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Impact of anthropization on the spatio-temporal dynamics of the forest landscapes of the Ngaoundéré cliff, Adamawa – Cameroon.

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Abstract

The anthropogenic impact on the temporal dynamics of the Ngaoundéré cliff landscapes was studied from the diachronic analysis of three Landsat-type satellite images (Landsat7 1976, Landstat 7 1996 and Landstat 8 2016) supplemented by field missions verification in the field. The results indicate that forest formations in 2016 cover 65.90% of the study area against 92.85% in 1976. This part of the Adamawa region whose landscape matrix was once dominated by savannas and forest galleries is today more and more degraded. The transition matrix showed a decline of 37.03% in wooded savannas, 7.52% in gallery forests and a slight trend in natural plant ecological succession. The farm-fallow class, which was lower in 1976, saw its proportion increase substantially by four in 2016. The bare soil-camp complex became the third land-use unit with 18.88% of the area of study. In both wooded savannahs and forest galleries, mean area and dominance values declined, confirming the fragmentation of the landscape. On the other hand, in dry forests, shrub savannahs, farm-fallow and bare-soil encampments, the creation of new tasks and their aggregation revealed a change in the spatial structure of this landscape.

Keywords: Landscape dynamics, land use, anthropogenic pressure, vegetation formation, Ngaoundéré.

Introduction

In the Adamawa region of Cameroon, increased anthropogenic pressure on natural resources has been observed, as well as overexploitation of the soil due to systematic deforestation along major highways and poor farming practices (Tchobsala *et al.*, 2010, Nyasiri, 2014). Increasing anthropogenic pressures on natural resources are leading to dysfunction of terrestrial ecosystems and loss of biodiversity (Roche, 1998). This translates into a dynamic of the spatial structure of landscapes. Further amplified by inappropriate modes and systems for exploiting vailable resources, these changes have a direct impact on land use and landscape configuration. The natural processes of vegetation succession are then disrupted by human activity through the exploitation of timber and various cultural techniques, mainly shifting cultivation (Vink, 1983). The landscape, a geographical area composed of a set of interacting ecosystems, is dynamic (Bogaert and Mahamane, 2005). Understanding this spatiotemporal dynamics is crucial because of interactions with human activities (Schlaepfer, 2002). The landscape dynamics could thus be highlighted and quantified by analyzing the composition and configuration of its elements. The spatial structure of landscape ecosystems can therefore contribute to informing the ecological processes that take place there (Fortin, 2002). Numerous studies at the regional level have shown a decrease in forest area without really quantifying this phenomenon. The work of Tchotsoua (1996, 2006), based on the methods of management, conservation, management of savannahs and Adamawa territories, and a mapping study of deforestation, revealed a strong forest decline in the area of Adamawa. Satellite images of land use in Ngaoundéré showed that savanna area decreased by 10.8% in 2001 compared to 1951 (Tchotsoua, 2006). Because of the proximity (less than 100 km), the cliff is a supplier of food products in the capital (Nyasiri, 2014). As a result, the pressure on natural resources continues to grow. This is why monitoring and quantifying the dynamics of land use in this area is necessary to draw attention to these landscapes, which are highly dependent on the ancestral cultural practices of the population. Although ecological studies on biodiversity have been carried out for a number of years, no analysis of the spatial structure has yet been undertaken to highlight the changes in land use of the Ngaoundéré cliff. It is therefore important to complement these studies with a landscape approach to reconcile the soil and its biodiversity.

The aim of our study is to show and quantify, from diachronic data and landscape ecology techniques, the dynamics in time and space of land use of this test area of the Adamawa.

To reach the set objective, we hypothesized that the development of human activities in the forest landscape of the Ngaoundéré cliff leads to a change in its spatial structure.

Materials and Methods

Study area

The Adamawa region, which covers an area of 63700 km^2, is characterized by the cliff that crosses it from east to west, a true rampart dividing between the north and south of the country (MINEPAT, 2002). The study site is located between 07°40'05.3" and 07°40'48.4" North latitude and 013°32'47.4" and 13°33'13.1" east longitude. It is located at an average elevation of about 697 to 884 m (Figure 1).

