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Spatio-Temporal Distribution of Phytoplankton and Water Quality of Some Rivers of Haute Sanaga Department (Central Africa)

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Abstract

In Cameroon, rivers are subjected to physicochemical disturbances, which increase the degradation of water quality. The aim of this study was to determine the spatio-temporal diversity of the phytoplankton groups and to evaluate the environmental parameters of the sampling sites in order to assess the quality of water in two hydrographic networks. Physicochemicals analyzes were carried out according to the standard methods while phytoplankton organisms were harvested by direct sampling and analyzed by the Utermöhl method. The analysis of Ammonia Nitrogen, Dissolved Oxygen, Electric Conductivity, Nitrates, Orthophosphates, pH, Temperature, and Turbidity.of water revealed the poor state of health of the water. Data from the Long Dry Season differed significantly ($p < 0.05$) from those recorded in other seasons. The phytoplankton communities were made up of Chlorophyta, Chrysophyta, Cyanophyta, and Euglenophyta with 11 classes dominated by Bacilliarophyceae (12 210 Ind/mL) and Cyanophyceae (6 208 Ind/mL). Phytoplankton densities were higher the Long Rainy Season and much lower in the Small Dry Season than in the Long Dry Season. Station near NODISCAM indicated significant organic pollution

under the effect of agro-industrial discharges operating upstream of this company. For this station, the different values showed significant differences ($p < 0.05$) from one station to another. Finally, spatio-seasonal variations of phytoplankton densities showed logical responses to changes of physicochemical conditions in the environment. This work highlights the need to treat wastewater from collection channels before its dump into the natural environment, to prevent progressive eutrophication of the receiving aquatic environment, and poisoning by water consumption.

Keywords: water quality, phytoplankton, physicochemical properties, wastewater, season

1. Introduction

Urban and industrial effluents are, in most cases, major causes of ecological imbalance in continental ecosystems, besides wastewater discharges from agro-industrial companies, which are also of significant importance (Adjahouinou et al., 2012). This is the reality in most African countries where rivers are subject to physical and chemical disturbances resulting in an increased degradation of water quality (Taffouo et al., 2017), a change in the structure of settlements and decrease in biodiversity (Zébazé Togouet, 2008; Onana et al., 2014). The dense hydrographic network of the towns of Mbandjock and Nkoteng is highly impacted by human disturbance due to the plantations and factories of the Cameroon's main sugar industry. In these localities, the Sanaga River is the main collector and source of a large drinking water supply project called Drinking Water Supply Project for the City of Yaoundé and its Surroundings (PAEPYS). In river Kondé (Wouri hydrosystem), Onana et al. (2014) found that plankton is abundant, very sensitive to variations in environmental conditions, and can therefore be used as a biological indicator of pollution and environmental change. The phytoplankton lives freely, passively as suspended photosynthetic microorganisms in the water column (Iltis, 1980). Its communities have a very high renewal rate; moreover variations in abundance and community structure consecutive to environmental changes are rapidly perceptible (Taffoua et al., 2017). Thus, since the Ramsar Convention of 2 February 1971, phytoplankton has been used as indicator in freshwater quality assessment protocols (Bridgewater & Kim, 2021). Indeed, it is an excellent indicator of the ecological status of water bodies. However, phytoplankton groups can only achieve the role of bioindicators if operators succefully identify the main species associated to external water inputs, diffuse pollution and hydraulic developments carried out in natural and artificial water bodies (Rimet et al., 2008). This work aimed to determine the spatio-temporal diversity of the phytoplankton groups and to evaluate the environmental parameters of the sampling sites in order to assess the quality of water in two different hydrographic networks.

2. Materials and Methods

2.1 Study Area

The towns of Mbandjock (4°27’28’’ North latitude; 11°54’09’’ East longitude, altitude 585 m) and Nkoteng (04°31’00’’North latitude; 12°01’59’’ East longitude, altitude 650 m) are located in the department of Haute Sanaga in the Centre Region Cameroon. Watercourses of the Sanaga hydrosystem network drain these cities. The climate is a bimodal rainfall equatorial

type, alternating two dry seasons and two rainy seasons with a seasonal breakdown as follows: the Long Dry Season (LDS) from December to mid-March, the Small Rainy Season (SRS) from mid-March to May, the Small Dry Season (SDS) from June to August, and the Long Rainy Season (LRS) from September to November (Suchel, 1987). The average annual temperature varies between 22°C and 28°C while the rainfall fluctuates between 1 600 mm^3 and 2 000 mm^3 per year (PDP, 2010). The rivers investigated are bordered by vast sugar cane plantations (40 000 hectars), two SOSUCAM (Cameroon Sugar Company) factories and the NODISCAM (an agro-industrial company specialised in the manufacture of whisky). Activities carried out in this catchment area are exclusively agricultural and industrial. The sampling stations were chosen according to the width of the riverbed, water depth and flow speed (APHA, 2017). The data of this work are those from 12 sampling stations covering the entire study area (Figure 1).

