental need to adopt new agricultural land management techniques? Such questions can be asked. Knowing dynamics of land use/occupation is starting point for sustainable land management. Regular updates of land use/occupation maps help to understand rate at which changes in land use/occupation are taking place and drivers of these changes, in order to show need to adopt new agricultural techniques.

MATERIALS AND METHODS

Study area

This study was conducted in Koumbia and Dédougou communes, located respectively in the Southern Sudanese and Northern Sudanese agro-ecological zones of Burkina Faso. Koumbia is a rural commune located in the Tuy province (Hauts-Bassins region), between 3°25'00" and 3°55'00" west longitude ; and 10°55'00" and 11°25'00" north latitude. It is limited to North by the communes of Houndé and Boni, to East by those of Founzan and Gueguere, to South by those of Bondigui and Karangasso Vigué, and to West by that of Léna (Coulibaly, 2012). Dédougou is an urban commune, both capital of Mouhoun province and that of Boucle du Mouhoun region. The commune of Dédougou is located in northwest Burkina Faso, at approximately 230 km from Ouagadougou (political capital of the country) and 182 km from Bobo Dioulasso (economic capital), between 3°15'00"and 3°45'00" West longitude and 12°10'00"and 12°50'00" North latitude.



Map 1. Study area

It is limited to East by the rural commune of Douroula ; to West by the rural communes of Sanaba and Bourasso; to North by those of Sono and Gassan; and to South by those of Ouarkoye, Kona and Safané. Map 1 below shows the geographical location of the study area. According to results of 2006 General Census of Population and Housing (GCPH), Koumbia had an estimated population of about 36,252 inhabitants, the second most populated commune of Tuy province after Houndé (76,998 inhabitants according to the same source). With an area of about 1358 km^2, the average density was 26.69 inhabitants/km^2. It is home to three classified forests covering 457 km^2, or 33.65% of the communal surface area, which automatically reduces the area reserved for agropastoral activities. At the same date, Dédougou had an estimated population of about 86,965 inhabitants, i.e. 6% of the region's population. With a surface area of 1353 km^2, the average density was 64.27 inhabitants/km^2. Because of its status of regional city, this population is divided into urban (44.68%) and rural (55.32%) population spread over thirty-eight (38) villages (INSD, 2009). On the basis of an annual population growth rate of 3.1%, the communes of Koumbia and Dédougou should have 55,585 and 133,342 inhabitants respectively in 2020. With the predominance of agriculture and livestock farming, the increase of average densities combined with rural nature of population is source of pressure on natural resources in general and on farmland in particular. Geomorphologic landscape is marked by presence of two large groups. The residual relief and the sedimentary basin. The first is composed of rocky and cuirassed buttes and hills, cuirassed plateaus and eroded or uneroded slopes. It is less represented at Koumbia (17.2% of the communal surface area) than at Dédougou (37.33%). The second large ensemble is mainly composed of glacis, shallows, terraces and alluvial plains, and settling ponds. Contrary to the residual relief, glacis are more represented in Koumbia (75% of the area of the commune) than in Dédougou (54.02%). In addition, Koumbia has more shallows (6.32%) than Dédougou (2.72%). On the other hand, the alluvial plains occupy 7.46% of the communal area in Dédougou, whereas they are very little represented in Koumbia. Soil types correspond to these geomorphological units. A total of ten types common to the two communes and two other characteristics of each zone were identified. Poor in general, these soil types belong to five classes : the class of iron and manganese sesquioxide soils, the class of hydromorphic soils, the class of browned soils, the class of ferralitic soils and the class of raw mineral soils. According to the climatic zoning done by the National Agency of Meteorology (ANAM), Dédougou commune is located in the Sudano-Sahelian domain characterized by a rainfall between 600 and 900 millimeters (mm) of water per year, while that of Koumbia is located in the Sudanian domain where rainfall exceeds 900 mm/year. The average annual rainfall at the Koumbia observation post between 1987 and 2016 is 944.62 mm/year compared to 820.86 mm/year for the Dédougou synoptic station. This rainfall, although relatively abundant, is characterized by interannual variability and bad spatial and temporal distribution, which affect the success of agropastoral activities.

Collect of Landsat satellite images

Different types of classifications using either mono-temporal images (Dimobe *et al.,* 2015), multi-temporal images (Zoungrana *et al.,* 2015) or in association with ancillary data (Treitz and Howarth, 2000) are nowadays used for land use/occupation mapping. In this study, only mono-temporal images are used. Six mono-temporal and georeferenced Landsat images from three different dates were acquired via the United States Geological Survey's (USGS) GLOVIS website (https://glovis.usgs.gov/). With a resolution of 30m/30m, they are Landsat 5 (TM, 1990), Landsat 7 (ETM+, 2002) and Landsat 8 (OLI-TIRS, 2016) images. The choice of these images is justified by their availability and quality. The shooting period (October) makes it easy to distinguish fields from other land use/occupation units. Table 1 below shows characteristics of Landsat images used.

Satellite images processing

Satellite images processing required several phases. After acquisition, they were submitted to a pre-processing which consisted to : 1- Apply radiometric improvements in order to increase readability and facilitate their interpretation, 2- Make band combinations to obtain multispectral images, and 3- Extract study area. Colored composition 5 (near infrared), 4 (red), 3 (green) was applied to the images of 2016, while those of 2002 and 1990 received colored composition 4 (near infrared), 3 (red), 2 (green). These different bands, in the order indicated, were placed in the red, green and blue channels, giving a colored composition in false color. Near infra-red allowing to detect chlorophyll activities, this colored composition has advantage of being able to differentiate vegetation from other land use/occupation units. ENVI 4.7 software was used for image pre-processing. A field control was then carried out to check the land use/occupation units identified on the colored composition. To do this, a provisional classification of the most recent images (those of 2016) using "maximum of likelihood" algorithm was carried out.

