

Species Diversity of Cyanobacteria and Desmids of a Drinking Water Source under Anthropogenic Pressure, and Their Implication in Toxin Production and Water Quality in Sub-Saharan Africa (Burkina Faso, Western Africa)

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Abstract

Drinking water sources in many African countries have been progressively degraded over the past decades. This degradation due to human activities leads to the proliferation of algae, especially toxin-producing cyanobacteria. The presence of toxigenic algae in water has adverse consequences on human and animal health. This study aimed to determine the diversity and density of Cyanobacteria and Desmids and to identify toxin-producing cyanobacteria and environmental variables that influenced the structure of these groups of microalgae in the Loumbila reservoir in Burkina Faso located in the western part of Africa. Algal samples were collected and physico-chemical parameters were measured. Plankton species were observed under a light microscope and identified using standard methods. Species density was determined by cell counting using a Fuchs-Rosenthal chamber. Kruskal Wallis and Pearson correlation tests were performed using R software. A canonical analysis was performed using CANOCO software. In total, 205 algal species were inventoried, of which 83 species composed of 37 species of Cyanobacteria and 46 species of Desmids were identified. *Microcystis aeruginosa*, *Staurodesmus convergens* and *Cosmarium connatum* var *africanum* had the highest presence index respectively (100%, 83.333% and 77.77%). Among cyanobacteria species, toxin-producing species (30 species) and microcystin-producing species (28 species) had the highest number. In terms of species density, *Microcystis aeruginosa* was the most abundant species. The density of toxin-producing

cyanobacteria was positively correlated ($p < 0.05$) with temperature, pH, dissolved oxygen, transparency, nitrates, and orthophosphates. However, at $p < 0.05$, desmids community was only correlated with dissolved oxygen, transparency, and conductivity. Furthermore, canonical analysis showed that temperature, dissolved oxygen, transparency, and orthophosphates influenced the density of both cyanobacteria and Desmids. These results reveal the high occurrence of toxin-producing cyanobacteria and certainly high toxins produced in the drinking water source. Basic tools should be developed for monitoring of cyanotoxins in drinking water sources and drinking water supplied to population to consider cyanotoxins during water treatment.

Keywords

Desmids, Diversity, *Microcystis aeruginosa*, Water Quality, Toxin Production

1. Introduction

Drinking water supply is a vital issue for people living in the African continent, as the continent is experiencing high population growth thereby increasing water needs [1]. Few developing countries have the capacity to control the quality of this water [2]. More than 80% of wastewater worldwide, and more than 95% in some developing countries, are still discharged into the environment without treatment [2] impacting water resources. In 2017, the number of people without access to basic water services was 785 million worldwide, including a worrying number of people drawing water directly from surface water points, estimated at 144 million [3]. Many countries face a gap between the growing demand for water and the availability of knowledge about the water quality of potential surface water resources [2].

In Burkina Faso, specifically in the city of Ouagadougou, the population has experienced an average annual growth rate of about 6.4% [4]. This galloping population growth is not without consequences for the growth of the city, creating other problems, notably that of drinking water supply [5]. The city is supplied by the “Office National de l’Eau et de l’Assainissement (ONEA)”, the only public drinking water utility. This company obtains water from two reservoirs, one of which is the Loumbila reservoir to serve the city of Ouagadougou. The water from this reservoir is used for market gardening, watering animals, fishing and major public works. These activities, especially agricultural, have led to the advanced degradation of its quality. However, in this reservoir, which is so important for its various functions, few data are available on the microalgal communities, which represent one of the most important communities for assessing the quality of aquatic environments. The only study available on the microalgal community of this reservoir is the work of Zerbo [6] that was a major contribution to the knowledge of phytoplankton. In fact, the degradation of an aquatic ecosystem leads to algal blooms that considerably reduce the availability of oxy-

gen and light in the water [7]. Some algal groups, such as Desmids, due to their low tolerance to inorganic salts are indicators of trophic status and water pollution [8] [9]. Cyanobacteria are highly adaptable to colonize terrestrial and aquatic ecosystems [10]. They can become abundant with high nutrient concentrations (nitrates and orthophosphates), making them important indicators of water quality [9]. Small variations in physico-chemical parameters such as pH, conductivity, dissolved oxygen and total hardness can contribute to the development of a diverse Desmid community [11]. Some species of Desmids are considered acidophilic, acid-neutrophic and oligotrophic [12]. In addition, the soil, the morphological characteristics, and the low water flow of the water body have an effect on the formation of a specific community of cyanobacteria [13] and desmids also.

Despite being indicators of water quality, some microalgae are clearly circumscribed in their ability to produce specific metabolites including toxins [14] [15]. Toxic cyanobacterial species have been reported in freshwaters in over 45 countries and in many brackish, coastal and marine environments [16] where some synthesize biotoxins and produce metabolites responsible for the bad taste of water and fish flesh and their death, unpleasant odors, for public health problems [17] [18] [19]. Considering species diversity of cyanobacteria and desmids, and their implication in toxins production and water quality of the Loumbila reservoir in Burkina Faso, this study aimed to characterize the pollution level of a water body under anthropogenic pressure and provide related scientific data for future protection of populations using drinking water supplied from such source. Specifically, the aim is to determine the diversity and density of the two groups of algae in Loumbila reservoir, to establish the relationship between them and water quality of the reservoir, to determine on the basis of available literature, cyanotoxin-producing species and related produced toxins in water, to show the importance of taking the elimination of these toxins into account in the drinking water treatment process.

2. Material and Methods

2.1. Study Site

This study was carried out in the Loumbila reservoir (**Figure 1** and **Figure 2**) located about 20 km north-east of Ouagadougou. This reservoir is located between 12°28' and 12°35' North latitude and 1°23' and 1°30' West longitude. This locality is subject to a north Sudanian climate, with a dry season from October to May and a rainy season from June to October. The maximum of rain is observed in August. The average annual rainfall varies between 700 and 800 mm but can reach 1000 mm. The reservoir has an estimated current area of 1500 ha and a maximum depth of 6.6 m [20]. Three (03) sampling points were selected along a longitudinal gradient using a GPS (Global Position System) and physically marked during the first fieldwork. These three points were chosen considering some physical parameters such as transparency and position of the station,

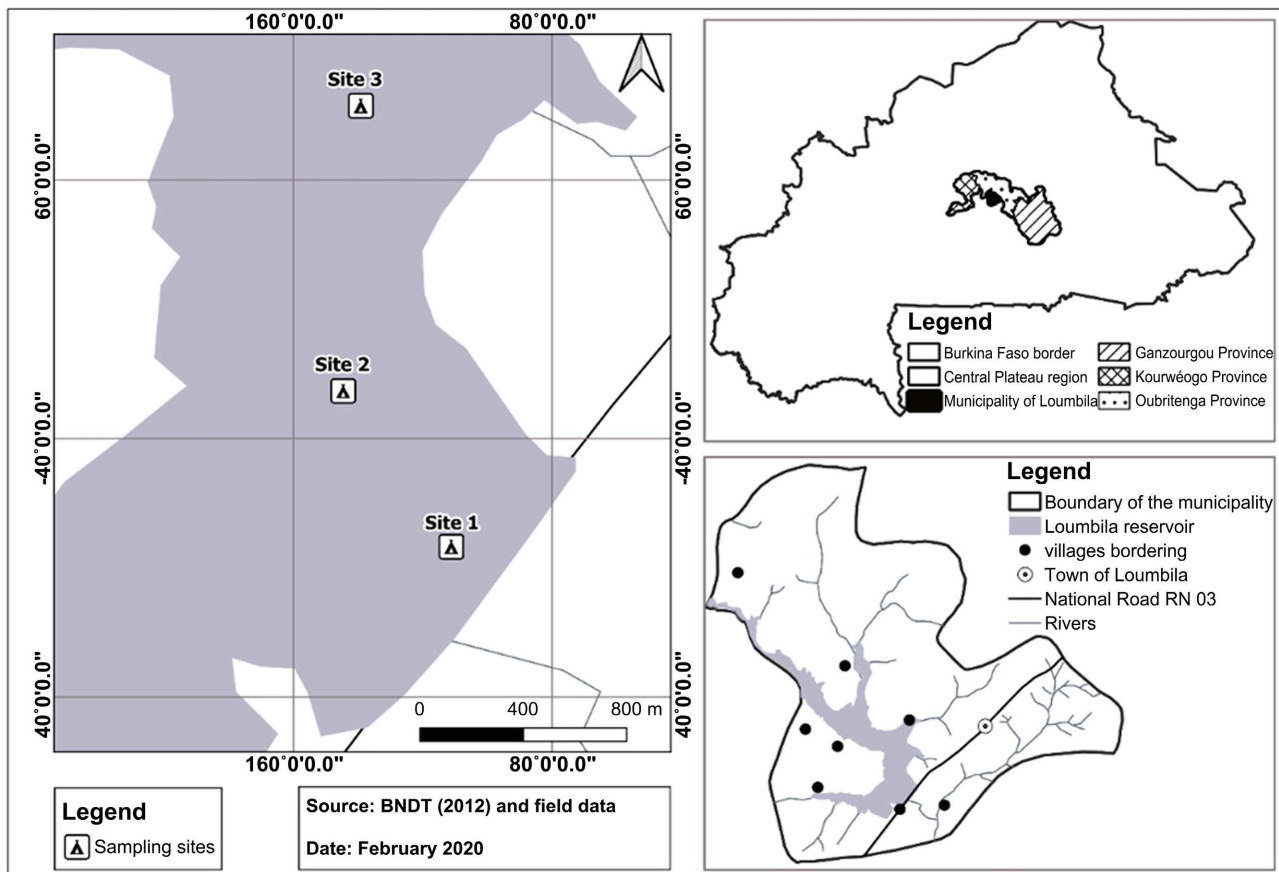


Figure 1. Location of the study area and the different sampling sites.



