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(RESEARCH ARTICLE)



Microalgal structure and diversity in some canals near garbage dumps of Bobongo basin in the city of Douala, Cameroun

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Abstract

Anarchical and galloping anthropization is increasingly degrading the wetlands. This study aimed at determining the structure, diversity and spatiotemporal variation of microalgae from a few canals in the vicinity of garbage dumps of the Bobongo basin to propose methods of ecological management of these risk areas. Sampling took place from March 2016 to April 2019. Pelagic algae as well as those attached to stones and macrophytes were sampled in 25 stations. These algae samples were brought back to laboratory for identification and counting. The specific richness amounts to 13 classes, 34 orders, 52 families, 69 genera and 116 species. The dominant class is that of Bacillariophyceae (33 species) with a proportion of 28.45%. Results based on correspondence factor analysis revealed 3 groups of stations (clusters): the group I from stations 16, 21 and 25 consisted of exclusive species such as *Cyclotella ocellata*, *Cymbella gamma*, *Gomphosphaeria natans*, *Navicula cryptocephalla* and *Tabellaria flocculosa*. Group II from stations 18, 22, 23 and 24 consisted of exclusive species such as *Aphanizomenon flosaquae*, *Aphanocapsa holsatica*, *Astasia limpida* and *Ulothrix zonata*. Group III was made up of species common to all stations. *Cyclotella ocellata*, *Cymbella gamma*, *Gomphosphaerium natans*, *Navicula cryptocephalla* and *Tabellaria flocculosa* are hydrocarbon-polluting species. Our analysis is, to our knowledge, the first demonstrate the use of microalgal species as indicators of pollution in the context of environmental management for better monitoring of the quality of watercourses. In addition, these species can be used as bio-purifiers of polluted water in hydrocarbon.

Keywords: Bobongo basin; Microalgal diversity; Pollution; Channel

1. Introduction

Wetlands are areas where water is the main determinant of the environment, and associated plant and animal life [1]. These wetlands are one of the most productive environments worldwide. They are the cradle of biological diversity and provide water and primary productivity from which countless species of plants and animals depend for their survival [2, 3]. Douala, economic capital of Cameroon, has a vast hydrographic network with important lowland swamps, most of which is influenced by anarchic anthropization [4].

Indeed, Cameroon experiences difficulties to implement its urbanization policies for many years. A body of events including 1980-1990 and 2007 global economic crisis, devaluation of the currency and following restrictive policies have been pointed with the finger. As a consequence, precarious and unhealthy neighborhoods such as "Cite-berge",

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"Bobongo" and "Ndogpassi IIIa" have proliferated in Douala [5]. This economic constraint has led people to settle in areas classified as non-constructive (lowland swamp) hence the conjunction of certain anthropization-related factors that exacerbate the vulnerability of exposed populations. A concrete example concerns the management of household waste in different neighborhoods [6]. It is well known that the waste management is one of the most worrying socio-environmental issues in the city of Douala [7].

Although the garbage collection national company does not fully cover the sectors because of insufficient collection trucks and certain hard-to-reach sectors, populations close to drains and canals take advantage of this to dump their garbage [8]. These current waters contain a large amount of pigsties, cesspools and anarchic landfills [5, 6]. The proliferation of precarious and unhealthy neighborhoods in these lowlands results from laxity of heads of blocs and neighborhoods as well as public authorities [9].

Micro-algae are organisms that react directly to sudden changes in the environment related to pollution and their presence depends on the degree of pollution [10]. Some species can disappear and others resist as a result of pollution and its level. Some authors showed that resistant species or groups of species can find satisfactory conditions even though the pollution of their environment. These can grow abundantly by inhibiting growth of others sympatric species [11].

The understanding of structure and functioning of these micro-algae would be helpful in fight against pollution of hydrosystems through their potential of remediation. Management studies of risk areas have been carried out by urban planners for long. These concerned spatial risk analyzes, exposures and vulnerabilities to floods. Very few studies addressed structure and functioning of photosynthetic micro-organisms in a given hydrosystem [11, 12, 13]. This study therefore aimed at determining the structure and, the spatial and temporal variation of micro-algae of some canals near the garbage dumps of the Bobongo basin to propose methods of ecological management of these risk areas.

2. Material and methods

2.1. Presentation of study area

Douala is subdivided into 11 sub-watersheds [4]. The study area is part of the northern equatorial climate zone. The average annual temperature is 26.4 °C. Precipitation shows that Douala is rainy with rainfall extending over 9 months with an average ranging from 800 mm (August) to 300 mm (February). The average annual humidity, evaporation and isolation is 78.3%, 50.6% and 109.6% respectively. The prevailing wind carries the monsoon [4]. The study took place in the Bobongo sub-watershed, which includes: Cite-Berge, Bobongo and Ndogpassi IIIa neighborhoods (Fig. 1). The main anthropogenic activities in the study area include pigs and sheep farming, automobile mechanics and trades. Waste from these activities as well as households are directly dumped in canals that drain them to the rivers. There are specific canal disposal points that lead to physical pollution (plastics bottles and papers) and organic pollution (pigs manures and chickens droppings).

Sampling took place from March 2016 to April 2019. The study was conducted in 25 waste disposal points (stations) (Table 1). These points located in canals have been chosen according to the extent of the pollution which directly offers a particular aspect to the hydrosystem.

2.2. Sampling

2.2.1. Qualitative sampling of micro-algae

The qualitative aspect of phytoplankton was determined from samples contained in 5 L buckets and filtered using a plankton net (200 L of water filtered in total). After harvesting, samples were immediately fixed by addition of formaldehyde 5%. The solid substrate, like submerged vegetation in the stream was sampled. These plants were pressed and scraped for larger diameter species. The contents were rinsed in a container with distilled water. Sample was shaken and filtered through a sieve to remove remains of macrophytes, small pebbles, leaves or other large particles. The content was fixed with formaldehyde 5% again.

2.2.2. Quantitative sampling of micro-algae

The quantitative sampling of phytoplankton was done by filtration after collection of 100 L water using a 5 L bucket. A jar was used for collecting periphyton which was thereafter pressed and scraped on a surface of (30×30) cm². This

was diluted with distilled water up to 60 mL and then fixed with formaldehyde 5%. Each jar has been labeled and samples were introduced into a cooler for dark storage.