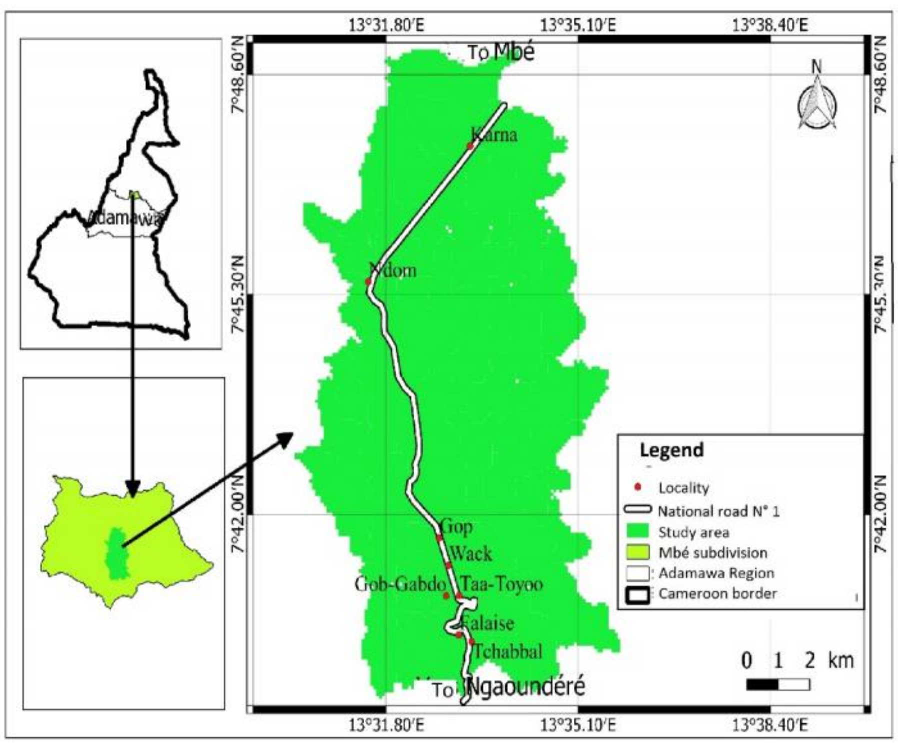


Figure 1: Location map of the study area

The climate is of the Sudano-Guinean type, mild and cool, characterized by two seasons: a rainy season and a dry season (Yonkeu, 1993). The annual rainfall is 1479 mm with a coefficient of variation of 9.8%. Extreme temperatures vary between 5 and 7°C for minima, then between 30 and 35°C for maxima (Mope, 1997).

In the Adamawa in general and particularly in Ngaoundéré, the vegetation is constituted by the open savannah with the presence of species like *Adansonia digitata*, *Zizyphus mauritiana*, *Tithonia diversifolia*, *Vitex donania*, *Annona senegalensis*, *Piliostigma thoningii*, *Entada africana* from Lateral transition from dense forest to graminaceous and grass savanna consisting of species such as *Manihot esculenta*, *Cassia javanica*, *Annona squamosa*, *Hibiscus esculentus*, *Hibiscus sabdarifa*, *Arachis hypogea*, *Pennisetum purpureum* (Mapongmetsem, 2005).

The Adamawa plateau has altitudes of an average altitude of 1100 m, over which large basaltic flows are poured accompanied by trachytes and trachyphonolites (Ngounouno, 1998). The center of the plateau is marked by soft forms barely accentuated and marshy valleys dotted with mountains or "Ngao" and volcanic cones. To the west of the city, we have mountainous terrain with the hills still called "Tchabals" and volcanism covers the North, East and South (Ngounouno *et al.*, 2001).

The main economic activities are agriculture, cattle breeding, beekeeping and fishing (MINEF, 1994). According to the agricultural census of 1984, the agricultural activity occupies 827 ha. Total production is 140,000 tonnes and production per hectare is 145 tonnes. The agriculture in the city is also marked by an important market gardening practice with the production of *Lycopersicon esculentum*, *Ipomea batatas*, *Solanum tuberosum*, *Lactuca sativa*, *Daucus carota*, etc. (Mapongmetsem, 2005). The cultivation of yams in the North and cassava in the South allows the survival of populations composed of Dourou or Dii in the North to the foot of the cliff, Mboum in the Center and the East, Baya, Tikar and Nyem-Nyem in South West.

Satellite and auxiliary data

As part of a characterization of land use dynamics in our study site, the analysis required the use of remote sensing data (satellite images and aerial photographs) and thematic maps. Topographic maps at 1: 200.000 were used as basic maps as well as field surveys and documents of the Regional Archive of Adamawa.

Pretreatments of images

Radiometric improvements (Bonn and Rochon, 1992, Tapobopda and Fotsing, 2010) have been applied to increase the readability of images and to facilitate their interpretation. They were followed by georeferencing operations in the UTM-31 WGS-84 Nord reference system.

Resampling the pixels

The MSS pixels (57 m resolution) were brought to the resolution of TM and ETM + pixels (30 m) to make possible overlays and comparisons (Billen and Cornélis 2000, Escadafal 2007). To do this, the method of cubic resampling, which significantly improves the sharpness of the images without unduly altering their radiometry, has been chosen (Caloz *et al.*, 1993).

Digital classification of images

Colored compositions were created by combining the channels 4 for the infrared [0.75-0.90 μm], 3 for the red [0.63-0.69 μm] and 2 for the green [0.52- 0.60 μm] in color order Red, Green, Blue. There followed a visual interpretation and the identification of training areas. On the basis of proven field knowledge, we opted for supervised classification using the "maximum likelihood" algorithm (Koné *et al*., 2007, Maarouhi, 2011) to produce classified matrix files.

Cartographic rendition of classifications

The merging of the results from the various classification stages made it possible to retain the relevant classes of land use. Classified images have been filtered. The filter was made from the Spatial Analysis Tools tool (Majority filter) with a window size of 8x8 pixels. The classification process generated descriptive statistics on the areas of different types of land cover for each of the three dates. The comparison of the three maps and the three corresponding statistical series made it possible to highlight changes in vegetation cover between 1976, 1996 and 2016. Finally, three transition matrices were obtained by crossing the occupation maps twice between the two ground (Robin, 2002, Godard, 2005, Mamoudou, 2009). Using the ArcGIS 9.3 Analysis Tools module, the crosses made it possible to obtain the spatial mutations of the classes over the three intervals: 1976-2006, 1996-2016 and 1976-2016.

