(RESEARCH ARTICLE)

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Mapping of soil degradation factors and their impacts on plant biodiversity

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Abstract

To contribute to the knowledge of the factors of soil degradation and the loss of biodiversity in the corridors of the Benue National Park, the general objective of this work is to identify the factors of soil degradation and determine their impacts on plant biodiversity. Hence, it will it will be necessary to do an inventory on the factors of soil degradation in the corridors of the BNP; study between 2005 and 2015 by remote sensing and Geographic Information Systems (GIS), the land use of the Areas of Hunting Interest in which the corridors are located and make inventory on the floristic diversity of the park. The transect method was used to identify soil degradation factors. The aerial mapping made it possible to highlight the different classes of land use as well as their areas.

The floristic inventory carried out using the transect method made it possible to do a study on the distribution of the flora. Among the soil degradation factors inventoried, agriculture (74.22%) is practiced more in all corridors. It is followed by the town planning process (9.53%), carbonization (7.19%), pastoral practice (6.56%) and gold panning (2.50%). A satellite view showed an extension of land use from 1.41% for bare soil to 36.57% (fields) to the detriment of the initial vegetation. The floristic inventory revealed an equitable distribution of vegetation according to their abundance. In view of these results, it is important to set up strategies for the conservation and restoration of biodiversity.

It therefore seems urgent to undertake methods to restore these soils.

Keywords: Soil degradation; Corridor; Benue National Park; Mapping of soil

1. Introduction

The soil is a living medium (Roose, 2010), due to its position as an interface with the other compartments of the environment (atmosphere, biosphere, hydrosphere), it plays an important role in the regulation of the major planetary cycles with example of water and carbon (Aubert, 2012).

Unfortunately, this multi-service structure, formed over several millennia, is fragile, perishable and non-renewable on a human scale (Burrow, 2015). In addition, soils have not always been at the centre of human concerns (CSFD, 2010) hence, poor management and more particularly the overexploitation of its resources induce their progressive degradation (Pratt, 2007). According to the United Nations Convention to Combat Desertification (UNCCD), soil degradation is a process of reduction or loss of its productivity and its biological and/or economic complex; it is also an alteration of its physical, biological and chemical properties (Dosso, 2016; CSFD, 2010). Since the 20th century, this process has accelerated (UNCCD, 2013) and is becoming a major environmental problem (Omar et al., 2013). Being

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aware of this threat, the United Nations (UN) declared 2015 the International Year of Soils (IYS) and December 5 as World Soil Day (FAO, 2015a; Thiombiano, 2015).

Cameroon, Africa in miniature, is not on the side-lines of this phenomenon of soil degradation, in particular the North Region where Man and his activities added to the irregularity of the rains and the very high average annual temperatures are the engines of acceleration of this phenomenon (COMIFAC, 2010; Endamana et al., 2007; Yemefack et al., 2004). This Region has three protected areas (about 44% of its surface area) communicating with each other through corridors belonging to the Benue National Park (BNP) (MINEPAT, 2013). Since the departure of the BNP from Non-Governmental Organizations (NGOs) in 2005, the corridors have no longer been permanently monitored by the team in charge. As a result, they have been transformed into vast deforested expanses thanks to the sites of human activities shaped by the increasingly numerous populations (Endamana & Etoga, 2006), in search of agricultural land, housing and income-generating activity.

Faced with this pressure on the soil and therefore on the biodiversity which is the reason for the creation of this park, it is important to react especially that; in the North Region, few studies have been a concern in the research on soil management and conservation strategies, mainly in the BNP and its corridors. In this area, the last work on the soil dates from 1974 (Brabant & Humbel, 1974). It is in this context that the present study was carried out with general objective to identify the factors of soil degradation and their impacts on plant biodiversity.

More specifically it involves:

- Inventorying the factors of soil degradation in the corridors of the BNP;
- Study between 2005 and 2015 by remote sensing and Geographic Information Systems (GIS) the land use of the Areas of Hunting Interest in which the corridors are located;
- Inventory on the floristic diversity of the park.

