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Quantitative and qualitative analysis of phytoplankton population in relation to environmental factors at the targeted sampling stations on the Burundian littoral of Lake Tanganyika

Lambert Niyoyitungiye, Anirudha Giri and Bhanu Prakash Mishra

Abstract

The present study was conducted at 4 sampling sites of Lake Tanganyika and was intending to identify and estimate the spatial abundance of phytoplankton in relation to physico-chemical attributes. The species composition analysis of the samples has listed 115 species of phytoplanktons belonging to 7 families from all sampling sites. The relative diversity index of families has indicated that Bacillariophyceae is the most dominant family in comparison to others families with 50 species (43.4%) followed by the family Chlorophyceae with 31 species (27%). The family Cyanophyceae was found very scarce with 3 species (2.6%).

Regarding quantitative data, the results of species richness and the Cumulative abundance of the sampling sites showed that phytoplankton species and density were variable among stations. Rumonge site holds first position with 115 species which was the maximum of all species identified comprising 3450 individuals per liter followed by Kajaga site with 107 species comprising 2482 individuals per liter, then Mvugo site with 101 species containing 1506 individuals per liter and in the last position was Nyamugari site with 86 species comprising 1031 individuals per liter. Furthermore the results of Canonical Correlation Analysis (CCorA) between the environmental parameters and phytoplankton composition at sampling sites have shown that the abundance and proliferation of some phytoplankton species are negatively or positively affected by the physico-chemical parameters concentration because, some physico-chemical variables were found either inhibitors or accelerators for phytoplankton species growth.

Keywords: Phytoplankton, quantitative and qualitative analysis, physico-chemical attributes, Lake Tanganyika

1. Introduction

Considered as the basic component of an aquatic food chain, Phytoplanktons are the source of oxygen and the main autochthonous primary producers of all types of water bodies [1]. Phytoplanktons constitute the basis of nutrient cycle of an ecosystem; hence play an important role in maintaining equilibrium between living organisms and abiotic factors [2]. Since phytoplanktons are the primary producers forming the first trophic level of food chain in aquatic system, the qualitative and quantitative studies are of great importance to assess the water quality [3-6]. Their standing crops and their species composition show the water quality in which they are growing [7]. Phytoplanktons are the producers, the basis of the aquatic ecosystem and therefore are sought as the main component of any freshwater system. They play an important role in solving various environmental problems, production of useful substances and understanding the aquatic ecosystem [8]. As species composition of phytoplanktons community changes in response to the environmental variations [9], a thorough knowledge of phytoplankton abundance and its quality in relation to environmental condition is essential for fish culture. The dominance, community structure and seasonality of phytoplankton in tropical wetlands are strongly variable and are depending on nutrient status, morphometry of the underlying substrate, water level and other regional factors [10-12]. Phytoplankton is the main biological elements used to assess the ecological status of surface water bodies and the change in biotic parameters and gives a good indication of energy turnover in aquatic environments, due to its sensitivity to any change in the environment [13, 14],

Many authors emphasized the importance of phytoplankton as Bioindicators in different aquatic systems [15-17]. Both the qualitative and quantitative abundance of plankton in a water body are of great importance for imposing sustainable management policies as they vary from location to location and aquatic systems in the same place and with similar ecological conditions [18]. Little or no studies on water quality and phytoplankton diversity and abundance in Lake Tanganyika have been done. Hence the present study was undertaken to assess the phytoplankton community at selected

stations of Lake Tanganyika in relations to environmental variables.

2. Materials and Methods

2.1 Study area

The data collection on fish species and water sample for laboratory analyses was carried out at 4 sampling sites (Kajaga, Nyamugari, Rumonge and Mvugo) belonging to the Burundian Littoral. The Table1 and Figure1 show the geographical location of the study areas:

Table 1: Geographical location of the study sites

Study sites	Geographical Location				
	Province	Commune	Longitude-East	Latitude-South	Altitude
Kajaga	Bujumbura Rural	Buterere	029° 17' 56''	03° 20' 55''	783 m
Nyamugari	Bujumbura Rural	Kabezi	029° 20' 24''	03° 30' 27''	776 m
Rumonge	Rumonge	Rumonge	029° 26' 03''	03° 58' 23''	767 m
Mvugo	Makamba	Nyanza-Lac	029° 34' 06''	04° 17' 42''	810 m

