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Using Diatom Assemblages and Physicochemical Parameters to Characterize Waterfalls in Western Highlands of Cameroun, West Africa

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Authors' contributions

This work carried out in collaboration among all authors. Author BN designed the study and wrote the first draft of the manuscript. Authors NVF, FT and TJ managed the analysis of the study and literature searches. Author GJP wrote the protocol. Author KMF performed statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

Diatoms are mostly aquatic plants, growing in various environmental conditions and habitat. Because of their high sensitivity to environmental variations and rapid response to degradation, they are used as biological indicators. This study aimed to analyses the physicochemical parameters and diatoms assemblages of waterfalls. This will allow determining the key environmental factors that are responsible for both diatoms and *Podostemaceae* spatial and temporal distribution in the studied area.Water and diatoms samples were taken respectively for the physicochemical and biological analysis. Diatoms samples were collected by scraping the

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bedrocks and submerged plants; diatoms were subsequently identified to the species level using a light microscope. For physicochemical data analysis, a principal component analysis approach was used while diatom's data were submitted to a correspondence trophic analysis. A total of 169 diatom species were identified in both waterfalls. *Podostemaceae* poor waterfalls were more species-rich (127) than the rich ones (110). *Podostemaceae* poor and *Podostemaceae* rich waterfalls were characterized with low mineralization, low values of pH and oxygen saturated water. The observed assemblages were composed of oligotrophic to eutrophic species, acidophilic, neutrophilic and high to moderate oxygen saturated water taxa. The ecology of different species revealed that dissolved oxygen was the main parameter which controls the distribution of diatoms, and probably the *Podostemaeceae* one in the two type of waterfalls *Podostemaceae* poor waterfalls are characterized by *Fragilariacapucina* and *Gomphonema gracile.* Podostemacea rich waterfalls were characterized by *Eunotiafaba, Eunotiarhomboïdea*, *Pinnularia microstauron, Gomphonema procerum* and *Gomphonema clavatum*.

Keywords: Waterfalls; diatoms; water quality; Highland Cameroon; aquatic plants; microhabitats.

1. INTRODUCTION

Waterfalls are usually microhabitats, favourable to a particular group of plants; they are the only environments where plants of the family *Podostemaceae* can develop [1]. According to [1], *Podostemaceae*are involved in carbon uptakeand primary production. They are also used as food by aquatic herbivores and insect [2].In Cameroon, *Podostemaceae* are not present in all waterfalls [3] probably due to the differences among waterfalls. In the highland of Sudano - Guinean zone, almost all of the population is engaged in agriculture and livestock farming; these activities can release waste in the environment. In the long run, these releases can change the physicochemical parameters of water and consequently the loss of some species.

The presence of *Podostemaceae* in somewaterfalls probably reflects specific environmental characteristics that should be important to identify. Given the fact that the physicochemical analysis gives only instantaneous variations, the monitoring of water quality from diatomic bioindicators has proved necessary. The determination of diatomic bioindicators can be used to evaluate the short-term changes in the water quality of these environments. Given the difficulty of accessing the waterfalls, this research is important in making known the diatoms from this little-explored regions, as well as the determination of the diatomic indicators of these environments.

Diatoms are mostly aquatic microscopic plants, growing in various environmental conditions and habitat. They can supply useful information about the productivity and health of aquatic ecosystems and are thus used as bioindicators, because of their presence and diversity in most of the environments [4]. Their ecology and their high sensitivity to environmental variations are well known [1]. These algae have been the subject of numerous studies in East Africa [5,6,7]. In Cameroon, published data from [8,9] led to the identification of large number of algal species and demonstrated their relationship with physicochemical parameters in the lacustrine environments. In running water, with the exception of a few research done in Mfoundi's river around Yaoundé [10], very few studies have been done on the algal diatoms including those of the waterfalls. The objective of this study is to characterize each type of waterfall, through the physicochemical analysis and diatoms assemblages. This will allow determining the key environmental factors that are responsible for both diatoms and *Podostemaceae* spatial distribution in the studied area.

2. MATERIALS AND METHODS

2.1 Study site

The study was conducted in the western highland (5°30 ' N and 10°30' E) of Cameroon (Fig. 1). The western region is a hilly landscape made up of rounded mountain sand ancient volcanoes with the highest altitude in mount Bambouto at 2047 m. Patches of residual forests are encountered however at high altitude, preserved as sacred forest in the villages around the traditional Chief domain. The climate of West region is a Cameroonian altitude type with a rainy season from mid- March to mid- November and dry season from mid -November to mid - March. The average temperature is 20.46°C in West region [11]. Six waterfalls were sampled during six months, including three in the rainy season (August, September and October 2008) and three in the dry season (January, February and March 2009). The studied waterfalls were chosen based on the presence of *Ologotrophic indicator* plants known as *Podostemaceae.*

Two waterfalls are rich in *Podostemaceae* (Mami -water (MW) and Ligang-Foto (LG)) while waterfalls located in Balatchi (BT), Lepe (LP), Mintsie (MI) and Metschie (MT) are poor *Podostemaceae*. The analyzed samples were taken in all cases at the relevant waterfall (downstream), and above the waterfall (upstream). The parameters measured for water samples or *in situ* were: temperature (TEMP), pH (pH), electric conductivity (COND), total dissolved solids (TDS), orthophosphates (PO_4^{3-}), nitrates (NO^{3-}), sulphates (SO_4^{2-}) and total iron (FER).