2.3. Laboratory procedures

2.3.1. Qualitative Analysis of micro-algae

Sub-samples of 10 mL were done using beakers for performing qualitative analysis of micro-algae. Micro-algae specimens were allowed for sedimentation at the bottom of beakers for 24 h. Thereafter, a drop of each sample was mounted slide and cover slide for microscopic examination (OLYMPUS) under right light. Two preparations were made for each sample. Identification were carried out directly under the light microscope (OLYMPUS) using identification keys described elsewhere [15, 16, 17, 18, 19, 20, 21]. To be noted, drawings and photographs were made for hard-to-identify individuals for more details about their measurements.

2.3.2. Quantitative Analysis of micro-algae

After depositing sampled jars, homogenization was performed. Sub-samples of 10 mL per beaker were made. After stirring each beaker left at rest and under the lee of light for 24 hours, 1 mL of contents was taken using a micropipette and then poured into counting plates of Malassez. An OLYMPUS photonic microscope was used for counting individuals. At least 200 individuals were counted. The counting unit of the filaments was set at 100 µm as 1 individual. Colonies and coenobes were considered as 1 individual [22].

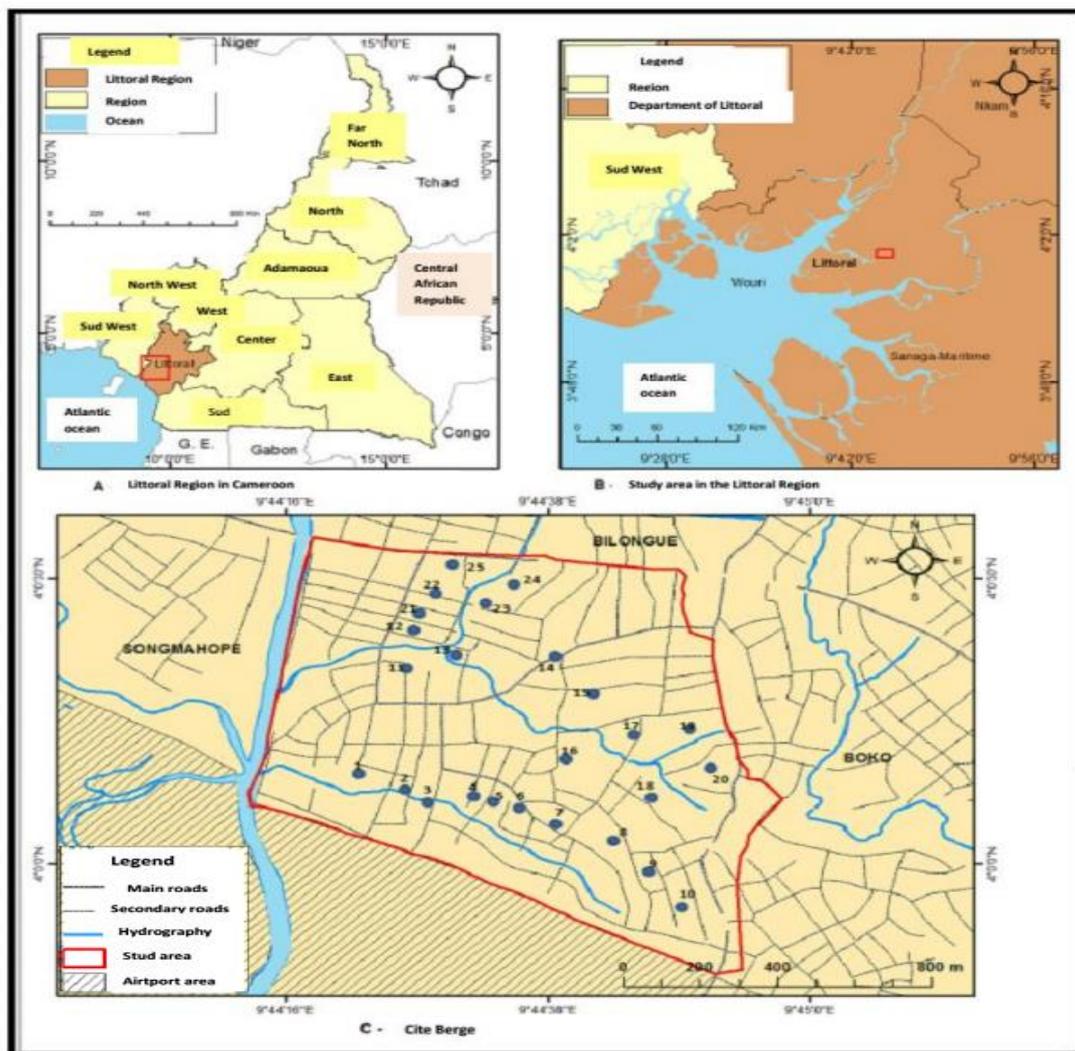


Figure 1 Location of the study area (Mapping Institute modified by Ndjouondo [14])

Table 1 Geolocation of study stations

Stations	Longitude (x)	Latitude (y)	Denomination of points	Type of waste
1	582505	442642	Two iron bridges	Household waste and plastics bottles
2	582240	442807	Saint-Angel	plastics bottles, Household waste
3	582282	442818	Laugh	Household waste and plastics bottles
4	582329	442806	Bangoua bridge	Household waste and plastics bottles
5	582399	442751	No respect	Pig manure and plastics bottles
6	582480	442646	Entry to know	Household waste and plastics bottles
7	582880	442519	White house	Household waste and plastics bottles
8	582442	442942	Bayanguam bridge	Plastics bottles, Household waste
9	582087	442890	One maouth	Pig manure
10	581952	442778	Third bridge	Plastics bottles and household waste
11	582010	442794	Libanese bridge	Household waste and plastics bottles
12	581876	442647	Pigstry bridge	Household waste
13	582108	442426	Bridge little Paris	Plastics bottles, household waste and Pig manure
14	582241	442366	Bridge thousand problems	Household waste and plastics bottles
15	582517	442186	Small market bridge	Household waste and plastics bottles
16	582462	442210	Cemetery bridge	Household waste
17	581900	442468	Bridge block 6	Household waste and plastics bottles
18	581987	442826	Second bridge	Household waste and Pig manure
19	582400	443010	Carrefour Mauritius	Household waste and Pig manure
20	581953	443095	Bridge block 7	Household waste and Pig manure
21	582407	443054	Under mango	Household waste and Pig manure
22	582121	442341	Stunt bridge	Household waste, chicken droppings and Pig manure
23	582606	442623	Bangou's home	Household waste, chicken droppings and Pig manure
24	582610	442588	Behind Shell	Household waste, chicken droppings and Pig manure
25	582666	442645	Bridge picasso entrance	Pig manure and chicken droppings

2.4. Determination of ecological parameters

2.4.1. Specific richness

The specific richness (S) is defined by the total number of taxa identified in a sample. It is an element that indicates the specific variety of the stand in other words its species richness. Species richness may well be a distinctive criterion of the ecosystems or stations studied within a given ecosystem.