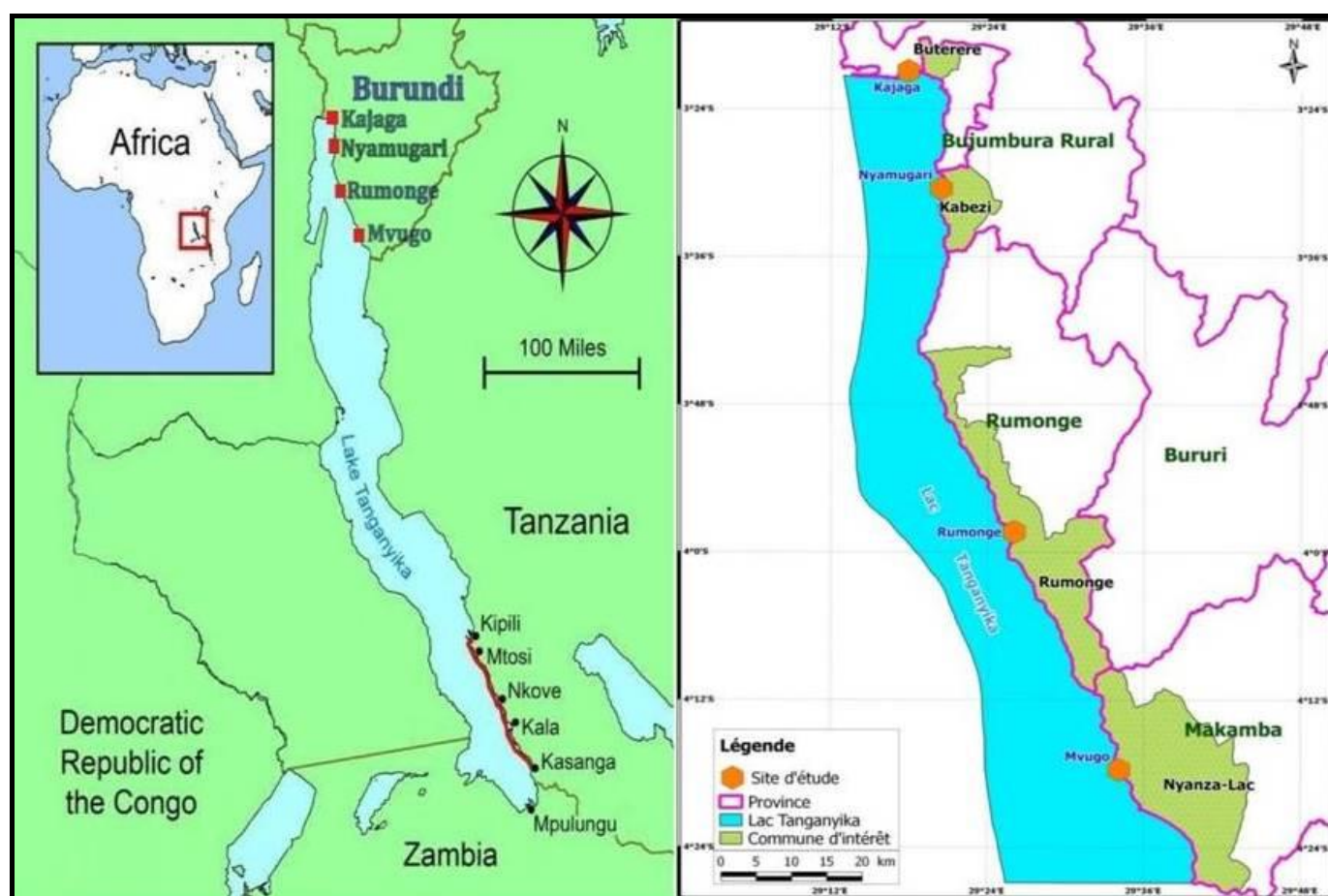


Fig 1: Map of the study area showing sampling sites

2.2 Collection of water samples for physico-chemical analysis

The field data collection has lasted 3months (January, February and March, 2018). The water sample for Physical and chemical analyzes was collected using plastic containers in the morning time. Temperature, Electrical conductivity, pH

and dissolved oxygen have been measured in-situ using electrometric method (conductivity meter and pH-meter) while the remaining parameters were determined in Laboratory using the standard methods [19, 20]. The methods adopted for water quality analysis and the used instruments are listed in the Table2:

Table 2: Analytical methods adopted to determine quality of lake water

Parameters	Methods	Equipments
Turbidity (NTU)	Turbidity tube method	Turbidimeter, Turbidity tube or Nephelometer
Temperature	Temperature sensitive probe	Mercury thermometer
Total Dissolved Solids	Evaporation method, Electrometric, and Gravimetric method	Conductivity meter
Transparency	Secchi Disk Visibility Method	Secchi disk
pH, Electrical Conductivity	Electrometric Method	pH-meter, Conductivity meter
Dissolved Oxygen	Alsterberg Azide Modification of the Winkler's Method.	Dissolved Oxygen meter
Total hardness, Calcium and Magnesium	EDTA Titration Method	-
Chlorides	Titration by AgNO ₃ , Mohr's method.	-
BOD	5 days incubation at 20 °C followed by titration	BOD Incubator
Total alkalinity	Titration by H ₂ SO ₄	-
COD	Digestion followed by titration	COD Digestor
Total Carbon, Total Nitrogen	Titrimetric method	-
Total Phosphorous	Digestion and ascorbic acid Spectrophotometric Method	Spectrophotometer
Iron, Lead, Cadmium, Chromium, Copper, Selenium, Arsenic.	Atomic Absorption Spectrophotometric Method	Spectrophotometer

2.3 Collection of water samples for Phytoplankton identification

Water sample was collected from the surface in the morning time. 100 liters of the collected water were filtered through a cloth net of mesh size 63 µm and diameter 16cm. The final volume of the filtered sample was 125ml and was preserved by adding 5ml of 4% formalin solution and kept for 24 hours undisturbed to allow the sedimentation of phytoplankton organisms. After 24 hours, the supernatant was removed carefully using pipette and the final volume of concentrated sample ready for analysis was 50ml. For both qualitative and quantitative analysis, Phytoplanktons were identified by observation under light microscope compounds in species and family level using identification keys as per Mpawenayo [21]. The species belonging to each group were recorded and the number of individuals in each species was counted. The number of organisms was expressed as total organisms per liter using the formula according to Lackey's drop method.

2.4 Species biodiversity measurement

Specific richness (S), Relative diversity index of family, Shannon Wiener Index (H') (1949) and Pielou's evenness index (1966) (E) have been used for measuring Alpha diversity while Beta diversity was measured using Jaccard Index [22] and Sorensen Index [23]. Indeed:

- I. The Specific richness (S) is the simplest measure of biodiversity and provides simply the total number of species recorded on a site and its ecological value is therefore limited [24]. Two species richness indices are widely used: Margalef's diversity index ($D_{ma} = (S-1) / \ln N$) and Menhinick's diversity index ($D_{me} = S / \sqrt{N}$), Where: N = the total number of individuals in the sample, S = the total number of species recorded.
- II. The relative diversity index of family = $100 * (n_{ef} / N_{te})$ and represents the number of species in a family over the total number of species, multiplied by 100. It is expressed as a percentage, Where: n_{ef} = number of species in a family; N_{te} = total number of species in the sample.
- III. Shannon-Weaver Index (1949) represents the average information provided by a sample on the stand structure

from which the sample originates and how individuals are distributed among different species [25]. It is the most commonly used index in ecology [26-29] as it considers both abundance and species richness. It is calculated as follows: Shannon Wiener Index (H') = $-\sum_{i=1}^S [ni/N * \log_2(ni/N)]$, Where: S = Total number of species in the sample, ni = Number of individuals of a species in the sample, N = Total number of individuals of all species in the sample. It varies from 0 to infinity. The higher the value of the index H', the greater the diversity. H' is minimal (= 0) if all individuals in the population belong to a single and same species. This index is maximal when all individuals are equally distributed over all species [26, 30].

