



(RESEARCH ARTICLE)

## Impact of the chemical properties of different soil units on the dynamics of vegetal biodiversity in the Benoue National Park and its Western and Northern peripheries

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### Abstract

This work aims at determining the impact of soils' chemical properties on the dynamics of biodiversity in the Benoue National Park (BNP) of Cameroon and its peripheries (surrounding hunting concessions N° 1, 4, 5 and 7). Nine, out of the sixteen soil units encountered in the BNP were studied, because of their accessibility. On each of these nine soil units studied, three elementary plots were materialized for the collection of soil samples and for the study of vegetation dynamics. The chemical parameters were evaluated according to appropriate methods and the dynamics of the vegetation was obtained by carrying out a floristic inventory. Heterogeneity was observed in the chemical parameters of the different soil units. Soil units S5 and S6 are the most damaged regarding their low organic matter content ( $0.95 \pm 0.78\%$ ) and ( $1.02 \pm 0.33\%$ ), their carbon ( $5.53 \pm 4.54 \text{ g.kg}^{-1}$ ) and ( $5.91 \pm 1.93 \text{ g.kg}^{-1}$ ) and nitrogen ( $1.20 \pm 0.45 \text{ g.kg}^{-1}$ ) and ( $1.89 \pm 0.41 \text{ g.kg}^{-1}$ ) contents and a very low C/N ratio ( $4.72 \pm 3.96$ ) and ( $3.29 \pm 1.37$ ) respectively. These soils also have a low floristic abundance S5 ( $22 \pm 0.53$  individuals) and S6 ( $8 \pm 1.86$  individuals) unlike S4 which has good chemical properties, according to its OM ( $5.60 \pm 0.83 \%$ ) and carbon ( $32.49 \pm 4.79 \text{ g.kg}^{-1}$ ) content, and C/N ratio ( $22.38 \pm 6.84$ ). Consequently, its floristic abundance ( $75 \pm 1.37$  individuals) and diversity ( $18.42 \%$ ) are considerable. These results show that the degree of chemical degradation varies according to soils. Elsewhere chemical properties of the soil influence the dynamics and sustainability of the biodiversity.

**Keywords:** Benoue National Park; Degradation; Soil unit; Biodiversity

### 1. Introduction

The Northern Region of Cameroon has three national parks (Benoue, Faro and Bouba Ndjida) and 27 surrounding hunting concessions (ZIC) which occupy 45 % of the area [1]. These protected areas (PA) have been established for the protection and conservation of the biodiversity [2]. Unfortunately, population increase, development of anthropogenic activities around this protected areas and climate change pressure are obstacles to the achievement of the above-mentioned objectives [3]. The consequences (loss of biodiversity and soil fertility) of these phenomena are visible at several levels, namely on the biodiversity and the support soils [4] [5]. Subsequently, the Benoue National Park (BNP) and its western and northern peripheries which constituted our studied sites faced a loss in its biodiversity for several years [6].

To overcome the problem of biodiversity loss, many approaches have been tried in the BNP, aiming at guaranteeing ecological integrity and ensuring that the management of flora and fauna resources contributes to the fight against poverty [7]. Despite all these initiatives and the studies undertaken on the management and conservation of

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biodiversity, the results remain mitigated and as time goes on, a decrease in local biodiversity is still observed [1]. For instance, *Afzelia Africana* (highly prized by giraffes) is becoming scarce while several faunal species are threatened with extinction. Moreover, the Lycaon (*Lycaon pictus*) and the western black rhinoceros / Central Africa (*Diceros bicornis longipes*) are extinct since 2004 [8]. Between 2000 and 2013 in BNP, the hippopotamus population dropt to almost 50 % [8]. The main aspect that has not been considered in the studies carried out so far to justify the loss of biodiversity in the BNP, is the undeniable relationship that exists between the flora and the soil. The soil is the nutrients reservoir of plants, which in turn, constitute food source for animals in the given ecosystem [9]. Soil degradation is therefore a threat not only for plants but also for animals [10] [11].

Soil degradation is a process of reducing or losing its productivity; it is also a deterioration of its physical, biological and chemical properties [12] [13] [14]. According to IPBES [15], the soils are in a critical state, causing severe consequences on biodiversity, climate change and the stability of our societies. Per year, 12 million hectares of soil stop fulfilling their essential ecological role for biodiversity as a result of their degradation [16] [15]. Chemical soil degradation is of no less importance compared to other forms of degradation but it is often overlooked [17].

