Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 11, No. 5, p. 74-91, 2017
http://www.innspub.net

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RESEARCH PAPER

Inducement of sustainable management planning of Mozogo-Gokoro National Park (Cameroon) by images processing

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Article published on November 08, 2017

Key words: Vegetation, Diachronic study, Controls tracks

Abstract

In accordance with the implementation of forest management sustainability of protected areas, this work is based on detection of changes in the vegetation of the Mozogo-Gokoro National Park, located in ecologically fragile semiarid region of the Far North of Cameroon, as well as a search for explanatory mechanisms. A processing of Landsat images of years 1982, 1987, 2001 and 2015 have been done and then put in combination with demographic and rainfall data. Three large vegetable mosaics classes are distinguished over the years. The analysis of their spatiotemporal evolution translated a decrease in area of galleries forests in favor of dense to clear dry forests or more open vegetation, with an annual reduction rate of -0.33 % between 1982 and 2015. The vegetation indices (Normalized Difference Vegetation Index and Generalized Difference Vegetation Index) have a decreasing trend between 1982 and 2001 and an increase between 2001 and 2015, proof of a reforestation. A few significant differences of their values are observed between years showing certain stability of the vegetation, but not in account statistically with rainfall and population density. There is a worry about the 1.73 % per year expansion speed in surface of more open vegetation. Therefore, control actions are envisaged to limit this extension of savannah, most likely related to human impacts.

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Introduction

The nonstop anthropisation and climate variability affecting dry land ecosystems are often detrimental to the vitality and development of their populations. Changes in natural ecosystems are generally harmful to human societies that live there, because of the fragility of these environments. Poccard-Leclercq and Xue (2004) particularly assert the sensitivity of these dry areas to any environmental changes, related to climate variability and anthropogenic pressures. The deterioration of vegetation is here due to population growth (Potapov *et al.*, 2012; Mayaux *et al.*, 2013) to urbanization and climate change (Gonzalez *et al.*, 2012).

Rapid population growth, which increases the land requirements and spontaneous urbanization, are identified as one of the major ecological scourges that the Earth faces (Rossi, 1999). Despite varying socio-cultural influences between human societies over time, deforestation is generally seen in close correlation with the contacting forests population growth. It is recognized that the increase or decrease in population density in a given area is closely correlated with the evolution of vegetation (Megevand, 2013).

Climate variability, defined as natural intra and inter-annual variation of climate (Al Hamndou and Requier-Desjardins, 2008), has a great influence in the dynamics of vegetation in dry areas. Rainfall is a climate factor, representing an indicator adapted to local studies in these areas. It is established that in semi-arid and arid environments, the vegetation is especially sensitive to rainfall variations (Diello *et al.*, 2005; Philippon *et al.*, 2008). The scarcity of rainfall, variability in its distribution and its unpredictability, are climatic constraints, which increase in the Sudanian and Sahelian areas, and are determining factors controlling ecosystem and vegetation change (Ozer *et al.*, 2010).

These disturbance factors of ecosystem stability are taken into account in Cameroon, in the strategic environmental and forest policies, with the wake of incentive international initiatives (Republic of Cameroon, 2015). There can be cited as examples the National Plan for Adaptation to Climate Change, the National Action Plan for the Fight against Desertification, and the National Action Plan on biodiversity (Republic of Cameroon, 2012). These planning documents stress that in the Sudanian and Sahelian northern part of the country, where the study site, the Mozogo-Gokoro National Park (MGNP) is located, such factors like wood energy consumption and overgrazing are major direct causes of deforestation and degradation of vegetation. These reports also call for more efficient management of protected areas considered as biodiversity hotspots. The sustainable conservation of vegetation and in this perspective the increase in the carbon sequestered are related to the international mechanism REDD+ (Reducing Emissions due to Deforestation and forest Degradation, sustainable forest management and forest conservation). This article is undertaken in accordance with the various national sectorial strategies conducive to sustainable forestry management in Cameroon. The detection of changes in vegetation can be considered as important criteria of alarm, to trigger adaptation and/or mitigation strategies, or control of this vegetable dynamics. Remote sensing is one of the right tools for the global direct monitoring of degradation of vegetation or apprehension of changes in plant cover (Aman *et al.*, 2001; Xue and Su, 2017) and implementation of sustainable development (Franklin, 2001).

Spatiotemporal dynamics studies of vegetation using remote sensing are numerous in the Sudanian and Sahelian zones in Africa like those of Diallo *et al.* (2011), Maârouhi *et al.* (2011) and in the same area in Cameroon (Yengué, 2000; Wafo, 2008). But, studies of interactions between vegetation and environmental factors has been relatively low (Karlson and Ostwald, 2015).

The aims of this paper are firstly, a description and a projection into the future of spatial and spectral evolution of the vegetation of MGNP; secondly, a seeking of explicative mechanisms in such way to assess links with population density and rainfall, two factors likely to be involved in vegetation dynamics;

thirdly, finish with some proposals measures for a sustainable management of the park.

Material and methods

Study site

The study site was created as a protected area since 1932 and built in a national park in 1968.

It is located in the far North region of Cameroon, 10° 56' to 10° 96' North latitude and 13° 54' 13° 58' East longitude, and covers an area of 1,400 ha with lack of a buffer zone (Figure 1).

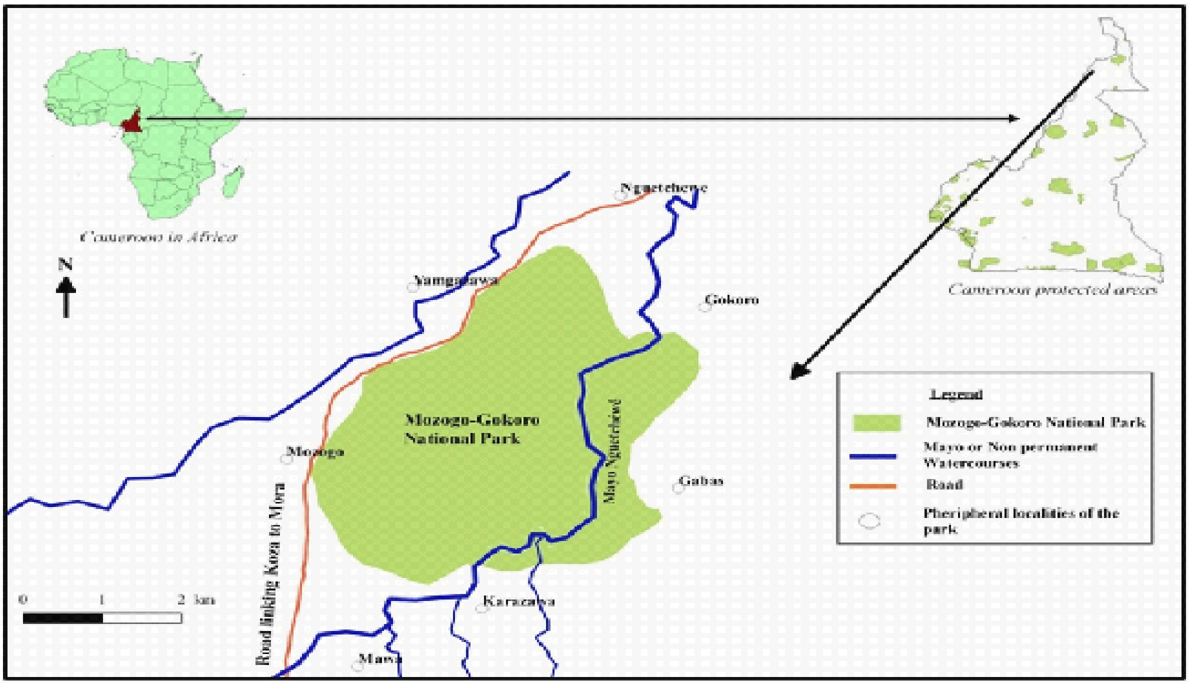

Fig. 1. Location of Mozogo-Gokoro National Park with peripheral localities.

