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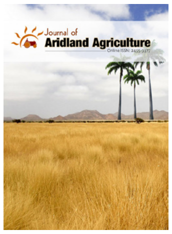

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Spatio-temporal dynamics of land use and land cover change in the commune of Dori, Burkina Faso

Moussa Ganamé[1]*, Philippe Bayen[1,2], Benjamin Lankoandé[1,3], Eugène N. Balma[1,4], Adjima Thiombiano[1]

[1]Laboratory of Plant Biology and Ecology, University Joseph Ki-Zerbo, Ouagadougou, Burkina Faso, [2]Training and Research Unit in Applied Science and Technology, University of Dédougou, Burkina Faso, [3]University of Fada N'Gourma, Burkina Faso, [4]Ministry of the Environment, Green Economy and Climate Change

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***Corresponding Author:**
Moussa Ganamé
E-mail: emanagassoum@yahoo.com

ABSTRACT

Land use and land cover (LULC) is a fundamental variable in the sustainable management of natural resources. Understanding land use and land cover change is essential for the study of environmental phenomena. This study investigates LULC change in Dori Commune in Burkina Faso over the period 1995-2015. The methodological approach is based on the analysis of Landsat images from three time points (i.e., 1995, 2006 and 2015). Data analysis revealed a 16.86% decrease in natural vegetation and an 80% increase in anthropogenic areas between 1995 and 2015. According to the matrix of changes, areas of tree steppe was more converted into shrub/grassy steppe with a rate of 6.45% against 1.42% in farmland in the study period. Shrub/grassy steppes were also converted into farmlands with a rate of 13.77% in the same period. The study found that human activities were the main drivers of LULC change in the study area. The variability in rainfall likely also contributed to the observed LULC change. The study's findings can help with decision-making elsewhere in sub-Saharan Africa.

Keywords: Agricultural lands, Land use class, Vegetation cover, Landsat imagery

INTRODUCTION

The global environment is facing severe challenges such as rapid changes in land use and land cover (LULC), which is the prominent ecological symbol on the earth's surface. In the last two-three decades, sub-Saharan African countries have faced extreme-droughts, large population growth, and civil war, resulting in rapid land use and land cover (LULC) changes and associated environmental and socioeconomic issues across the region (Brink & Eva, 2009). In Burkina Faso, as in the other Sahelian countries, aridity is a constant factor of the natural environment. As a consequence, agricultural crop production, animal husbandry and food security are threatened in the country. The very fragile ecological balance requires special attention for a rational use of the country's natural resources (Yelkouni, 2004). The economy of Burkina Faso is largely based on agro-sylvo-pastoral activities. For example, agriculture and animal husbandry employ over 86% of the working population (Thiombiano & Kampmann, 2010). These activities generate strong pressures on natural resources and induce land degradation, including biodiversity losses, soil erosion, and the amplification of other environmental problems (Ngo Makak *et al.*, 2018). In addition, an annual population growth of around 3.1% (INSD, 2008) combined with the detrimental effects of climate change on agricultural landscapes, means farmers are increasingly claiming new lands and pastoralists new pastures. This transformation of natural ecosystems into agricultural land (and urban areas) is one of the major causes of habitat degradation and fragmentation (Foley *et al.*, 2005). Rapid LULC change and associated detrimental effects on the environment and livelihoods of local populations is therefore evident in many parts of Burkina Faso.

The situation of rapid LULC change in Burkina Faso means there is an urgent need to find solutions to meet the growing needs of local populations without further accelerating landscape degradation. Thus, monitoring the dynamics of LULC change is essential to define management strategies that allow a balance between production and conservation (Paré *et al.*, 2008). According to Etefa *et al.* (2018), knowing the LULC status of a given area and at a given point in time is important for understanding the interactions of human activities with the environment (Kpedenou *et al.*, 2017). Moreover, information on the dynamics of LULC change assists in monitoring environmental changes and developing effective land management and planning strategies at both national and local levels (Etefa *et al.*, 2018). Information on LULC change has also become one of the most critical inputs for greenhouse gas accounting and terrestrial carbon management.

