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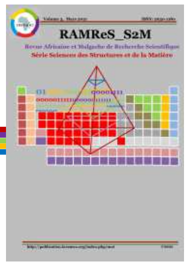

Physico-chemical parameters and cyanobacterial communities of the Ebrié lagoon (Côte d'Ivoire): application to the risk of efflorescence

Mel Hayo Vianney[1,*], Lozo Roméo N'Guessan[2], Ouffoué Koffi Sébastien[3,4], Bamba Kafoumba[1], Kouassi N'Guessan[5], Ngohang Franck Estime[6], Ziao Nahossé[1]

[1]*Laboratoire de Thermodynamique et de Physicochimie du Milieu (LTPCM), Université NANGUI ABROGOUA, Abidjan, Côte d'ivoire*
[2]*Laboratoire des Milieux Naturels et Conservation de la Biodiversité, Université FELIX HOUPHOUËT BOIGNY, Abidjan, Côte d'ivoire*
[3]*Laboratoire de Constitution et Réaction de la Matière (LCRM), Université FELIX HOUPHOUËT BOIGNY, Abidjan, Côte d'ivoire*
[4]*Centre Ivoirien Antipollution (CIAPOL), Ministère de l'environnement et du développement durable, Abidjan, Côte d'ivoire*
[5]*Laboratoire Central de l'Environnement du Centre Ivoirien Antipollution (LCE-CIAPOL), Abidjan, Côte d'ivoire*
[6]*Laboratoire Pluridisciplinaire des sciences (LAPLUS), Ecole Normale Supérieure, Libreville, Gabon*

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***Abstract*:**

Cyanobacteria blooms in aquatic ecosystems lead to adverse effects in the water through the production of a variety of toxins that pose risks to wildlife and human health. For better management, appropriate monitoring programs must be put in place in potential risk areas. In our study, we examined the physico-chemical and biological indicators involved in blooms in order to map some surface waters of the Ebrié lagoon. The sampling was conducted from May 2021 to March 2022, on the lagoon ecosystem of the coastal region ranging from the cities of Grand-Bassam to Jacqueville via Abidjan. The physico-chemical parameters of the water were measured using a WTW model 3430 multi-parameter in eight stations (Azuretti, Grand-Bassam, Koumassi, Koumassi 05, Adiapodoumé, Bietry, Marcory and Jacqueville). Sampling of taxa was done with a plankton net of 20 µm mesh size. A light microscope was used to observe the various samples taken. Documents from various authors have helped to identify the different taxa. The results of the observation of the morpho-anatomical criteria of the cyanobacteria collected allowed us to identify 13 taxa grouped into 8 genera. Among these taxa, 3 are attached to species recognized as potentially toxic (*Microcystis aeruginosa*, *Oscillatoria* sp. and *Anabaena* sp.). The physico-chemical parameters contributed to making the environment favorable to the development of microalgae, particularly cyanobacteria. Our study has shown that the alert levels are not reached and that only vigilance levels are raised during the low water season. All of the surveyed sites would be potential risk areas.

***Keywords*:** Cyanobacteria; Efflorescence; Ebrié lagoon; Physico-chemical parameters; Cyanotoxins.

*Corresponding author:
Email address: hvmel33@gmail.com *(H.V. Mel)*

1. Introduction

Aquatic ecosystems are deteriorating all over the world due to the increasingly intense pressure exerted by human populations on the aquatic environment. This situation leads to a multitude of problems related to the use of water and its resources, in particular the loss of biodiversity, the pollution of water bodies and public health problems [1, 2].

The eutrophication already observable in coastal ecosystems, especially in the tropics, is a perfect illustration of this. In West Africa, the main problem associated with the degradation of aquatic environments is the increase in blooms of macrophytes and microalgae, particularly cyanobacteria [3].

Globally, many environmental and health problems are induced by cyanobacterial blooms, such as the decrease in dissolved oxygen concentrations in water which causes suffocation of aquatic life, the production of toxins [4, 5], the mortality of wild aquatic and terrestrial animals resulting from the ingestion of toxins [6], and food poisoning (allergies, diarrhea, vomiting).

In Côte d'Ivoire, these observations have not been fully confirmed, as data on blooms and associated risks are relatively limited. In view of the increase in the number of water bodies affected by cyanobacteria, there is an urgent need to set up a database resulting from research and monitoring activities [7]. One of the study methods used consists of carrying out *in situ* surveys to find out the favorable physicochemical environment and the characteristics of the blooms (spatial and temporal scale, quantitative aspect, associated species, toxicity) [8]. The brackish water ecosystem of the Ebrié lagoon represents a relevant study site to carry out a preliminary sweep. The majority of published works hydrological [9, 10], microbiological [11], physico-chemical [12, 13], confirm the importance of this lagoon environment.

The main objective is to identify a few areas of the Ebrié lagoon, potentially favorable to blooms, in order to help manage this harmful phenomenon. This turns out to be a concern of interest in a context where climate change is altering the ecological regime of ecosystems. This work proposes to establish the mapping of some risk areas of some water bodies in the coastal region between the cities of Grand-Bassam, Abidjan and Jacqueville through the exploitation of limiting environmental (dissolved oxygen, pH, temperature, nitrate, nitrite) and biological (genus and species of cyanobacteria) data.

2. Material and methods

2.1. Study area

This study was carried out in the waters of the Ebrié lagoon. The Ebrié lagoon, with an area of 523 km^2, is part of the Ebrié lagoon system which stretches over 130 km along the Gulf of Guinea between 3°58' and 4°91' West longitude and between 5°09' and 5 °41' North latitude [11].

It is a closed ecosystem located on the Atlantic coast of Côte d'Ivoire. It receives effluents from numerous industries and domestic wastewater from the greater agglomeration of Abidjan and surrounding towns and villages [11]. There are 3 lagoon seasons: a low water season (January to April), where the continental inputs are negligible and the maximum marine influence; a rainy season (May to August) when there is heavy rainfall followed by inflows from rivers such as the Agnéby and the Mé and a flood season (September to December), marked by the arrival of water from the Comoé river [14, 15].