This park is peripheral to the Mandara Mountains, and belongs to a geomorphologic unit comprising the plains of Diamaré, Mora and Kaélé, with an altitude of around 450 m (Sandjong Sani *et al.*, 2013a). Advanced soils such as gleyic solonetz and planosols on anatexie granite and gneiss, poorly developed soils dewatered from ancient alluvial of temporary water courses (Mayo) and flooded soils of clay settling plain (vertisols waterlogged) can be found in the study zone (Brabant and Gavaud, 1985).

The climate is a sudano-sahelian type, with oscillating annual rainfall between 800 to 1000 mm, and average temperatures from 27 to 28° C (Sandjong Sani *et al.*, 2013b). The analysis of the Standardized Precipitation Index (SPI) from known criteria (World Meteorological Organization, 2012), suggests an interannual variability of rainfall in the study area, with observation of majority years of slight dryness and mild humidity from 1982 to 2015 (Table 1 and Figure 2).

A large period of drought is observed, from 1982 to 1990. It is consistent with the rainfall data obtained in the Sahelian and Sudanian regions. Indeed, the space of time (1970-1990), is deemed as being marked by a long episode of drought in these environments (Ozer *et al.*, 2010; Diallo *et al.*, 2011).

The vegetation consists mainly of a mosaic of dense dry forests, gallery forests and shrub thickets. A birdlife, reptiles and some mammals have been identified in the park. The MGNP shows several indications of a reference ecosystem in the Sudano-Sahelian zone (Sandjong Sani *et al.*, 2013a). However, it suffers from significant anthropogenic threats (Sandjong Sani *et al.*, 2013b).

The largely agricultural local population is quite dense and exponentially growing (Figure 3). There is obviously a very important human pressure in the riparian zone of MGNP, likely to impact on the park vegetation. A very large land pressure may also be exercised on the outskirts of the park, especially with the lack of a buffer zone.

Methods

Determination of diachronic vegetation covering and explicative elements

Selection and acquisition of satellite images

The space of time selected for image acquisition is the dry season, on January and February especially. Jensen (1983) recommends that period, in studies to detect observable change in vegetation. He argues that pictures acquired during sunny periods for the detection of change in land covering, have a high contrast and reduce problems related to differences in sun angles, the dissimilarities in soil moisture and vegetation phenological changes. During this time too, the vegetation cover and chlorophyll activity is still discernible, and the presence of naked spaces also distinguishable, with the advantage of a reduction in cloudiness, one of the factoring that could affect the picture quality.

The inter-annual variation of rainfall, by exerting a great impact on the vegetation (Diallo *et al.*, 2011), constitutes another criterion that has allowed the choice of pictures. Selected pictures cover all the major periods observed in rainfall variability. The spatial resolution, another indicator for the selection of image data, must be quite high. The downloaded images, come from different sensors: MSS (Multi Spectral Scanner), TM (Thematic Mapper), ETM + (Enhance Thematic Mapper) OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor) Landsat (Table 2). These sensors are recognized having resolutions, considered as acceptable and workable scale of observation, in the study area.

They-have-been used by several authors (Hountondji, 2008; Wafo, 2008; Maârouhi *et al.*, 2011) for almost identical work.

Spectral and spatial analyzes of vegetation

The spectral information, to distinguish different forest types, is based on their structure and state of degradation (DeFries *et al.*, 2007; Barima, 2010). To obtain reliable results, a set of operations is required in the processing of our images. Software such as ENVI 5.1, ERDAS 2014 and QGIS 2.14 have been helpful in this process, and XLSTAT 2017 used for statistical analyzes.

After appropriate pretreatment (images enhancement by atmospheric correction, image by image registration, identification of the best multi-channel spectral combination), detection of spatiotemporal land occupation changes took place at the end of supervised classifications with maximum likelihood, because of the enough mastery of ground realities. In carrying out any combinations of land use elements, supervised classifications allow reconciliations, as far as possible, to the realities on the ground in the sequence of years. It was therefore undertaken to maintain the various spectral classes over time, to facilitate the interpretation of the processed images, using a fairly common nomenclature from Yangambi conference. The assessment of changes is simply based on the analysis of extension, regression or stability of each spectral class.

Otherwise, processing images and extracting spectral vegetation indices values were performed, including NDVI: Normalized Difference Vegetation Index, defined by Tucker (Tucker, 1979) and some GDVI ($GDVI^2$, $GDVI^3$ and $GDVI^4$): Generalized Difference Vegetation Index or Generalized Difference Vegetation Indices set by Wu (2014). This last author considers appropriate, the use of GDVI in dry areas, but with low sensitivity for very dense forest formations.

The NDVI formula is: $NDVI = (NIR - R) / (NIR + R)$, and the GDVI indices are calculated as follows: $GDVI^n = GDVI\hat{}n = (SR^n - 1) / (1 + SR^n) = (NIR^n - R) / (NIR^n + R)$, with $SR = NIR / R$, NIR: Near Infra Red, R: Red, n the whole number which may belong to the set (1, 2, 3, 4... n). When $n = 1$, $GDVI = NDVI$.

Extraction points of these indices are located at the main vegetation classes, previously identified in the classifications. These land components of the park correspond to three inventory field units, carried out in parallel work, including geographical points of plot location; then 30, 35 and 40 extraction points respectively for the inventory unit, the smallest to the largest. To limit the differences between images, and significantly reduce all forms of disruption, indices values were standardized from 0 to 1 for each year of extraction, according to the formula:

$S = \frac{x-xmin}{xmax-xmin}$, where S is the standardized index

value, x the real value of the index and xmax and xmin respectively the maximum and minimum index values obtained during a year of extraction. In each identified vegetation class, the averages of each group of index values obtained are then compared both in function of years and the type of indices by the Conover and Iman method associated with the Kruskal-Wallis test.

Distinction of explanatory mechanisms

The explanatory mechanisms land covering mutations are distinguished by correlating vegetation indices values to interannual data of rainfall and population density, using canonical analysis of correlations. This is a factor analysis approach, always necessary for the understanding of ecological phenomena (Ramade, 2009). Vegetation indices values for the intermediate years are calculated on the basis of the interannual evolution rates. Rainfall data, only available climate information in the field is obtained from SODECOTON stations (Cotton Development Company in Cameroon), closest to our study site (primarily in Mozogo in the West, and in case of deficiency, Guetale near the town of Koza in the south and Nguetchewe in the north of the park). Population densities are estimated in different years, assuming that trends are discernible from the regression line on their variation during the three main population censuses in Cameroon: 1976, 1987 2005 (Republic of Cameroun, 2005).

Prospective analyses and foundation for sustainable management orientation

A predictive analysis is performed, based on average annual rates of spatial expansion of the different classes or the measuring of the growth of land use units in a given period. By choosing as variable the area of each land use class, the following formulas (Bernier, 1992; Oloukoi *et al.*, 2006) were applied to obtain this data through the years. First, the rate of annual average spatial expansion (T) is evaluated by:

$T = [\ln Sj - \ln Si / t \times \ln e] \times 100$;

where t is the number of years of evolution; Si and Sj the class areas respectively for an old year i and for a more recent year j; ln, the natural logarithm; lne, the natural logarithm of e base = 1; (e = 2.71828). Then, considering the hypothesis or maintaining and constancy of factors behind changes (anthropogenic and climatic pressures), calculating theoretical values of different projection surfaces (Sp) in time (2020, 2025, 2030 and 2035 horizon) is based on the formula:

$Sp = e^{[T \times t \times \ln e / 100 + \ln Si]}$

where Sp is the projection surface, t is the number of projection years; T the average annual rate of spatial expansion; Si the calculated area during a given year later; lne, the natural logarithm of e base = 1; (e = 2.71828).