Validation of image classifications

The verification of the validity of the classifications' performance was carried out using three confusion matrices comparing the thematic classes obtained digitally and the reference data collected in the field. Several elements, namely the visual interpretation of the colored compositions of the images, standard and improved (Bougherara, 2010) as well as the various field missions, were decisive. Indeed, the verifications and observations of the local populations, resource persons, allowed correcting and validating the supervised classifications. The ENVI 4.3 and ArcGIS 9.3 software were respectively used for image processing and the creation of the Geographic Information System (GIS). A GPS was used to recognize occupancy classes during the ground truth check.

Methods of treatment and analysis

To do this, land-use changes between three dates (1976, 1996 and 2016) were quantified using the transition matrix and spatial structure indices to assess the influence of on this landscape.

Transition Matrix

The transition matrix between two states (t0 and t1) is obtained from the values given by the GIS software and processed in Excel. These values come from the superimposition of the two maps using GIS software to detect changes in land use between these dates. It corresponds to a square matrix describing in a condensed manner, the changes of state of the elements of a system during a given period (Schlaepfer, 2002). The columns of the matrix represent the area of each class of the most recent year while the lines represent that of the previous year (Arouna, 2012). The areas of the different land cover classes were calculated from the crossing of the maps of the different periods using the Intersect function of the Arctoolbox ArcFool 9.3 toolbox.

From the transition matrix, we can calculate the average annual rate of space expansion or the conversion rate of a class.

Annual average rate of spatial expansion: The calculation of the annual average rate of spatial expansion was made using the formula adopted by Oloukoï *et al*. (2013).

$$Ta = \frac{S2 - S1}{S1(t2 - t1)} x100$$

With Ta the annual average rate of spatial expansion, S1 and S2 are the areas of a land-use category in year t1 and year t2.

Conversion rate: The conversion rate of a vegetation class corresponds to the degree of transformation undergone by this vegetation class by converting to other classes. It is obtained from the transition matrix (Arouna, 2012) according to the formula:

$$Tc = \frac{ST - Ss}{\sum ST} \text{ x } 100$$

With Tc the conversion rate, ST the areas of the units of occupation of the soil resulting from the conversion of a plant formation, Ss the area of the same formation remained stable at the date t1.

Calculation of spatial structure indices

The rest of the analysis consisted of calculating a number of spatial structure indices.

The number of spots belonging to a given class j (nj) has been determined. This index informed us about the fragmentation of a class between two periods. Indeed, the increase in the number of tasks of a class may be due to the fragmentation of this class (Davidson, 1998).

- The total area (atj) occupied by class j (in km²) was calculated according to the equation where aij is the area of the i-th spot of class j:

$$a_{tj} = \sum_{i=1}^{nj} aij$$

- The dominance Dj (a) indicating the proportion of area occupied by the dominant spot in the class j has also been taken into account. This is the share occupied in the total area (atj) by the largest task of the class j noted amaxj (McGarigal and Marks, 1995):

$$Dj(a) = \frac{amaxj}{atj} x\ 100 \quad 0 < Dj(a) \leq 100.$$

He higher value of dominance, the less the class is fragmented.

- The average area ($\overline{atj}$) (the average value of the area of the spots of class j) was calculated according to the following formula:

$$\overline{atj} = \frac{atj}{nj}$$

- The diversity of j-spot areas, noted (Hj (a)), was calculated by the Shannon index (Bogaert and Mahamane, 2005). The Shannon diversity index is given by the following formula where ln represents the natural logarithm.

$$Hj(a) = -\sum_{i=1}^{ni} \left(\frac{aij}{atj} \ln \frac{aij}{atj}\right)$$

- The form index of the class j (IFj) has been given by the following formula:

$$IFj = \frac{p2tj}{atj}$$

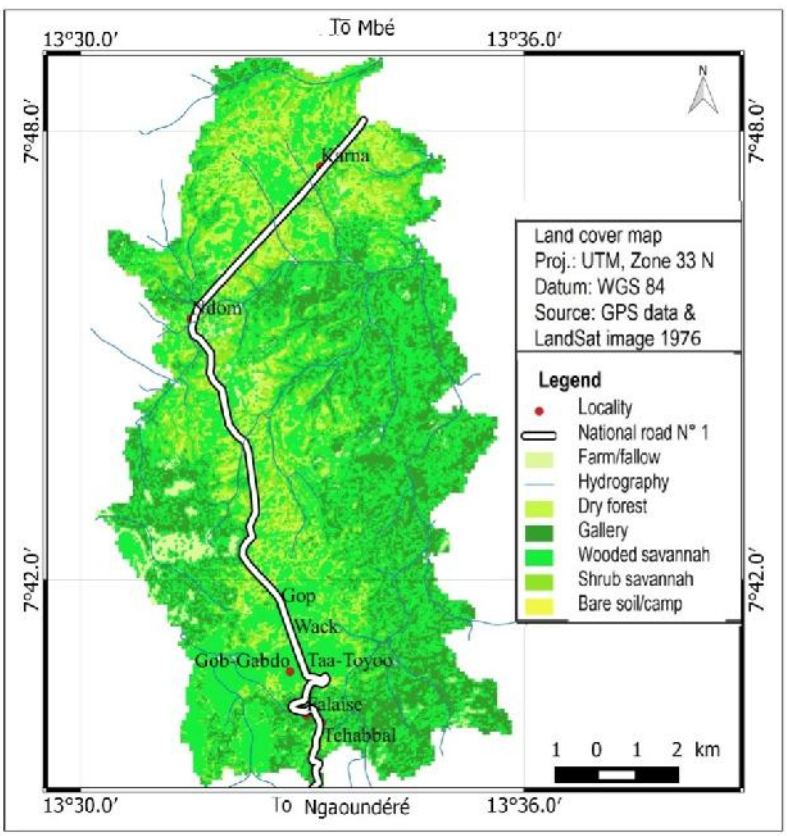
where ptj is the total perimeter of class j. The shape index is based on a perimeter ratio principle on the area.