On the basis of the provisional maps, control points distributed over the entire study area were generated and then entered into a Garmin-type portable GPS. Maps were printed in A3 format and a field survey sheet containing information on location of the site, land use type resulting from the provisional classification and land use type in the field was elaborated for field control. After field verification, results were compared and the errors were corrected in order to make a fairly complete and definitive images classification. The proper processing was carried out with the "maximum of likelihood" algorithm. A total of seven units were selected : gallery forests, woody to woody savannas, grassy to shrubby savannas, water bodies, bare soil, habitat and farming areas. This nomenclature is an adapted form of Land use/cover Database (LU/LCD) of 2012. Official database covering all national territory, the 2012 LU/LCD is the most recent and therefore closer to the reality of the field in 2016. However, due to low resolution of Landsat images, which does not allow to see certain details, it has been adapted for needs of this study. Indeed, for reasons of physiognomic resemblance, the woody and woody savannas have been merged. Also, the burnt areas were included in the grassy to shrubby savannas. Fields, fallow land, bare soil and rural habitat were all considered as farming areas. Are then considered as habitat, urban agglomerations.

This unit (habitat) has moreover been digitized before being merged after classification. Bare soil was considered only at the edges of rivers. ENVI 4.7 software was used for image processing, while Arc GIS 10.2 was used for vectorization and mapping. This classification itself concerns the images of 2016. For the 1990 and 2002 images, special attention was paid to changes due to temporal differences. To ensure that the 2016 land use/occupation units have content equivalent to that of 1990 and 2002, only training plots with unchanged pixels were selected. Spatial evolution rates of different units have been evaluated by one of the formulas applied to measure the growth of macroeconomic aggregates between two periods (Oloukoi *et al.,* 2006; Ouédraogo, 2015). The variable considered here is surface area S. For S1 and S2 corresponding respectively to surface areas of land use/occupation unit in 1990 and 2016, the annual average spatial evolution rate T is evaluated using the following formula :

$$T = \frac{(\ln S2 - \ln S1)}{t \ln e} \times 100$$

Where : t is the number of years of evolution,

ln, neperian logarithm,

e, the base of the neperian logarithms (e= 2.71828)

Transition Matrix was used to describe spatial dynamics in Koumbia and Dédougou communes between 1990 and 2016 (Oloukoi *et al.,* 2006; Ouédraogo, 2015; Avakoudjo *et al.,* 2014). It is a double-entry table allowing to describe changes in the state of land use/occupation categories between two dates (Ouédraogo, 2015; Pontius *et al.,* 2014; Inoussa *et al.,* 2011).

Socio-economic surveys

Household surveys were conducted to assess socio-economic and environmental situation. They were carried out in the intervention sites of the BIOPROTECHSOL project, which fully financed this study. In total, 176 households in Koumbia and 57 in Massala were randomly selected in such a way to cover the entire village area. During this stage, emphasis was placed not only on the characterization of cropping system, but also and especially on farmers' perceptions of evolution of vegetation cover and cropping areas. Survey data collect required a household questionnaire, a Global Positioning System (GPS) and a digital camera. These have been entered into Sphinx software and then exported to SPSS (Statistical Packages for Social Sciences) for processing and analysis. This consisted to recode some variables and produce descriptive statistics.

RESULTS AND DISCUSSION

Exactness of classifications

It has been evaluated analogously (Mama *et al.,* 2003). Different indicators of accuracy were used to assess quality of classification : overall accuracy, Kappa coefficient, omission and commission errors, class purity and cartographic validity indices. Overall precision of each of the three classified images of Koumbia commune (1990, 2002, 2016) is greater than 88% with Kappa indices greater than 85% (see tables 2, 3 and 4 of the confusion matrices below). For good land use/occupation mapping, the standard overall accuracy is set between 80 and 85% (Treitz and Rogan, 2004). For some authors, land use study can be validated if Kappa coefficient is between 50 and 75% (Oloukoi *et al.,* 2006; Pontius, 2000; Jansen *et al.,* 2008). In view of results presented in the confusion matrices, it can be concluded that classifications are reliable and statistically acceptable. For Dédougou commune, the overall precision is greater than 95% for each of the images and the Kappa indices are greater than 93% (see tables 5, 6 and 7 below).

Table 1. Characteristics of Landsat images used

Images characteristics Study area	Shooting date	Landsat image type	Images coordinates (Path/Row)	Projection system n	Spatial resolution
Koumbia	19/10/1990	TM	196/52	UTM zone 30	30m/30m
	28/10/2002	ETM+	196/52	UTM zone 30	30m/30m
	26/10/2016	OLI-TIRS	196/52	UTM zone 30	30m/30m
Dédougou	03/10/1990	TM	196/51	UTM zone 30	30m/30m
	28/10/2002	ETM+	196/51	UTM zone 30	30m/30m
	26/10/2016	OLI-TIRS	196/51	UTM zone 30	30m/30m

TM: Thematic Mapper; ETM+: Enhanced Thematic Mapper Plus; OLI-TIRS: Operational Land Imager-Thermal Infrared Sensor

Table 2. Confusion matrix of Koumbia's maximum likelihood classification (1990)

Classified data	GSS	FA	GF	WB	WWS	BS	Total	CE	CPI
GSS	1585	33	0	0	0	0	1618	2.04	97.96
FA	6	1872	0	0	6	11	1895	1.21	98.79
GF	0	0	1807	0	341	0	2148	15.88	84.12
WB	0	0	0	61	0	0	61	0	100
WWS	0	3	202	0	1822	0	2027	10.11	89.89
BS	0	28	0	0	0	74	102	27.45	72.55
Total	1591	1936	2009	61	2169	85	7851		
OE	0.38	3.31	10.05	0	16	12.94			
CVI	99.62	96.69	89.95	100	84	87.06			
Global Accuracy : 91.97% ; Kappa Index : 0.89									