NDVI and GDVI extracted have been used too to develop simple correlations with certain values of diversity and structure derived from the parallel study of vegetation. High statistical significance thresholds allow predictions. With the exploitation of our results (including threats to the stability of vegetation) and literature, some measures to be applied are proposed, for a spatial dynamic control of vegetation of the park favorable for its sustainable management.

Results

Land occupation units in dynamic evolution

Spatial changes are observable by remote sensing between 1982 and 2015 (Figures 4 and 6). The situation of the occupation of space in the park shows

5 land cover classes, including three vegetable classes: mosaic of gallery forests, dense dry forests and shrub thickets (class 1), mosaic dense to clear dry forest and shrub thickets (class 2), mosaic clear dry forest, wooded savanna and shrub thickets (class 3), Mayo Nguetchewe bed, pools or significantly sandy surfaces (class 4), bare soil, few vegetated areas or fields of crops (class 5).

They are illustrated by figure 5. The weakest kappa coefficient is 0.71 in 1982, and the other values ≥ 0.95.

Table 1. Distribution of Standardized Precipitation Index (SPI) values classes in the riparian zone of the park from 1982 to 2015.

SPI values from 1982 to 2015	Interpretation of SPI	Number of years	Percentage
SPI ≥ 2	Extreme humidity	0	0,00
1,5 ≤ SPI < 2	High humidity	1	2,94
1≤ SPI < 1,5	Moderate Humidity	4	11,76
0 ≤ SPI < 1	Light moisture	13	38,24
-1 < SPI ≤ 0	Mild drought	12	35,29
-1,5 < SPI ≤ -1	Moderate drought	3	8,82
-2 < SPI ≤ -1,5	Strong drought	0	0,00
SPI ≤-2	Extreme drought	1	2,94
	Total	34	100

Table 2. List of satellite images to process, their characteristics and corresponding sensors.

Satellites	Sensors	Path /Row	Acquisition date	Number of bands	Selected spatial resolutions
Landsat 3	MSS	199/52	February 25, 1982	4	60 m
Landsat 5	TM	185/52	January 31, 1987	7	30 m
Landsat 7	ETM+	185/52	January 13, 2001	8	30 m
Landsat 8	OLI and TIRS	185/52	January 12, 2015	11	30 m,

The evolution of vegetated areas over time is illustrated in Figure 6. It may be noted unstable variations, alternating decreases and increases in surfaces for Classes 1 and 2, and a slow increase for Class 3. This analysis is confirmed in table 3, with the annual and general rate of change each vegetation class with an interpretation of the trend.

Table 3. Annual rates of change of vegetation classes and interpretation.

Classes	Percentage of evolution in the class (annual rate of change)				T	Interpretation of change
	1982-1987	1987-2001	2001-2015	1982-2015	1982-2015	1982-2015
1	-15.98 (-2.66)	-11.61 (-0.77)	19.63 (1.31)	-11.16 (-0.33)	-0.35	Regressing
2	23.55 (3.93)	2.44 (0.16)	-11.30 (-0.75)	12.26 (0.36)	0.34	Increasing
3	22.06 (3.68)	-3.69 (-0.25)	53.10 (3.54)	79.98 (2.35)	1.73	Increasing

T = Annual growth rate (Bernier, 1992).

By reviewing the results of remote sensing showing the spatiotemporal evolution of the park vegetation, Class 3 (mosaic of clear dry forest, savanna woodlands and shrub thickets), is perceptible sparsely in 1982, and not in a precise area.

The park would not have been presented at the time, vegetation damage of great magnitude. However, it must also be said that the resolution of 60 m of the image processed, can justify the difficulty of perception.

Table 4. Comparison of the different years of index extraction for each vegetation class.

Extraction classes	Years	Vegetation indices			
		NDVI	GDVI^2	GDVI^3	GDVI^4
		$\mu \pm \sigma$	$\mu \pm \sigma$	$\mu \pm \sigma$	$\mu \pm \sigma$
Class 1	1982	$(0.65 \pm 0.22)^{a}$	$(0.65 \pm 0.23)^{a}$	$(0.65 \pm 0.23)^{ab}$	$(0.65 \pm 0.24)^{ab}$
	1987	$(0.49 \pm 0.20)^{b}$	$(0.53 \pm 0.2)^{bc}$	$(0.58 \pm 0.21)^{ab}$	$(0.64 \pm 0.21)^{ab}$
	2001	$(0.29 \pm 0.15)^{c}$	$(0.44 \pm 0.16)^{c}$	$(0.54 \pm 0.18)^{b}$	$(0.60 \pm 0.20)^{b}$
	2015	$(0.62 \pm 0.15)^{a}$	$(0.64 \pm 0.15)^{ab}$	$(0.68 \pm 0.14)^{a}$	$(0.73 \pm 0.13)^{a}$
Class 2	1982	$(0.53 \pm 0.21)^{a}$	$(0.53 \pm 0.22)^{a}$	$(0.53 \pm 0.22)^{a}$	$(0.53 \pm 0.23)^{a}$
	1987	$(0.26 \pm 0.15)^{b}$	$(0.29 \pm 0.16)^{b}$	$(0.33 \pm 0.18)^{b}$	$(0.38 \pm 0.19)^{b}$
	2001	$(0.11 \pm 0.05)^{c}$	$(0.16 \pm 0.08)^{bc}$	$(0.19 \pm 0.10)^{c}$	$(0.20 \pm 0.11)^{c}$
	2015	$(0.22 \pm 0.12)^{b}$	$(0.24 \pm 0.13)^{c}$	$(0.27 \pm 0.14)^{b}$	$(0.30 \pm 0.15)^{b}$
Class 3	1982	$(0.53 \pm 0.17)^{a}$	$(0.53 \pm 0.17)^{a}$	$(0.53 \pm 0.18)^{a}$	$(0.53 \pm 0.19)^{a}$
	1987	$(0.23 \pm 0.17)^{b}$	$(0.25 \pm 0.18)^{b}$	$(0.28 \pm 0.19)^{b}$	$(0.33 \pm 0.19)^{b}$
	2001	$(0.10 \pm 0.08)^{c}$	$(0.15 \pm 0.12)^{c}$	$(0.17 \pm 0.16)^{c}$	$(0.18 \pm 0.18)^{c}$
	2015	$(0.20 \pm 0.07)^{b}$	$(0.22 \pm 0.08)^{bc}$	$(0.25 \pm 0.08)^{bc}$	$(0.29 \pm 0.09)^{bc}$

(a, b, c): Set of letters indicating groups of years of extraction formed for each class of vegetation and type of index, using Conover and Iman method associated with the Kruskal-Wallis test; the presence of an identical letter indicates the similarity between years; μ = Average , σ = Standard deviation.

Table 5. Comparison of vegetation classes for each year of extraction and type of index.