2.2 Water Analysis

In the field, temperature (°C), electrical conductivity (µS.cm^{-1}) and total dissolved solids (mg L^{-1}) of water samples were measured using a multimeter Conductivity/TDS HACH apparatus. The pH was measured directly using a pH meter SUNTEX TS-2. The DR / 2000 HACH spectrophotometer was used to measure sulphates, nitrates and orthophosphates content (mg.L^{-1}) following appropriate methods.

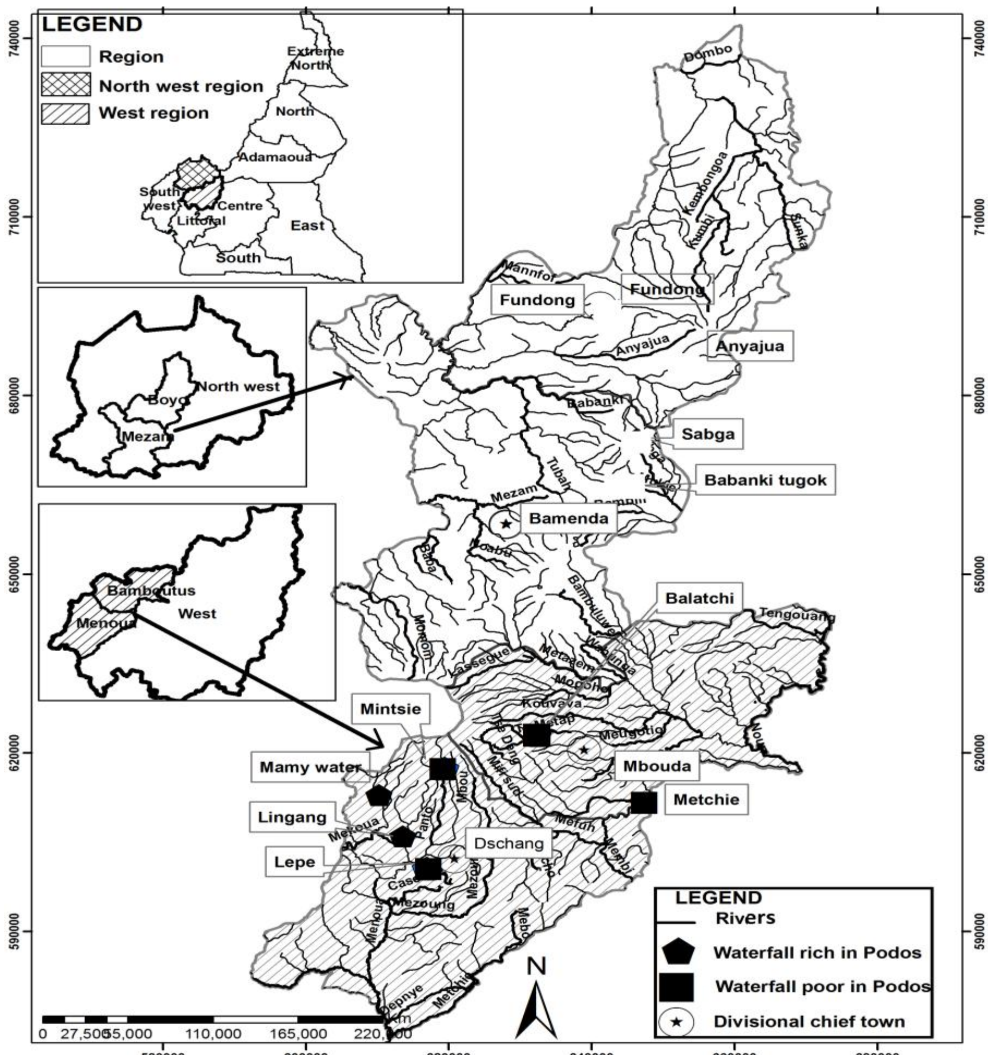

Fig. 1. Localization of the ten sampling points in the Northwestern and West region of Cameroon

2.3 Biological Analysis

Diatom samples were collected upstream and downstream of each waterfall by scraping the rocks, dead organic matter in suspension or fixed in the water. Samples for the identification of diatoms were treated with water peroxyde for two hours at 40 to 50°C. Such treatment destroys the organic matter contained in the samples and deflocculates clays. Samples were further cleaned with distilled water, two to three times to eliminate small size suspended organic or clayed matter. Two to three drop of remaining prepared sample were used to mount permanent slides. The identification was made using a light microscope, Olympus brand BHT -2 equipped with Nomarski optics. Diatoms encountered were identified at species level, at 1000x magnification with the identification keys of Bourrelly P [12], Bourrelly P et al. [13], Compère P [14], Compère P [15], Compère P [16], Gasse F [6], Krammer K et al. [17], Krammer K et al [18], Krammer K et al [19], Lude et al. [20].

2.4 Statistical Analysis

The physicochemical and diatoms data were submitted to Principal Component Analysis, (PCA) and correspondence Analysis (CA) respectively, using the Ade 4 package of R software. These multivariate analyses allow determining the major algal assemblages as well as environmental factors that determine their variability in space and in time. It thus precise the environmental parameters that better influence the development of the diatoms flora in the studied ecosystems

3. RESULTS

3.1 Physicochemical Characteristics of Waterfalls

Overall, the conductivity (CDT) and the total dissolved solids (TDS) showed comparable variations, with higher values in *Podostemaceae* poor waterfalls. These values were higher and showed high fluctuations in the dry season in both type of waterfalls. In the rainy season, the conductivity varied from 11.70µS cm^{-1} to 100.00µS cm^{-1} in rich waterfalls, and 24.30µS cm^{-1} to 64.40µS cm^{-1} in poor waterfalls. The maximum value was higher in *Podostemaceae* rich waterfalls than the poor ones, even if the later waterfalls showed a higher value (Tables 1 and 2).