2.4.2. Diversity indices

A body of diversity indices were computed namely Shannon-Weaver index, equilibrium of Pielou, dominance index, heterozygosity, Simpson's index and Hill index [14]. 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: $H' = -\sum_{i=1}^S ((ni/N) \times \log_2 (ni/N))$, with ni = number of individuals belonging to a species, N = total number of species. The regularity of Pielou (J) is given by the formula: $J = H'/\log_2 S$, with S = total volume. The dominance index "d" of Berger and Parker which has the formula $d = N_{max}/N$. 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, that is to say, 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. Simpson's D index is $D = WNi(Ni-1)/N(N-1)$ or $D = WPi^2$. This index represents the probability that two individuals selected at random from a sample belong to the same species. To know the number of dominant species, the Hill index is calculated = $(1/D)/\exp H'$.

2.4.3. Density of micro-algae

Density (D) of micro-algae was computed using the following formula [22]: $D = Ni \times 1000 \times v/V$, where D is the number of individuals per liter (ind/L), Ni = number of individuals for a given species, V = volume of the sample and v = volume of the subsample counted in mL.

2.5. Statistical analysis

Microsoft Office Excel 2010 was used for keying and coding data collected during the study. Qualitative and quantitative variables were presented as frequency and mean \pm standard deviations respectively in charts. Correspondence Factor Analysis (CFA) was applied to stand composition to group sampling sites according to their floristic similarities. These analyses were performed using XLSTAT software version 11.0.0.28844 and Past version 3.02a for the dendrograms.

3. Results

3.1. Specific wealth of the study area

The specific richness of environment amounts to 13 classes, 34 orders, 52 families, 69 genera and 116 species. The dominant class is that of Bacillariophyceae (33 species) with a proportion of 28.45% (Table 2). The least important classes are those of Pyramimonadaphyceae, Trebouxiophyceae and Ulophyceae with 1 species each (00.86%). The specific richness varied between the studies stations (Fig. 2). The highest values were reported at stations 7 and 17 with 26 species while the lowest values were recorded at stations 2 and 9 with 12 species. Besides, Diatoms were present at all stations whith a maximum of 19 species at station 7. They are followed by Cyanophyceae and Chlorophyceae classes.

Table 2 Specific richness of the study area.

Classes (Proportions)	Orders	Families	Genera	Species
Bacillariophyceae (28.448%)	Bacillariales	Bacillariophyceae	1	2
	Cocconeidales	Achnanthidiaceae	1	1
	Cymbellales	Cymbellaceae	1	5
		Gomphonemataceae	1	1
		Fragilariales	Fragilariaceae	2
	Naviculales	Staurosiraceae	1	1
		Naviculaceae	1	1
		Diploneidaceae	1	1
		Naviculaceae	1	6
		Pinnulariaceae	2	4
Rhopalodiales	Rhopalodiaceae	1	1	

	Surirellales	Surirellaceae	1	1
	Tabellariales	Tabellariaceae	3	6
Chlorophyceae (09.482%)	Chaetophorales	Chaetophoraceae	1	2
		Uronemataceae	1	1
	Chlamydomonales	Chlamydomonaceae	2	2
	oedogoniales	oedogoniaceae	1	2
	Sphaeropleales	Selenastraceae	1	2
		Radiococcaceae	1	1
		Hydrodictyaceae	1	1
Conjugatophyceae (09.482%)	Desmidiiales	Closteriaceae	1	2
		Desmidiaceae	4	5
		Gonatozygaceae	1	1
	Zygnematales	Zygnemataceae	3	3
Coscinodiscophyceae (02.586%)	Aulacoseirales	Aulacoseiraceae	1	3
	Coscinodiscales	Coscinodiscaceae	1	3
	Melosirales	Melosiraceae	1	1
Cryptophyceae (02.586%)	Cryptomonadales	Cryptomonadaceae	1	2
	Pyrenomonadales	Pyrenomonadaceae	1	1
Cyanophyceae (20.689%)	Chroococcales	Gomphosphariaceae	1	1
	Nostocales	Aphanizomenonaceae	4	6
		Nostocaceae	1	2
		Rivulariaceae	1	2
	Oscillatoriales	Oscillatoriaceae	1	1
		Microcoleaceae	1	1
		Oscillatoriaceae	1	3
	Spirulinales	Spirulinaceae	1	3
	Synechococcales	Merismopediaceae	3	5
Dinophyceae (04.310%)	Gloeodinales	Gloeodiniaceae	1	2
	Gymnodinales	Gyrodiniaceae	1	1
	Peridinales	Peridiniaceae	1	2
Euglenophyceae (06.896%)	Euglenales	Euglenoideae	1	3
		Phacaceae	2	3
		Euglenaceae	1	2
Mediophyceae (07.758%)	Stephanodiscales	Stephanodiscaceae	3	7
	Thalassiosirales	Skeletonemataceae	1	1
		Thalassiosiraceae	1	1
Peranemea (01.724%)	Natomonadida	Astasiidae	1	2
Pyramimonadophyceae (00.862%)	Pyramimonadales	Pyramimonadaceae	1	1
Trebouxiophyceae (00.862%)	Chlorellales	Chlorellaceae	1	1
Ulophyceae (00.862%)	Ulothricales	Ulothricaceae	1	1