Figure 2. Photograph of a view of the water plan of the Loumbila reservoir. **Note:** (A) Water troubled by human activities; (B) Space used as a place for animals to roam and for the practice of market gardening.

availability and accessibility of water during the study period (January 2014 to June 2015). Thus, the first station (point 1) is characterised by a higher water

transparency than the other two. Its banks are protected by stone barriers, filter dikes and grass bards (anti-erosion devices). The second station (point 2) is characterised by agricultural activities on part of the water body in this area during the dry season. The third station (point 3) is characterised by the presence of a beach where activities such as swimming and the use of motorised boats are frequent, resulting in a high level of water agitation at this point.

2.2. Collection of Biotic and Abiotic Data

Samples were collected monthly over a period of 18 months going from January 2014 to June 2015. During the sampling days, they were collected between 11:00 am and 1:00 pm. Thus, two types of samples were taken. The first sample was collected with a cylindrical-conical plankton net of 20 µm mesh and 25 cm diameter. This sample was used for the qualitative analysis of microalgae. The second type of sample was collected with a 1 litre bottle and used for the quantitative analysis. After each collection, the contents of the net were emptied into 50 ml jars and the 1litre bottle content were immediately preserved with 8% formaldehyde. In addition, during the collection of the algae, pH and temperature were measured with HANNA handheld electronics (model HI98129), conductivity and dissolved oxygen with a conductivity meter model WTW 3110SET1 and an oximeter model WTW 3205SET3 respectively. Water was collected using 500 ml jars and stored according to the method described by [21] for analysis of the main algal nutrients (nitrates and orthophosphates) in the laboratory using a DR 3800[®] molecular absorption spectrophotometer.

2.3. Identification of Algal Species

Algal samples were examined, photographed using an OPTIKA B-350 microscope and a SONY camera. Species identification was carried out on the basis of the images taken using standard works [22] [23] [24] [25] [26] and following the taxonomical criteria of AlgaeBase (www.algaebase.org/search/species/).

2.4. Quantitative Analysis of Microalgae

The assessment of the algal biomass in the reservoir was done by determining the density of algae in sub-samples (5 ml/sample) obtained from initial samples. The method described by Zongo *et al.* [7] was used to determine the density of algae in each subsample. For this, a Fuch-Rosenthal chamber was filled with a homogeneous subsample. For the particles to settle, this subsample was kept stable for 5 minutes before counting all the cells in the chamber up to four times for each sample. Thus, the following formula was used to determine the density of the algae [7].

$$D = \frac{N10^6V}{3.2(V + v)} \quad (1)$$

D is the density of the algae; N is the number of individuals per chamber; V is the volume of the sample taken and v is the volume of formalin used for preser-

vation

2.5. Classification of Cyanobacterial Species According to Their Toxin Production

This classification concerns toxin-producing cyanobacteria. As toxin analyses have not been carried out during this activity, identification of toxin-producing cyanobacteria was based on previous studies [16] [17] [27] [28]. Thus, according to Bernard [17], they were grouped into three families according to the cyanotoxic effects: hepatotoxins (main target organ: the liver), neurotoxins (target organ: the nervous system) and dermatotoxins (target organ: the skin). Depending on the mechanism of toxicity, the same toxin can be produced by different genera and a genus can produce several types of toxins [27].

2.6. Statistical Analysis of Data

To test the variability of physico-chemical parameters between the sampling sites defined in the reservoir, a Kruskal-Wallis test was performed to compare these parameters between sites. Cyanobacteria and Desmids indices were used to compare the presence of these algal groups at the same site and across the three sites. In addition, the presence indices of toxin-producing and non-toxin-producing cyanobacteria were also compared. For this purpose, Anova and Kruskal-Wallis tests were applied to these different data respectively. The software R version 3.6.1 was used for these different analyses.

Correlation analyses were performed with the same software to determine the correlation between environmental variables and the density of Desmids, cyanobacteria, toxic and non-toxic cyanobacteria. The pH, transparency, conductivity, dissolved oxygen, nitrate, orthophosphate and monthly density of these algal groups were used for this analysis. The correlation matrix was established to determine the correlation coefficients between the different parameters and the density of algal groups. In fact, the correlation coefficient makes it possible to determine and measure the intensity of the relationship between two variables. When this coefficient is equal to 1, it shows an absolute link between the variables and when it is equal to 0, it shows an absence of link. The calculation of this coefficient gives an idea of the possible relationships between parameters.

To study the distribution of phytoplankton genera in relation to environmental parameters in the Loumbila reservoir, a redundancy analysis (RDA) was performed. Matrices representing the monthly densities of the different genera and the monthly evolution of physico-chemical parameters were used for this analysis. It allows analyzing the links between environmental and biotic variables [9] and cross-reference monthly microalgae density data with monthly environmental data. Based on a logarithmic transformation $\log(x + 1)$ of the phytoplankton genus density, the Monte Carlo permutation test (permutation 499) was performed to highlight the environmental variables that best influence the genus density. The RDA was performed using CANOCO for Windows version 4.5.

3. Result

3.1. Physical and Chemical Characteristics of the Water in the Loumbila Reservoir

Table 1 presents the spatial variations of the mean values of the environmental factors of the Loumbila water. The Kruskal-Wallis test shows that at $p < 0.05$, physico-chemical characteristics of the three sites were different except temperature ($p > 0.05$). Thus, except for the mean values for dissolved oxygen and transparency, the other parameters showed higher mean values at site 2 than at the other sites. However, the results in **Table 2** indicate a minimum temperature of 24°C in December and a maximum of 32°C in May. The mean values of pH, dissolved oxygen and water transparency increased significantly in March (8.43; 7.7 mg·l⁻¹ and 1.15 m respectively) and decreased in July (7.5; 4.5 mg·l⁻¹ and 0.21 m respectively). The highest average value of electrical conductivity (83.33 $\mu\text{S}\cdot\text{cm}^{-1}$) was observed in March and the lowest value (48.33 $\mu\text{S}\cdot\text{cm}^{-1}$) was recorded in August. The chemical parameters (nitrate and orthophosphate) also had the highest values in March (6.46 mg·l⁻¹ and 3.46 mg·l⁻¹ respectively) and lower values in August (0.68 mg·l⁻¹ and 0.33 mg·l⁻¹ respectively).

3.2. Diversity of Cyanobacteria and Desmids

During this study, 205 algal taxa were identified in the Loumbila reservoir. Of these, Desmids and cyanobacteria had the highest number of taxa (46 and 37 species respectively). Due to the high number of these algal groups and their ecological importance in water quality, only these two algal groups were considered for the different analyses. The species of cyanobacteria and Desmids were divided into 12 and 6 genera respectively. Among these different genera identified, the genus *Cosmarium* (34.7%) was the most diverse (16/46 species) of the

Table 1. Spatial variations in physico-chemical parameters.

Parameters	Site 1	Site 2	Site 3	Significance
Temp	28.14a ± 2.74	28.12a ± 2.56	28.20a ± 2.66	ns
pH	7.41a ± 0.19	8.51c ± 0.46	7.85b ± 0.24	***
Oxy	7.15b ± 1.16	5.18a ± 0.82	7.04b ± 1.43	***
Transp	0.70a ± 0.24	0.43b ± 0.15	0.59ab ± 0.26	**
Cond	62.98a ± 13.59	77.02b ± 7.97	64.20a ± 14.51	**
Nitra	1.84a ± 1.93	5.55b ± 2.31	2.20a ± 1.30	***
Orthop	1.42a ± 1.22	2.845b ± 1.30	1.65a ± 1.67	**

Note: The table shows the different mean values of the physico-chemical parameters (Kruskal Wallis test). The averages of three columns of the same parameter followed by the same letter are not significantly different from each other ($p > 0.05$) and those followed by different letters are significant ($p < 0.05$). Temp = temperature; pH = hydrogen potential; Oxy = dissolved oxygen; Transp = Transparency; Cond = Conductivity; Nitra = Nitrate; Orthop = Orthophosphate; *** = $p \leq 0.0001$; ** = $p \leq 0.001$; * = $p \leq 0.01$; ns = not significant.

Table 2. Mean values and standard deviations of physico-chemical variables.

