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Trophic Status of Yamoussoukro Lakes and Ecological Impacts of Anthropogenic Activities

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ABSTRACT

Eutrophication, the natural aging process of an aquatic system, can be accelerated by enrichment of nutrient, particularly nitrogen and phosphorus, from anthropogenic discharges. This study aimed to determine the trophic status and assess the ecological impact of the Yamoussoukro lakes. To achieve this, first of all, the physicochemical pollution parameters were determined using the AFNOR, and HACH methods. Then, the trophic status of the lakes was assessed using the Organisation for Economic Co-operation and Development (OECD) grid. Finally, the phytoplankton biomass of these lakes was quantified as well as their coverage rates using the traveling inventory method. The results obtained reveal that the waters of these lakes were moderately oxygenated and loaded with biodegradable organic matter. Chlorophyll-a levels were high in almost all lakes (>10 µg/L). All the lakes waters studied in the town of Yamoussoukro could be classified as hypereutrophic. This eutrophication is manifested by an increased proliferation of invasive aquatic plants occupying more than half of the surface area of the lakes (from 50% to 100% coverage rate) with the main species being *Nelumbo nucifera* (Lotus).

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INTRODUCTION

Eutrophication is a natural and very slow process, by which water bodies receive nutrients loads. These nutrients come from anthropogenic activities such as industrial, urban and domestic wastewater, discharged into aquatic systems. The main parameters

considered as indicators of trophic status of waters are nitrogen and phosphorus (Morgenstern et al., 2015; Akilinson, 2021). However, phosphorus is generally the main limiting nutrient for phytoplankton growth in freshwater systems (Sterner, 2008). Many physicochemical factors such as temperature,

pH, dissolved oxygen content must also be considered. Several authors have shown that eutrophication causes undesirable changes in aquatic ecosystems, such as toxic algae blooms, oxygen depletion and increased fish mortality (Smith and Schindler, 2009; Akilinson, 2021).

This situation is observed in several cities including Yamoussoukro, the political capital of Ivory Coast, which is full of numerous natural and artificial lakes created to receive runoff water and for the beautification of the city. Several studies have been conducted on the specific case of the lakes in Yamoussoukro, including the one by N'guessan et al. (2011) which evaluated the trophic status of these lakes while identifying and characterizing the sources of eutrophication. As for Sadat et al. (2011), they evaluated the physicochemical quality of these lakes by a multidimensional analysis. However, little information is available on the biomass produced and an update is necessary on the trophic status of these lakes. Hence, the general objective of this work was to evaluate the trophic degree of the lakes of Yamoussoukro and their ecological repercussions.

MATERIALS AND METHODS

Determination of physico-chemical parameters

One sampling station was identified for each investigated lake; thus, a total of 14 stations were established. The sampling stations were chosen based on the presence or absence of sources of anthropogenic disturbance likely to influence the quality of the lake waters. To do this, not only the type of occupation on the nearby slope was taken into account as well as the physiognomy of the banks at each sampling site. Table 1 shows the GPS coordinates of the sampling points. The water was taken at a depth of 20 cm. The bottle was filled completely and capped underwater to avoid trapping air bubbles that could alter the sample characteristics. Immediately after collection, each sample was filtered through a 200 μm mesh nylon cloth and placed in

polyethylene bottles wrapped with aluminum foil to prevent light penetration, for physicochemical analyses. Each bottle was first rinsed twice with the sample water to preserve its characteristics. Every sample was stored in a cooler containing dry ice to keep them not only in the dark but also at a temperature of around 4°C until they reached the laboratory. Each sample is identified by means of a sampling label bearing a sample code, the date and time of collection and the geographical coordinates of the collection location. Sampling took place from March 14 to 18, 2023 at about 9:30 a.m GMT. Three samples were collected at each station, corresponding to a total of 42 samples. Water samples were collected using a Van Dorn hydrological bottle of a capacity 2.5 liters, packaged in polyethylene bottles, and covered with aluminum foil to protect them from light rays. The storage and transport of water samples were carried out in a cooler. The location of the sampling stations was done using a Garmin GPS.