As part of our work, eight sites located in three sectors according to the classification of Durand and Skubich [14] were selected (Table 1, Figure 1). The LJ station is located in Jacqueville, a rural area. This station is impacted by the weight of household waste and runoff from agricultural plantations. The Bs and Azu stations are located in Grand-Bassam, a rural area undergoing urbanization. These stations receive domestic discharges and are under the influence of the Comoé river, especially during periods of flooding. AD, HKB, K05, K2 and Biet stations are located in Abidjan, urban area. These stations are subject to anthropogenic pressure (domestic and industrial discharges) of varying intensity. We also note the oceanic influence via the Vridi channel and the presence of invasive aquatic plants indicating the influence of continental waters.

These natural and anthropogenic stress factors contribute to considerably modify the physicochemical conditions of the lagoon and the diversity of microalgae, particularly cyanobacteria.

Table 1
Geographical coordinates of the sampling stations.

			Geographical coordinates	
Sector	Location	Code	Longitude	Latitude
Grand-Bassam (S1)	Grand-Bassam	Bs	5.197041	- 3.732280
	Azuretti	Azu	5.204771	- 3.777905
Abidjan (S2)	Adiapodoumé	AD	5.334260	- 4.127184
	Bietry	Biet	5.269287	- 3.963281
	Koumassi 05	K05	5.314723	- 3.940397
	Koumassi	K2	5.271352	- 3.960395
	Marcory	HKB	5.313131	- 3.976629
Jacqueville (S3)	Jacqueville	LJ	5.233862	- 4.427908

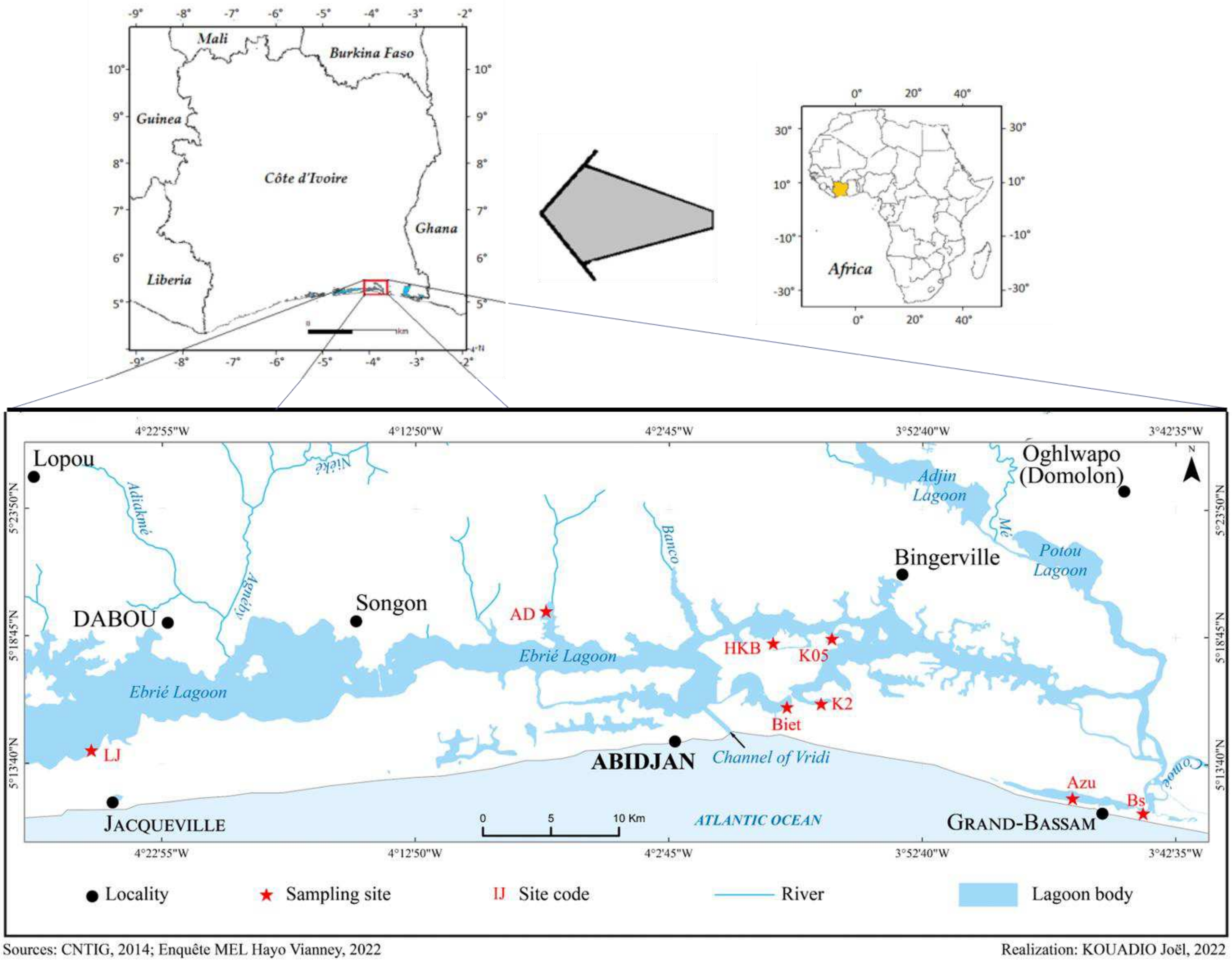


Fig. 1. Location map of sampling sites.

2.2. Sample collection

The water samples were taken from May 2021 to March 2022. This period covers the three lagoon seasons according to Morlière [15], which considerably influence the physicochemical characteristics of the lagoon. Each sampling site was located by GPS coordinates. Phytoplankton collection was carried out with a 20 µm mesh plankton net from a boat and then the contents of the collector transferred into a 60 mL pillbox. Also, a direct sample was taken with the pill dispenser. Preservation is carried out by adding 5% formaldehyde. Water samples were taken 50 cm below the surface using a sampler. The content of the sampler is collected in 1 L polypropylene bottles, previously decontaminated. On the bottle, the following indications were given: date, name and code of the sampling station. The water samples are kept in a cooler containing ice packs to avoid any risk of degradation during transport to the laboratory for the determination of nitrogen compounds (nitrites and nitrates). The retention period does not exceed 4 weeks.

