Journal of Environmental Protection, 2024, 15, 552-571
https://www.scirp.org/journal/jep
ISSN Online: 2152-2219
ISSN Print: 2152-2197

Physico-Chemical and Structural Assessment of Akono Riparian Forest Watershed, Tributary of the Nyong Basin (Centre-Cameroon) at Different Stages of Degradation

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How to cite this paper: Didier, N.R., Ajonina, G.N., Rose, N.N.C. and Minette, T.E. (2024) Physico-Chemical and Structural Assessment of Akono Riparian Forest Watershed, Tributary of the Nyong Basin (Centre-Cameroon) at Different Stages of Degradation. *Journal of Environmental Protection*, **15**, 552-571.
https://doi.org/10.4236/jep.2024.155032

Received: January 28, 2024
Accepted: May 28, 2024
Published: May 31, 2024

Abstract

Freshwater bodies are natural resources that should be exploited to the fullest, while maintaining the sustainability of ecosystems and ecosystem services which they support. Riparian forests are more important as they contain rivers which are vital sources of fresh water for local populations. However, the quality and quantity of water issued from the watershed depend on the structural state of these forests. The aim of this work was to assess the physico-chemical and structural state of the Akono gallery forest. To achieve this, fieldwork consisted of selecting six major streams of the watershed including Ndjolong, Menyeng adzap, Emomodo, Mvila, Negbe and Ossoé kobok. On each of these, two stations, one intact and one degraded, were marked by transects. The method involved measuring Hydrometric parameters (depth, length, width) of the stream and Physico-chemical parameters of water in the streams while dendrometric parameters were measured along 100 m-transects laid using the point-centred quarter method modified for water bodies to collect tree, shrub and palm variables such as trunk diameter, crown diameter and height. Macrophytes and species identification were carried out using standard botanical procedures. Results showed that, the majority of physico-chemical parameters measured differed significantly between intact and degraded stations ($P < 0.05$). This difference is thought to be linked to the undeveloped state of the intact stations and the disturbed state of the degraded stations. There was higher floristic diversity in the intact sites than in the degraded sites subjected to silvicultural activities. Simpson's index showed high dominance on intact sites (0.608), marked by the relative dominance of the species *Pentachletra mancrophylla*, whereas on degraded sites, this index was low and characterized by the relative dominance of species *Piptadeniastrum africanum*. Sorensen's index (0.56) and CFA showed that the different stands were homogeneous. We can affirm that the riparian forests of Akono watershed are towards a state of stability notwithstanding the perpetuation of anthropological actions.

Keywords

Akono Gallery Forest, Physico-Chemical Parameters, Floristic Diversity, Dendrometric Parameters

1. Introduction

The 1992 Rio de Janeiro conference raised global awareness of the threats to the environment and natural resources, including water. Consequently, the question of water availability and access is undoubtedly becoming one of the major issues facing humanity [1]. Moreover, sustainable water resource management requires the adoption of a holistic approach that takes into account the interactions between water, forests, other land uses and socio-economic factors in watersheds [2]. In this respect, the third World Water Forum held in Kyoto, Japan, in 2003, served as a guide to integrating an understanding of the biophysical interactions between forests and water into water management policies, since the biological, chemical and physical characteristics of forest soils are particularly well suited to providing good quality water and regulating the hydrology of watercourses [3]. On its part, Cameroon, by adhering to the Millennium Development Goals (MDGs) and other international and sub-regional initiatives, is committed to pursuing reforms aimed at reducing poverty through Integrated Water Resources Management (IWRM). This efficient management of water resources justifies the fact that it has an economic value, both in the immediate and longer term (the notion of sustainable development), which is often ignored by states with very high water potential. Their fish resources help to feed the population [4]. Indeed, they constitute powerful centers of interest for recreation, tourism and fish farming, capable of stimulating local and regional economies. However, the conversion of forests to crops and other uses almost always results in the deterioration of water quality and water shortages [5]. The ecological importance of riparian forests has been extensively reviewed by many authors. This importance is located: they play a critical role in hydrology in system sustenance and integrity: As pointed out by [6] these forests own their dynamics, structure and composition (species and habitat diversity and food webs) to river processes of inundation, sediments dynamics (transport of sediments), and biogeochemistry and nutrient cycling hence the erosive forces of water. The characteristic plant species, plant communities and associated aquatic or semi-aquatic animal species are intrinsically linked to the role of water as both an agent of natural disturbance and as a critical requirement of biota survival. They are also transition ecosystems. between terrestrial systems and open water systems but most heavily influenced by terrestrial ones. They attract species from both systems and are often very productive regions with high species richness [7]. In addition, they have a high level of primary productivity. Many support important populations of wildlife and plants including endangered species, terrestrial mammals such as primates and often a spectacular concentration of birds. Numerous aqua-forest areas form part of international flyways for migratory birds. Moreover, water quality and quantity in watersheds are increasingly threatened by overexploitation, misuse and pollution, and the case of Cameroon particularly in the forest of the Akono watershed where there is growing awareness that both these aspects (quantitative and qualitative) are strongly influenced by forests [8]. Observations made in this forest reveal negative consequences for this highly important ecosystem. These consequences include the abusive felling of trees, the diversion of the riverbed, agro-pastoral activities near the river, and the abusive harvesting of fish resources. The majority of anthropological factors influence water quality and the aquatic ecosystem by causing numerous degradations and pollution due to various human activities, over and above the quantity of water used for domestic and industrial purposes. In addition, it is known that many natural (abiotic, biotic) and anthropological factors have an impact on the quality and quantity of water and on the aquatic ecosystem as a whole. To the best of our knowledge, few studies have been carried out other general studies on the degradation of Akono riparian forests in relation to the quality of available water other than general studies. The general objective of this study was to assess the physicochemical and structural state of the Akono riparian forest. More specifically, it will assess the physicochemical characteristics of the water in the tributaries of the Akono watershed, and determine the species richness and plant community structure of the watershed's riparian forests at different levels of degradation.

2. Materials and Methods

Study site description

The Akono watershed is a tributary of the Nyong located in the Central Cameroon region, more precisely in the Mefou-et-Akono Division. It has a surface area of around 610 km^2 and an estimated population of 8000 ([9] [10]). The watershed is characterized by extensive dense secondary forest, with a marked presence of anthropogenic activities, particularly agricultural. It is drained by the Akono River, 45.9 km long. The Akono rises in the town of Mbankomo and flows into the Nyong in the town of Akono. It has a multitude of tributaries, six of which were the subject of this study (**Figure 1**).