Months	Temp	pH	Oxy	Transp	Cond	Nitra	Orthop
Jan-14	24.3 ± 0.17	7.9 ± 0.40	7.03 ± 1.33	0.7 ± 0.20	65.76 ± 7.29	3.73 ± 1.57	3.2 ± 0.98
Feb-14	25.16 ± 1.26	8.13 ± 0.78	7.33 ± 1.15	0.71 ± 0.19	75.46 ± 6.58	4.46 ± 1.33	3.46 ± 0.25
Mar-14	28.43 ± 0.06	8.26 ± 0.76	7.7 ± 1.21	0.84 ± 0.22	83.33 ± 4.04	5.1 ± 1.39	4.06 ± 1.66
Apr-14	30.53 ± 0.40	8.23 ± 0.78	6.9 ± 1.08	0.71 ± 0.14	84.5 ± 6.56	2.2 ± 2.42	1.76 ± 0.46
May-14	31.33 ± 0.58	7.7 ± 0.50	7.23 ± 1.34	0.64 ± 0.09	83.66 ± 6.35	2 ± 2.60	1.5 ± 0.35
Jun-14	30.93 ± 0.23	7.63 ± 0.42	5.13 ± 1.21	0.25 ± 0.08	74.96 ± 6.00	0.80 ± 2.59	0.62 ± 0.76
Jul-14	29.06 ± 0.81	7.5 ± 0.46	4.5 ± 0.96	0.21 ± 0.16	57.33 ± 10.97	1.07 ± 1.24	0.47 ± 0.48
Aug-14	29.5 ± 0.87	7.6 ± 0.36	4.63 ± 0.51	0.26 ± 0.13	48.33 ± 10.12	0.68 ± 0.49	0.33 ± 0.49
Sept-14	29.2 ± 1.04	7.76 ± 0.45	4.73 ± 0.64	0.31 ± 0.17	52.33 ± 17.04	1.23 ± 0.12	0.35 ± 0.32
Oct-14	27.66 ± 0.58	7.7 ± 0.46	5.76 ± 0.75	0.54 ± 0.13	61.76 ± 11.72	2.3 ± 2.02	1.02 ± 1.66
Nov-14	26.66 ± 0.58	7.73 ± 0.40	6.66 ± 1.44	0.60 ± 0.16	59.33 ± 16.17	2.3 ± 2.19	1.11 ± 1.41
Dec-14	24 ± 0.00	8.03 ± 0.55	7.1 ± 1.48	0.71 ± 0.21	56.5 ± 9.53	2.6 ± 2.89	1.56 ± 2.02
Jan-15	24.5 ± 0.00	7.86 ± 0.55	7.13 ± 1.24	0.70 ± 0.21	59 ± 13.28	2.6 ± 2.77	2.2 ± 1.30
Feb-15	25.33 ± 0.58	8.23 ± 0.71	7.23 ± 1.50	0.77 ± 0.29	63 ± 12.12	2.56 ± 2.93	2.4 ± 0.62
Mar-15	28 ± 0.00	8.43 ± 0.78	7.66 ± 1.45	0.76 ± 0.15	81 ± 1.73	2.66 ± 3.56	3.36 ± 0.68
Apr-15	30.16 ± 1.44	8.26 ± 0.70	7.13 ± 1.24	0.71 ± 0.14	74 ± 6.93	1.66 ± 2.25	1.3 ± 0.53
May-15	32 ± 0.3	8.06 ± 0.67	7.16 ± 1.27	0.64 ± 0.09	77 ± 1.73	1.2 ± 1.95	1.1 ± 0.61
Jun-15	30 ± 0.50	7.6 ± 0.40	5.23 ± 0.50	0.28 ± 0.02	67.33 ± 5.05	1.5 ± 3.40	1.4 ± 1.96

Note: Temp = temperature; pH = hydrogen potential; Oxy = dissolved oxygen; Transp = Transparency; Cond = Conductivity; Nitra = Nitrate; Orthop = Orthophosphate.

Desmidiaceae and the genus *Oscillatoria* (21%) was the most diverse (8/37 species) of the Cyanobacteria. The number of species (Figure 3) of Cyanobacteria and Desmidiaceae was high in March (23 and 18 species respectively) and low in July (4 and 1 species respectively). Analysis of the species occurrence index indicated that *Microcystis aeruginosa* (Kütz.) Kütz (100%), *Cosmarium connatum* (Bréb.) Ralfs var. *africanum* Fritsch et Rich (77.77%) and *Staurodesmus convergens* Ralfs (83.33%) had the highest occurrence indexes of all species in Loumbila reservoir. The Anova test carried indicated that there was no significant difference ($p > 0.05$) between the occurrence of cyanobacteria and Desmids at the same sampling site. However, this test did show significant differences between the presence index of Cyanobacteria ($p < 0.0013$) and Desmidiaceae ($p < 0.0012$) at the three sampling sites.

Of the 12 genera of cyanobacteria studied, 10 genera composed of 30 species were identified as toxin producers (Table 3). The number of species producing microcystins is the most important with 30 species producing this toxin (Figure 4) out of 37 species in total. They are followed respectively by those producing anatoxins, cylindrospermopsins, saxitoxins, aphysiatoxins and lyngbyatoxins. Thus, the Kruskal-Wallis test carried out between the presence indices of toxin-producing

Table 3. Cyanobacteria genera and their associated toxins in the Loumbila reservoir.

Toxic cyanobacteria	Toxins
<i>Anabaena</i>	Microcystins, Anatoxins, Saxitoxins
<i>Anabaenopsis</i>	Microcystins, Anatoxins
<i>Cylindrospermopsis</i>	Cylindrospermopsins, Saxitoxins
<i>Merismopedia</i>	Microcystins
<i>Microcystis</i>	Anatoxins, Microcystins
<i>Lyngbya</i>	Lyngbyatoxins, microcystins Saxitoxins, Anatoxins
<i>Oscillatoria</i>	Anatoxins, microcystins Cylindrospermopsins
<i>Phormidium</i>	Anatoxins, microcystins, Saxitoxins, Aphysiatoxins
<i>Pseudanabaena</i>	Microcystins
<i>Spirulina</i>	Microcystins

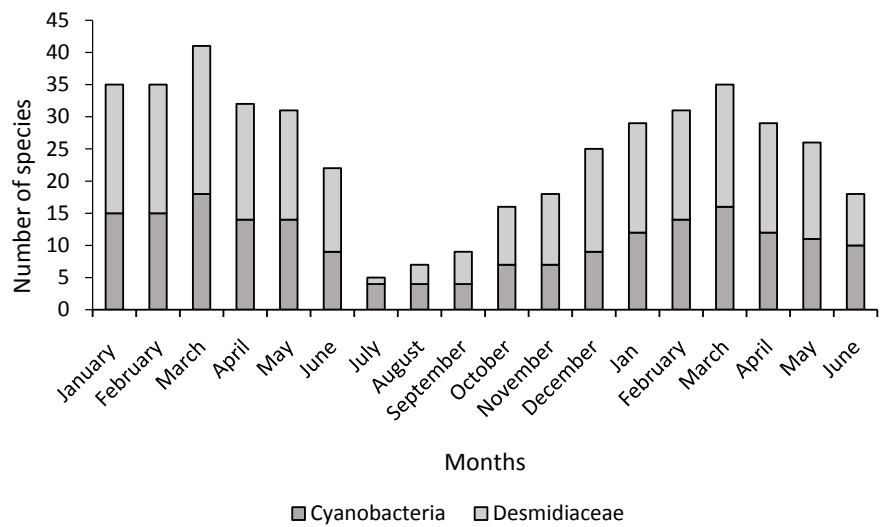


Figure 3. Monthly diversity of cyanobacteria and Desmids.

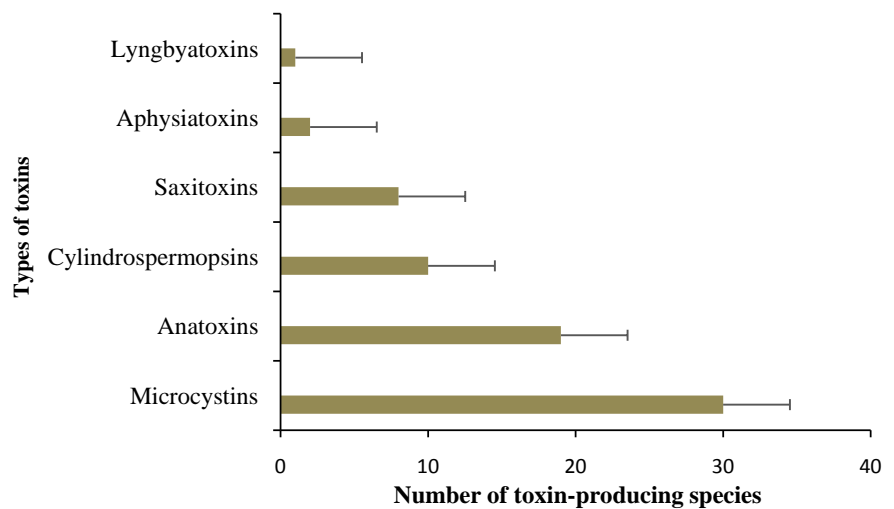


Figure 4. Histogram of toxin type as a function of the number of toxin-producing species in the Loumbila reservoir.

and non-toxin-producing cyanobacteria showed a significant difference ($p < 0.00129$).

A variety of toxin-producing species of cyanobacteria was obtained (Figure 5). The list of cyanobacterial species and their associated toxins (Table 4) indicates that the same toxins can be produced by several species of cyanobacteria and one species of cyanobacteria can also produce several types of toxins.

3.3. Relationship between Algal Density and Water Quality

Pearson's correlation coefficient analysis (Table 5) showed a positive correlation between Desmidiaceae density and dissolved oxygen ($r = 0.68$; $p < 0.002$), transparency (0.52 ; $p < 0.0285$) and conductivity (0.62 ; $p < 0.005$). Cyanobacteria densities were positively correlated with temperature ($r = 0.76$; $p < 0.0002$), pH ($r = 0.68$; $p < 0.001$), dissolved oxygen ($r = 0.67$; $p < 0.002$), transparency ($r = 0.69$; $p < 0.001$), nitrate ($r = 0.87$; $p < 0.000002$) and orthophosphate ($r = 0.77$; $p < 0.0001$). Toxin-producing cyanobacteria density was also positively correlated with temperature ($r = 0.79$; $p < 0.00009$), pH ($r = 0.63$; $p < 0.004$), dissolved oxygen ($r = 0.61$; $p < 0.007$), transparency ($r = 0.64$; $p < 0.004$), nitrate ($r = 0.88$; $p < 0.000001$) and orthophosphate ($r = 0.76$; $p < 0.0002$).