The temperature varied from 18.3 to 23.4°C in *Podostemaceae* rich waterfalls, and from 17.17 to 24.60°C in *Podostemaceae* poor waterfalls. In the dry season, it varied from 17.60 to 25.6°C in *Podostemaceae* rich waterfalls and from 17.70 to 24.2°C in *Podostemaceae* poor waterfalls. Overall, the temperature values were higher in waterfall rich in *Podostemaceae*, compared to the *Podostemaceae* poor waterfalls.

In the rainy season, orthophosphates varied from 0.07 to 0.78 $mg.L^{-1}$and from 0.00 to 1.64 $mg.L^{-1}$, in *Podostemaceae* rich and poor waterfalls respectively. This trend was the same in the dry season, although the values were slightly lower.

Poor waterfalls areas of intense agricultural activities were more concentrated in the sulphates than the *Podostemaceae* rich waterfalls. However, in the dry season the rich waterfalls showed the highest fluctuations and the highest sulphates levels (Table 2). The total iron concentrations followed the same variations as sulphates.

Globally, the total iron, sulfates, total dissolved solids and conductivity were higher in poor waterfalls, compared to the *Podostemaceae* rich waterfalls. The other parameters, orthophosphate and pH appeared higher in the *Podostemaceae* rich waterfalls.

Nitrates were higher in *Podostemaceae* poor waterfalls in rainy season and higher in *Podostemaceae* rich waterfalls in dry season. Moreover, the two types of waterfalls experienced seasonal variations of orthophosphates and nitrates (higher in rainy season than in dry season), the conductivity and dissolved total solids (higher in dry season than rainy season).

3.2 Spatial and Temporal Variation of the Physicochemical Properties in Waterfalls

Principal component analysis (PCA) was performed with eight physicochemical variables measured during the sampling period and related to studied sites. The first two axes used in this analysis had a total inertia of 55.08%, with respectively 34.7% and 20.38% for the 1 and 2 axes (Fig. 2).

Total dissolved solids (-0.77%), conductivity (-0.78%), temperature (-0.54%) and sulphates (-0.64%) are correlated to the axis 1 and located to its negative side (group 1). Axis 2 is characterized at the negative side by

Table 1. Values min, max, median, mean, quartiles, inter- quartile of the measured parameters in rich and poor *Podostemaceae*'s waterfalls in the rainy season (August, September and October)

	Ph		Cond		Tds		Temp		Ortho		Nitr		Sulf		Fert	
	Rich waterfalls	**Poor waterfalls**	**Rich waterfalls**	**Poor waterfalls**	**Rich waterfalls**	**Poor waterfalls**	**Rich waterfalls**	**Poor waterfalls**	**Rich waterfalls**	**Poor waterfalls**	**Rich waterfalls**	**Poor waterfalls**	**Rich waterfalls**	**Poor waterfalls**	**Rich waterfalls**	**Poor waterfalls**
MIN	6,00	6,30	11.70	24,30	5.70	5,70	18.30	17,17	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX	8.6	7.6	100	64.40	50.00	33.50	23.40	24.20	0.78	1.64	10.60	11.60	12.00	25.00	2.00	1.00
1st QU	6.27	6.62	22.22	36.05	11.00	18.03	19.25	17.70	0.14	0.04	1.50	1.10	1.00	1.00	0.06	1.00
MEDIANE	6.92	7.05	28.40	40.75	14.15	20.30	20.20	19.80	0.22	0.09	1.70	1.75	1.50	1.00	0.15	1.00
3rd QU	7.60	7.42	39.25	47.28	17.75	23.60	21.60	22.45	0.36	0.15	2.00	3.00	4.00	2.00	1.00	1.00
INTER QU	1.33	0.8	17.03	11.23	6.75	5.57	2.35	4.75	0.22	0.11	0.5	1.90	3.00	1.00	0.94	0.00
MEAN	6.50	5.83	32.85	38.53	16.27	19.10	20.49	16.86	0.29	0.26	2.34	2.47	2.84	2.50	0.61	0.86

Min = minimum value, Max = maximum value, QU = quartile, inter QU = inter quartile, SD=Standard deviation

Table 2. Values min, max, median, mean, quartiles, inter- quartile of the measured parameters in rich and poor *Podostemaceae*'s waterfalls in the dry season (January, February and March)