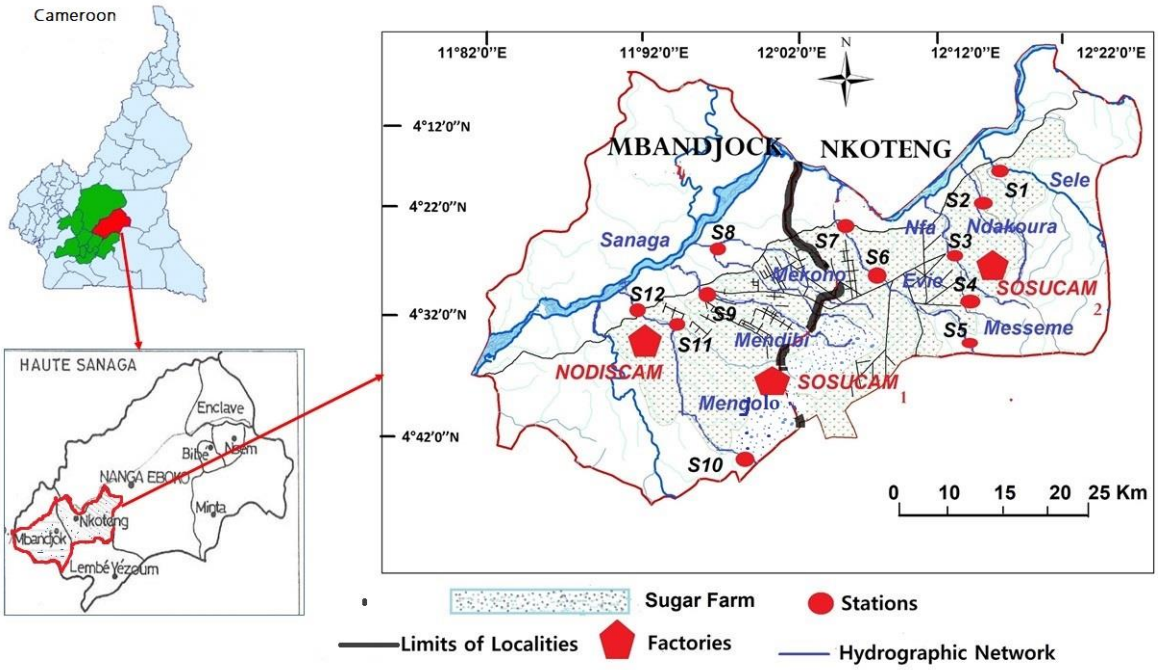

Figure 1. Location map of the study area and sampling stations. Code S_1 to S_{12} designate the sampling stations

2.2 Measurement of Physicochemical Parameters and Sampling of Algae

Sampling was carried out monthly from January 2016 to January 2017. Samples for physicochemical analyzes were collected directly at the surface using polyethylene vials. Some parameters were measured directly on the field. Temperature was measured using a mercury column thermometer graduated to $1/100^{th}$ degree. The depth was estimated using a weighted and graduated string. The speed was evaluated indirectly by determining, with the help of a stopwatch, the time taken by the front of a neutral dye (methylene blue) to go through previously defined distance. The speed V (m/s) was calculated using the formula: V= d/t where d = distance (m) and t = time (s).

The percentage of Dissolved Oxygen saturation was measured using a HACH HQ14d,

Oxymeter, Electrical Conductivity using a HANNA HI 99300 portable TDS/Conductivity Meter. Other parameters such as Turbidity and nutrients (NO_3^-, NH_4^+ and PO_4^{3-}) were evaluated in the laboratory using the colorimetric method with the HACH/DR (2010). These analyzes were carried out according to techniques and recommendations of APHA (2017) and Rodier et al. (2009).

2.3 Identification and Enumeration of Algal Species

The biotic parameters studied are phytoplankton and chlorophyll pigments. chlorophyll a, b, c and pheopigment contents were calculated using the trichromatic method equations of Jeffrey & Humphrey (1975) and Lorenzen (1967) modified as follows:

- Chl.a (mg/m^3) = 11.85 (OD 664) – 1.54 (OD 647) – 0.08 (OD 630);
- Chl.b (mg/m^3) = 21.03 (OD 647) – 5.43 (OD 664) – 2.66 (OD 630);
- Chl.c (mg/m^3) = 24.52 (OD 630) – 7.60 (OD 647) – 1.67 (OD 664);
- Pheopigments (mg/m^3) = 26.7 (1.7 (OD 665) – (OD 630)); where (OD = Optical Density).

The phytoplankton density was assessed using the method of Druart & Rimet (2008). These microorganisms were collected by direct sampling at the surface of water using a clean and transparent 500 ml glass vial, then fixed with 2.5 ml of a Lugol solution. After 48 hours of sedimentation, the supernatant was gently removed; the sub-sample of approximately 15 ml was preserved. After homogenization, 1 ml of the sub-sample was pipetted and observed in a Sedgewick-Rafter counting cell with an inverted microscope (Olympus CK2). Identification of at least 400 individuals per sample was carried out for an accuracy of 95% (APHA, 2017), using appropriate keys (Kemka, 2000; Bourrelly, 1990; 1985; 1981; Iltis, 1980; Ettl et al., 1978). Phytoplankton was counted according to the Utermöhl method at 400x and 1000x magnification. The count was duplicated to minimize the risk of error. Due to the abundance of particules and organisms in some samples, dilution to 1/10th or 1/20th with distilled water was essential to facilitate enumeration of genera with scans, from left to right, of the surface of the counting cell with alternating transects. The density D (Ind/mL) of phytoplankton was calculated using the formula: D= Ni*S / (v*s) where S = area of the counting cell (1 000 mm^2), Ni = number of individuals counted, s = area of the total counted field and v = volume of sedimented sample (5 ml) (Druart & Rimet, 2008).