For the assessment of LULC change, remote sensing data play an important role through their ability to provide quantitative information on the spatio-temporal dynamics of LULC (Tekle & Hedlund, 2000). Several authors have been interested in the analysis of LULC change in Burkina Faso using remote sensing (Dimobe *et al.*, 2015, 2017; Kadeba *et al.*, 2015, 2019; Soulama *et al.*, 2015; Ngo Makak *et al.*, 2018; Millogo *et al.*, 2017). However, in Dori Commune in the Sahelian zone in the northeastern part of the country, very few studies investigated the LULC change dynamics. The only study is that of Kadeba *et al.* (2015) who worked on the dynamics of land use and plant diversity in the Gourouol watershed. Landsat images of the years 1992, 2002 and 2010 used by these authors certainly cover the watershed but not the entire commune of Dori. This does not make it possible to understand the problems of urbanization and the increase in population in connection with the evolution of the types of land use and occupation. Dori Commune is experiencing overexploitation of natural resources due to the exponential increase in population. Although a baseline of LULC is necessary to help in decision-making for the sustainable management of natural resources, no LULC maps have been developed for Dori Commune. This study therefore investigates the spatial and temporal dynamics of LULC change in Dori Commune between 1995 and 2015. Specifically, it aimed to (i) develop LULC maps for 1995, 2006 and 2015; and (ii) quantify the extent and types of LULC change between 1995 and 2015.

MATERIEL AND METHOD

Study area

The study was conducted in the commune of Dori located in northeastern Burkina Faso (Figure 1). Phytogeographically, the site is part of the Sahelian zone (Fontès & Guinko, 1995). The vegetation is characterized by Sahelian species, including *Boscia augustifolia* A. Rich., *Pterocarpus lucens* Guill. & Perr, *Balanites aegyptiaca* (L.) Del., *Ziziphus mauritiana* Lam., *Piliostigma thoningii* (Schumach.) Milne-Redh., *Bauhinia rufescens* Lam. Rainfall is characterized by an irregular distribution, with a mean precipitation lower than 600 mm/year, of which about 90% falls between July and August.

Data collection

Three datasets were used to analyze the LULC change in Dori Commune: topographic maps, Landsat satellite images (1995, 2006 and 2015) and on-ground surveys.

Topographic maps

Topographic maps were used to define the administrative boundaries of Dori Commune and extract the precise locations of villages, roads and rivers. These maps were provided by the National Topographic Data Base (BNDT) "plus" of the Geographical Institute of Burkina Faso (GIB).

Landsat satellite images

Three multi-temporal Landsat images were selected to analyze the LULC change in Dori Commune. Thus, the TM (Thematic