- The disturbance index (U) is defined as the ratio of the cumulative area of anthropogenic classes in the landscape and the cumulative area of natural classes (O'Neill *et al.*, 1988). Fragstats 4.2.1. allowed the calculation of different ecology indices of the landscape; it is accompanied by detailed documentation concerning the calculation of the indices and their ecological interpretation.

Results

Mapping and dynamics of land use classes

Six land cover classes were finally mapped (Figure 2a). They are represented by forest galleries, dry forests, wooded savannahs, shrub savannas, farm-fallow and the whole bare soil-camp. The discrimination between these different land cover classes is statistically significant for the 1976, 1996 and 2016 images. The results of the performance analysis give for each of the classified images the overall accuracies of 86.07%, 85.16%, 84.60% and Kappa coefficients of 74.58%, 69.34% and 74.16% respectively for the three periods of the study. The analysis of the transfers of occupations between 1976 and 2016 essentially two phenomena: the reduction and the opening of the landscape. The reduction concerns dense plant formations (forest galleries and tree savannahs). The opening of the landscape is remarkable especially in the degraded part where the bare ground - encampments and the mosaics of the farms - fallows are developed (Figure 2b).



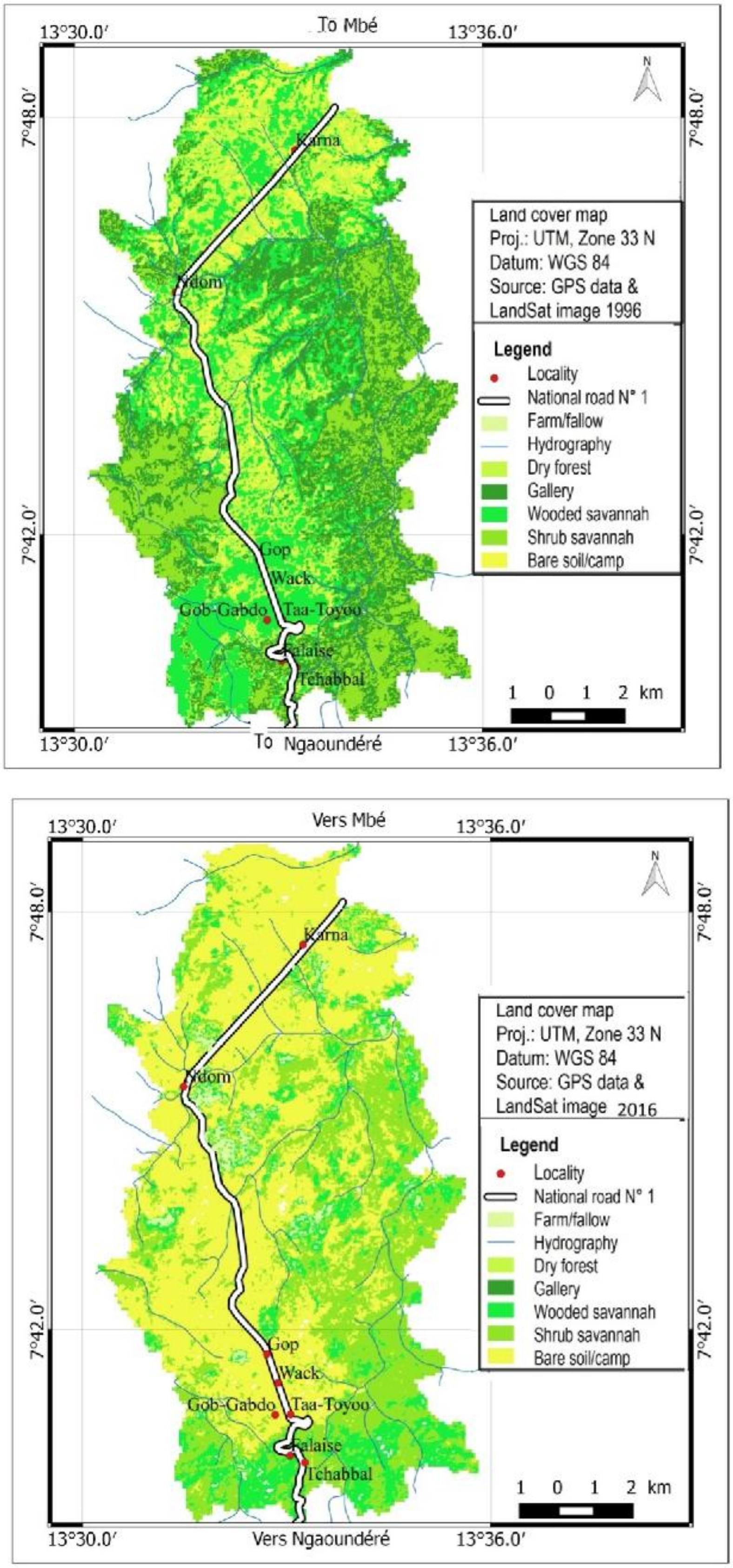


Figure 2a: 1976, 1996 and 2016 Cliff Land Cover Maps

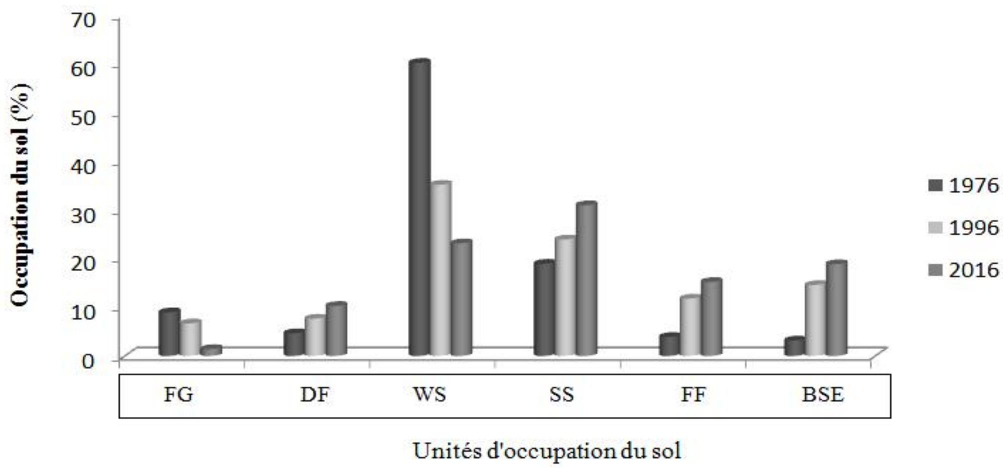


Figure 2b: Dynamics of land use between 1976 and 2016 in the study area

Transformations of landscape occupation: transition matrix

Transformations operated during 1976 – 1996

Table 1 gives the percentages of changes made between different land cover classes between 1976 and 1996 in our test area. It can be seen from this table that the landscape was dominated by wooded savannas, shrubby savannahs and forest galleries with respective proportions of 60.20%, 18.97% and 08.98% in 1976. The rate of wooded savannas rose from 60.20% in 1976 to 35.18% in 1996. That of shrub savannas rose from 18.97% in 1976 to 23.95% in 1996, an increase of 04.98%. At the gallery level, the rate increased from 8.98% in 1976 to 06.73% in 1996. Between these two periods, a significant rate of transformation was observed: 10.22% of savannas evolved into