Temperature, pH, conductivity, turbidity and dissolved oxygen (DO) were measured using a YSI 6920 V2 multi-parameter probe. For each measurement, the previously calibrated probe is immersed in water and after stabilization, the reading is taken on the device's digital display screen. Analyses of chemical parameters (NH_4^+ , NO_3^- , NO_2^- , PO_4^{3-} , COD, BOD_5), physical parameter (total suspended solids), and biological parameter (chlorophyll-a) were carried out within 48 hours according to standardized methods (Afnor, 2001 ; Hach, 2007 ; Rodier et al., 2009).

Analysis equipment

In situ measurements of environmental parameters (temperature, dissolved oxygen, pH, conductivity, turbidity) were performed using a YSI 6920 V2 multi-parameter probe. Several instruments were used for laboratory analyses : a SELECTA mineralizer for sample mineralization and a DR 6000 spectrophotometer for nutrient analysis (NH_4^+ ,

NO₃⁻, NO₂⁻, PO₄³⁻) and chlorophyll-a. A filtration device, a desiccator, and a balance were used to determine total suspended solids.

Statistical analysis

The aim of this study was to provide a descriptive assessment of the measured parameters rather than to test specific hypotheses or compare predefined groups. As a result, the statistical analysis was limited to descriptive statistics, including the calculation of means and standard deviations. No comparative statistical tests were performed, as the study design did not involve clearly defined independent groups or conditions suitable for inferential analysis. Consequently, the results are presented as mean ± standard deviation.

Assessment of the trophic status of lakes

Due to the lack of criteria for determining the trophic status of lakes in tropical areas, the limit values for phosphorus and chlorophyll-a concentrations were used according to the OECD International Cooperative Freshwater Monitoring Programme which was applied to temperate lakes (OECD, 1982 ; Mama, 2010) (Table 2). These thresholds are used to determine the trophic status of many temperate lakes. P_T is the average total phosphorus level, Chl_{mean} is the average chlorophyll-a level and Chl_{max} is the maximum chlorophyll-a level.

The average of point data is obtained by taking the quotient of the sum of the n observed values x_i by the number n : $\bar{X}$

$$= \frac{\sum_{i=1}^n X_i}{n}$$

Ecological impacts

Determination of the coverage rate and identification of species

The data were collected using the survey method, which consisted of a traveling inventory (Ouattara et al., 2018). This involves traveling through the biotopes in all directions

to identify and record invasive plant species and locate them using a GPS. The area occupied by these invasive plants was measured. Then, the outline of the stands was recorded using a GPS to determine the area occupied by the species. The rate of invasion by these plants was calculated as follows:

$$\text{coverage rate (\%)} = \frac{\text{area occupied by plants}}{\text{total area}} \times 100$$

As part of this study, a proposed list of invasive plants was developed based on some existing lists of Invasive Alien Species (IAS) in Ivory Coast. Published books and articles, reports on invasive plants were consulted (Neuba et al., 2014 ; Noba et al., 2017). This provisional list served as a support for the inventory of invasive aquatic plants in the lakes studied.

Calculation of phytoplankton biomass by chlorophyll-a measurement

Chlorophyll-a, present in all groups of algae, is the most abundant photosynthetic pigment. Pagès (1991) suggests that phytoplankton, as a converter of light energy would be better described through its photosynthetic pigments. The transformation of chlorophyll-a (chl-a) contents into carbon (C) following the work of Dessery et al. (1984) was done by the formula :

$$C = [\text{chlorophyll-a}] \times 30.$$

Carbon (C) accounts for approximately 12% of the fresh weight of a cell (Pridmore and Hewitt, 1984). The phytoplankton biomass was calculated by the formula below:

$$\begin{aligned} \text{biomass}(\mu\text{g/L}) &= \frac{C \times 100}{12} \\ &= \frac{[\text{chl } a] \times 30 \times 100}{12} \\ &= [\text{chl } a] \times 250 \end{aligned}$$

[chl a] = chlorophyll-a levels ;

C = phytoplankton carbon mass ;

250 is conversion coefficient.

Table 1 : Surface water sampling points and their GPS coordinates.