Land degradation as a result of human activities exposes the planet to the sixth massive extinction of species [18]. According to this author [18], the protection of biodiversity and ecosystemic services that are vital in maintaining life on earth and ensuring human well-being, avoiding, reducing, reversing, and restoring degraded lands are urgent priorities. According to Humbel and Barbery [19], soils' degradation varies, depending on their respective bedrocks. The last study was carried out in the present research site in 1973 and it focused more on a physical description of soil properties, without showing its impact on biodiversity [20]. The general objective of this work is to determine the impact of the chemical properties of different soil units on the dynamics of biodiversity in BNP and its western and northern peripheries. It specifically focuses on (1) the determination of the degree of degradation of the different soil types, (2) the presentation of the current state of the vegetation's dynamics in the BNP and (3) the exposition of the impact of chemical degradation of the different soil units on the loss of biodiversity in this PA.

## 2. Material and methods

### 2.1. Presentation of study site

Located in the North Region of Department of Mayo-Rey, Tchollire district, between latitudes 7 ° 55 'and 8 ° 40' North and longitudes 13 ° 33 'and 14 ° 02' East, and at 160 km from Garoua city, the Benoue National Park and its western and northern peripheries cover a total area of 443.232 ha [21] [22].

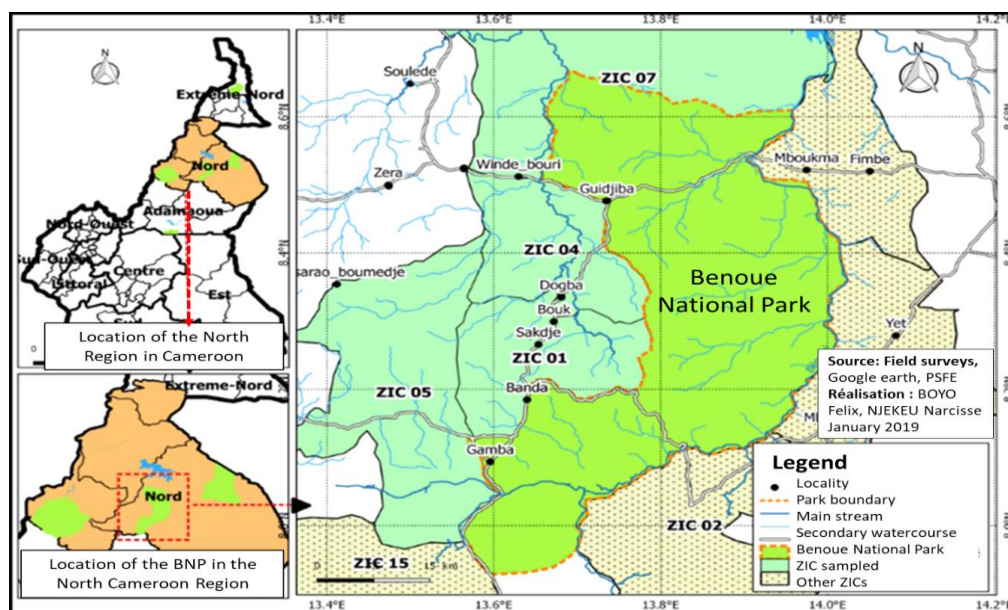


Figure 1 Location map of the site

The Park or central area covers a surface of 180.000 ha and the peripheries consist of four surrounding hunting concessions (ZIC) namely ZIC N° 1 (*Sakdjé*, 39.552 ha), N° 4 (known as Bel Eland, 40.640 ha), ZIC N° 5 (known as Cobas, 85.120 ha) and ZIC N° 7 (known as Elephants, 97.920 ha) (Figure 1) [23]. Among the ZIC, there are Multi-Use Zones (MUZ) which are spaces allocated to the populations for the practice of their activities [24].

This protected area is crossed by several roads including the national N° 1 which connects Adamawa Region to North Region and the road linking Guidjiba and Tchollire [7].

## 2.2. Presentation of different soil units

Soil is the main material used in this study. The inventory of soil units in the study area was made using the soil map of Cameroon "Poli at 1/200 000", established by the Overseas and Scientific and Technical Research Office [20]. This geo-referenced map has been joined to the map of the Benoue National Park and its western and northern peripheries using the QGIS program to facilitate this inventory. Among the 16 soil units identified with geographic references, nine of them were considered in this work, because of their accessibility (Table 1) [20] [25].