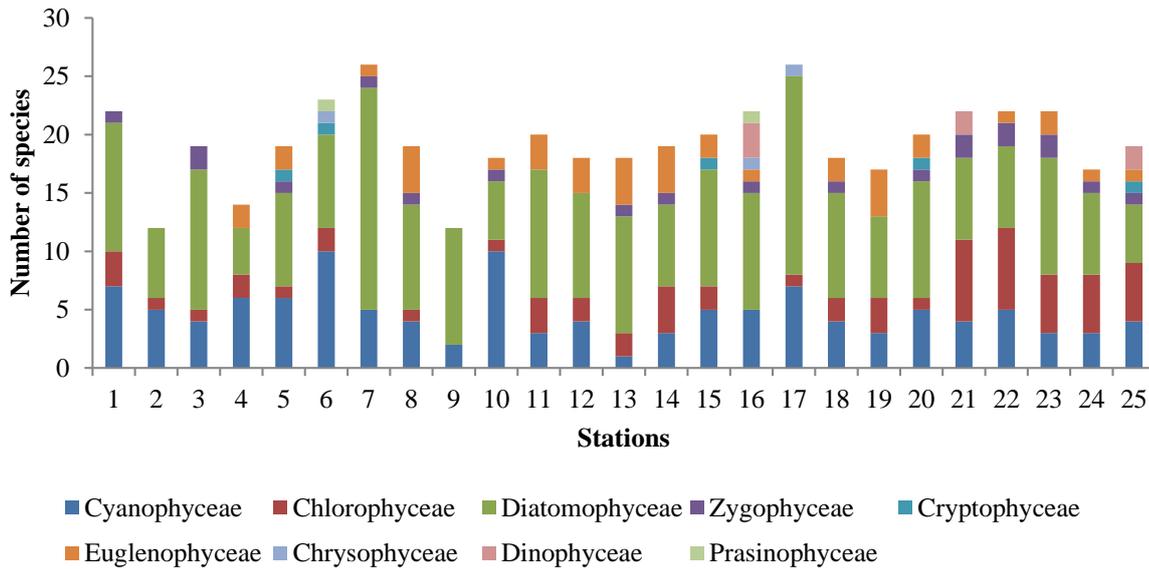


Figure 2 Specific richness of the different classes of microalgae with regard to the study stations.

3.2. Diversity indices of study stations

The diversity indices of the different study stations vary in a "sawtooth" way (Fig. 3). However, the highest values appear mainly between stations 21 and 25. The dominance index of Simpson is close to 0 and varies from 0.05 (station 21) to 0.17 (station 2). The Shannon-Weaver diversity index is low and ranges from 2.08 (station 2) to 2.97 (station 21). The Hill index varies from 0.57 (station 7) to 0.91 (station 24). The regularity of Pielou varies from 0.81 (station 1) to 0.97 (station 24). The dominance of Berger-Parker varies from 0.08 (station 24) to 0.35 (station 2).

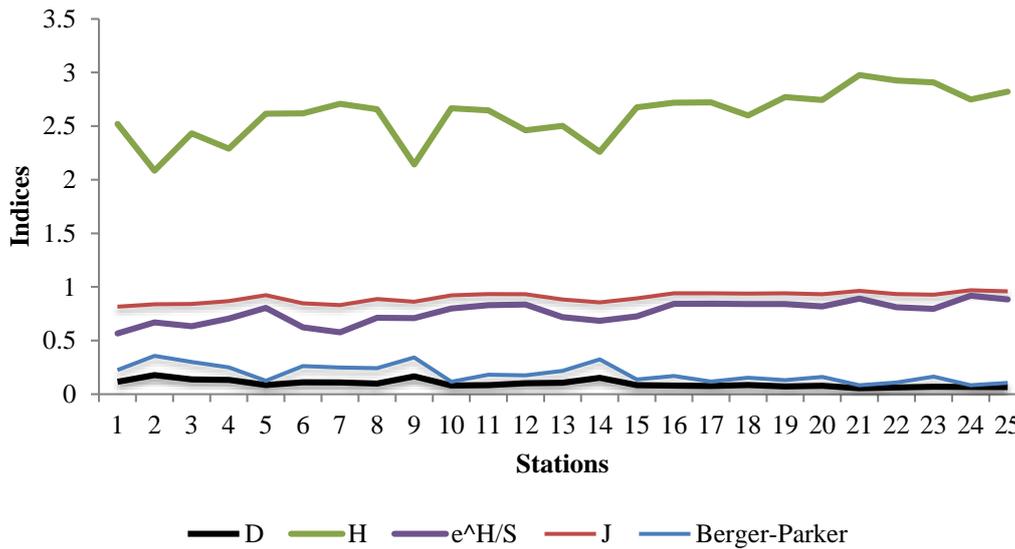


Figure 3 Variation in diversity indices with regard to study stations (D = Simpson dominance, H = Shannon-Weaver index, e^H/S = index of Hill, J = regularity of Pielou).

3.3. Approximation of study stations according to floristic similarities

Results based on correspondence factor analysis show 3 groups of stations defined by species that are common to them (Fig. 4). The F1 and F2 axis (20.71% of inertia) are positively correlated to the group I consisting of stations 16, 21 and 25 by the exclusive species such as *Cyclotella ocellata*, *Cymbella gamma*, *Gomphosphaeria natans*, *Gyrodinium rubricaudatum*, *Melosira varians*, *Merismopedia elegans*, *Navicula cryptocephala*, *Oscillatoria boryana*, *Peridinium* sp., *Phacus longicauda*, *Pleurotaenium ehrenbergii*, *Stigeoclonium* sp. and *Tabellaria flocculosa*. Group II is positively and