	Ph		Cond		Tds		Temp		Ortho		Nitr		Sulf		Fert	
	Rich waterfalls	**Poor waterfalls**	**Rich waterfalls**	**Poor waterfalls**	**Rich waterfalls**	**Poor waterfalls**	**Rich waterfalls**	**Poor waterfalls**	**Rich waterfalls**	**Poor waterfalls**	**Rich waterfalls**	**Poor waterfalls**	**Rich waterfalls**	**Poor waterfalls**	**Rich waterfalls**	**Poor waterfalls**
MIN	5.50	6,60	13.80	32,00	6.90	16,00	17.60	17,70	0.03	0.00	0.30	0.00	0.00	0.00	1.00	0.00
MAX	7.80	7.60	49.00	67.40	24.50	33.50	25.60	24.20	2.16	1.64	11.90	11.60	3.00	25.00	2.00	1.00
1st QU	0.00	6.63	32.15	36.05	16.08	18.02	20.95	17.70	0.09	0.04	0.50	1.10	1.00	1.00	1.00	1.00
MEDIANE	6.35	7.05	35.75	40.75	17.80	20.30	21.65	19.80	0.12	0.09	1.25	1.75	2.00	1.00	1.00	1.00
3rd QU	6.96	7.42	40.00	47.28	20.00	23.60	22.45	22.45	0.46	0.15	3.65	3.00	3.00	2.00	1.00	1.00
INTER QU	6.96	0.81	7.85	11.23	3.2	5.58	1.50	4.75	0.37	0.11	3.15	1.90	2.00	1.00	0.00	0.00
MEAN	4.51	5.82	35.39	38.53	17.66	19.10	21.53	16.86	0.42	0.26	2.63	2.47	1.83	2.50	1.02	0.86
SD	3.26	2.84	7.54	21.51	3.77	10.57	1.65	8.41	0.39	0.18	1.98	1.74	1.02	2.00	0.17	0.35

Min = minimum value, Max = maximum value, QU = quartile, inter QU = inter quartile, SD=Standard deviation

Fig. 2. Plot F1x F2 axis of the PCA carried out with all the samples of *Podostemaceae* rich and poor waterfalls. Each sample being represented by the average values of physico-chemical parameters. A: spatial representation of parameters and B: spatial representation of the samples. The code for each sample includes the initials of the waterfall, (example LP = Lepe), the collection month (M = March), the collection point in the waterfall (V = downstream M = upstream), and the sample number (96) for the sample LPMV96

orthophosphate, nitrate and total iron (group 2) which are opposed to pH (Fig. 2A).

Considering the position of water samples on plane 1/2, we identified 3 groups (1,2 and 3) located on the negative and positive side of the axis 1 respectively. The first group consists of samples from *Podostemaceae*rich waterfalls (MWSV104, LGSV110) collected in the rainy season (September) and those of the poor falls (MTMV42, BTMV30) collected in dry season (March). Group 3 is composed by MIMV48, LPMM12 samples collected in March in *Podostomaceae* poor waterfalls (Fig. 2B). The majority of the remaining samples are characterized by pH which is more correlated with axis 2 on the positive side.This result reveals that the season is the principal element which distinguishes the two types of waterfalls.

In order to better characterize the relationships of the dynamic of environmental variables over the year in poor waterfalls, a second PCA was performed (Fig. 3).

In that analysis, data of *Podostemaceae* rich waterfalls were separated from those of the *Podostemaceae* poor waterfalls. The first three axes of *Podostemaceae* poor waterfalls have a total inertia of 76.16%. The factorial plane 1/2 revealed that axis 1 (34.2%) is characterized on the positive side by total dissolved solids (0.95%), and temperature (0.79%). These variables characterized the waterfalls of the Metchie in the dry season, associated samples are MTJV40 and MTF41. The opposite site of axis 1 is not characterized by any physic-chemical parameter. Axis 2 is characterized on the positive side by the pH and the total iron content (0.70 and 0.75% respectively) associated to samples of Balatchi (BTOV27) (Fig. 3B). These parameters are opposed to sulphates (-0.70%) which characterizes the sample of Mintsie (MISM20, MISV44) located at an intensive agricultural area.Axis 3(14.96 % of inertia) shows the influence of pH which is associated to orthophosphate at the positive side (Fig. 3A). They characterized waterfalls of Lepe (LPOM9 and LPOV33). These parameters are opposed to nitrate and total iron, located on the negative side of the axis and mainly represented by sample of Balatchi (BTFM5, BTFV29, BTJM4 and MIF47) (Fig. 3b).

