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Research Article

Diversity of Cyanobacteria in Some Polluted Wetlands of Nkwen in Bamenda (North-West, Cameroon)

Ndjouondo Gildas Parfait*, Muyang Rosaline Fosah, Ache Neh Teke, Choula Tegantchouang Fridolin

Department of Biology, Higher Teacher Training College, The University of Bamenda, Bamenda, Cameroon

Abstract

Human activities more and more intensify the pollution of aquatic ecosystems. These pollutants lead to some Cyanobacteria proliferation causing "blooms" or "efflorescence" and disappearance of sensitive species. The aim of the study was to determine the composition and variation of Cyanobacteria community in some polluted wetlands of Nkwen in Bamenda. Sampling of Cyanobacteria took place from October 2022 to September 2023 by using plankton net for phytoplankton and scrubbing for periphyton. Some hydromorphological and physicochemical parameters of water were measured in situ and in the laboratory. Results showed that species richness of microalgae amounted to 11 families divided into 22 genera and 46 species. Oscillatoriaceae constituted the most important family (26.66% with 12 species) of the Cyanobacteria community, in the study sites. Shannon-Weaver's index was weak and varied between 1.24 (site 6) and 2.65 (site 2). These results showed that wetlands of Nkwen had a Cyanobacteria community more abundant where the water velocity is low, with high nitrates and phosphates contents. Different Cyanobacteria families with strong proliferation in polluted waters (sites 1, 2 and 3) were: Oscillatoriaceae, Gloeotrichiaceae, Rivulariaceae, Nostocaceae, Merismopediaceae, Microcoleaceae, Microcystaceae and Tolypotrichaceae. On the other hand, the families abundantly present in less polluted waters (sites 4, 5 and 6) were: Chroococcaceae, Pseudanabaenaceae and Aphanizomenonaceae. Thus, physicochemical parameters have an influence on the composition and structure of Cyanobacteria community in wetlands of Nkwen in Bamenda. Monitoring, based on biological indices of Cyanobacteria, could be developed to prevent the risks of perturbation of these wetlands.

Keywords

Cyanobacteria Community, Physicochemical Parameters, Wetlands, Nkwen, Bamenda

1. Introduction

Cyanobacteria are photosynthetic prokaryotic microorganisms found in wetlands and also known as Cyanophytes or Cyanophyceae that inhabit a wide variety of habitats as free living, epiphytic, symbiotic or parasitic plants [1]. They form a component of the base of the aquatic food chain, and their photosynthetic activity aerates the habitat. Hence, they are of great importance in aquaculture. *Spirulina* and *Nostoc* are sources of proteins, edible to man. Nitrogen fixing forms (*Anabaena* and *Nostoc*) increase the nitrogen content of the habitat and supply nitrates in symbiotic relationships where they enhance the nutritive quality of the host plant, which could be used as green manure, fodder, and fish feed. Some

*Corresponding author: parfaitgildas@gmail.com (Ndjouondo Gildas Parfait)

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act as bio-fertilizers, a fact that can be utilized effectively in improving plant nutrition, especially in rice and wheat production. As producers of growth hormones, they improve yield of rice (e.g. *Phormidium tenue*). Consequently they are essential in rice based economies. Some are capable of producing antibiotics (*Microcystis*, *Nostoc* and *Scytonema*) [2].

Cyanobacteria prevent soil erosion; help in soil water retention, sodium removal and act as the first colonizers in land reclamation. Blooms of some species release toxins and lead to anoxia in the habitat to the detriment of the biota. *Phormidium* is known to reduce the quality of brine. Some of these Cyanobacteria have been observed in Cameroon. There is therefore the need to harness them or combat the obnoxious forms [3]. Control of blooms is expensive hence the need to use biological control measures. They are systematically classified in the plant kingdom, as they possess both bacterial (absence of nucleus and intracellular organelles) and algal characteristics (presence of chorophyll a, and phycobiliproteins and ability to make photosynthesis). They present a significant morphological diversity. They can be found either in isolated unicellular form or in colonies; or in the form of a trichome, which corresponds to a chain of cells (thallus) without a sheath; or in the form of a filament, which is a thallus with a sheath. They are generally distinguished according to their morphological characteristics: cell size, presence of sheath, color. However, these characteristics vary according to the environmental conditions, and make species identification difficult [4]. Thanks to their great capacity for adaptation, cyanobacteria are able to colonize a large number of terrestrial and aquatic environments (fresh and marine water). Some species are adapted to extreme environments such as glaciers, hot springs or volcanic ash, as they can withstand extreme temperatures, low pH or variable light conditions. Indeed, Cyanobacteria are photo-autotrophic (they derive their energy from light through photosynthesis). Consequently, light is one of the essential factors for their development [5].

However, some species can survive in total darkness for long periods. In the aquatic environment, Cyanobacteria are either planktonic or pelagic if they proliferate in suspension in a water column; or benthic when they develop attached to a support. Their presence becomes problematic when certain species multiply rapidly and form a mass visible to the naked eye (on the surface or in the water) which is called a "bloom" of Cyanobacteria. In some cases, these Cyanobacteria blooms cause a change in the color of the water (red, green and blue-green) and a foul smell. Their presence is observed more and more frequently on all continents. It is becoming a growing international concern due to the ecological, sanitary and economic consequences of their proliferation [6].

In whatever way, some wetlands are used as dumping grounds for liquid and solid waste, which causes environmental pollutions. Research indicates that these wetlands which constituted up to twenty seven percent (27%) of the city of Bamenda in 1984 have now been reduced to less than six percent (6%) just 38 years later, due to urbanization and industrialization [7]. This phenomenon is a call for concern as some associations and councilors of Bamenda II and III councils organized a protest in 2017 against the construction of an industrial plant on a wetland in Nkwen by a business tycoon. These anthropogenic disturbances of wetlands undoubtedly have the propensity to induce climate disruption and global environmental consequences. It is certainly with this awareness that countries around the world have decided to celebrate Wetlands Day on the second of February since 1971. Furthermore, despite the human pressure on wetlands, there are also natural and biological stressors such as bacteria and algae in the water that affect the natural state of wetlands, including climate change, invasions of other species and pests. The increase pressure on wetlands from all these stressors has reduced natural ecological functions such as the ability to enhance groundwater storage and reduced carbon sequestration.