negatively correlated to F1 and F2 respectively. It includes stations 18, 22, 23 and 24 from the species that are exclusive to them. These are: *Aphanizomenon flosaquae*, *Aphanocapsa holsatica*, *Astasia torta*, *Diatoma mesodon*, *Diatomella* sp., *Euglena mutabilis*, *Gomphonema parvulum*, *Nostoc palludosum*, *Pinnularia gibba*, *Pyramimonas* sp., *Spirulina subsalsa*, *Staurastrum aculeatum*, *Synechocystis aquatilis*, *Tabellaria fenestrata*, *Thalassiosira pseudonana*, *Ulothrix zonata* and *Xanthidium* sp. Group III consists of the species common to all the stations: *Actinastrum* sp., *Anabaenopsis* sp., *Ankistrodesmus gracilis*, *Ankistrodesmus* sp., *Aphanocapsa litoralis*, *Aulacoseira crenulata*, *Aulacoseira* sp., *Caloneis bacillum*, *Chlamydomonas* sp., *Closterium acerosum*, *Closterium* sp., *Coscinodiscus amplus*, *Coscinodiscus angstii*, *Coscinodiscus* sp., *Cosmarium margaritatum*, *Cryptomonas ovata*, *Cryptomonas* sp., *Cyclostephanos* sp., *Cyclotella gamma*, *Cyclotella stelligera*, *Cymbella gadjana*, *Cymbella kappii*, *Cymbella naviculiformis*, *Cymbella* sp., *Cymbella ventricosa*, *Diatoma sigma*, *Diatoma* sp., *Diatoma tenuis*, *Diatomella balfouriana*, *Diploneis elliptica*, *Epithemia adnata*, *Euglena spirogyra*, *Euglena viridis*, *Fragilaria capucina*, *Fragilaria mormonorum*, *Fragilariforma viriscens*, *Gloeodinium montanum*, *Gloeocystis* sp., *Gonatozygon monotaenium*, *Gyrodinium rubricaudatum*, *Lepocynclis* sp., *Merismopedia* sp., *Microcoleus lacustris*, *Mougeotia* sp., *Navicula Cryptotenelloides*, *Navicula gregaria*, *Navicula lenzii*, *Navicula nivalis*, *Navicula* sp., *Nitzschia fonticola*, *Nitzschia sigma*, *Nodularia* sp., *Nostoc endophytum*, *Oedogonium acuminatum*, *Oedogonium alternans*, *Oscillatoria chalibae*, *Oscillatoria granulosa*, *Pediastrum duplex*, *Peridinium pusillum*, *Phacus orbicularis*, *Phacus* sp., *Phacus onyx*, *Pinnularia* sp., *Planothidium lanceolatum*, *Pseudostaurosira brevistriata*, *Raphidiopsis curvata*, *Raphidiopsis mediterranea*, *Raphidiopsis* sp., *Rhodomonas* sp., *Rivularia aquatica*, *Rivularia* sp., *Spirogyra* sp., *Spirulina subtileissima*, *Spirulina tenuis*, *Skeletonema costatum*, *Staurastrum acerosum*, *Stephanodiscus alpinus*, *Stephanodiscus hantzschui*, *Stephanodiscus* sp., *Synechocystis aquatilis*, *Chloromonas granulata*, *Trachelomonas hispida*, *Trachelomonas* sp., *Uronema elongatum* and *Zygnema stellinum*.

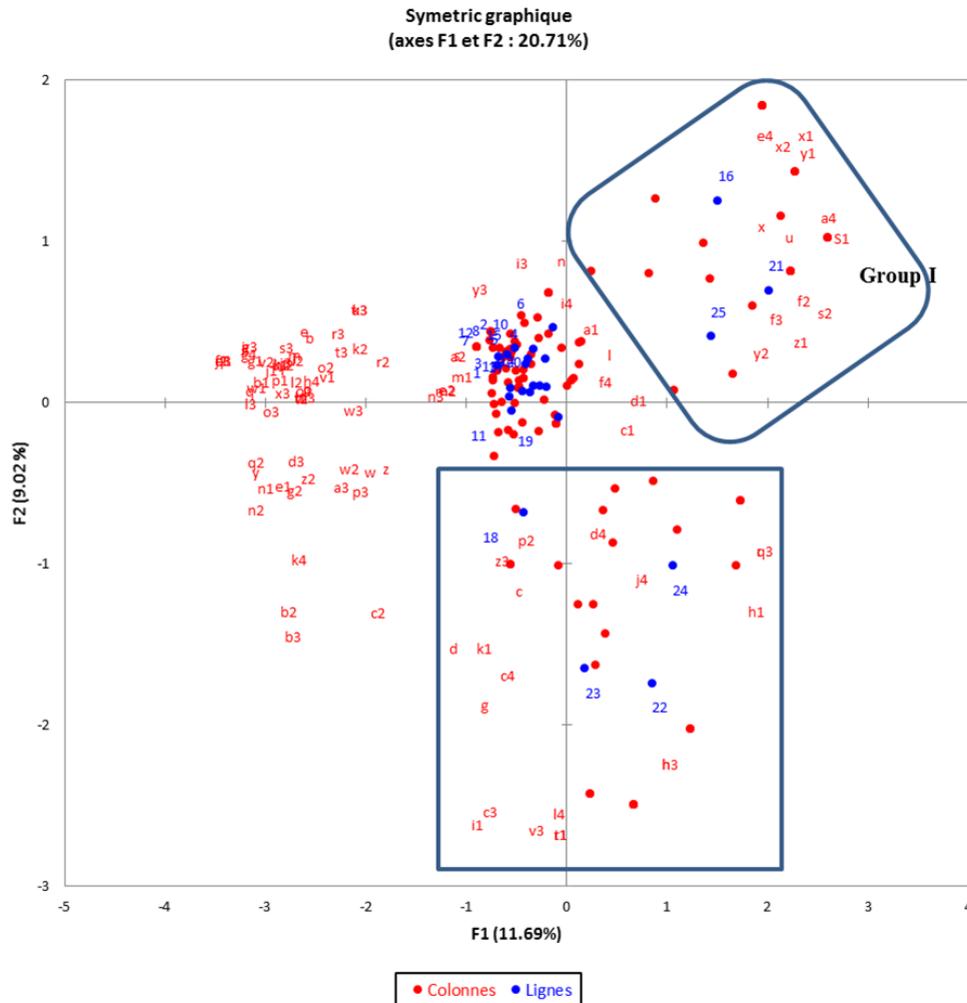


Figure 4 Approximation of the study stations according to the micro-algae species according to the F1 × F2 factorial designs of the correspondence factor analysis