Type of vegetation index and extraction classes		Years			
		1982	1987	2001	2015
		$\mu \pm \sigma$	$\mu \pm \sigma$	$\mu \pm \sigma$	$\mu \pm \sigma$
NDVI	Class 1	$(0.65 \pm 0.22)^{a}$	$(0.49 \pm 0.20)^{a}$	$0.29 \pm 0.15)^{a}$	$(0.62 \pm 0.15)^{a}$
	Class 2	$(0.53 \pm 0.21)^{b}$	$(0.26 \pm 0.15)^{b}$	$(0.11 \pm 0.05)^{b}$	$(0.22 \pm 0.12)^{b}$
	Class 3	$(0.53 \pm 0.17)^{ab}$	$(0.23 \pm 0.17)^{b}$	$(0.10 \pm 0.08)^{b}$	$(0.20 \pm 0.07)^{b}$
GDVI^2	Class 1	$(0.65 \pm 0.23)^{a}$	$(0.53 \pm 0.20)^{a}$	$(0.44 \pm 0.16)^{a}$	$(0.64 \pm 0.15)^{a}$
	Class 2	$(0.53 \pm 0.22)^{b}$	$(0.29 \pm 0.16)^{b}$	$(0.16 \pm 0.08)^{b}$	$(0.24 \pm 0.13)^{b}$
	Class 3	$(0.53 \pm 0.17)^{ab}$	$(0.25 \pm 0.18)^{b}$	$(0.15 \pm 0.12)^{b}$	$(0.22 \pm 0.08)^{b}$
GDVI^3	Class 1	$(0.65 \pm 0.23)^{a}$	$(0.58 \pm 0.21)^{a}$	$(0.54 \pm 0.18)^{a}$	$(0.68 \pm 0.14)^{a}$
	Class 2	$(0.53 \pm 0.22)^{b}$	$(0.33 \pm 0.18)^{b}$	$(0.19 \pm 0.10)^{b}$	$(0.27 \pm 0.14)^{b}$
	Class 3	$(0.53 \pm 0.18)^{ab}$	$(0.28 \pm 0.19)^{b}$	$(0.17 \pm 0.16)^{b}$	$(0.25 \pm 0.08)^{b}$
GDVI^4	Class 1	$(0.65 \pm 0.24)^{a}$	$(0.64 \pm 0.21)^{a}$	$(0.60 \pm 0.20)^{a}$	$(0.73 \pm 0.13)^{a}$
	Class 2	$(0.53 \pm 0.23)^{b}$	$(0.38 \pm 0.19)^{b}$	$(0.20 \pm 0.11)^{b}$	$(0.30 \pm 0.15)^{b}$
	Class 3	$(0.53 \pm 0.19)^{ab}$	$(0.33 \pm 0.19)^{b}$	$(0.18 \pm 0.18)^{b}$	$(0.29 \pm 0.09)^{b}$

(a, b): Set of letters indicating groups of vegetation classes formed for each index and year of extraction, using Conover and Iman method associated with the Kruskal-Wallis test; the presence of an identical letter indicates the similarity between classes; μ = average , σ = standard deviation.

In 1987, 2001 and 2015, all classes are well observed, with variations of areas discernible. More open vegetations are observed these years, certainly because of an increase of degradation phenomenon. Detected changes in vegetation cover show a gradual evolution of classes 2 and 3, to the detriment of the class 1.

Conservation trend of vegetation showing by diachronic assessment of some vegetation indices

In comparing the standardized average values of vegetation indices, NDVI and GDVI, in the succession of different years of extraction (Table 4), there emerges a fluctuating variation, but sometimes close statistically, indicating some stability in the vegetation. In different vegetation classes, several index values observed can be combined in the same statistical group, regardless of the time factor.

Table 6. Evolution of the main vegetation classes area in future (horizon 2020, 2025, 2030 and 2035).

Vegetation Classes	Si 2015 in ha (%)	Annual growth rate in %	Projection surfaces in ha (Percentages)			
			2020	2025	2030	2035
Class 1	611.87 (38.24)	-0.35	601.32 (37.58)	590.94 (36.93)	580.75 (36.30)	570.73 (35.67)
Class 2	799.01 (49.94)	0.34	812.72 (50.79)	826.66 (51.67)	840.84 (52.55)	855.27 (53.45)
Class 3	97.79 (6.11)	1.73	106.62 (6.66)	116.25 (7.27)	126.74 (7.92)	138.18 (8.64)

However, there is a strong discrimination between Class 1 in one hand and classes 2 and 3 on the other hand, from the year 1987 (Table 5). The little confusion from the similarities of the year 1982 can translate the original homogeneity of vegetation, or detection difficulties related to the resolution of the image. The standard deviations are sometimes high, show a high variance, certainly linked to the presence of some gap spaces in vegetation.

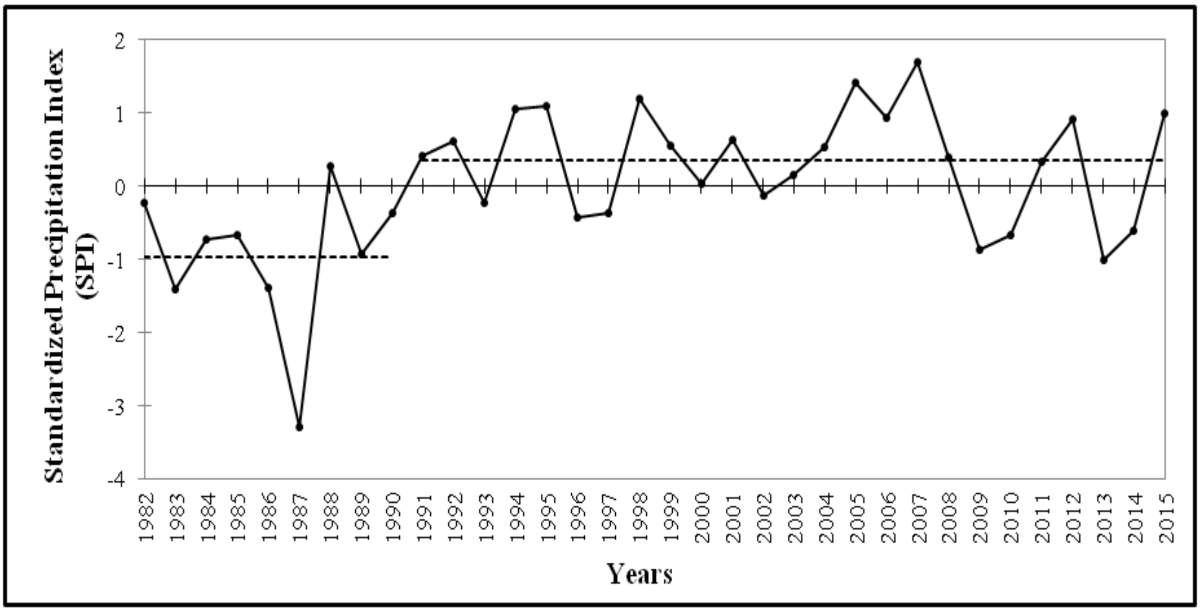

Fig. 2. Variation of standardized precipitation index (SPI) over the years at MGNP.

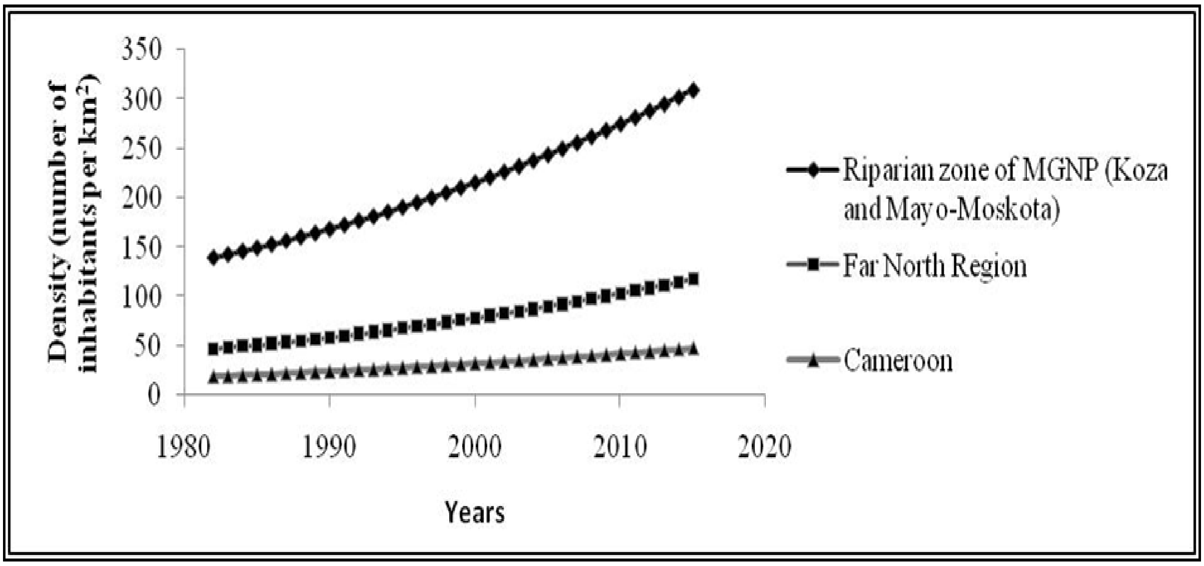

Fig. 3. Population Density from 1982 to 2015 (Source of data: Republic of Cameroun, 2005).