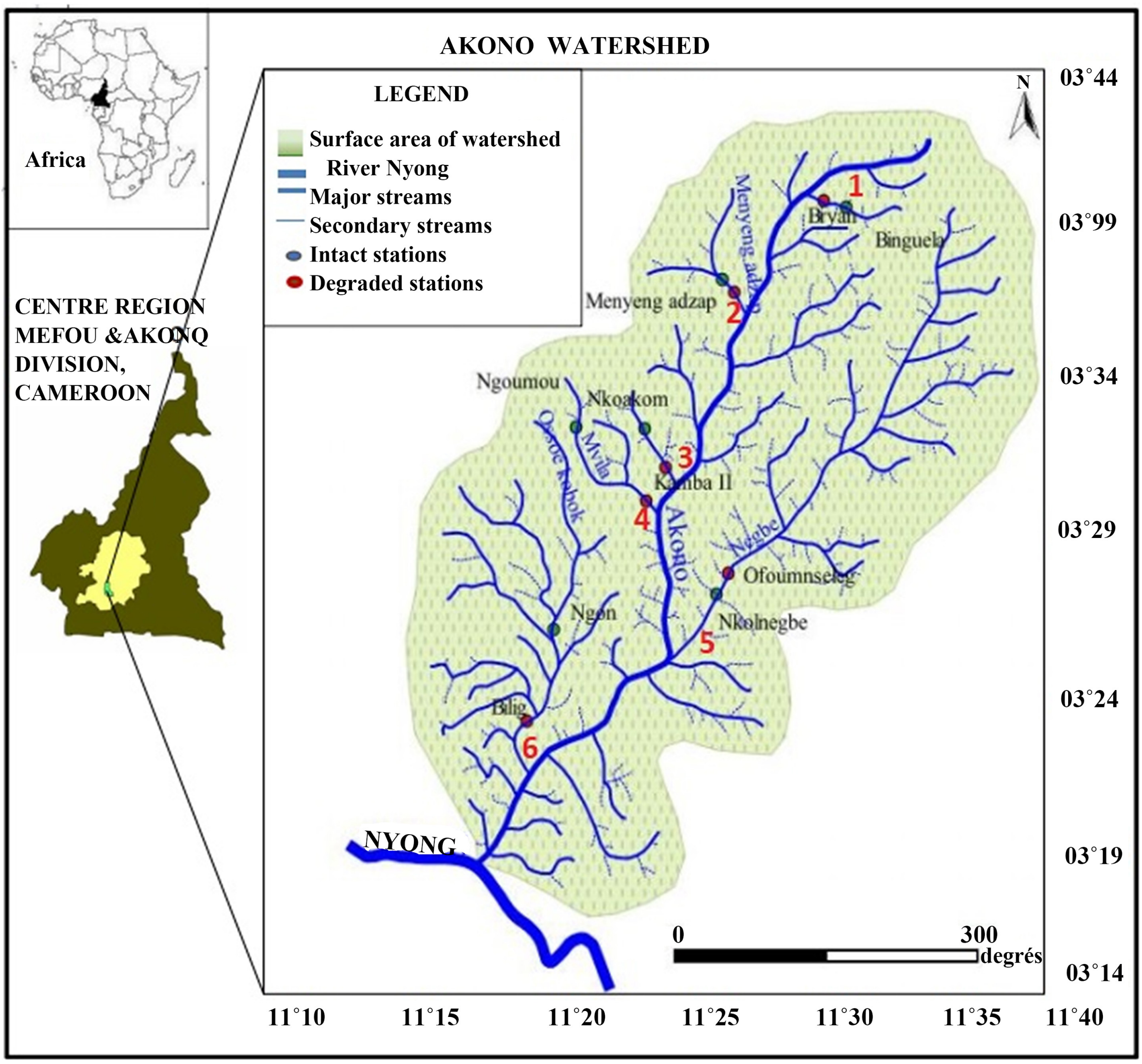

Figure 1. Map showing the Akono watershed showing River Nyong and her six (06) principal tributaries where sampling stations where choice (red dots: degraded, green dots: intact forests).

2.1. Data Collection

2.1.1. Choice and Description of Sampling Stations

After surveying all 06 tributaries, 12 stations were selected categorized into intact and intact forests according to Table 1.

Six (06) rivers major rivers were then selected including the Ndjolong (Nd), Menyeng adzap (Me), Emomodo (Em), Mvila (Mv), Negbe (Ne) and Ossoé kobok (Os). On each of these rivers, 02 sampling stations were selected, one of which was intact and the other little or not degraded, for a total of 12 stations. Intact stations were selected on the basis of the absence of human activity on the banks, abundant natural vegetation, characterized by stilt-rooted trees such as *Uapaca guineensis* (Figure 2).

Degraded stations were selected on the basis of the presence of human activity on the riverbanks. They were marked by agricultural activities, fallow fields and fish farming (Figure 3).

Table 1. Descriptive guide for the classification of riparian forest vegetation [11].

Vegetation description criterion	I-Qualitative description			
	Intact	Degraded	Highly degraded	Deforested
Vegetation type	Mixture of at least three layers (top, middle and bottom)	Mixture of at least two layers	Mixed vegetation with an open canopy, large trees are rare	Few or no trees, vegetation dominated by grasses and shrubs
Canopy closure	Dense and continuous with little or no sunlight penetration	Dense but interrupted with low sunlight penetration	Very open with sunlight penetration but shaded areas present	Very open with full sunlight penetration
Under growth vegetation density in terms of woody perennials, trees, shrubs, etc.	Very low, very free passage	Intermediate free passage	High, no free movements	Very high (vegetation composed of thick bushes and areas of bare earth)
Indicators (proportion of tree growth stages)	Weak presence of seedlings and saplings	Average presence of seedlings and saplings	High presence of seedlings, saplings and posts	High presence of grasses, shrubs and stunted vegetation
Forest soil moisture and litter humidity	High relative humidity and very moist litter	Moderate humidity at times, not very wet litter	Low humidity and dry litter	Very low humidity and very dry litter that burns easily
II- Quantitative criteria (REDD + criteria)				
Surface (ha)	1	1	1	1
% maximum big trees retained	70 - 100	50	10	0
Canopy height (m)	≥5	≥5	≥5	0
Canopy closure (%)	≥30	<30	<10	0

Six (06) transects were marked out at each sampling station, i.e. three (03) on each bank (Figure 4). The work strategy adopted enabled the study to be carried out in two phases: the first consisted of surveying the entire watershed, and the second of setting up the elongated transects, each measuring 100 m^2 (50 m long and 2 m wide). All the individuals of the forest stand present in each transect were identified and their parameters measured. Quadrats (4 quarters), laid out in three cross-shaped points [10] at 0, 25 and 50 m intervals respectively, were used to count macrophytes (Figure 4). At each station, water physico-chemical parameters were taken on the banks using a Hanna multi-parameter. River and hyrometric parameters (width, length and depth) parameters were also measured.

Figure 2. Characteristic intact stations.

Figure 3. Characteristic degraded stations.