Source : Processing of 1990 Landsat TM images (Path : 196 ; ROW : 52)

Table 3. Confusion matrix of Koumbia's maximum likelihood classification (2002)

Classified data	WWS	GF	GSS	FA	WB	BS	Total	CE	CPI
WWS	1886	135	0	0	0	0	2021	6.68	93.32
GF	660	1956	0	0	0	0	2616	25.23	74.77
GSS	0	0	917	1	2	0	920	0.33	99.67
FA	88	1	0	2303	0	8	2400	4.04	95.96
WB	0	0	0	0	224	0	224	0	100
BS	0	0	0	9	0	260	269	3.35	96.65
Total	2634	2092	917	2313	226	268	8450		
OE	28.4	6.5	0	0.43	0.88	2.99			
CVI	71.6	93.5	100	99.57	99.12	97.01			
Global Accuracy : 89.30% ; Kappa Index : 0.85									

Source : Processing of 2002 Landsat ETM+ images (Path : 196 ; ROW : 52)

Table 4. Confusion matrix of Koumbia's maximum likelihood classification (2016)

Classified data	WB	GSS	WWS	GF	FA	BS	Total	CE	CPI
WB	94	0	0	4	0	0	98	4.08	95.92
GSS	0	1736	0	0	0	0	1736	0	100
WWS	0	0	832	37	0	0	869	4.26	95.74
GF	2	0	30	268	0	0	300	10.67	89.33
FA	0	35	0	0	1761	11	1807	2.55	97.45
BS	0	0	0	0	93	63	156	59.62	40.38
Total	96	1771	862	309	1854	74	4966		
OE	2.08	1.98	3.48	13.27	5.02	14.86			
CVI	97.92	98.02	96.52	86.73	94.98	85.14			
Global Accuracy : 95.73% ; Kappa Index : 0.93									

Source : Processing of 2016 Landsat OLI-TIRS images (Path : 196 ; ROW : 52)

GSS : Grassy to Shrubby Savannas ; WWS : Woody to Woody Savannas ; GF : Gallery Forests ; FA : Farming Areas ; BS : Bare Soil ; H : Habitat ; WB : Water Bodies ; OE : Omission Errors ; CE : Commission Errors ; CVI : Cartographic Validity Index ; CPI : Class Purity Index

Table 5. Confusion matrix of Dédougou's maximum likelihood classification (1990)

Classified data	WB	BS	GF	WWS	GSS	FA	Total	CE	CPI
WB	264	0	1	0	0	0	265	0.38	99.62
BS	0	240	0	0	0	100	340	29.41	70.59
GF	0	0	1748	554	0	0	2302	24.07	75.93
WWS	0	0	108	1674	0	2	1784	6.17	93.83
GSS	0	0	1	0	963	45	1009	4.56	95.44
FA	0	35	3	37	2	2066	2143	3.59	96.41
Total	264	275	1861	2265	965	2213	7843		
OE	0	12.73	6.07	26.09	0.21	6.64			
CVI	100	87.27	93.93	73.91	99.79	93.36			
Global Accuracy : 88.67% ; Kappa Index : 0.85									

Source : Processing of 1990 Landsat TM images (Path : 196 ; ROW : 51)

Table 6. Confusion matrix of Dédougou's maximum likelihood classification (2002)

Classified data	WB	BS	FA	GSS	GF	WWS	Total	CE	CPI
WB	285	0	0	0	10	0	295	3.39	96.61
BS	0	192	28	0	0	0	220	12.73	87.27
FA	0	7	1843	1	2	1	1854	0.59	99.41
GSS	0	0	11	1059	0	0	1070	1.03	98.97
GF	4	0	0	0	724	88	816	11.27	88.73
WWS	0	0	0	0	81	1238	1319	6.14	93.86
Total	289	199	1882	1060	817	1327	5574		
OE	1.38	3.52	2.07	0.09	11.38	6.71			
CVI	98.62	96.48	97.93	99.91	88.62	93.29			
Global Accuracy : 95.81% ; Kappa Index : 0.94									

Source : Processing of 2002 Landsat ETM+ images (Path : 196 ; ROW : 51)

Table 7. Confusion matrix of Dédougou's maximum likelihood classification (2016)

Classified data	WB	BS	FA	GSS	WWS	GF	Total	CE	CPI
WB	311	0	0	0	0	1	312	0.32	99.68
BS	0	262	29	0	0	0	291	9.97	90.03
FA	0	5	1893	0	3	15	1916	1.2	98.8
GSS	0	0	1	1055	0	0	1056	0.09	99.91
WWS	0	0	4	0	603	27	634	4.89	95.11
GF	4	0	0	0	6	609	619	1.62	98.38
Total	315	267	1927	1055	612	652	4828		
OE	1.27	1.87	1.76	0	1.47	6.6			
CVI	98.73	98.13	98.24	100	98.53	93.4			
Global Accuracy : 98.03% ; Kappa Index : 0.97									

Source : Processing of 2016 Landsat OLI-TIRS images (Path : 196 ; ROW : 51)