2.3. Qualitative analysis of phytoplankton

The observation was carried out using a brand NL CD-120 light microscope equipped with a camera. The observation of the morpho-anatomical characters of cyanobacteria allowed us to identify the genus and the species. Documents of various authors contributed to identify the different taxa.

2.4. Measurement of physical water parameters

Water temperature, dissolved oxygen and pH, were chosen because these parameters influence and can reflect the development of the efflorescence phenomenon. The measurements were carried out *in situ* using a multiparameter WTW 3430 and in the laboratory with a pH meter. The measurement in the field is preceded by a check in air saturated with water vapor of the electrochemical probe for the multiparameter. The pH meter is also calibrated with standard solutions at pH values 4, 7 and 10. Temperature and dissolved oxygen readings are obtained by directly immersing the probe in water.

2.5. Methods of analysis of chemical parameters of water

Nitrogen compounds to be measured are nitrates (NO_3^-) and nitrites (NO_2^-). These compounds will provide information on the trophic level of the water body and therefore on the capacity of the environment to support the development of phytoplankton biomass.

The principle of measurement is based on Beer Lambert's law which indicates the proportionality of the optical density with the thickness of the solution (sample analyzed) and the concentration of the chemical element sought. After addition of the appropriate reagent, the sample water-reagent mixture is introduced into the HACH DR6000 spectrophotometer which displays the concentration of the ion compared to the control. The concentrations of (NO_3^-) and (NO_2^-) were respectively determined according to the methods of reduction with cadmium and diazotization.

An evaluation was made according to the categories of susceptibility of the National Health and Medical Research Council (NHMRC), if recreational uses appeared on these bodies of water. The classification of the body of water is carried out according to its capacity to allow development of cyanobacteria, by assigning a susceptibility category, and based on a history of cyanobacteria blooms, when data are available. Susceptibility categories are defined based on environmental data such as: temperature, total phosphorus concentration, thermal stratification, and history of cyanobacterial contamination [16].

3. Results

3.1. Physico-chemical parameters

3.1.1. Temperature

The water temperature of the Ebrié lagoon shows a difference of 5.7°C between the maximum average value recorded in March (33.2°C) for the city of Grand-Bassam and the minimum average value recorded in July (27.5°C) for the city of Jacqueville. The evolution of the water temperature is similar in the three cities (Figure 2, Table 2); we noted, in fact, a drop in temperature from May to July (rainy season) and from December to January, then a gradual increase from July to December and from January to March (low water season).

Table 2
Temperature (°C) of the waters of the Ebrié lagoon (May 2021- March 2022).

	May	Jul	Sept	Oct	Dec	Jan	March
Bs	30.0	28.5	29.0	29.3	30.7	29.4	32.2
Azu	30.3	28.3	29.6	29.7	30.8	29.3	34.2
AD	29.7	27.3	29.2	29.0	31.0	29.8	30.6
Biet	29.6	28.3	29.6	29.7	30.7	29.3	31.0
K05	30.1	27.4	29.7	30.0	31.0	29.8	30.4
HKB	28.1	27.7	30.0	30.1	30.8	29.4	30.3
K2	30.1	28.4	29.7	29.7	30.7	29.4	31.6
LJ	29.1	27.5	29.3	29.4	30.4	29.8	31.9
SD	0.7	0.5	0.3	0.4	0.2	0.2	1.3

Jul*: July;* ***Sept****: September;* ***Oct****: October;* ***Dec****: December;* ***Jan****: January;* ***Bs****: Grand-Bassam station;* ***Azu****: Azuretti station;* ***AD****: Adiapodoumé station;* ***Biet****: Bietry station;* ***K05****: Koumassi 05 station;* ***HKB****: Marcory station;* ***K2****: Koumassi station;* ***LJ****: Jacqueville station;* ***SD****: Standard deviation.*

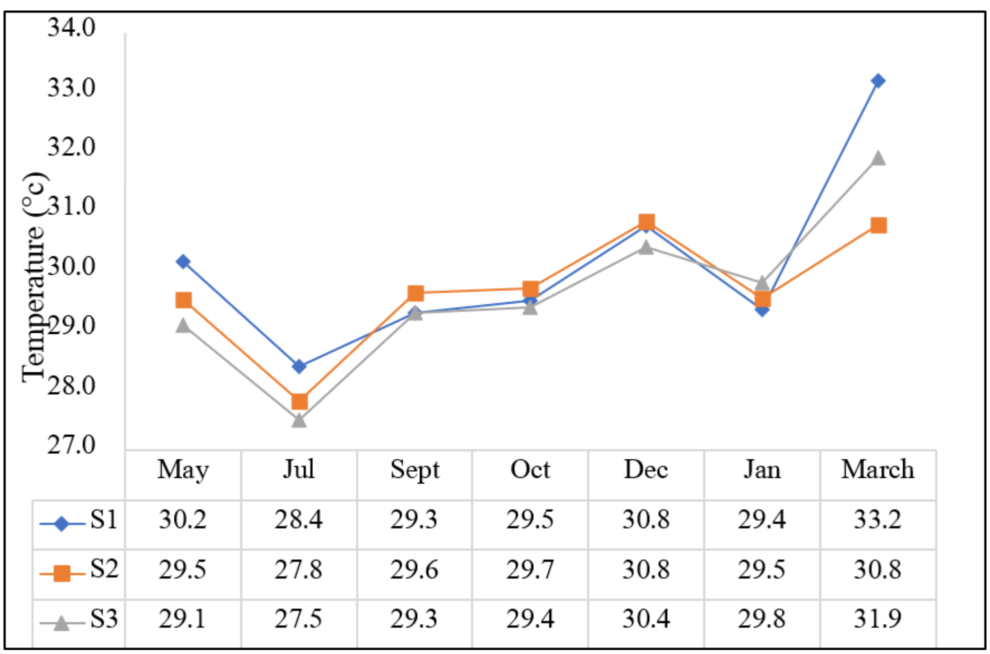


Fig.2. Water temperature variations of each area (May 2021-March 2022).