The maintenance and restoration of the aquatic ecosystems are well illustrated by a study of the biodiversity communities. This biodiversity especially the Cyanobacteria community are affected by the change or disturbance of the concerned hydrosystems. A few of such studies have been done in the study of algal communities in some wetlands in the North-West Region.

The aim of the study was to determine the composition and variation of Cyanobacteria community in some polluted wetlands of Nkwen in Bamenda (North West, Cameroon).

2. Materials and Methods

2.1. Description of Study Sites

Six (6) sites were delimited (Figure 1). Each site was found around a bridge, and near the road because accessibility and security. Site 1 (5°57’45.80244” N and 10°10’4.97892” E) is located in Mile 2, opposite “Miracle informatique”. This River is polluted by waste coming from household, market, HYSACAM, CONGELCAM and pig manure. The wastes are dumped directly in the river. The vegetation surrounding the site is dominated by pioneer species like *Alternanthera sessilis* and *Commelina benghalensis*. Site 2 (5°58’33.2634” N and 10°10’39.01548” E) is located in Mile 3, Farmer’s house junction. It’s located in a polluted zone where the source of pollution is waste coming from household and farms. The vegetation surrounding the site is dominated by young macrophytes like *Echinochloa pyramidalis*, *Acroceras zizanoides* and *Leersia hexandra*. Sites 3 and 4 are located in Mile 4, respectively near FOKOU and Health center. In Site 3 (5°59’2.38164” N and 10°10’50.36196 E), the main activities are agriculture, fishing, car wash and pig farming producing pesticides, chemical manures, household waste and pig manures in the wetlands. The vegetation in this site is dominated by *Pennisetum purpureum* and *Echinochloa pyramidalis*. Site 4 (5°59’22.7724”

N and 10°11'29.4468" E) is less polluted by water coming from surrounding highlands. Site 5 (5°59'58.08696" N and 10°12'26.1918" E) is located in Mile 5, behind SHUMAS, less polluted. The vegetation in this site is dominated by transition species like *Alchornea cordifolia* and *Raphia* sp. Site 6 (6°00'22.06944" N and 10°13'1.50456" E) is located in Mile 6, Apostolic junction, less polluted. The main anthropogenic activities are construction of buildings. The vegetation found in this site is a secondary forest dominated by *Raphia* sp., *Alchornea cordifolia* and *Eucalyptus* sp.

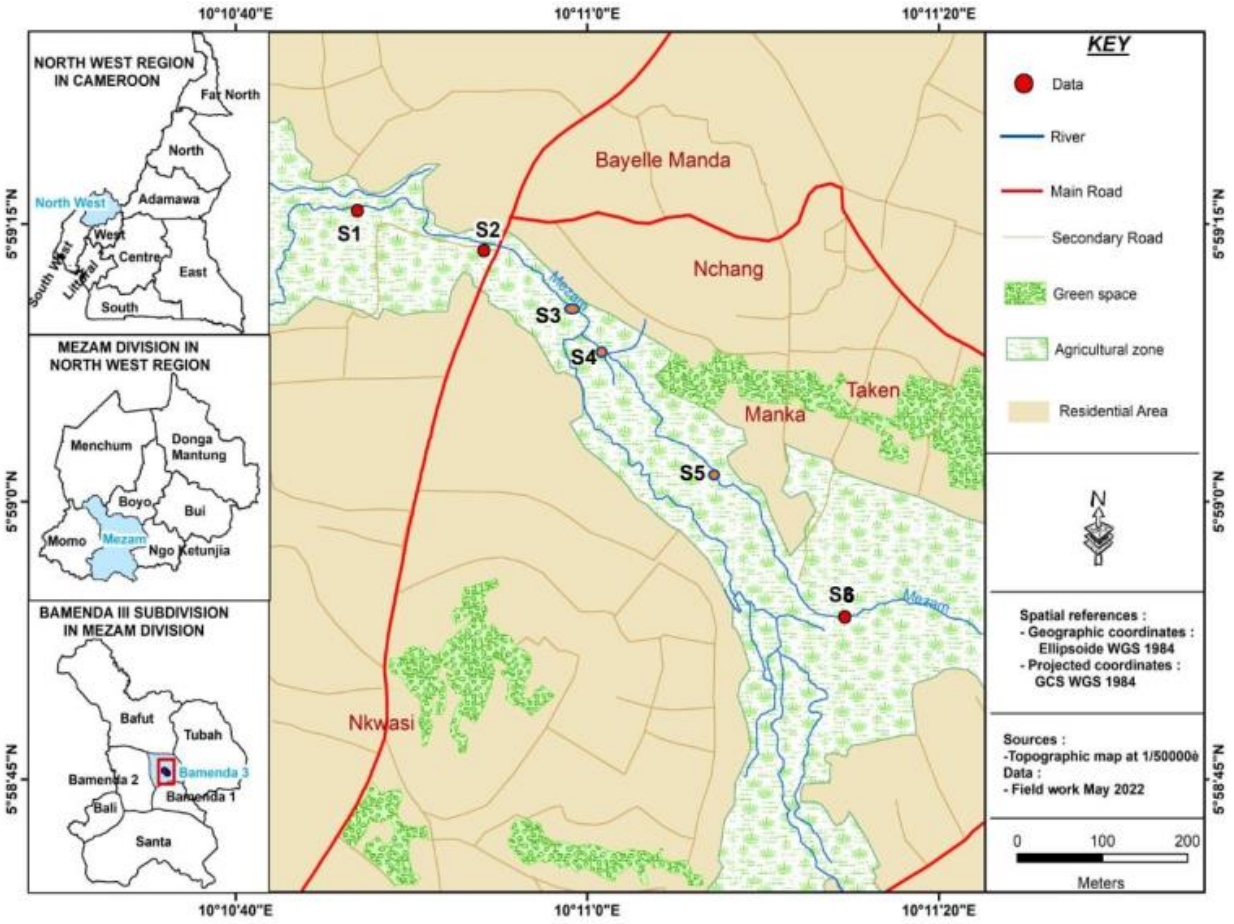

Figure 1. *Localization of the study area and sites [1] modified.*

2.2. Sampling and Determination of Physicochemical Parameters in the Study Sites

The physicochemical parameters were measured between 8:00 and 11:00 a.m. in all the sites. Temperature, electrical conductivity, hydrogen potential, salinity and total dissolved solids were measured with a Temperature/pH/Salinity/Conductivity/TDS multi-parameter of OAKTON instruments Trademark. The dissolved oxygen was measured with an Oxymeter of WTW Trademark. Some water samples were collected with polyethylene (PE) bottles of 1.5 L and stored at -5 ℃, in darkness inside a cool box for the analysis of nitrates, total phosphorus and biochemical oxygen demand (BOD_5) by using spectrophotometer methods [9].