Sample	GPS coordinates		Area (m ²)	Status
	Latitude	Longitude		
L1	6°50'18,3"	5°16'14.3"	182 142.83	Artificial
L2	6°50'03,3"	5°16'19.0"	122 815.14	Artificial
L3	6°49'40,8"	5°16'32.0"	673 39.91	Artificial
L4	6°49'24,4"	5°16'47.3"	98 642.44	Artificial
L5	6°48'42,9"	5°17'08.2"	605 439.46	Artificial
L6	6°48'31,5"	5°17'23.9"	174 980.97	Artificial
L7	6°48'53,1"	5°16'27.6"	631 14.90	Artificial
L8	6°49'09,4"	5°16'25.1"	107 308.19	Artificial
L9	6°49'21,0"	5°16'13.3"	123 016.80	Artificial
L10	6°49'27,2"	5°15'53.5"	194 173.64	Artificial
L11	6°47'43,0"	5°14'17.5"	383 201.96	Natural
L12	6°50'43,7"	5°13'27.0"	228 591.34	Natural
L13	6°52'39,7"	5°14'04.5"	322 422.37	Natural
L14	6°49'28,5"	5°17'50.6"	35 226.26	Natural

L : Lake

Table 2 : Classification of trophic status according to the OECD study (1982).

Class of trophic states	Trophic status index (mg/m ³)		
	P _T	Chl _{mean}	Chl _{max}
Ultra-oligotrophic	< 4,0	< 1,0	< 2.5
Oligotrophic	< 10.0	< 2.5	< 8.0
Mesotrophic	10 – 30	2.5 – 8.0	8.0 – 25
Eutrophic	35 – 100	8 – 25	25 – 75
Hypereutrophic	> 100	> 25	> 75

RESULTS
Determination of physical and biological parameters

Water temperatures accross the stations of lakes ranged from 29 to 32.6°C. The waters of stations L1, L7 and L12 were slightly acidic while the other lakes had slightly basic waters. The lowest electrical conductivities were recorded in stations L11 and L12 with average values of 170.8 and 150.1 µS/cm respectively.

Except for station L7 which had an average value of 1000 µS/cm, the other stations had values between 200 and 500 µS/cm. Stations L11, L12, L13 and L14 had turbidity values below 15 NTU. However, station L1 had an average value of 286.67 NTU. Except for Lake L8, which had an average dissolved oxygen concentration of 18.37 mg/L, all others had values below 10 mg/L. Lake L7 shows a particularly low chlorophyll-a concentration

(1.75 µg/L), whereas other lakes ranged between 8 and 45 µg/L. Total suspended solids (TSS) in the surface waters of these 14 lakes range from 5 to 50 mg/L. Detailed results were shown in Table 3.

Determination of chemical parameters

The chemical oxygen demand (COD) varied in the order of 50 to 75 mg/L for lakes L1, L2, L3, L4 and L7. Only station L6 had a COD value exceeding 200 mg/L. The ratio of chemical oxygen demand to biological oxygen demand (COD/BOD₅) was about 1.7 in almost all stations. Stations L5 and L7 record the highest concentrations of total nitrogen (5.2 and 7.2 mg/L respectively). The other stations had values in the order of 1 mg/L or even lower than 0.1 mg/L. With the exception of station 7, which had a particularly high total phosphorus concentration (133 mg/L), the other stations had concentrations in the order of 1 mg/L or lower than 1 mg/L. For this parameter, the recommended threshold is 0.01 mg/L (Clune et al., 2020). Nutrients (NO₃⁻, NO₂⁻, NH₄⁺ and PO₄³⁻) had particularly high concentrations in Lake L7 and low concentrations in stations L2, L3, L4, L5, L8, L9, L10, L11, L12, L13 and L14. All details were recorded in Table 4.

Eutrophication status of the Lakes

The chlorophyll-a concentration values of 8 to 40 mg/m³ observed in Table 3 show a

significant production of algal biomass in different lakes and highlight the eutrophic or hypereutrophic nature of the system (the system is eutrophic if the Chl-a content is greater than 8 mg/m³ and hypereutrophic if this concentration is greater than 40 mg/m³) according to the OECD classification. However, considering the results of total phosphorus (concentrations greater than 100 mg/m³), all lakes were in a status of hypereutrophy (Table 5).

Extent of infestation in the lakes of Yamoussoukro

Several ecological impacts have been observed due to human activity discharges within the lakes. These primarily concern the invasion of aquatic weeds, expressed by the coverage rate or the rate of plant invasion and the phytoplankton biomass of the lakes. Invasive aquatic plants were present in all the lakes studied and in large quantities, occupying more than 50% of their total surface area, as highlighted in Table 6. The species present in almost all the lakes was *Nelumbo nucifera* (Lotus). Lakes L8 and L9 had the highest phytoplankton biomass (10745 and 10422.5 µg/L, respectively), followed by Lake L10 with 9045 µg/L. The other lakes had biomass concentrations ranging from 437.5 to 7745 µg/L.