The representations in the form of curves of the evolution of vegetation indices (Figures 7 and 8) over time in the different vegetation classes help to detect, the slight difference between the classes 2 and 3 (little more low values in class 3). It can be noted overall, in decrypting these graphics, the decrease of indices values over the years, but more significantly in classes 2 and 3. Two major phases are distinguished: firstly a more or less gradual decrease until 2001, and secondly a rise from 2001 to 2015.

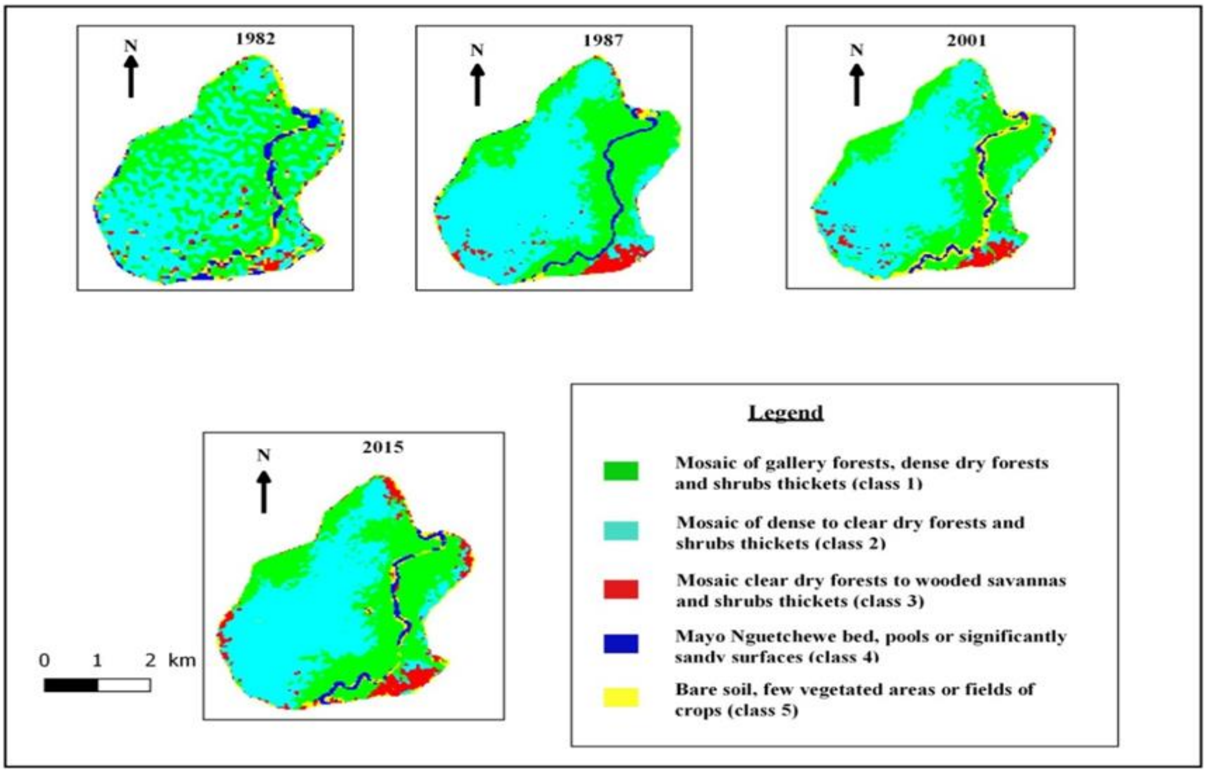

Fig. 4. Evolution of principal land covers and uses elements in the park from 1982 to 2015.

It must initially believe in climate impact, but also a degrading human action. Concerning the light vegetable revitalization in recent years, in addition to the favorable climate, an explanation could arise from the translation of a rise of protection measures, in line with a policy or effective sustainable management strategies. There would thus have reduced the degrading action of the local population during this period.

Difficult explanation of changes mechanisms

Vegetation indices values are not highly affected by rainfall variability, as well as population density (Figure 9). These factors, whose influence is demonstrated on vegetation, would not have a major impact, enough to cause significant changes to these values. However a small noticeable difference, in the correlated data, highlights a preponderance of influence of anthropogenic factors, through population density compared to the rainfall.

Prospective trends of vegetation classes surfaces

Different Calculated areas of the park vegetation classes have been projected into the future time (Table 6). Given this table of changing surfaces of these classes, it may be considered in 2035 horizon, an increase in the area of Class 3 particularly characterized by more open vegetation, from 6.11 % to 8.11 % of the park surface, an increase of class 2 area from 49.95 % to 53.45 % and a reduction of class 1 area from 38.24 % to 35.67 %. So, if a sustainable and efficient management of the park is not assured, it is a possibility of increasing the spatial extent of dense to clear dry forests, and wooded grassland at the expense of gallery forests. The maintenance of existing constraints (climatic and anthropogenic pressures) could generate such changes.