In each station, information with regards to the width of the river course (wet bed), the surface area inside water were taken. The velocity of the water was determined using permanganate and a stopwatch. To do that, permanganate was thrown into the river and was timed for a distance of 10 m. The calculations were done using the following formula: V = d/t; V is water velocity in m/s, d is distance in m and t is time in s. The river depth was measured with a calibrated stick by inserting in 3 parts of the water (in the 2 banks and in the middle of the water). The transparency of the water was measured with Secchi disk by inserting it vertically in the water. The nature of riverbed substrates was written down.

2.3. Sampling and Analysis of Cyanobacteria

The sampling of Cyanobacteria was done at the study sites by using plankton net for phytoplankton. The sample was transferred into a 150 mL bottle. For phytobenthos, a surface

of 30 × 30 cm^2 was delimited respectively on the rock sides exposed to the water, scraped and on macrophytes bound in the water; macrophytes on this surface were detached and squeezed. The residues were transferred in a 150 mL bottle and fixed by 10% formalin for preservation.

In the laboratory, after dumping and homogenization of samples, some subsamples more concentrated were diluted by distilled water in the 100 mL beakers; the less concentrated samples were transferred directly in the 50 mL beakers; but the microfiltration was done on the concentrated samples. After 24 h sedimentation, a drop of each subsample was mounted between slide and lamella, and observed by the microscope with 3 replications. Some identification keys were used during the analysis [5, 10, 11].

For quantitative analysis, after homogenization of samples, 1 mL of each was taken by a micropipette and dumped in the Malassez's slide; then mounted in the light microscope where the counting was done. During the counting, 1 isolated cell, 1 colony and 1 filament of 100 µm was considered as 1 individual.

2.4. Determination of Biological Parameters

Species richness is the total number of taxa identified in a sample. It is an element that indicates the specific variety of the stand that is its species richness. This property may be a distinctive criterion of the ecosystem or stations studied within a given ecosystem.

Simpson's D index is D = WNi (Ni-1)/N(N-1) or D = Wpi2. This index represents the probability that two individuals selected at random from a sample belong to the same species.

The Shannon-Weaver (H') index represents a wealth of information on the stand structure of a given sample and how individuals are distributed among different species. A low diversity index indicates that the community is young with high multiplication rate with dominance of one or a few species, while a high index characterizes mature populations with a complex specific composition with a stability relatively large population. The Shannon diversity index (H') for a sample corresponds to the value calculated from the formula: H' = -∑((ni/N) × log2 (ni/N)) with ni = number of individuals belonging to a species, N = total number of species.

The regularity of Pielou (J) is given by the formula: J = H'/log2S, with S = total volume.

The dominance index "d" of Berger and Parker which has the formula: d = Nmax/N; Nmax is the maximum abundance or number of the most common individuals in the medium and N is the total abundance. It establishes the dominance of the species and shows that, if d is weak it tends to 0, the diversity is great, and the dominance is zero. When d tends to 1, one or a few species are dominant and a low diversity.

To know the number of dominant species, the Hill index is calculated = (1/D)/expH'.

Sorensen's Similarity index (S) is given by S = 2c/(2c+a+b). Let A and B be two media, c = number of species common to both media; a = number of species present in the medium A and b = number of species present in the medium B. Sorensen's similarity index (S) varies from 0 (lack of similarity) to 1 (identical media),

2.5. Density of Microalgae

Number of object/mL of taxon I (Ni) is obtained with: Ni = [(xi ×A ×a ×v)/1000 ×c)] ×d, with xi: number of counted objects, A: volume of Malassez's cell, a: total number of fields, v: sedimented volume in mL, c: number of counted fields, and d: diluted factor.

2.6. Statistical Analysis

Microsoft Office Excel software was used for keying and coding data collected during the study. Qualitative and quantitative variables were presented as frequency and mean ± standard deviations respectively in charts. One-way ANOVA was used to study the difference among sites, where significant values ($P < 0.05$) was obtained and least significant difference test was subsequently applied to detect the specific point of difference among variables and correlation among physicochemical, biodiversity was conducted. These analyses were performed using XLSTAT software and PAST for the dendrograms, principal components analysis and bar chats.

3. Results

3.1. Some Abiotic Parameters of Water Related to Cyanobacteria in the Study Sites

Hydro-morphological parameters were variables in the study sites (Table 1). Depth and width depended on rainfall. The minimal value of depth was 35 ±35 cm obtained in site 4 and the highest value was 100 ±80 cm obtained in site 5. In the same way, width varied from 3 ±3 m in site 2 to 20 ±10 m in site 3. Transparency showed that water was much diluted in the sites and varied from 30 ±15 cm site 4 to 65 ±20 cm in site 5. Velocity varied from 0.16 ±0.10 m/s in site 2 to 0.96 ± 0.90 m/s in site 3. Study sites showed different granulometry but 3 types of sediments were dominant (Sand, mud and rocks). Rocks were variable from 80 ±10% in site 2 to 2 ±1% in site 6, mud was variable from 90 ±15% in site 6 to 5 ±3% in site 2, and sand was variable from 80 ±14% in site 2 to 5 ± 5% in site 3.

Temperature was less variable and upper to 20 ℃ favorable to the development of organisms. The highest value was 24.5 ±5.6 ℃ in site 6 (Table 1).

Mineral parameters were highest in sites 1, 2 and 3 significantly different to sites 4, 5 and 6 with lowest values (Table 1). Electrical conductivity, total dissolved solids, and salinity ranged respectively from 227.5 ± 45.67 µS/cm, 203.87 ±

100.45 ppm, 175.02 ± 46.5 ppm in site 1 to 23.6 ± 20.34 µS/cm, 15.2 ± 13.41 ppm, 17.32 ± 15.45 ppm in site 5. Ecologically, pH was neutral (between 6.5 and 7.5). It was ranged from 7.21 ± 0.95 site 2 to 6.55 ± 0.55 site 5. Organic parameters were fewer variables in the sites. Nitrates were ranged from 6.45 ± 0.75 mg/l in site 1 to 0.81 ± 0.75 mg/l in site 5. Phosphates were ranged from 6.18 ± 0.45 mg/l in site 2 to 0.85 ± 1.15 mg/l in site 5. Biological demand oxygen was significantly different in the sites with highest value obtained in site 3 of 12200 ± 2150 mg/l.