The canonical analysis of the environmental variable and the density of the different genera of Cyanobacteria and Desmids showed a strong correlation

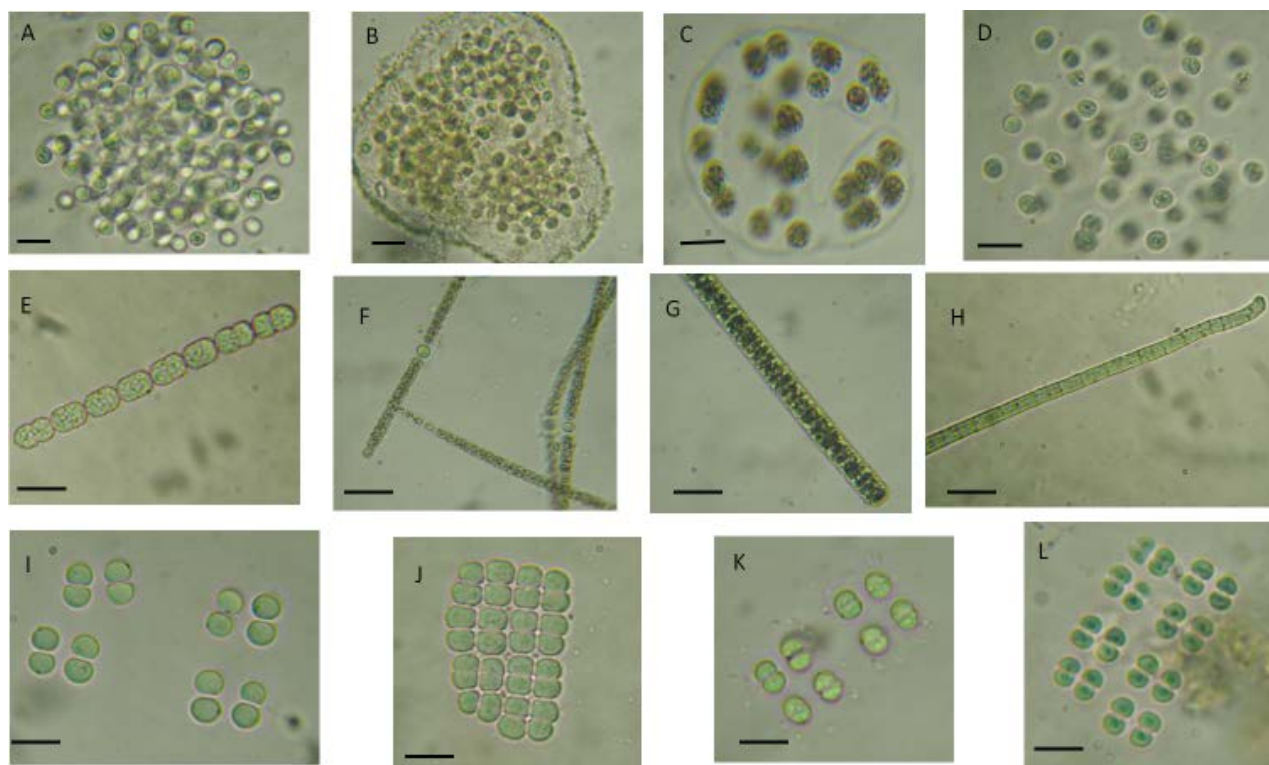


Figure 5. pictures of some toxin-producing cyanobacteria specie. **Note:** (A) *Microcystis incerta*; (B) *Microcystis aeruginosa*; (C) *Microcystis wesenbergii*; (D) *Microcystis flos-aquae*; (E) *Anabaena constricta*; (F) Group of four (04) individuals of *Anabaena bergii* var. *bergii*; (G) *Oscillatoria annae*; (H) *Phormidium chalybeum*; (I) *Merismopedia glauca*; (J) *Merismopedia elegans*; (K) *Merismopedia minima*; (L) *Merismopedia punctata*. Scale bars: 20 μm .

Table 4. List of toxin-producing cyanobacteria species and their associated toxins.

Species	Types of toxins
<i>Merismopedia elegans</i> A. Br.	
<i>Merismopedia ferrophiila</i> Hindak	Microcystins
<i>Merismopedia glauca</i> (Ehrenb.) Näg.	
<i>Merismopedia minima</i> G. Breck	
<i>Merismopedia punctata</i> Lemm.	
<i>Microcystis aeruginosa</i> (Kütz.) Kütz.	
<i>Microcystis flos-aquae</i> (Wittr.) Kirchner	Anatoxins, Microcystins
<i>Microcystis incerta</i> Lemm.	
<i>Microcystis Wesenbergii</i> Kom.	
<i>Anabaena constricta</i>	
<i>Anabaena bergii</i> var. <i>bergii</i> fo. <i>Bergii</i>	Microcystins, Anatoxins, Saxitoxins
<i>Anabaena</i> sp.	
<i>Anabaenopsis</i> sp.	Microcystins, Anatoxins, Saxitoxins
<i>Cylindrospermopsis raciborskii</i> (Wolosz.) Seena. & Raju	Cylindrospermopsins, Saxitoxins
<i>Cylindrospermopsis</i> sp.	
<i>Lyngbya</i> sp	Lyngbyatoxins, microcystins Saxitoxins, Anatoxins
<i>Oscillatoria chalybea</i> var. <i>insularis</i> Gardn.	
<i>Oscillatoria hamelii</i> Frémy	
<i>Oscillatoria lemmermannii</i> Wolosz	
<i>Oscillatoria limosa</i> Gom.	Anatoxins, microcystins Cylindrospermopsins
<i>Oscillatoria princeps</i> Vaucher ex Grom.	
<i>Oscillatoria sancta</i> (Kütz.) Grom.	
<i>Oscillatoria</i> sp.	
<i>Oscillatoria subbrevis</i> Schmidle	
<i>Phormidium chalybeum</i>	Anatoxins, Microcystins, Saxitoxins, Aphysiatoxins
<i>Phormidium subfuscum</i> Kütz. ex Grom.	
<i>Pseudanabaena constricta</i> (Szafer) Lauterb.	Microcystins
<i>Pseudanabaena limnetica</i> (Lemm.) Kom.	
<i>Spirulina gigantea</i> Schmidle	Microcystins
<i>Spirulina jenneri</i> (Hassall) Kütz.	

between these variable (**Figure 6**). Temperature (Temp) ($p < 0.002$), dissolved oxygen (Oxy) ($p < 0.018$), transparency (Transp) ($p < 0.004$) and orthophosphates (OrthoP) ($p < 0.002$) significantly influenced the density of Cyanophyceae

Table 5. Relationship (Pearson's coefficient) between physico-chemical parameters and the density of Desmids, cyanobacteria, toxin-producing cyanobacteria and non-toxin-producing cyanobacteria.

	Desmid	cyano	cyatox	cynont	Temp	pH	Oxy	Transp	Cond	Nitra	OrthoP
Desmid	1.00										
cyano	0.06	1.00									
cyatox	-0.01	0.99	1.00								
cynont	0.74	-0.37	-0.45	1.00							
Temp	0.15	0.76	0.79	0.42	1.00						
pH	0.44	0.68	0.63	-0.04	-0.34	1.00					
Oxy	0.68	0.67	0.61	0.26	-0.38	0.85	1.00				
Transp	0.52	0.69	0.64	0.10	-0.46	0.84	0.90	1.00			
Cond	0.62	0.10	0.05	0.41	0.39	0.41	0.50	0.41	1.00		
Nitra	0.06	0.87	0.88	-0.34	-0.53	0.65	0.59	0.59	0.31	1.00	
OrthoP	0.35	0.77	0.76	-0.10	-0.32	0.65	0.70	0.63	0.56	0.92	1.00

Note: Desmid = Desmidiaceae; cyano = cyanobacteria; cyatox = toxin-producing cyanobacteria; cynont = non-toxin producing cyanobacteria Temp = temperature; Oxy = dissolved oxygen; Cond = conductivity; Transp = transparency; Nitra = Nitrates; OrthoP =Orthophosphates.

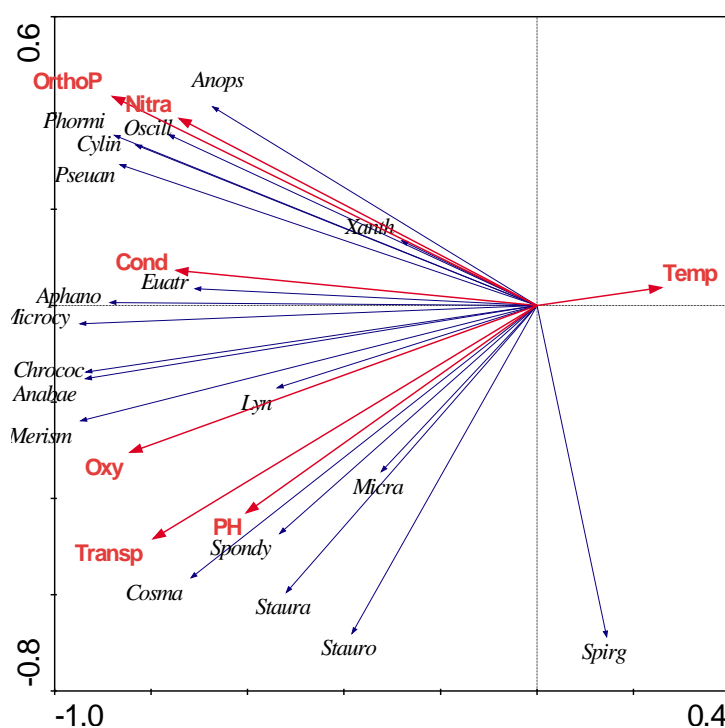


Figure 6. Diagram of the ordination of Cyanobacteria and Desmids genera and environmental variables of the Loubmila reservoir. **Note:** Temp = temperature; Oxy = dissolved oxygen; Cond = conductivity; Transp = transparency; Nitra = Nitrates; Orthop = Orthophosphates. Aphano = *Aphanocapsa*; Chrococ = *Chroococcus*; Merism = *Merismopedia*; Microcy = *Microcystis*; Anabae = *Anabaena*; Anops = *Anabaenopsis*; Cylin = *Cylindrospermopsis*; Lyn = *Lyngbya*; Oscill = *Oscillatoria*; Phormi = *Phormidium*; Pseuan = *Pseudanabaena*; Spirg = *Spirulina*; Cosma = *Cosmarium*; Euatr = *Euastrum*; Micra = *Micrasterias*; Spondy = *Spondylosium*; Staura = *Staurastrum*; Stauro = *Staurodesmus*; Xanth = *Xanthidium*.

and Desmid genera in Loumbila reservoir ($P < 0.05$). But pH, nitrates and conductivity (Cond) did not significantly influence the density of these microalgae in the reservoir ($P > 0.05$). Thus, genera (Figure 6) such as *Cylindrospermopsis* Seenayya & Subba Raju (Cylin), *Oscillatoria* Vaucher (Oscill), *Phormidium* Kütz. Ex Gomont (Phorm), *Pseudanabaena* Laut. (Pseuan) were correlated with orthophosphates (OrthoP) ($r = 0.47$). The genera *Merismopedia* Meyen (Merism), *Microcystis* Kütz (Microcy), *Chroococcus* Näg. (Chrococ) and *Anabaena* Bory de St Vincent (Anabae) were correlated with dissolved oxygen (Oxy) ($r = 0.53$). *Cosmarium* Corda (Cosma), *Spondylosum* Bréb. (Spondy), *Staurastrum* Meyen (Staura) and *Stauroidesmus* Teiling (Stauro) were correlated with transparency ($r = 0.65$).