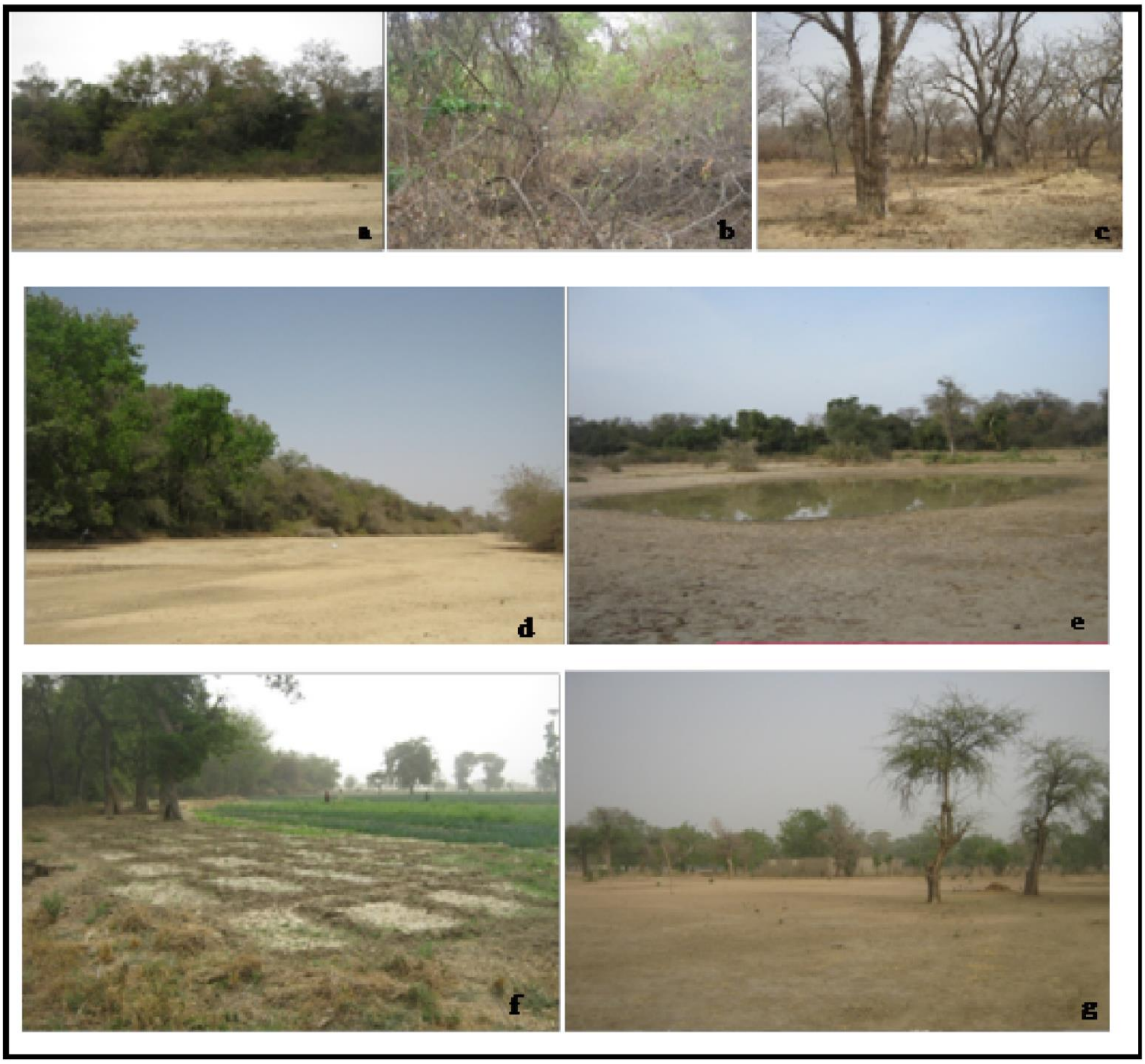

Fig. 5. Land occupation classes representative images: a) class 1, b) class 2, c) class 3 d) Class 4: Mayo Nguetchewe bed, e) Class 4: artificial pool, f) Class 5: Field of crops, g) Class 5: Low vegetation covered ground.

Tracks to control changes in Vegetation for a sustainable management

The spatial and temporal evolution of vegetation of MGNP generated patterns, allowing the realization of a blueprint of main actions for the sustainable management of the park (Figure 10). The major areas of intervention proposed also draw on the results of an ethno-ecologic survey conducted in the riparian zone of the MGNP in a parallel study. However, there is the evidence of a need for integration of biophysical field data from the study site to a more appropriate ecological monitoring, and an impulse coming at the state level in such process, in respect of national and international forest policy in force. The use of various techniques and tools, like the Geographical Information Systems, will be used for the enforcement.

Discussion

The results of the spatiotemporal evolution of the park vegetation show some significant changes between 1982 and 2015, which suggests a trend to savannisation and the reduction of more dense forest formations. It is generally related to the influence of anthropogenic and climatic factors (Andela *et al.*, 2013; Bamba *et al.*, 2015). Several works in this region of Cameroon and in the Sahelian and Sudanian zones in general, prove this growing evolution of deforestation, linked to the direct action of man.

Yengue (2000) highlights in the Far North region of Cameroon, areas of growth (34 %), of maintenance (35 %) and of decrease (31 %) of tree density. Wafo (2008) observe this phenomenon of anthropogenic degradation in several protected areas in the region. In MGNP, he nevertheless point out an improvement of forest zones between 1986 and 2001, period concerned by the extension of Class 2 in our study.

In addition, it is noted a few islands of progressive breakthrough of Class 1, especially between 2001 and 2015, confirming equally the trend observed by Wafo (2008) between 1986 and 2001. In a similar eco-geographical area in West Africa, in W National Park in Benin, studies show the regression of forest formations about 22.70 % to 17.00 % between 1972 and 2008 (Avakoudjo *et al.*, 2014).

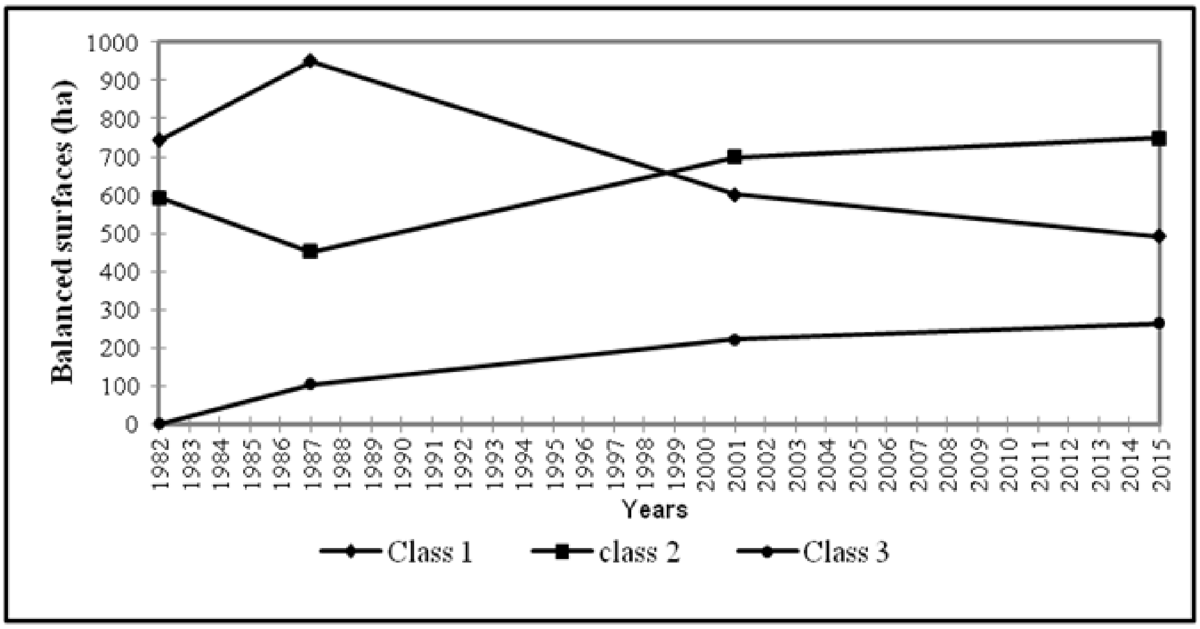

Fig. 6. Evolution of areas of vegetation classes in the park from 1982 to 2015.

Structural and compositional changes in vegetation typically explain the mutations observed by remote sensing (Benjaminsen, 1996). Misclassification, relating to the similarity of spectral responses, can disrupt the analysis and induce nonexistent transformations. These confusions are illustrated by most of the classified images. However, with kappa coefficients ranging from 0.71 in 1982, to values ≥ 0.95 for the other images, our classifications are valid, according to the criterion of Pontius (2000).

Moreover, there is a finding of inconstancy of vegetation indices values, certainly being the emanation of regular disturbances of vegetation structure and even the floristic composition. The GDVI (GDVI^2, GDVI^3 and GDVI^4), compared with NDVI, confirmed in our analysis, a slight rise in vegetable spectral information, in line with the characterization of these indices in dry areas by Wu (2014).

It is important to precise that the tests of some basic remote sensing vegetation indices, recalled by Lyon *et al.*, (1998), Wu (2014) and Xue and Su (2017), have not been satisfactory in the sense of improving spectral information. These indices include: Soil-Adjusted Vegetation Index (SAVI), Transformed Soil Adjusted Vegetation Index (TSAVI), Atmospherically Resistant Vegetation Index (ARVI), Soil Adjusted Atmospherically Resistant Vegetation Index (SARVI) and Enhanced Vegetation Index (EVI).

It must be point out nevertheless, the possibility of using others interesting vegetation indices in this geographical area. For instance, Mfondoum Ngandam *et al.* (2016) assess soil degradation in the far North region of Cameroon calculation of some spectral indices and their crossing with statistical neo-band.