savannahs shrubs against 3.50% shrubby savannas that have become savannahs, a flow of 06.72%. For classes, which were only slightly represented in 1976, there was an increase in area. For the bare land-encampments, its occupation of the landscape goes from 3.21% in 1976 to 14.61% in 1996. As for the farm-fallows, its triple rate going from 03.94% in 1976 to 11. 83% in 1996; this increase comes from the conversion of 0.12% of the bare soil-encampments, 1.50% of the forest galleries, 1.25% of the shrub savannas and 06.22% of the wooded savannas. Dry forests are up by 03%. In general, we observe that the rates of occupation of the dry forest, shrub savanna, farm-fallow and bare-camp classes increased between 1976 and 1996. This increase was mainly at the expense of the forested galleries and wooded savannas.

Table 1: Land-use transition matrix of the cliff (%) between 1976 and 1996 obtained after superimposition of the two land cover maps (1976-1996).

1976/ 1996	FG	DF	WS	SS	FF	BSE	Total
FG	**5,76**	0	0,15	0,61	1,5	0,96	8,98
DF	0	**3,03**	0,4	1,27	0	0	4,7
WS	0,55	2,5	**31,13**	10,22	6,22	9,58	60,2
SS	0,42	1,85	3,5	**11,48**	1,25	0,47	18,97
FF	0	0,32	0	0,37	**2,74**	0,51	3,94
BSE	0	0	0	0	0,12	**3,09**	3,21
Total	6,73	7,7	35,18	23,95	11,83	14,61	**100**

Transformations operated during 1996 – 2016

During the 1996 to 2016 period, wooded savannas increased from 35.18% to 23.17% of the study area, a decrease of 12.01%. There are some shreds of gallery forests (1.46%). In contrast, shrub savannas increased by 7.02%. Farm-fallow mosaics increased from 11.83% to 15.22%. The bare-land-encampment complex became the third land-use unit with 18.88% of the area of the study area. Dry forests go from 7.70% to 10.30%. The classes gallery forests and wooded savannahs are therefore the main providers of space in other classes. Thus, about 05.27% of the landscape occupied by forest galleries in 1996 was degraded to dry forests (0.28%), wooded savannas (0.87%) and shrub savannas (1.80%) in farm-fallows (1.10%) and in bare soil-encampments (1.63%). As for savannahs, 20.22% of area has been conserved; the rest evolved into dry forests (0.31%), shrub savannas (9.60%), farm-fallows (1.33%) and bare soil-camps (1.04%).

Table 2: Land-use transition matrix of the cliff (%) betwen1996 and 2016 obtained after superimposition of the two land cover maps (1996-2016).