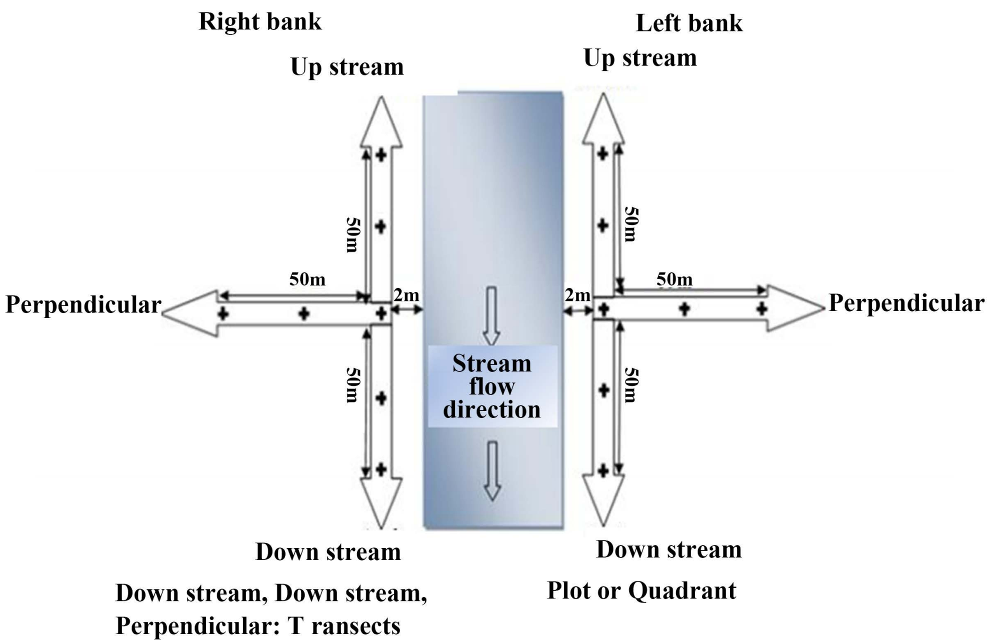

Figure 4. Layout and figuration of transects and quadrats illustrating Point-Centered Quarter Method of sampling with modification of sampling vegetation around water bodies.

2.1.2. Characterization of the Physico-Chemical Environment

To facilitate the determination of stream volume of discharge, the stream length, width and depth between two given points (A and B) at each sampling station were measured using a 100 m graduated and depth with a graduated pole. Current velocity was measured using a floating polystyrene object from the point

A to point B and a stopwatch to measure the time (t) taken by the floating object to travel between the two points. Temperature, TDS, turbidity, pH, electrical conductivity and dissolved oxygen were determined in situ using a Hanna multiparameter.

2.1.3. Floristic Characterization

Targeted sampling approach was used to locate stations points while plant communities within stations were sampled and characterized by means of transects and quadrats to record plant species (**Table 2**). Along each transect, for each tree, shrub, palm and macrophyte data were collected. Using standard forest mensuration procedures [12], trunk diameter (at a height of 30 cm for shrubs, 1.30 m for non stilt rooted trees and 30 cm above the stilt roots for stilt rooted trees), crown diameter (arithmetic mean of two perpendicular ground distances in meters between visually projected crown edges of the tree using a 100 m tape) and heights using Suunto hypsometer and local names to identify species. The PCQM systematically placed at 0 m, 25 m and 50 m from the transect was used to sample macrophytes (**Figure 4**). Overall, species identification was carried out in the field and later using identification keys for certain species.

2.1.4. Data Analysis

Characterization vegetation structural and diversity analysis into intact and degraded stations took into account floristic and structural parameters: Seedlings (0 - 5 cm); Poles (5 - 10 cm); Post (10 - 30 cm); Standards (30 - 50 cm); Mature (50 - 100 cm); and Hyper mature (100+). These structural parameters refer to the spatial distribution of woody species according to different diameter classes. Floristic parameters describe plant composition and specific distribution through the following indices:

The Relative Frequency of a species is:

$F = (Fi/Ft) \times 100$ with:

F = Relative Frequency

Fi = number of stations containing species 1;

Ft = total number of stations sampled.

Relative Density of a species is: $D = (n \times 100)/N$; where D is relative density en %, n = total number of individuals of this species; and N = total stand size

Table 2. Sampling method used.

Sampling unit	Sampling technique	Element assessed
Location of sampling points within stations	Targeted	Vegetation layer;
Transect location	Point center method (PCQM)	Trees; Shrubs; Palms.
Quadrat locations	Point center method (PCQM) systematically placed at 0 m, 25 m et 50 m from the transect	Macrophytes

Relative dominance of a species is: d = Nmax/N. where

Nmax is the area covered by a species

N surface area covered by all species.

Importance Value Index, IVI = D + d + F [13].

IVI = Importance Value Index

D = Densité relative;

d = Relative dominance;

F = Relative frequency

Diversity parameters were assessed on the basis of:

Simpson's similarity index (D') expresed as $D = \Sigma Pi^2$ où Pi = Sörensen index of presesnce given by $K = (2c/2a + b \times 100$ where c = number of species present in both stands, a = number of species belonging only to the first stand, and b = number of species belonging only to the second stand.

2.1.5. Statistical Analysis

The parametric ANOVA test was used to compare stream flow and physico-chemistry and vegetation cover between intact and degraded sites. These analyses were carried out using Xlstat 2014 and SPSS software at the 5% significance level which were also used to perform PCA and CFA in order to allocate stations according to abiotic parameters and to group sampling stations according to their floristic similarities. Microsoft Office 2010 Excel spreadsheets were used to construct the bar charts. Spearman correlation was used to determine relationships between physicochemical parameters and flora.