**Table 1** Classification of sampled soils

N°	Classes	Subclasses	Groups	Subgroups	Names
1	Loped mineral soils	Non-climatic origin	Of lithosolic erosion	On various rocks	S1
2	Slightly developed soils	Non-climatic origin	From alluvial contribution, modal or hydromorphic	On recent alluvium	S2
3	Soils with iron sesquioxides	Iron-rich tropical soils	Modal leached	On coarse weathered or buildup arena	S3
			With concentration	On micaschists	S4
				On acid volcanic rocs	S5
				On weathered material with kaolinite	S6
		Fersialitic	A reserve calcareous and slightly leached-under developed facies	On foliated rocks with black minerals	S7
4	Sydromorphic soils	Minerals	Pseudogley soils with perched water table (leached facies with great worm activity)	On feldspathic rocks	S8
				Leached and vertisolic soils or ferruginous concentration soils	S9

Source: Brabant and Humbel; CPCS [20] [25]

## 2.3. Determination of the chemical properties of different soil units and their degree of degradation

On each of the nine soil units identified, three plots of 100 \* 100 m were materialized and composite soil samples were taken between 0-30 cm depth with the Edelman auger (10 cm in diameter and 20 cm high) [26]. The samples were dried in open air for 10 to 15 days, crushed and then sieved (with a 2 mm sieve) according to Ndiaye *et al.*, [27].

The humidity of the samples was determined according to the standard gravimetry principle based on the NF ISO 11464, 2006 standard method. The organic carbon (OC) was measured according to [28] and the result was converted to obtain the values of organic matters (OM) in the soil using the factor 1.724 OM (Equation 1)

$$OM = OC \times 1.724 \quad (1)$$

The total amount of nitrogen was determined through Kjeldahl's method [29]. The pH-water and pH-KCl were determined using an electrode pH meter in a soil solution (soil / water or soil / KCL mixture) [30]. The ash content was quantified according to AFNOR [31].

## 2.4. Determination of the state of plant diversity in the BNP and its Western and Northern peripheries

A floristic inventory was carried out according to the different soil units and, to their occupations (covered soil) using the method of transects. On plots of one hectare (100 x 100 m), sub plots of 20 x 100 m were materialized to facilitate the inventory following a straight path [32]. This inventory took into account only woody trees with a height of at least one meter.

## 2.5. Floristic diversity analysis

The Shannon index measures the specific diversity of environments as well as the distribution of individuals within species. This index is calculated according to the equation (2):

$$H' = - \sum_{i=1}^S (p_i) \log_2 (p_i) \quad (2)$$

Where  $P_i$  is the number of individuals of a given species  $i$ ,  $i$  ranging from 1 to  $S$  ( $S$  = total number of species).  $H'$  is between 0 and  $\ln(S)$ . The closer this  $H'$  approaches 0, the more minimal the diversity and the more  $H'$  approaches  $\ln(S)$ , the greater the diversity [33].

The Simpson's index is used to calculate the dominance of a specie in an environment and to measure the probability that randomly selected individuals do not belong to the same group. This index varies between 0 and 1 and there is dominance when the values approach 0. This index is calculated according to the equation (3) [34];

$$D = \frac{N(N-1)}{\sum n(n-1)} \quad (3)$$

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

The Pielou index made it possible to measure the distribution of species with regard to their abundance within the same community. Its values vary from 0 to 1. It tends towards 0 when the dominance of one of the species is observed and towards 1 when there is a balance in the distribution of individuals within the species (Equation 4):

$$E = - \frac{H'}{\log_2(S)} \quad (4)$$

If  $0 \leq E \leq 0.6$ , then Pielou's equitability rate is low and the occurrence of the phenomenon of dominance is observed in the community. If  $0.7 \leq E < 0.8$ , then Pielou's equitability rate is average.

If  $0.8 \leq E \leq 1$ , Pielou's equitability rate is high: there is a lack of dominance in the community [33]

By the way, the Ascending Hierarchical Classification (HAC) has made it possible to gather species into increasingly large classes, on the basis of the measurements of similarity or distance. The results of this type of classification are represented as a dendrogram. HAC is different from the others by its use of a close variance analysis, aiming at assessing classes' distances [35]. In this work, the CAH was used to group the species on the one hand, soils, and on the other hand, the similarity of the stands on the basis of the average abundance of the species [35].

## 2.6. Statistical analysis

The different values obtained were analyzed using Microsoft Excel 2010 and Xlstat 2016 which made it possible to separate the treatment averages (Kruskal-Wallis test) from the Ascending Hierarchical classification and the production of histograms. The Past software made it possible to measure floristic diversity by calculating the Shannon, Simpson and Pielou indices to compare plant formations as a function of soil units.

# 3. Results and discussion

## 3.1. Degree of degradation of different soil units according to their chemical properties

The parameters evaluated (humidity, organic matter, carbon, nitrogen, C/ N ratio, pH and ash content) vary according to different soil units (Table 2).