Table 1. *Some hydro-morphological and physicochemical parameters of the study sites.*

Parameters		**Site 1**			**2**			**3**		
		Min	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**
Depth (cm)		55	150	75 ± 65b	35	105	45 ± 40a	50	120	60 ± 55b
Width (m)		4	8	5 ± 4a	3	6	3 ± 3a	17	25	20 ± 10b
Transparency (cm)		45	55	51 ± 20b	30	45	40 ± 10a	37	56	45 ± 26a
Velocity (m/s)		0.67	0.89	0.74 ± 0.22c	0.15	0.26	0.16 ± 0.10a	0.76	0.98	0.96 ± 0.90d
Sediments (%)	Rocks	75	85	80 ± 10b	5	20	15 ± 11a	5	20	15 ± 10a
	Sand	10	15	15 ± 10a	75	85	80 ± 14c	5	10	5 ± 5a
	Mud	5	10	5 ± 5a	3	10	5 ± 3a	70	85	80 ± 12c
Ts (℃)		20.3	25.5	23.1 ± 5.2a	20.4	25.4	23.2 ±4.9a	20.1	24.5	23.2 ± 5.5a
TDS (ppm)		195.45	225.41	203.87 ± 100.45e	125.67	156.34	130.25 ± 67.56d	115.01	150.23	125.75 ± 60.65d
COND (µS/cm)		214.45	235.67	227.5 ± 45.67e	167.55	195.34	176.34 ± 35.54d	185.25	210.25	198.25 ± 43.24d
Salinity (ppm)		165.95	185.14	175.02 ± 46.5d	65.45	89.45	78.21 ± 45.55c	75.45	95.15	85.24 ± 30.45c
pH		6.15	7.01	6.98 ± 0.68a	6.98	7.35	7.21 ± 0.95a	7.01	7.25	7.15 ± 0.30a
Oxydability (mg/l)		3.15	4.23	3.86 ± 1.54a	4.12	5.34	4.25 ± 0.74a	3.01	3.75	3.25 ± 0.43a
Nitrates (mg/l)		6.01	7.25	6.45 ± 0.75b	4.24	5.32	4.59 ± 0.95b	5.2	6.12	5.7 ± 2.45b
PO (mg/l)		4.66	6.43	5.32 ± 1.85b	6.01	6.78	6.18 ± 0.45b	4.05	4.75	4.25 ± 4.78b
DBO5 (mg/l)		9903	11905	11254 ± 2102d	10678	12000	11300 ± 2456d	11965	12800	12200 ± 2150e

Parameters		**Site 4**			**5**			**6**		
		Min	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**
Depth (cm)		30	75	35 ± 35a	55	175	100 ± 80c	60	150	80 ± 46b
Width (m)		12	23	15 ± 11b	3	7	5 ± 4a	5	10	5 ± 4a
Transparency (cm)		29	55	30 ± 15a	40	65	65 ± 20b	20	45	30 ± 21a
Velocity (m/s)		0.25	0.45	0.31 ± 0.15b	0.12	0.25	0.16 ± 0.13a	0.38	0.45	0.41 ± 0.22b
Sediments (%)	Rocks	5	10	5 ± 3a	15	25	20 ± 15a	1	2	2 ± 1a
	Sand	65	85	80 ± 15c	25	35	30 ± 20b	5	14	8 ± 10a
	Mud	5	20	15 ± 5a	45	60	50 ± 35b	75	95	90 ± 15c
Ts (℃)		20.6	24.2	23.98 ± 5.6a	20.2	26.7	24.1 ± 4.6a	21.3	25.8	24.5 ± 5.6a

Parameters	Site 4			5			6		
	Min	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**
TDS (ppm)	45.65	66.15	52.16 ±45.54b	10.4	25.0	15.2 ±13.41a	75.45	115.45	99.78 ±85.25c
COND (µS/cm)	84.25	134.54	103.23 ±86.54c	17.5	65.4	23.6 ±20.34a	65.45	86.43	75.29 ±54.50b
Salinity (ppm)	54.34	70.85	68.23 ±54.64b	10.25	25.45	17.32 ±15.45a	42.45	67.55	56.23 ±35.45b
pH	6.50	7.04	6.68 ±1.35a	6.25	6.85	6.55 ±0.55a	6.55	6.98	6.79 ±0.50a
Oxydability (mg/l)	3.14	3.86	3.48 ±0.56a	2.15	2.87	2.54 ±0.75a	3.50	4.01	3.87 ±1.25a
Nitrates (mg/l)	3.25	4.35	3.82 ±1.13b	0.65	1.23	0.81 ±0.75a	2.25	3.25	2.87 ±1.65b
PO (mg/l)	2.15	3.01	2.79 ±1.04b	0.65	1.45	0.85 ±1.15a	2.14	2.95	2.74 ±0.95b
DBO5 (mg/l)	3145	3950	3450 ±604b	215	276	235 ±215a	1050	1650	1250 ±715c

Min = minimal, Max = Maximal, Ts = temperature of water, TDS = total dissolved solids, COND = electrical conductivity, PO = phosphates, DBO5 = biological demand oxygen; cases on the same line with the same letter mean no significant difference with $p<0.05$.

3.2. Biological Parameters of Study Sites

3.2.1. Species Richness

Total species richness of the study sites amounted to 3 orders divided in 11 families, 22 genera and 46 species (Table 2). The most represented family was that of Oscillatoriaceae (26.08%) with 12 species (Figure 2).