3. Results

3.1. Physico-Chemistry of the Aquatic Environment

The stream flow variation profile recorded in the intact stations shows the lowest flow values, with a minimum of 0.03 m^3/s (Menyeng Adzap) and a maximum of 3.32 m^3/s (Negbe). The average stream flow at these intact stations is 1.05 ± 0.87 m^3/s. At degraded stations, stream flow varied between 0.25 m^3/s (Emomoro) and 3.95 m^3/s (Negbe), with a high mean value of 1.67 ± 1.53 m^3/s. Stream flow differed significantly between intact and degraded stations ($P = 0.000$) (**Figure 5**). Other physico-chemical parameters are shown in that same figure. As far as temperature is concerned, the degraded stations show the highest values, with an average of 23.23 ± 0.12˚C, whereas the temperature values at the intact stations are the lowest, with an average equal to 23.31 ± 0.39˚C. Furthermore, there was a significant difference between intact and degraded stations ($P = 0.000$). During the study period, pH values varied a little between the intact stations (6.25 for the Mvila, and 5.48 for the Ossoé kobok), with an average of 5.82 ± 0.31. On the other hand, in the degraded stations, the average pH was 5.58 ± 0.28, with the lowest value, 5.16, obtained at Emomodo. On the other hand, pH did not differ significantly between intact and degraded stations (P = 0.163). Conductivity values at intact stations ranged from 19.66 µS/cm (Mvila) to 28.33 µS/cm (Negbe), with an average of 22.97 ± 2.95 µS/cm, while at degraded stations, values varied from 17 µS/cm (Negbe) to 37.66 µS/cm (Menyeng Adzap), with an average of 22.44 ± 7.73 µS/cm. It should be noted that electrical conductivity differed significantly between intact and degraded stations (P = 0.000). As for TDS values, an average of 0.0114 ± 0.0015 ppt was obtained at intact stations, with a variation ranging from 0.0097 ppt (Mvila) to 0.0142 ppt (Negbe). For degraded stations, TDS values fluctuated between 0.0085 ppt (Negbe) and 0.0188 ppt (Menyeng Adzap), with an average value of 0.0112 ± 0.0038 ppt. TDS differed significantly between the stations studied (P = 0.000). As for dissolved oxygen, values obtained at intact stations varied little between 1.01 ppm (Menyeng adzap) and 4.83 ppm (Emomodo), with an average equal to 2.91 ± 1.54 ppm. At degraded stations, low dissolved oxygen levels were recorded, with a minimum value of 0.10 ppm obtained at Emomodo and an average of 1.92 ± 1.05 ppm. Furthermore, dissolved oxygen did not differ significantly between intact and degraded stations (P = 0.176). Finally, the intact stations recorded high turbidity values, with an average of 52.81 ± 46.11 FNU. Degraded stations, on the other hand, had low turbidity values, with an average of 12.83 ± 3.51 FNU. Turbidity differed significantly between the stations studied (P = 0.000) (**Figure 5**).

3.2. Summary of Physico-Chemical Data Using Correspondence Factorial Analysis (CFA)

The first two axes F1 (45.45% inertia) and F2 (25.79% inertia) of the FCA account for 71.24% of the information explained, and discriminate the stations into two groups characterized by the physico-chemical parameter assemblages in the rivers studied (**Figure 6**). These two clearly differentiated groups highlight two structures based on water Physico-chemistry. Group 1 is made up of four degraded stations subject to the effect of temperature and two intact stations subject to the high effects of dissolved oxygen and pH; Group 2 is made up of four intact stations subject to the influence of turbidity and two degraded stations subject to the effects of TDS and electrical conductivity (**Figure 6**).

3.3. Spearman Correlation in Intact and Degraded Stations

3.3.1. Spearman Correlation at Intact Sites

Analysis of the Spearman correlation matrix between physico-chemical parameters shows that in intact stations, strong positive correlations exist between stream flow and optical density and total biomass, between pH and optical density, between electrical conductivity and TDS, between optical density, turbidity and vegetation density, and finally between total biomass and vegetation density (**Table 3**).

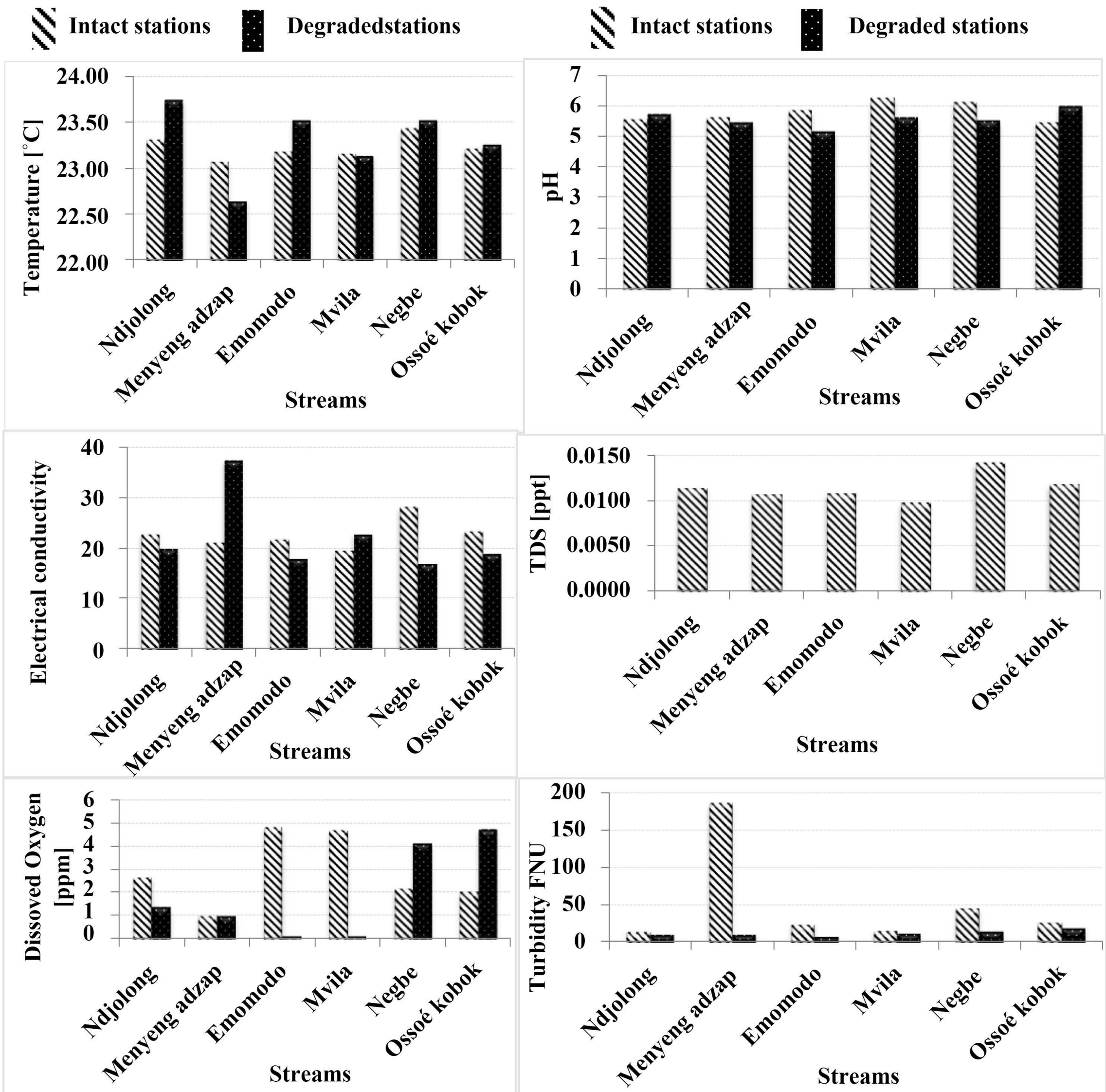

Figure 5. Some physico-chemical characteristics of the aquatic environment of observation stations of Akono watershed.