- IV. Pielou's evenness index (E) (1966) also called equidistribution index [31] measures the equitability or equidistribution of the species in the station in comparison with an equal theoretical distribution for all the species. Evenness is calculated according to the following formula: $E = H' / H'_{max} = H' / \log_2 S$,
- V. Where: H' = Shannon-Weaver Index, $H'_{max} = \log_2 S$, S = Total number of species present, log₂: the logarithm in base 2. The evenness index (E) varies from 0 (single species dominance) to 1 (equidistribution of individuals in the samples. It is maximal when the species have identical abundances in the population and it is minimal when a single species dominates the whole population.
- VI. Jaccard Index and Sorensen Index are primarily used for comparing the number of common species between 2 sites in relation to the total number of species recorded. These indices vary from 0 to 1. They take the value 0 when there is no common species between two transects and 1 when all the species are common. They are calculated as follows:
 - **Jaccard's Index:** $S_j = \frac{c}{A+B+C}$. This index can be modified to a coefficient of dissimilarity by taking its inverse: Jaccard's dissimilarity coefficient = $1 - S_j = \frac{A+B}{A+B+C}$

- **Sorensen's Index:** $S_s = \frac{2C}{2C+A+B}$. This measure is very similar to Jaccard's measure and can also be modified to a coefficient of dissimilarity by taking its inverse: Sorensen's dissimilarity coefficient = $1 - S_s = \frac{A+B}{2C+A+B}$.

Where: S_j = Jaccard's similarity coefficient, S_s = Sorensen's similarity coefficient, C = Number of species common or shared between two sampling station, A = Number of species present only in the first sampling station, B = Number of species present only in the second sampling station.

2.5 Statistical Analysis

All the Statistical analyzes were performed using: SPSS 20, XLSTAT 2019 and PAST 3.06 and those analyzes includes:

- Pearson's correlation analysis** to assess pair wise associations between Physico-chemical variables and the strength of their relations;
- Multivariate analyzes including:** Correspondence Factor Analysis (CFA) and Canonical Correlation Analysis (CCorA) which summarize the data correlation

structure described by several quantitative variables by identifying underlying factors common to the variables for explaining a significant portion of the data variability. They allow the practitioner to reduce the number of variables and make the information less redundant.

3. Results

3.1 Physico-chemical characteristics of water

In the present investigation, the physical and chemical parameters evaluated were Turbidity (Tur), Temperature (Te), Potential of Hydrogen (pH), Transparency (Tr), Total Alkalinity (TA), Electrical Conductivity (EC), Total Dissolved Solids (TDS), Chlorides (Cl⁻), Total Hardness (TH), Calcium (Ca²⁺), Magnesium (Mg²⁺), Iron (Fe), Total Carbon (TC), Total Nitrogen (TN), Total Phosphorus (TP), Dissolved Oxygen (DO), % of Oxygen Saturation, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and some heavy metals like Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Selenium (Se) and Arsenic (As). The spatial variation of the analysis results are presented in Table 3.

Table 3: Spatial variation of Physico-chemical characteristics of water.

Parameters	Kajaga	Nyamugari	Rumonge	Mvugo
Tur (NTU)	0.5	9.8	1.5	0.65
Te (°C)	27.1	28	29.8	29.4
Tr (cm)	210	130	175	180
pH	8.85	8.88	8.82	8.5
TA (mg.L ⁻¹)	300.5	340.6	335.6	355.6
EC (μS/cm)	662	664	658	661
TDS (mg.L ⁻¹)	443.54	444.88	440.86	442.87
Cl ⁻ (mg.L ⁻¹)	47	30.8	39.25	35.15
TH (mg. CaCO ₃ .L ⁻¹)	210.4	189.2	211.3	172.9
Ca ²⁺ (mg.L ⁻¹)	54.65	34.95	43.18	39.22
Mg ²⁺ (mg.L ⁻¹)	17.93	24.74	25.11	18.19
Fe (mg.L ⁻¹)	0.021	0.018	0.161	0.089
TC (mg.L ⁻¹)	80.4	78.92	71.32	79.45
TN (mg.L ⁻¹)	0.379	0.1502	0.1079	0.1908
TP (mg.L ⁻¹)	1.572	1.671	0.786	0.685
DO (mg.L ⁻¹)	7.514	7.393	7.162	7.212
DO (%)	94.5	94.66	94.99	94.03
COD (mg.L ⁻¹)	75	30	25	25
BOD (mg.L ⁻¹)	15	10.6	8	7.5
Cd (ppm)	0.002	0	0	0
Cr (ppm)	0.031	0.04	0.002	0
Cu (ppm)	0.162	0.081	0.079	0.008
Pb (ppm)	0.083	0.062	0.079	0.034
Se (ppm)	0.006	0.002	0	0
As (ppm)	0	0	0	0

3.2 Phytoplanktons analysis

The specific composition analysis of the samples has listed 115 species of phytoplanktons belonging to 7 families from all sampling sites (Table 4). The relative diversity index of families has indicated that Bacillariophyceae or Diatomophyceae is the most dominant family in comparison to others families with 50 species (43.4%). The family Chlorophyceae holds second position with 31 species (27%), the family Dinophyceae occupies the third position with 16 species (14%), the family Xanthophyceae contains 6 species (5.2%) and holds the fourth place, the family Zygothryxaceae with 5 species (4.3%) holds the fifth position. The family Myxophyceae comprised of 4 species (3.5%) and occupied the sixth position. The family Cyanophyceae was in the last

position with 3 species (2.6%).

Regarding quantitative data, the results of species richness (S) and the Cumulative abundance (Figure 2) of the sampling sites showed that Rumonge site holds first position with 115 species which was the maximum of all species identified comprising 3450 individuals per liter, Kajaga site holds the second position with 107 species comprising 2482 individuals per liter, Mvugo site in third place with 101 species containing 1506 individuals per liter and in the last position was Nyamugari site with 86 species comprising 1031 individuals per liter. The relative abundance (the number of individuals per liter) of each species and the scientific names (Binary names) of all phytoplankton species recorded with their corresponding families are given in details in the Table 4