Table 8. Land use/occupation at Koumbia in 1990, 2002 and 2016

Land use/occupation units	Land use/occupation in 1990		Land use/occupation in 2002		Land use/occupation in 2016	
	Surface area (ha)	Part (%)	Surface area (ha)	Part (%)	Surface area (ha)	Part (%)
GF	5223.29768	3.84507	4720.06746	3.47462	4562.52475	3.360007978
H	13.58067	0.01	34.27382	0.02523	105.89424	0.077984342
WB	34.88323	0.02568	130.66933	0.09619	234.91521	0.173000043
WWS	76,861.91849	56.58104	55,887.03607	41.14062	38,527.24244	28.37285254
GSS	34,532.5317	25.42074	32,454.78853	23.89123	24,462.80061	18.01528972
BS	77.99921	0.05742	84.03352	0.06186	98.12555	0.072263198
FA	19,099.73488	14.06006	42,533.07819	31.31025	67,797.60187	49.92860218

Source : Processing of Landsat 1990 TM ; ETM+, 2002 and OLI-TIRS, 2016 images (Path : 196 ; Row : 52)

Land use/occupation dynamics between 1990 and 2016

During 1990-2016 period, land use/occupation has undergone major changes. At Koumbia, while woody to woody savannah occupied 56.58% of total surface area of the commune, or 76,861.91 ha in 1990, it decreased to 55,887.03 ha or 41.14% in 2002 and then to 28.37% in 2016. This regression of surface area of natural vegetation also concerns grassy to shrubby savannah. In fact, this unit went from 34,532.53 ha (or 25.42% of the communal area) in 1990 to 32,454.78 ha (about 23.89% of the communal area) in 2002 and then to 24,462.80 ha (or 18.01%) in 2016. As for the cultivated areas, they increased from 19,099.73 ha or 14.06% in 1990 to 42,533.07 ha or 31.31% in 2002 and then to 67,797.60 ha or 49.92% in 2016. The other land use/occupation units, although not very representative, have also changed in a different way. Apart gallery forests, whose surface area decreased from 3.84% in 1990 to 3.36% in 2016, water bodies, habitat and bare zones have seen their surface areas increased. Table 8 above shows the results of the different land use/occupation units in Koumbia commune in 1990, 2002, and 2016. In twenty-six years, surface area of woody to woody savannah and grassy to shrubby savannah have declined by nearly 50% and 29.16% respectively. The average regression rates are -2.65% and -1.32% per year respectively. During the same period, the area under cultivation more than tripled (it was multiplied by 3.5), for an average annual expansion rate of 4.87%.

Land use/occupation dynamics and change rates of different units in Koumbia commune are presented in table 8 above. At Dédougou, grassy to shrubby savannas extended over 76,543.17 ha or 56.58% of the area of the commune in 1990. It decreased to 44,172.22 ha or 32.65% in 2002 and then to 16.64% in 2016. Woody to woody savannah occupied only 15,710.56 ha or 11.61% of the commune in 1990. However, in 2002, they occupied only 2.58% of the communal territory, or 3,491.51 ha, and then increased to 6,171.85 ha, or 4.56% of the commune. Concernig cultivation areas, they increased from 41,888.36 ha or 30.96% of communal surface area in 1990 to 86,186.72 ha (63.71% of the commune) in 2002 and then to 104,300 ha or 77.09% in 2016. The other land use/occupation units have experienced equally diverse developments. Gallery forests and habitat have seen their surface areas increased from 0.16 to 0.30% and from 0.39 to 1.11% of the commune's surface area respectively between 1990 and 2016. Water bodies and bare soil have almost stagnated. Results of different land use/occupation units for 1990, 2002, and 2016 in the commune of Dédougou are given in Table 10 below. In twenty-six years, the surface area of grassy to shrubby savannahs has been reduced by more than 70%, at an average rate of -4.7% per year. Woody to woody savannas, even if their regression is not linear, have seen their surface area fall by more than 60%, at an average rate of -3.59% per year. The cultivated areas, for their part, increased by 149% during the same period, equivalent to an average annual expansion rate of 3.5%.

Table 9. Temporal dynamics of land use/occupation and annual expansion rate of the different units at Koumbia between 1990 and 2016

Land use/occupation units	Dynamic between 1990-2002 (%)	Dynamic between 2002-2016 (%)	Dynamic between 1990-2016 (%)	Annual average expansion rate between 1990-2016 (%)
GF	-963	-3.33	-1265	-0.52
H	152.37	208.96	679.74	7.89
WB	274.59	79.77	573.43	7.33
WWS	-27.28	-31.06	-49.87	-2.65
GSS	-6.01	-24.62	-29.16	-1.32
BS	7.73	16.76	25.8	0.88
FA	122.68	59.39	254.96	4.87

Source : Processing of Landsat 1990 TM ; ETM+, 2002 and OLI-TIRS, 2016 images (Path : 196 ; Row : 52

Table 10. Land use/occupation at Dédougou in 1990, 2002 and 2016

Land use/occupation units	Land use/occupation in 1990		Land use/occupation in 2002		Land use/occupation in 2016	
	Surface area (ha)	Part (%)	Surface area (ha)	Part (%)	Surface area (ha)	Part (%)
GF	218.13783	0.161267851	223.76803	0.165430221	418.73219	0.30952549
WB	250.32963	0.185067035	240.40483	0.177729697	256.49154	0.18959772
GSS	76,543.17906	56.58786467	44,172.22293	32.65623147	22,514.63981	16.6427496
WWS	15,710.56033	11.61471306	3491.51886	2.581256738	6171.85565	4.56221591
BS	123.12069	0.09102231	170.01244	0.125689069	110.87578	0.08195902
FA	41,888.36619	30.96779133	86,186.72274	63.71727255	104,300	77.0982257
H	530.60633	0.392273741	779.65024	0.576390252	1509.3769	1.11572657

Source : Processing of Landsat 1990 TM ; ETM+, 2002 and OLI-TIRS, 2016 images (Path : 196 ; Row : 51)

