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Seasonal and Spatial Variations of Phytoplankton in Relation to Physico-Chemical Parameters in Adjin Lagoon, Abidjan, Côte d'Ivoire, West Africa

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Abstract

Investigations were carried out on spatial and seasonal composition, distribution and abundance of phytoplankton in Adjin lagoon located in south-eastern of Côte d'Ivoire. Samples were collected at six stations during the four seasons in 2013 year. Freshwater inflow from Bété, Djibi and Mé Rivers influenced the variability of nutrients concentration in this lagoon. From a seasonal point of view, the parameters studied are significantly affected by freshwater inputs during the rainy season. This period is characterized by high values of turbidity, suspended solids and nutrients in the water. Overall, 66 taxa from six phyla were recorded. The Chlorophyta had the highest species diversity and Cyanobacteria had the highest relative abundance throughout the year. The temporal distribution of phytoplankton showed that the highest values of density were recorded in the long rainy season and the lowest values in the long dry season. Spatially, the highest abundance ($297,927 \times 10^3$ cells·L^{-1}) of phytoplankton was found in station 3 and the lowest ($74,222 \times 10^3$ cells·L^{-1}) in the station 5.

Keywords

Adjin Lagoon, Distribution, Diversity, Phytoplankton, Nutrients

1. Introduction

Phytoplankton play an important role in a watercourse's food chain, biogeochemical cycles, climatic processes [1] [2] and constitute a major group of primary producers in aquatic ecosystem [3]. They initiate the aquatic food chain, by serving as food to primary consumers such as zooplankton, which in turn transfer energy when consumed by higher trophic animals such as finfish [4].

Moreover, phytoplankton composition and abundance are considered as bio-indicators of water quality variations because of their sensitivity and rapid responses to changes in environmental conditions such as pH, light, temperature, salinity, turbidity and nutrients [5] [6] [7]. Thus, the species composition, relative abundance, spatial and temporal distribution of these aquatic biota are an expression of the environmental health or biological integrity of a particular water body. They are good biomonitoring candidates for assessing the health status of an aquatic environment [8] [9].

In West Africa, phytoplankton in brackish environments has been widely [10] [11] [12]. In Côte d'Ivoire, where the lagoon system is dense (1200 km^2), studies on phytoplankton have only concerned the Ébrié Lagoon [13] [14] [15], [3], Grand-Lahou lagoon [16], Aby lagoon [3] [17], and Fresco lagoon [18].

Unfortunately, small coastal ecosystems have not received special attention compared to larger environments. However, these lagoons are a great source of wealth, especially for the local populations. These waters are used for fishing, swimming, washing dishes, laundry, washing and cooking food, and as drinking water [19].

Like other lagoons in Côte d'Ivoire, Adjin Lagoon needs to be studied in order to ensure its effective and sustainable management. This lagoon, the subject of this study, is located in an area influenced by high anthropogenic pressure due to the development of agro-industrial plantations on its watershed [20] [21]. This hydrosystem is the life unit of several villages, with artisanal fishing as their main activity. The input of domestic wastewater, agricultural effluents (fertilizers and pesticides) and the discharge of all kinds of effluents into these lagoon waters can be sources of chemical pollution (organic, metallic). Wastewater, fertilizers and pesticides can be sources of nutrient enrichment (nitrogen and phosphorus) favoring phytoplankton development [22].

Adjin is a coastal Lagoon located in the Abidjan district in the south-eastern of Côte d'Ivoire. Despite its ecological importance, studies on the phytoplankton communities of this lagoon and in particular, the variation of species composition over time remains scanty.

The aim of this study was to examine the temporal variation, species composition, phytoplankton abundance and to highlighting the presence of potentially toxic phytoplankton in Adjin lagoon, during the four seasons of one year.

2. Materials and Methods

2.1. Study Area

Adjin Lagoon is located between latitudes 5˚22'N - 5˚26'N and longitudes 3˚49'W - 3˚55'W. It is separated from the Ebrié lagoon system by Potou Lagoon with which it communicates by a natural channel (**Figure 1**). Adjin Lagoon has an area of 20 km^2 for a perimeter of 40.72 km and an estimated volume of 25 km^3.