Table 4: Qualitative and quantitative results of phytoplankton population

	Family → Species	Acronyms	Kajaga (NLL ⁻¹)	Nyamugari (NLL ⁻¹)	Rumonge (NLL ⁻¹)	Mvugo (NLL ⁻¹)
I	Bacillariophyceae					
1	<i>Amphora coffaeiformis</i>	AC	32	15	43	20
2	<i>Amphora ovalis</i>	AO	35	16	47	22
3	<i>Cocconeis pediculus</i>	CPe	18	9	24	11
4	<i>Cocconeis placentula</i>	CP	16	8	21	10
5	<i>Cyclotella operculata</i>	CO	24	12	32	15
6	<i>Cymatopleura solea</i>	CS	18	9	23	11
7	<i>Epithemia turgid</i>	ET	23	11	31	15
8	<i>Eumotia bilunaris</i>	EB	35	16	47	22
9	<i>Fragilaria Montana</i>	FM	40	18	54	25
10	<i>Gyrosigma attenuatum</i>	GAt	27	13	36	-
11	<i>Gyrosigma nodiferum</i>	GN	30	14	41	19
12	<i>Navicula bahusiensis</i>	NB	31	15	42	19
13	<i>Navicula distinct</i>	ND	18	9	23	11
14	<i>Navicula elliptica</i>	NE	29	14	39	18
15	<i>Navicula gastrum</i>	NG	20	10	27	-
16	<i>Navicula pupula</i>	NP	26	-	35	16
17	<i>Navicula radiosa</i>	NRa	23	-	30	-
18	<i>Navicula rhynchocephala</i>	NRh	10	6	12	-
19	<i>Navicula tanganyikae</i>	NTa	10	6	13	7
20	<i>Nitzschia acicularis</i>	NAc	25	12	34	16
21	<i>Nitzschia acula Hantzsch</i>	NAH	24	12	32	15
22	<i>Nitzschia adapta</i>	NA	36	16	48	22
23	<i>Nitzschia bacata</i>	NBa	38	18	52	24
24	<i>Nitzschia Lacustris</i>	NLa	25	12	33	15
25	<i>Nitzschia Lancettula</i>	NL	20	10	26	12
26	<i>Nitzschia nyassensis</i>	NN	22	11	29	14
27	<i>Nitzschia palea</i>	NPa	18	9	24	11
28	<i>Nitzschia rostellata</i>	NR	39	18	53	24
29	<i>Nitzschia sigma</i>	NSi	41	19	56	25
30	<i>Nitzschia speculum</i>	NS	34	16	46	21
31	<i>Nitzschia tubicola</i>	NT	16	8	21	10
32	<i>Rhopalodia gracilis</i>	RG	7	-	9	5
33	<i>Schizostauron crucicula</i>	SC	16	-	21	10
34	<i>Surirella aculeate</i>	SAC	20	10	26	12
35	<i>Surirella acuminata</i>	SA	10	6	13	7
36	<i>Surirella debesi</i>	SD	15	8	19	-
37	<i>Surirella füllebornii</i>	SF	7	4	8	4
38	<i>Surirella gradifera</i>	SG	9	5	11	5
39	<i>Surirella heideni</i>	SH	5	3	5	-
40	<i>Surirella lancettula</i>	SLa	6	4	7	4
41	<i>Surirella latecostata</i>	SL	12	-	15	8
42	<i>Surirella margarifera</i>	SM	10	-	12	6
43	<i>Surirella plana</i>	SP	20	10	26	12
44	<i>Surirella reichelti</i>	SRe	7	4	8	4
45	<i>Surirella rudis</i>	SR	15	8	20	10
46	<i>Surirella spiraloides</i>	SSp	10	-	12	5
47	<i>Surirella striatula</i>	SS	14	7	18	9
48	<i>Surirella striolata</i>	SSSt	11	6	14	7
49	<i>Surirella subrobusta</i>	SSu	10	-	13	7
50	<i>Surirella tanganyikae</i>	ST	18	9	23	11
II	Chlorophyceae					
51	<i>Ankistrodesmis nitzschioides</i>	AN	19	9	25	12
52	<i>Ankistrodesmus bemarkii</i>	AB	41	19	56	25
53	<i>Botryococcus braunii</i>	BB	27	13	36	17
54	<i>Cerasterias raphidioides</i>	CR	25	12	33	15
55	<i>Chodatella longiseta</i>	CL	18	9	23	11
56	<i>Chodatella subsalsa</i>	CSu	18	9	24	11
57	<i>Closterium leibleinii</i>	CLe	20	10	27	13
58	<i>Crucigenia tetracantha</i>	CT	-	6	14	-
59	<i>Dictyosphaerium pulchellum</i>	DP	31	15	42	-
60	<i>Dimorphococcus lunatus</i>	DL	-	14	39	18
61	<i>Gloeocystis rehmani</i>	GR	33	15	45	21
62	<i>Gloeocystis gigas</i>	GG	15	8	20	10
63	<i>Hyalotheca mucosa</i>	HM	33	15	44	20
64	<i>Monoraphidium arcuatum</i>	MA	41	18	55	25
65	<i>Monoraphidium circinale</i>	MC	36	16	49	22
66	<i>Monoraphidium griffithii</i>	MG	39	17	53	24

67	<i>Monoraphidium komarkovae</i>	MK	43	19	59	27
68	<i>Nephrocytium lunatum</i>	NLu	27	-	36	17
69	<i>Oocystis lacustris</i>	OL	19	8	25	12
70	<i>Oocystis parva</i>	OP	18	8	23	11
71	<i>Pediastrum boryanum.</i>	PB	27	12	36	17
72	<i>Pediastrum Clathratum</i>	PC	25	11	33	15
73	<i>Pediastrum duplex</i>	PD	36	15	48	22
74	<i>Pediastrum integrum</i>	PI	32	14	43	20
75	<i>Pediastrum simplex</i>	PS	43	19	59	27
76	<i>Pediastrum tetras</i>	PT	22	10	29	14
77	<i>Scenedesmus bijugatus</i>	SB	-	-	33	15
78	<i>Sphaerocystis Schroeteri</i>	SSc	-	-	31	15
79	<i>Tetracoccus botryoides</i>	TB	18	9	23	11
80	<i>Tetraedron minimum</i>	TM	15	8	20	10
81	<i>Westella botryoides</i>	WB	18	9	23	11
III	Cyanophyceae					
82	<i>Oscillatoria earlei</i>	OEa	30	14	40	18
83	<i>Oscillatoria angusta</i>	OA	28	13	37	17
84	<i>Oscillatoria pseudogeminata</i>	OPs	45	20	61	28
IV	Dinophyceae					
85	<i>Glenodinium pulvisculus</i>	GP	-	-	9	-
86	<i>Gloeotrichia natans</i>	GNa	-	-	13	7
87	<i>Gomphosphaeria aponina</i>	GA	14	-	18	-
88	<i>Lyngbya limnetica</i>	LL	22	-	29	14
89	<i>Lyngbya perelegans</i>	LP	19	-	25	12
90	<i>Merismopedia aeruginosa</i>	MAe	8	-	10	5
91	<i>Merismopedia elegans</i>	ME	10	-	12	6
92	<i>Merismopedia glauca</i>	MGl	13	-	16	8
93	<i>Merismopedia punctata</i>	MP	10	-	12	-
94	<i>Microcystis elabens</i>	MEI	13	-	17	-
95	<i>Nostoc carneum</i>	NC	7	-	9	-
96	<i>Nostoc piscinale</i>	NPi	15	-	19	10
97	<i>Oscillatoria cortiana</i>	OC	20	-	26	13
98	<i>Oscillatoria princeps</i>	OPr	-	-	14	8
99	<i>Oscillatoria tanganyikae</i>	OTa	14	-	18	10
100	<i>Oscillatoria tenuis</i>	OT	-	-	8	5
V	Myxophyceae					
101	<i>Anabaena tanganyikae</i>	AT	23	11	30	15
102	<i>Anabaenopsis circularis</i>	ACi	19	-	25	13
103	<i>Anabaenopsis Tanganyikae</i>	ATa	26	12	35	17
104	<i>Chroococcus turgidus</i>	CTu	14	-	18	-
VI	Xanthophyceae					
105	<i>Ophiocytium cochleare</i>	OCo	28	13	37	19
106	<i>Ophiocytium elongatum</i>	OE	46	21	62	29
107	<i>Ophiocytium gracilipes</i>	OG	29	13	39	19
108	<i>Ophiocytium majus</i>	OM	25	12	33	16
109	<i>Ophiocytium parvulum</i>	OPa	30	14	41	20
110	<i>Ophiocytium capitatum longispinum</i>	OCL	38	18	52	25
VII	Zygophyceae					
111	<i>Closterium aciculare</i>	CA	26	12	33	16
112	<i>Closterium diana pseudodiana</i>	CPs	39	17	51	24
113	<i>Closterium gracile</i>	CG	30	14	41	20
114	<i>Closterium jenneri</i>	CJ	42	18	54	26
115	<i>Closterium kiitzingii</i>	CK	35	16	46	22
116	Total number of species		107	86	115	101
117	Total of Individuals/Liter		2482	1031	3450	1506