Table 11. Temporal dynamics of land use/occupation and annual expansion rate of units at Dedougou between 1990 and 2016

Land use/occupation units	Dynamic between 1990-2002 (%)	Dynamic between 2002-2016 (%)	Dynamic between 1990-2016 (%)	Annual average expansion rate between 1990-2016 (%)
GF	2.58	87.12	91.95	2.5
WB	-3.96	6.69	2.46	0.09
GSS	-42.29	-49.02	-70.58	-4.7
WWS	-77.77	76.76	-60.71	-3.59
BS	38.08	-34.78	-9.94	-0.4
FA	105.75	21.01	148.99	3.5
H	46.93	93.59	184.46	4.02

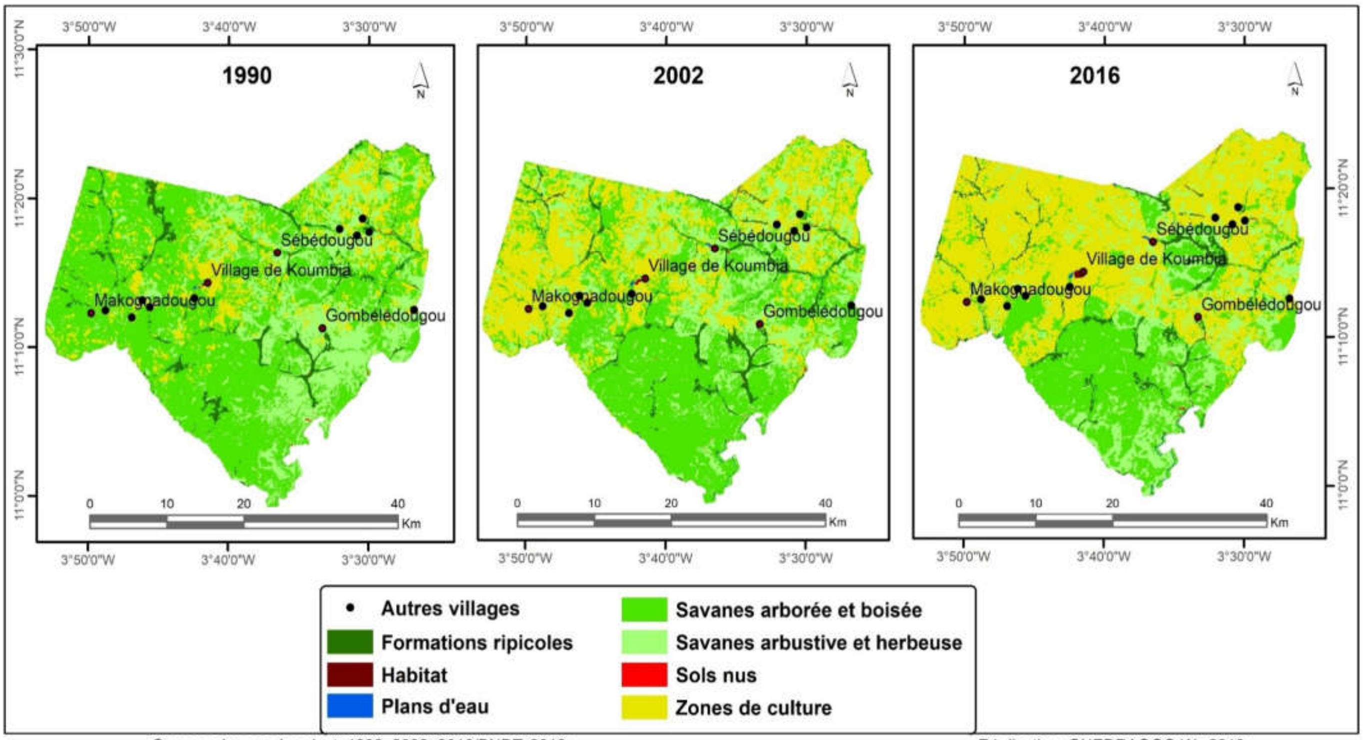
Source : Processing of Landsat 1990 TM ; ETM+, 2002 and OLI-TIRS, 2016 images (Path : 196 ; Row : 51)

The totality of change rates for the different land use/occupation units is presented in Table 11 above ; while maps 2 and 3 illustrate spatial and temporal evolution of land use/occupation units in the communes of Koumbia and Dédougou between 1990 and 2016.

Transition matrices of land use/occupation units in Koumbia and Dédougou between 1990 and 2016