Regardless of soil units, humidity is low ( $H < 2\%$ ) and varies significantly ( $F = 22.169$ ;  $P = 0.005$ ) (Table 2). At these low humidity values, the risk of degradation increases and plants can no longer absorb water. The study period (dry season), which is characterized by very hot temperatures, may be responsible for the low water content of the soils.

Soils OM content varies significantly ( $F = 21.750$ ;  $P = 0.005$ ) being higher ( $4\% < MO < 8\%$ ) in S4 ( $5.60\% \pm 0.83$ ), S7 ( $5.14\% \pm 0.10$ ) and S3 ( $4.23\% \pm 1.51$ ). Meanwhile, this content is lower ( $OM < 1.5\%$ ) in S5 ( $0.95\% \pm 0.78$ ) and S6 ( $1.02\% \pm 0.33$ ). The high OM contents reveal that the soils are well supplied and a good cohesion of the various physical parameters (structure, porosity, water retention or storage). The high OM contents reveal also a good biological activity ensuring the plant nutrition through actions of degradation and mineralization of the litter may be in existence. Moreover, the low levels of organic matter ( $OM < 1.5\%$ ) indicate that soils no longer have nutrient reserves, hence, limiting the soil biomass, which indicates a decline in fertility and its inability to adapt to growing conditions.

These results are different from those of [20] for S3 (MO between 0.1 % and 1.9 %), S4 (MO between 1.6 % and 1.8 % and can 2.8 %) and S7 (MO = 2.2 %) which have experienced an increase of organic matter content with time. This may result from the properties of the bedrock and the long fallow period which would have favored the development of biological activity. Despite the distance between both studies, the results are similar for S5 (MO = 0.8%) and S6 (OM varying between 1.6% and 1.3%) which kept a low content.

**Table 2** Average values of chemical parameters of soils units

Soil units	Humidity (%)	OM (%)	C (g.kg <sup>-1</sup> )	N (g.Kg <sup>-1</sup> )	C/N	pH water	pH KCL	AC
S1	1.24 <sup>ab</sup> ± 0.21	3.14 <sup>ab</sup> ± 1.37	18.18 <sup>ab</sup> ± 7.95	1.49 ± 0.20	12.87 <sup>ab</sup> ± 7.47	7.05 <sup>ab</sup> ± 0.00	6.66 <sup>ab</sup> ± 0.00	95.53 <sup>ab</sup> ± 3.61
S2	1.37 <sup>ab</sup> ± 0.45	3.97 <sup>ab</sup> ± 2.39	23.05 <sup>ab</sup> ± 13.84	2.26 ± 0.77	12.63 <sup>ab</sup> ± 10.06	7.45 <sup>ab</sup> ± 0.05	6.30 <sup>a</sup> ± 0.13	96.08 <sup>ab</sup> ± 2.44
S3	1.43 <sup>ab</sup> ± 0.41	4.23 <sup>ab</sup> ± 1.51	24.53 <sup>ab</sup> ± 8.74	1.65 ± 0.91	14.49 <sup>ab</sup> ± 4.53	7.56 <sup>b</sup> ± 0.21	6.65 <sup>ab</sup> ± 0.31	95.77 <sup>ab</sup> ± 1.51
S4	1.95 <sup>b</sup> ± 0.39	5.60 <sup>b</sup> ± 0.83	32.49 <sup>b</sup> ± 4.79	1.65 ± 0.91	22.38 <sup>b</sup> ± 6.84	7.33 <sup>ab</sup> ± 0.22	6.53 <sup>ab</sup> ± 0.16	94.40 <sup>a</sup> ± 0.83
S5	0.79 <sup>a</sup> ± 0.10	0.95 <sup>a</sup> ± 0.78	5.53 <sup>a</sup> ± 4.54	1.20 ± 0.45	4.72 <sup>ab</sup> ± 3.96	6.97 <sup>a</sup> ± 0.00	7.16 <sup>b</sup> ± 0.00	99.05 <sup>b</sup> ± 0.78
S6	1.12 <sup>ab</sup> ± 0.47	1.02 <sup>a</sup> ± 0.33	5.91 <sup>a</sup> ± 1.93	1.89 ± 0.41	3.29 <sup>a</sup> ± 1.37	7.51 <sup>b</sup> ± 0.00	6.69 <sup>ab</sup> ± 0.00	98.98 <sup>b</sup> ± 0.33
S7	1.63 <sup>ab</sup> ± 0.04	5.14 <sup>ab</sup> ± 0.10	29.83 <sup>ab</sup> ± 0.55	1.56 ± 0.45	20.00 <sup>ab</sup> ± 4.73	7.35 <sup>ab</sup> ± 0.00	6.90 <sup>ab</sup> ± 0.00	94.86 <sup>ab</sup> ± 0.10
S8	1.94 <sup>b</sup> ± 0.47	3.25 <sup>ab</sup> ± 0.33	18.83 <sup>ab</sup> ± 1.94	2.30 ± 1.36	9.98 <sup>ab</sup> ± 3.78	7.30 <sup>ab</sup> ± 0.14	6.57 <sup>ab</sup> ± 0.28	96.75 <sup>ab</sup> ± 0.33
S9	1.83 <sup>ab</sup> ± 0.54	3.57 <sup>ab</sup> ± 2.81	20.73 <sup>ab</sup> ± 16.30	2.66 ± 1.37	9.09 <sup>ab</sup> ± 7.24	7.42 <sup>ab</sup> ± 0.27	7.01 <sup>b</sup> ± 0.23	96.43 <sup>ab</sup> ± 2.81
F	22.169***	21.750***	21.750***	15.837	21.90***	22.917***	26.933***	20.443***
P	0.005	0.005	0.005	0.045	0.005	0.003	0.001	0.009