Where: N.I.L⁻¹: Number of Individuals per Liter

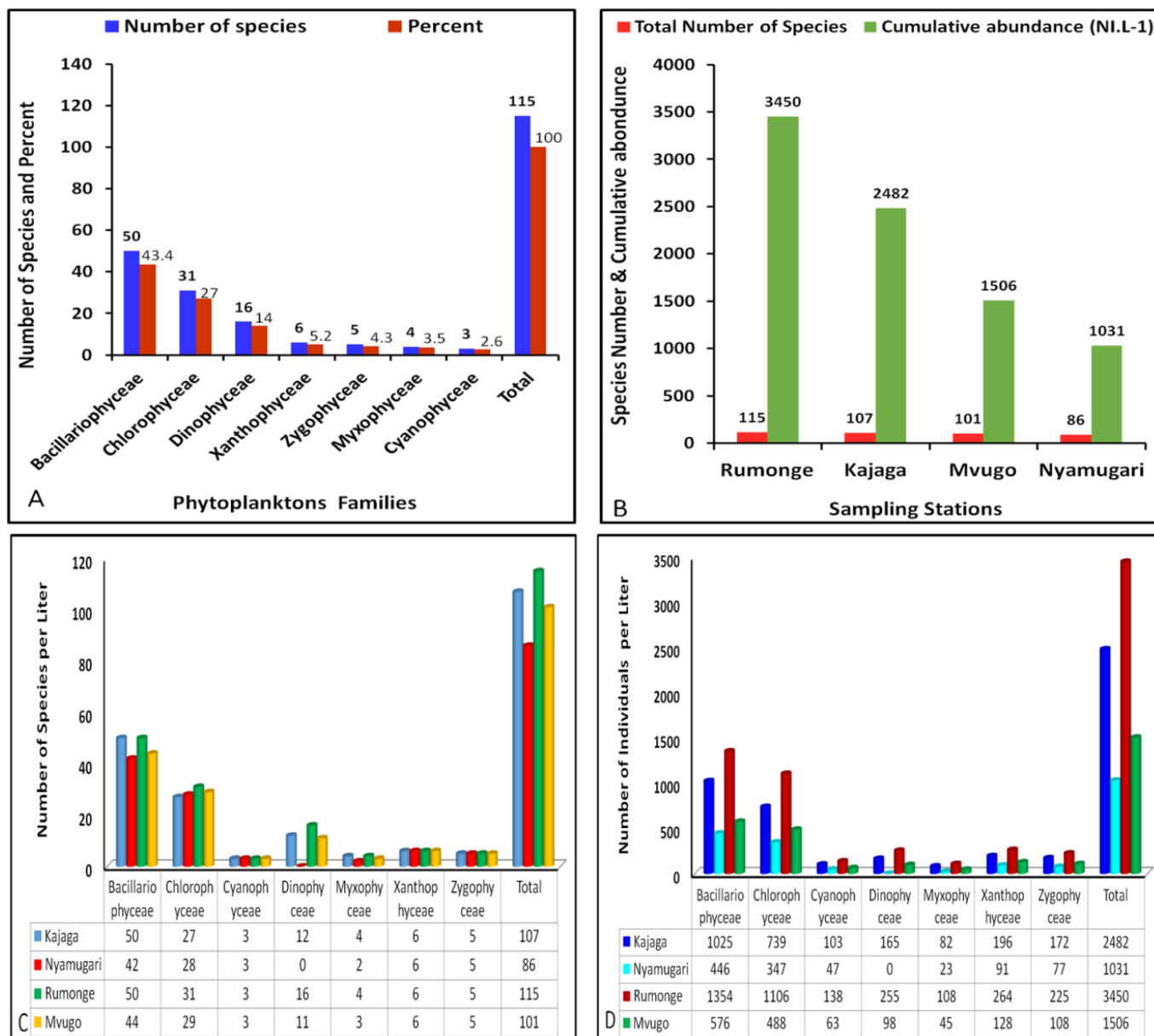


Fig 2: Relative diversity index of phytoplankton families (A), species richness & Cumulative abundance of phytoplankton individuals (B), density of phytoplankton species (C) and individuals (D) by station and family

3.3 Correspondence Factor Analysis

Correspondence Factor Analysis (CFA) is a descriptive analysis method for studying a contingency table by replacing a table of data that is difficult to analyze with an approximate simpler tables and unlike the PCA, the CFA offers the particularity of providing a common representation space for variables and individuals by using a reduced table or a frequencies table. CFA explores linkages, similarities and dissimilarities between individuals based on their distances on the factorial planes. CFA therefore studies the association between two qualitative variables as well as the proximities between the modalities of these variables.

