LANDUSE/LANDCOVER CHANGE PROCESS IN A TROPICAL SEMI-ARID ZONE: CASE OF TWO RURAL COMMUNES (CHADAKORI AND SAÉ-SABOUA) IN MARADI REGION, REPUBLIC OF NIGER

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Abstract
The study aimed to analyze the process of Landuse/Landcover change of two rural communes (Saé Saboua and Chadakori) of Maradi region (Republic of Niger) over the past 28 years (1986 – 2014), through landscape structure analysis by diachronic cartographic approach and landscape indices. Mixed classification of temporal series of Landsat images led to identifying six Landuse/Landcover (LULC) classes, namely ”cultivated land under shrubs and trees”, ”cultivated land under trees”, “continuous cropland”, ”fallow/pasture land”, ”forest reserve”, and ”settlement”. The composition and structure of the studied landscapes have greatly changed from 1986 to 2014. The class ”cultivated land under trees” was the landscape matrix in 1986 with 38.65% of landscape total area but in 2001 and 2014 the class ”continuous cropland” became the landscape matrix. The changes also affected the ”forest reserve” which was transformed to smallholder agricultural land from 1986 to 2014. The area occupied by classes ”cultivated land under trees” changed from 38.65% in 1986 to 8.78% in 2014; and from 1986 to 2014, the area occupied by ”fallow/pasture land” has decreased of about 16%. The decrease in these classes was in favor of ¨continuous crop land¨, ¨settlement¨ and “cultivated land under shrubs and trees” which respectively gained 38%, 0.3% and 8.15% of their areas in 1986. The results of this study reflect the problem of access to land and even land saturation in semi-arid region, a consequence of strong population growth. They also contribute to a better rethinking of agricultural practices in order to initiate adaptation and resilience strategies for the population facing food insecurity and poverty.

Keywords: Landuse/Landcover, Landscape structure, GIS/Remote Sensing, Landscape change, Anthropization, Land management, Sahel, Niger Republic

1. Introduction

In recent years, global climate change and human activity have no doubt affected physical and biological systems (Marthews et al., 2019), particularly in the semi-arid regions experiencing rising temperatures, frequent drought events and changes in precipitation regimes since the 1970s (John et al., 2009; Mertz et al., 2011; Sarr, 2012). According to IFAD and UNEP (2013), seventy percent of the 1.4 billion people are living on less than US$1.25 a day live in rural areas where agriculture is a major livelihood activity and where the majority only has access to small (<2 ha) areas of agricultural land (World Bank, 2007). In Niger, 81% of the population lives in rural areas with land becoming increasingly insufficient because of the high rate of population growth (3.7%) leading to increased natural resource consumption (World Bank, 2015). With a view to increasing food security and reducing poverty, smallholders are pushed to expand their farm holdings, leading to exacerbated natural resource degradation (forest, soil, water) (Lawali and Yamba, 2012). This degradation is manifested through a reduction in biodiversity and plant cover (Mahamane et al., 2007), and soil erosion (Sultan and Janicot, 2004). Other ecological consequences include, loss of key species, with others becoming endangered and threatened (Currit and Easterling, 2009), and land fragmentation (Fuller, 2001). Furthermore, the management of natural resources has become more constrained and complex due to the several levels of interactions among ecological, political, socioeconomic, demographic and behavioral factors (Kim and Ellis, 2009). To better understand how humans and climate factors are influencing LULC changes, remote sensing and geographic information system (GIS) are now being applied widely because of its quick analysis and near accurate results and ability to present visual and spatial information (Zang, 2003; Diouf et al., 2012). This study is aimed at providing landscape change information to resource managers and decision makers and is also about understanding the relations between landscape spatial structure and anthropogenic factors in a part of semi-arid zone of Niger.