The values are significant according to the columns;  $P = 5\%$ . OM = organic matter; AC = ash content; C = Carbon; N = Nitrogen; S2: Slightly evolved soils of non-climatic origin of hydromorphic alluvial supply on recent alluvium; S4: Soils with tropical ferruginous iron sesquioxides with concretion on micaschists; S5: Soils with tropical ferruginous iron sesquioxides with concretion on acid eruptive rocks; S7: Soils with fersiallitic iron sesquioxides with calcium reserve and little leached-facies little developed on flaky rock with black minerals; S8: Hydromorphic mineral pseudogley soil with a perched tablecloth (high worm activity laundry facies) on mica schist; S9: Leached and vertical hydromorphic soils; \*\*\* significative value

Carbon content significantly varies ( $F = 21.750$ ;  $P = 0.005$ ) with values approaching the average content ( $C > 35 \text{ g / kg-1}$ ) in S4 ( $32.49 \pm 4.79 \text{ g / kg-1}$ ), unlike S5 ( $5.53 \pm 4.54 \text{ g.kg}^{-1}$ ) and S6 ( $5.91 \text{ g.kg}^{-1} \pm 1.93$ ) which are very poor ( $C < 35 \text{ g.kg}^{-1}$ ). Yemefack *et al.* [36], in a study carried out in a virgin forest of South Cameroon, also obtained low carbon contents ( $12 \text{ g.kg}^{-1}$ ) at a depth between 10 to 35 cm. Roose *et al.* [37] also obtained, in woody savannah plots, a stable carbon rate around  $7 \text{ g.kg}^{-1}$ .

Nitrogen content does not significantly vary ( $F = 15.837$ ;  $P = 0.045$ ) and is very low ( $N < 2 \text{ g.kg}^{-1}$ ) in the six soils units studied (except for S2, S8 and S9). Berlier *et al.* [38], in their work, obtained different nitrogen values, ranging from 0.6 to  $0.7 \text{ g.kg}^{-1}$ , in forest and savannah areas. This difference can be explained by the kind of environments where different climatic conditions prevail.

The C/N ratio varies significantly ( $F = 21.90$ ;  $P = 0.005$ ), being very low ( $C/N < 8$ ) in S5 ( $4.72 \pm 3.92$ ) and S6 ( $3.29 \pm 1.37$ ) but higher ( $15 < C/N < 25$ ) in S4 ( $22.38 \pm 6.84$ ) and S7 ( $20 \pm 4.73$ ). The low values of C / N ratio reflect an excessive degradation of organic matters, which makes the soil unfit to maintain microorganisms while the high values are indicative of poor decomposition of organic matters resulting from poor drainage, poor soil aeration, poor biological activity according to Brabant and Humbel [20], S7 soils have a C/N ratio (18) which is similar to that of the present study.

pH varies significantly ( $F\text{-pH}_{\text{H}_2\text{O}} = 22.917$ ;  $P = 0.003$ ), ( $F\text{-pH}_{\text{KCl}} = 26.933$ ;  $P = 0.001$ ), depending on soil units. Regardless of soil units and the type of pH (water and KCl), according to Landon [39] the values are between 5.5 and 7.5 which is the interval in which most of the plants grow. These results are similar to those of Brabant and Humbel [20] who obtained values ranging from 5.6 to 7.2 for these different soil units. The mineral element content of the soils studied varies significantly ( $F = 20.443$ ;  $P = 0.009$ ) and shows that the soils studied are rich in mineral elements (Table 2).

These previous results show that the degree of degradation varies depending on the soil units, so chemical parameters fluctuate. S4 and S7 have better chemical properties and are less degraded than S1, S2, S3, S8 and S9 which have intermediate chemical values and consequently, a moderate degradation. S5 and S6 have the lowest and most critical contents and are therefore the most degraded.