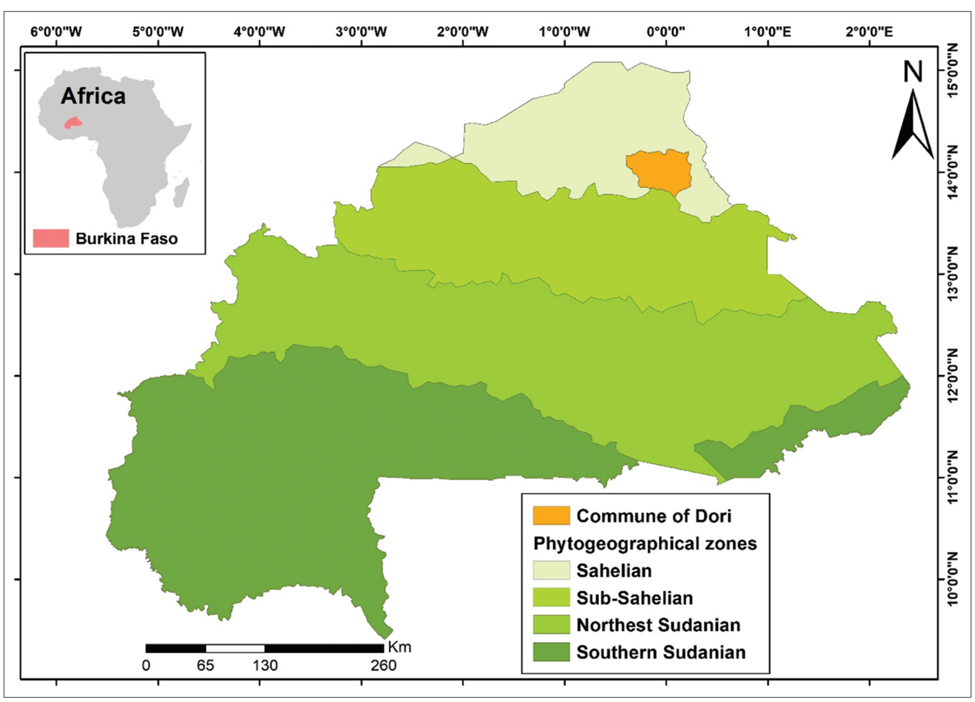

Figure 1: Location of the study area

Mapper) scene from 1995, ETM+ (Enhanced Thematic Mapper Plus) scene from 2006, and the OLI-TIR 8 scene (Operational Land Image) from 2015 were downloaded free of charge from the "United States Geological Survey's portal (http//glovis.usgs.gov/). Defined administrative boundaries were used to locate and extract data for Dori Commune through each scene. The Landsat image pixels had a 30m resolution, meaning each pixel characterized a 900 m^2 area on the ground (Ozswald *et al.*, 2010). This was sufficient to distinguish the landscape structures of the study area. Images were captured from the months of May, November and September, which correspond with the dry season and allow an optimal distinction of LULC classes (Dimobe *et al.*, 2017). In fact, the images acquired during the dry season show a strongly reduced cloudiness; thus limiting atmospheric biases (Oszwald *et al.*, 2010). A false color composite was applied to each image, followed by visual interpretation.

On-ground data collection

Accurately detecting LULC change from satellite images alone remains difficult; therefore, it is necessary to complement satellite data with data collected in the field (Dimobe *et al.*, 2015, 2017). To verify the results of the LULC classifications and provide details for areas that were difficult to interpret on different color composites, vegetation and ecological data were collected using the provisory LULC map derived from the Landsat image of 2015. Thus, 80 Areas of Interest (AOI) were generated proportionally by LULC classes. The geographical coordinates of the classes generated were transferred into a Global Positioning System (GPS) (to facilitate their identification in the field) and a field survey sheet was developed to collect the following information: the location of the site, the LULC classes resulting from the provisional classification, and the LULC classes identified in the field. Precise information on thematic classes is essential for a reliable classification of satellite images (Dimobe *et al.*, 2015; Cheruto *et al.*, 2016). Google earth images were also used to refine the assignment of thematic classes to the different spectral signatures.

DATA ANALYSIS

Image preprocessing

Data preprocessing brings together the operations of geometric and radiometric corrections, mosaicking and extraction of the study area. The radiometric improvements correct the effects of the different artefacts, which disturb the radiometric measurement, while the cones make it possible to superimpose on other cartographic reference documents (Shlien, 1997). The geometric correction was not necessary because the images downloaded were already georeferenced in the UTM WGS 1984 system. Also, because the study area is covered by a single Landsat scene (path 194, rows 05), a mosaicking operation was not necessary. The study area was extracted from Landsat images using the clipping tool of ArcGIS 10.2 software. As this processing can lead to the loss of information, the option of resampling by the "Nearest Neighbor" method, which retains the original radiometric values of the image, was adopted. To synthesize information with a view to a good discrimination of the LULC classes, the images underwent different color composites by combining the bands 4-3-2 for Landsat TM and TM+ and 5-4-3 for the OLI-TIR 8 image (Girard & Girard, 1999).