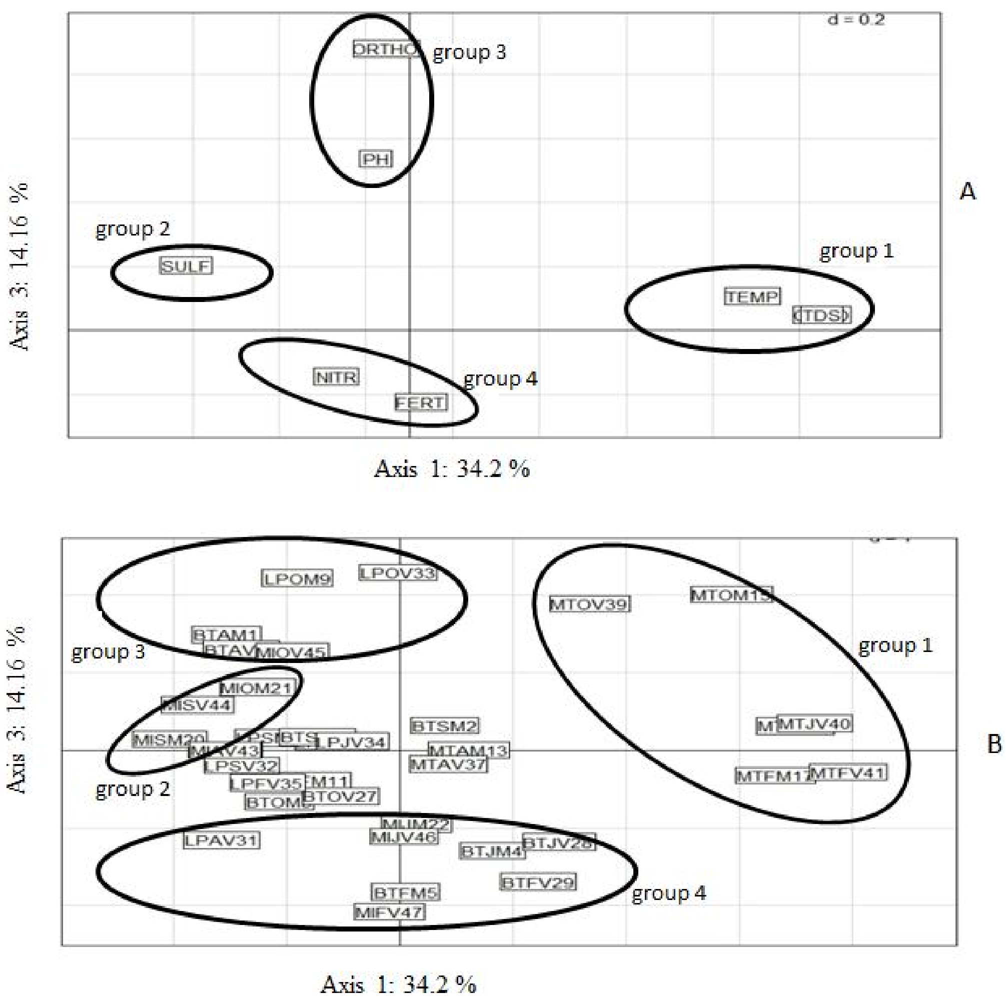

Fig. 3. Plot F1x F3 axis of the PCA conducted on the physicochemical parameters (A) and samples (B)of the *Podostemaceae poor* waterfalls

The opposition between the samples of the rainy season (group 3), located at the positive site of axis 2 and those of the dry season (group 4) located at the negative site of axis 2, probably indicates inter-seasonal variability of these parameters. These results are comparable to those of riche waterfalls.

The factorial plane 1/2 (53.1% of inertia) of data from *Podostemaceae* rich waterfalls showed that component F1 (33.42% inertia) is negatively correlated to total dissolved solids (-0.90%). This parameteris associated with samples collected in the dry season (March),of Mamy water (MWMV108) and Lingang (LGMV114)which are *Podostemaceae* rich waterfalls from the western region.

Axis 2 is correlated at the positive side to nutrients (nitrates and orthophosphates), samples collected in the rainy season. These nutrients are opposed to sulphates, located at the negative side of the axis (Fig. 3).Sulphates are associated to samples collected during the rainy season, in villages Lingang (LGAM73, LGAV109, LGOV111, and LGJV112).

The season is the criterion that distinguishes the two types of waterfalls. Poor waterfalls was mainly characterized by higher mineralization parameters like higher values of total dissolved solids (Metchie), by higher sulphates content (Mintsie), by higher pH value and orthophsphates concentration (Lepe) and low nitrates content (Balatchi). Rich waterfalls were characterized by and by higher mineralization: total dissolved solids (Lingang and Mamy waterfrom western region). In general, the western region waterfalls (mostly poor in *Podostemaceae's* waterfalls, excepted Mamy water and Lingang) seem to present high values of conductivity compared to the northwest (mostly rich in *Podostemaceae*). It would be interesting to see how these characteristics affect the diatom flora.

3.3 Relationship between Diatoms and Physicochemical Characteristics of the Water in the Waterfalls

In order to determine the factors that most influence the distribution of diatoms and *Podostemaceae* in the waterfalls, a correspondence analysis (CA) was performed on samples collected monthly, each defined by the specific composition and the abundance of diatoms. Axis 1 opposes the samples of group 1, located at positive side that were collected at Metchie (MTSV and MTAM), Mintsi (MISV), Lepe (LPAM and LPAV) and Balatchi waterfalls (BTAV) during rainy season (August and September) to group 2 located at negative side, with samples collected also from Metchie's (MTJM, MTFM) and and Lepe (LPMM) (Fig. 4A).

Water samples of group 1 sites were characterized by higher mineralization, low nitrates, whereas water samples of group 2 showed higher mineralization and higher orthophosphates content. The species associated with group 1 according to the analysis, showing relatively high contribution (> 15 %) and thus positively correlated (representation's quality> 39%) with axis 1 is *Gomphonema gracile* (Ehr.) [21]. Other species that are highly correlated to the axis (14-25%), despites their low contribution (0.68 to 5.93%), comprise *Achnanthes inflate* (Kützing) (Grunow) [5], *Eunotia bilunaris* (Ehr.) [5], *Fragilaria bidens* [5], *Fragilaria pinnata* [5], *Hantzschia amphioxis* [21], *Pinnularia microstauron* (Ehr.) Cleve [21]. The main characteristic species of the group 2 is *Gomphonema pumillum* (Grunow) [21], (AC = 13.07% and 30.04% RQLT).