2. Materials and methods

Study site

The study was conducted in Chadakori and Saé Saboua, two rural communes of Maradi region, located between latitudes 13°5’97” and 13°9’14” North and longitudes 7°6’03”and 7°49’02” East in south central Niger Republic (Figure 1). It occupies an estimated area of 2,566 km^2. It experiences a semi-arid climate characterized by a short rainy season that is followed by eight months of dry season (Sadda et al., 2016). The mean annual precipitation over the past 30 years is about 469.4 mm. The mean annual temperature is 28oC with a relative humidity averaging 56% (DNM, 2015). The hydrological network in the area consists essentially of temporal ponds which do not last to allow the development of irrigated crops.

The soil is principally sandy and loamy sandy, and is less fertile, even though it supports some woody vegetation dominated by *Piliostigma reticulatum* Hochst, *Ziziphus mauritiana* L., *Guiera senegalensis* J.F. Gmel, *Combretum nigricans* Lepr., *Combretum glutinosum* Pierr., *Combretum micranthum* G.Don., *Faidherbia albida* A.Chev., and *Commiphora africana* Engl.

The human population of the study area was estimated at 208,349 inhabitants in 2012, with 51.8% being women, compared with only 135,700 inhabitants in 2001, corresponding to an average annual growth rate of 3.97%, slightly higher than national rate (3.7%) (INS, 2014). Scarcity of natural resources, continued decline in agricultural productivity, followed by rampant food crisis, decline in purchasing power of households caused by the adverse impact of climate

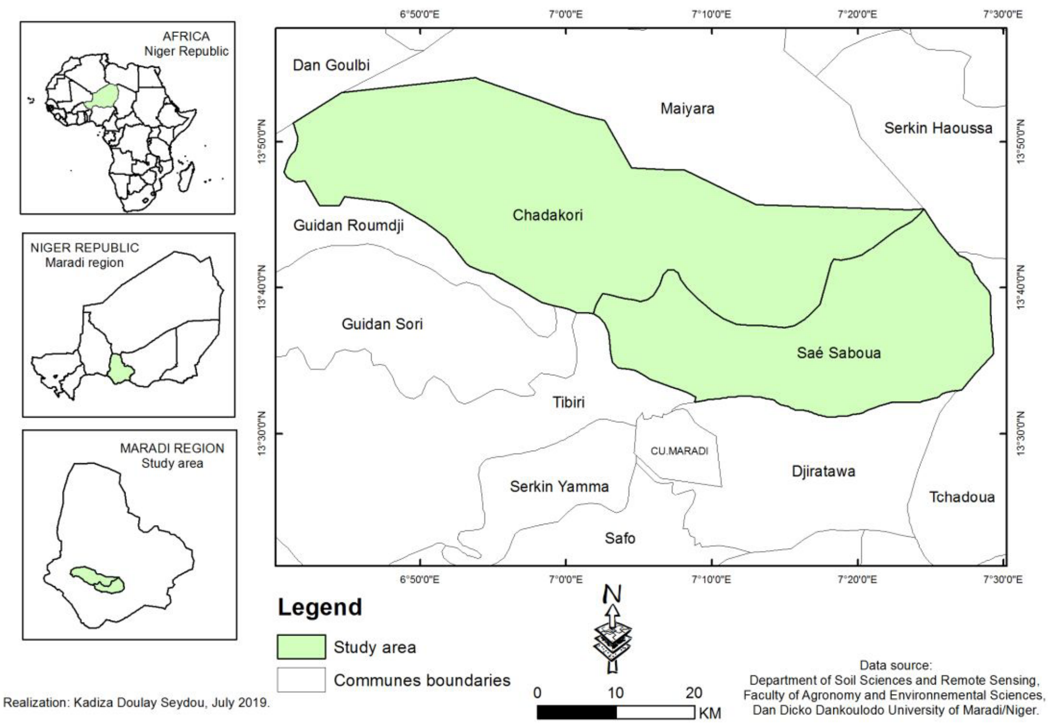

Fig. 1. Geographic localization of Saé-saboua and Chadakori communes in Maradi Region (Republic of Niger)

change have all combined to increase the vulnerability of people, who are often pushed to migrate from rural to urban centers (Lawali and Yamba, 2012).