4. Discussion

4.1. Occurrence of Cyanobacteria and Desmidiaceae in the Loumbila Reservoir

In the Loumbila reservoir, Cyanobacteria and Desmids showed a remarkable diversity with 37 and 46 species recorded respectively. Chlorophytes, more precisely Desmids, were the most diverse. The high diversity of species in this family is justified by their ability to adapt and grow under various physico-chemical and environmental conditions [23] [29]. In fact, Desmids are characteristic of freshwater [8]. The considerable diversity of this group of algae was observed in the Bagré reservoir [23] and in temporal ponds [9]. A strong predominance of desmids was found in the Bia River [24] and in the Bandama River [30] of Ivory Coast, in the aquatic systems of Brazil [31], in the high mountain lakes of the Artabel Lakes Natural Park (Gümüşhane, Turkey) [32]. The diversity of this algal group is marked by the genus *Cosmarium* which accounts for 34.7% of all Desmid species. This could be related either to the ecological characteristics of this genus or to the very high diversity of this genus. In fact, the highest diversity of *Cosmarium* species was recorded in dystrophic ecosystems by [29]. Furthermore, among Desmid species, *Stauroidesmus convergens* (Ehr.) Teil. and *Cosmarium connatum* (Breb.) Ralfs var. *africanum* Frisch and Rich had the highest occurrence index. That indicates an adaptivity of the two species to the environmental conditions of the Loumbila reservoir. Species like *Stauroidesmus convergens* can even regenerate its capsule in the absence of nutrients such as nitrates and orthophosphates [33].

The diversity of cyanobacteria also characterises the environmental conditions of the waters of the Loumbila reservoir. Indeed, the genus *Oscillatoria* was the most diverse (21%) compared to the other genera of cyanobacteria recorded in the Loumbila reservoir. This could be due to the environmental characteristics of the water in this reservoir. In fact, *Oscillatoria* species prefer to grow in water bodies containing hard, alkaline, polluted water rich in essential nutrients [34] [35]. Among the cyanobacteria species, *Microcystis aeruginosa* had the highest presence index (100%). This could be explained by the ability of this species to

grow at different states of water transparency in the reservoir. In fact, Scott [36] showed that the ability of *M. aeruginosa* to grow well beyond a range of light intensities gives it a competitive advantage over other algae. In addition, temperatures above 25°C are favourable for the development of this species [37] and, at the same time, favourable for the increase of toxins (microcystins) in the water [38]. Consequently, its excessive development in an aquatic environment can constitute a real health problem for water users (animals and humans) in this environment.

In the Loumbila reservoir, no significant difference ($p > 0.5$) was observed between the diversity of desmids and cyanobacteria at the same site. Physico-chemical quality of water in the reservoir seems to be favourable to the development of both Desmids and cyanobacteria groups. They both have high plasticity and occur in various freshwater habitats although Desmids have a preference for oligotrophic environments [11] [39] [40]. Furthermore, cyanobacteria are an extremely diverse group whose adaptability and ability to tolerate extreme conditions allow them to be found worldwide [40] [41]. However, Desmids are distributed in freshwaters at very low conductivity and nutrient concentration [42]. Furthermore, there was spatial variation in the diversity of these two algal groups ($p > 0.05$) between the three sampling sites. This indicates that the different sampling sites have different environmental characteristics. Thus, the spatial variation in phytoplankton diversity is due to the disparity in ecological distributions of organism types and variability in climatic and geographical conditions [43].

4.2. Physico-Chemical Variables and Algae Structure

The physico-chemical parameters of the water in the Loumbila reservoir vary greatly from one site to another, with exception of temperature. Temperature is mainly impacted by climatic conditions which are practically the same throughout the reservoir. Thus, variables such as air temperature, solar radiation, wind speed, flow rate, groundwater flow can have an impact on the water temperature in a river [44]. Compared to the Loumbila water temperature (Table 1 & Table 2), similar water temperatures have been noted by other authors in the warm tropics where they range from 25°C to 32°C [45] [46]. However, with the exception of the mean values for dissolved oxygen and transparency, the other parameters showed higher mean values at site 2 than at the other sites. This could be due to the consequences of the different anthropogenic activities carried out at this site. This is confirmed by the work of Kuffour *et al.*, [47] who indicated that the nitrate level in Lake Bosomtwe in Ghana could be attributed to the use of nitrogen fertilizers along the lake shore by most farmers. In fact, this site is subject to very intense anthropic pressure with market gardening and water abstraction by public works companies. Numerous studies [48] [49] [50] have indicated that the intensification of agricultural activities is causing serious ecological problems and is the main cause of water source degradation. The low values of transpa-

rency and dissolved oxygen at site 2 could be related either to irrigation back-wash that clouds the water or to the presence of agricultural activities producing organic matter into the water. In fact, Sánchez-Colón and Schaffner [51] have indicated that the low transparency of the water is due to the high amounts of inorganic and organic matter in suspension. Also, the presence of oxidizable organic matter can lead to a decrease in dissolved oxygen concentration due to oxygen depletion through aerobic decomposition of organic waste by microorganisms [52].

Furthermore, physico-chemical parameters such as pH, transparency, dissolved oxygen, conductivity, nitrates, and orthophosphates content peaked in March. This could be explained not only by the degradation of organic matter from agricultural soil leaching but also by the clarity of the water at this time. In fact, some of these parameters are related to each other. Water clarity affects the amount of oxygen produced by the environment [52] which in turn is involved in oxidation reactions to transform ammonium into nitrates and phosphorus into orthophosphates. In the same way, Ouattara *et al.* [5] demonstrated that nitrates are produced by the oxidation of ammonium to nitrate and then to nitrite. However, during the period of July and August characterized by the strongest rainfall, these parameters were observed to be low in water of the Loumbila reservoir. This is mainly related to the dilution of water by rainwater and the non-degradation of agricultural organic matter.

Overall, the conductivity of the water was low at all three sites ($<100 \mu\text{S}\cdot\text{cm}^{-1}$). This could be explained by the low concentrations of ions such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), bicarbonate ions (HCO_3^-), sulphate ions (SO_4^{2-}) and chloride ions (Cl^-) in the water [5]. In fact, the higher the concentration of these ions in water, the higher the conductivity of the water. Furthermore, the average pH values (6 - 8) characterize the water in the reservoir as water where life develops optimally. This is comparable to the work of [53] who observed similar pH values in ponds on the southern side of the Togodo Biosphere Park (South Togo). Average values of dissolved oxygen (5 - $8 \text{ mg}\cdot\text{l}^{-1}$) could be explained by the high intensity of algal photosynthesis which releases a large amount of oxygen. Thus, the analytical results indicated that if the density of cyanobacteria and Desmids increases, dissolved oxygen level also increases in the reservoir.

Average nitrates and orthophosphate levels were respectively high than $0.3 \text{ mg}\cdot\text{l}^{-1}$ indicating high nitrates and phosphates concentrations in water of Loumbila reservoir. At certain content in water, nitrates and phosphates characterized a eutrophication of water and favor the proliferation of microalgae [23]. Their presence in river water favors the increase of primary productivity and their excess in surface water is considered as a warning for algal blooms [54]. This is confirmed by the results of the analyses (Pearson correlation test and canonical analysis) which showed that orthophosphates have an influence on the density of cyanobacteria. Phosphorus remains the predominant factor in water to increase

productivity and the trophic status index [55] [56]. Indeed, [57] showed that phosphorus concentration was the key in the regulation of nitrogen-fixing cyanobacteria, such as *Microcystis aeruginosa*. This is supported by Djabourabi *et al.* [58] and Taffouo *et al.* [59] who observed a positive correlation of orthophosphates with Cyanobacteria.

Except for conductivity, other parameters such as pH, temperature, dissolved oxygen, transparency, nitrate and orthophosphate showed a positive correlation with cyanobacteria and toxin-producing cyanobacteria. This could be explained by the adaptability of cyanobacteria to extreme conditions. Indeed, cyanobacteria are known to be highly adaptable and have been found in a wide range of aquatic and terrestrial environments and even in every imaginable habitat [19] [40]. However, it is only dissolved oxygen, transparency and conductivity that have a positive correlation with the density of Desmidiaceae. This could be due to the ecological characteristics of this group of algae to grow in waters less polluted by nutrients (nitrates and orthophosphates) and transparent. The sensitivity of this group of algae to environmental conditions is often used in water quality assessments [60] [61].