Axis 2 opposes samples of group 3, located at the positive side; these samples were collected in the rainy season, at the upstream of the Metchie's waterfall (MTOM and MISM) or during the dry season upstream and downstream (MIJV AND MIJM) as well as in Balatchi waterfall (BTFV). Samples of group 4 that appears at the negative side of axis 2 were collected at the downstream of the Lepe's waterfall in September and October in the rainy season (LPSM and LPOM) (Fig. 3A). Water sample associated to group 3 are characterized by relatively higher mineralization, and law nitrogen values compared to water sample of group 4 (from Lepe, with higher pH and orthophosphates). Species associated to group 3 were *Gomphonema clavatum* Ehr [21] and *Fragilaria construens* (Gasse 1986) with relative higher contribution (> 23 %) and correlation (> 41 %). *Eunotia sp*, *Fragilaria berolinensis* [5], *Fragilaria ulna* var. *oxyrhynchus* Kützing (Lange-Bertalot) [19], *Fragilaria capucina* Desmazieres var. *vaucheriae* (Kützing) Lange-Bertalot [19], *Gomphonema clavatum var. bestimte* Ehrenberg [21] and *Navicula radiosa*var. *Fal lax*Lange-Bertalot [21] are well correlated to the axis (16 to 55 %), although they are less involved in the construction of this axis 2 as shown by their lower contributions (1.22 to 7.12 %). This result suggests that some other parameters cover the expression of that species in the milieu. The characterization of poor *Podostemaceae* waterfalls by species of oxygen-saturated media *Fragilaria capucina* and *Gomphonema gracile* shows that they are rich in oxygen.

The CA made on diatoms of *Podostemaceae* rich waterfalls showed a total inertia of 24.58% for the two first axis (Fig. 5).

From Fig. 5A, axis 1 (15.26% inertia) individualizes at the positive side sample BKMV, which was collected in dry season (March) in the waterfall. Water sample was characterized by high levels of nitrates and orthophosphates (group 1). The species with high contribution (36--61 %) and good correlation (>99%) to the axis are *Eunotiafaba* Grunow [19] and *Eunotia rhom boïdea* [19] (group 1). On the axis 2, only SGAV sample collected during the rainy season from Sabga stands out on the positive side. At this time of year, water was characterized by high levels of nutrients. *Pinnularia microstauron* (Ehr.) Cleve [21] (AC = 36.65% and 83.02% = RQLT), *Gomphonema procerum* [5], (AC= 14, 96% and RQLT = 82, 69%) and *Gomphonema clavatum* [21] (AC= 15, 98% and RQLT = 77, 98%) characterize the axis (group 2). Other species such as *Achnanthes lapidosa* [5], *Gomphonema minutum* (Ag.) Agardh [21], *Fragilaria capucina* var. *vaucheria*, *Fragilaria capucina* (group 3) are well represented on this axis (13 to 82%) even though they contribute little (0.12 to 8%) to its construction.

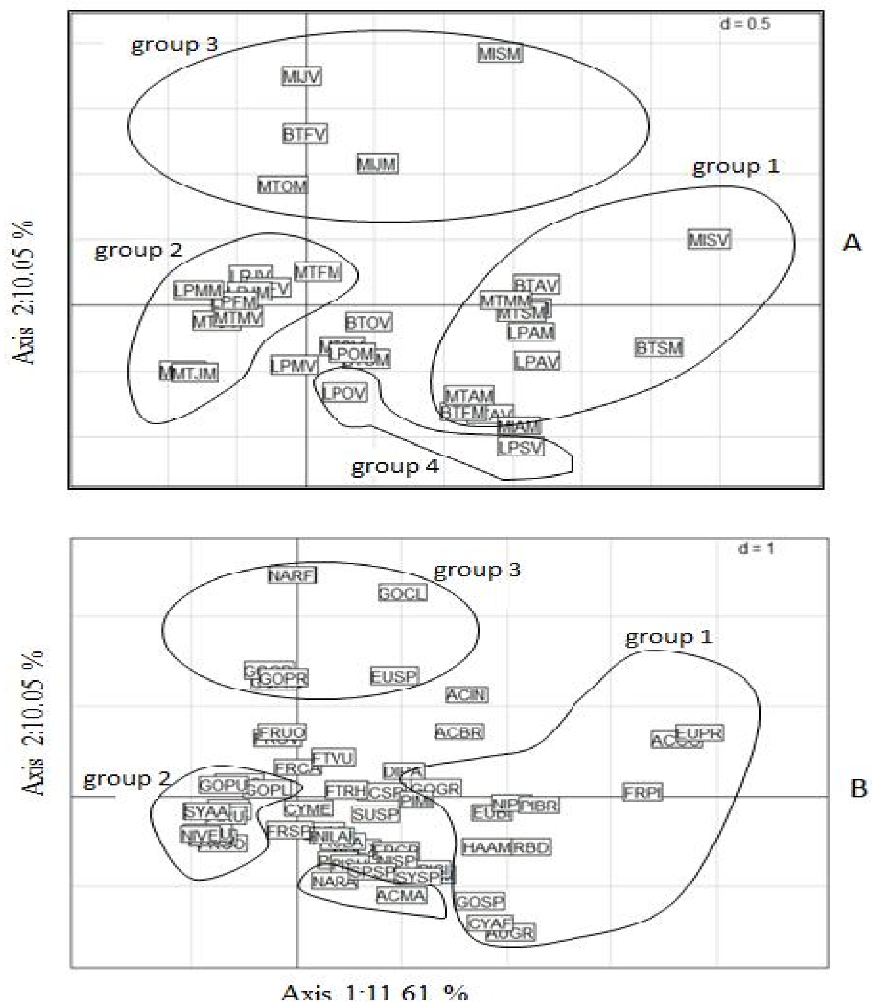

Fig. 4. Plot F1 x F2 axis of the CA performed on samples (a) defined by the abundances of diatoms species (b) in *Podostemaceae* rich waterfalls