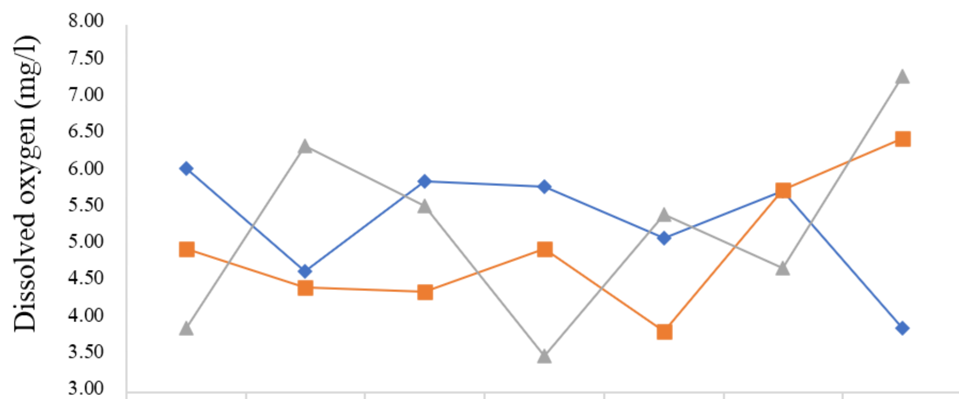
3.1.2. Dissolved oxygen

The average dissolved oxygen contents of the waters of Abidjan decrease from May (4.95 mg/L) to December (3.83 mg/L) then increase from December to March (6.45 mg/L) (Figure 3). A peak of over 7 mg/L was recorded in March at Jacqueville and the lowest value was also recorded there in October (3.5 mg/L). The dissolved oxygen contents show spatial and temporal variations for the different stations (Table 3).

Table 3
Dissolved oxygen content (mg/L) of the waters of the Ebrié lagoon (May 2021-March 2022).

	May	Jul	Sept	Oct	Dec	Jan	March
Bs	5.90	4.10	4.34	7.11	4.10	5.32	3.48
Azu	6.19	5.20	7.40	4.50	6.11	6.17	4.28
AD	6.40	7.25	5.17	6.33	4.20	4.80	5.24
Biet	4.55	3.61	3.97	4.00	3.90	4.11	12.40
K05	5.73	5.16	4.65	6.65	3.02	6.85	7.94
HKB	4.97	2.94	3.92	4.80	4.72	7.54	4.11
K2	3.09	3.20	4.15	3.00	3.30	5.46	2.57
LJ	3.87	6.35	5.54	3.50	5.42	4.69	7.30
SD	1.18	1.54	1.16	1.53	1.04	1.16	3.20

Jul: *July;* ***Sept***: *September;* ***Oct***: *October;* ***Dec***: *December;* ***Jan***: *January;* ***Bs***: *Grand-Bassam station;* ***Azu***: *Azuretti station;* ***AD***: *Adiapodoumé station;* ***Biet***: *Bietry station;* ***K05***: *Koumassi 05 station;* ***HKB***: *Marcory station;* ***K2***: *Koumassi station;* ***LJ***: *Jacqueville station;* ***SD***: *Standard deviation.*



	May	Jul	Sept	Oct	Dec	Jan	March
S1	6.05	4.65	5.87	5.81	5.11	5.75	3.88
S2	4.95	4.43	4.37	4.96	3.83	5.75	6.45
S3	3.87	6.35	5.54	3.50	5.42	4.69	7.30

Fig. 3. Dissolved oxygen content variations of each area (May 2021-March 2022).

3.1.3. pH

The pH values by sector show small variations and are around 7. The highest pH was observed in March in Abidjan with an average value of 7.66 (Figure 4). The difference observed in the pH values (Table 4) is due to the oceanic and continental inputs which vary according to lagoon seasons.

Table 4
pH of the waters of the Ebrié lagoon (May 2021-March 2022).

	May	Jul	Sept	Oct	Dec	Jan	March
Bs	7.11	6.70	7.30	7.30	6.68	7.03	6.23
Azu	6.90	7.03	8.11	7.30	7.21	7.42	7.89
AD	7.10	6.20	6.21	6.90	6.95	7.11	6.42
Biet	7.35	7.62	7.29	6.70	7.15	7.48	9.11
K05	7.35	6.4	6.64	7.40	7.03	7.20	6.51
HKB	7.60	6.22	7.21	7.30	7.20	7.65	7.94
K2	7.10	6.81	6.84	6.50	7.10	7.55	8.32
LJ	7.50	6.48	6.82	7.20	7.09	7.17	6.51
SD	0.24	0.47	0.56	0.33	0.17	0.23	1.09

***Jul**: July; **Sept**: September; **Oct**: October; **Dec**: December; **Jan**: January; **Bs**: Grand-Bassam station; **Azu**: Azuretti station; **AD**: Adiapodoumé station; **Biet**: Bietry station; **K05**: Koumassi 05 station; **HKB**: Marcory station; **K2**: Koumassi station; **LJ**: Jacqueville station; **SD**: Standard deviation.*