Classification of satellite images

Supervised classification using the "maximum likelihood" algorithm was performed to generate the LULC maps for Dori Commune. The "maximum likelihood" algorithm was used because it is considered the most powerful algorithm in the classification of thematic maps in the field of LULC change (Lagabrielle *et al.*, 2007). Three-quarters of the geographic coordinates collected in the field were used to develop the training sites required to supervised classification, for all LULC classes. Seven LULC categories were determined as the dominant types for the study area: riparian forest, tree steppes, shrub/grassy steppes, farmlands, habitat areas, water bodies, and bare soil. One-third geographic coordinates collected in the field was used to validate the classification results. Thus, the classified land cover pixel was compared to the reference data of LULC classes and used to generate a confusion matrix (Kadéba *et al.*, 2015; Dimobe *et al.*, 2017). The confusion matrix was used to generate the overall accuracy, user and producer's accuracies, and the Kappa index.

Change detection

To determine the occurred LULC change, a post-classification change algorithm was performed using the ENVI 4.7 software. The results are changed matrices from which the nature, rates, and magnitude of LULC changes were derived.

The rates of change for each LULC category were calculated using the following formula (Djaouga *et al.*, 2017; Agbanou *et al.*, 2018):

$$\Delta_s = \frac{s_{p2} - s_{p1}}{t_2 - t_1}$$

Δ_s is the rate of change (extension or regression in ha/year);
S_{P1} = area occupied by the LULC category considered in year 1 (ha);
S_{P2} = area occupied by the LULC category considered in year 2 (ha);
t_1 = year 1; t_2 = year 2.

RESULTS

Assessment of the classifications accuracy

The evaluation of the performance of the classification showed that the discrimination between the different LULC classes is statistically significant for each of the classified images. Indeed, the values of the overall accuracy varied between 98.15% and 99.10%. The Kappa coefficient was between 0.98 and 0.99.

The confusion matrix analysis revealed very close similarities between classified points and benchmarks.

Spatial distribution of LULC categories in 1995, 2006 and 2015

Classification maps derived from the three time points are presented in Figure 2, showing the distribution of the seven LULC classes identified in Dori Commune. We could not distinguish shrub-steppe from grass-steppe on the one hand, and the other hand farmlands from agroforestry areas, therefore these LULC classes were merged due to their physiognomic similarities.

According to the 1995 LULC classification map, shrub/grassy steppes were the dominant LULC class, covering 56.12% of the land area in Dori Commune. This was followed by tree steppes (covering 21.72%), farmlands (18.93%), and riparian forest (1.63%). In 2006, Dori Commune was still dominated by shrub/grassy steppes (slightly reduced to 54.08% of the land area), and the area of farmlands had increased to 24.63% of the land area. By 2015, the area of farmland had further increased to 33.07% but was still less than the area covered by the shrub/grassy steppe (reduced to 48.25%). At this time, the tree steppes had also reduced to 12.82%, and bare soils and riparian forests covered 2.82% and 1.54%, respectively (Table 1).

PATTERNS OF LULC CHANGE

Change pattern from 1995 to 2006

The LULC classes characterizing the landscape of Dori Commune underwent enormous changes between 1995 and 2015. Between 1995 and 2006, the positive values of the average rate of spatial expansion showed an extension of the area of farmlands, habitats, water bodies and bare soil. On the other hand, the riparian forest, the tree steppes, and the shrub/grassy steppes all experienced area regressions (Table 2). The speed of change was most pronounced for the riparian forest (68.89%).

Between 2006 and 2015, the areas covered by tree steppes and shrub/grassy steppes were further regressed. In contrast, the areas of the other LULC classes expanded (Table 3). In this period, the change rates of the tree steppes and the shrub/grassy steppes were -1,148.82 ha/year and -29.61 ha/year, respectively (Table 3).