Table 3. Spearman's correlation matrix for intact stations.

Variables	Discharge [m³/s]	Tem. [˚C]	pH	EC [µS/cm]	TDS [ppt]	D.O. [ppm]	Turb. [FNU]	Total Biomass	vegetation density
Discharge [m³/s]	1	0.464	**0.600**	−0.371	−0.371	**0.771**	**0.543**	**0.771**	**0.657**
Temp.[˚C]		1	0.145	**−0.638**	**−0.638**	0.145	−0.319	0.377	**0.551**
pH			1	0.086	0.086	**0.714**	**0.600**	0.371	**0.600**
CE [µS/cm]				1	**1.000**	−0.257	−0.143	0.029	−0.200
TDS [ppt]					1	−0.257	−0.143	0.029	−0.200
D.O. [ppm]						1	**0.771**	**0.600**	**0.771**
Turb. [FNU]							1	0.143	0.200

Continued

Total Biomass	**1**	**0.771**
Vegetation density		**1**

Values in bold are different from 0 at significance level alpha = 0.05.

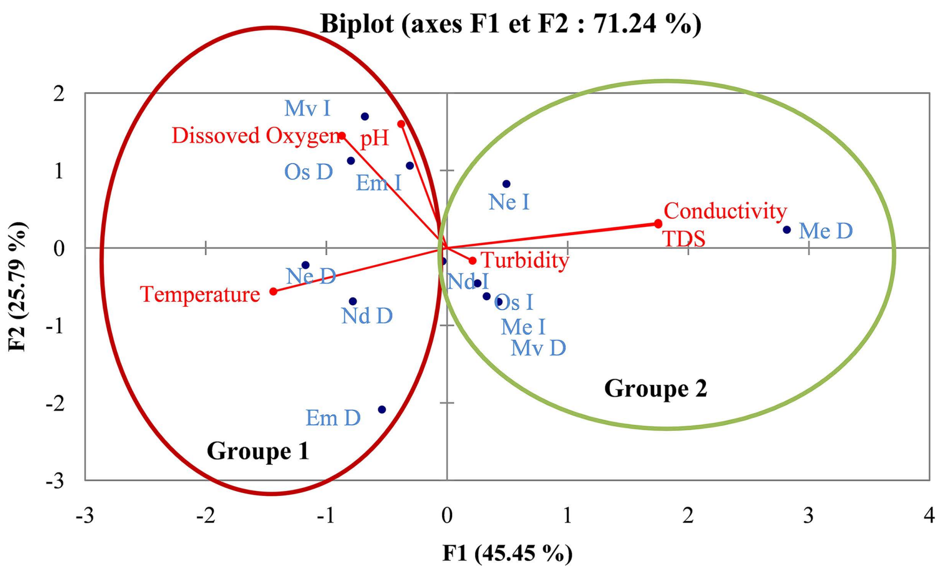

Figure 6. Projections of stations, described by their physico-chemical variations, on the plane of the first two factorial axes of the CFA on the rivers studied: Ndjolong (Nd), Menyeng adzap (Me), Emomodo (Em), Mvila (Mv), Negbe (Ne) and Ossoé kobok (Os) in intact/undegraded stations (I) and degraded stations (D).

3.3.2. Spearman Correlation in Degraded Stations

Analysis of the Spearman correlation matrix between physico-chemical parameters shows that in degraded stations, strong positive correlations exist between stream flow, temperature, electrical conductivity and TDS, between temperature, electrical conductivity and TDS, and between electrical conductivity and TDS (**Table 4**).

3.4. Species Richness and Structure in the Intact and Degraded Stations of the Rivers Studied

3.4.1. Species Richness and Structure of Plant Communities in the Rivers Studied

Some 17 tree and shrub species were identified in intact stations, classified in 15 families including Acanthaceae (01), Apocynaceae (02), Asteraceae (01), Caesalpiniaceae (01), Fabaceae (01), Ficaceae (01), Rubiaceae (01), Moraceae (02), Myrtaceae (01), Phyllanthaceaeles (01), Poaceae (01), Sapindaceae (01), Sterculiaceae (01), Terminaliaceae (01), Uapacaceae (01) and Urticaceae (01). The representation proportions show that the Apocynaceae and Moraceae families are the most represented, with 11.76% each, while all other families are represented by 01 species, corresponding to 5.88% (**Table 5**). In addition, the highest importance value index was obtained for Justicia secunda (82.80%) and *Pentachletra* *mancrophylla* (71.76%), which also had the highest dominance percentage of 54.24%. *Uapaca guineensis* (113%), *Pentachletra mancrophyll*a (84.44%) In terms of relative frequency, *Justicia secunda* (66.67%), *Psidium goyava* and lianescent species have the highest values, each with 33.33% (Table 6). As for Relative Density, the highest value was obtained for *Justicia secunda* (15.02%) (Table 5).

Table 4. Spearman correlation matrix for degraded stations.

Variables	Discharge [m³/s]	Temp. [˚C]	pH	CE [µS/cm]	TDS [ppt]	D.O. [ppm]	Turb. [FNU]	Total Biomass	Vegetation density
Discharge [m³/s]	**1**	**0.886**	−0.086	**0.829**	**0.829**	−0.086	−0.086	**−0.771**	0.086
Temp [˚C]		**1**	−0.143	**0.886**	**0.886**	0.086	−0.200	−0.657	0.200
pH			**1**	−0.371	−0.371	0.486	−0.029	−0.486	−0.314
CE [µS/cm]				**1**	**1.000**	−0.257	0.200	−0.371	0.143
TDS [ppt]					**1**	−0.257	0.200	−0.371	0.143
D.O [ppm]						**1**	**−0.714**	−0.257	**0.600**
Turb. [FNU]							**1**	0.314	−0.543
Total Biomass								**1**	0.143
Vegetation density									**1**

Values in bold are different from 0 *at significance level alpha* = 0.05.

Table 5. Structural indices for intact stations.