4.3. Occurrence of Toxin-Producing Cyanobacteria in the Reservoir

The toxin producing cyanobacteria are becoming more and more common worldwide and pose a danger to drinking water [41]. In freshwaters, there are more than 50 species of cyanobacteria that have the capacity to produce dangerous toxins to organisms and humans [62] [63]. Among the toxin-producing species, those producing microcystins are the most important. Microcystins are produced by several genera, including *Microcystis*, *Anabaena*, *Oscillatoria*, *Merismopedia*, *Lyngbya*, *Phormidium*, *Pseudanabaena* and *spirulina* [62]. Being the most produced toxins, they are the most widespread and the most frequently implicated in human and animal poisonings [62] [64]. In addition, species producing other toxins such as neurotoxins [65] were recorded including *Microcystis* species. Genus *Microcystis* produces both hepatotoxin and neurotoxin. It is the most frequently toxic genus encountered in tropical Africa, Asia and Central America [64] [66]. *Microcystis aeruginosa* is a cyanobacterium that forms blooms and produces cyclic hepatotoxins (microcystins) toxic to humans [67] [68]. As observed in reservoirs of Ghana [69], in most common waters of South Africa [70], *M. aeruginosa* species is found to be the most abundant species that could produce important microcystin in the water of the Loumbila reservoir. The higher occurrence of toxin-producing species compared to non-toxin-producing species indicates degradation conditions of water quality of a drinking water source favourable to toxin-producing species. A remarkable presence of toxin-producing cyanobacteria may lead to the increase of cyanotoxins in the water habitats and that is consequently a health problem for the populations supplied in drinking water from these water sources.

4.4. Considering Treatment of Algal Toxins in African Countries

The identification of toxic cyanobacterial species in Loumbila Reservoir is an important database that helps know the different types of toxins that could occur in the Reservoir. Consequently, we can imagine the impact of toxin producing species on water quality and thereby on the health of population using water. In fact, so far algal toxins are not considered in the drinking water treatment process in most developing countries. Of the 54 countries in Africa, only 21 have notable research information in the area of cyanobacterial blooms over the past decade and 11 of the 21 countries have recorded toxicity and physicochemical parameters related to the presence and abundance of toxic cyanobacteria and cyanobacterial blooms [67]. Although the fact that cyanotoxins are the most studied in freshwaters worldwide, and that there are undoubtedly many cases of problems related to these algal toxins, they remain largely hidden in water quality and drinking water supply records [71] [72]. Indeed, the presence of cyanobacteria and their toxins in water bodies used as drinking water source is a problem for the services that make these waters drinkable [73]. Cyanotoxins can be present in drinking water, depending on their concentration in surface waters and the effectiveness of the treatment method [41]. In countries without adequate water treatment, the population may be exposed to intracellular toxins and dissolved cyanotoxins [28]. These cyanobacterial toxins are structurally diverse and cause numerous health problems in humans and animals [73] [74]. Indeed, cyanotoxins can cause short-term gastroenteritis, nausea, vomiting, fevers, flu-like symptoms, sore throat, blistering, ear and eye irritation, skin rashes, discomfort, abdominal pain, visual disturbances, kidney damage, liver failure leading to death, pneumonia, dermatitis, intrahepatic hemorrhage and liver tissue failure in humans [16] [74] [75] [76]. Chronic and long-term exposure to microcystins can cause tumors, liver and colon cancers [76] [77]. Therefore, given these adverse effects on human health, people who drink water containing these cyanotoxins may fall victim to these various diseases in countries where the removal of cyanotoxins is not taken into account during drinking water treatment process. It is imperative and even wise to identify the different types of cyanotoxins and to take them into account in the drinking water treatment process in African countries, especially sub-Saharan countries. Under these conditions, chlorine can be combined with adsorption with activated carbon to remove these cyanotoxins from these waters during drinking water treatment [41]. But the cost of advanced treatment for cyanotoxin removal is high and the chemicals used in the treatment process have health drawbacks [41]. Therefore, in developing countries where financial resources are often lacking, it would be important to focus on monitoring toxin-producing cyanobacteria in raw water while searching for low-cost treatment methods. For this purpose, it would be interesting to set up a water quality monitoring policy based on the analysis of physico-chemical parameters (especially nitrates and orthophosphates) and biological parameters. In addition, it would also be important to raise the awareness

of residents around the reservoir about good hygiene practices and the control of the use of chemical and organic inputs in agriculture in order to reduce the quantity of water pollutants that favour the development of cyanobacteria.

5. Conclusion

The diversity and density of Cyanophyceae and Desmidiaceae in the water of the Loumbila reservoir were found to be important and characterize the water quality of this drinking water source under anthropogenic pressure. The results of this study showed that the different activities around the reservoir have impact on the physico-chemical quality of the water and consequently on the diversity of cyanobacteria and Desmids. In addition, most cyanobacteria species are found to be able to produce toxins, especially microcystins. *Microcystis aeruginosa* species, a microcystin producer was highly present in the reservoir compared to all other species. These results draw the attention of drinking water treatment services to consider the elimination of toxins by using chlorine combined with activated carbon adsorption in the treatment process before supplying water for drinking water supply to the populations. Furthermore, for the reduction of these cyanotoxins in the water, there is an urgent need to take measures to protect this reservoir by controlling activities that increase nutrients contents and cyanobacteria growth in the water.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Koffi Ahoutou, M., Yao Djeha, R., Kouamé Yao, E., Quiblier, C., Niamen-Ebrottié, J., Hamlaoui, S., Tambosco, K., Perrin, J.L., Troussellier, M., Bernard, C., Seguis, L., Bouvy, M., Pédrón, J., Koffi Konan, F., Humbert, J.F. and Kalpy Coulibaly, J. (2021) Assessment of Some Key Indicators of the Ecological Status of an African Freshwater Lagoon (Lagoon Aghien, Ivory Coast). *PLoS ONE*, **16**, e0251065. <https://doi.org/10.1371/journal.pone.0251065>
- [2] Damania, R., Desbureaux, S., Rodella, A., Russ, J. and Zaveri, E. (2019) Quality Unknown: The Invisible Water Crisis. World Bank, Washington DC. <http://hdl.handle.net/10986/32245>
- [3] UNICEF (2020) Feuille de route pour l'eau de l'UNICEF: Accès universel à des services durables d'approvisionnement en eau à l'horizon 2030.

- [4] RGPH (2006) Recensement général de la population et de l'habitation (RGPH) de 2006 du Burkina Faso—Résultats Définitifs.
- [5] Ouattara, Y., Guiguemde, I., Diendere, F., Diarra, J. and Bary, A. (2012) Pollution des eaux dans le bassin du Nakambe: Cas du barrage de Ziga. *International Journal of Biological and Chemical Sciences*, **6**, 8034-8050. <https://doi.org/10.4314/ijbcs.v6i6.47>
- [6] Zerbo, P. (2004) Contribution à l'étude de la diversité du phytoplancton d'eau douce: Cas du réservoir de Loumbila, Burkina Faso. Université de Ouagadougou, Ouagadougou.
- [7] Zongo, B., Zongo, F., Toguyeni, A. and Boussim, J.I. (2017) Water Quality in Forest and Village Ponds in Burkina Faso (Western Africa). *Journal of Forestry Research*, **28**, 1039-1048. <https://doi.org/10.1007/s11676-017-0369-8>
- [8] Kadiri, M.O. (2002) A New Desmid in Nigeria. *Global Journal of Pure and Applied Sciences*, **8**, 223-237.
- [9] Zongo, B., Zongo, F., Thiombiano, A. and Boussim, J.I. (2019) Phytoplankton Assemblages and Community Structure in Tropical Temporary Freshwater Ponds in Sub-Saharan Africa. *Journal of Phycology*, **55**, 789-800. <https://doi.org/10.1111/jpy.12843>
- [10] Lavoie, I., Laurion, I., Warren, A. and Vincent, W. (2007) Les fleurs d'eau de cyanobactéries: Revue de littérature. Rapport de recherche (R916), INRS, Centre Eau Terre et Environnement, Québec.
- [11] Akar, B. and Şahin, B. (2014) New Desmid Records of Karagöl Lake in Karagöl-Sahara National Park. *Turkish Journal of Fisheries and Aquatic Sciences*, **14**, 269-274.
- [12] Krasznai, E., Feher, G., Borics, G., Várbíró, G., Grigorszky, I. and Tóthmérész, B. (2008) Use of Desmids to Assess the Natural Conservation Value of a Hungarian Oxbow (Malom-Tisza, NE-Hungary). *Biologia*, **63**, 928-935. <https://doi.org/10.2478/s11756-008-0144-6>
- [13] Đorđević, N.B. and Simić, S.B. (2014) Cyanobacterial Blooms in Oligosaline and Alkaline Microaccumulation before and after Rehabilitation. *Polish Journal of Environmental Studies*, **23**, 1975-1982.
- [14] Ariyadej, C., Tansakul, R., Tansakul, P. and Angsupanich, S. (2004) Phytoplankton Diversity and Its Relationships to the Physico-Chemical Environment in the Banglang Reservoir, Yala Province. *Songklanakarín Journal of Science and Technology*, **26**, 595-607.
- [15] Newcombe, G., Chorus, I., Falconer, I. and Lin, T.F. (2012) Cyanobacteria: Impacts of Climate Change on Occurrence, Toxicity and Water Quality Management. *Water Research*, **46**, 1347-1348. <https://doi.org/10.1016/j.watres.2011.12.047>
- [16] Codd, G.A., Morrison, L.F. and Metcalf, J.S. (2005) Cyanobacterial Toxins: Risk Management for Health Protection. *Toxicology and Applied Pharmacology*, **203**, 264-272. <https://doi.org/10.1016/j.taap.2004.02.016>
- [17] Bernard, C. (2014) Les cyanobactéries et leurs toxines: Cyanobacteria and cyanotoxins. *Revue Francophone des Laboratoires*, **2014**, 53-68. [https://doi.org/10.1016/S1773-035X\(14\)72405-0](https://doi.org/10.1016/S1773-035X(14)72405-0)
- [18] Lance, E., Briant, L., Carpentier, A., Acou, A., Marion, L., Bormans, M. and Gérard, C. (2010) Impact of Toxic Cyanobacteria on Gastropods and Microcystin Accumulation in a Eutrophic Lake (Grand-Lieu, France) with Special Reference to *Physa* (= *Physella*) *acuta*. *Science of the Total Environment*, **408**, 3560-3568. <https://doi.org/10.1016/j.scitotenv.2010.04.050>