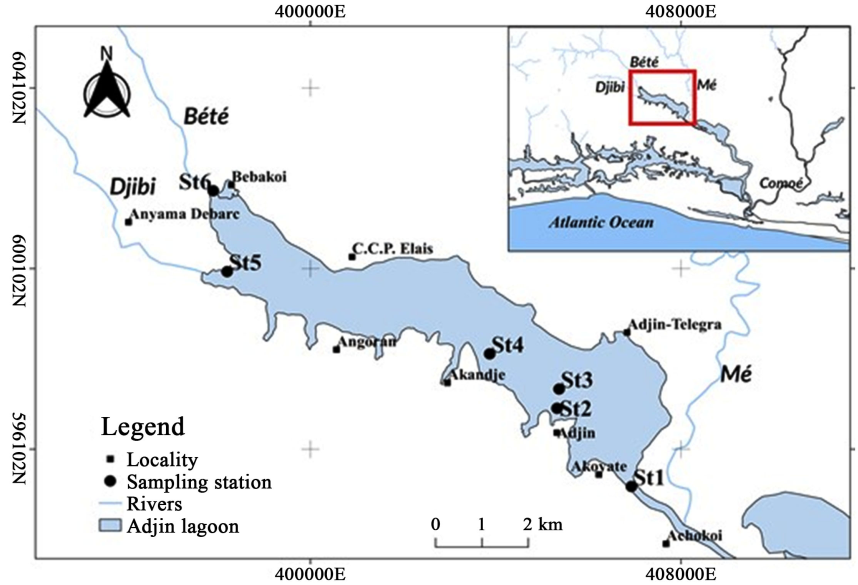


Figure 1. Map of the sampling stations in Adjin lagoon, Côte d'Ivoire.

It is part of Abidjan network lagoon. The lagoon receives freshwater from Bété, Djibi and Mé rivers downstream [20]. The lagoon covers a surface area of 20.2 km^2 characterized by depths from 2 to 14 m which can reach 20 m at the outlet of river Mé. The mean depth is estimated to be 5 m. These waters are used for fishing, aquaculture, domestic waste (sewage, garbage) and agricultural runoff using pesticides which are sources of nitrogen and phosphorus nutrients. Furthermore, the proximity of many villages, plantations and farms to this lagoon is a pointer to amount of anthropogenic wastes that find its way to this water body. All these anthropogenic pressures acting directly or indirectly on the water contribute to the degradation of the quality of lagoon waters [20] [23] [24]. The climate in the study area is close to equatorial. It includes two rainy seasons separated by two dry seasons. The long rainy season (LRS) from April to July is followed by the short dry season (SDS) in August. The short rainy season (SRS) is from September to November, while the long dry season (LDS) is from December to March [24]. The sites were selected based on number of factors including geographical location, anthropogenic activity/major water use and access.

2.2. Sampling Sites

Four cruises of sampling were carried out in January (long dry season), June (long rainy season), August (short dry season) and November (short rainy season) 2013. Six stations (St) were selected within Adjin Lagoon for the study (**Figure 1**). The stations were selected based on spatial variability, vulnerable locations and incidence of freshwater discharges as shown in **Table 1**.

2.3. Water Samples Collection and Analysis of Environmental Parameters

A total of ten physico-chemical parameters for water quality control were evaluated. Temperature, pH, salinity and dissolved oxygen were measured in *situ* using the HI 9828 pH/ORP/EC/DO multiparameter brand HANNA. A turbidimeter HI 98703 brand HANNA was used to measure turbidity *in situ*.

Samples (1 L) were taken with a Niskin bottle at the depth of 1 m below the surface and were collected in polyethylene bottles, stored on ice and immediately transported to the laboratory for chemical parameters study. Nitrates (NO_3^-), ammonium (NH_4^+) and orthophosphates (PO_4^{3-}) were estimated by following standard methods (AFNOR standards ISO 7890-3; T 90015; T 90023 respectively). Total Suspended Matter (TSM) was measured according to AFNOR T 90105. Chlorophyll *a* (Chl-*a*) was analyzed by spectrophotometric method according to [25] after filtering the water samples through GF/C Whatman filter paper (0.45 µm). For all the spectrophotometric analyses, a double beam UV-Visible Spectrophotometer (SHIMADZU UV/visible-1700 pharma) was used.

For statistical analysis, parametric test of one-factor ANOVA (Software Statistica 7.1) was used to compare the mean values of the tested parameters for all the sampling seasons because the data were distributed normally (Kolmogorov-Smirnov test). Significance level was defined as $p < 0.05$.