Satellite data acquisition and pre-processing

To analyze 28 year LULC changes, three Landsat satellite images from different sensors, different spatial resolutions, different tiles and different dates (1986 - MSS: Multispectral Scanner; 2001 - ETM+: Enhance Thematic Mapper Plus; and 2014 - OLI/TIRS: Operational Land Imager/Thermal Infrared Sensor) (Table 1), were acquired through the tool Earth Explorer from United States Geological Survey (USGS) official website (http://earthexplorer.usgs.gov/ on 15/07/2015). The choice of the sensors is based on their resolutions according to the study objectives; and the availability of the

Table 1. Details of acquired Landsat images

Satellite ID	Sensor ID	Path/ Row	Acquisition date	Spatial resolution	Band
Landsat 3	MSS	189/051	14/10/1986	60m	Band 1 (0.50-0.60) Band 2 (0.60-0.70) Band 3 (0.70-80)
		190/050	23/10/1986		
Landsat 7	ETM+	189/051	22/09/2001	30m	Band 2 (0.52-0.60) Band 3 (0.63-0.69) Band 4 (0.76-90)
		190/050	29/09/2001		
Landsat 8	OLI/ TIRS	189/051	21/11/2014	30m	Band 3 (0.53-0.59) Band 4 (0.63-0.67) Band 5 (0.85-87)
		190/050	28/11/2014		

images. Two scenes (Path 189 Row 051 and Path 190 Row 050 according to the World Reference System WRS2) necessary to cover the entire study zone were taken during the dry season when the biomass reflectance values are lowest for the achievement of the goal of this study.

Image radiometric correction and atmospheric calibration were done by their provider. An operation of mosaicking of the two scenes of the closest date was done to obtain a single image. Specially, the image of 1986 was resampled using the nearest neighbor algorithm to harmonize the images spatial resolution (from 80 m to 30 m resolution for the MSS sensor image) (Schowengerdt, 2007).

Additional pre-processing operations were done under the software ENVI 4.5 ® in order to correct and/or improve images geometrically and radiometrically. So, the operations of visual improvement as smoothing, contrast linear adjustment at 2%, and image editing (false color composite) to better differentiate vegetation classes (Diouf et al., 2012). These operations facilitated their reading, visual interpretation on the screen, and preparation for the ground controls.

Image classification and accuracy assessment

Mixed classification approach was applied on the three multispectral images for an analytical and/or selective extraction of needed information. At first, the visual interpretation of these images according to color, texture, structure, and shape of image objects was done to determine the number of main LULC classes. Then an unsupervised classification using the Isodata algorithm which groups the pixels of each image in objective LULC classes, based on its reflectance values.

To improve the classification and determine the land use classes, ground truthing points were identified in each of the established LULC classes. The gathered information was then used to establish the training sites corresponding to objects recognized as representative of a class on the pre-processed image. The supervised signature extraction with the maximum likelihood algorithm was employed to perform the classification of the satellite images. It used statistical training sites to calculate the probability of membership of each pixel to one of the classes (Bonn and Rochon, 1992).

Post-classification operations such as the application of a majority Kernel filter (3x3 pixels window) to reduce the "salt and pepper" effect on the classified image (Abdourahamane et al., 2015), and the combination of some very close classes in connection with land use was applied. In order to validate the classification of the different images, a confusion matrix was used to assess the quality of the classification with the Kappa coefficient (K) and statistics on errors of commission and omission (Story and Congalton, 1986; Sadda et al., 2016).