1996 / 2016	FG	DF	SW	SS	FF	BSE	Total
FG	**1,05**	0,28	0,87	1,8	1,1	1,63	6,73
DF	0	**6**	0	0,35	0,64	0,71	7,7
WS	0,31	2,68	**20,22**	9,6	1,33	1,04	35,18
SS	0,1	0,9	2,08	**18,72**	0,85	1,3	23,95
FF	0	0,44	0	0,5	**10,42**	0,47	11,83
BSE	0	0	0	0	0,88	**13,73**	14,61
Total	1,46	10,3	23,17	30,97	15,22	18,88	**100**

Transformations operated during 1976 – 2016

For 40 years, that is, from 1976 to 2016, there was a regression of forest galleries and wooded savannas and an increase in other types of land use. In fact, of the 8.98% of the landscape area occupied by the forest gallery class in 1976, only 1.11% was conserved and the rest was converted in 2016 to other types of occupation, ie 0.22%. in dry forests, 0.36% in wooded savannas, 3.10% in shrub savannas; 2.33% in farm-fallows and 1.86% in bare soil-encampments. In wooded savannahs, on 60.20% of occupied space in 1976, up to 37.89% was transformed into forest galleries (0.30%), dry forests (4%), shrub savannas (12.44%), in farm-fallows (9.03%) and in bare soil-camps (12.12%). The forest gallery shrank by about 83.74% while the proportion of savannah shrank by 61.51%. As for the other classes, they have seen their proportions increase. The proportion of farm-fallow was multiplied by 3.86, from 3.94% in 1976 to 15.22% in 2016. That of bare soil-encampments was multiplied by 5.88. For the shrub savanna class, its proportion has increased from 18.97% to 30.97%, an increase of 12% in 2016. The annual rate of increase of dry forests, shrub savannahs, farm-fallows and bare soil-encampments is respectively 2.98%, 1.58%, 7.16% and 12.20%.

Table 3: Land-use transition matrix of the cliff (%) between 1976 and 2016 obtained after superimposition of the two land cover maps (1976-2016).

1976 / 2016	FG	DF	WS	SS	FF	BSE	Total
FG	**1,11**	0,22	0,36	3,1	2,33	1,86	8,98
DF	0	**4,12**	0,1	0,13	0,25	0,1	4,7
WS	0,3	4	**22,31**	12,44	8,83	12,32	60,2
SS	0,05	1,83	0,4	**14,35**	1	1,34	18,97
FF	0	0,13	0	0,95	**2,07**	0,79	3,94
BSE	0	0	0	0	0,74	**2,47**	3,21
Total	1,46	10,3	23,17	30,97	15,22	18,88	**100**

Dynamics of the spatial structure of the landscape

Table 3 summarizes the different spatial structure indices calculated in each of the five classes in 1976, 1996 and 2016.The number of spots increases between 1976 and 2016; this indicates fragmentation with fragmentation of the initial spots. But it is of varying degrees. For farm-fallow and bare-camp classes, the number of spots was multiplied by five and six, respectively. It has tripled for dry forests and shrub savannas. At the level of wooded savannas, it quadrupled. This fragmentation of the number of spots is confirmed by the decrease in average areas in all classes. From 1976 to 2016, the average area of the spots is approximately divided by two, five and ten respectively for shrub savannas, dry forests and wooded savannas. It drops considerably for gallery forests with a quotient that is substantially twenty-one. As for bare soil-encampments, the variation is very small with a decrease of 0.04 km^2. On the other hand, the average area of the spots increased for the farm-fallow class; the reverse process is noticed, that is, creation. Dominance values decrease for forest gallery and wooded savanna classes. The dominance of gallery forests increased from 44.48% in 1976 to 28.44% in 1996 and 6.73% in 2016. For savannah wooded, it went from 74.05% in 1976 to 35.94% in 1996 2016 and 20.16% in 2016. This shows that these two classes provide space for other types of land use. This decline in the dominance value for these classes between 1976, 1996 and 2016 reflects the importance of the environmental degradation phenomenon and therefore the anthropization of the natural occupation classes. Indeed, for 40 years, the spots that dominated these classes by their sizes were fragmented. On the other hand, the value of dominance increases for shrub savanna classes (31% to 48.22%), fallow land - farms (17.54% to 32.44%) and all bare soil - encampments (35.63% to 51.95%). The increase in dominance values for these classes, remarkably in 2016, reflects the process of training or aggregation of tasks in these three classes. Shannon's index tells us about homogeneity within classes. The higher this index, the more spots there are and its value decreases as the areas of the spots are disproportionate. The Shannon index decreases for most classes. As for the class of shrub savannas, it remains almost constant (3.23 to 3.28). This confirms the tendency of equitability between forest spots in which many small spots have replaced the few big ones present in 1976 as already shown by the dominance values. Anthropization is also revealed by the evolution of the index of forms with classes. It can be seen that for all classes where the land use rate increases, the value of the shape index increases. At the level of all bare grounds - camps, this value increased from 20.66 in 1976 to 26.53 in 2016 and in the farm-fallows, it went from 25.50 to 53.21. For dry forests, the value of the form index increased from 21.33 in 1976 to 33.33 in 2016. In shrub savannas, this value rose from 43.33 in 1976 to 79.45 in 2016 and represents the largest value of class shape indices in 2016. As for gallery forests and wooded savannahs, they see the value of their index decrease respectively from 38.76 in 1976 to 19.09 in 2016 and 43.33 in 1976 to 28, 77 in 2016. The decrease in the value of the shape index can be interpreted as a decrease in the complexity of shapes and a trend towards more compact forms.