Families	Species	R.F. (%)	R.D. (%)	D (%)	IVI (%)
Acanthaceae	*Justicia secunda*	66.67	15.02	1.11	82.80
Apocynaceae	*Alstonia boonei*	16.67	0.43	0.25	17.34
	Pleiocarpa pycnatha	16.67	2.58	0.79	20.04
Asteraceae	*Vernonia amigdalina*	16.67	0.43	0.0008	17.10
Caesalpiniaceae	*Berlinia bracteosa*	16.67	0.86	6.41	23.94
Fabaceae	*Pentachletra mancrophylla*	16.67	0.86	54.24	71.76
Ficaceae	*Ficus exasperata*	16.67	4.72	0.07	21.46
Moraceae	*Chlorophora excelsa*	16.67	0.43	0.07	17.16
	Treculia africana	16.67	0.43	1.57	18.66
Myrtaceae	*Psidium goyava*	33.33	3.00	0.03	36.36
Phyllanthacea	*Phyllanthus discoideus*	16.67	0.43	0.45	17.54
Poaceae	*Phyllostachys viridiglaucescens*	16.67	4.72	0.97	22.36
Sapindaceae	Espèces lianescentes	33.33	3.00	0.29	36.63
Sterculiaceae	*Theobrama cacao*	16.67	0.43	0.02	17.12
Terminaliaceae	*Terminalia superba*	16.67	0.86	2.46	19.99
Uapacaceae	*Uapaca guineensis*	16.67	1.72	0.17	18.55
Urticaceae	*Musanga cecropioides*	16.67	3.00	3.97	23.65

RF: Relative frequency, RD: Relative Density, D: Dominance, IVI: Important Value Index.

Of the species recorded on the degraded sites, 12 families were found to be present. A total of 14 species of trees, shrubs and lianas make up these families, including Acanthaceae (01), Apocynaceae (01), Burseraceae (01), Caesalpiniaceae (01), Fabaceae (02), Myristicaceae (02), Rubiaceae (01), Rutaceae (01), Sapindaceae (01), Sterculiaceae (01), Uapacaceae (01), Urticaceae (01). The representation proportions show that the Fabaceae and Myristicaceae families are the most represented, each with 14.28%, while all the other families are represented by a single species corresponding to 7.14% (Table 6). Furthermore, the highest importance value index was obtained for lianescent species (115%), *Uapaca guineensis* (113%), *Pentachletra mancrophylla* (84.44%) and *Justicia secunda* (84.32%). These species also have the highest Relative Frequency values, at 100%, 100%, 83.33% and 83.33% respectively (Table 6). In terms of Relative Density, the highest values were obtained for lianescent species (13.72%) and *Uapaca guineensis* (5.99%), while *Piptadeniastrum africanum* and *Uapaca guineensis* were the species with the highest dominance percentages, at 7.78% and 6.76% respectively (Table 6).

3.4.2. Distribution of Vegetation Components by Size Classes (Diameter Classes)

Intact and degraded stations have vegetation consisting of trees, shrubs and palms. However, intact sites are characterized by a higher number of trees (246), shrubs (955) and palms (111). Tree densities ranged from 186 stems/ha (degraded sites) to 820 stems/ha (intact sites) (Figure 7(a) and Figure 7(b)). This distribution of diameter classes between intact and degraded sites shows a significant difference (P = 0.000) between the two.

Table 6. Structural indices at degraded sites.

Families	Species	R.F. (%)	R.D. (%)	D (%)	I.V.I. (%)
Acanthaceae	*Justicia secunda*	83.33	0.83	0.15	84.32
Apocynaceae	*Pleiocarpa pycnatha*	16.67	0.75	0.07	17.48
Burseraceae	*Dacryodes edulis*	16.67	0.08	0.33	17.08
Caesalpiniaceae	*Berlinia bracteosa*	16.67	0.08	0.67	17.42
Fabaceae	*Pentachletra mancrophylla*	83.33	0.91	0.20	84.44
	Piptadeniastrum africanum	16.67	0.08	7.78	24.53
Myristicaceae	*Pycnanthus ongolensis*	16.67	0.08	0.16	16.91
	Staudtia kamerunensis	16.67	0.08	0.05	16.80
Rubiaceae	*Mitragyna ciliata*	16.67	0.08	0.01	16.76
Rutaceae	*Citrus sinensis*	16.67	0.08	0.07	16.82
Sapindaceae	Espèces lianescentes	100	13.72	1.67	115
Sterculiaceae	*Theobrama cacao*	16.67	0.42	0.04	17.1
Uapacaceae	*Uapaca guineensis*	100	5.99	6.76	113
Urticaceae	*Musanga cecropioides*	33.33	0.25	0.41	34.00

RF: Relative frequency, RD: Relative Density, D: Dominance, IVI: Important Value Index.

3.4.3. Correspondence Factorial Analysis of Plant Communities in the Rivers Studied

The first two axes F1 (28.09% inertia) and F2 (21.83% inertia) of the FCA account for 49.92% of the information explained, and discriminate the stations into two groups characterized by the plant assemblages in the streams studied (Figure 8). These two clearly differentiated groups highlight two structures based on vegetation. The first group is made up of intact stations, with the exception of the degraded Ndjolong station (Nd D). This group is characterized by the following tree and shrub species: AB: *Alstonia boonei*, BB: *Berlinia bracteosa*, CE: *Chlorophora excels*, CS: *Citrus sinensis*, DE; *Dacryodes edulis*, L:Liane, MC1: *Mitragyna ciliata*, PM: *Pentachletra mancrophylla*, PD: *Phyllanthus discoideus*, PA: *Piptadeniastrum africanum*, PP: *Pleiocarpa pycnatha*, PO: *Pycnanthus ongolensis*, SK: *Staudtia kamerunensis*, TS: *Terminalia superba*, TC: *Theobrama* cacao, TA: *Treculia africana*, UG: *Uapaca guineensis*; palms: PC: *Palmae calamoideae*; macrophytes: DS: *Diplazium sammatii*, Msp: *Marantochloa sp*. A second group made up solely of degraded stations characterized by tree and shrub species: FE: *Ficus exasperata*, JS: *Justicia secunda*, MC2: *Musanga cecropioides*, PV: *Phyllostachys viridiglaucescens*, PG: *Psidium goyava*, TS: *Terminalia superba*, VA: *Vernonia amigdalina*; palms: EG: *Eleais guineensis*, PC: Palmae calamoideae, RF: *Raphia foranifera*; grasses: CO: *Chromolaena odorata*, CA: *Costa afer*, CI: *Cyperus iria*, IA: *Ipomoea aquatica*, MP: *Mimosa pudica*, PP: *Permisitum purpureum* (Figure 8).

3.4.4. Biocenotic Indices of the Rivers Studied

Simpson's index at intact sites was lower (0.354) than at degraded sites (0.608). These results reflect low plant diversity at intact stations and high diversity at degraded stations. The value of Sörensen's similarity index is greater than 0.5 overall, taking the stations studied in pairs. They therefore show relatively high similarities in the specific composition of plant communities (Table 7).