The 115 phytoplanktons species are distributed in the 4 sampling sites based on their ecological preferences. The species located on the right side of the F1 axis are most abundant at Kajaga and Nyamugari sites where the environmental conditions are favorable for their development than in the other two sites. They probably belong to the families Chlorophyceae, Xanthophyceae, Cyanophyceae, Zygophyceae and Bacillariophyceae (Figure 3B). For example, the species SH, NRh, GAt, SD, NG, DP, CG, CA most prefer Kajaga site than OT, OPr, GNa, SSc, SB species which are most abundant at Mvugo site (Figure 3A).

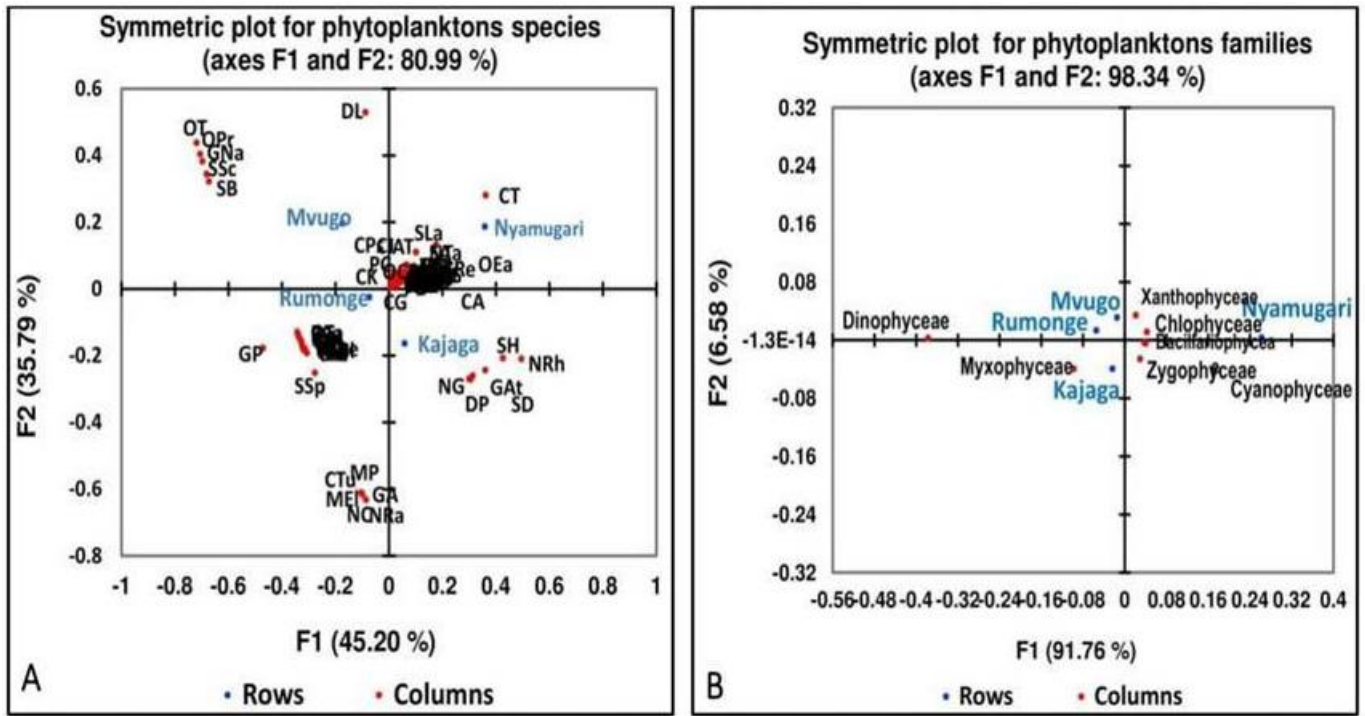


Fig 3: CFA plot showing linkages between the sampling sites and phytoplanktons species (A) and CFA plot showing linkages between the sampling sites and phytoplanktons families (B).

3.4 Effect of physico-chemical attributes of water on the abundance of Phytoplanktons population.

Physico-chemical parameters play a major role in determining the density, diversity and occurrence of phytoplanktons

population in the water bodies. The Figure4 shows the relationship between the environmental factors (Physico-chemical variables) and phytoplanktons assemblages at the sampling sites using Canonical Correlation Analysis.

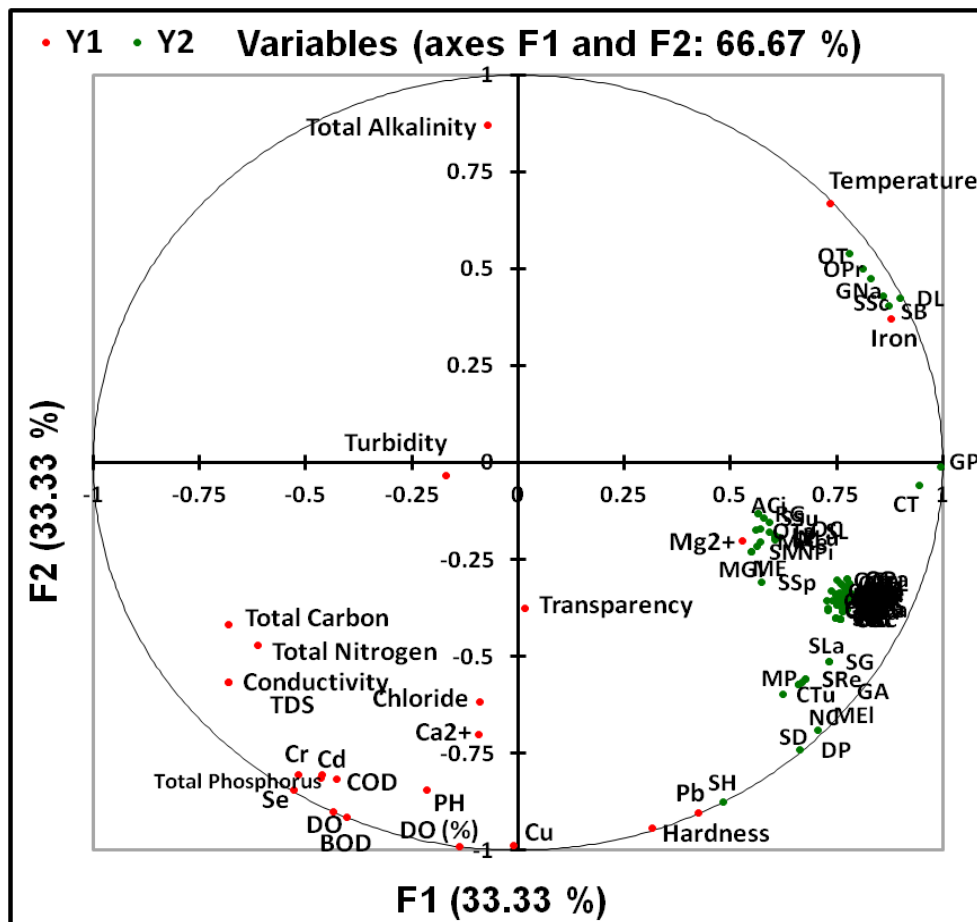


Fig 4: Canonical Correlation Analysis (CCorA) bi-plot showing relationship between the environmental parameters and phytoplankton composition at sampling sites.