2.4 Statistical Analysis of the Data

Results are expressed as follows mean ± confidence interval. Discriminant Factor Analysis (DFA) was performed to assess the relationship between environmental variables studied and phytoplankton surveys of the 12 stations. The Spearman correlation test was used to search for the existence of significant correlation between variables. The Kruskal-Wallis test associated with the Mann-Whitney "U" test permitted to verify the spatial and temporal significance of differences between means of abiotic and biotic parameters. All calculations were performed with XLStat version 7.5.2., the software Microsoft Office Excel 2016 and SPSS 20.0.

3. Results and Discussion

3.1 Analysis of Hydrologic Parameters

Seasonal mean values of the depth and water velocity in the different sampling stations are given in Table 1. In all stations, the relatively ($p > 0.05$) higher values of these parameters were almost recorded during the LRS and the lowest in LDS.

Table 1. Seasonal values of hydrologic parameters in each station. Codes S_1 to S_{12} designate the sampling stations.

Stations	Depth (m)				Water velocity (m/s)			
	LDS	SRS	SDS	LRS	LDS	SRS	SDS	LRS
S_1	0.5±0.04 [a]	1±0.02 [a]	1±0.02 [a]	1.3±0.01[a]	0.15±0.01 [a]	0.17±0.01 [a]	0.16±0.01 [a]	0.19±0.01 [a]
S_2	1.5±0.03 [a]	1.5±0.03 [a]	1.8±0.02[a]	1.9±0.01[a]	0.13±0.01 [a]	0.16±0.01 [a]	0.14±0.01 [a]	0.18±0.01 [a]
S_3	1.3±0.01 [a]	1.1±0.03 [a]	1±0.04 [a]	1.5±0.02[a]	0.15±0.01 [a]	0.19±0.01 [a]	0.17±0.02 [a]	0.25±0.02 [a]
S_4	1.1±0.03 [a]	1.5±0.04 [a]	1.2±0.01[a]	2± 0.04 [a]	0.15±0.01 [a]	0.17±0.01 [a]	0.16±0.01 [a]	0.18±0.02 [a]
S_5	1.1±0.03 [a]	0.5±0.01 [a]	1.8±0.04[a]	1.9±0.02[a]	0.16±0.01 [a]	0.21±0.01 [a]	0.18±0.03 [a]	0.25±0.03 [a]
S_6	0.8±0.02 [a]	1.1±0.03 [a]	1.3±0.03[a]	1.8±0.04[a]	0.33±0.03 [a]	0.36±0.02 [a]	0.43±0.04 [a]	0.53±0.03 [a]
S_7	1.2±0.02 [a]	0.8±0.02 [a]	0.5±0.01[a]	2.1±0.03[a]	0.25±0.02 [a]	0.49±0.02 [a]	0.23±0.02 [a]	0.92±0.03 [a]
S_8	0.9±0.02 [a]	0.7±0.02 [a]	1.1±0.01[a]	1.8±0.03[a]	0.34±0.01 [a]	0.37±0.03 [a]	0.33±0.01 [a]	0.42±0.02 [a]
S_9	1.5±0.03 [a]	1.7±0.04 [a]	1.7±0.02[a]	1.8±0.04[a]	0.3±0.01 [a]	0.5±0.03 [a]	0.57±0.01 [a]	0.77±0.02 [a]
S_{10}	1.3±0.04 [a]	1.4±0.04[a]	1.2±0.03[a]	1.6±0.03[a]	0.2±0.01 [a]	0.46±0.01[a]	0.15±0.01 [a]	0.56±0.02 [a]
S_{11}	1.1±0.03 [a]	1.4±0.03 [a]	1.3±0.02[a]	1.5±0.02[a]	0.15±0.01 [a]	0.17±0.04 [a]	0.11±0.01 [a]	0.25±0.01 [a]
S_{12}	1.3±0.03 [a]	1.5±0.04 [a]	1.5±0.01[a]	1.9±0.03[a]	0.19±0.03 [a]	0.25±0.02 [a]	0.2±0.04 [a]	0.39±0.04 [a]

In each row, values with same letter are not significantly different.

3.2 Analysis of Physicochemical Parameters

In the study area, the water temperature (°C), electric conductivity (µS/cm) and pH (UC) mean values, although appeared higher in LDS and lower in LRS, didn't fluctuate significantly between seasons ($p > 0.05$). Apart from Dissolved O_2 (%) which was higher in LRS, all the other physicochemical parameters: Turbidity (NTU), NH_4^+ (mg/L), PO_4^{3-} (mg/L) and NO_3^- (mg/L) were significantly ($p < 0.05$) lower in LRS, but higher in LDS (Table 2).