2. Material and Methods

2.1. Presentation of the study area

2.1.1. Location

The corridors of the Benue National Park (BNP) are located on its western ring road and itself is located in the North-Cameroon Region and more particularly in the Mayo Rey Division, between 7°55 and 8°40 latitude North and 13°33 and 14°02 East longitude (WWF & SNV, 2000). It is surrounded by eight Hunting Interest Zones (HIZ N° 1, 2, 3, 4, 5, 7, 9 and 15.) which together constitute alongside the BNP the Benue Technical Operational Unit (TOU) (Figure 1) (Endamana et al., 2007).
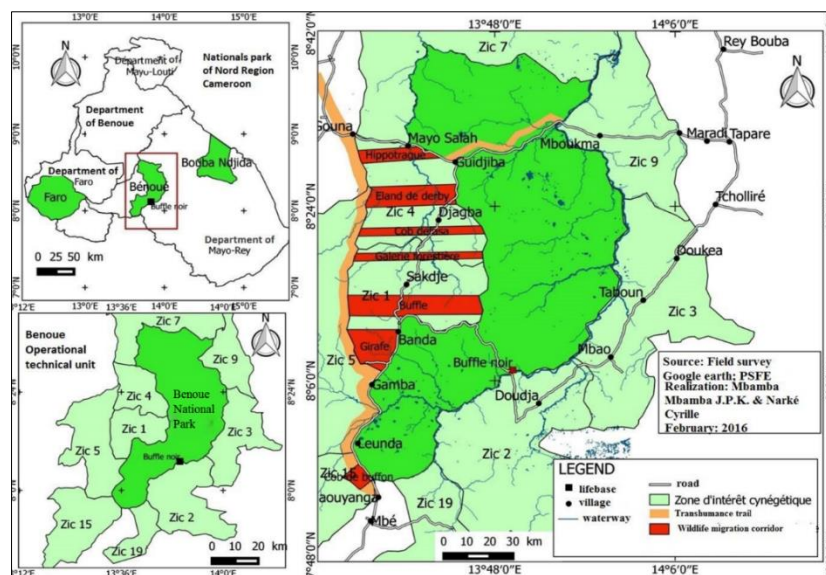

Figure 1 Presentation of the study area

The BNP has seven corridors that bear the names of some emblematic animals found there. These are located in three of the eight HIZs listed above. This is HIZ No. 1 called Sakdjé (39,552 ha) which includes the corridors: Forest Gallery (0.5 km), Buffalo (3 km) and Giraffe (8 km); HIZ N° 4 called Bel Eland (40.64 ha) with corridors: Hippotrague (5.2 km), Derby Eland (7 km) and Cob Défassa (2 km) and ZIC N° 15 called Faro Coron (76,128 ha) with the only Cob de Buffon corridor (4.6 km) (Saleh, 2013; Endamana, &Etoga, 2006).

2.2. Inventories of soil degradation factors in the corridors of the Benue National Park

The method used to inventory the degradation factors in the BNP corridors consisted in standing at an entry point of the chosen corridor, then using a Global Positioning System (GPS), the first waypoint is recorded (geographical coordinates) and the compass was used to cover a straight distance of six kilometres. After this distance, we marked the second waypoint before making a 90° angle according to the point of entry into the corridor to evolve in a parallel way for two kilometres to the national road N° 1. At the end of this journey, the third waypoint was recorded, which made it possible to achieve a perpendicular angle to exit the corridor.

On the area delimited by the route, it was a question of noting any trace or any human activity likely to be a threat to the ground. This method, which is an adaptation of the one used by Siroma (2007), was used in all the corridors with the exception of the Forest Gallery corridor where, instead of two kilometres, it was rather a varying distance between 250 and 300 m that was travelled and of the Cob de Buffon corridor, where only one kilometre was travelled in depth. The method was repeated three times in each corridor on different routes.