Change pattern from 1995 to 2015

Superimposing of the LULC classes maps of 1995 on those of 2015 shows an increase in farmland areas with an average annual rate of 10%. In contrast, the areas of tree steppes, shrub/grassy steppes, and riparian forests decreased at average annual rates

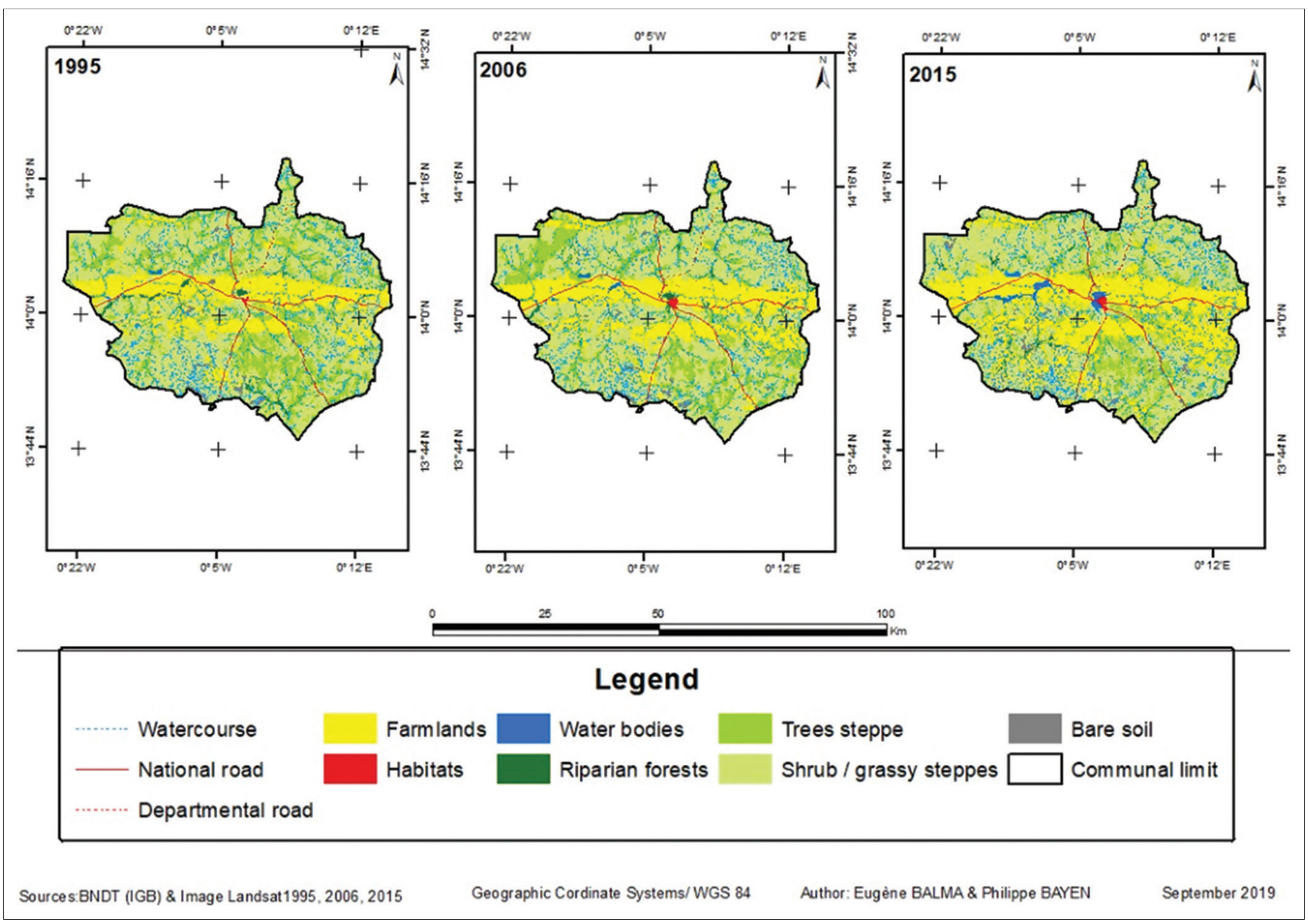

Figure 2: Land use land cover maps of the commune of Dori

of -41%, -30% and -89%, respectively. Habitats and bare soil areas also increased in the period 1995-2016 (Table 4).