Table 2. Seasonal values of physicochemical parameters: Ammonia Nitrogen (NH_4^+), Dissolved Oxygen (Dissolved O_2), Electric Conductivity (E.C), Nitrates (NO_3^-), Orthophosphates (PO_4^{3-}), pH, Temperature, and Turbidity. Codes: Long Dry Season (LDS), Small Rainy Season (SRS), Small Dry Season (SDS), Long Rainy Season (LRS)

physico-chemical parameters	Seasons			
	LDS	SRS	SDS	LRS
NH_4^+ (mg/L)	2.66±0.26 [a]	1.48±1.28[a]	2.05 ± 1.57 [a]	0.36 ±0.30 [b]
Dissolved O_2 (%)	65.5±11.64 [a]	42.8 ±13.24[b]	68 ±0.70 [a]	71.13 ±1.86[a]
E.C (µS/cm)	54.87±11.87 [a]	45±11.07 [a]	43.95 ±5.25 [a]	40.83±7.94[a]
NO_3^- (mg/L)	55.5±31.04 [a]	11.8±9.8 [b]	13± 9.6 [b]	0.36±0.30 [c]
PO_4^{3-} (mg/L)	365±329 [a]	91±76.16 [b]	0.7 ±0.32 [c]	0.38 ±0.11 [c]
pH (U.C)	7.99±0.16 [a]	6.5±0.01 [a]	6.93±0.13 [a]	6.33±0.01 [a]
Temperature (˚C)	28.8±1.5 [a]	24.3±0.6 [a]	24.6±0.30 [a]	24.2 ±0.70 [a]
Turbidity (NTU)	70±30.72 [a]	20.7±14.4 [b]	60 ±33.28 [a]	18.5 ±8.32 [b]

In each row, values with same letter are not significantly different, those with different letters are significantly different.

3.3 Phytoplankton Diversity

3.3.1 Chlorophyll pigments in the Differents Stations

Mean values of the chlorophyll a, chlorophyll b, chlorophyll c and pheopigments in the different stations are given in Table 3. In the overall study area, the average pigments content varied significantly ($p < 0.05$) as follows: pheopigments (0.42 ± 0.01 µg/L) > chorophyll a (0.34 ± 0.03 µg/L) > chorophyll b (0.14 ± 0.01 µg/L) > chlorophyll c (0.08 ± 0.01 µg/L). Spatially, chlorophyll a was more concentrated than the other pigments in S_1 and S_7; likewise chlorophyll b in S_9 and S_{10}, pheopigments in S_2, S_3 and S_{12}. Codominance of pheopigments and chlorophyll a was noticed in S_4, S_6 and S_{11}, then that of pheopigments and chlorophyll b in S_8 (Table 3).

Table 3. Spatial variation of chlorophyll pigments content. S_1 to S_{12} designate the sampling stations

Stations	Chlorophyll pigments (µg/L)			
	Chlorophyll a	Chlorophyll b	Chlorophyll c	Pheopigments
S_1	0.35±0.01 a/C	0.02±0.01 b/C	0.06±0.01 b/C	0.17±0.01 ab/DE
S_2	0.18±0.03 b/E	0.01±0.01 c/C	0.02±0.01 c/D	0.59±0.03 a/B
S_3	0.26±0.04 b/D	0.03±0.01 c/B	0.04±0.01 c/D	0.47±0.01 a/C
S_4	0.28±0.01 a/D	0.04±0.01 b/B	0.05±0.01 b/C	0.34±0.01 a/D
S_5	0.28±0.02 b/D	0.02±0.01 c/C	0.03±0.01 c /D	0.41±0.01 a./C
S_6	0.41±0.04 a/B	0.02±0.01 b/C	0.04±0.01 b/D	0.41±0.01 a/C
S_7	0.72±0.01 a/A	0.31±0.08 c/A	0.09±0.02 d/C	0.49±0.01 b/C
S_8	0.16±0.03 ab/E	0.3±0.04 a/A	0.09±0.01 b/C	0.3±0.01 a/D
S_9	0.07±0.01 c/F	0.39±0.01 a/A	0.13±0.01 b/AB	0.17±0.01 b/DE
S_{10}	0.26±0.02 ab/D	0.45±0.02 a/A	0.23±0.01 ab/A	0.13±0.01 b/E
S_{11}	0.21±0.02 a/D	0.06±0.01 b/B	0.12±0.01 ab/AB	0.20±0.01 a/DE
S_{12}	0.96±0.03 b/A	0.03±0.01 d/C	0.08±0.01 c/C	1.39±0.03 a/A
Means	0.34 ±0.03 b	0.14±0.01 c	0.08±0.01 d	0.42±0.01 a
Frequency (%)	34.6±8.32 a	8.3±2.56 c	14±4.48 b	43.1±11.52 a

In each column, values with same letter are not significantly different. In each line, lowercase values with same letter are not significantly different.

The decreasing occurrence profile of these pigments was: pheopigments 43.1 ± 11.52 %, ≥ chorophyll a (34.6 ± 8.32 %) > chorophyll c (14 ± 4.48 %) and > chlorophyll b (8.3 ± 2.56 %) (Table 3).

3.3.2 Diversity of Phytoplankton in the Study Area

As far as phytoplankton is concerned, 63 genera belonging to 36 families, 23 orders, 11 classes and 4 phyla were identified (Table 4). Chlorophyta was the most diverse phyla with 23 genera (36.5 %), 13 families, 10 orders and 6 classes. In the decreasing order, it was followed by Cyanophyta made up of 19 genera (30.2%), 9 families, 5 orders and 2 classes, then Chrysophyta with 18 genera (28.6%), 12 families, 7 orders and 2 classes and at least Euglenophyta with 3 genera (4.8%), 2 families, 1 order and 1 classe (Table 4). From the density view, Chrysophyta was more abundant (14 046 Ind/mL) than Chlorophyta (12 117 Ind/mL), Cyanophyta (6208 Ind/mL), and Euglenophyta (84 Ind/mL).