The activities identified were based on their indices. Thus, agriculture has been identified by crop residues, small traditional huts, and vast deforested areas with bare soils with the presence of cattle manure. Pastoral practice by the presence of oxen, pruned trees, and hoof prints, cow dung, grazed areas; Gold panning by the presence of active gold miners or holes and cuttings. Carbonization by observing kilns or charcoal debris. Urbanization by observing houses or huts.

2.3. Mapping of land use in the corridors of the park

Land use mapping was carried out for HIZs 1 and 4, in which there are six corridors. It was made thanks to satellite images of December 2005 (date which marks the departure of NGOs from the park and the abundance of corridors to the populations) and December 2015. These images allowed a diachronic comparison of the spatio-temporal evolution of the 'land use. Both raw images were downloaded from http://earthexplorer.usgs.gov.

2.4. Assessment of the effect of soil degradation on plant biodiversity

The floristic inventory was carried out in the corridors using the transect method. On one-hectare plots (100 x 100 m), sub-plots of 20 x 100 m were marked out to facilitate the inventory following a straight path (Jiagho et al., 2016). This floristic inventory led to the calculation of three indices:

- The Shannon index, which measures the specific diversity of environments as well as the distribution of individuals within these species. This index is calculated according to the formula below (Shannon, 1948; Shannon & Weaver, 1963, cited by Diwediga et al., 2015).

$$H' = -\sum_{i=1}^{S} (pi) \log2 (pi)$$

Pi: number of individuals of a given species, i ranging from 1 to S (total number of species).

Simpson's interaction index was used to calculate the dominance of a species in an environment and to measure the probability (between 0 and 1) that randomly selected individuals do not belong to the same group. It is calculated according to the following formula (Simpson, 1949 cited by Manfo et $al.,$ 2015).

$$D = \frac{N(N-1)}{\sum_{n}(n-1)}$$

N = total number of individuals n = number of individuals (variation from 1 to infinity) in the population of each species.

- The Pielou index makes it possible to measure the distribution of species according to their abundance within the same community. Its values vary from 0 to 1 (Piélou, 1969 cited by Diwediga et al., 2015).

$$J = -\frac{H'}{\log 2(S)}$$

2.5. Statistical analyses

To assess the various parameters studied, the various measurements carried out were the subject of statistical analyses using Microsoft Excel 2010 and XLSTAT 2016 software used for calculations (mean, standard deviation and chi 2). Satellite images were processed and analysed using QGIS 2.12 and ENVI (the Environment for Visualising Images) 4.7 software.

3. Results and discussion

3.1. Soil degradation factors in the corridors of the Benue National Park (BNP)

The increasing population (due to the migrant population, mostly from the Far North Region) in the villages surrounding the Benue National Park (BPN) is the source of human pressure which is in full swing in the corridors. Five anthropogenic activities or soil degradation factors (agriculture, pastoral practice, carbonisation, urbanisation and gold panning) have been inventoried in the seven corridors (Hippotrague, Eland de Derby, Cob Défassa, Galerie Forestière, Buffalo, Giraffe and Cob de Buffon), account of BNP (Table 1). The activity quota of the present study differs from that of Aoudou et al. (2020) obtained in a study carried out in 2016 in the 6 BNP corridors housed in HIZs 1 and 4. In these HIZs, they identified 9 anthropogenic activities (logging, poaching, pastoral activity, agriculture, gold panning, urbanisation, roads and carbonisation).