Statistical analysis of landscape change

GIS operations (ArcGIS 10.2 ©) such as vectorization of classified images, extraction, and layout of the portion corresponding to the limits of the study area were used to develop LULC maps corresponding to the three selected dates (1986, 2001 and 2014). So, to characterize Chadakori and Saé Saboua communes' landscape structure, three (3) landscape composition metrics were calculated by using Fragstats 4 software. These are:

- *Number of patches (NP)* is a simple measurement of the landscape composition determines the degree of heterogeneity or fragmentation of that landscape.

$$NP = n_i \quad (1)$$

ni=number of patches in the class type i. The more the number of patches, the more fragmented the class is (McGarigal, 2015).

- *Class area (CA)* is a measure of landscape composition; specifically, how much of the landscape is comprised of a particular class type. It was calculated as follows:

$$CA = \sum_j^n aij \left(\frac{1}{10,000}\right) \quad (2)$$

a_{ij}=area (m^2) of a patch *j* in the class *i*.

- *PLAND*, is a measure of landscape composition and is calculated as follows:

$$PLAND\,(\%) = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A} \quad (3)$$

PLAND=*Pi*=proportion of the landscape occupied by LULC class type *i* (0<PLAND≤ 100); n=number of patches; a_{ij}=area of patch *j* in class *i* (m^2); and *A*=total landscape area (m^2).

LULC change detection was performed through transition matrix, a cross-tabulation which describes the change status among LULC classes from a time T_0 to T_1 (Schlaepfer, 2002). The transformations in a given class are either against or in favor of another. On the diagonal are the proportions of classes that remained stable during the considered period. The resulting tabulations displayed quantitative data for the overall LULC change (from 1986 to 2014) and the intermediary changes (from 1986 to 2001; and from 2001 to 2014).

3. Results

Landuse/landcover mapping

Six (6) LULC classes were identified through mixed classification (Figure 2). These are “cultivated land under shrubs and trees”, “cultivated land under trees”, “continuous cropland”, “fallow/pasture land”, “settlement”, and “forest reserve”. The proportions of classes varied between the considered years (Figure 3). The overall accuracy and Kappa index (Table 2) indicates a very good to an excellent classification according to Landis and Koch (1977).

Spatio temporal analysis of LULC Change from 1986 to 2014

The spatiotemporal analysis of LULC in 1986 reveals “cultivated land under trees” at 38.65% of the landscape total area to being the landscape matrix (Figure 3), while the class “forest reserve” at 0.81% has the smallest proportion in the landscape. From