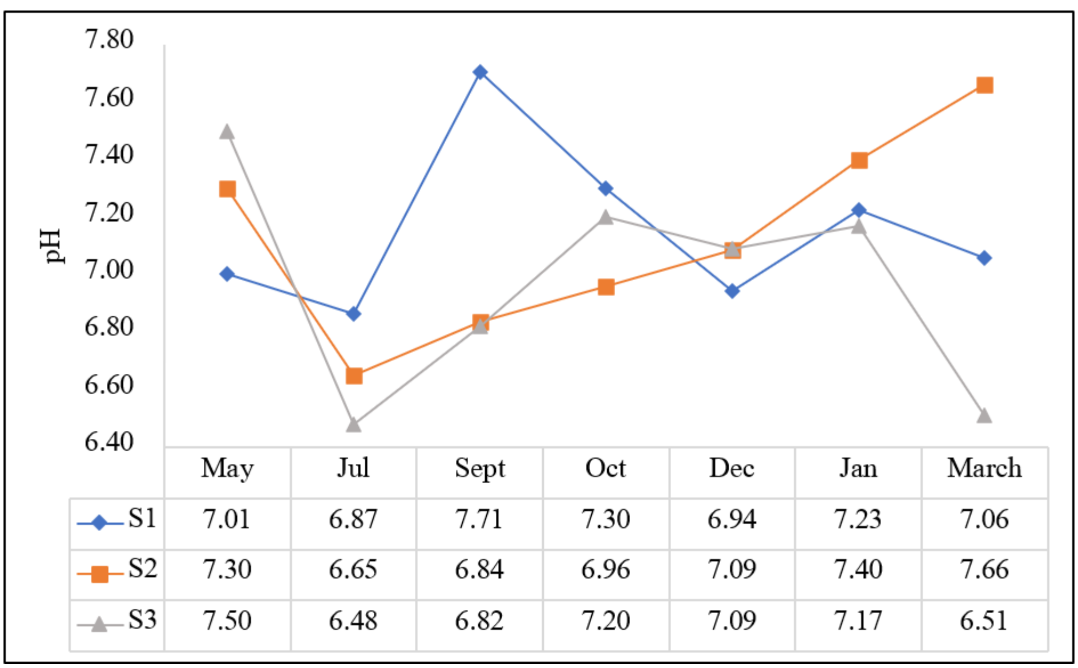


Fig. 4. pH variations of each area (May 2021-March 2022).

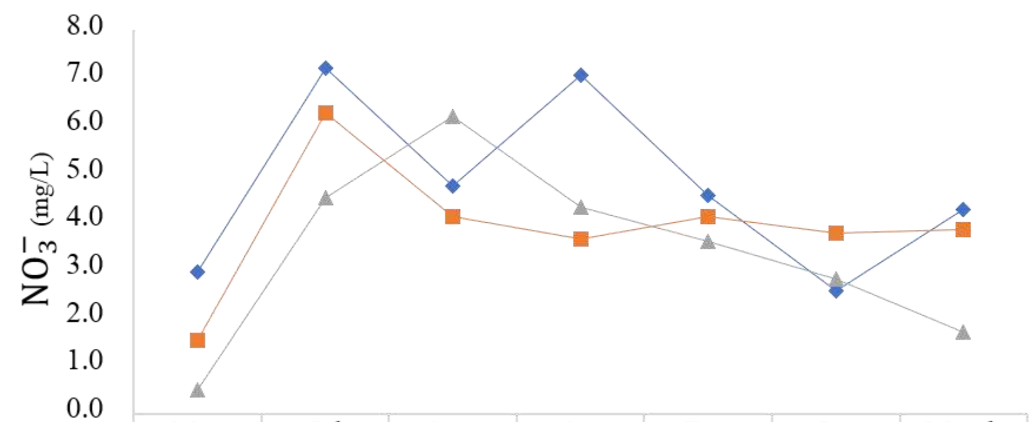
3.1.4. Nitrates

The concentrations of NO_3^- at the various stations reveal relatively high values in July (rainy season) ranging from 2.1 to 10.8 mg/L (Table 6). The highest mean value (7.2 mg/L) is observed at Grand-Bassam. These values show a spatial variation of NO_3^-, translating an intensity variable nitrogen contribution on the water levels of the lagoon according to the sectors and the stations.

Table 5
Nitrate concentrations (mg/L) in the waters of the Ebrié lagoon (May 2021-March 2022).

	May	Jul	Sept	Oct	Dec	Jan	March
Bs	2.1	7.3	4.1	4.9	4.1	1.9	5.1
Azu	3.8	7.1	5.4	9.2	5.0	3.2	3.4
AD	0.9	5.1	3.0	4.0	3.3	3.0	2.9
Biet	2.3	5.1	6.5	3.4	4.2	3.3	5.1
K05	1.2	7.2	4.2	4.7	6.3	4.2	3.8
HKB	1.3	10.8	3.1	1.7	3.6	3.6	4.5
K2	1.9	3.1	3.8	4.4	3.1	4.7	2.9
LJ	0.5	4.5	6.2	4.3	3.6	2.8	1.7
SD	1.03	2.36	1.34	2.12	1.05	0.86	1.19

***Jul**: July; **Sept**: September; **Oct**: October; **Dec**: December; **Jan**: January; **Bs**: Grand-Bassam station; **Azu**: Azuretti station; **AD**: Adiapodoumé station; **Biet**: Bietry station; **K05**: Koumassi 05 station; **HKB**: Marcory station; **K2**: Koumassi station; **LJ**: Jacqueville station; **SD**: Standard deviation.*



	May	Jul	Sept	Oct	Dec	Jan	March
S1	3.0	7.2	4.8	7.1	4.6	2.6	4.3
S2	1.5	6.3	4.1	3.6	4.1	3.8	3.8
S3	0.5	4.5	6.2	4.3	3.6	2.8	1.7

Fig. 5. Nitrates variations of each area (May 2021-March 2022).

3.1.5. Nitrites

Figure 6 shows regular average concentrations of NO_2^- in the waters of the Ebrié lagoon over the entire study period. The values recorded are on average 0.06 mg/L. These values per station fluctuate between 0.01 and 0.23 mg/L over all the months of sampling.

Table 6
Nitrite concentrations (mg/L) in the waters of the Ebrié lagoon (May 2021-March 2022).