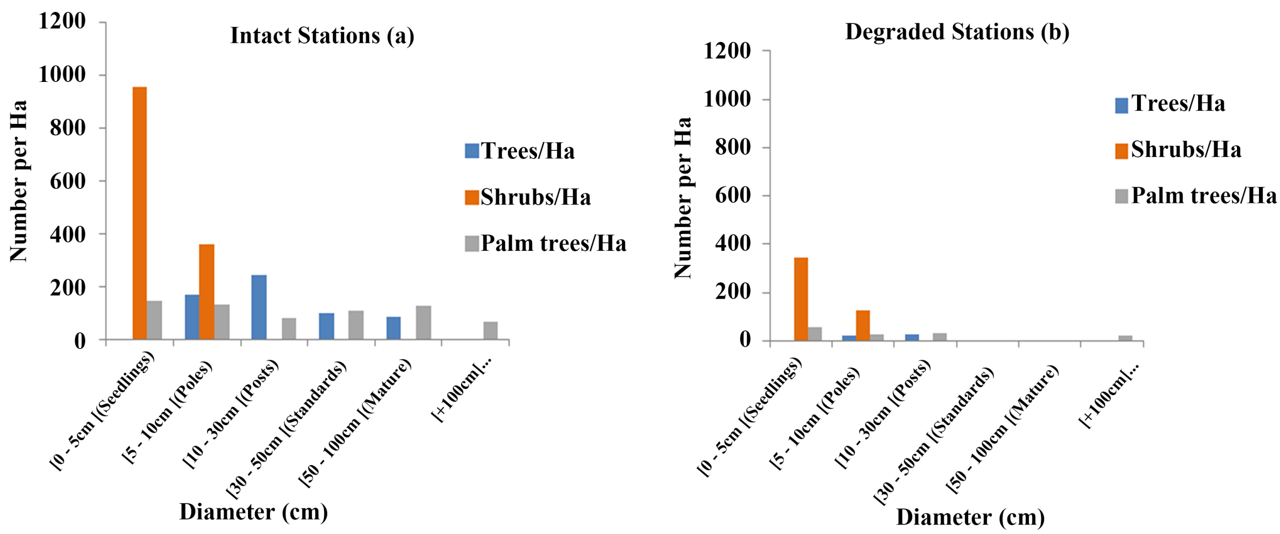

Figure 7. Distribution of the different components of the vegetation in diameter class in intact **(a)** and degraded **(b)** stations.

Table 7. Station diversity index.

Indice	Diversité de Simpson		Similitude de Sörensen
	Stations intactes	Stations dégradées	
Valeur	0.354	0.608	0.56

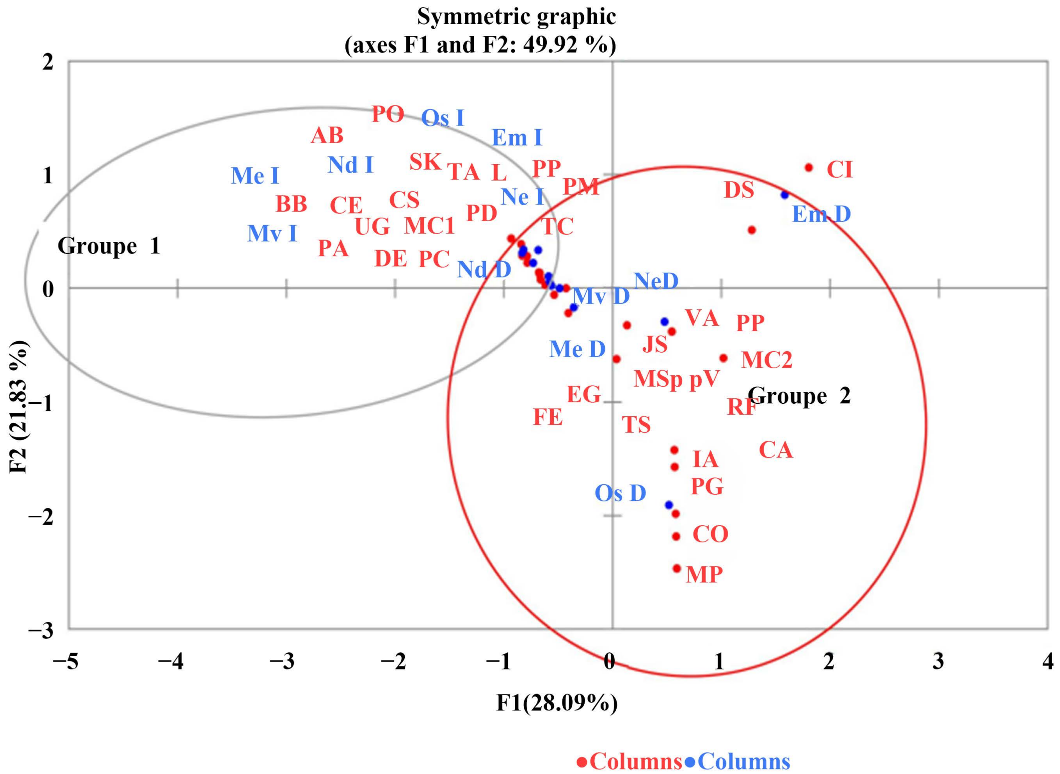

Figure 8. Correspondence factor analysis based on the density matrix of tree, shrub, palm and macrophyte species recorded at the different stations: AB: *Alstonia boonei*, BB: *Berlinia bracteosa*, CE: *Chlorophora excels*, CS: *Citrus sinensis*, DE; *Dacryodes edulis*, FE: *Ficus exasperata*, JS: *Justicia secunda*, L:Liane, MC1: *Mitragyna ciliata*, MC2: *Musanga cecropioides*, PM: *Pentachletra mancrophylla*, PD: *Phyllanthus discoideus*, PV: *Phyllostachys viridi glaucescens*, PA: *Piptadeniastrum africanum*, PP: *Pleiocarpa pycnatha*, PG: *Psidium goyava*, PO: *Pycnanthus ongolensis*, SK: *Staudtia kamerunensis*, TS: *Terminalia superba*, TC: *Theobrama cacao*, TA: *Treculia africana*, UG: *Uapaca guineensis*, VA: *Vernonia amigdalina*; palms: EG: *Eleais guineensis*, PC: *Palmae calamoideae*, RF: *Raphia foranifera*; grasses: CO: *Chromolaena odorata*, CA: *Costa afer*, CI: *Cyperus iria*, DS: *Diplazium sammatii*, IA: *Ipomoea aquatica*, Msp: *Marantochloa* sp, MP: *Mimosa pudica*, PP: *Permisitum purpureum*.