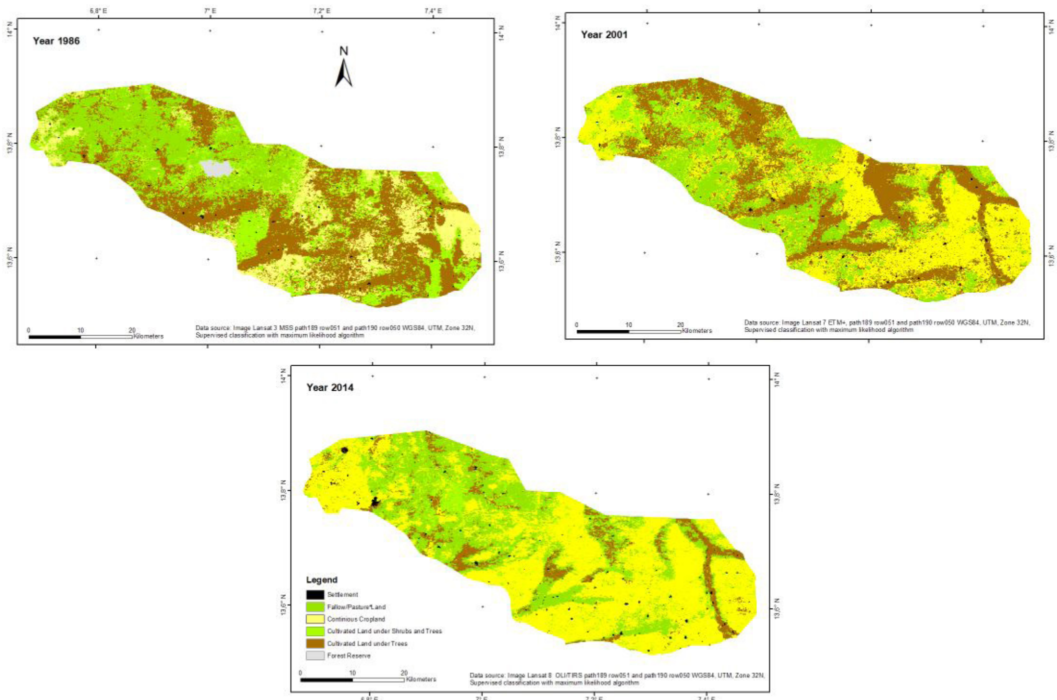

Fig. 2. Chadakori and Saé-saboua landscapes changes from 1986 to 2014

Table 2. Images classification accuracy

	1986	2001	2014
Kappa index (%)	90.49	91.53	91.43
Overall accuracy (%)	89.43	93.41	93.18

1986 to 2001 (intermediate period T_1) “cultivated land under trees” and “fallow/pasture land” classes have decreased to the gain of “continuous cropland” class mainly (Table 3) which became the landscape matrix (36.17% of the total area). A slight increase was observed in “cultivated land under shrubs and trees” class whereas the class “forest reserve” has completely disappeared in the landscape (Figure 3). In the intermediate period T2 (2001 – 2014) the same tendency of reduction was observed in all the LULC classes except “continuous cropland” class representing the landscape matrix at 2014 (53.33%), “settlement” class (0.63%) and “cultivated land under shrubs and trees” class which increased by about 7% (Figure 3).

The transition matrix (Table 3) reveals that change of LULC class area, from 1986 to 2014, is characterized by regressive and/or progressive trends according to the classes and considered intermediate periods (1986-2001; 2001-2014). Indeed, “cultivated land under trees”, “forest reserve” and “fallow/pasture land” classes’ area present a continuous regressive trend, with

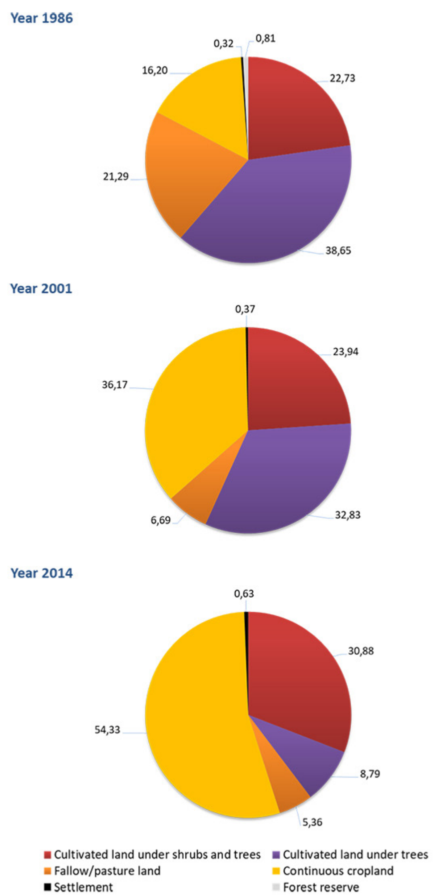

Fig. 3. Variations of Landuse/Landcover (LULC) classes’ area proportion from 1986 to 2014

Table 3. Transition matrix from 1986 to 2014 (STL= Settlement, CCL= Continuous cropland, CLST= Cultivated land under shrubs and trees, F/PL= fallow/pasture land, CLT= Cultivated land under trees, FR= Forest Reserve)