Table 2. *Species richness of study sites.*

Orders	Families	Genera	Number of Species
Nostocales	Nostocaceae	*Anabaena*	1
		Anabaenopsis	1
		Nordularia	1
		Nostoc	4
		Raphidiopsis	2
	Aphanizomenonaceae	*Aphanizomenon*	2
	Merismopediaceae	*Aphanocapsa*	3
		Merismopedia	3
	Rivulariaceea	*Calothrix*	3
		Rivularia	2
	Gloeotrichiaceae	*Gloeotrichia*	1
	Pseudanabaenaceae	*Limnothrix*	1
	Tolypothrichaceae	*Tolipothrix*	1
Chroococcales	Chroococcaceae	*Coelosphaerium*	1
		Synechococcus	1
		Synechocystis	2

Orders	Families	Genera	Number of Species
Oscillatoriales	Microcystaceae	*Microcystis*	3
	Oscillatoriaceae	*Oscillatoria*	8
		Lyngbya	3
	Microcoleaceae	*Microcoleus*	1
		Phormidium	1
		Planktothrix	1

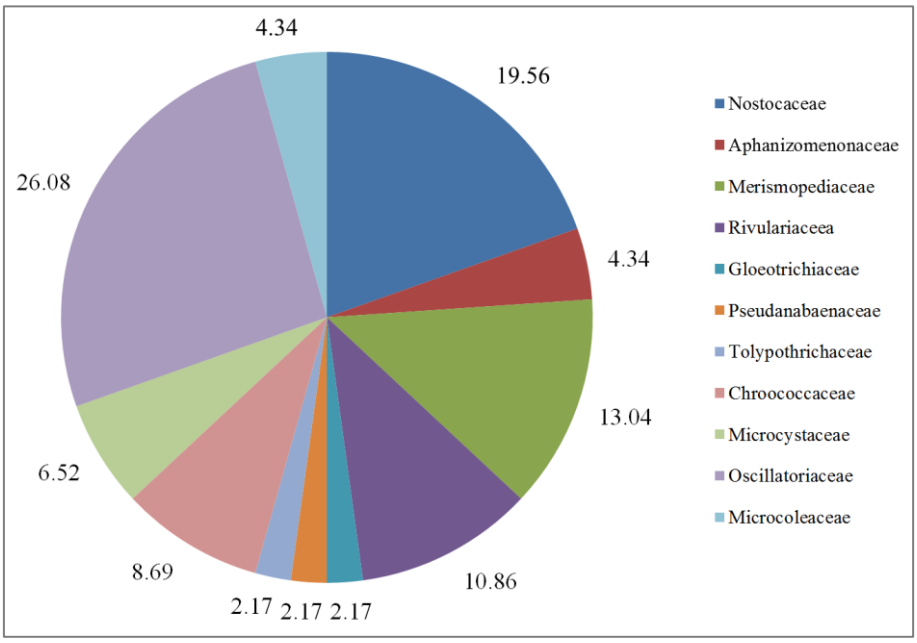

Figure 2. *Proportions (%) of different families according to the number of species.*

3.2.2. Diversity Indices

The number of species was variable in the study sites (Table 3). The average highest value obtained was 5 ± 1 species (site 6) and the average lowest value obtained was 22 ± 4 species (site 2). Dominance was variable in the study sites. The highest value was obtained in site 6 of 0.3189 ± 0.0037 and the lowest value was obtained in site 2 of 0.08864 ± 0.00253. Simpson was variable in the study sites. The highest value was obtained in site 2 of 0.9114 ± 0.0026 and the lowest value was obtained in site 6 of 0.6809 ± 0.0035. Shannon-Weaver's index was weak and varied between 1.239 ± 0.007 (site 6) and 2.659 ± 0.021 (site 2). Pielou's equitability index was variable in the sites. The highest value was 0.924 ± 0.0087 (site 5) and the lowest value was 0.7591 ± 0.0118 (site 4). Hill's index was also variable in the study sites. The highest value was 0.8632 ± 0.0063 obtained in site 6 and the lowest value was 0.5053 ± 0.0166 obtained in site 4.

Table 3. *Variation of some diversity indices in the study sites.*

Site		Parameters					
		Taxa (S)	Dominance (D)	Simpson (1-D)	Shannon (H')	Evenness (e^H/S)	Equitability (J)
1	Min	7	0.2408	0.7476	1.694	0.6044	0.7708
	Max	10	0.2524	0.7592	1.726	0.6241	0.7855

Site		Parameters					
		Taxa (S)	**Dominance (D)**	**Simpson (1-D)**	**Shannon (H')**	**Evenness (e^H/S)**	**Equitability (J)**
	Average	9 ±2	0.2465 ±0.0059	0.7535 ±0.0059	1.71 ±0.016	0.6145 ±0.0101	0.7784 ±0.0076
	Min	18	0.08652	0.9088	2.638	0.6356	0.8534
2	Max	25	0.09117	0.9135	2.677	0.6609	0.866
	Average	22 ±4	0.08864 ±0.00253	0.9114 ±0.0026	2.659 ±0.021	0.6494 ±0.0138	0.8603 ±0.0069
	Min	12	0.2453	0.734	1.772	0.588	0.7694
3	Max	13	0.266	0.7547	1.826	0.621	0.7931
	Average	13 ±1	0.2551 ±0.0109	0.745 ±0.011	1.805 ±0.033	0.6052 ±0.0172	0.7819 ±0.0129
	Min	16	0.1672	0.8187	2.117	0.4887	0.7473
4	Max	19	0.1813	0.8327	2.18	0.5203	0.7694
	Average	17 ±2	0.1739 ±0.0074	0.8261 ±0.0074	2.151 ±0.034	0.5053 ±0.0166	0.7591 ±0.0118
	Min	9	0.1454	0.8461	2.011	0.8302	0.9153
5	Max	9	0.1539	0.8546	2.046	0.8599	0.9313
	Average	9 ±0	0.1489 ±0.0035	0.8507 ±0.0046	2.032 ±0.021	0.8461 ±0.0159	0.924 ±0.0087
	Min	5	0.3159	0.6774	1.232	0.8569	0.8886
6	Max	6	0.3226	0.6841	1.246	0.8692	0.8989
	Average	5 ±1	0.3189 ±0.0037	0.6809 ±0.0035	1.239 ±0.007	0.8632 ±0.0063	0.8939 ±0.0053

Max: maximum, Min: minimum

3.2.3. Similarity Between the Study Sites According to the Species

According to the similar number of species between the study sites, the similarity was high between sites 2 and 4 (8 species), followed by sites 1 and 2 (5 species) (Figure 3). Between sites 1 and 5, sites 1 and 6, there was not similarity (0 species). Sorensen's similarity index was high between site 2 and 4 with 42%, and secondly between 1 and 4 with 36% (Table 4).