4. Discussion

4.1. Water Physico-Chemical Parameters

Generally speaking, the values obtained for physico-chemical parameters are higher at intact stations than at degraded stations, with the exception of stream flow rate and temperature. Specifically, the average stream flow rate at intact stations (1.05 ± 0.87 m3/s) is significantly lower than at degraded stations (1.67 ± 1.53 m3/s). Indeed, according to [14], the persistence of agricultural practices is generally accompanied by a significant increase in stream flow. Also, the removal of forest cover increases stream flow and in the long term can lead to drying up [15]. In addition, the strong negative correlation between stream flow and total vegetation biomass (r = −0.77) confirms these findings at degraded sites. With regard to temperature, degraded stations had the highest values compared to intact stations. This may be due, among other things, to the low vegetation cover at degraded sites and the high vegetation cover at intact sites. These observations are similar to the results obtained by [16] on the Nsapé and Ngoua rivers. In contrast to the above-mentioned parameters, the mean pH value in the intact stations (5.82 ± 0.31) is slightly higher than in the degraded stations (5.58 ± 0.28). This result can be explained by the fact that the substrate found in all these stations has the same characteristics. Furthermore, according to [17], water pH depends on the nature of the substrate and the origin of the water. [18] points out that the majority of aquatic species tolerate a pH between 5 and 9, which represents the usual pH limits in natural areas. In this study, mean values from TDS and electrical conductivity measurements were high at intact sites (0.0114 ± 0.0015 ppt, 22.97 ± 2.95 µS/cm), in contrast to degraded sites (0.0112 ± 0.0038 ppt, 22.44 ± 7.73 µS/cm). This difference in mean values can be explained, on the one hand, by the geochemical nature of the rocks encountered in the intact stations [19] and, on the other hand, by the low mineralization of the water in the degraded stations. The perfect, positive correlation between TDS and electrical conductivity (r = 1) at both intact and degraded sites confirms the close relationship between these two parameters. Waters from intact sites had a higher mean dissolved oxygen value (2.91 ± 1.54 ppm) than those from degraded sites (1.92 ± 1.05 ppm). This result is thought to be linked to the high photosynthetic activity of algae and aquatic plants at these sites [20]. The positive correlation between dissolved oxygen and total vegetation biomass (r = 0.771) confirms these findings at intact sites. Finally, the presence of litter and decomposing matter, which accumulates in the water in the form of suspended particles, could explain the high mean turbidity value in intact stations (52.81 ± 46.11 FNU) compared to degraded stations (12.83 ± 3.51 FNU). However, according to [21], the higher the suspended particle density, the more turbid the water.

The CFA carried out on the basis of the values of the 09 physico-chemical parameters measured thus enables us to differentiate between two major groups within the various study stations. The first group is made up mainly of intact stations, characterized by their relatively high dissolved oxygen concentration. These stations, whose physico-chemical characteristics are similar overall, can be likened to eutrophic waters and make up the least polluted sites in our study. The group of predominantly degraded sites is characterized by waters with low dissolved oxygen levels and high levels of organic matter. In fact, these plants receive water rich in organic matter from the surrounding plantations, which seems to be a consequence of the aerobic degradation of the organic substances contained in these discharges [22].

4.2. Species Richness, Structure and Diversity of Plant Communities in the Watercourses Studied

The plant communities in the watercourses studied included Acanthaceae, Apocynaceae, Asteraceae, Caesalpiniaceae, less Fabaceae, Ficaceae, Rubiaceae, Moraceae, Myrtaceae, Phyllanthaceae, Poaceae, Sapindaceae, Sterculiaceae, Terminaliaceae, Uapacaceae, Urticaceae, Burseraceae, Caesalpiniaceae, Myristicaceae and Rutaceae. Whether intact or degraded stations, the representation proportions show that the Fabaceae, Myristicaceae, Apocynaceae and Moraceae families are the most diverse. Values for species richness and diversity are higher in intact than in degraded environments. On this subject, [23] concluded after a study that the more degraded the environment, the less diverse it is. This assertion makes sense insofar as the observations made on degraded stations reveal the various anthropogenic pressures to which these watercourses are subjected. The low number (24) of species and the dominance of species such as *Uapaca guineensis* and lianas in the intact sites would characterize the unexploited aspect of these sites. The greater or lesser number of species in degraded sites would be due to the appearance of new species that are favorable to the new environmental conditions following silvicultural activities. However, strains of the original vegetation still exist despite degradation [24]. For example, the species *Diplazium sammatii* (fern), which is a macrophyte characteristic of forest undergrowth, dominates in both intact and degraded stations, but their abundance in degraded stations marks the change in the floristic composition of the natural forest due to human actions [25]. Furthermore, tree density in degraded stations (155 stems/ha) is not within the range of 400 to 650 stems/ha for natural tropical forests according to [26]. The same observations were made by [27] on intact and degraded forests in Madagascar. Furthermore, the distribution of diameters by tree, shrub and palm class in intact and degraded stations shows an irregular or inverted J-distribution with a dominance of seedlings. This distribution in degraded stations is also thought to be due to the presence of humans on the banks of the watercourses studied, characterized by subsistence agriculture, in contrast to the intact stations, which show no human disturbance. In addition, the high Simpson's index values in the intact stations (0.608) and low values in the degraded stations (0.354), followed by Sorensen's index (56.25%) obtained between the different stations, confirm that the two surveys belong to the same plant community, with the dominance of one species in the degraded stations.

5. Conclusion

This study aimed to assess the state of the riparian forest in the Akono watershed. The majority of physico-chemical parameters measured differed significantly between intact and degraded stations. This difference is linked to the almost primary state of the intact stations and the disturbed state of the degraded stations. The Spearman correlations obtained between total vegetation biomass and flow rate, total vegetation biomass and temperature, and vegetation density and dissolved oxygen at the degraded stations confirm the influence of riparian forest conditions on physico-chemical parameters in the Akono watershed. A study of the plant communities reveals the presence of a significant diversity of flora in both the intact and degraded stations subject to silvicultural activities. Simpson's index shows a high dominance of the species *Pentachletra mancrophylla* on intact sites, whereas on degraded sites, this index was low and characterized by the relative dominance of the species *Piptadeniastrum africanum*. Sorensen's index shows that these two surveys belong to the same stand, hence the result obtained with the CFA. On the basis of the above, we can affirm that the riparian forests of the Akono watershed are in a precarious state of stability, as the perpetuation of anthropic actions would constitute a brake on their natural or artificial restoration, which could increase the surface area of the so-called degraded stations. For the sustainable management of this riparian forest, several actions should be taken to maintain the quantity and quality of water needed for the local population to flourish in the Akono watershed. In another part, many measures may be taken to deal with water issues in Akono watershed including: People should be well sensitized on the socioeconomic importance of watershed to the communities around the watershed and the entire Nyong basin and the need for preventive measures. The activities of nearby forest reserves like the Dja forest reserve that depends on the watershed should be reinforced by conservation authorities. Finally, more research is carried out to study the status of the watershed and water supply dynamics to neaby towns of Akonolinga, Yaounde and the environment from the Akono watershed.

Acknowledgements

The authors would like to thank Cameroon Wildlife Conservation Society, Mangrove & Coastal Wetlands Research Centre for the availability of in situ data and for land cover data used in this study and Institute of Fisheries and Aquatic Sciences for information on the data base.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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