2001 / **1986**	CCL	CLST	STL	F/PL	CLT	PF	Total
CCL	**14.01**	1.57	0.00	0.60	0.02	0.00	16.20
CLST	20.13	**0.34**	0.00	0.27	2.01	0.00	22.75
STL	0.00	0.00	**0.31**	0.00	0.01	0.00	0.32
F/PL	1.61	8.92	0.01	**5.68**	5.05	0.00	21.27
CLT	0.32	13.01	0.05	0.1	**25.17**	0.00	38.61
PF	0.1	0.1	0.00	0.04	0.57	**0.00**	0.81
Total	36.17	23.94	0.37	6.69	32.83	0.00	**100**
2014 / **2001**							
CCL	**31.12**	0.90	0.00	4.15	0.00	0.00	36.17
CLST	18.03	**5.70**	0.01	0.01	0.19	0.00	23.94
STL	0.00	0.00	**0.36**	0.00	0.01	0.00	0.37
F/PL	5.02	0.22	0.25	**1.20**	0.00	0.00	6.69
CLT	1.35	24.06	0.00	0.00	**7.42**	0.00	32.83
Total	55.33	30.88	0.63	5.36	8.78	0.00	**100**
2014 / **1986**							
CCL	**10.70**	5.08	0.00	0.42	0.00	0.00	16.20
CLST	19.03	**0.10**	0.01	0.60	3.01	0.00	22.75
STL	0.00	0.11	**0.12**	0.08	0.01	0.00	0.32
F/PL	0.03	11.86	0.00	**4.08**	5.32	0.00	21.29
CLT	24.08	13.52	0.50	0.08	**0.43**	0.00	38.61
PF	0.49	0.21	0.00	0.10	0.01	**0.00**	0.81
Total	54.33	30.88	0.63	5.36	8.78	0.00	**100**

a degree of regression for class "cultivated land under trees" higher during T_2 than T_1 , while it is more important in T_1 than T_2 for class "fallow/pasture land" (Table 3). As for the class "forest reserve", it has completely disappeared from the landscape in favor of classes related to crops. This loss of class area was mainly in favor of the "continuous cropland" and "cultivated land under shrubs and trees" classes. A continuous progressive trend during all the intermediate periods (T_1 and T_2) was observed in "continuous cropland", "cultivated land under shrubs and trees" and "settlement" classes to the detriment of the "fallow/pasture land" and "cultivated land under trees" classes in particular.

In each class some area proportion stay unchanged in terms of land use, from one intermediate period to another. These stable areas present increased proportions during the intermediate periods for "continuous cropland" and "cultivated land under shrubs and trees" classes, whereas they decreased significantly in "cultivated land under trees" and "fallow/pasture land" classes (Table 3).

Process of landscape change

To determine the landscape change-induced processes from 1986 to 2014, the decision tree proposed by Bogaert et al. (2004) was used. So, five major landscape transformations processes took place in the studied landscape. These transformations vary among classes and they differ from period to period. During the past 28 years (from 1986 to 2014), patches aggregation ($n_{2001}<n_{1986}$ and $a_{2001}> a_{1986}$) in T_1 and patches creation ($n_{2014}>n_{2001}$ and $a_{2014}>a_{2001}$) in T_2 are the main change processes in "cultivated land under shrubs and trees" class (Figure 4A). Likewise, there was a patches suppression in cultivated land under trees class aches in the landscape throughout the 28 years ($n_{2001}<n_{1986}$ and $a_{2001}<a_{1986}$; $n_{2014}< n_{2001}$ and $a_{2014}< a_{2001}$) (Figures 4B). The main processes influencing changes in "continuous cropland" class are patches creation ($a_{2001}>a_{1986}$ and $a_{2014}> a_{2001}$) during T_1 and patches aggregation ($n_{2014}<n_{2001}$ and $a_{2014}>a_{2001}$) during T_2 (Figure 4C). In "settlement" class, there was a creation of patches all through the period T and the existing patches increased in size ($a_{1986}<a_{2001}<a_{2014}$) (Figure 4D). Patches fragmentation process which dominated "fallow/pasture land" class during the T_1, is replaced by patches suppression process during T_2 (Figure 4E).