2.4. Collection and Analysis of Phytoplankton Samples

Five liters of surface water were collected with a Niskin bottle, concentrated using 20 µm phytoplankton net, stored in polyethylene bottles and fixed with 5% buffered formalin. For species identification, phytoplankton samples were examined using a light microscope triocular type Olympus BX40 equipped with tracing and measuring devices.

Table 1. Description of the sampling stations in Adjin lagoon during 2013 campaigns.

Stations	Geographic coordinates (m)	Description
Station 1 (St1)	X = 406,929 Y = 595,276	Confluence of the Adjin lagoon with the channel connecting Adjin lagoon to Potou Lagoon (downstream Adjin)
Station 2 (St2)	X = 405,324 Y = 597,008	Receives factory waste of the manufacture of fish food and wastewater from Adjin village
Station 3 (St3)	X = 405,368 Y = 597,435	Location of the aquaculture ponds on Adjin Lagoon
Station 4 (St4)	X = 403,870 Y = 598,214	Located in the center of Adjin Lagoon, receives drainage water from rubber tree and oil palm industrial plantations, and those from village plantations
Station 5 (St5)	X = 398,202 Y = 600,036	Located at the mouth of Djibi river, receives urban waste from a part of the municipality of Abobo located from upstream of Adjin lagoon
Station 6 (St6)	X = 397,903 Y = 601,827	Located at the mouth of the river Bété

Samples for diatoms analyses were treated with 10% nitric acid on a hot plate for 10 min and then left to cool. Then, after several rinses with distilled water, 100 µL of the sample was spread on a cover slip and left to dry at room temperature before being permanently mounted using Naphrax.

Identification and classification of phytoplankton were carried out using standard monographs and publications, [3] [15] [16] [18] [26]-[36]. The quantitative estimation of the phytoplankton was done using Uehlinger as described by [37]. The counts of unicellular, colonial, or filamentous algae were expressed as cells·L^{-1}.

3. Results

3.1. Physical and Physico-Chemical Parameters

The physical and physico-chemical parameters recorded at the six stations during the four seasons are presented in **Table 2**.

During the sampling period, mean values of temperature varied slightly (26.72˚C ± 0.09˚C to 29.21˚C ± 1.14˚C). The average pH varied between 6.26 ± 0.56 (SRS) and 7.02 ± 0.36 (LDS). These values (temperature and pH) showed no significant ($p > 0.05$) seasonal variation during the sampling period. However, the highest values were obtained in January corresponding to the LDS and the lowest in the SDS. The highest values of salinity and dissolved oxygen were recorded during the LDS (0.02 ± 0.01 and 7.21 ± 0.45 mg·L^{-1} respectively) and the lowest during rainy periods. Salinity was around zero depending on the time of sampling and became zero in the SRS. No significant variation ($p > 0.05$) of dissolved oxygen values was observed among the four seasons. The values of total suspended matter content fluctuated between 9.57 ± 3.38 mg·L^{-1} (LDS) and 14.88 ± 12.00 mg·L^{-1} (LRS). Values of turbidity ranged from 6.80 ± 2.99 NTU (LDS) to 25.93 ± 6.77 NTU (SRS). Turbidity and Total Suspended Matter (TSM) were significantly higher in the rainy seasons compared to the LDS. As for Chl-*a*, significant lowest concentrations were obtained in the SRS (33.89 ± 7.48 µg·L^{-1}) compared to the other three seasons (58.27 ± 10.21 µg·L^{-1}, 43.83 ± 7.10 µg·L^{-1} and 47.49 ± 17.20 µg·L^{-1} respectively in the LDS, the LRS and the SDS). In regards of nutrients (**Table 2**), the lowest average values were found in January in the LDS and the highest in June, August, and November (rainy periods). With respect to nitrates, ammonium and ortophosphates concentrations, the lowest means values are respectively 0.95 ± 0.51 mg·L^{-1}, 13.67 ± 6.35 µg·L^{-1} and 0.036 ± 0.004 mg·L^{-1}. The dissolved nutrients concentrations were significantly lower ($p < 0.05$) in LDS than in the rainy seasons.