Table 1 Occurrence of soil degradation factors in the Benue National Park corridors

Activités anthropiques	Corridors							Activities (%)
	Hip	ED	CD	FG	B	Gif	CB	
Agri	79.66	54.13	66.67	91.67	81.55	73.33	76.92	74.22
Urb	0	32.11	19.61	0	0	0	15.38	9.53
Carb	0	0	4.90	0	12.62	23.33	0	7.19
PP	10.17	6.42	8.82	6.48	5.83	3.33	7.69	6.56
GP	10.17	7.34	0	1.85	0	0	0	2.50

Legend: Agri: agriculture; PP: pastoral practice; Carb: carbonisation; GP: gold panning; Urb: urbanisation; Hip: Hippotrague; ED: Eland de Derby, CD : Cob Défassa, GF : Forest Gallery, B : Buffalo, Gif : Giraffe, CB : Cob de Buffon.

Overall, anthropogenic activities are significantly practiced ($\chi2$ = 228.46; dof = 24; P < 0.01) depending on the corridors. Agriculture (74.22% of anthropogenic activities) (Table 1) was practiced predominantly and insignificantly according to the corridors ($\chi2$ = 12.17; dof = 6; P < 0.01). This result can be justified by the dependence of populations on this practice. Vounserbo (2011) showed that logging (61.54%) was the predominant activity in six corridors with the exception of the Cob de Buffon corridor. The difference between these results may be due to the years that separate the two works and to the method adopted by the latter and whose point of entry into the corridor was parallel to the national road N°1. Tagueguim (2010) on the other hand, showed that pastoral practice and poaching are more represented than agriculture. In the dry season, agricultural practices prior to sowing are characterised by the cutting of almost all the trees in the fields and by the use of herbicides which leave the soil bare during the off-seasons. These results are contrary to those of Vounserbo (2011) and Boukeng (2015) who noticed that extensive slash-and-burn agriculture was the cause of the destruction of vegetation cover in the corridors.

In the rainy season, the physiognomy of the corridors is made up of maize crops (Zea mays; L., 1753), peanuts (Arachis hypogea; L., 1753), cotton (Gossypium hirsitum; L.) and yam (Dioscorea rotonda).

Unfortunately, agricultural practices weaken the soil and make it vulnerable to bad weather, one of the notorious consequences, which is the process of erosion, facilitated by sowing mostly in the direction of the slope. The phenomena

of water erosion in sheets and rills are the most observed with their corollary in terms of loss of arable land and including soil for agriculture. Agricultural activity was closely linked to the construction of huts in the corridors for various purposes (shelter, storage of crops, place to live, etc.).

The urbanization process (9.53% of anthropogenic activities) (Table 1) was encountered significantly ($\chi 2 = 107.74$; ddl = 6; P < 0.01) in three corridors: Derby Eland, Cob Défassa and Cob by Buffon. In these corridors, the urbanization is done in an artisanal way using mud bricks for the construction of huts, straw for the construction of traditional huts, fences and thatched huts for the construction of hut roofs. In some corridors, the floors are heavily stressed to the point where the courtyards have served as home gardens.

The carbonization activity (7.19%) is practiced differently ($\chi 2 = 71.14$; P < 0.01; dof = 6) in the Giraffe, Buffalo and Cob corridors of Défassa (Table 1). This practice consists of cutting and storing wood, followed by burial, carbonisation until charcoal harvesting and marketing. Coal, an important source of income for local residents, is the cause of deforestation and passive pollution.

Pastoral practice did not vary significantly according to the corridors ($\chi 2 = 4.04$; ddl = 6; P > 0.05) (Table 1). It was more practiced in the dry season and mainly involved cattle breeding. This activity contributes to deforestation, more particularly of the species Afzelia africana (Fabaceae) called in the local language "Bambam". The large number of individuals per herd has favoured overgrazing and soil compaction of the tracks created by the cattle. In the rainy season, these tracks become channels for the flow of water.

Gold panning, which consists of the artisanal search for gold, has been practiced both on dry land and in the beds of the Mayos. The intensive practice of gold panning was significant ($\chi 2 = 33.37$; P < 0.05; dof = 6) in Eland de Derby, than in Hippotrague and Forest Gallery (Table 1).