### 3.2. State of the plant diversity of the BNP and its peripheries

#### 3.2.1. Composition and flora richness

Plant inventory resulted in a total of 1.293 individuals classified under 30 species, 26 genera and 20 families. S2 soils are floristically the richest, with  $110 \pm 1.61$  individuals, 19.30 % of species (table 3). They are followed by S4 soils which have  $75 \pm 1.37$  individuals, 18.42 % of species. In contrast, S6 soils were those which had the smallest number of individuals ( $8 \pm 1.86$ ) for 6.14 % of species. This result shows that the species belonging to these families are capable of growing on a wide range of soil. Among these species, *Isobertlinia doka* (27.92 %) from Fabaceae family, is the only species found on eight of the nine soil units. This high presence of *I. doka* can be justified by its ability to be an undemanding plant from their food resources interest (edaphic source). When it grows, it is gregarious and /or associated with other woody species, namely *Piliostigma thonningii* which was the second most abundant species (7.12%). *P. thonningii* (encountered on six soils) like *I. doka*, quickly colonizes environments and grows on almost all types of soil except sandy soils. *Burkea africana* (6.19% of individuals present on seven soils) is one of the most encountered species which grow on a diversity of soils, especially those which are light, sandy, loose and sometimes, on rocky hills or silty clay soils. *Entada africana* (4.95 % of total individuals) are the most abundant species among the Mimosaceae family and *Parkia biglobosa* (3.25 % of individuals), both present on seven soils each.

**Table 3** Richness and plant diversity measured as a function of soil units

	S1	S2	S3	S4	S5	S6	S7	S8	S9
S (%)	7.02	19.30	14.04	18.42	9.65	6.14	7.89	12.28	5.26
D	$10 \pm 0.72$	$110 \pm 1.61$	$60 \pm 1.53$	$75 \pm 1.37$	$22 \pm 0.53$	$8 \pm 1.86$	$39 \pm 1.58$	$73 \pm 1.54$	$32 \pm 3.61$
Log <sub>2</sub> (S)	2.00	3.00	3.00	3.00	2.00	2.00	2.00	3.00	2.00
H'	2.00	2.00	3.00	3.00	2.00	2.00	2.00	2.00	1.00
D	1.00	0.86	1.00	0.93	1.00	0.84	1.00	0.83	1.00
E'	0.94	1.00	1.00	1.00	0.77	0.96	0.52	0.60	0.64

S: specific richness; D: density; Log<sub>2</sub> (S): maximum diversity; H': Shannon index; D: Simpson's index; E': Pielou fairness; S1: raw mineral soils of non-climatic origin of lithosol erosion on various rocks; S2: poorly evolved soils of non-climatic origin of hydromorphic alluvial input on recent alluvial deposits; S3: soils with tropical ferruginous iron sesquioxides leached maudaux on a coarse weathering or accumulation arena; S4: soils with ferruginous tropical iron sesquioxides with concretion on mica schists; S5: soils with tropical ferruginous iron sesquioxides with concretion on acidic eruptive rocks; S6: soils with tropical ferruginous iron sesquioxides with concretion on kaolinite alteration materials; S7: soils with fersiallitic iron sesquioxides with calcium reserve and little brown leaching; S8: facies little developed on flaky rock with black minerals; S9: leached and vertical hydromorphic soils or ferruginous soils with concretion.

These results are different from those of Narke [40] who worked in the transition zone between the Benoue National Park and the Faro National Park. He obtained, on a large number of plots (60) and on areas smaller than those in this study (400 m<sup>2</sup>), 2,861 woody species classified under 35 families. The most dominant of them were Cesalpiniaceae (33.68%), Combretaceae (17.63%), and Mimosaceae (7.71 %). The similarity between these two results resides in the dominance of the Cesalpiniaceae family and species such as *Isobertlinia doka* (312 individuals), *Burkea africana* (218 individuals), and *Piliostigma thonningii* (119 individuals). Contrary to the results in this study, the second dominant family is that of the Combretaceae with the taxa *Terminalia laxiflora* (145 individuals), *Combretum collinum* (102 individuals), *Terminalia macroptera* (96 individuals). The Mimosaceae family comes third with different species of Acacias (*A. dudgeoni*, *A. hockii*, *A. polyacantha*, *A. siberiana* ...) and *Antada africana*.