Table 4. Biodiversity and density of phytoplankton in the study area

Phyla	Classes	Orders	Families	Species		Overall species density (Ind/mL)
				Names	**%** of number of species per phyla ( )	
CHLOROPHYTA (*)	Chaetophyceae (1)	Chaetophorales	Chaetophoraceae	*Stigeoclonium* spp.	**36.5 %**	287
		Sub –total 1				**287**
	Chlorophyceae (2)	Chlorococcales	Oocystaceae	*Ankistrodesmus fusiformis*		2907
				Selenatrum spp.		2223
		Chlamydomonadales	Volvocaceae	*Volvox aureus*		319
		Sphaeropleales	Characiaceae	*Characium* spp.		3
			Microsporaceae	*Microspora* spp.		15
		Ulotrichales	Ulotrichaceae	*Ulothrix zonata*		4
		Volvocales	Phacotaceae	*Phacotus* spp.		12
		Sub –total 2				**5483**
	Desmidiaceae (3)	Desmidiales	Desmidiaceae	*Micrasterias* spp.		352
				Desmidium spp.		1175
				Xanthidium spp.		3
			Gonatozygaceae	*Gonatozygon* spp.		273
		Sub –total 3				**1803**
	Prasinophyceae (4)	Pyraminadales	Pyraminonaceae	*Pyramimonas* spp.		5
		Sub –total 4				**5**
	Trebouxiophyceae (5)	Chlorellales	Chlorellaceae	*Actinastrum* spp.		278
		Sub –total 5				**278**
	Zygnemaphyceae (6)	Zygnematales	Mesotaeniaceae	*Pleurotaenum trabecula*		108
				Stauratum ophiura		58
				Euastrum spp.		5
				Mesotaenium spp.		44
				Closterium spp.		2137
				Cosmarium spp.		204
			Zygnemataceae	*Mougeotia operculata*		16
				Spirogyra spp.		1673
				Cylindrocystis spp.		16
			Sub –total 6			**4261**
Sub-total A	**6**	**10**	**13**	**23**		**12 117**

Table 4. Biodiversity and density of phytoplankton in the study area (continued)

EUGLENOPHYTA (**)	Eugleunophyceae	Euglonales	Euglenaceae	*Euglena* spp.	**4.8 %**	53
				Trachemonas angustispina		23
			Phacaceae	*Phacus* spp.		8
			Sub –total 7			**84**
Sub-total B	**1**	**1**	**2**	**3**		**84**
CHRYSOPHYTA (***)	Bacillariaphyceae	Fragilariales	Fragilariaceae	*Fragilaria* spp.	**28.6 %**	3799
				Synedra spp.		1029
			Tabellariaceae	*Tabellaria fenestrata*		108
		Eunotiales	Eunotiaceae	*Eunotia bilunaria*		754
		Naviculales	Stauroneidaceae	*Stauroneis* spp.		433
				Cyclotella stelligera		148
			Naviculaceae	*Navicula* spp.		4640
				Surirella tenera		185
				Amphora spp.		482
			Diploneidaceae	*Diploneis* spp.		153
			Diadesmidaceae	*Diadesmis confervacea*		2
		Bacillariales	Bacillariaceae	*Nitzschia* spp.		60
				Denticula spp.		8
				Fragilariopsis cylindrus		148
			Surirellales	*Cymatopleuro* spp.		83
		Cymbellales	Gomphonemataceae	*Gomphonema parvulum*		15
		Achnanthales	Achnanthaceae	*Achnanthes turgida*		163
		Sub –total 8				**12 210**
	Chrysophyceae	Ochromonadales	Dinobryonaceae	*Dinobryon* spp.		1836
		Sub –total 9				**1836**
Sub-total C	**2**	**7**	**12**	**18**		**14 046**

Table 4. Biodiversity and density of phytoplankton in the study area (continued)

CYANOPHYTA (****)	Cyanophyceae	Pseudanabaenales	Pseudanabaenaceae	*Microchaete investiens*	**30.2 %**	140
				Heteroleibleinia spp.		15
				Stigeoclonum aestivale		287
		Chroococales	Cyanobacteriaceae	*Synechococcus aeruginosa*		52
			Microcystaceae	*Microsystis clachista*		18
			Chroococcaceae	*Synechocystis aquatilis*		23
				Coelosphaerium confertum		3
		Oscilliatoriales	Oscillatoriaceae	*Limnothrix redekei*		82
				Spirulina major		271
				Lyngbya martensiana		4
				Oscillaria spp.		4740
			Microcoleaceae	*Microcoleus lacustris*		140
				Trachelomonas angustispina		13
				Trichodesmium lacustre		359
		Nostocales	Nostaceae	*Nostoc piscinale*		9
				Anabaena subcylindrica		11
				Raphidiopsis mediterranea		24
			Rivulariaceae	*Rivularia globiceps*		5
		Sub –total 10				**6196**
	Sciadiaceae	Mischococcales	Xanthophyceae	*Harpochytrium* spp.		12
		Sub –total 11				**12**
Sub-total D	**2**	**5**	**9**	**19**		**6208**
Total (A+B+C+D)	**11**	**23**	**36**	**63**	**100**	**32 455**

3.3.3 Spatio-Temporal Variations of Phytoplankton Communities

The phytoplankton species richness fluctuated spatially and temporarily. Its maximum and minimum numbers were registed in SRS with 23 taxa at S_6 and 3 taxa at both S_{11} and S_{12}.