- [19] Pentecost, A. and Whitton, B.A. (2000) Limestones. In: Whitton, B.A. and Potts, M., Eds., *the Ecology of Cyanobacteria*, Springer, Dordrecht, 257-279. https://doi.org/10.1007/0-306-46855-7_9
- [20] Bounou, M., Sinaré, Y., Zamba, A.I., Santos, M.J. and Kabré, G.B. (2020) The Population of Monogeneans on the Gills of *Sarotherodon galilaeus* (Linnaeus, 1758) (Cichliformes: Cichlidae) and the Impact of Abiotic and Biotic Parameters. *International Journal of Fisheries and Aquatic Studies*, **8**, 11-17.
- [21] Rodier, J., Legube, B. and Merlet, N. (2009) L'Analyse de l'eau. 9e Édition, Dunod, Paris.
- [22] Bourrelly, P. (1985) Les algues d'eau douce: Les algues bleues et rouges. Société nouvelle des Editions Boubée, Paris.
- [23] Zongo, F., Zongo, B., Boussim, J.I. and Couté, A. (2008) Nouveaux taxa de micro-algues dulçaquicoles pour le Burkina Faso (Afrique de l' Ouest): I-Chlorophyta. *International Journal of Biological and Chemical Sciences*, **2**, 508-528. <https://doi.org/10.4314/ijbcs.v2i4.39780>
- [24] Ouattara, A., Podoor, N., Teugels, G.G. and Gourène, G. (2000) Les micro-algues de deux cours d'eau (Bia et Agnébi) de Côte d'Ivoire. *Systematics and Geography of Plants*, **70**, 315-372. <https://doi.org/10.2307/3668650>
- [25] Compère, P. (1974) Algues de la région du Lac Tchad. II—Cyanophycées. *Cahiers O.R.S.T.O.M., Série Hydrobiologie*, **8**, 165-198.
- [26] Zongo, B., Zongo, F., Ouéda, A., Couté, A. and Boussim, J.I. (2011) Étude des genres *Actinotaenium* (Näg.) Teiling et *Cosmarium* Corda ex Ralfs (Desmidiaceae / Chlorophyta) dans les mares temporaires des régions du Centre, de l'Est et du Nord du Burkina Faso. *International Journal of Biological and Chemical Sciences*, **5**, 554-569. <https://doi.org/10.4314/ijbcs.v5i2.72114>
- [27] Buratti, F.M., Manganelli, M., Vichi, S., Stefanelli, M., Scardala, S., Testai, E. and Funari, E. (2017) Cyanotoxins: Producing Organisms, Occurrence, Toxicity, Mechanism of Action and Human Health Toxicological Risk Evaluation. *Archives of Toxicology*, **91**, 1049-1130. <https://doi.org/10.1007/s00204-016-1913-6>
- [28] Funari, E. and Testai, E. (2008) Human Health Risk Assessment Related to Cyanotoxins Exposure. *Critical Reviews in Toxicology*, **38**, 97-125. <https://doi.org/10.1080/10408440701749454>
- [29] Fužinato, S.M., Cvijan, M. and Stamenković, M. (2011) A Checklist of Desmids (Conjugatophyceae, Chlorophyta) of Serbia. II. Genus *Cosmarium*. *Cryptogamie, Algologie*, **32**, 77-95. <https://doi.org/10.7872/crya.v32.iss1.2011.077>
- [30] Lozo, N.R., Berté, S., Kouassi, B.A.T., Ouattara, A. and Kouamélan, E.P. (2019) Chlorophyceae (Chlorophyta) du fleuve Bandama (Côte d'Ivoire). *International Journal of Innovation and Applied Studies*, **26**, 633-651.
- [31] Freitas, L.C. and Loverde-Oliveira, S.M. (2013) Checklist of Green Algae (Chlorophyta) for the State of Mato Grosso, Central Brazil. *Check List*, **9**, 1471-1483. <https://doi.org/10.15560/9.6.1471>
- [32] Şahin, B., Akar, B. and Barinova, S. (2020) Cohabitant Charophyte Algal Flora and Its Ecology in High-Mountain Lakes of the Artabel Lakes Nature Park (Gumushane, Turkey). *Botanica Serbica*, **44**, 11-25. <https://doi.org/10.2298/BOTSERB2001011S>
- [33] Gouvêa, S.P., Vieira, A.A.H. and Lombardi, A.T. (2002) No Effect of N or P Deficiency on Capsule Regeneration in *Staurodesmus convergens* (Zygnematophyceae, Chlorophyta). *Phycologia*, **41**, 585-589. <https://doi.org/10.2216/i0031-8884-41-6-585.1>
- [34] Halder, N. (2017) Taxonomy and Biodiversity of the Genus *Oscillatoria* Vauch. ex

- Gom. (Cyanoprokaryota: Oscillatoriales) with Ecological Notes from Hooghly in West Bengal, India. *Brazilian Journal of Biological Sciences*, **4**, 89-101. <https://doi.org/10.21472/bjbs.040710>
- [35] Vijayakumar, S., Thajuddin, N. and Manoharan, C. (2007) Biodiversity of Cyanobacteria in Industrial Effluents. *Acta Botanica Malacitana*, **32**, 27-34. <https://doi.org/10.24310/abm.v32i0.7026>
- [36] Scott, W.E., Barlow, D. and Hauman, J.J.H. (1981) Studies on the Ecology, Growth and Physiology of Toxic *Microcystis Aeruginosa* in South Africa. In: Carmichael, W.W., Eds., *the Water Environment. Environmental Science Research*, Springer, Boston, 49-69. https://doi.org/10.1007/978-1-4613-3267-1_5
- [37] Fadel, A., Atoui, A., Lemaire, B.J., Vinçon-Leite, B. and Slim, K. (2015) Environmental Factors Associated with Phytoplankton Succession in a Mediterranean Reservoir with a Highly Fluctuating Water Level. *Environmental Monitoring and Assessment*, **187**, Article No. 633. <https://doi.org/10.1007/s10661-015-4852-4>
- [38] Rapala, J., Sivonen, K., Lyra, C. and Niemelä, S.I. (1997) Variation of Microcystins, Cyanobacterial Hepatotoxins, in *Anabaena* spp. as a Function of Growth Stimuli. *Applied and Environmental Microbiology*, **63**, 2206-2212.
- [39] Coesel, P.F., and Meesters, K.J. (2007) Desmids of the Lowlands: Mesotaeniaceae and Desmidiaceae of the European Lowlands. BRILL, Leiden.
- [40] Gaysina, L.A., Saraf, A. and Singh, P. (2018) Cyanobacteria in Diverse Habitats. In: Mishra, A.K., Tiwari, D.N. and Rai, A.N., Eds., *Cyanobacteria: From Basic Science to Applications*, Academic Press, Cambridge, 1-28. <https://doi.org/10.1016/B978-0-12-814667-5.00001-5>
- [41] Cheung, M.Y., Liang, S. and Lee, J. (2013) Toxin-Producing Cyanobacteria in Freshwater: A Review of the Problems, Impact on Drinking Water Safety, and Efforts for Protecting Public Health. *Journal of Microbiology*, **51**, 1-10. <https://doi.org/10.1007/s12275-013-2549-3>
- [42] Ngearnpat, N. and Peerapornpisal, Y. (2007) Application of Desmid Diversity in Assessing the Water Quality of 12 Freshwater Resources in Thailand. *Journal of Applied Phycology*, **19**, 667-674. <https://doi.org/10.1007/s10811-007-9191-6>
- [43] Arumugam, S., Sigamani, S., Samikannu, M. and Perumal, M. (2016) Assemblages of Phytoplankton Diversity in Different Zonation of Muthupet Mangroves. *Regional Studies in Marine Science*, **3**, 234-241. <https://doi.org/10.1016/j.rsma.2015.11.005>
- [44] Bélanger, M., El-Jabi, N., Caissie, D., Ashkar, F., and Ribí, J.M. (2005) Estimation de la température de l'eau de rivière en utilisant les réseaux de neurones et la régression linéaire multiple. *Revue des Sciences de l'eau / Journal of Water Science*, **18**, 403-421. <https://doi.org/10.7202/705565ar>
- [45] Konan, K.S., Kouassi, A.M., Adingra, A.A., Dongui, B.K. and Gnakri, D. (2008) Variations Saisonnières des Paramètres Abiotiques des Eaux D'une Lagune Tropicale: La Lagune de Grand-Lahou, Côte D'ivoire Kouakou. *European Journal of Scientific Research*, **21**, 376-393.
- [46] Zinsou, H.L., Attingli, A.H., Gnohossou, P., Adandedjan, D. and Laleye, P. (2016) Caractéristiques physico-chimiques et pollution de l'eau du delta de l'Oueme au Bénin. *Journal of Applied Biosciences*, **97**, 9163-9173. <https://doi.org/10.4314/jab.v97i1.3>
- [47] Kuffour, C., Esumang, D.K., Akotoye, H.K., Kuffour, R.A. and Abraham, J.D. (2021) Pesticide and Nutrient Loads of Lake Bosomtwe in the Ashanti Region of Ghana. *Journal of Water Resource and Protection*, **13**, 794-806. <https://doi.org/10.4236/jwarp.2021.1310042>