### 3.2.2. Floristic diversity according to soil units

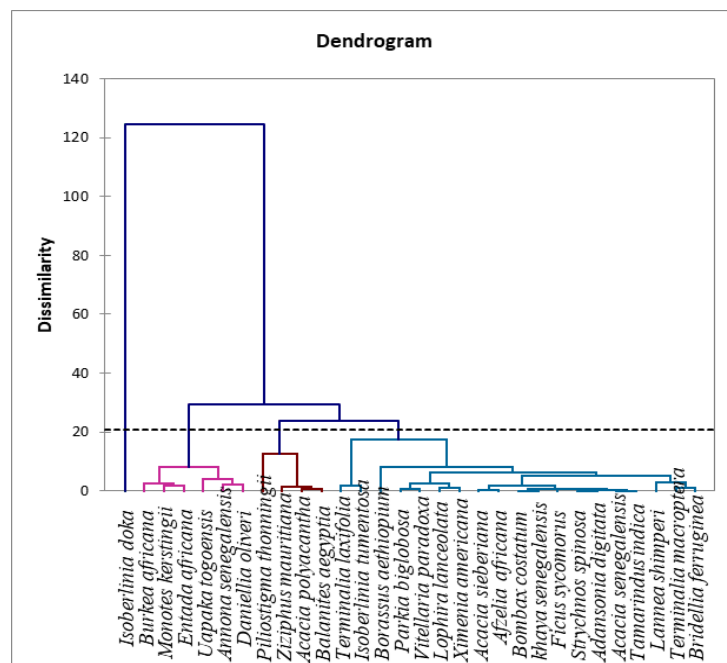
In Table 3, the Shannon, Simpson and Pielou indices are recorded. The Shannon index calculated for the different soil units indicates that S1, S3, S4, S5, S6 and S7 soils have values equal to the maximum diversity and are therefore more diverse than S2, S8 and S9 soils which values are below the maximum diversity. In the majority of soil units studied, Simpson index is closer to 1, indicating an absence of dominance. Pielou's index ( $0 \leq H' \leq 0.6$ ) is being low in S7, S8 and S9, an occurrence of dominance in the vegetal community under study is evident. The same Pielou index in S1, S2, S3, S4 and S6 is high ( $0.8 \leq E \leq 1$ ), inferring therefore an absence of in the vegetal community (Table 3).

In addition to the different indices, S1, S3, S4 and S6 are characterized by specific heterogeneity in the communities studied, showing therefore a good distribution of species according to their abundances. On the other hand, soils S8 and S9 show specific homogeneity in the communities and therefore poor distribution as a function of abundance. Although poor in species, soils S1 and S6 are diversified unlike soils S9 which are poor in species by being less diversified.

These results are similar to those of Vounserbo [41] who worked in the corridors of ZIC 1 and 4 of the Benoue National Park. From this study, it appears that the vegetation is diversified, based on the calculations of the Shannon-weaver indices, which vary between 3.6 and 4.5. According to him, this high diversity reflects the presence in each corridor of a multitude of plant species which are all relatively abundant.

### 3.2.3. Ascending Hierarchical Classification of Species according to Soil

Depending on the distribution and abundance of species per unit of soil, the Ascending Hierarchical Classification (ACH) shows a link between individuals who fall into four distinct classes (Figure 2 and Table 4). The dendrogram (Figure 2) shows that *Isobertlinia doka* is the species with the highest dissimilarity, solely constituting the first class and present on eight of the nine soils; particularly profuse on S2 soils and less present on S1 soils (Table 4).



**Figure 2** Ascending Hierarchical Classification of Plant Species

The second class, the most crowded, is made up of 19 species found on all soils with high representativeness on S2 soils and low representativeness on S6 soils (Table 4). The third class consists of 6 species distributed among all of the soil units and with dominance over S2 and S4 soils (Table 4). The fourth and last class is made up of 4 species encountered on seven of the nine soils, with a strong presence on S3 soils and a weak presence on S9 soils (Table 4). These results show once again that S2 soils contain the largest number of individuals grouped according to their species.

These results are different from those of Oumar [42], who, in a study on the vegetation in Benoue National Park and Bouba Ndjida Park, found 16 classes with a varying number of individuals. The most diverse class he found had 32 species. 9 classes were the least diversified with one species each. The difference in these studies can be explained by the difference of the sites studied and their specific characteristics.