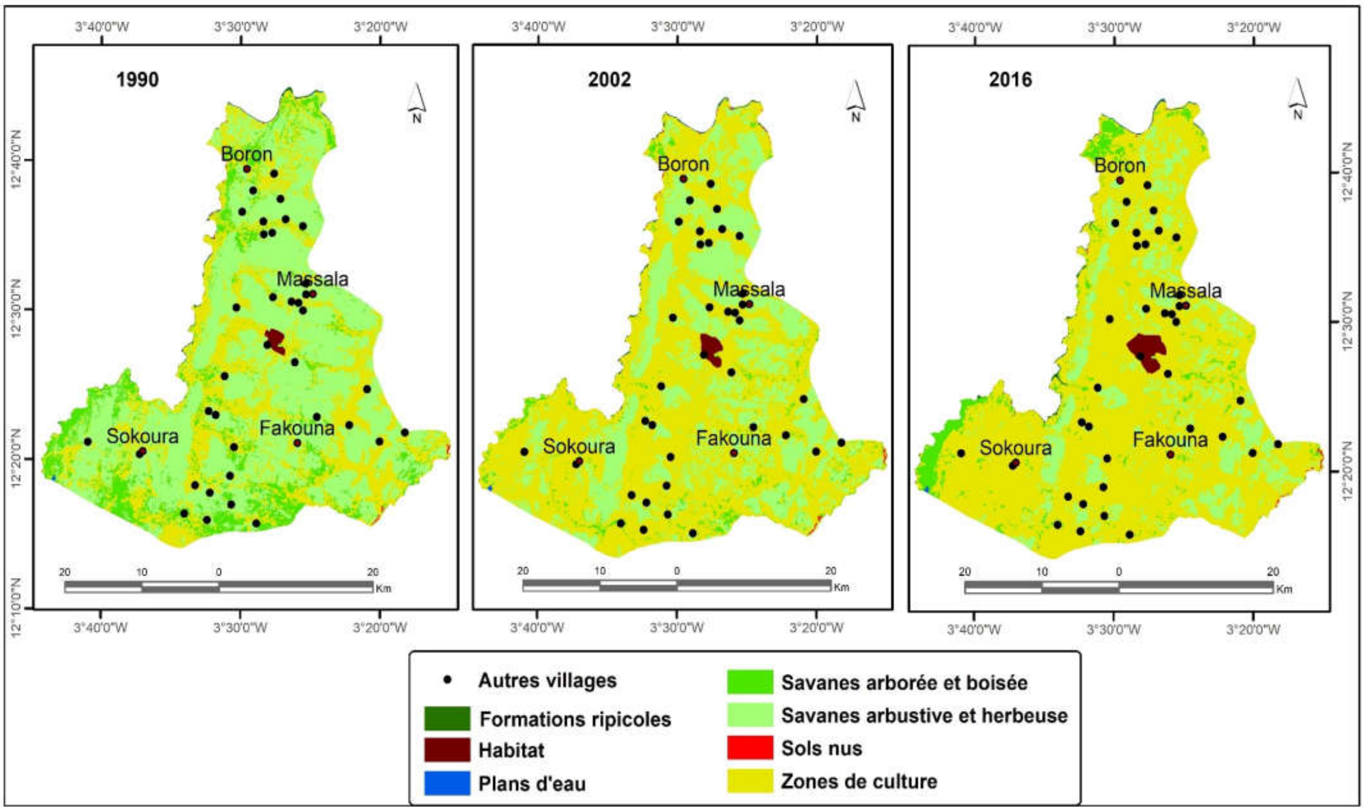
Changes in land use/occupation between 1990 and 2016 are seen through transition matrices of land use/occupation units between 1990 and 2016 (Tables 12 and 13). In these tables, diagonals show the surface areas unchanged between the two dates ; columns show surface area gains to the detriment of other units ; and rows show area losses to other units. The balance sheets in terms of surface area gains and losses are presented in the last columns. Results in table 12 show that in Koumbia, there was an increase in the area under cultivation in the order of 48,699.95 ha. This increase was mainly to the detriment of woody to woody savannas and grassy to shrubby savannas, which lost 36,858.44 ha and 13,511.91 ha respectively to farming areas. Gallery forests have also lost 1,716.10 ha to the benefit of farming areas. Although results in Table 12 show an increase in the surface area of cultivated areas between 1990 and 2016, the latter lost respectively 2,323.72 ha ; 904.52 ha ; 90.91 ha ; 60.20 ha and 22.79 ha to the benefit of woody to woody savannas, grassy to shrubby savannas, gallery forests, habitat and bare soil. Woody to woody savannas, grassy to shrubby savannas, and gallery forests are the three units whose areas declined between 1990 and 2016 in favor of others.

In fact, Woody to woody savannas have lost a total of 3,301.26 ha to the benefit not only of farming areas (3,6858.44 ha), but also grassy to shrubby savannas (7,445.46 ha) and gallery forests (2,415.80 ha). Conversion of this unit to water bodies, habitat and bare soil is minimal. As shown in table 12, 178.29 ha of Woody to woody savannah have been converted to water bodies, 33.81ha to habitat and 13.84 ha to bare soil. At the same time, this unit benefited from 4,798.30 ha of grassy to shrubby savannah and 1,509.42 ha of gallery forests between 1990 and 2016. The balance sheets in terms of area gains and losses of these last two units are 10,064.17 ha and 647.21 ha respectively between the two dates. At Dédougou, the surface of farming area increased by 62,393.96 ha to the detriment of grassy to shrubby savannas and woody to woody savannas which lost respectively 52,981.46 ha and 12,527.04 ha. Bare soils, gallery forests and water bodies lost respectively 93.08 ha, 92.37 ha and 27.65 ha to farming areas between 1990 and 2016. At the same time, 1,837.90 ha ; 759.35 ha ; 446.95 ha ; 191.43 ha and 74.86 ha respectively of this unit were converted into woody to woody savannahs, grassy to shrubby savannahs, habitat, gallery forests and bare soils. Grassy to shrubby savannas, woody to woody savannas and bare area are the units whose surfaces decreased between 1990 and 2016 in favor of others. Grassy to shrubby savannas decreased the most because they lost 54,028.53 ha between the two dates in favor of cultivated areas (52,981.46 ha), woody to woody savannas (1,766.01 ha) and habitat (537.01 ha). However, grassy to shrubby savannas benefited in addition to the 759.35 ha of cultivated areas and 541.19 ha of woody to woody savannas. Apart from the 12,527.04 ha converted into farming areas, woody to woody savannas have also lost 84.86 ha and 10.52 ha to gallery forests and water bodies.