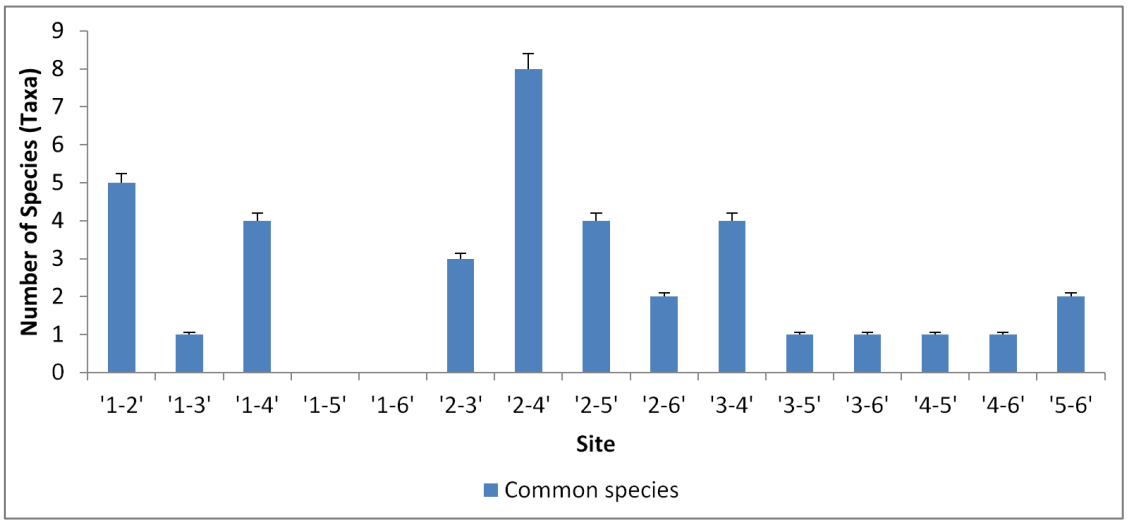

Figure 3. *Variation of the number of Species in the study sites.*

Table 4. *Sorensen's similarity index between the study sites.*

Site	1	2	3	4	5	6
1	1					
2	0.29	1				
3	0.11	0.18	1			
4	0.36	0.42	0.29	1		
5	0.00	0.24	0.10	0.07	1	
6	0.00	0.15	0.14	0.09	0.30	1

3.2.4. Density of Different Families in the Study Sites

Total density of Cyanobacteria was high in site 5 with a value of about 18800 Ind./l (Figure 4). Site 2 followed with a value of about 11700 Ind./l. The family getting the highest density was Aphanizomenonaceae, about 8000 Ind./l observed in site 5. This followed by Oscillatoriaceae with about 7900 Ind./l. The lowest density was obtained in site 2 by Gloeotrichiaceae with 100 Ind./l.

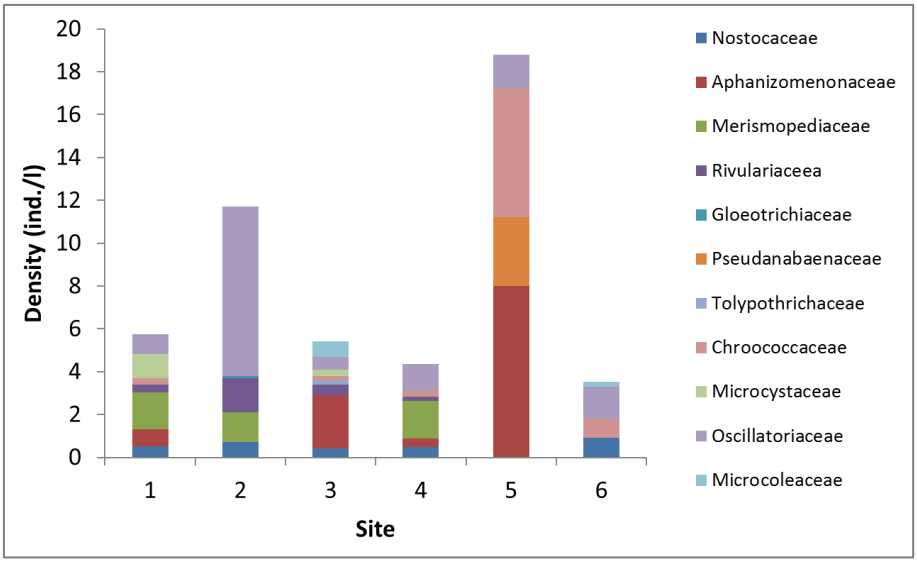

Figure 4. *Variation of densities of the different families in the study sites.*

3.2.5. Distribution of Different Families According to Physicochemical Parameters in the Study Sites

The principal component analysis F1×F2 with 72.05% inertia grouped the sites according to 9 abiotic parameters (Figure 5). The factorial axis F1 (53.51% inertia) was positively correlated with: oxidability, total phosphorus, hydrogen potential, biochemical oxygen demand, electrical conductivity, total dissolved solids, salinity and nitrates. It was negatively correlated with water temperature. However, the factorial axis F2 (18.55% inertia) was positively correlated with: water temperature, oxidability and total phosphorus. It was negatively correlated with: hydrogen potential, biochemical oxygen demand, total dissolved solids, salinity and nitrates. These physicochemical parameters divided the sites into two groups: group 1, presenting very high physicochemical parameters, was made up of sites 1, 2 and 3. Group 2, presenting low physicochemical parameters, was made up of sites 4, 5 and 6. Different cyanobacteria families with strong proliferation in polluted waters (sites 1, 2 and 3) were: Oscillatoriaceae, Gloeotrichiaceae, Rivulariaceae, Nostocaceae, Merismopediaceae, Microcoleaceae, Microcystaceae and Tolypotrichaceae. On the other hand, the families abundantly present in less polluted waters (sites 4,

5 and 6) were: Chroococcaceae, Pseudanabaenaceae and Aphanizomenonaceae.