**Table 4** Distribution of individuals in classes according to soil units

Classe	S1	S2	S3	S4	S5	S6	S7	S8	S9
1	5.00	111.00	19.00	21.00	19.00	0.00	63.00	70.00	53.00
2	1.16	7.10	2.89	4.10	1.37	0.21	1.05	4.58	1.42
3	0.50	12.83	4.17	12.50	2.83	3.33	2.17	0.50	1.83
4	0.00	2.00	20.50	13.25	1.50	0.00	5.25	14.75	1.25

S1: Raw mineral soils of non-climatic origin of lithosol erosion on various rocks; S2: Slightly evolved soils of non-climatic origin of alluvial hydromorphic input on recent alluvial deposits; S3: Soils with tropical ferruginous iron sesquioxides leached maudaux on coarse arena of alteration or accumulation; S4: Soils with tropical ferruginous iron sesquioxides with concretion on mica schists; S5: Soils with tropical ferruginous iron sesquioxides with concretion on acidic eruptive rocks; S6: Soils with tropical ferruginous iron sesquioxides with concretion on kaolinite alteration materials; S7: Soils with fersiallitic iron sesquioxides with calcium reserves and little brown leaching,) facies little developed on flaky rock with black minerals; S8: Mineral hydromorphic pseudogley soil with a perched tablecloth (laundry facies with high worm activity) On mica schist; S9: Leached and vertical hydromorphic soils.

### 3.3. Impact of chemical degradation of the different soil units on the loss of biodiversity

The table 5 shows impact of different chemical properties on the vegetation's density by soil units. According to the exploitation of this table, the most diversified soils are S2, S3, S4 and S8 which have a good organic matter, carbon nitrogen and ratio C/N. Therefore, the less diversified soils are S1, S5 and S6 which show poor content in the majority of chemical parameter study.

**Table 5** Abundance of the vegetation in function of chemical properties of soil

Parameters	Qualifications	S1	S2	S3	S4	S5	S6	S7	S8	S9
<b>OM (%)</b>	Very low (<1.5 %)					x	x			
	low (1.5 < OM < 2.5 %)									
	moderate (2.5 et 4 %)	x	x						x	x
	good (4 < OM < 8 %)			x	x			x		
<b>C (g.Kg<sup>-1</sup>)</b>	Very low (<10 g.Kg <sup>-1</sup> )					x	x			
	low (10 < C < 25 g.Kg <sup>-1</sup> )	x	x	x				x	x	x
	moderate (25 < C < 35 g.Kg <sup>-1</sup> )				x					
	high (> 35 g.Kg <sup>-1</sup> )									
<b>N (g.Kg<sup>-1</sup>)</b>	low (N < 2 g.Kg <sup>-1</sup> )	x		x	x	x	x	x		
	moderate (2 g.Kg <sup>-1</sup> < N < 4 g.Kg <sup>-1</sup> )		x						x	x
	high (N > 5 g.Kg <sup>-1</sup> )									
<b>C/N</b>	low < 8					x	x			
	good (8 < C/N < 15)	x	x	x					x	x
	bad (15 < C/N < 25)				x			x		
<b>Density of vegetation</b>	Very low (< 15)	x					x			
	low (15 < D < 30)					x				
	moderate (30 < D < 50)							x		x
	high (> 50)		x	x	x				x	

OM = organic matter; AC = ash content; C = Carbon; N = Nitrogen; S2: Slightly evolved soils of non-climatic origin of hydromorphic alluvial supply on recent alluvium; S4: Soils with tropical ferruginous iron sesquioxides with concretion on micaschists; S5: Soils with tropical ferruginous iron sesquioxides with concretion on acid eruptive rocks; S7: Soils with fersiallitic iron sesquioxides with calcium reserve and little leached-facies little developed on flaky rock with black minerals; S8: Hydromorphic mineral pseudogley soil with a perched tablecloth (high worm activity laundry facies) on mica schist; S9: Leached and vertical hydromorphic soils



#### 4. Conclusion

The general objective of this work was to determine the impact of the chemical properties of the different types of soil on the dynamics of biodiversity in the Benoue National Park and its western and northern peripheries. The chemical parameters of the nine soil units identified varied according to the different soil units. The results obtained allowed them to be classified according to three levels of degradation, namely: slightly degraded soils (S4 and S7), moderately degraded soils (S1, S2, S3, S8 and S9) and highly degraded soils (S5 and S6). These chemical parameters have influenced the distribution and abundance of the vegetation, which is unevenly distributed on the different soil units. The degraded soils, S6, were the poorest floristically, while S2 (moderately degraded) and S4 soils (slightly degraded) were the richest floristically. Among the 30 species identified, *Isoberlinia doka* is the most abundant species, represented on eight of the nine soils, with a strong presence on S2 soils and a weak presence on S1 soils. Other parameters such as physical, biological and anthropogenic parameters can be responsible for the dynamics of vegetation. It will therefore be important to extend the studies to these parameters.

#### Compliance with ethical standards

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##### *Disclosure of conflict of interest*

If two or more authors have contributed in the manuscript, the conflict of interest statement must be inserted here.

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