3.2. Community Composition

A total of 66 phytoplankton taxa were identified in the six stations belonging to 6 phyla (**Table 3**). The chlorophyta with 34 taxa were the most diversified with 51.51% of total species, followed by the cyanobacteria (18.18%), Euglenophyta (15.15%), Bacillariophyta (10.61%) Dinophyta (3.03%) and Haptophyta (1.52%) as indicated on **Table 3** and **Table 4**).

Table 2. Values of physico-chemical parameters in Adjin Lagoon during 2013 campaigns.

Parameters	January	June	August	November
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Temp (˚C)	$29.21^{a} \pm 1.14$	$28.21^{a} \pm 0.53$	$26.72^{a} \pm 0.09$	$29.15^{a} \pm 1.04$
pH	$7.02^{a} \pm 0.36$	$6.91^{a} \pm 0.50$	$6.65^{a} \pm 0.21$	$6.26^{a} \pm 0.56$
Salinity	$0.02^{a} \pm 0.01$	$0.01^{ab} \pm 0.01$	$0.01^{ab} \pm 0.00$	$0.00^{b} \pm 0.00$
DO (mg·L^{-1})	$7.21^{a} \pm 0.45$	$6.67^{a} \pm 1.14$	$6.32^{a} \pm 1.03$	$6.79^{a} \pm 1.25$
TSM (mg·L^{-1})	$9.57^{a} \pm 3.38$	$14.88^{b} \pm 12.00$	$10.49^{a} \pm 10.83$	$13.45^{b} \pm 3.40$
Turb (NTU)	$6.80^{a} \pm 2.99$	$21.75^{b} \pm 13.46$	$12.32^{c} \pm 9.56$	$25.93^{b} \pm 6.77$
Chl-*a* (µg·L^{-1})	$58.27^{a} \pm 10.21$	$43.83^{ab} \pm 7.10$	$47.49^{ab} \pm 17.20$	$33.89^{b} \pm 7.48$
NO_3^- (mg·L^{-1})	$0.95^{a} \pm 0.51$	$3.11^{b} \pm 1.07$	$2.34^{b} \pm 0.82$	$3.11^{b} \pm 1.41$
NH_4^+ (µg·L^{-1})	$13.67^{a} \pm 6.35$	$85.67^{b} \pm 19.62$	$90.50^{b} \pm 33.72$	$66.13^{b} \pm 19.11$
PO_4^{3-} (mg·L^{-1})	$0.036^{a} \pm 0.004$	$0.100^{b} \pm 0.004$	$0.045^{a} \pm 0.002$	$0.064^{b} \pm 0.008$

Temp = temperature; DO = Dissolved Oxygen; TSM = Total Suspended Matter; Turb = turbidity; Chl-*a* = Chlorophyll *a*.

Table 3. List of phytoplankton taxa identified during 2013 campaigns at the six stations (St) of Adjin lagoon.

Phytoplankton	St 1	St 2	St 3	St 4	St 5	St 6
Cyanobacteria						
Anabaena affinis Lemmerman	+	+	+	+	+	+
Anabaena sp.	-	+	+	-	-	+
A. spiroides kleb	+	+	+	+	+	+
Chrooccocus turgidus(Kützing) Nägeli	+	+	+	+	+	-
Merismopedia elegans Braun	-	-	-	+	+	+
Microcystis aeruginosa Kützing	+	+	+	+	+	+
M. flos-aquae (Wittrock) *Kirchner*	+	+	+	+	+	+
M. incerta (Lemmerman) Lemmerman	+	+	+	+	-	-
Oscillatoria princeps Vaucher	-	+	+	+	+	+
Oscillatoria sp.1	-	-	+	+	-	+
Oscillatoria sp.2	+	+	+	+	+	+
Oscillatoria sp.3	-	-	-	+	+	-
Subtotal Dinophyta	**7**	**9**	**10**	**11**	**9**	**10**
Dinophysis sp.	-	-	-	+	+	+
Protoperidinium sp.	+	+	+	+	+	+
Subtotal Chlorophyta	**1**	**1**	**1**	**2**	**2**	**2**
Actinastrum hantzschii Lagerheim	+	-	+	-	+	+
Ankistrodesmus bibraianus (Reinsch) Korshikov	-	+	+	-	-	+