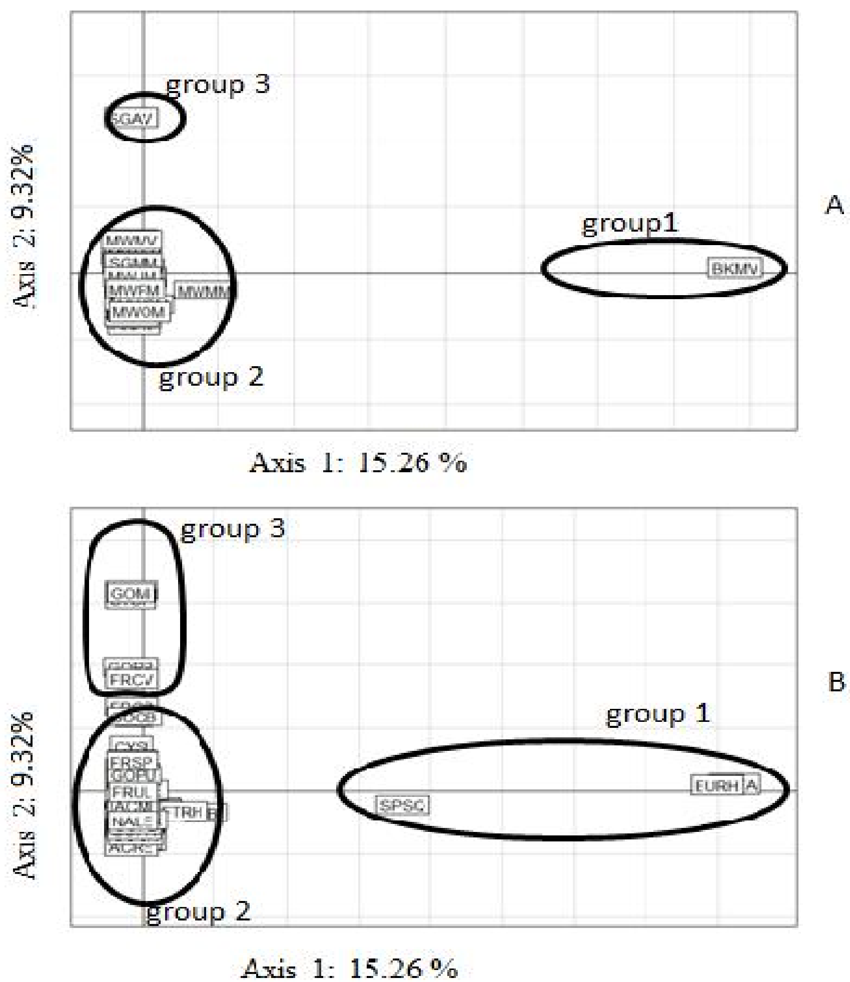

Fig. 5. Plot F1x F2 axis of the CA performed on samples (a) defined by the abundances of diatoms species (b) in *Podostemaceae poor* waterfalls

4. DISCUSSION

4.1 Physicochemical Parameter of the *Podostemaceae* Rich and Poor Waterfalls

In general, total iron, sulphates, total dissolved solids and conductivity were higher in poor *Podostemaeceae*'s waterfalls, compared to the rich ones.The higher mineralization observed in *Podostemaceae* poor waterfalls can be due to the difference in the nature of the land crossed by various rivers. In fact, the nature of the land crossed by various rivers may influence the variability of water characteristics, through erosion and alteration of different rocks. Indeed, on the southern flank of the Bambouto Mountains, where the Balatchi's waterfall is located, there is a granito - gneissic bedrock, covered with basalt. Alteration of this basalt under the effect of temperature and pH favors ion exchange which can be responsible of high conductivity values and therefore of the higher mineralization of water [22]. The other parameters, nitrates, orthophosphates and pH appear higher in rich *Podostemaceae* waterfalls compared to the poor waterfalls.

These variations of nutrients between different sites can be explained by the spatial variability of human activities. In western Cameroon, human activities are concentrated on agriculture, which uses large amounts of water for irrigation during dry season and large amounts of fertilizers and pesticides in both seasons. The value of mineralization and other parameters (nutrients) were globally lower in both types of studied waterfalls, compared to the values obtained by [10] in the Mfoundi's river in Yaounde Cameroon. This difference may be due to the intensity of human activities around the various types of zones. In the studied area of western and particularly the northwestern region, human impacts are still relatively low compare to watersheds of Mfoundi's river in Yaounde, a town of more than two millions people, where industries constantly inject non treated waste water into the river [23].

The two types of waterfalls experienced seasonal variations of orthophosphates and nitrates (higher in rainy season, compared to dry season), conductivity and total dissolved solids (higher in dry season compared to rainy season). These seasonal variations can be explained by changes throughout the year of factor such as intensity of erosion and leaching which are greater during the rainy season, and consequently drain more organic and inorganic pollutants in aquatic ecosystems. This characteristic can be more pronounced in great rivers as Metchie with higher flowing rate than in Lepe waterfall where the amount of water is used upstream for crop irrigation.