	May	Jul	Sept	Oct	Dec	Jan	March
Bs	0.01	0.09	0.10	0.20	0.20	0.03	0.04
Azu	0.04	0.03	0.03	0.15	0.20	0.01	0.01
AD	0.03	0.01	0.03	0.10	0.04	0.10	0.09
Biet	0.07	0.02	0.02	0.01	0.03	0.12	0.05
K05	0.12	0.04	0.04	0.23	0.09	0.05	0.04
HKB	0.04	0.09	0.09	0.03	0.14	0.03	0.02
K2	0.04	0.21	0.07	0.20	0.03	0.03	0.04
LJ	0.10	0.10	0.01	0.01	0.09	0.03	0.01
SD	0.04	0.06	0.03	0.09	0.07	0.04	0.03

***Jul**: July; **Sept**: September; **Oct**: October; **Dec**: December; **Jan**: January; **Bs**: Grand-Bassam station; **Azu**: Azuretti station; **AD**: Adiapodoumé station; **Biet**: Bietry station; **K05**: Koumassi 05 station; **HKB**: Marcory station; **K2**: Koumassi station; **LJ**: Jacqueville station; **SD**: Standard deviation.*

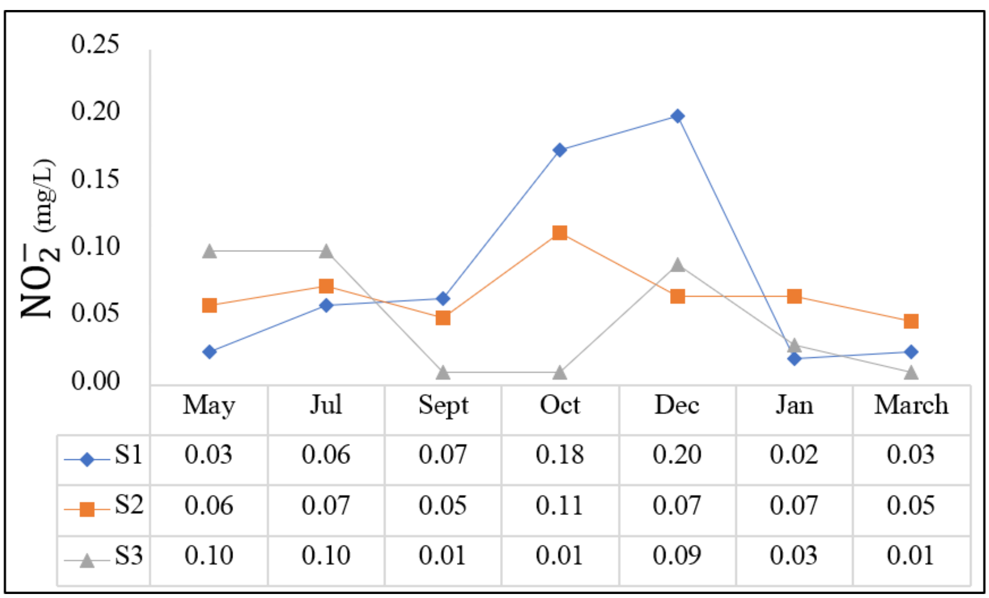


Fig. 6. Nitrites variations of each area (May 2021-March 2022).

3.2. Spatial distribution of cyanobacteria

In our study, the identification was made according to the morphological keys of cyanobacteria described by [17, 18]. The distribution of cyanobacteria observed in each sample, caries according to the station on which the sampling was carried out (Table 7). We identified 13 taxa in the eight stations. The genera appearing in the form of cells grouped together in clusters (or colonies) are: *Aphanocapsa, Chroococcus, Merismopedia* and *Microcystis,* and the genera occurring in filamentous form (or Trichome) are: *Anabaena*, *Cylindrospermum*, *Oscillatoria* and *Spirulina.*

One taxon is present on the eight sampling stations. This is *Oscillatoria princeps*. The genus *Oscillatoria* is able to resist all the climatic and physico-chemical changes of the environment according to Jacques [19]. Concerning the phytogeographical distribution, the species are all cosmopolitan (12) and subcosmopolitan (1). The inventoried taxa are found in fresh water (8), both in fresh and marine water (2). The species *Anabaena sp*., *Microcystis aeruginosa* and *Oscillatoria sp*., all freshwater species, are recognized as potentially toxic. They all meet at the HKB station during the study period. Among these stations, the richest in taxa is the LJ station and the least rich is Azu.and AD.

Table 7
Spatial distribution of cyanobacteria taxa inventoried in the Ebrié lagoon (May 2021 to March 2022).

Cyanobacteria	Sampling stations							
	Bs	Azu	AD	Biet	K05	HKB	K2	LJ
Anabaena sp.				x				x
Aphanocapsa elachista	x		x					x
Aphanocapsa incerta				x			x	x
Chroococcus dispersus		x			x			x
Cylindrospermum sp.	x			x	x			x
Merismopedia sp.				x				x
Microcystis aeruginosa	x				x	x		x
Microcystis sp.				x		x		
Oscillatoria princeps	x	x	x	x	x	x	x	x
Oscillatoria acuta							x	
Oscillatoria sp.				x		x		
Spirulina meneghiniama					x	x		
Spirulina okensis	x							

4. Discussion

4.1 Physico-chemical characteristics

The waters of the Ebrié lagoon revealed an average temperature above 25°C during the study period. Temperatures of this order (> 25°C) are favorable for the growth of cyanobacteria, by stimulating metabolic activities such as: enzymatic activity, photosynthesis, respiration and nutrient absorption [20, 21].

There is a start of dissolved oxygen saturation (12.4 mg/L) at the Biet station during the month of March 2022 (low water season). This would be indicative of an increase in the photosynthetic activity of aquatic plants, and in this case, probably of phytoplankton [22]. Since cyanobacteria are primary producers, oxygen is their main metabolic waste. The presence of a large quantity of phytoplankton and/or cyanobacteria can lead to a considerable production of oxygen in the water and increase dissolved oxygen at the surface [23]. There are also episodes of low dissolved oxygen concentration at the HKB station in July (2.94 mg/L) and at the K2 station in March (2.57 mg/L). This decrease in dissolved oxygen could be attributed to the decomposition of organic matter which requires high oxygen consumption [24]. This rapid consumption of oxygen is likely to affect aquatic life, in particular the suffocation of fish and other aquatic organisms.