1976	FG	DF	WS	SS	FF	BSE
nj	5	4	13	20	8	7
atj (km^2)	38,52	20,16	258,26	81,38	16,9	13,78
$\overline{atj}$ (km^2)	7,70	5,04	19,87	4,07	2,11	1,97
Dj (%)	44,48	18,12	74,05	31	17,54	35,63
Hj	4,75	1,76	3,4	3,23	1,87	1,84
Ifj	38,76	21,33	50,8	43,33	25,5	20,66
1996						
nj	7	8	22	48	17	23
atj (km^2)	28,87	33,03	150,92	102,75	50,75	62,68
$\overline{atj}$ (km^2)	4,12	4,13	6,86	2,14	2,99	2,73
Dj (%)	28,43	22,67	35,94	45,53	29,22	44,93
Hj	2,85	1,42	3,41	3,26	1,32	1,66
Ifj	32,5	25	36,98	60,8	40,5	23,88
2016						
nj	17	12	52	63	20	42
atj (km^2)	6,26	44,19	99,4	132,86	65,29	81
$\overline{atj}$ (km^2)	0,37	3,68	1,91	2,11	3,26	1,93
Dj (%)	6,73	24,13	20,16	48,22	32,44	51,95
Hj	3,36	3,8	3,33	3,28	1,02	1,55
Ifj	19,09	33,33	28,77	79,45	53,21	26,53

Notation: nj: number of tasks of a class j; atj: area of a class j; $\overline{(atj)}$: mean area of the spots of a class j; Dj: dominance of a class j; Hj: Shannon index of a class j; IFj: form index of a class j. Forest Galleries (FG), Dry Forest (DF), Wooded Savannahs (WS), Shrubs Savannas (SS), Farm-Fallows (FF) and the Bare Soil-Encampemens (BSE).

Effect of anthropogenic activities on the spatial structure of vegetation cover

The variations of the spatial structure indices of the vegetation cover as a function of time are illustrated by trend curves (Figure 3). Depending on the quality of the adjustment given by the R^2 coefficient of determination, two regression models were selected: the power model (mean area of the spots) and the polynomial model (number of spots, dominance and disturbance index).). All relationships in this figure are highly significant ($p < 0.01$).

Figure 3A shows the existence of a polynomial relationship between the number of spots in the cells and the time. The coefficient of determination ($R^2 = 1$) indicates that time explains 100% of the variations in the number of spots in the landscape. The polynomial curve of the regression illustrates an increase in the number of forest spots as time goes on. The proportions occupied in the landscape by the vegetation cover evolve according to a negative polynomial correlation with time (Figure 3B). Indeed, the more time evolves, the more the area occupied by the vegetation cover in the landscape decreases. This regression is expressed by a coefficient of determination ($R^2 = 1$) demonstrating that, time accounts for 100% of the variation of the area occupied by the forest class in the landscape.

The dominance of the largest task and time are inversely related according to a second order polynomial regression (Figure 3C). This model presented the coefficient of determination ($R^2 = 1$) as the other indices. Two groups of values of dominance as a function of time can be detected. From 1976 to 2005, dominance values decreased and increased slightly between 2005 and 2016.

Calculation of the linear correlations between these indices taken in pairs revealed that all three indices are correlated with each other. These highly significant correlations ($p < 0.01$) have determination coefficients ($R^2 = 1$). The number of spots is inversely correlated with the other indices, which are the total area of the class and the dominance of the largest spot.