Sources: Images Landsat, 1990, 2002, 2016/BNDT, 2012; Réalisation: OUEDRAOGO W., 2019

Map 2. Spatial and temporal dynamics of land use/occupation at Koumbia



Sources: Images Landsat, 1990, 2002, 2016/BNDT, 2012; Réalisation: OUEDRAOGO W., 2019

Map 3. Spatial and temporal dynamics of land use/occupation at Dédougou

However, space gains to the detriment of other units including cultivated areas (1,837.90 ha), grassy to shrubby savannas (1,766.01 ha), gallery forests (22.44 ha) and water bodies (6.86 ha) resulted in a loss of 9,538.70 ha between 1990 and 2016. The area gains and losses of the other units are presented in tables 12 and 13 below.

Justification of land use/occupation units evolution

Farming area extension to the detriment of natural vegetation as main results of diachronic analysis of land use/occupation is evidence that agriculture is primary cause of deforestation. These results correlated with peasant perception.

Table 12. Transition matrix of land use/occupation at Koumbia between 1990 and 2016

		2016								
		GF	H	WB	WWS	GSS	BS	FA	Total 1990	Change
1990	GF	1859.48369	0	3.25017	1509.42859	132.08606	3.62976	1716.10037	5223.97864	-647.21661
	H	0	11.87421	0	0	0	0	1.70646	13.58067	92.31356
	WB	0.88809	0	32.19514	1.35	0.09	0	0.36	34.88323	200.14707
	WWS	2415.80005	33.8196	178.29859	29,916.2519	7445.46058	13.84776	36,858.44001	76,861.91849	-38,301.26921
	GSS	205.03834	0	17.81152	4798.30221	15,960.88344	38.58777	13,511.91612	34,532.5394	-10,064.17735
	BS	4.63223	0	0.72	11.59238	25.31327	19.39168	16.34964	77.9992	20.24895
	FA	90.91963	60.20042	2.75488	2323.7242	904.5287	22.79118	15,694.81586	19,099.73487	48,699.95359
	Total 2016	4576.76203	105.89423	235.0303	38,560.64928	24,468.36205	98.24815	67,799.68846	135,844.6345	

Source : Processing of Landsat 1990 TM and OLI-TIRS, 2016 images (Path : 196 ; Row : 52)

Table 13. Transition matrix of land use/occupation at Dédougou between 1990 and 2016

		2016								
		GF	H	WB	WWS	GSS	BS	FA	Total 1990	Change
1990	GF	69.94431	0	33.25359	22.44344	0	0.12648	92.37001	218.13783	200.59436
	H	0	523.87384	0	0	0	0	6.73249	530.60633	978.77057
	WB	36.17959	0	179.62893	6.86794	0	0	27.65318	250.32964	6.16191
	WWS	84.86813	1.53259	10.52828	2537.63644	541.19462	7.75773	12,527.04254	15,710.5603	-9538.70467
	GSS	31.26362	537.0118	6.90803	1766.01231	21,214.08843	6.43374	52,981.46113	76,543.1791	-54,028.5393
	BS	5.0453	0	2.30451	0,99	0	21.69369	93.0872	123.1207	-12.24492
	FA	191.43124	446.95867	23.86821	1837.90553	759.35676	74.86414	38,553.98164	41,888.3662	62,393.962
	Total 2016	418.73219	1509.3769	256.49155	6171.85566	22,514.63981	110.8758	104,282.3282	135,264.3	

Source : Processing of Landsat 1990 TM and OLI-TIRS, 2016 images (Path : 196 ; Row : 51)

Indeed, anarchic land clearing is perceived by 86.93% of respondents in Koumbia and 96.49% of those of Massala as the main cause of deforestation. Results of this study corroborate those of Dimobé, (2017) who worked in the Bontioli Wildlife Reserve, the Dano and Bolgatenga watersheds and the Nazinga game ranch ; and those of Zoungrana and al, (2015) who worked in southwest Burkina Faso. Results also corroborate the work of Makak and al. (2018) who showed that between 1999 and 2009, farming area increased by 201% in the commune of Koumbia. These results are also consistent with those of Oloukoi and al. (2006) who worked in the Hills Department of Benin. Although extension of cultivated areas to the detriment of natural vegetation is noted, regression of savannah is also due to factors such as bush fires and excessive logging. In Koumbia and Massala villages, they are perceived by 99.43 and 83.52% respectively; and 86.93 and 98.24% of the respondents as the main sources of vegetation cover degradation. In addition to these main causes, other no less important causes include climate change, perceived by about 40.34% of respondents at Koumbia versus 36.84% at Dédougou and animals divagation. At Koumbia in particular, the presence of woody to woody savannas, as well as grassy to shrubby savannas, is due to the presence of three classified forests, such as those of Kapo, Bambou and Mou. Evolution of cultivated areas from 1990 to 2016 is the result of combination of socio-economic, demographic and environmental factors. Firstly, extension of cultivated areas is the direct consequence of galloping demographic trend. In fact, Hauts-Bassins and Boucle du Mouhoun regions, which are home to the communes of Koumbia and Dédougou respectively, experienced strong population growth from 1985 to 2006, which continued until 2020 according to projections made by National Institute of Statistic and Demography. This situation does not spare the communes concerned by this study. Estimated at 36,252 and 86,965 inhabitants respectively in 2006, Koumbia and Dédougou should 55,585 and 133,342 inhabitants respectively in 2020. Population growth is partly linked to the migration phenomenon. Surveys results show that Koumbia commune is a site of major migratory flows from northern regions of the country.