The pH values observed in the months of July (rainy season) and September (flood season) are mostly acidic (pH less than 7). This can be explained by the preponderance of water inflows of continental origin [14] and the direct effects of rainwater, all of which is acidic.

Aquatic life is favored by a pH between 6.5 and 8.5; March is the month in which we observe non-standard values, namely the highest pH (9.11) and low pH (6.23; 6.42; 6.51). When the abundance of cyanobacteria increases, the pH of the water tends to increase as well. This trend is explained by the fact that cyanobacteria, like the rest of phytoplankton, consume the carbon dioxide (CO_2) dissolved in the water. Thus, the existing balance between the different carbonate forms (H_2CO_3, HCO_3^-, CO_3^{2-}) is shifted to a higher concentration of the deprotonated forms (towards the carbonate ion CO_3^{2-}) increasing the pH of the water [25]. According to Levine and Schindler [26], the increase in pH and the decrease in the concentration of dissolved CO_2 favor cyanobacteria over other groups of phytoplankton. In other words, the proliferation of cyanobacteria creates an alkaline environment which favors them and stimulates their growth. Our results are in agreement with those of Yéo [27], carried out on the Adjin-Potou peri-urban lagoon system.

As for the low pH observed in March, this result can be explained by the rejection of CO_2 molecules in the water, by algae or other aquatic plants, resulting in decreased pH values. Brock [28] indicates that a pH of the medium below 5 eliminates the life and growth of cyanobacteria. This observation is contrary to that of [29] who remarks that cyanobacteria proliferate more in an acid medium.

According the Ivorian limit for surface waters for concentrations of NO_3^- (50 – 100 mg/L), we observe that the waters of the Ebrié lagoon are within the limit of acceptability. Inorganic nitrogen ($NO_3^-$and NO_2^- in the case of our study) is the most bioavailable, i.e., easily used and absorbed by organisms that live in brackish water systems. Nitrogen's role as a plant nutrient may promote excessive growth of cyanobacteria [30,31].

4.2. Potentially toxic cyanobacteria

The present study was undertaken in order to make an inventory of the species of cyanobacteria in general, particularly to determine the potentially toxic genera in the waters of the Ebrié lagoon. Several factors, often interacting, influence the composition of cyanobacterial communities in brackish waters. The identification of cyanobacteria collected in the waters of the Ebrié lagoon shows a population composed of genera to which are attached species recognized as potentially toxic for aquatic vertebrates and/or invertebrates and consequently for humans and the environment. These are *Anabaena* sp., *Microcystis aeruginosa* and *Oscillatoria* sp. Indeed, the latter can produce toxic secondary metabolites, cyanotoxins, grouping together molecules of various chemical structures, capable of affecting the health of certain consumers of the trophic chain, including humans, through accumulator vectors such as seafood and fish [31]. On the other hand, a genus of cyanobacteria can produce several different cyanotoxins, and more than one genus can produce the same toxin: the genera, cited in table 8 below, are therefore not the only ones able to produce the toxin associated with them.

The species *Anabaena* sp., *Microcystis aeruginosa* and *Oscillatoria* sp are freshwater species. However, their presence at stations Biet (under oceanic influence), Bs (influence by the Comoé river) and K05 (both under marine and continental influence depending on the seasons) clearly characterizes the significant ecological plasticity and the ability to adapt to any type of environment of cyanobacteria [19]. *Microcystis aeruginosa* was the most present at the site level. This could be explained by the fact that this genus is the most widespread throughout the world, especially during freshwater, brackish and freshwater blooms, as pointed out by Oudra *et al.* [33] in Morocco and Julien *et al.* [34] in Cote d'Ivoire. The comparison of the results of this study with those of previous studies carried out on the Ebrié lagoon, reveals differences in the number of genera listed according to the year of study. The works of Seu-Anoi [11] report, in addition to the 3 genera that we have identified, the presence of the genera *Aphanizomenon, Cylindrospermopsis, Planktothrix and Pseudoanabaena*. Those of Yao [35], in the Aghien lagoon, report the presence of 4 genera of potentially toxic cyanobacteria *(Microcystis, Oscillatoria, Anabaena, Planktothrix)*. These differences could be related to the characteristics specific to each harvesting environment, but especially to the sampling periods [36].

Table 8
Toxin-producing cyanobacteria in fresh and marine waters with proven toxicity to humans [31, 32].