4.2 Relationship between Diatoms and Physicochemical Characteristic in Poor and Rich *Podostemaceae's* Waterfalls

Diatom flora showed that *Podostemaceae* poor waterfalls were richer (127 species) than the rich waterfalls (110 species). This number of species is very high compared to the number of species (70 species) numbered by [24] in waterfalls of Dari in Turkey.

The PCA result reveals that the season is the principal element which distinguishes the two types of waterfalls.The rich waterfalls (Mamy-water and Lingang) are characterized by higher mineralization in rainy season. Result also revealed the opposition along the axis of samples from the waterfall of Mintsie, characterized and samples of the waterfall of Metchie on the positive side, showing higher mineralization. This variation in the mineral content can be attributed to degradation of organic matter, and/ or the alteration of rock [22] that might be variable from one site to another. Indeed, the sample of the waterfall of Mintsie that intervenes mainly in the construction of axis 1 was taken during the rainy season, while that of the waterfall of Metchie was collected in the dry season. Thus, this pattern might also be evidence in these areas where the very anthropogenic activity is agriculture in the watershed, the variation of seasonal hydrological impacts between the rainy and dry season. It is likely that the rainy season runoff would have drained a large amount of organic and inorganic ions from Mintsie towards the shallows rivers, while high temperatures would have favored the evaporation of water and the rocks alteration in the waterfall of Metchie.

According to the floristic analysis, *Podostemaceae* poor waterfalls were characterized by group 2 composed by *Gomphonema gracile*, and *Gomphonema pumillum*in higher mineralized water (Metchie and Mintsie), *Gomphonema clavatum* in higher pH and orthophosphates (Lepe), *Fragilaria construens* low nitrates (Balatchi).These species grow well in mesotrophic environments, at neutral pH, low salinity and saturated in oxygen [25]. The differences observed in the environmental parameter like pH can be due to the adaptation of species to such variation *Podostemaceae* rich waterfalls were differentiated by PCA results, by nitrates orthophosphates and iron contents. Species associated with the axis 1 were acidophilous species, preferring oligotrophic and saturated oxygen waters, in accordance with analyzed physicochemical characteristics. The Correspondence Analysis(CA) grouped together most of the *Podostemaceae* rich waterfalls samples at the origin of the axis, there is a low differentiation between samples defined by the specific abundances. However, acidophilic species such as FTRH (*Frustulia rhom boides*) and FRBI (Fragilaria *biceps*) and others are clustered at the negative side of axis 2 (group 3), whereas the samples around the origin of the axis are essentially characterized by species which are neutrophilic to alkaliphilic. This result shows that pH is also important parameter which is responsible for spatial distribution sample species as showed in other studies in Central Africa [8]. The second axis of the FAC, with the sample of SBGA which has strongly contributed to the construction of this axis characterized by highly content of sulphates and associated diatoms taxa were indifferent species according to trophic level, at neutral pH and moderate oxygen water content.

The result, confirmed by those of the PCA and CA does not agree with the idea that *Podostemaceae* are very sensitive to pollution

[3]. In all cases, it is possible that the level of pollution according to the studied parameters was not sufficiently high to alter thedevelop high concentrations of nutrients. There may be other physicochemical parameters that have not been considered during this work which can better explain the spatial distribution of the *Podostemaceae* in studied sites. The nutrient levels are probably not the primary factor of the *Podostemaceae's* distribution in the waterfalls. However, this result suggests that in rich *Podostemaceae* waterfalls, high fluctuations in nutrients and low oxygenation and pH are responsible for the diatom distribution.

5. CONCLUSION

The analysis of the algal flora in this study revealed that the poor *Podostemaceae*'s waterfalls are richer in species compared to the rich *Podostemaceae*'s waterfalls. This was explained by factors such as higher mineralization of water, the higher values of pH, the higher oxygen content of the poor *Podostemaceae*'s waterfalls. The two types of waterfalls experienced seasonal variations of orthophosphates and nitrates (higher in rainy season than in dry season), conductivity and total dissolved solids (higher in dry season than rainy season). Changes in water quality and diatoms assemblages can be linked to changes in chemical conditions during the year that involve significant variations in rainfall and temperature. In all the waterfalls, although the dissolved oxygen content was not collected the ecology of different species revealed that dissolved oxygen, low mineralization, pH, and nutrients contentare the main parameter which control the distribution of diatoms, and probably the *Podostemaeceae* in the two type of waterfalls. Rich *Podostemaceae* waterfalls are probably less saturated with oxygen than poor ones. Indeed, the characterization of poor *Podostemaceae* waterfalls by species of oxygen-saturated media *Fragilaria capucina* and *Gomphonema gracile* shows that they are rich in oxygen. In addition, poor *Podostemaceae* waterfalls are mainly characterized by high mineralization and by the species *Fragilaria capucina* and *Gomphonema gracile* which are species of saturated oxygen milieu. In rich *Podostemaceae* waterfalls, however, it is the strong fluctuations in nutrients that characterize the environment, and the species encountered are *Pinnularia microstauron*, *Gomphonema clavatum*, and *G. procerum.* The season is the criterion that distinguishes the two types of waterfalls. Poor waterfalls was mainly characterized by higher mineralization: total dissolved solids (Metchie), by higher sulphates content (Mintsie), by higher pH value and orthophsphates concentration (Lepe) and low nitrates content (Balatchi). Rich waterfalls (Lingang and Mamy) were characterized higher level of mineralization: total dissolved solids.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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