Actinastrum hantzschii Lagerheim, G. = a, *Anabaenopsis* sp. = b, *Ankistrodesmus gracilis* (Reinsch) Korshikov = c, *Ankistrodesmus* sp. = d, *Aphanizomenon flosaquae* Ralfs ex Bornet, E & Flahault, C = e, *Aphanocapsa holsatica* (Lemmermann) G. Cronberg & Komarek = f, *Aphanocapsa litoralis* Hansgirg = g, *Astasia limpida* Dujardin = h, *Aulacoseira crenulata* (Ehrenberg) Thwaites = i, *Aulacoseira* sp. = j, *Caloneis bacillum* (Grunow) Cleve = k, *Chlamydomonas* sp. = l, *Closterium acerosum* (Ehrenberg) Ralfs = m, *Closterium* sp. = n, *Coscinodiscus amplus* Ehrenberg = o, *Coscinodiscus angustii* Gran = p, *Coscinodiscus* sp. = q, *Cosmarium margaritatum* (P. Lundell) J. Roy & Bisset = r, *Cryptomonas ovata* Ehrenberg = s, *Cryptomonas* sp. = t, *Cyclostephanos* sp. = u, *Cyclotella gamma* Sovereign = v, *Cyclotella ocellata* Pantocsek = w, *Cyclotella stelligera* (Cleve & Grunow) Van Heurck = x, *Cymatopleura solae* (Brébisson) W. Smith = y, *Cymbella gadjana* Maillard = z1, *Cymbella kappii* (Chlonoky) Chlonoky = a1, *Cymbella naviculiformis* Auerswald ex Heiberg = b1, *Cymbella* sp. = c1, *Cymbella ventricosa* Kützing = d1, *Diatoma mesodon* (Ehrenberg) Kützing = e1, *Diatoma signata* Dujardin = f1, *Diatoma* sp. = g1, *Diatoma tenuis* C. Agardh = h1, *Diatomella balfouriana* Greville = i1, *Diatomella* sp. = j1, *Diploneis elliptica* (Kützing) Cleve = k1, *Epithemia adnata* (Kützing) Brébisson = l1, *Euglena mutabilis* F. Schitz = m1, *Euglena spirogyra* Ehrenberg = n1, *Euglena viridis* (OFMüller) Ehrenberg = o1, *Fragilaria capucina* Desmazières = p1, *Fragilaria mormonorum* (Grunow) CSBoyer = q1, *Fragilariforma viriscens* (Ralfs) DMWilliams & Round = r1, *Gloeodinium montanum* GAKlebs = s1, *Gloeocystis* sp. = t1, *Gomphonema parvulum* (Kützing) Kützing = u1, *Gomphosphaeria natans* Komarek & Hindak = v1, *Gonatozygon monotaenium* De Bary = w1, *Gyrodinium rubricaudatum* Kofoid & Swezy = x1, *Lepocynclis* sp. = y1, *Lyngbya martensiana* Meneghini ex Gomont = z1, *Melosira varians* C. Agardh = a2, *Merismopedia elegans* A. Braun ex Kützing = b2, *Merismopedia* sp. = c2, *Microcoleus lacustris* Farlow ex Gomont = d2, *Mougeotia* sp. = e2, *Navicula cryptocephala* Kützing = f2, *Navicula cryptotenelloides* Lange-Bertalot = g2, *Navicula gregaria* Donkin = h2, *Navicula lenzii* Hstedt = i2, *Navicula nivalis* Ehrenberg = j2, *Navicula* sp. = k2, *Nitzschia fonticola* (Grunow) Grunow = l2, *Nitzschia sigma* (Kützing) W. Smith = m2, *Nodularia* sp. = o2, *Nostoc endophytum* Bornet & Flahault = p2, *Nostoc palludosum* Kützing ex Bornet & Flahault = q2, *Oedogonium acuminatum* (Hirn) Tiffany = r2, *Oedogonium alternans* Wittrock & P. Lundell ex Hirn = s2, *Oscillatoria boryana* Bory ex Gomont = t2, *Oscillatoria chalibae* Mertens ex Gomont = u2, *Oscillatoria granulosa* Corda = v2, *Pediastrum duplex* Meyen = w2, *Peridinium pusillum* (Pénard) Lemmermann = x2, *Peridinium* sp. = y2, *Phacus longicauda* (Ehrenberg) Dujard = z2, *Phacus orbicularis* K. Hübner = a3, *Phacus* sp. = b3, *Phacus onyx* Pochmann = c3, *Pinnularia gibba* (Ehrenberg) Ehrenberg = d3, *Pinnularia* sp. = e3, *Planothidium lanceolatum* (Brébisson ex Kützing) Lange-Bertalot = f3, *Pleurotaenium ehrenbergii* (Ralfs) De Bary = g3, *Pseudostaurosira brevistriata* Grunow = h3, *Pyramimonas* sp. = i3, *Raphidiopsis curvata* FEFritsch & MFRich = j3, *Raphidiopsis mediterranea* Skuja = k3, *Raphidiopsis* sp. = l3, *Rhodomonas* sp. = m3, *Rivularia aquatica* De Wildeman = n3, *Rivularia* sp. = o3, *Spirogyra* sp.1 = p3, *Spirulina subsalsa* Oersted ex Gomont = q3, *Spirulina subtillissima* Kützing ex Gomont = r3, *Spirulina tenuis* (Brühl & Biswas) Geitler = s3, *Skeletonema costatum* (Greville) Cleve = t3, *Staurastrum acerosum* M. Schmidt = u3, *Staurastrum aculeatum* Meneghini ex Ralfs = v3, *Stephanodiscus* sp. = w3, *Stephanodiscus alpinus* Hustedt = x3, *Stephanodiscus hantzschii* Grunow = y3, *Stigeoclonium aestivale* (Hazen) Collins = z3, *Stigeoclonium* sp. = a4, *Synochocystis aquatilis* Sauvageau = b4, *Tabellaria fenestrata* (Lyngbye) Kützing = c4, *Tabellaria flocculosa* (Roth) Kützing = d4, *Chloromonas granulata* (Peterfi) Gerloff & Ettl = e4, *Thalassiosira pseudonana* Halse & Heimdal = f4, *Trachelomonas hispida* (Perty) F. Etape = g4, *Trachelomonas* sp. = h4, *Ulothrix zonata* (F. Weber & Mohr) Kützing = i4, *Uronema elongatum* Hodgetts = j4, *Xanthidium* sp. = k4, *Zygnema stellinum* (OF Müller) C. Agardh = l4.

3.4. Density variation of study stations

The total micro-algal density was $40.15 \times 10^6 \pm 10.10 \times 10^6$ ind/L and varied from $24 \times 10^5 \pm 2.17 \times 10^5$ ind/L at station 1 to $8 \times 10^5 \pm 3.76 \times 10^5$ ind/L at station 9 (Fig. 5). It varies between the different classes and study stations, from a maximum value for Cyanophyceae for stations 6 and $15 \times 10^5 \pm 2.72 \times 10^5$ ind/L, followed for station 17 of $10.5 \times 10^5 \pm 4.44 \times 10^5$ ind/L.