Continued

A. falcatus (Corda) Ralfs	-	+	+	+	+	+
A. fusiformis Corda	-	-	-	-	-	+
A. gracilis (Reinsch) Korshikov	-	-	-	-	-	+
Ankistrodesmus sp.1	+	-	+	-	+	-
Ankistrodesmus sp.2	-	-	+	-	+	+
Closterium gracile Brébisson ex Ralfs	-	-	+	+	-	-
Coelastrum reticulatum (P. A. Dang) Senn	+	-	+	+	+	+
Cosmarium decorum West & G. S. West	+	+	+	+	-	+
C. spinuliferum West & G. S. West	+	+	+	+	+	+
Cosmarium sp.	+	+	+	+	+	+
Euastrum sp.	+	+	+	+	-	+
Micrasterias sp.	-	-	-	+	-	-
Pandorina morum (Müller)Bory	-	-	-	-	+	-
Pediastrum biradiatum var. *longecornutum* Gutwinski	-	-	-	-	+	-
P. duplex Meyen	+	+	+	+	+	+
P. tetras (Ehrenberg) Ralfs	-	-	+	-	-	+
Pseudostaurastrum sp.	-	+	+	-	-	+
Scenedesmus bernardii G.M. Smith	-	-	+	-	-	-
S. bicaudatus Dedussenko	-	-	+	-	-	+
S. *dimorphus* (Turpin) Kützing	-	-	+	-	-	+
S. denticulatus Lagerheim	+	-	-	+	-	-
S. ecornis (Ehrenberg) Schodat	-	-	+	-	+	+
S. obtusus Meyen	-	-	-	-	+	+
S. quadricauda (Turpin) Brébisson	+	+	+	+	+	+
Schroederia sp.	-	-	+	+	+	+
Spirogyra sp.	-	-	-	-	+	-
Staurastrum cingulum (West & G. S. West) G.M. Smith	+	-	-	+	+	-
S. gracile Ralfs ex Ralfs	+	+	+	+	+	+
S. polymorphum Brébisson	+	+	+	+	+	+
S. volans West & G. S. West	-	+	+	+	+	+
Staurodesmus convergens (Ehrenberg ex Ralfs)Teiling	-	-	-	-	+	-
S. triangularis (Lagerh) Teiling	-	-	+	-	-	+
Subtotal Bacillariophyta	**13**	**12**	**24**	**16**	**20**	**23**
Aulacoseira ambigua (Grunow) Simonsen	+	+	+	+	+	+
A. granulata (Ehrenberg) Simonsen	+	-	+	+		-

Continued

A. granulata var. *angustissima* (otto Müller) Simonsen	+	-	+	+	+	+
Eunotia sp.	-	+	-	-	+	+
Fragilaria sp.	-	+	-	-	-	-
Frustulia sp.	+	-	+	-	-	+
Ulnaria ulna (Nitzsch) P.Compère	+	+	+	+	+	+
Subtotal Euglenophyta	**5**	**4**	**5**	**4**	**5**	**5**
Euglena proxima P.A. Dangeard	-	-	+	-	-	+
Lepocinclis acus (O.F. Müller) B. Marin & Melkonian	+	+	+	+	+	+
L. spirogyra Ehrenberg	-	-	-	+	+	-
Phacus curvicauda Svirendo	+	+	+	-	+	+
P. longicauda (Ehrenberg) Dujardin	+	+	+	+	+	+
Phacus sp.	-	-	-	-	+	-
P. tortus Lemmerman	-	+	+	-	-	+
Trachelomonas hispida (Perty) F. Stein	-	+	+	-	-	-
T. planctonica Svirenko	-	-	-	-	+	-
T. similis A. C. Stokes	-	-	-	-	+	-
Subtotal Haptophyta	**3**	**5**	**6**	**3**	**7**	**5**
Dictyocha sp.	-	-	+	-	-	-
Subtotal	**0**	**0**	**1**	**0**	**0**	**0**
Total phytoplankton abundance	29	31	47	36	43	44

Symbols + = present; - = not identified.

Table 4. Distribution of the algal flora in Adjin lagoon and frequency of presence of the phyla during 2013 campaigns.

Phytoplankton	Number of taxa	Percentage (%)
Cyanobacteria	12	18.18
Bacillariophyta	7	10.61
Dinophyta	2	3.03
Chlorophyta	34	51.51
Euglenophyta	10	15.15
Haptophyta	1	1.52
Total	66	100

The Chlorophyta had the highest species diversity (**Table 3** and **Table 4**) and Cyanobacteria had the highest relative abundance throughout the year (**Figure 2**). The majority of Cyanobacteria belonged to *Microcystis aeruginosa* (28.93%), *Anabaena affinis* (20.15%*)*, *Oscillatoria* sp.2 (13.28%), *Microcystis flos-aquae* (11.76%), and 10.51%), to *Anabaena spiroides*.