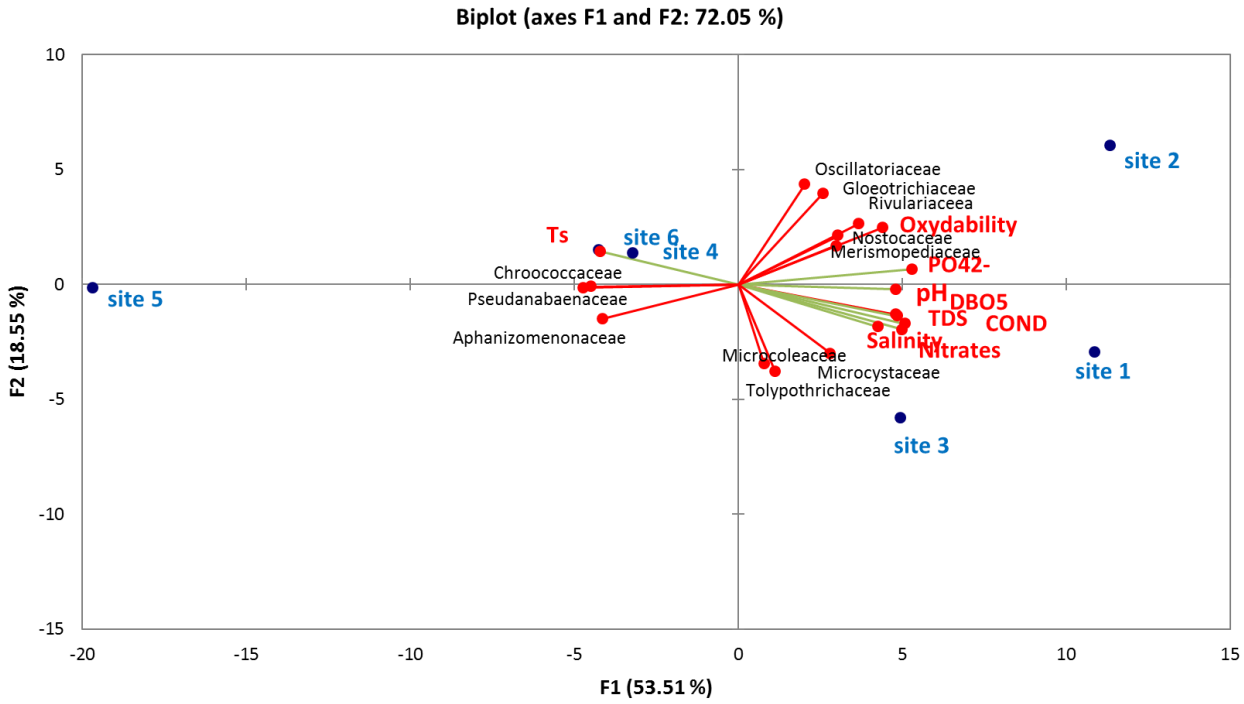

Figure 5. *Distribution of Cyanobacteria families according to physicochemical parameters and sites.*

In general, the total density of Cyanobacteria depended not only on nutritional factors (nitrates and total phosphorus) but also on water mineralization parameters such as salinity, electrical conductivity, total dissolved solids, as well as the velocity of the water (Figure 6). The linear regression (model equation: Density = 12.963485-10.3215*Velocity) showed a 95% confidence interval between the total density per site and the water velocity.

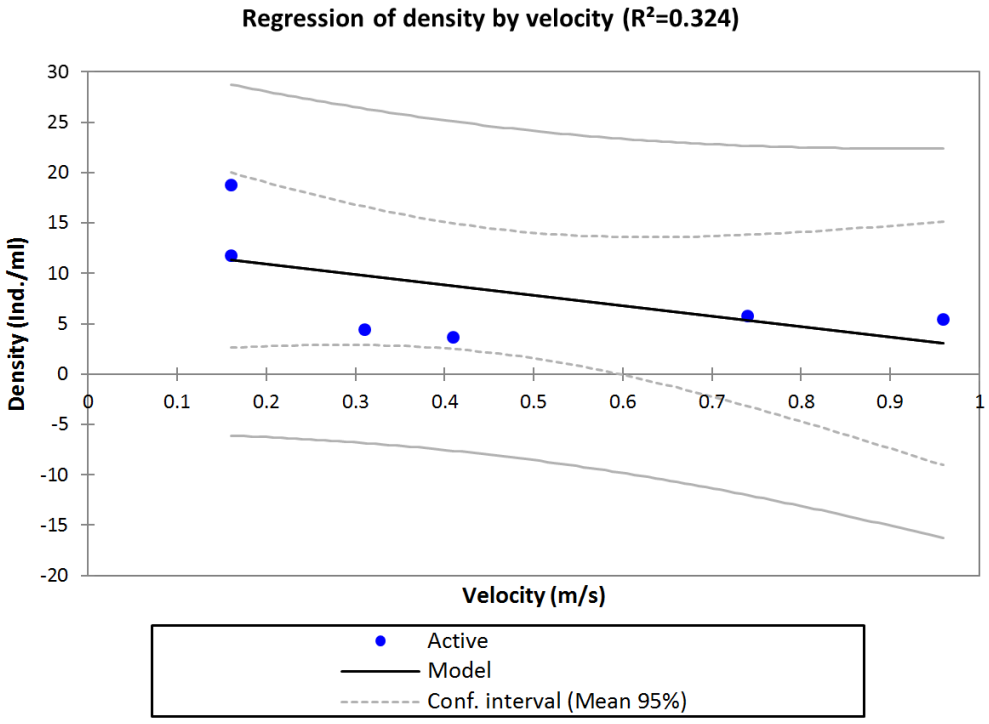

Figure 6. *Linear regression of density by velocity in the study sites.*

4. Discussion

Temperature influences the rate of chemical and biological activities in the aquatic environment [12]. The temperature values in the 6 study sites were within the norms (20-30 ℃) [13]. The lowest temperature was at site 1 because there is riparian bridge cover which reduces the water surface exposed to light. The highest temperature at site 6 was probably due to the increased load of suspended solids, soil particles and decomposed organic matter in the river, as they absorb more heat [14]. Thus, the variation in temperature among the sampling sites was due to anthropogenic activities in the study area catchment. The pH value of the 6 sites was within the permissible range and these results are similar to those of Motto et al.'s study in Londji River, where the pH values vary between 6 and 7, determinants of a biodiversity rich environment [15]. Electrical conductivity (EC) is a useful indicator of mineralization in a water sample. EC is an indication of the total amount of ionisable salts in solution as it gives a numerical expression of the ability of a solution to conduct electric current [16, 17]. Most mineral salts in solution are good conductors. In contrast, organic compounds are poor conductors. Conductivity varied from 227.5 ± 45.67 µS/cm and 23.5 ± 20.34 µS/cm. It is positively correlated with salinity and TDS and describes an increasing gradient of dissolved salts in the environment and confirms that the waters of wetlands of Nkwen would be good conductors of electric current. The results are higher than those of Ndjouondo et al.'s study within the Batika River, Yabassi (44.25-58.25 µS/cm) [1]. Total dissolved solids at all sites in the wetlands of Nkwen were within the WHO stated tolerance limits of 500 mg/l as the maximum tolerance limit [18].