The results of CCorA show that the abundance and proliferation of phytoplankton species are negatively or positively affected by the physico-chemical parameters concentration. Indeed, the proliferation and the growth of all phytoplankton species located in the first quadrant and the majority of species situated in the fourth quadrant of the trigonometric circle are affected strongly and negatively by physico-chemical parameter doses located in the third quadrant (Total carbon, Total Nitrogen, TDS, Conductivity, pH, DO (%), BOD,COD, etc). That means, the increase in concentration of the environmental variables inhibits the growth and the proliferation of these species. On the other hand, the growth of phytoplankton species (OT, OPr, GNa, SSc, SB, DL, GP, CT, ACi, OTa, SL, MG, ME, SSp, etc) is

accelerated by the temperature, iron and magnesium. Furthermore, it is also observed that transparency, total hardness and Lead affect positively the proliferation of SH, SD, DP, MP, CTu, SRe, GA, SG, MEI, SLa, etc. As a general principle, it can be admitted that physico-chemical variables located in the third quadrant are inhibitors for phytoplankton species growth while those belonging to the first and the fourth quadrants are accelerators of phytoplankton species growth.

3.5 Phytoplanktonic species diversity analysis

Phytoplanktonic species diversity among the sampling stations using diversity indices are given in the Table 5.

Table 5: Phytoplanktons species diversity indices

Diversity indices	Sampling Stations			
	Kajaga	Nyamugari	Rumonge	Mvugo
1. Shannon Weiner Index ($H' = \sum_{i=1}^S [ni/N * \log_2(ni/N)]$)	6.591	6.330	6.670	6.519
2. Pielou's evenness ($E = H' / \log_2 S$)	0.978	0.985	0.974	0.979
3. Species richness (S)	107	86	115	101
4. Margalef index ($D_{ma} = (S-1) / \ln N$)	13.803	12.395	14.117	13.561

Theoretically, Shannon Weiner Index varies from 0 to infinity and increases with diversity increase. For the current investigation, this index is high and varies from 6.33 to 6.67. A great phytoplanktonic diversity is recorded at Rumonge station while a small diversity is found at Nyamugari station. Pielou's evenness shows the species equidistribution in the population and ranges from 0 to 1. It has 1 value when the species have identical abundances in the population and it is 0 when a single species dominates the whole population. For the present case, it ranges from 0.974 to 0.985 for phytoplanktons and is close to 1 value in all sampling sites which shows that all species have almost the same abundance. Regarding Species richness, it has been shown that by direct counting of the number of species per stations, Rumonge site

occupies the first place with 115 species, followed by Kajaga site with 107 species, then Mvugo site with 101 species and lastly Nyamugari site with 86 species.

Margalef's diversity index was ranging from 12.395 to 14.117 with the same sequence of species richness per stations as observed for direct counting. Apart from Nyamugari station where Margalef's diversity index was low, the other 3 stations have indices a little bit high and close, which show that the environmental conditions propitious to the development of phytoplanktons are almost the same.

Correlation between the various diversity Indices: Pearson's correlation

Table 6: Correlation between phytoplankton diversity indices

Plot	SWI	PE	SR	MI	SI	SID	SRI	HDI
SWI	1							
PE	-0.989**	1						
SR	0.999**	-0.993**	1					
MI	0.991**	-0.978*	0.984**	1				
SI	-0.994**	0.988**	-0.990**	-0.998**	1			
SID	0.955*	-0.988**	0.966*	0.936*	-0.954*	1		
SRI	0.998**	-0.993**	0.996**	0.995**	-0.998**	0.963*	1	
HDI	-1**	0.988**	-0.999**	-0.989**	0.992**	-0.953*	-0.997**	1

** Correlation is significant at the 0.01 level (1-tailed)

* Correlation is significant at the 0.05 level (1-tailed)

SWI: Shannon Weiner Index, **PE:** Pielou's Evenness, **SR:** Species Richness and **MI:** Margalef Index.

Pearson's correlation shows negative and positive correlation and all the diversity indices are strongly and significantly correlated two by two (Table 6). In fact, the positive correlation between two variables indicates that the increasing in value of these two variables go hand in hand while negative

correlation indicates that the increase in value of one leads to the decrease in value of the other and vice versa.

3.6 Similarity between Phytoplankton species richness of sampling stations

Table 7: Jaccard and Sorensen's Similarity Index of Phytoplankton species among Sampling stations.

Phytoplankton	Kajaga	Nyamugari	Rumonge	Mvugo	Planktons
Kajaga	1	0.77	0.93	0.84	Jaccard's Similarity Index
Nyamugari		1	0.75	0.73	
Rumonge			1	0.88	
Mvugo				1	

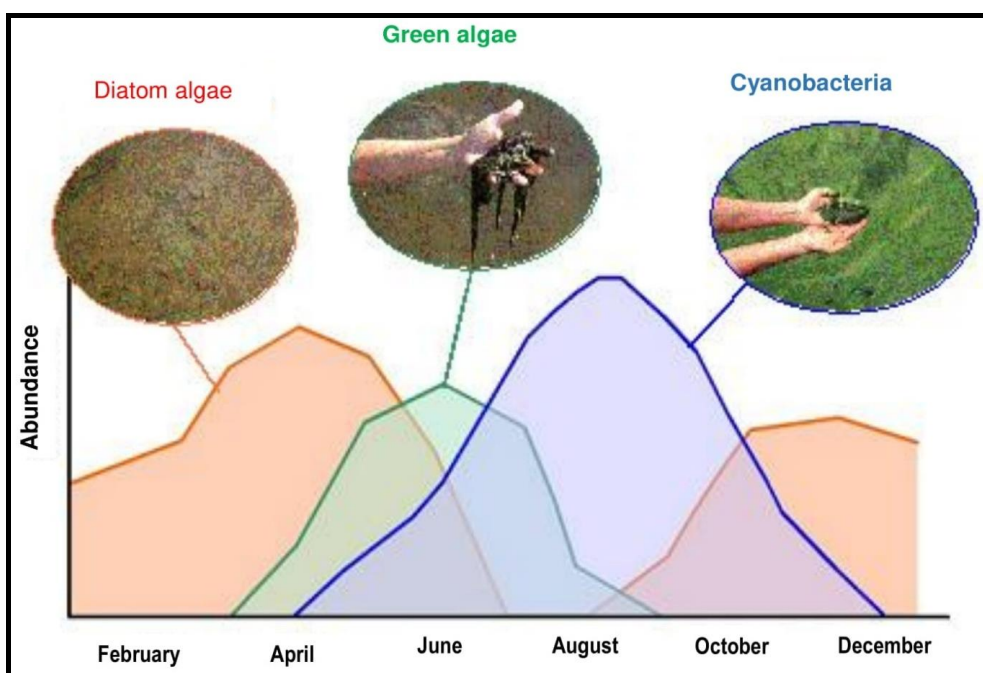
Kajaga	1	0.87	0.96	0.91	Sorensen's Similarity Index
Nyamugari		1	0.86	0.84	
Rumonge			1	0.94	
Mvugo				1	