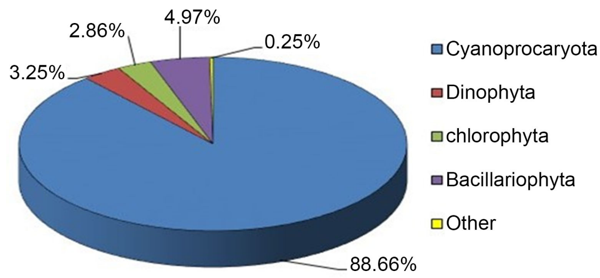


Figure 2. Phytoplankton composition from all six sites in Adjin lagoon during the four seasons in 2013.

3.3. Spatial and Temporal Distribution of Phytoplankton

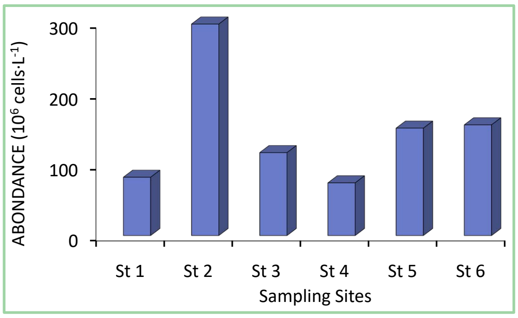
The spatial distribution of phytoplankton showed that the peak richness value (47 taxa) was recorded at station 3, while the lowest values were recorded at stations 1 (29 taxa). Among the phytoplankton, sixteen taxa (24%) were common to all stations. Across the sampling stations, the major taxa of phytoplankton in terms of diversity was Chlorophyta (**Table 4**). However, Cyanobacteria dominated in the cell numbers at all stations (more than 50%) except at station 6, where bacillariophyta dominate as indicating on **Figure 3(b)**. The total cell numbers at the stations studied ranged from 74,222,000 cells·L^{-1} to 297,927,000 cells·L^{-1} at stations 4 and 2 respectively (**Figure 3(a)**).

The temporal distribution of phytoplankton showed that the lowest values 48,032,000 cells·L^{-1}) in January corresponding to the LDS and the highest values (490,453,800 cells·L^{-1}) were recorded in June corresponding to the LRS (**Figure 4(a)**). Cyanobacteria cells were a major component of phytoplankton biomass (more than 50%) during the study months (June, August and November) excepting January, where Dinophyta was the most abundant group. Other taxa formed by the Haptophyta and Euglenophyta, have very low densities (0 - 160 × 10^3 cells·L^{-1}) during the study period (**Figure 4(b)**).

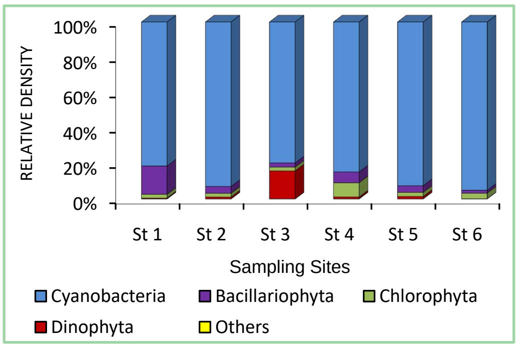
4. Discussion

The seasonal variations in physicochemical parameters indicate the great influence of rainfall on the physico-chemical hydrology of tropical waters [38] [39]. The freshwater condition was indicated by zero salinity level during the four seasons. The rains could have had dilution effects on the water from the lagoon as well as increased the level of freshwater discharge from the river basins into the Lagoon. Indeed, according to [40], Adjin Lagoon waters are almost exclusively in continental origin during the year. The relatively low conductivity levels recorded during wet season could also be attributed to the dilution effect of the rains during the season. Its increase during dry season, indicating that ionic salts accounts mostly for conductivity of the Adjin Lagoon [19] [41].

Water temperature and turbidity are the most important parameters among various physical factors affecting the distribution and seasonal variation of phytoplankton growth [42].