TRANSITION OF LULC CLASSES

Transition from 1995 to 2006

The transition matrix of the LULC classes between 1995 and 2006 is recorded in Table 5. In 1995, 56.13% of the study area was occupied by shrub/grassy steppes. Between 1995 and 2006, 2.24% of the shrub/grassy steppes transitioned to farmlands and 7.34% to tree steppes. The unchanged area of the shrub/grassy steppes was 44%. Over the same period, 9.15% of the tree steppes area was converted to different LULC classes, specifically to farmlands, riparian forest, water bodies, shrub/grassy steppes, and bare soil at rates of 1.28%, 0.43%, 0.04%, 4.19% and 0.09%, respectively. The unchanged area of the tree steppes was 12.57% over this time. The areas of habitat and bare soil classes increased significantly, from 0.007% in 1995 to 0.15% in 2006, and from 1.39% in 1995 to 1.46% in 2006, respectively. Farmland areas also increased, from 18% in 1995 to 24.63% in 2006.

From 2006 to 2015

The transition matrix of LULC classes between 1995 and 2006 are presented in Table 6. The results showed that 38.07% of the shrub/grass area was unchanged, while 7.49%, 6% and 2.09% were converted to respectively, farmlands, tree steppe and bare soil. Concerning the tree steppes, 3.74, 7.48% and 0.16% were converted respectively, to farmlands, shrub/grass steppes, habitats and bare soils. From 2006 to 2016, 10.63% of the vegetation area was transformed to anthropized zone.

Table 1: Land use/land cover statistics between 1995 and 2015

LULC/classes	Area in 1995 (ha)	% in 1995	Area in 2006 (ha)	% in 2006	Area in 2015 (ha)	% in 2015
Riparian forests	4192,87	1,63	3799,65	1,48	3957,12	1,54
Trees steppe	55909,05	21,72	45622,94	17,73	32985,97	12,82
Shrub/grassy steppes	144425,59	56,12	139141,83	54,08	124143,42	48,25
Farmlands	48718,69	18,93	63368,54	24,63	85070,10	33,07
Habitats	176,86	0,07	387,01	0,15	592,07	0,23
Water bodies	374,31	0,15	1183,35	0,46	3154,44	1,23
Bare soil	3570,92	1,39	3766,31	1,46	7366,52	2,86

Table 2: Conversion rate, rate of change in land use/land cover classes and deforestation rate between 1995 and 2006

LULC/classes	Area in 1995 (ha)	Area in 2006 (ha)	T(%)	ΔS (ha/an)	R
Riparian forests	4192,87	3799,65	68,89	-35,75	-0,007
Tree steppes	55909,05	45622,94	42,13	-935,10	
Shrub/grassy steppes	144425,59	139141,83	21,22	-480,34	
Farmlands	48718,69	63368,54	15,81	1331,80	
Habitats	176,86	387,01	14,48	19,10	
Water bodies	374,31	1183,35	100,00	73,55	
Bare soil	3570,92	3766,31	6,02	17,76	

(T (%): Conversion rate, Δs (ha/year): Rate of change, R: Deforestation rate)

Table 3: Conversion rate, rate of change in LULC classes and deforestation rate between 1995 and 2006

LULC classes	Area in 2006 (ha)	Area in 2015 (ha)	T(%)	ΔS (ha/an)	R
Riparian forest	3799,65	3957,12	89,33	14,32	-0,017
Tree steppes	45622,94	32985,97	70,30	-1148,82	
Shrub/grassy steppes	139141,83	124143,42	29,61	-1363,49	
Farmlands	63368,54	85070,10	13,93	1972,87	
Habitat	387,01	592,07	10,57	18,64	
Water bodies	1183,35	3154,44	3,52	179,19	
Bare soil	3766,31	7366,52	70,92	327,29	

(T (%): Conversion rate, Δs (ha/year): Rate of change, R: Deforestation rate)

Table 4: Conversion rate, rate of change in land use units and deforestation rate between 1995 and 2006