Immigrants influx is such that in some villages like Koumbia, they outnumber the natives. Even Massala village is populated only by natives, it is clear that the commune of Dédougou was a first choice destination for internal migrants from Burkina Faso. The phenomenon of immigration was at the origin of land saturation in this region, which led to the reorientation of migrants towards new agricultural pioneer fronts. Population growth combined with traditional and itinerant agriculture on burnt land has resulted in the shortening or even disappearance of fallow land (Dimobé, 2017; Bamba *et al.,* 2008). In addition to demographic factors, socio-economic factors also justify expansion of farming areas. Development of cotton cultivation, coupled with the adoption of new unsustainable agricultural practices, encourages expansion of family farms (Gomgnimbou *et al.,* 2009). This is exacerbated by the increasing needs of a growing population. Increasing of cultivation surface areas size is also explained by the multiplication farms due to generational conflicts that lead to the scission of some households. Environmental factors are not to be underestimated. Climate change and variability with its corollary of extreme climatic phenomena is a determining factor in agricultural production especially in this West Africa region, which is very vulnerable to this new climatic situation (Ouoba, 2013). In addition to extreme climatic phenomena, soil erosion and desertification, two slow processes that affect food security are also taking place. Indeed, when bare soils are exposed to extreme climatic events, this leads to their erosion and depletion of organic matter (Pender *et al.,* 2012). To compensate low land productivity, larges areas of natural vegetation are converted into cropland every year. Combination of demographic, socio-economic and environmental factors reveals disequilibrium between populations needs and natural resources availability, especially farming land (Hountondji, 2008). Result is a deterioration of socio-economic conditions of rural households. Surveys results clearly indicate that population has a good perception of land saturation. The extension of fields as a response to the low productivity of agricultural land seems to have reached its limits in both localities. It is therefore time to think seriously about agricultural intensification on land already being farmed.

Biochar, an innovative agro-ecological technique

Biochar is a very carbon-rich charcoal obtained by pyrolysis of organic matter (Lehmann, 2012; Peacocke and Joseph, 2014; Lévesque, 2017). It differs of charcoal in its primary function. Indeed, it is mainly used for soil amendment (enhancing soil fertility) and carbon sequestration (reducing the amount of CO2 released into the atmosphere) (Shackley *et al.,* 2010). According to the general literature, biochar improves soil physical, chemical and biological properties, thus inducing positive effects on crop growth. Its highly porous structure is the main characteristic that makes it very attractive in agriculture. This characteristic of biochar is responsible for the high water retention capacity of soil and the increase of its specific surface. Biochar amendment improves parameters such as bulk density, porosity, water retention capacity, stability and aggregate formation (Ding *et al.,* 2016).

Improvement of soil fertility by biochar is possible either by the nutrients it contains or by its physico-chemical properties that allow a good use of nutrients inherent to the soil or fertilizers (Sohi *et al.,* 2009; Olmo *et al.,* 2014). In terms of soil chemical properties, biochar addition to soil increases nitrogen, phosphorus, potassium and total carbon content (Biederman *et al.,* 2013; Mukherjee *et al.,* 2014). Studies have shown that biochar action is much more effective in poor and acidic soils because it increases pH and Cation Exchange Capacity of these soils. It increases soil capacity to retain nutrients, reducing soil acidity and limiting leaching (Kruger *et al.,* 2009; Chintala *et al.,* 2014; Nemati *et al.,* 2015). From a soil biology perspective, biochar provides a niche for microorganisms responsible for organic matter degradation into mineral matter. Indeed, addition of biochar to soil increases its microbial biomass and creates important changes in community composition (Warnock *et al.,* 2007; Anderson *et al.,* 2011; Gul *et al.,* 2015). According to these authors, addition of biochar could potentially influence growth of certains groups of microorganisms involved in the nitrogen, carbon and phosphorus cycle in the soil. Other authors argue that addition of biochar to soil can promote growth of certains groups of microorganisms beneficial to plant growth (Graber *et al.,* 2010; Kolton *et al.,* 2011; Harel *et al.,* 2012). These improvements in the physicochemical and biological characteristics of soils by biochar result in improved crop yields. While some studies have shown an increase in yields with biochar alone (Chan *et al.,* 2008), others have found a more positive response when biochar is combined with fertilizer (Steiner *et al.,* 2007).

However, the agronomic benefit of biochar depends on the application rate and its chemical composition, as well as soil type (Chintala *et al.,* 2011; Unger and Killorn, 2011). In parallel to these agronomic virtues, biochar decreases the concentration of CO2 and other greenhouse gases in atmosphere because of its physico-chemical and biological properties (Lévesque, 2017). According to the existing literature, biochar adoption is a good strategy to offset a large part of carbon emitted by fossil fuel combustion and loss of plant biomass due to land use change (Whitman *et al.,* 2009; Roberts *et al.,* 2010). This is due to its ability to sequester much of carbon in soil in a stable form for hundreds or even thousands of years (IBI, 2015: http://www.biochar-international.org/biochar/carbon) and its potential to reduce emissions of greenhouse gases such as methane (CH4) and nitrous oxide (N2O).

Conclusion

Diachronic analysis of land use/occupation in Koumbia and Dédougou communes between 1990 and 2016 showed preponderance of the increase in farming areas to detriment of natural savannah. At Koumbia, farming area increased by a factor of 3.5, while that of wooded to woody savannas; and grassy to shrubby savannas decreased by 50% and 29.16% respectively. At Dédougou, the area of grassy to shrubby savannas decreased by more than 70% and that of woody ato woody savannas by more than 60%, while the area under cultivation increased by 149%. Population growth, inappropriate agricultural techniques and environmental factors are responsible for this increase in the area of farming zones. The decrease in the area of natural vegetation is due not only to land clearing for cultivation but also to other factors such as excessive logging and bush fires. The expansion of fields as a response to low land productivity has reached its limits, because there is almost no space to create new fields. From an environmental point of view, it is necessary to intensify production on already exploited land. The biochar technique implementation to recovery degraded soils is therefore an absolute necessity. It remains to be known its potential of extension in view of the prevailing socio-economic situation.

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