The nitrate levels observed at the sampling sites were below the WHO limit of 50 mg/l [18]. Although the nitrate values are below the standards, the fluctuating values at the sampling sites are indicators of human influence on the Nkwen Rivers. Site 1 being the most affected could be due to sources of chemical contamination from various anthropogenic activities such as runoff from fertilized agricultural land, sewage, landfill, decaying plant debris and waste from Nkwen market. The results are lower than those obtained by Tsafack's study in the Nkwen River (1.52-6.85 mg/l) and higher than those obtained by Ndjouondo et al.'s study in the Batika River, Yabassi (0.81-1.55 mg/l) [1, 8]. According to World Health Organization, the maximum allowable limit for phosphate is 5 mg/l [18]. The obtained phosphorus values were higher than this classification, which could be due to intense human activities such as agriculture, industries, wastewater, and household waste. Ammonia, nitrates and phosphates are essential nutrients for Cyanobacteria, but when present in excessive amounts they can stimulate undesirable growth such as algal blooms. Excessive nutrient inputs lead to an explosion of phytoplankton. The results obtained are higher than those obtained by Tsafack's study in the Nkwen River (0.86-3.05 mg/l), Ndjouondo et al.'s study in the Batika River (0.15-0.23 mg/l), and Severes et al.'s study in some unexplored water bodies in a rapidly developing industrial region in India (0.15-0.67 mg/l) [1, 8, 19].

Pollution sensitive and tolerant organisms are present in "clean" waters, but it is the absence of sensitive organisms coupled with the presence of tolerant organisms that may indicate damage [20]. The results of the species richness amounting to 46 species showed a significant richness in the sampling sites with the most represented family being the Oscillatoriaceae (26.66% with 12 species). The higher proportions of cyanobacteria appear exclusively during periods of stable weather and high temperature. Their success could be explained by the nutrient status of the environment and the water temperature which is close to the optimal culture temperature (above 20 ℃) of the species concerned, associated with the high turbidity of the water. These results are similar to those of Pratibha et al.'s study who sampled Cyanobacteria in wetlands in the industrialized district of Sambalpur, India showed 55 species; and different to those of Gupta's study who worked on diversity of Cyanobacteria of Broknes Peninsula of Larsemann Hills, East Antarctica showed 16 species [21, 22]. The results are not consistent with those found by Motto's study where Bacillariophyceae are more represented (59.67%) in the Londji River in Kribi [15]. This could be explained by the faster flow of water in this river from upstream to downstream compare to the above mentioned river. Cyanobacteria live in freshwater where higher water flows are known to threaten their multiplication due to their size and ability to detach from supports and drift in the current. Furthermore, this difference in results could also be attributed to differences in water quality. The family Oscillatoriaceae was identified as the dominant family in terms of abundance in the study sites. These results are consistent with those found by Dibong and Ndjouondo's study in the Kambo and Longmayagui rivers in Douala where 105 species were identified, of which 70.39% of Cyanobacteria community was Oscillatoriaceae [4].

The Shannon-Weaver index obtained was between 1.24 and 2.65. Standard values are between 1.5 and 3.5 [23]. A low cyanobacteria diversity index (site 6) indicated that the community is young with a high multiplication rate with the dominance of one or a few species or that the population is under the influence of a single growing species. The high diversity index (site 2) showed that the population is not under the influence of a single developing species but rather a strong development of several different individuals. This result is lower than those obtained by Dibong and Ndjouondo's study in the Kambo and Longmayagui rivers (3.8-4.95) indicating rich diversity [4]. The regularity close to 1 justified the stability of the community showing that site 5 (0.92) is the most stable site. This result is slightly high compared to Motto et al.'s study in the Londji River who found community stability between the values 0.8 and 0.9

[15].

Cyanobacteria densities showed a large variation between sites as the family Oscillatoriaceae appeared to be the densest family in site 1. This is because Cyanophyceae form blooms (blooms) in streams polluted with organic matter. Watercourses with a very slow current velocity polluted by organic matter undergo a strong eutrophication by letting efflorescence appear through the multiplication of one or several species. These results are in line with those of Aurousseau who worked on the evaluation of the impact of rivers on eutrophication in the coastal strip in France, Groga who was interested in the structure, functioning and dynamics of phytoplankton in Lake Ta'abo in Ivory Coast and Sana'a who addressed the structure, dynamics and physico-chemical and phytoplanktonic typologies of the Bou Regreg estuary in Morocco [24-26].

5. Conclusion

The overall objective of the study was to determine the composition and variation of cyanobacteria community in some polluted wetlands of Nkwen in bamenda (North-West, Cameroon). The inventory of cyanobacteria identified a total of 11 families divided into 22 genera and 46 species. Oscillatoriaceae constituted the most important familly (26.66% with 12 species) of the cyanobacteria community, in the study sites. Cyanobacteria community has abundant species where the velocity of water is low with high nitrates and phosphates contents. Some physico-chemical parameters (salinity, electrical conductivity and total dissolved solids) divided study sites in 2 groups according to the degree of pollution; polluted area grouping sites in town (1, 2 and 3) where Oscillatoriaceae, Gloeotrichiaceae, Rivulariaceae, Nostocaceae, Merismopediaceae, Microcoleaceae, Microcystaceae and Tolypotrichaceae were dominant and less polluted area grouping sites at the peripheral town area (4, 5 and 6) with less anthropogenic activities where Chroococcaceae, Pseudanabaenaceae and Aphanizomenonaceae were dominant. The physico-chemical relationship with the abundance of species explains the generic existence probability of cyanobacteria communities and could be used as indicator of ecological status of wetlands. The diversity and abundance of the cyanobacteria community is influenced by anthropogenic activities in the wetlands of Nkwen. Thus, physico-chemical parameters have an influence on the diversity and structure of the cyanobacteria development in the wetlands of Nkwen (Bamenda, Cameroon). Monitoring, based on biological indices of cyanobacteria, could be developed to prevent the risks of eutrophication of these wetlands.

Conflicts of Interest

The authors declare no conflicts of interest.

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