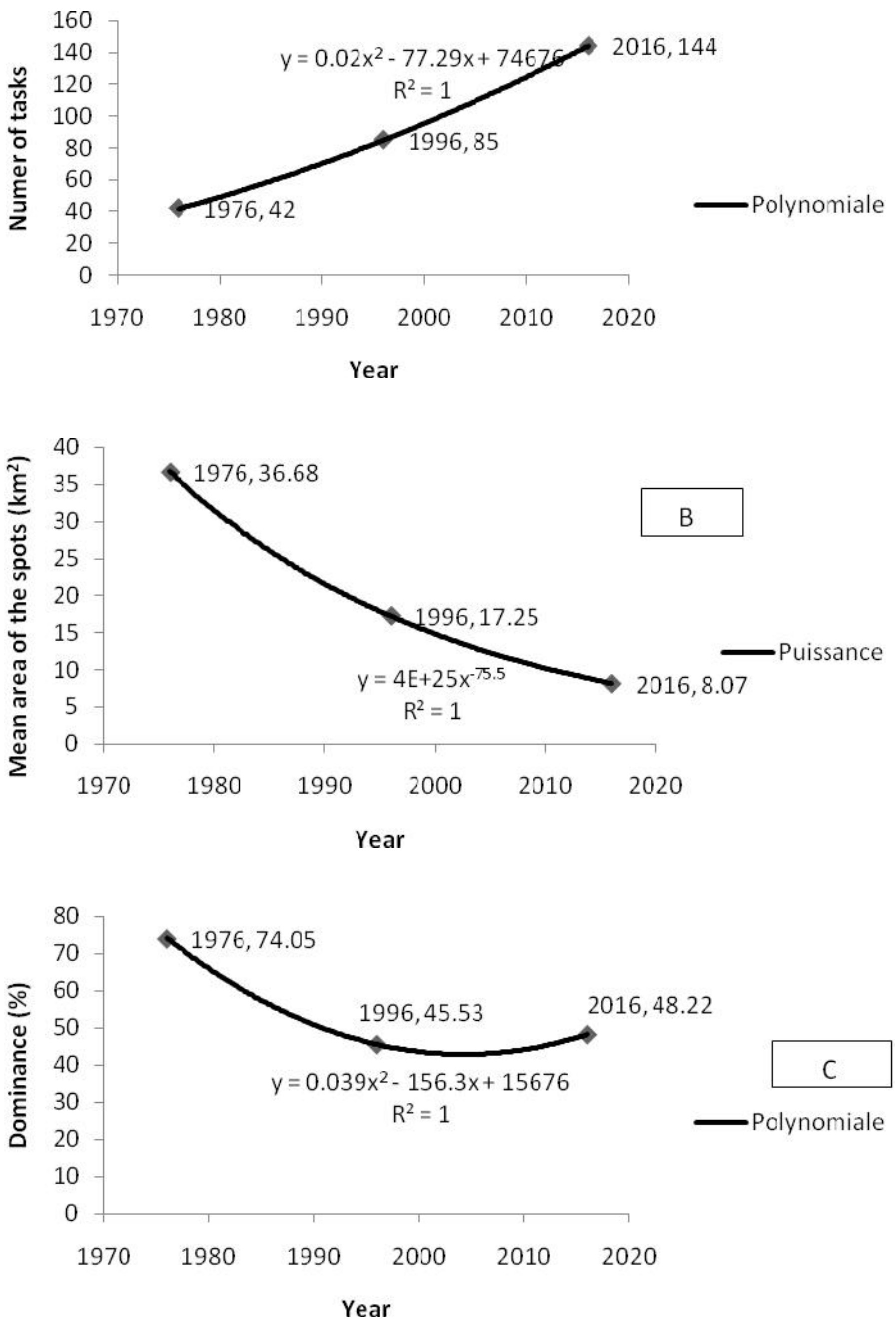


Figure: 3 Evolution of spatial structure indices over time.

Discussion

The results obtained show a regression of the natural vegetal formations in favor of the farm-fallows and the whole bare grounds-encampments. The rate of regression of natural formations is 30% in 40 years. This rate is explained by a strong extension of farm-fallows, bare soil and encampments. Farm-fallows are scattered throughout the study area but are not very noticeable on the 1976 land-use maps because of their tiny sizes. The conversion of natural landscapes into degraded landscapes leads to changes in the spatial configuration of landscapes (Casado, 2007). The annual average regression rate of natural plant formations is estimated at 0.75%.

The indices of the spatial configuration of the spots of the different classes made it possible to highlight the spatio-temporal dynamics in the landscape. The analysis of the transition matrix revealed a degradation of forest and savannah ecosystems, an anthropization marked by the increase of the total area of farm-fallows and finally, a weak tendency to the resumption of the vegetation between 1976 and 2016. The low rate of restoration of natural formations is a sign of disturbance of these ecosystems. This situation is caused in the study area by a reduction of fallow time and an acceleration of clearing due to soil leaching. According to Mama *et al.* (2013), the pressure on natural plant formations is also accentuated by the food crops that lead the rotation on newly cleared land. Ancestral nature conservation practices based on the development of myth and fear are no longer respected by the younger generation today because of the socio-economic changes in human societies. Forest degradation is marked by greater fragmentation. Arouna (2012) confirms the fragmentation of forests in Djidja in central Benin through agriculture, carbonization and logging by local populations. It is demonstrated by a sharp increase in the density of spots as well as a decrease in their average size. As for the dominance index, it decreases for the classes of gallery forests and wooded savannas as it increases for shrub savanna classes, fallow fields and all bare soil - camps. Also, the anthropization is remarkable by the increase of the total area of the farm-fallows, and the increase of the index of dominance of this class. The amplitudes of the spatial dynamics are therefore stronger in the two natural classes (forest galleries and wooded savannas). In addition, the trends observed between the two groups of classes (forest-savanna groups and farm-fallows) are moving in the opposite direction. These results reflect the reality of the trend of landscape dynamics in this part of Adamawa, where the transition from a self-subsistence economy to a market economy, driven by the cultivation of yam, cassava and rice. maize, is at the root of social changes that also affect the landscape. The most remarkable finding in the evolution of the land use is the increasing evolution of the agricultural hold that is accompanied by fragmentation (Bogaert and Hong, 2003) and a homogenization of the landscapes via the expansion of agricultural tasks (Sabatier *et al*., 2010). Several authors including Reounodji (2002), Barima (2009), Diallo *et al*. (2010) and Oloukoï (2012) also confirmed the regressive trend of natural plant formations due to anthropogenic activities

Conclusion

The present study has made it possible, thanks to the transition matrix supported by the calculation of spatial structure indices, to quantify the changes made in the landscape of the Ngaoundéré cliff. Three major transformations have been identified, namely the degradation of the forest ecosystem, the extension of anthropic classes and a low trend of natural plant ecological succession. These changes are mainly due to anthropogenic disturbances. Indeed, demographic pressure and unsustainable farming practices have contributed to the change in land use. The spatial configuration of the landscape has changed dramatically in 40 years. The natural formations, namely the forest galleries and the savannahs, have reduced their area in favor of the mosaics of farm-fallows and the whole bare ground-camps. 69.18% of the landscape constituted by the gallery forests and savannahs planted in 1976, only 24.63% of surface occupy these two formations in 2016; the rest has been transformed into dry forests, shrub savannahs, farm-allows and bare soils - camps. This is a concern for the restoration of the ecosystem where these two classes occupy an important place. So to help conserve biodiversity through habitat, awareness of the population is needed. First, for the creation, development and management of the forest area, a guarantee of the sustainable management of natural resources and in which people can draw forest products for their usual needs. Then by improving the archaic agrarian system very "devourer and wasteful land" in favor of a system of agroforestry intensive cultivation procedure and more economical from the point of view of the area.

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