With regard to the densities of the different phytoplanktonic classes, the Bacillariophyceae was the dominant class with a mean annual density of 12 210 Ind/mL, where *Navicula* spp. (4 640 Ind/mL) and *Fragilaria* spp. (3 799 Ind/ mL) were the major taxa. This class was followed by Cyanophyceae with a mean annual density of 6 196 Ind/mL, *Oscillatoria* spp. (4 740 Ind/mL) being the more prevalent taxa (Table 4).

The other classes which counted more than 1 000 Ind/mL were in decreasing order: Chlorophyceae (5 483 Ind/mL), Zygnemaphyceae (4 261 Ind/mL), Chrysophyceae (1 836 Ind/mL), and Desmidiaceae (1 803 Ind/mL).

The density of phytoplankton also varied spatially and temporarily, the lowest and highest values were 0 and 5 125 ± 480 Ind/mL respectively in LDS and LRS in S_{12}.

At this latter station this density increased progressively from LDS to LRS. While at S_5 and S_6 it decreased progressively through time. In the other stations, the seasonal density of phytoplankton was serrated (Table 5).

Table 5. Species richness and density of phytoplankton collected at each station. Long Dry Season (LDS), Small Rainy Season (SRS), Small Dry Season (SDS), Long Rainy Season (LRS); S_1 to S_{12} designate the sampling stations.

In each column, values with same letter are not significantly different. In each line, lowercase values with same letter are not significantly different.

The species richness of Prasinophyceae, Chaetophyceae, Trebouxiophyceae, Chrysophyceae, Sciadaceae and Euglenophyceae (except in SRS for this latter class) never exceed one (1) species/season. Four classes were totally absent during some seasons e.g. Prasinophyceae and Chaetophyceae in LRS, Chrysophyceae in SDS, and Sciadiaceae in LDS, SRS and LRS. The density of Chaetophyceae and Trebouxiophyceae increases from LDS to SDS for the first class and from LDS to LRS for the second one. Significant seasonal variation of these phytoplankton classes density were also noticed ($p < 0.05$) (Table 6).

Table 6. Seasonal variations of species richness and density of the different classes of phytoplankton collected in study area. Long Dry Season (LDS), Small Rainy Season (SRS), Small Dry Season (SDS), Long Rainy Season (LRS); Chae.: Chaetophyceae; Chlo.: Chlorophyceae; Des.: Desmidiaceae; Pra.: Prasinophyceae; Treb.: Trebouxiophyceae; Zyg.: Zygnemaphyceae; Eug.:Euglenophyceae; Baci.: Bacillariophyceae; Chry.: Chrysophyceae; Cya.: Cyanophyceae; Scia.: Sciadiaceae; *= Chlorophyta, .**= Euglenopyta, .***= Chrysophyta, .****= Cyanophyta.

In each row, values with same letter are not significantly different.

3.3.4 Analysis of Correlations Between Abiotic Parameters and the Density of Phytoplankton Classes

Many responses were noticed between water abiotic parameters and the density of some phytoplankton classes (Table 7). Positive significant correlations were obtained between:

-Temperature and Chlorophyceae ($r = 0.98$; $p < 0.01$), Bacillariaphyceae ($r = 0.70$; $p < 0.01$), and Chrysophyceae ($r = 0.91$, $p < 0.001$);

- pH and Zygnemaphyceae ($r = 0.63$; $p < 0.01$), Sciadiaceae ($r = 0.5$; $P<0.05$) and Chaetophyceae ($r = 0.45$; $p < 0.05$)

-Turbidity and Chlorophyceae ($r = 0.99$; $p < 0.001$), Bacillariaphyceae ($r = 0.67$;

$p < 0.01$), and Chrysophyceae ($r = 0.93$, $p < 0.05$);

- Depth and Cyanophyceae ($r = 0.6$; $p < 0.05$);

Conversely negative significant correlations were found between:

- pH and Chlorophyceae ($r = - 0.63$; $p < 0.05$) (Table 7).

Table7 : Correlations between abiotic parameters and density of phytoplankton classes, Chae.= Chaetophyceae; Chlo.= Chlorophyceae; Des.= Desmidiadeae; Pra.=Prasinophyceae; Treb.=Trebouxiophyceae; Zyg.= Zygnemaphyceae; Eug.= Euglenophyceae; Baci.= Bacillariophyceae; Chry.= Chrysophyceae; Cya.= Cyanophyceae; Scia.= Sciadiaceae; D = Depth; Tem = Temperature; Tur.= Turbidity; W.v = water velocity.

* : significant correlation at 5%, ** : significant correlation at 1%, *** : significant correlation at 1‰.

3.3.5 The Discriminant Factor Analysis

The discriminant factor analysis explained 54.81% of information obtained from different phytoplankton assemblages.

One could notice that along axis 2, high pH conditions favoured the development of Sciadiaceae, Chaetophyceae and Zygnemaphyceae on the one hand, and on the other hand that the high values of orthophosphates and water velocity favoured the pullulation of Prasinophyceae, Trebouxiophyceae, Euglenophyceae, and Cyanophyceae. On axis 1 Bacillariophyceae, Chrysophyceae, Chlorophyceae preferred environments that were rich in nitrate and ammonium ions, with high values of temperature, turbidity and electric conductivity but quite poor in dissolved oxygen (Figure 2).