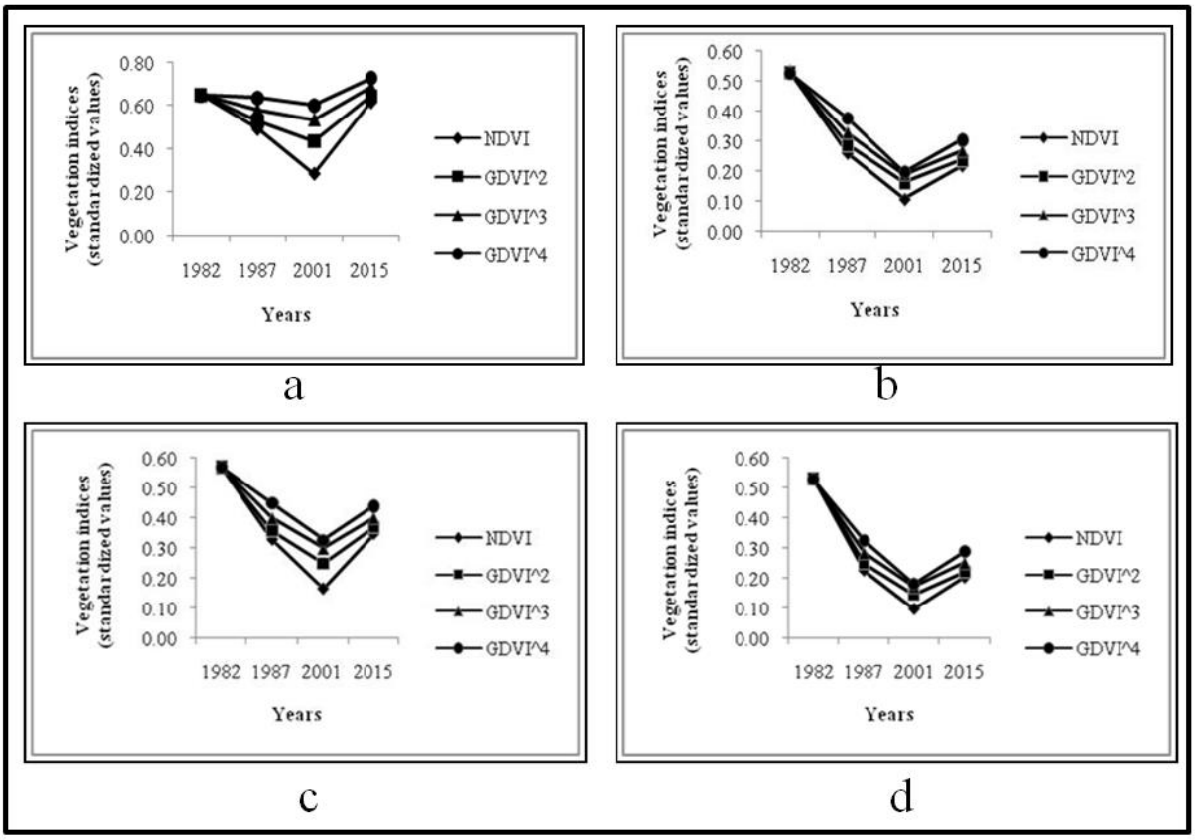

Fig. 7. Interannual evolution and distinction of vegetation indices: a) in Class 1; b) in Class 2; c) in Class 3; d) in the full vegetation.

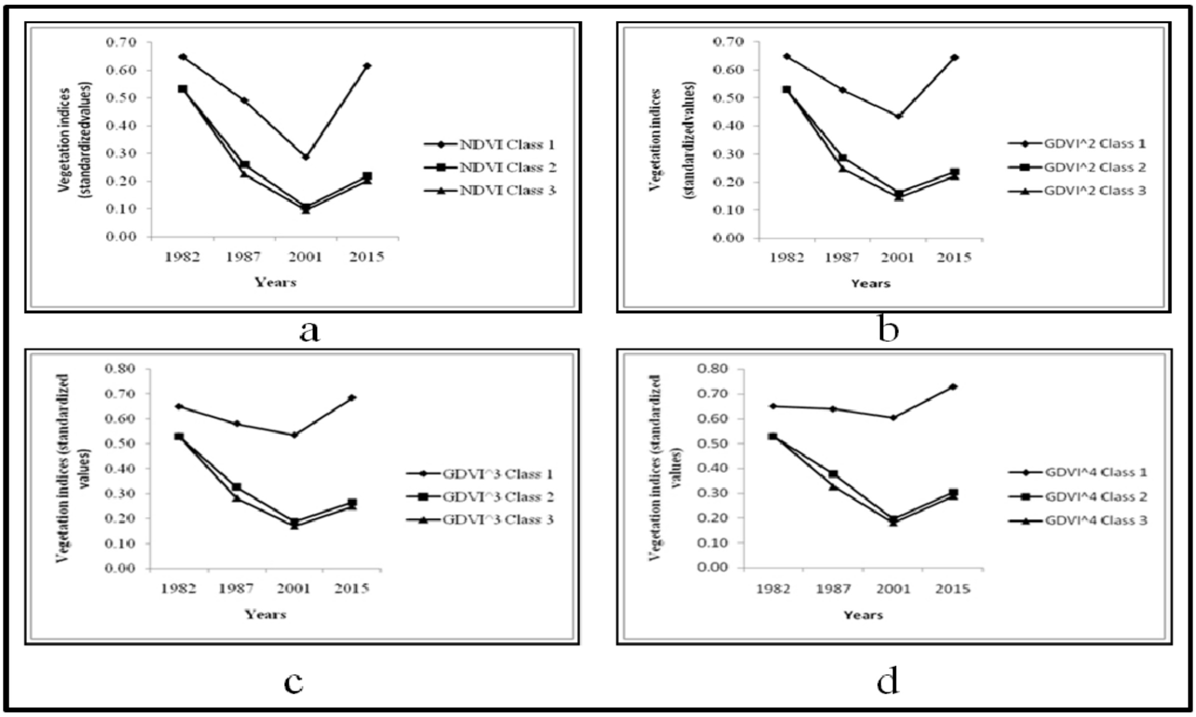

Fig. 8. Interannual evolution of vegetation indices values showing difference between vegetation classes: a) NDVI; b) $GDVI^2$; c) $GDVI^3$; d) $GDVI^4$.

The VOD index (Vegetation Optical Depth) or optical depth of vegetation, from satellites using microwave (radar), is proposed by Tian *et al.*, (2016), for an efficient estimation of plant biomass in the semi-arid Sahelian zone and even in other arid areas.

Andela *et al.*, (2013) assert that NDVI is most responsive to canopy cover and greenness, and also to herbaceous vegetation, while VOD is sensitive to aboveground biomass and woody vegetation.

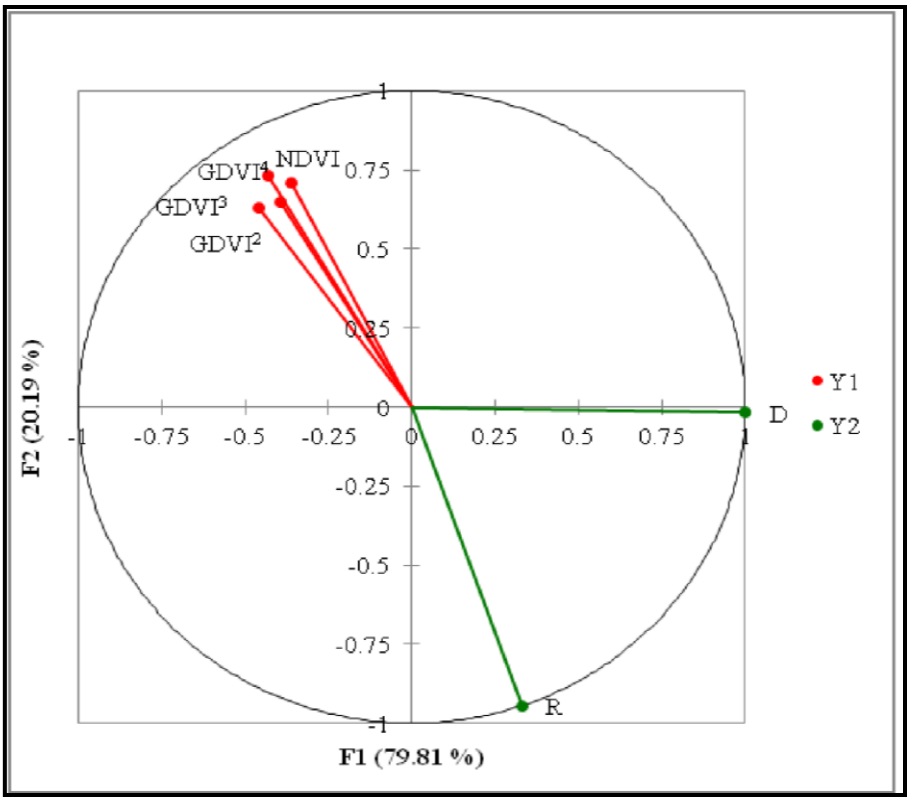

Fig. 9. Canonical correlation analysis to determine the influence of rainfall (R) and population density (D) on the NDVI and GDVI indices.