Usually, Jaccard and Sorensen's Similarity Index varies from 0 (when there is no common species among habitats) to 1 (when all species are shared between habitats). From the Table 7, it has been shown that Jaccard and Sorensen indices give different coefficient values for the same pair of distinct sampling stations but they reflect both, the same information. Indeed, Rumonge x Kajaga pair was top with a high similarity coefficient of 0.96 and 0.93 for Sorensen and Jaccard's index respectively. This means that the environmental conditions impacting on phytoplankton distribution are different. Furthermore, all the values obtained for different pairs of sampling stations are above the average (0.5) and are greater than or equal to 0.73, which means that more than half of the total species belonging to each of the sampling sites are common.

4. Discussion

Phytoplankton is at the basis of the aquatic food chain. The quality of the water in particularly the nutrients influences its population. The phytoplankton investigation thus shows the trophic status and the presence of organic population in the ecosystem. Eutrophication is a Nutrient enrichment in water bodies and is a common phenomenon with algal proliferation. In freshwater ecosystems, phytoplankton are composed of different classes of algae such as green algae (chlorophyceae), yellow or brown algae (dinophyceae), diatoms (bacillariophyceae) and cyanobacteria (cyanophyceae) [32]. The qualitative and quantitative fluctuations of phytoplankton found in Lake Tanganyika are primarily related to warm climatic conditions. It is well known that with the increase of seasonal temperatures from 10 °C to 30 °C, phytoplanktonic groups grow rapidly and a qualitative change is performed in such a way that diatoms will be replaced by chlorophyceae and then by cyanobacteria [32, 33]. During the present investigation, 115 species of phytoplankton belonging to

7 families have been recorded in all sampling sites. Diatoms and green algae were shown to be more abundant than other algae encountered with 50 and 31 species respectively. This is due to the fact that the investigation was conducted in February month until early March, which are the most favorable periods for the development of diatoms, reputed to be most abundant in the spring-time, precisely in February where water is fresh and chlorophyceae which are known to be most abundant in March (Figure 5). Dense phytoplankton helps in producing 10 times more oxygen than it consumes and plays therefore an important role in compensating for respiratory losses without increasing further energy expenditures. The dinoflagellates were also abundant with 16 species. However, large and rapid variations in abundances of planktonic blooms of dinoflagellates are observed during the summer. The latitudinal distribution of dinoflagellate cysts in marine sediments is related to the surface waters temperature [34-36], while their offshore distribution is depending on other factors such as salinity, hydrodynamics and mineral salts. Indeed, temperatures between 22 °C and 30 °C are necessary for the growth of dinoflagellates [37, 38] and this is in accordance with the results obtained for temperature in the present study which ranged from 27.1 °C to 28.95 °C throughout the study period. The families Xanthophyceae, Zygothryxaceae and Myxophyceae were shown to be very less abundant and comprised of 6; 5 and 4 species respectively. The family Cyanophyceae was in the last position with 3 species. The very low presence of cyanobacteria is due to environmental conditions that were not propitious to their development during the survey period (January-March). Indeed, the temperature rise and the warming of the waters of Lake Tanganyika finally occur at the end of the dry season (September), leading to the proliferation of cyanobacteria and thus causing algal bloom. The algal development is therefore seasonal as shown on the Figure 5.



Source : <https://www.rappel.qc.ca/IMG/jpg/Image-Lac5-3.jpg>

Fig 5: Types of algae depending on the time of year

5. Conclusion

The specific objective of the current investigation was to assess the qualitative and quantitative statement of phytoplankton community and to highlight the effect of environmental factors on the abundance and spatial distribution of phytoplankton species.

The results of qualitative analysis have reflected the occurrence of 115 species of phytoplanktons belonging to 7 families from all sampling sites and the relative diversity index of families has indicated that Bacillariophyceae is the most dominant family in comparison to other families with 50 species (43.4%). The family Chlorophyceae holds the second position with 31 species (27%), the family Dinophyceae occupies the third position with 16 species (14%), the family Xanthophyceae contains 6 species (5.2%) and holds the fourth place, the family Zygothryxaceae with 5 species (4.3%) holds the fifth position. The family Myxophyceae comprised of 4 species (3.5%) and occupied the sixth position. The family Cyanophyceae was in the last position with 3 species (2.6%).

Regarding quantitative data, the results of specific richness and the cumulative abundance of the sampling sites showed that phytoplankton species and density were variable among stations. Rumonge site holds first position with 115 species which was the maximum of all species identified comprising 3450 individuals per liter, followed by Kajaga site with 107 species comprising 2482 individuals per liter, then Mvugo site with 101 species containing 1506 individuals per liter and in the last position was Nyamugari site with 86 species comprising 1031 individuals per liter.

The results of CCA show that the increase in concentration of the environmental variable such as Total carbon, Total Nitrogen, TDS, Conductivity, pH, DO (%), BOD, COD, etc affect the proliferation and the growth of phytoplankton species. On the other hand, the growth of phytoplankton species (OT, OPr, GNa, SSc, SB, DL, GP, CT, ACi, OTa, SL, MG, ME, SSp, etc) is accelerated by the temperature, iron and magnesium. Furthermore, it is also observed that transparency, total hardness and Lead affect positively the proliferation of SH, SD, DP, MP, CTu, SRe, GA, SG, MEI, SLa, etc.

5. Declaration of Conflicting Interests

The authors declare that they have no potential conflict of interest to report with respect to the research, authorship and publication of this article.

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