4. Discussion

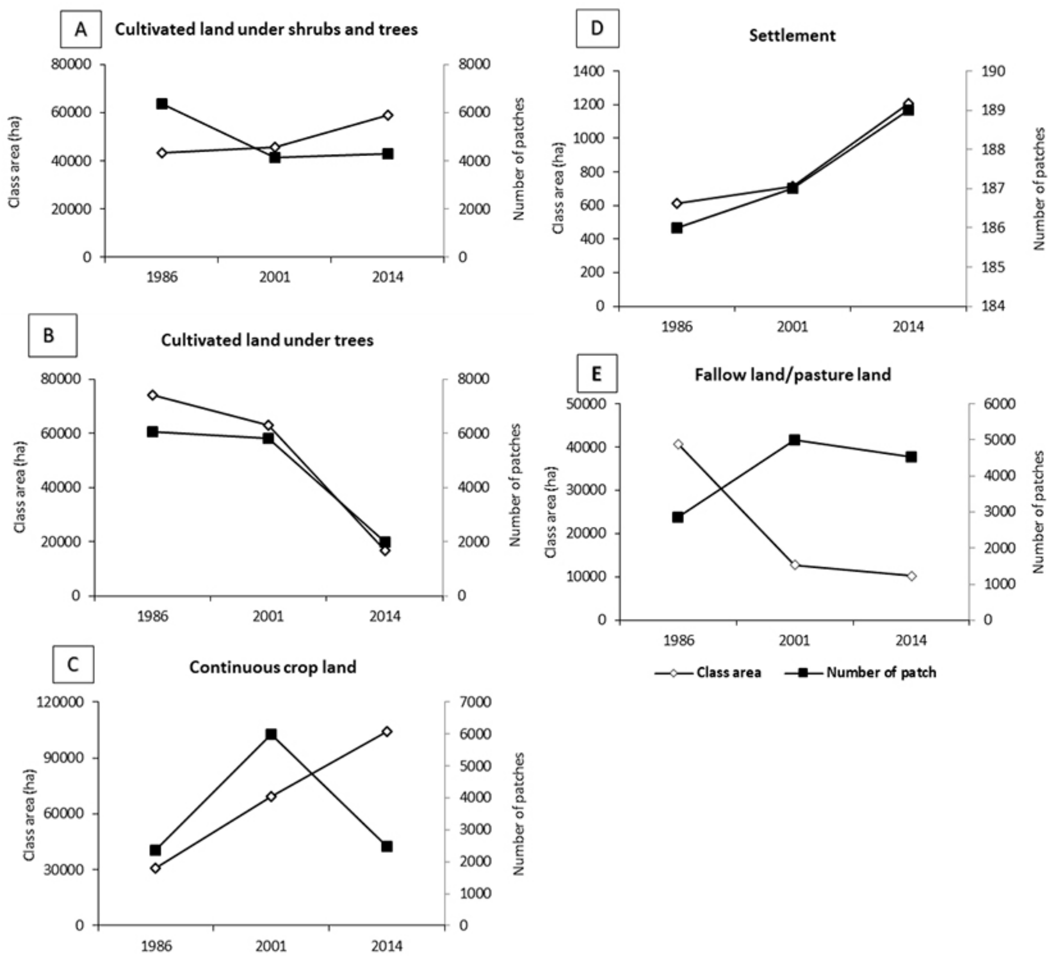

Fig. 4. Change of number of patches and class area from 1986 to 2014

The Kappa values above 90% obtained during the study showed that the mixed classification method is reliable and statistically acceptable (Landis and Koch, 1977). The lower resolution of the Landsat MSS sensor relative to that of ETM+ and OLI/TIRS sensors impacted on kappa and overall accuracy values recorded for the 1986 map. This is a challenge faced in the classification of MSS sensor due to their low spatial resolution (Barima, 2007; Leroux, 2012; Abdourahamane et al., 2015). It is also important to note that the three data is quiet few to evaluate the process of 28 years. However it allows to see a broad view of the change.