In short, the spatial and spectral changes in vegetation perceived by remote sensing between 1982 and 2015 are partly in agreement to peasant perception (Sandjong Sani *et al.*, 2013b), with a regressive trend of dense vegetation becoming more clear. About the factors explaining change in spectral evolution of vegetation, population density growth over time (likely to accentuate various unlawful levies in the park) appears to be more interrelated with vegetation indices. Specifically in MGNP, land pressure linked to high population growth, is characterized by the practice of agriculture up to the edge of vegetation, various resources harvesting (Sandjong Sani *et al.*, 2013b), constituting some risks of loss of the local natural environment balance.

To understand our results about weak correlations between vegetation indices and the two factors retained (population density and rainfall), Li (1991), Li *et al.* (2013) and Nocentini *et al.* (2017) raise the complexity and controversy around the issue of the impact of external forces on vegetation. Yengué (2000) argues that in the study area, the population increase is not necessarily related to the reduction of timber resources. Li (1991) deduces the intervention of other factors in the deforestation phenomenon, by analyzing in China, along with the increase in population, both an increase and a decrease in forest area between 1949 and 1988. Raven (1991) meanwhile stressed the negative impact of riparian human communities on forest resources and a major role of several external actors.

Along the same idea, Agrawal (1994) notes in addition to the demographic changes, other factors that could influence the use and management of forests at the local level such as the local management institutions; the socio-cultural context; the policies of the State; technological progress and changes in market pressures.

In addition, De Fries *et al.*, (2007) point out major difficulties of perception of anthropogenic degradation using standard optical remote sensing methods. They claim that this undetectable degrading human impact is related eventually to some small clearing of the canopy, gradual loss of biomass and spectral resolution problems (lack of visibility) mean ability to distinguish changes in the automated data processing. However, regarding intraannual or interannual rainfall, several authors showed very strong correlations with NDVI in semi-arid and arid tropical zones (Camberlin *et al.*, 2007; Philippon *et al.*, 2008; Diallo *et al.*, 2011; Andela *et al.*, 2013; Hameed and Bannari, 2016). The effects of drought on vegetation include the raising of mortality of woody species, the decreased of perennial grasses, the increased of plant diseases and wilting in relation to physiological stress and the emergence of drought-tolerant and shade-intolerant species; which lead all to profound changes in vegetation structure and biodiversity (Diallo *et al.*, 2011; Bamba *et al.*, 2015). It is proved in dryland that the VOD changes with longer-term precipitation variations (Andela *et al.*, 2013). A study including the effects of rainfall at intraannual scale, or the influence of many others environment factors specifically on vegetation (using many others remote sensing techniques and analysis), is recommend in our site, for a more comprehensive understanding of its dynamics.

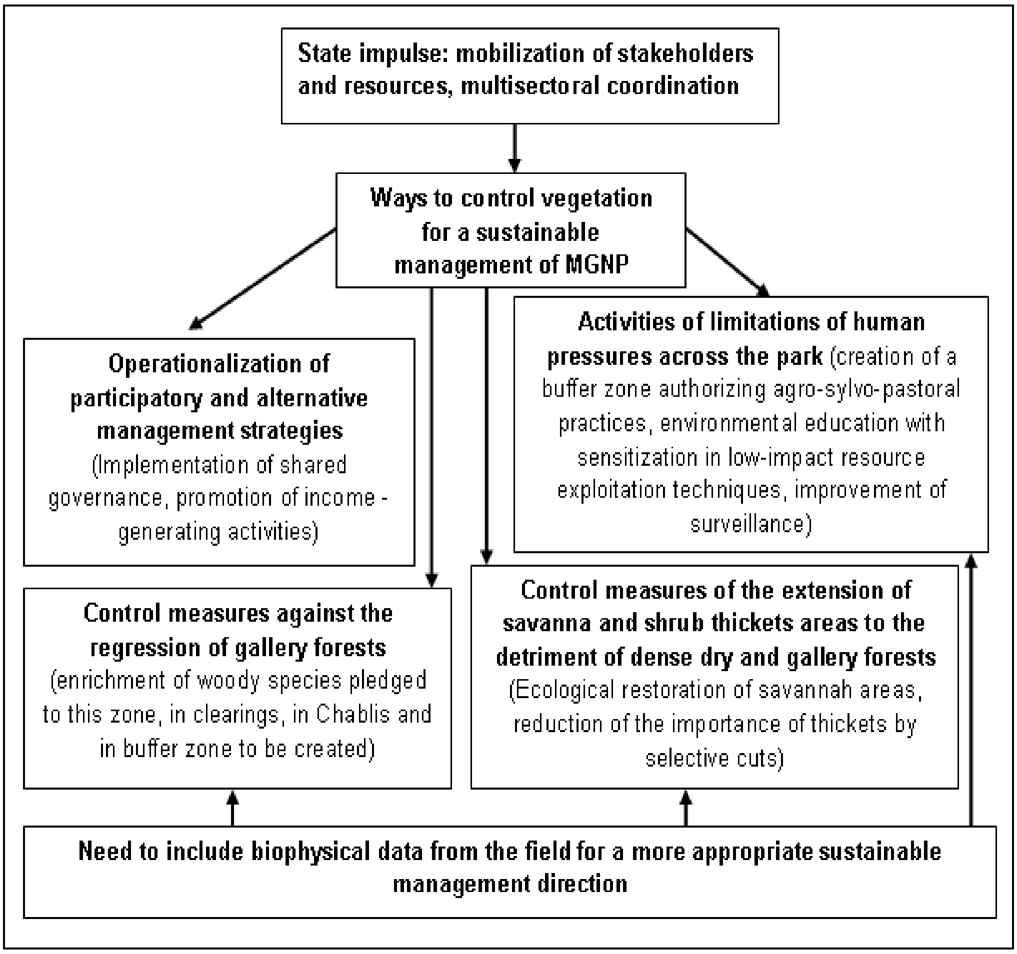

Fig. 10. Simplified diagram showing some proposals measures for sustainable management of MGNP issue from the study.

With the projection of an extent of spatial surfaces of dense to clear dry forests and wooded grassland at the expense of gallery forests, control tracks measures are proposed in this regard, in the direction of a sustainable management of the park. The assessment of the biophysical environment in the field is also found necessary in planning for effective management of protected areas (Hockings *et al.*, 2008). Several guidelines are stated in accordance with sustainable forest management concept (Foster *et al.*, 2010): best management practices /reduced impact logging, biodiversity conservation, forest protection, multi-scale planning, participatory forestry, and sustained forest production.

Conclusion

This study analyzes the diachronic evolution of vegetation in MGNP and brings out an explanation and control paths in the direction of sustainability management. Variations are seen in part of the Landsat images classifications (1982, 1987, 2001 and 2015) or extraction of vegetation indices such as NDVI and GDVI, discriminatively in the sense of savannisation, but also oscillating reforestation. Correlations between spectral values, with rainfall and demographics data participated in the argument of complexity of theses relationship. Although very few tangible results are obtained in these correlations (certainly the sign of good preservation of vegetation), rainfall and anthropogenic pressures remain problematic, particularly the increase in population density. Extending of more open vegetation provided is worrying and a planning of some control measures are proposed especially in this regard, for a sustainable management of the park. It will be more complete by considering field data.

Acknowledgments

We thank the International Foundation of Science for its financial support to the realization of this work.

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