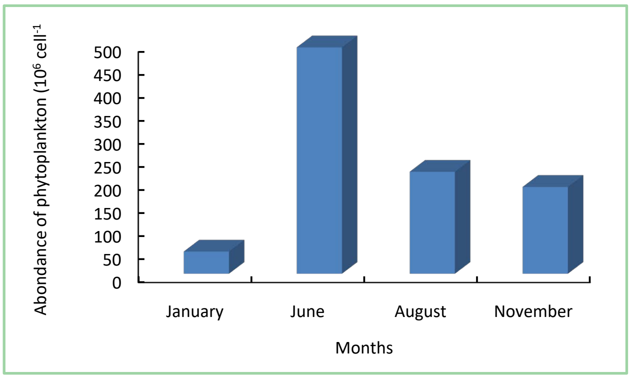


(a)

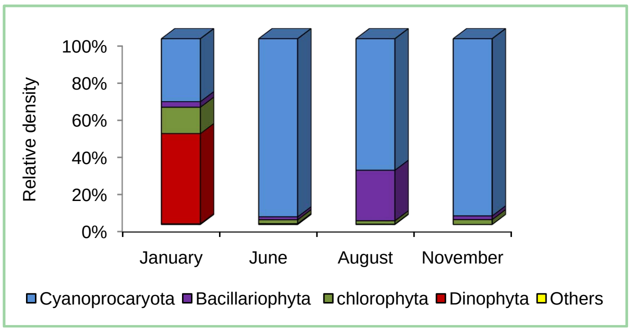


(b)

Figure 3. Spatial distribution of relative density (a) and abundance (b) of major phytoplankton groups in six sites during 2013 campaigns in Adjin Lagoon.



(a)



(b)

Figure 4. Seasonal variations of abundance and relative density of the main phytoplankton groups during 2013 campaigns in Adjin Lagoon.

The relatively high turbidity observed in the rainy seasons could be attributed to high level of particulate matters brought into the lagoon from surface runoffs during the season.

High dissolved oxygen concentration during the study result from the balance between physical (e.g. turbulence; diffusion and solubility of oxygen) and biogeochemical (e.g.; consumption; production; remineralization) processes [43]. In rainy period, higher values of dissolved oxygen may be due to precipitation and higher turbulence and in dry season which could be a function of warmer water temperatures that stimulate photosynthetic activity during this season in the prospected lagoon.

On the other hand, the decrease of dissolved oxygen concentration observed during the rainy season could be caused by the stratification and the removal of sediments due to runoff from land [44]. It could also reflect the natural and anthropogenic pressures that the Adjin lagoon has suffered from.

The concentrations of nitrate, phosphate and ammonium play important role as nutrients both for phytoplankton growth and production. These ones were estimated on a seasonal basis during the study. The concentrations recorded in long dry season were low than those recorded in the rainy seasons. Nutrients contribution to the ecosystem can be from dumping of untreated domestic sewage in the lagoon and lixiviation of fertilizers derived from oil palm plantations and pastures, as observed in other study [20] [23].

The limnological conditions (high values on the temperature and nutrients) and reduction the flow in the lagoon [22] were important factors favorable to increased phytoplankton biomass and density. Another important parameter observed was the phytoplankton chlorophyll *a* whose high concentrations were recorded during the study period.

The relatively similar phytoplankton species composition of all stations during the study period could be a result of the freshwater condition observed at all the stations. The abundance and richness of phytoplankton species in this study are generally found in other studies from coastal lagoons in Côte d'Ivoire [3] [18] [22].

Station 3, which has the highest number of taxa and the highest absolute phytoplankton density ($297{,}927 \times 10^3$ cells·L^{-1}), is the location of the aquaculture ponds on the Adjin Lagoon. Indeed, according to [45] waste from the production of food for fish farming and residues of food not consumed by fish (about 60% of the nitrogen contained in food) remain in the water and enrich it with nutrients which can promote the development of algae.

The Cyanobacteria (blue green algae) dominate the algal flora in this study in term of abundance. They are constantly present at all stations and during the four seasons of the sampling period. The preponderance of Cyanobacteria in the studied water is not due to the large number of species they contain, but rather to a very high number of filaments or cells gathered in colonies belonging to a very restricted group of dominant species. This dominance of Cyanobacteria has also been reported in Ebrié, Aby and Grand-Lahou Lagoons, Côte d'Ivoire [3].