One of the key striking changes in the landscape from 1986 to 2014 is the suppression of the "forest reserve" class. The conversion of this forest, the so-called Kourounkoussa, to agricultural land was as the result of policy change. The conversion of "cultivated land under trees" to "cultivated land under shrubs and trees" can be explained by the cutting down of trees by farmers to use as fuel, to clear the farms and by pastoralist herders to feed their animals. Because most of the trees in the area have good potential to regenerate, after some time new shoots start to germinate and grow to shrubs. Likewise, the conversion of Kourounkoussa forest reserve to agricultural land was as a result of policy change. That forest was preserved since 1953 with an initial area of 2,300 hectares but due to the increase in population size and an insufficiency of land, it became devastated. The population began hunting from the forest to cultivate their crops because of the reduction in their crop production amplified by the drought of 1970-1980s (Lawali and Yamba, 2012). This has caused a great reduction in the forest area. In 1986 only 1560 hectares remained. The government saw the need for land was becoming higher, compelling them to change policy. The forest was therefore allocated to farmers.

The conversion of "continuous cropland" towards "cultivated land under shrubs" was also observed by Ibrahim (2007), Abdou (2007), Boubé (2008) in Maradi region. This could be explained by the implementation of the policy of Assisted Natural Regeneration (ANR) since 1983 (Rinaudo, 2010) by the national authorities as a new strategy with a view to reversing the effect of drought in the second part of 20th century and anthropogenic actions (Hountondji, 2008; Ibro and Assoumane, 2009).

Consequently, the practice of Assisted Natural Regeneration (ANR) was developed through the support of several development projects including PDRM (Rural Development Project in Maradi) and PASADEM (Project for Food Security Support and Development in Maradi Region). However, in Saé-saboua and Chadakori communes, the practice of ANR is not fully developed, compared to other areas in Niger republic (Ibrahim, 2007).

The decrease in the class "cultivated land under trees" could be as the result of the cutting down of trees by the population for energy use and for the cultivation of some crops like tiger nuts which couldn't produce well under shadow. The extension of settlement may be explained by the increase in the population rate in Chadakori and Saé Saboua.

The decision tree proposed by Bogaert et al., (2004) and used in this study to identify transformation processes presents certainly many advantages, but it causes some significant questions all the same. Indeed, this tree uses the area, the perimeter and the number of patches as input data. The satellite images are raster data and the smallest element is represented by a pixel of square form. This smaller element is thus represented by a surface of 900 m^2. But for another type of image (Spot for example), the smallest surface will be different from 900m2. It should be noted also that this decision tree does not take into account certain parameters of space, such as the average size of the patch, the interior of the patch and the connectivity of the patch (Barima, 2007). But the fact that these characteristics are directly related to the process of fragmentation and that they are also less significant for the other processes of landscape change could explain the fact that these parameters are not be taken into account (Barima et al., 2009). Finally, another limit of this decision tree is the subjectivity of the value of t which makes it possible to make the distinction between the dissection and fragmentation. Indeed, no indication is given on this value. tobs can thus take values according to appreciations of the operator (Sadda et al., 2016).

5. Conclusion

Remote sensing and landscape metrics are good and reliable tools for understanding the spatial and temporal changes of semi-arid landscape. This study allowed us to characterize the spatiotemporal dynamics of the landscape of Chadakori and Saé Saboua which revealed it to be dynamic over the study period. These changes were in part as the result of human activities. Throughout their history, human societies have coevolved with their environment through change, instability, and mutual adaptation. The coupled human-environment systems should, therefore, be considered as a whole when we assess sustainability and vulnerability. The findings of this study represent a valuable tool for natural resource managers, in that it may be the basis for understanding the dynamics of Chadakori and Saé Saboua for a sound decision-making process.

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