It appears from the analysis on the inventory of human activities that the degree and rate of anthropisation varied according to the corridors but, were not similar under the base of the use of the soil resources. Anthropogenic activities, with multiple uses, have had in common the destruction of the flora and the biotope. The wood resulting from this destruction was exploited for personal and commercial purposes. However, these activities inevitably led to the creation of roads on which the speed of water flow was greater than on soils with vegetation cover whose herbaceous plants constitute a brake not only on erosion but also on the impact sunbeams and raindrops. However, the causes of these factors are multiple and diverse.
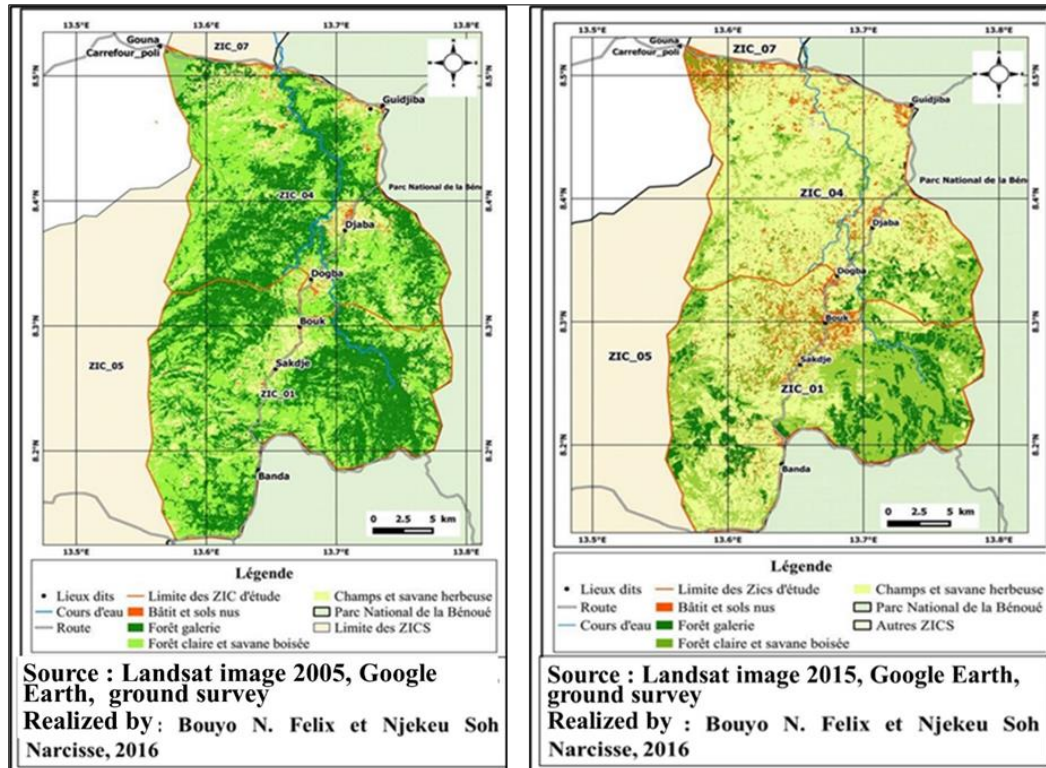
3.2. Land cover mapping between 2005 and 2015

The processing of Landsats images from 2005 and 2015 made it possible to establish Table 2 which presents the different classes of land use as well as the areas occupied by it. In 2005, plant formations (gallery forests, open forests and wooded savannahs) occupied the largest areas, ie a total of 78.34% against 20.69% of the areas occupied by bare soil and fields. On the other hand, in 2015, the area occupied by the various plant formations was 40.85%, i.e., a loss of 37.49% over 10 years. On the other hand, there is an increase in the areas of bare soil and fields which rose to 58.67%, an increase of 37.98%.