Chae.= Chaetophyceae, Chlo.= Chlorophyceae, Des.= Desmidiadeae, Pra.= Prasinophyceae, Treb.= Trebouxiophyceae, Zyg.= Zygnemaphyceae, Eug.= Euglenophyceae, Baci.= Bacillariophyceae, Chry.= Chrysophyceae, Cya.= Cyanophyceae, Scia.= Sciadiaceae, Ammo.= Ammonia Nitrogen, Chl.a = Chorophyll a, Chl.b = Chorophyll b, Chl.c = Chorophyll c, D = Depth, O_2 = Dissolved Oxygen, E.C = Electric Conductivity, Nitra.= Nitrates, Ortho.= Orthophosphates, Pheo.= Pheopigments, Tem = Temperature, Tur = Turbidity, W.v = water velocity.

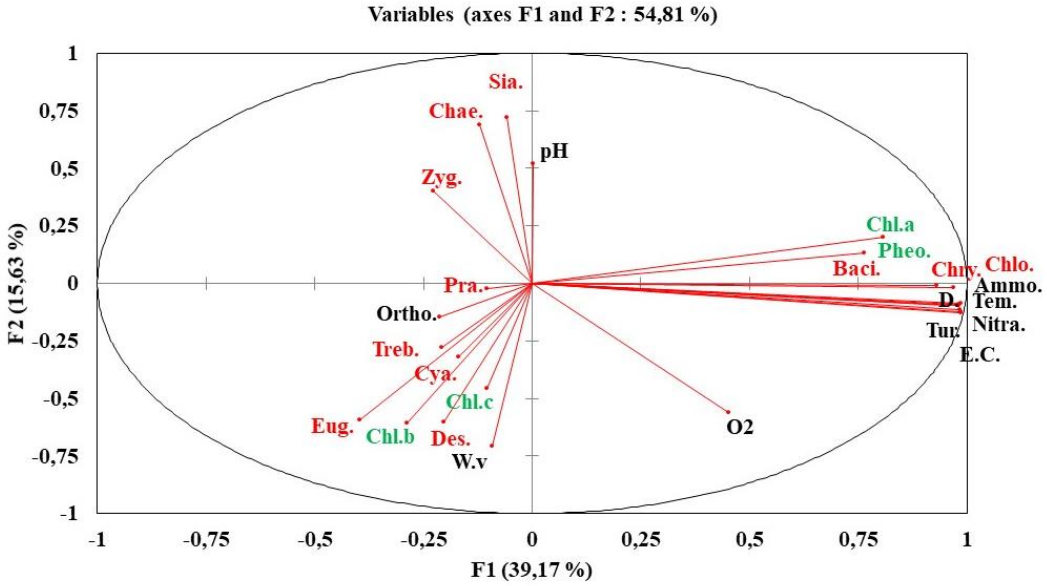

Figure 2. Discriminant factor analysis performed on the biotic and abiotic variables measured in the different sampling stations

3.4 Discussion

3.4.1 Physico-Chemical Parameters of the Study Stations

The relative high mean value of the temperature (28.8 ± 1.5°C) obtained during LDS (Table 2) depends strongly on the amount of sunlight that can increase this water parameter. In this connection, Antalé et al. (2013) stated that the temperature of surface waters depends closely on the amount of sunshine (28°C to 35°C) and exchanges with the atmosphere.

The mean values of electrical conductivity and turbidity were relatively lower during the Long Rainy Season (Table 2), probably due to the washout or runoff effect of products (from factories located near the wastercourses) intensively accumulated from LDS. In this regard, Onana et al. (2014) claimed that the high values of electrical conductivity and turbidity are related to the discharge of effluents of organic nature.

Dissolved Oxygen was relatively higher in LRS due to the water velocity, which also was relatively higher during that period (Table 1). In fact, flowing streams can regenerate themselves; rapid ones come alive again as oxygen is dissolved by the moving water (Hill, 1984). The concentration of oxygen in LDS (65.5 ± 11.64 %) and SDS (68 ± 0.70 %) could reflect biological processes such as photosynthesis (Brönmark & Hansson, 2000). In this respect, Kengne Tenkeu et al. (2020) argue that dissolved oxygen levels can affect algal blooms through phytoplankton photosynthesis.

During the current study, the pH remained within the range of natural waters (6.33 ± 0.01 to 7.99 ± 0.16 UC) (Table 2); in fact IBGE (2005) considers that the pH of natural water varies from 4 to 10 depending on the acidic or basic nature of the land crossed.

Concentration of mineral nitrogen (NH_4^+, NO_3^-) and orthophosphate (PO_4^{3-}) levels obtained were relatively high throughout the LDS: 2.66 ± 0.26 mg/L, 55.5 ± 31.04 mg/L and 365 ± 329 mg/L respectively. These elements are a very important nutrients source for algae growth; their concentrations may decrease in environments where algae have proliferated. Our results differ from those of Taffouo et al. (2017) in the Nkam River in the Littoral region: 0.57 mg/L (NO_3^-); 0.46 mg/L (NH_4^+); 0.17 mg/L (PO_4^{3-}). These high values recorded during the Long Dry Season could be attributed to the mineralisation of the critical mass of organic matter discharged directly by the NODISCAM effluent, near of station S_{12}, into the watercourse or simply carried by rainwater and runoff. According to Rodier et al. (2009), concentrations of more than 0.3 mg/L of NH_4^+ indicate significant organic pollution.