LULC classes	Area in 1995 (ha)	Area in 2015 (ha)	T(%)	ΔS (ha/year)	R
Riparian forests	4192,87	3957,12	89,25	-21,43	-0,012
Tree steppes	55909,05	32985,97	41,00	-2083,92	
Shrub/grassy steppes	144425,59	124143,42	29,89	-1843,83	
Farmlands	48718,69	85070,10	10,03	3304,67	
Habitat	176,86	592,07	0,70	37,75	
Water bodies	374,31	3154,44	15,36	252,74	
Bare soil	3570,92	7366,52	70,79	345,05	

(T (%): Conversion rate, Δs (ha/year): Rate of change, R: Deforestation rate)

Table 5: Matrix of land cover units change (in percentage) from 1995 to 2006

LULC classes		1995							Total 1995
		RCA/AT	RF	Ha	WB	TS	S/GS	BZ	
2006	Farmlands	15,94	0,12	0,03	0,01	0,58	2,24	0,01	18,93
	Riperian forest	0,20	0,51	0,00	0,27	0,38	0,25	-	1,61
	Habitat	0,01	-	0,06	-	-	-	-	0,07
	Water Bodie	0,01	0,02	-	0,10	0,01	0,01	-	0,15
	Tree Steppe	1,28	0,43	-	0,04	12,57	7,34	0,06	21,73
	Shrub/Grassy Savannas	7,13	0,39	0,06	0,04	4,19	44,22	0,09	56,13
	Bare soil	0,06	-	-	-	-	0,03	1,30	1,39
Total 2006		24,63	1,48	0,15	0,46	17,73	54,08	1,46	100,00

RCA/AT: Rainfed cultivation area/agroforestry territory, RF: Riparian formations, Ha: Habitation, WB: Water bodie, TS: Tree steppe, S/GS: Shrub/grassy steppe, BZ: Bare zones

Table 6: Matrix of land cover units change (in percentage) from 2006 to 2015

LULC classes		2006							Total 2006
		RCA/AT	RF	Ha	WB	TS	S/GS	BZ	
2015	Farmlands	21,20	0,09	0,05	0,38	1,18	1,57	0,17	24,63
	Riperian forests	0,49	0,16	-	0,19	0,33	0,28	0,03	1,48
	Habitations	-	-	0,13	-	-	0,01	-	0,15
	Water body	0,01	-	-	0,44	-	-	-	0,46
	Tree steppes	3,74	0,94	0,01	0,14	5,27	7,48	0,15	17,73
	Shrub/grassy steppes	7,49	0,33	0,03	0,07	6,00	38,07	2,09	54,08
	Bare zones	0,13	0,02	-	-	0,05	0,85	0,43	1,46
Total 2015		33,07	1,54	0,23	1,23	12,82	48,25	2,86	100,00

CA/AT: Rainfed cultivation area/agroforestry territory, RF: Riparian formations, Ha: Habitation, WB: Water bodie, TS: Tree steppe, S/GS: Shrub/grassy steppe, BZ: Bare zones

Transition from 2006 to 2015

The transition matrix of the LULC classes between 2006 and 2015 are presented in Table 6. The results showed that 38.07% of the shrub/grassy steppes area was unchanged, while 7.49% was converted to farmlands, 6% to tree steppes, and 2.09% to bare soil. Concerning the tree steppes, 3.74% of this area was converted to farmlands, 7.48% to shrub/grassy steppes, and 0.01 and 0.16%, respectively to habitats and bare soils. From 2006 to 2015, a total of 10.63% of the landscape that was covered in natural vegetation was transformed to anthropized zone.

DISCUSSION

Analyzing the spatio-temporal dynamics of LULC change in the study area over the period 1995-2015 has highlighted the substantial changes to the landscape of Dori Commune. The overall classification accuracy resulting from the analysis of the TM images from 1995, the ETM+ images from 2006, and OLI-TIR images from 2016 varied from 98.15% to 99.10%. According to Treitz and Rogan (2004), these values are satisfactory and show a high level of agreement between classified and reference points because they are higher than the threshold values (80-85) of the overall accuracy of classification maps. The values of the Kappa index, which varied between 0.98 and 0.99 in this study, also corroborate the accuracy and reliability of the discriminated LULC classes (Jansen *et al.*, 2008). Therefore, the classifications are considered accurate and statistically acceptable (Pontius, 2000).