Table 2 Evolution of land use between 2005 and 2015

Occupation du sol	Surface en 2005		Surface en 2015		Différences	
	Pourcentage	Hectare	Pourcentage	Hectare	Pourcentage	Hectare
Bâtis et sols nus	1.45	1648.01	2.86	3251.76	1.41	1603.75
Forêts galeries	33.57	44900.82	11.36	19723.37	22.21	25177.45
Forêts claires et savanes boisées	44.77	45172.32	29.49	33503.2	15.28	11669.12
Champs	19.24	21854.54	55.81	57097.37	36.57	35242.83

These results highlight the extent of degradation factors on the future of soils in the BNP. These results are different from those of Amadou (2015) who compared over a period of 10 years and showed a regression of 5.49% of gallery forests and 57.14% of open forests and wooded savannahs against an evolution. 14.87% bare soil.

The diachronic analysis of the Landsat images of 2005 and 2015 made it possible to draw up the maps illustrated by figure 2 which corroborates the statistics of table 2. Figure 3a which is the result of the processing of the 2005 image, shows the dominance of the green colour on the yellowish colour. This result reflects the dominance of plant cover over deforested areas. Conversely, in 2015 (Figure 2b), we observe a dominance of the yellowish colour over the greenish colour. Thus, in 10 years, we can see the impact of human activities on the regressing plant cover.

Figure 2 Land cover map between 2005 and 2015

These results illustrated by table 2 and figure 2 show in 10 years the impact of human activities on the sustainability of the vegetation cover which has considerably decreased over time.

3.3. Study of the specific diversity of soil flora

The floristic inventory carried out made it possible to identify 1051 individuals divided into 28 species, 24 genera and 17 families. These values are different from those of Aoudou et al. (2020) who obtained in the 6 corridors of the BNP 2869 individuals divided into 99 species, 70 genera and 36 families.

The results of this inventory made it possible to calculate the biodiversity indices:

The Shannon indexes whose values are in all the corridors close to the maximum diversity Ln (S) (Table 3) and indicated a specific heterogeneity in the communities studied and therefore a good distribution of species according to their abundances, this with regard to the complementary values of the Pielou and Simpson indices. This result is similar to that of Manfo et al. (2015) whose Shannon index indicated very high biological diversity in Plot 0 (4.45) and Plot 1 (3.63) but very low diversity in Plot 2 (0.62). Simpson's index was 0.13 in Plot 0, 0.006 in Plot 1 and 0.436 in Plot 2.

Table 3 Different indices of specific diversity of park corridors

Corridors							
Indices calculés	**Hip**	**ED**	**CD**	**GF**	**B**	**Gif**	**CB**
Taxa_S	27	25	24	24	23	22	27
Individuals	95	71	76	62	69	60	97
ln S	3.30	3.22	3.18	3.18	3.14	3.09	3.30
Shannon_H	3.25	3.04	3.05	3.04	3.01	2.93	3.16
Simpson_1-D	0.96	0.94	0.95	0.95	0.95	0.94	0.95
Equitability_J	0.98	0.95	0.96	0.96	0.96	0.95	0.96

Legend : Hip : Hippotrague ; ED : Eland de Derby ; CD : Cob Défassa ; GF : Galerie Forestière ; B : Buffle ; Gif : Girafe ; CB : Cob de Buffon

4. Conclusion

At the end of this work, the general objective which was to highlight the impact of the factors of degradation on the biodiversity of the corridors, it appears that: five main factors of degradation (agriculture, pastoral practice, gold panning, carbonisation and urbanisation) soils have been identified in the study area. Among these, agriculture appears to be the most degrading factor in all the corridors given the extent to which it is practiced and the techniques used.

Cartographic analysis by diachronic comparison of satellite images of Hunting Interest Zones No. 1 and 4, where six corridors are located, shows a loss in 10 years of 37.98% of forests and savannahs to the detriment of fields and bare floors. Despite this loss of vegetation, the biodiversity indices calculated show a good distribution of species according to their abundance. In view of its results, it is important to put in place measures to protect, restore and conserve biodiversity.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict-of-interest.

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