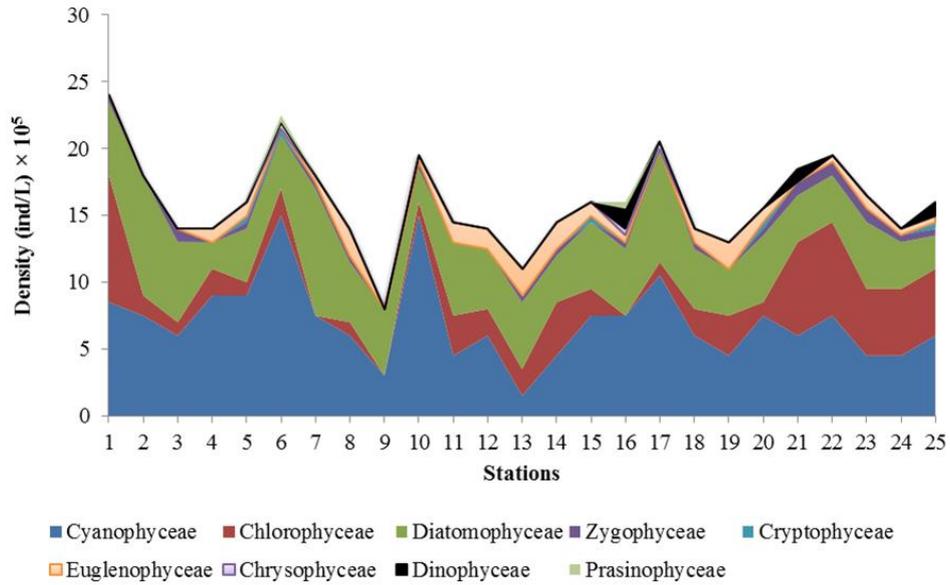


Figure 5 Variation of the dominant microalgal densities in the stations.

3.5. Geographical distribution of abundant microalgae with a frequency greater than 25% of samples

The cartographic analysis of variation of microalgae class densities in each station highlights a subdivision into two areas (Fig. 6). Area 1 is very marked by the dominance of 3 classes of microalgae: Cyanophyceae, Chlorophyceae and Bacillariophyceae. Area 2 is characterized by the dominance of 2 classes of microalgae namely Cyanophyceae and Bacillariophyceae. In this area the class of Chlorophyceae appears with low density.

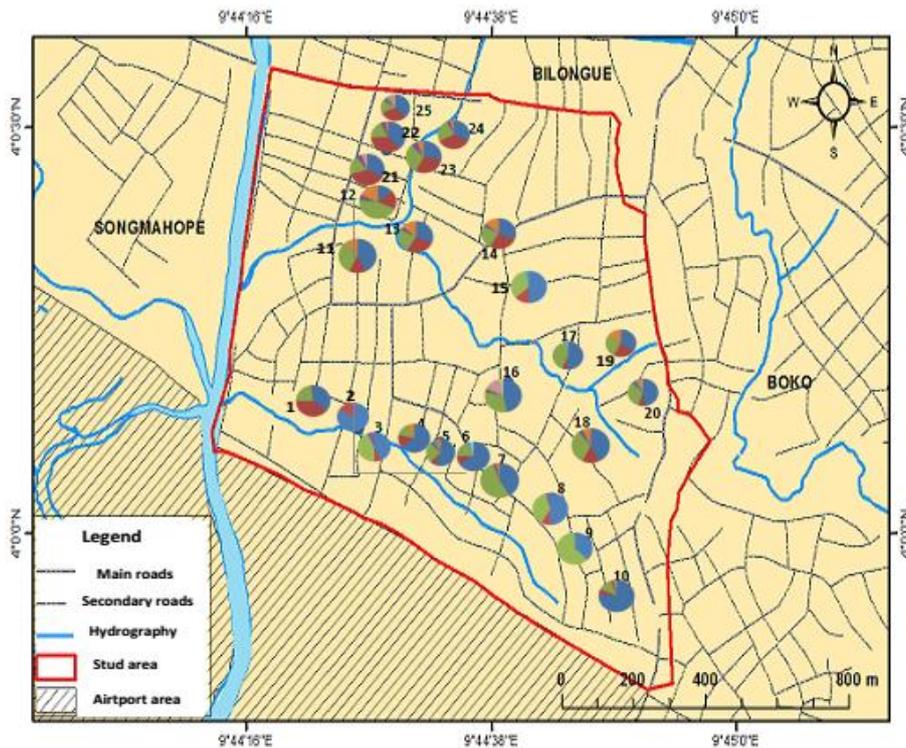


Figure 6 Spatial representation of the sectoral diagrams of different classes of microalgae according to the stations.

4. Discussion

The results of the species richness amounting to 116 species show a significant wealth in the sampling stations. These results are consistent with those of Dibong and Ndjouondo [23] who inventoried the algal microflora of rivers covering the Kambo and Longmayagui sub-watersheds. These authors obtained 105 species in these study sites. This similarity in results can be attributed to the fact that the sampling sites are exposed to same sources of pollution. In addition, these authors showed that the high temperatures which occur throughout the year select for development of microalgae and consequently for high species richness. According to Jourdan [24], temperature is an important factor in development of algae which develop optimally at temperatures close to 37 °C [25].

The most represented class was Bacillariophyceae with 33 species. According to OFEV [19], Diatoms are the most represented and dominant class in stream sampling. This would be due to their size and their ability to detach themselves from the supports to find themselves drifting in the current [19, 23, 26]. These results corroborate those of Dibong and Ndjouondo [23] who sampled microalgae of Kambo and Longmayagui rivers. These results are also in line with those of some authors who focused on phytoplankton from the Tongo'o Bassa River [13], and Miana and Tongo'o Bassa rivers in Douala [27]. Furthermore, our findings agreed with those of Ndjouondo *et al.* [14] who sampled the periphyton of the Batika and Tongo'o Bassa rivers. Conversely, our findings are not consistent with results of Millo [28] who reported Chlorophyceae was the most represented class in Batika river in Douala. This could be explained by the more rapid water flow in this river from upstream to downstream compare to those abovementioned. Higher water flows are known jeopardize the multiplication of diatoms [14]. Besides, this difference between results could also attribute to discrepancies related to quality of water. Indeed, Batika river is located in weakly anthropized forest area and thus less at risk of pollution of human origin. Leaching of soils due to precipitations are the only sources of pollution in this area.

The genera *Navicula* and *Cymbella* were reported as the most important in terms of abundance in our study. These findings are consistent with those found by Dibong and Ndjouondo [23] in Kambo and Longmayagui rivers in Douala. These authors showed that these both genera were abundant in waters polluted with organic matter. Besides, the number of species was highest at Station 7 because of the moderate pollution and the regular mixing of water by hens and ducks that easily access the deposited waste.