From a seasonal point of view, algal fluctuations are less important, but the phytoplankton appears less heterogeneous during the flood season (SRS). The lowest numbers are distinguished during the dry season and the maximum occurs during the long rainy season. Indeed, the higher phytoplankton abundance and species richness recorded during rainy than dry season could be attributed to influx of allochtonous nutrients as rivers (Comoé, Bété and Djibi) drains into the lagoon. The high level of those nutrients could have promoted phytoplankton production during the rainy than dry season. The relatively high phytoplankton abundance recorded in the rainy season agrees with the finding of [46] in the brackish coastal lagoon of Burullus in Egypt and by [22] in the Grand-Lahou Lagoon of Côte d'Ivoire.

The availability of nutrient would therefore be one of the main factors controlling the taxonomic composition of phytoplankton within lagoons [22]. The low biomass harvested during the short rainy season as well as the low concentrations of chlorophyll *a* are due to high turbidity and dilution of lagoon waters. During this season, the lagoon surface is also covered with freshwater plants preventing the penetration of light and reducing photosynthesis reactions. This low productivity in phytoplankton during this season was also observed by [14] in Ébrié Lagoon, [16] in Grand-Lahou Lagoon and by [3] in Aby Lagoon in Côte d'Ivoire.

During the long dry season, the high transparency of the water would favor the penetration of light into the water column, accentuating the photosynthetic activity, which would explain the high concentrations of chlorophyll a during this period. The work of [47], in Potou Lagoon (Côte d'Ivoire), reveals a seasonal evolution identical to that observed in this study. It is made by a flowering of Cyanobacteria, Dinophyta and Chlorophyta. During this period, the proliferation of Cyanobacteria is not related to the richness of the nutrients in the lagoon, as showed by the work of [48]. Indeed, some species of Cyanobacteria inventoried in our samples possess heterocytes. These Cyanobacteria (genus Anabaena) are able to fix atmospheric nitrogen through their heterocytes, and this allows them to proliferate in a poor environment in nitrogen. This proliferation would also be favored by high temperatures and high pH values [49]. As for Dinophytes, their proliferation coincides with low concentrations of nutrient salts. According to [22], Dinophyta are more competitive than other algae groups when the environment is poor in nutrients. This confirms that the competitive capacity of species to use low nutrient concentrations as an important factor in the phytoplankton succession [50].

Among taxa belonging to the genera *Microcystis, Anabaena, Dinophysis* and *Oscillatoria* that can produce toxins that may be harmful to human and animal health [51] [52] have been identified [52].

Management plans in Adjin Lagoon should be addressed to reduce sewage discharges into the receiving body. It will appear to be adequate for preserving and improving environmental quality as regards eutrophication and harmful algal blooms, principally in the waters of more restricted exchange of the lagoon.

The presence of harmful/toxic algal blooms during the study period, suggests the need to continue monitoring the occurrence of these organisms, and to control the harvesting of mollusks during the period of bloom (long rainy season).

In Adjin Lagoon, the seasonal evolution of the phytoplanktonic biomass differs from the phytoplanktonic density. Indeed, during the sampling period, the highest biomass amounts are recorded during the dry season while the highest densities occur in the rainy season. The difference between biomass and density could be explained by the spectrum evolution of the organisms'sizes.

The low densities observed during the long dry season corresponding of the period of high biomass, might be due to the growth of large-sized algae. The works by [53] carried out in the Barra Lagoon localized in Brazil, and those of [3] in Aby, Ebrié and Grand-Lahou lagoons in Côte d'Ivoire, highlight an evolution which counter to that observed in Adjin Lagoon.

5. Conclusion

This study shows the influence of seasonality on physico-chemical properties, especially turbidity and nutrients, which in turn determine the composition and distribution of phytoplankton in Adjin Lagoon. The high water residence time in the lagoon is a factor that helps maintain flowering conditions in this area. The study on phytoplankton shows that Cyanobacteria dominate in the waters. As for the seasonal evolution, the high densities are recorded during the rainy season. The phytoplankton population is predominantly composed of taxa living in tropical eutrophic waters, with potentially toxic taxa. The predominance of the study area's phytoplankton community in both wet and dry seasons by Cyano-bacteria relative to other branch lines may be an indication of a relatively high level of human anthropogenic activities in Adjin Lagoon watershed.

Conflicts of Interest

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

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