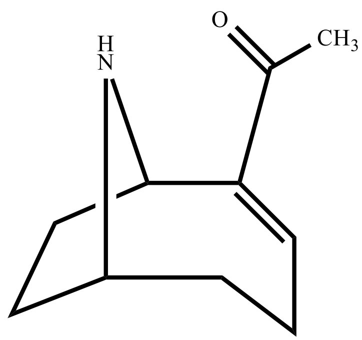
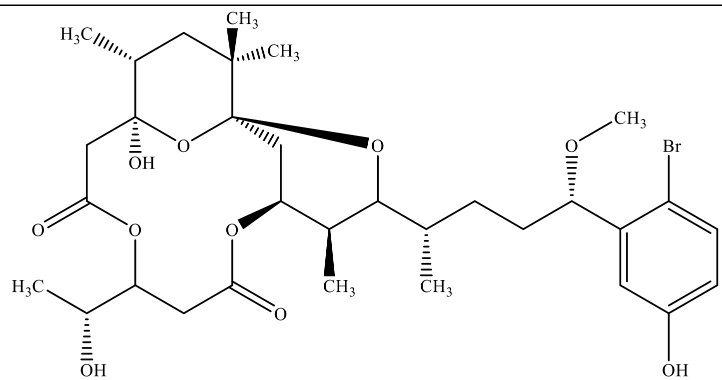
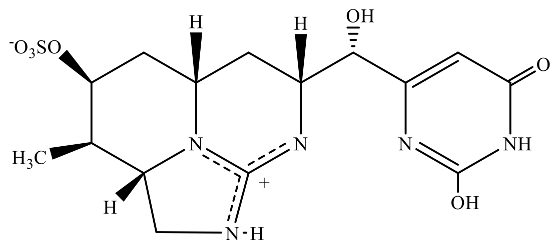
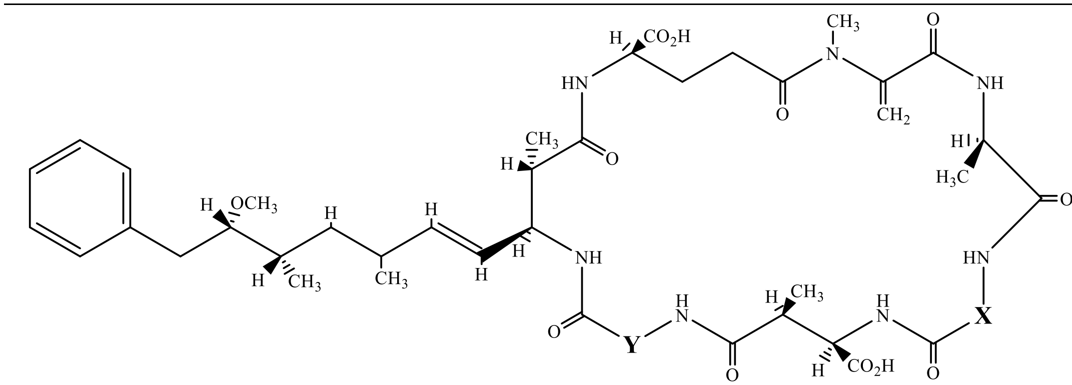
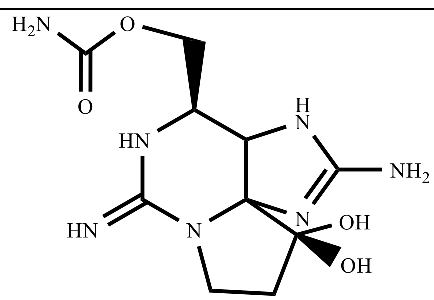
Chemical structure of cyanotoxin	Genera of proven producing cyanobacteria	Effects on humans	Detection zone on the Ebrié lagoon
 Anatoxin-a	***Anabaena***, *Aphanizomenon, Cylindrospermopsis, Planktothrix,* ***Microcystis***, ***Oscillatoria***, *Phormidium*	Numbness of muscles, salivation, respiratory paralysis leading to death	Biet, Bs, HKB, K05, LJ
 Aplysiatoxin	*Lyngbya, Schizothrix,* ***Oscillatoria***	Skin irritation, asthma	Biet, HKB

Table 8 (*continued*)

 Cylindrospermopsin	***Anabaena***, *Aphanizomenon, Cylindrospermopsis, Raphidiopsis,* ***Oscillatoria****, Lyngbya, Umezakia*	Gastroenteritis, dermatitis , pneumonia, liver inflammation, liver haemorrhage	Biet, Bs, HKB, K05, LJ
 Microcystin	***Anabaena***, *Anabaenaopsis, Aphanizomenon, Planktothrix,* ***Microcystis****, Phormidium*	Vomiting, diarrhoea, dermatitis, pneumonia, weak liver inflammation, liver haemorrhage	Biet, Bs, HKB, K05, LJ
 Saxitoxin	***Anabaena***, *Aphanizomenon, Cylindrospermopsis, Planktothrix, Lyngbya, Raphidiopsis*	Dizziness, headache, numbness of muscles, respiratory paralysis leading to death	Biet, LJ

*The genera in bold were observed during our study period***.**

4.3. Risk of efflorescence

The evaluation of the susceptibility categories shows that the waters of the Ebrié lagoon are classified in the "very high" susceptibility category due to having a "cyanobacteria history", that the surface water temperature is above 25°C and there is thermal stratification. This risk seems marked in the period of March corresponding to the low water season with a green color of the water, due to phycocyanin, a blue pigment characteristic of cyanobacteria [37]. This coloration was observed at stations Biet, HKB, K05 and Bs. The waters of the other stations being clear, would surely be linked to zooplankton, organisms that graze on phytoplankton, which are abundant during this period according to Seu-Anoi [11].

Cyanotoxins also act on natural ecosystems through their negative effects on living aquatic organisms (zooplankton, frogs, fish, turtles) [38, 39]. The fish mortality observed at Biet and HKB stations would be due to a probable bloom of *Microcystis,* characterized by a green coloration of the water body. For the Biet station, the presence of the diatom *Chaetoceros* should also be noted, a genus known to obstruct the gills of fish and cause their death [40].

Based on the presence of a toxic species, we can say that the entire study area, particularly the surveyed stations, are risk areas. This state is more marked for sector 2, centered around the city of Abidjan where we observed fish mortalities. This could be explained by the fact that the waters of this sector receive more nutrient discharges from domestic, agricultural and especially industrial activities [12]. All these nutrient inputs constitute a source of nutrients for the cyanobacteria which will multiply and form blooms [20]. It is therefore recommended to set up a suitable monitoring program.

5. Conclusion

This study highlighted the unstable and fragile nature of the Ebrié lagoon ecosystem, capable of rapid changes from one month to another, depending on the seasons. The absence of physico-chemical and biological data during a bloom before our study does not allow us to compare the trophic levels, therefore to accurately map the areas at risk. However, a certain amount of information emerges. The physico-chemical data that we have evaluated confirm the eutrophic nature of the Ebrié lagoon, thus justifying the favorable environment for cyanobacteria blooms. The favorable period would be during the low water season. Species *Anabaena* sp., *Microcystis aeruginosa* and *Oscillatoria* sp. are recognized as potentially toxic. The cyanotoxins likely to be produced belong to the main families: microcystins, saxitoxins, anatoxin-a, cylindrospermopsins and aplysiatoxins. This information would suggest that if cyanobacterial blooms were to develop on the Ebrié lagoon, they would probably start on the stations in sector 2 then 1 and finally 3.

A later study would be appropriate to complete the information specific to cyanobacteria following a quantitative aspect (chlorophyll and a number of cells for the different species). This will make it possible to better monitor the development of cyanobacteria and improve the search for cyanobacteria toxins in areas of interest for appropriate monitoring of aquatic ecosystems.

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