The diversity indices through different study stations varied in a "sawtooth" way. However, the most important values appear mainly between the stations 21 to 25. These results are not in line with those of Fokou [13], Dibong and Ndjouondo [23], Millo [28], and Kouefout [27] which showed that the specific richness increases from upstream to downstream in the same study rivers. However, the study stations are pollution points and vary according to the degree of pollution. Waters are stagnant at stations 21 to 25 owing to their obstruction by deposits of polyethylene bottles that promote the sedimentation of solid particles therefore contributing to the installation of the land. Dibong and Ndjouondo [11] found similar results and indicated that these canals are poorly maintained. As a result, this contributes to the proliferation of macrophytes and then facilitates the sedimentation of particles. In addition, residents dump pigs manures on the edge of these canals. When the rains come, they leave organic sludge that is brewed by the passage of motorcycles causing large temporary pool which could allow for a strong development of algae [5, 29].

According to Ndjouondo *et al.* [5], the poorly controlled extension of large urban centers has led to the proliferation of densely populated neighborhoods. In most cases these neighborhoods have developed in lowland areas, usually drained by a small stream. In these so-called "at risk" areas, populations are mainly poor and their principal means for water supply are drilling or wells dug not far from latrines. These areas are hallmarked by the absence or insufficiency of roads, and discharging household solid wastes into the drains. According to Ndjouondo *et al.* [22], riparian wetlands are special environments at the interface between aquatic and terrestrial environments that extend across rivers. They are characterized by the presence of water on the surface or near the surface of the soil temporarily or permanently. These wetlands are the seat of various functions such as the regulation of the water regime (clipping of flood peaks, support of low water levels) or the maintenance of water quality (retention and elimination of nutrients including phosphorus and nitrogen).

The results of the correspondence factor analysis revealed the presence groups of stations which isolate themselves from others by peculiarities. These features might be related to local residents' habits because they are much more spatially and temporally marked in the study area. Indeed, stations 1 to 10 are more polluted owing to household waste compare to stations 18 to 25 which are exposed to pollution from livestock waste such as pig slurry and chicken droppings. Stations 22 to 25 are also exposed to hydrocarbons from vehicles and motorcycles garages. According to Kouefout [27], species are distributed in environments with respect to the nature of pollutants and their level of

resistance to pollutants. The authors showed that the *Nostoc* and *Navicula* genera were resistant to organic pollution. These results are in agreement with our findings. The species *Nostoc palludosum*, *Navicula cryptocephala*, *Aphanizomenon flosaquae*, *Aphanocapsa holsatica*, *Astasia torta*, *Diatoma mesodon*, *Diatomella* sp., *Euglena mutabilis*, *Gomphonema parvulum*, *Pinnularia gibba*, *Pyramimonas* sp., *Spirulina subsalsa*, *Staurastrum aculeatum*, *Synochocystis aquatilis*, *Tabellaria fenestrata*, *Thalassiosira pseudonana*, *Xanthidium* sp., *Cyclotella ocellata*, *Cymbella gadjiana*, *Gomphosphaerium natans*, *Gyrodinium rubricaudatum*, *Melosira varians*, *Merismopedia elegans*, *Oscillatoria boryana*, *Phacus longicauda*, *Pleurotaenium ehrenbergii* and *Ulothrix zonata* tolerate organic pollution.

Densities of microalgae were variable between stations but the Cyanophyceae class appears to be invariably the densest class in each station. These results may be due to the fact that Cyanophyceae form efflorescence in streams polluted with organic matter where the speed of the current is very slow or zero. These results are in line with those of Aurrousseau [30] who worked on the evaluation of the impact of watercourses on eutrophication in the coastal band in France, Grogga [31] who focused on the structure, the functioning and the dynamics of phytoplankton in Lake Ta'abo in Côte d'Ivoire and Sana'a [10] who addressed the structure, dynamics and physico-chemical and phytoplanktonic typologies of the Bou Regreg estuary in Morocco. For these authors, the stagnant waters polluted with organic matter undergo strong eutrophication by letting appear efflorescence by the multiplication of one or a few species. Iltis [18] showed that these species are generally cyanobacteria in the intertropical region where water is warm all year.

5. Conclusion

The objective of the study was to determine the structure and the spatiotemporal variation of the micro-algae of some channels near the garbage dumpsites of the Bobongo sub-catchment in order to propose methods of ecological management of these risk zones. The specific richness amounts to 13 classes, 34 orders, 52 families, 69 genera and 116 species. The dominant class is that of Bacillariophyceae (33 species) with a proportion of 28.45%. The Shannon-Weaver Index was low and ranged between 2.08 (Station 2) and 2.97 (Station 21). The microalgal density was $40.15 \times 10^6 \pm 10.10 \times 10^6$ ind/L (range: $24 \times 10^5 \pm 2.17 \times 10^5$ - $8 \times 10^5 \pm 3.76 \times 10^5$ ind/L). Results based on correspondence factor analysis revealed 3 groups of stations (clusters): the group I from stations 16, 21 and 25 consisted of exclusive species such as *Cyclotella ocellata*, *Cymbella gamma*, *Gomphosphaeria natans*, *Navicula cryptocephala*, and *Tabellaria flocculosa*. This group was exposed to hydrocarbon pollution. Group II from stations 18, 22, 23 and 24 consisted of exclusive species such as *Aphanizomenon flosaquae*, *Aphanocapsa holsatica*, *Astasia limpida* and *Ulothrix zonata*. This group was exposed to pollution by pig manure and chicken dropping. Group III was made up of species common to all stations including *Anabaenopsis* sp., *Ankistrodesmus gracilis* and *Zygnema stellinum* for instance. *Cyclotella ocellata*, *Cymbella gamma*, *Gomphosphaerium natans*, *Navicula cryptocephala* and *Tabellaria flocculosa* are hydrocarbon-polluting species. These species could be used as indicators of pollution in the framework of environmental planning for a better follow-up of the quality of waters of this region. This study also contributes to the knowledge of algal biodiversity in Africa, in particular Cameroon. From species that are exclusive to polluted hydrocarbon waters, a real scourge in the cities of the rapidly expanding Saharan Africa, it would therefore be possible to popularize them, to determine the genetic factors at the origin of their proliferation in these risk zones in order to propose them in bioremediation.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest.

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