3.4.2 Chlorophyll Pigments

Chorophyll a and pheopigment levels peaked at station S_{12}: 0.96 ± 0.03 µg/L and 1.39 ± 0.03 µg/L respectively. The high level of chlorophyll reflects high photosynthetic activity and therefore high productivity (Lu et al., 2016). Indeed, many stations are located downstream the watercourses and represent receptacles of effluents from SOSUCAM and NODISCAM, which are rich in nitrogenous matter. Sommer (1989) stated that phytoplanktonic organisms are effective in predominantly nitrogen-rich environments.

3.4.3 Relationships Between Abiotic Parameters and Phytoplankton Variables

Different responses were obtained between abiotic parameters and the density of phytoplankton classes; so univariate analyses appeared inappropriate to discuss the ecology of such complex communities (Table 7 and Fig. 2). But in literature, it is known that ambient temperature, which influences water temperature, would be characteristic of tropical areas in warm zones (Iltis, 1980). Barendregt & Bio (2003) also stated that light, temperature, velocities, but also phosphorus, nitrogen and inorganic carbon influence algal growth in a river.

3.4.4 Phytoplankton Organisms

The overall taxonomic richness of phytoplankton (63 taxa) observed in all 12 stations is low compared to that (300 taxa) obtained by Kengne Tenkeu et al. (2020) in ponds (Eastern region of Cameroon). This huge discrepancy is likely a consequence of the different types of sampling environments: rivers in Mbandjock and Nkoteng versus lakes in the Easter region of Cameroon. Roxane & Reinhard (2015) also agree that the intensification of eutrophication in continental hydrosystems has undesirable effects such as the decrease in biodiversity and the increase in pollution-tolerant species. The analysis of the taxonomic composition of phytoplankton stands that Chlorophyta (36.5 %) was more prevalent, followed by Cyanophyta (30.2 %), Chrysophyta (28.6 %), and Euglenophyta (4.8 %). This dominant phylum, whose densities are generally high under α- or β-mesosaprobic to polysaprobic river conditions (Ebang et al. 2012), and which tolerates considerable organic pollution (Iltis, 1980), seems to characterize the middle course of the Sanaga river hydrographic network. *Oscillatoria* spp. (Cyanophyceae) dominated (6 208 Ind/mL) in all samples. It is known that they are highly competitive due to their ability to secrete different types of cyanotoxins (AFFSA/AFSSET, 2006), which inhibit the growth of other groups of algae and eliminate their predators such as zooplankton (Rimet et al., 2010). In addition, other taxa like *Nostoc* spp. (Cyanophyceae) and *Stigeoclonum* spp. (Chaetophyceae) are equipped with heterocysts, structures that allow them to fix atmospheric nitrogen. This property makes them very competitive with respect to other algae when nitrogen is limiting (Blais, 2002).

In the current study, Bacillariophyceae, with *Fragilaria* spp. (3 799 Ind/mL), *Navicula* spp. (4 640 Ind/mL), were also abundant due to certain environmental factors such as high turbidity. Its proportion in the phytoplankton samples in our study is similar to the results by Ebang et al. (2012) who found 39.57 % Bacillariophyceae in the Mfoundi River (Yaoundé-Cameroon), and Radji et al. (2013) with 27.12 % of Bacillariophyceae in aquatic ecosystems in southern Togo. The proportions of Chlorophyceae and Chrysophyceae are negatively impacted by the low acidic pH (during certain months December and February) of the waters, which is detrimental to their growth (Reimann et al., 1982). The low density of Prasinophyceae, Sciadiaceae, Chaetophyceae and Euglenophyceae likely results from the eutrophic characteristic of the waters analysed. In fact, these classes of phytoplankton proliferate in eutrophic aquatic environments where the waters are rich in nutrients (Iltis, 1980). This study confirms that the seasons influence variation of phytoplankton populations (Dibong et al. 2014; Radji et al. 2013; Priso & Ndongo 2012; Kemka et al. 2004).

Although, the few particularities made during the current study, it is suggested that high nitrogen and phosphorus load offers favourable conditions for the development and growth of different phytoplankton species. Aboim et al. (2019) also claim that the low water volume associated with high nutrient levels inputs, from urban or agricultural effluents, result in a great biological diversity and abundance of phytoplankton in some waterbodies. The correlations observed between some taxa and nutrients support the idea that the latter are responsible for phytoplankton densities (Kegne Tenkeu et al. 2020).

4. Conclusion

The results of this study indicated the poor state of health of the mid Sanaga hydrographic network through the taxonomic diversity of the phytoplankton, the physicochemical and hydrologic parameters. Spatio-temporal variations of phytoplankton densities are logically predicted by the changes of environmental conditions. The station S_{12}, located dowstream of SOSUCAM companies and NODISCAM, is the most impacted due to agro-industrial effluents from whisky and wines. The data obtained herein result in the urgent need to treat wastewater from collection channels before discharging into the natural environment; this avoids the risk of progressive eutrophication of the receiving aquatic milieu. In addition, it is established that the presence of some potentially toxic cyanobacteria species could be very dangerous for human health. In the long term, we suggest to the PAEPYS project (a national Drinking Water Supply Project for the City of Yaoundé and its Surroundings) which intends to supply more than 5 million people with drinking water, to evaluate certain phytoplankton toxins before finalizing their project.

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