- [48] Hepp, L.U., Milesi, S.V., Biasi, C. and Restello, R.M. (2010) Effects of Agricultural and Urban Impacts on Macroinvertebrates Assemblages in Streams (Rio Grande do Sul, Brazil). *Zoologia*, **27**, 106-113. <https://doi.org/10.1590/S1984-46702010000100016>
- [49] Sass, L.L., Bozek M.A., Hauxwell, J.A., Wagner, K. and Knight, S. (2010) Response of Aquatic Macrophytes to Human Land Use Perturbations in the Watersheds of Wisconsin Lakes, U.S.A. *Aquatic Botany*, **93**, 1-8. <https://doi.org/10.1016/j.aquabot.2010.02.001>
- [50] Leigh, C., Burford, M.A., Roberts, D.T. and Udy, J.W. (2010) Udy, Predicting the Vulnerability of Reservoirs to Poor Water Quality and Cyanobacterial Blooms. *Water Research*, **44**, 4487-4496. <https://doi.org/10.1016/j.watres.2010.06.016>
- [51] Sánchez-Colón, F.C. and Schaffner, Y.M. (2021) Identifying Nonpoint Sources of Phosphorus and Nitrogen: A Case Study of Pollution that Enters a Freshwater Wetland (Laguna Cartagena, Puerto Rico). *Journal of Water Resource and Protection*, **13**, 588-604. <https://doi.org/10.4236/jwarp.2021.138032>
- [52] Buhungu, S., Montchowui, E., Barankanira, E., Sibomana, C., Ntakimazi G. and Bonou, C.A. (2018) Caractérisation spatio-temporelle de la qualité de l'eau de la rivière Kinyankonge, affluent du Lac Tanganyika, Burundi. *International Journal of Biological and Chemical Sciences*, **12**, 576-595. <https://doi.org/10.4314/ijbcs.v12i1.44>
- [53] Assougnon, D.L., Agadjihouédé, H., Kokou, K. and Lalèyè, A.P. (2017) Caractérisation physico-chimique et diversité du peuplement phytoplanctonique des mares au sud de la réserve de faune de Togodo (sud-Togo). *International Journal of Biological and Chemical Sciences*, **11**, 1920-1936. <https://doi.org/10.4314/ijbcs.v11i4.40>
- [54] Ravindra, K., Rani, A.M.M. and Kaushik, A. (2003) Seasonal Variations in Physico-Chemical Characteristics of River Yamuna in Haryana and Its Ecological Best-Designated Use. *Journal of Environmental Monitoring*, **5**, 419-426. <https://doi.org/10.1039/b301723k>
- [55] Blais, S. (2002) La problématique des cyanobactéries (algues bleu-vert) à la baie Missisquoi en 2001. *Agrosol*, **13**, 103-110.
- [56] Kumar, P. and Mahajan, A.K. (2019) Evaluation of Trophic Status and Its Limiting Factors in the Renuka Lake of Lesser Himalaya, India. *Environmental Monitoring and Assessment*, **191**, Article No. 105. <https://doi.org/10.1007/s10661-019-7247-0>
- [57] Xie, L., Xie, P., Li, S., Tang, H. and Liu, H. (2003) The Low TN: TP Ratio, a Cause or a Result of *Microcystis* Blooms? *Water Research*, **37**, 2073-2080. [https://doi.org/10.1016/S0043-1354\(02\)00532-8](https://doi.org/10.1016/S0043-1354(02)00532-8)
- [58] Djabourabi, A., Sehili, N., Boussadia, M., Samar, F. and Bensouilah, M. (2014) Fluctuations des Paramètres Physico Chimiques et des Communautés Phytoplanctoniques dans le lac Oubeira (Nord-Est Algérien) *European Journal of Scientific Research*, **118**, 183-196.
- [59] Taffouo, V.D., Saya, R. adley I., Mbeng, L.O. and Eyango, M.T. (2017) Impacts des caractéristiques physico-chimiques des eaux sur la distribution du phytoplancton et des macrophytes de la rivière Nkam (Cameroun). *International Journal of Biological and Chemical Sciences*, **11**, 1766-1784. <https://doi.org/10.4314/ijbcs.v11i4.28>
- [60] Coesel, P.F.M. (2001) A Method for Quantifying Conservation Value in Lentic Freshwater Habitats Using Desmids as Indicator Organisms. *Biodiversity and Conservation*, **10**, 177-187. <https://doi.org/10.1023/A:1008985018197>
- [61] Nygaard, G. (1949) Hydrobiological Studies on Some Danish Ponds and Lakes. *Kongelige Danske Videnskabernes Selskab*, **7**, 293 p.

- [62] Briand, J.F., Jacquet, S., Bernard, C. and Humbert, J.F. (2003) Health Hazards for Terrestrial Vertebrates from Toxic Cyanobacteria in Surface Water Ecosystems. *Veterinary Research*, **34**, 361-377.
- [63] De Figueiredo, D.R., Reboleira, A.S.S.P., Antunes, S.C., Abrantes, N., Azeiteiro, U., Gonçalves, F. and Pereira, M.J. (2006) The Effect of Environmental Parameters and Cyanobacterial Blooms on Phytoplankton Dynamics of a Portuguese Temperate Lake. *Hydrobiologia*, **568**, 145-157. <https://doi.org/10.1007/s10750-006-0196-y>
- [64] Mowe, M.A., Mitrovic, S.M., Lim, R.P., Furey, A. and Yeo, D.C. (2015) Tropical Cyanobacterial Blooms: A Review of Prevalence, Problem Taxa, Toxins and Influencing Environmental Factors. *Journal of Limnology*, **74**, 205-224. <https://doi.org/10.4081/jlimnol.2014.1005>
- [65] Duy, T.N., Lam, P.K.S., Shaw, G.R. and Connell, D.W. (2000) Toxicology and Risk Assessment of Freshwater Cyanobacterial (Blue-Green Algal) Toxins in Water. In: Ware, G.W., Ed., *Reviews of Environmental Contamination and Toxicology*, Springer, New York, 113-185. https://doi.org/10.1007/978-1-4757-6429-1_3
- [66] Ndlela, L.L., Oberholster, P.J., Van Wyk, J.H. and Cheng, P.H. (2016) An Overview of Cyanobacterial Bloom Occurrences and Research in Africa over the Last Decade. *Harmful Algae*, **60**, 11-26. <https://doi.org/10.1016/j.hal.2016.10.001>
- [67] Haande, S., Ballot, A., Rohrlack, T., Fastner, J., Wiedner, C. and Edvardsen, B. (2007) Diversity of *Microcystis aeruginosa* Isolates (Chroococcales, Cyanobacteria) from East-African Water Bodies. *Archives of Microbiology*, **188**, 15-25. <https://doi.org/10.1007/s00203-007-0219-8>
- [68] El Ghazali, I., Saqrane, S., Saker, M., Youness, O., Oudra, B., Vasconcelos, V. and Del Campo, F.F. (2011) Caractérisation biochimique et moléculaire d'efflorescences à cyanobactéries toxiques dans le réservoir Lalla Takerkoust (Maroc). *Revue Des Sciences de l'eau / Journal of Water Science*, **24**, 117-128. <https://doi.org/10.7202/1006106ar>
- [69] Addico, G., Hardege, J., Komarek, J., Babica, P. and De Graft-Johnson, K.A.A. (2006) Cyanobacteria Species Identified in the Weijsa and Kpong Reservoirs, Ghana, and Their Implications for Drinking Water Quality with Respect to Microcystin. *African Journal of Marine Science*, **28**, 451-456. <https://doi.org/10.2989/18142320609504196>
- [70] Oberholster, P.J., Botha, A.M. and Cloete, T.E. (2005) An Overview of Toxic Freshwater Cyanobacteria in South Africa with Special Reference to Risk, Impact and Detection by Molecular Marker Tools. *Biokemistri*, **17**, 57-71. <https://doi.org/10.4314/biokem.v17i2.32590>
- [71] Harding, W.R. and Paxton, B.R. (2001) Cyanobacteria in South Africa: A Review. WRC Report No: TT 153/01.
- [72] Kadiri, M.O., Isagba, S., Ogbebor, J.U., Omoruyi, O.A., Unusiotame-Owolagba, T.E., Lorenzi, A.S., Bittencourt-Oliveira, M.C. and Chia, M.A. (2020) The Presence of Microcystins in the Coastal Waters of Nigeria, from the Bights of Bonny and Benin, Gulf of Guinea. *Environmental Science and Pollution Research*, **27**, 35284-35293. <https://doi.org/10.1007/s11356-020-09740-x>
- [73] Hitzfeld, B.C., Hoger, S.J. and Dietrich, D.R. (2000) Cyanobacterial Toxins: Removal during Drinking Water Treatment, and Human Risk Assessment. *Environmental Health Perspectives*, **108**, 113-122. <https://doi.org/10.1289/ehp.00108s1113>
- [74] Lopez, C.B., Jewett, E.B., Dortch, Q., Walton, B.T. and Hudnell, H.K. (2008) Scientific Assessment of Freshwater Harmful Algal Blooms. Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health of the Joint Subcommittee

on Ocean Science and Technology, Washington DC.

- [75] Cordeiro-Araújo, M.K., Chia, M.A., Arruda-Neto, J.D.T., Tornisielo, V.L., Vilca, F.Z. and Bittencourt-Oliveira, M.C. (2016) Microcystin-LR Bioaccumulation and Depuration Kinetics in Lettuce and Arugula: Human Health Risk Assessment. *Science of the Total Environment*, **566-567**, 1379-1386.
<https://doi.org/10.1016/j.scitotenv.2016.05.204>
- [76] Yoshida, T., Makita, Y., Nagata, S., Tsutsumi, T., Yoshida, F., Sekijima, M., Tamura, S.I. and Ueno, Y. (1997) Acute Oral Toxicity of Microcystin-LR, a Cyanobacterial Hepatotoxin, in Mice. *Natural Toxins*, **5**, 91-95.
- [77] Davis, T.W., Berry, D.L., Boyer, G.L. and Gobler, C.J. (2009) The Effects of Temperature and Nutrients on the Growth and Dynamics of Toxic and Non-Toxic Strains of *Microcystis* during Cyanobacteria Blooms. *Harmful Algae*, **8**, 715-725.
<https://doi.org/10.1016/j.hal.2009.02.004>