The accuracy of this study's LULC classification results could be explained by taking periods of images and the algorithm used in the classification. Indeed, the dry season images used in this study avoid confusion between crops and natural vegetation on the one hand, and on the other hand, between vegetation and bushfires which reflect in the near infrared and cause class confusion (Diallo *et al.*, 2011; Mama *et al.*, 2013). Among the range of methods available for the classification of satellite images, we opted for supervised classification using the maximum likelihood algorithm because according to Nagendra *et al.* (2006), it appears the most representative and involves the use of control areas. This method has also been used by several other authors in the sub-region West Africa (Forkuor, 2015; Folega *et al.*, 2012; Houessou *et al.*, 2013; Dimobe *et al.*, 2015; Zoungrana *et al.*, 2015). The analysis of the LULC change therefore allowed us to characterize the main LULC classes in Dori Commune.

The analysis of the LULC change dynamics in Dori Commune between 1995 and 2015 showed a decrease in tree formations in favor of mainly farmlands. These results are consistent with those of Barima *et al.* (2009) who concluded that multiple and repeated intrusions of man into forest areas, for various agricultural activities, and where the population density increases each year, would ultimately result in forest remnants being eliminated in favor of farms. This study also made it possible to understand the various LULC changes that have occurred and their underlying causes. Most significant among our findings was the level of reduction in the shrub/grassy steppes and tree steppes, at rates of -41% and -30%, respectively. These rates of reduction are well above the values of -15.07% and -1.03% obtained by Kadeba *et al.* (2019) in the Faga watershed located in the sub-Sahelian phytogeographic zone of Burkina Faso during the period 1992-2002.

We can conclude on the basis of the work of Soro *et al.* (2014) that the degradation of the natural vegetation cover observed in our study is due to both anthropogenic pressures and natural phenomena (climatic variability'). This assertion appears plausible insofar as there was an increase in the surface area of farmlands at an average annual rate of change of 10% to the detriment of steppe vegetation (both tree and shrub/grassy). Several authors have established the link between an increase in cultivation areas and a decline in woody vegetation cover (Gnoumou *et al.*, 2016). For Kadeba *et al.* (2019), population growth would induce an increase in cultivated areas. For these authors, the rapid growth of the human population of Burkina Faso in general and the Sahelian zone in particular, is in part due to the Ivorian political crisis between 2002 and 2011. This phenomenon has led to an increase in cultivated areas and consequently to the degradation of the vegetation cover.

We also observed an increase in the areas of riparian forest in 2006 and 2015. These results are similar to those of Kadeba *et al.* (2019). For these authors, the size of the pixels of the LandSat TM images (30m x 30m) which is quite coarse for riparian areas may constitute the explanatory factor.

CONCLUSION

Anthropogenic pressures are at the center of ecological disturbances and feed the process of landscape degradation and the slow reconstitution of ecosystems. This study made it possible to analyze the spatio-temporal dynamics of LULC change. The spatio-temporal cartography of the LULC of Dori Commune carried out over a twenty-year period, using Landsat TM 1995, ETM + 2006 and OLI 2015 satellite imagery, revealed a decrease of natural vegetation' area between 1995 and 2015. The natural vegetation cover decreased from 204,527 ha to 161,086 ha, a decrease of 16.86%, while the degraded lands experienced an increase in their area from 52,840 ha to 96,183 ha. These results confirm the hypothesis that natural tree formations in the study area are experiencing a regression. The matrix of changes made it possible to observe that tree steppes underwent a more marked transformation of 6.45% into a shrub/grassy steppe; and 1.42% into farmlands. The conversion of shrub/grassy steppes into mosaics of farmlands is notably observed with a conversion of 13.77%. This situation reveals the strong anthropogenic pressures being exerted on natural vegetation. Human activities are believed to be the main drivers of observed changes in LULC in the study area. The current observation is that in Dori Commune, the natural vegetation is being substantially disturbed by human activities. Population growth and human actions have accentuated the observed landscape degradation, thereby aggravating the effects of drought.

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