Table 3 : Results of the physical parameters of lake waters.

Lake	Temperature (°C)	pH	Conductivity (µS/cm)	Turbidity (NTU)	DO (mg/L)	Chl-a (µg/L)	TSS (mg/L)
L1	29.2±1.1	6.72±0.16	356.7±19.2	286.67±50.5	1.85±0.54	12.95±1.31	15±3
L2	30.3±2.4	8.48±0.22	205.1±12.3	40.12±7.6	7.8±1.66	10.72±1.26	5±1
L3	29.9±1.3	8.13±0.13	322.9±9.8	21.8±6.4	7.32±1.78	21.44±2.11	13±2
L4	29.7±2.6	8.08±0.09	402.1±14.2	27.7±7.2	7.8±2,1	27.38±2.7	35±3
L5	29.7±1.5	8.16±0.39	467.1±16.2	104.7±17.6	9.43±2.53	44.34±2.47	23±3
L6	30.5±1.1	7.59±0.17	456.9±34.5	45.2±9.3	4.55±0.37	30.98±1.97	27±4
L7	29.7±1.3	6.62±0.09	1000±108	31.3±5.7	1.77±0,61	1.75±0.05	24±3
L8	32.6±0.9	9.26±0.41	457.6±64.2	164.1±26.4	18.37±5.54	42.98±3.6	47±4

L9	30.4±0.8	8.32±0.31	366.1±44.6	86.08±19.8	8.51±3.1	41.69±4.31	21±3
L10	30.2±1.2	7.59±0.15	377.2±29.2	47.9±14.3	5.55±2.01	36.18±2.45	10±2
L11	29.5±0.9	7.47±0.11	170.8±9.3	7.3±1.7	6.27±0.95	10.86±1.69	9±2
L12	31.2±1.3	6.74±0.09	151.1±8.9	6.6±0.9	2.87±0.47	8.21±1.35	16±3
L13	29.7±0.9	8.55±0.12	198.6±10.2	14±2.3	8.27±2.96	12.11±1.45	5±1
L14	31.7±1.1	7.64±0.08	336.5±13.5	11.1±1.9	6.75±1.64	12.11±1.63	7±2

Table 4 : Results of the chemical parameters of lake waters.

Lake	COD	BOD ₅	NT	P _T	NO ₃ ⁻	NO ₂ ⁻	PO ₄ ³⁻	NH ₄ ⁺	COD/BOD ₅
	(mg/L)								
L1	68±4	40±4	<0.1	0.84±0.08	1.8±0.3	< 0.002	0.25±0.09	0.03±0.01	1.7
L2	66±5	38±3	0.8±0.2	0.73±0.09	< 0.1	< 0.002	0.11±0.06	0.04±0.01	1.73
L3	62±3	36±3	< 0.1	0.89±0.06	0.3±0.1	< 0.002	0.07±0.02	0.02±0.01	1.72
L4	54±2	31±2	< 0.1	0.92±0.07	2.1±0.9	0.008±0.002	0.04±0.01	< 0.01	1.74
L5	116±8	69±4	5.2±0.7	2.2±0.1	< 0.1	0.04±0.01	0.15±0.02	0.3±0.1	1.68
L6	208±23	120±11	3.7±0.6	1.65±0.09	< 0.1	< 0.002	0.07±0.02	1.74±0.09	1.73
L7	74±6	42±5	0.7±0.2	133±34	6.5±1.2	0.035±0.001	0.5±0.01	25±8	1.76
L8	164±12	96±7	7.2±0.9	3.3±0.9	< 0.1	< 0.002	0.16±0.09	0.19±0.07	1.71
L9	158±9	93±8	2.4±0.6	1.19±0.07	< 0.1	< 0.002	0.04±0.02	0.09±0.03	1.7
L10	85±5	50±6	1.9±0.3	1.39±0.06	< 0.1	< 0.002	0.4±0.1	0.07±0.02	1.7
L11	13±2	8±1	< 0.1	0.56±0.03	0.2±0.1	< 0.002	0.02±0.01	0.04±0.02	1.62
L12	105±8	61±5	< 0.1	0.92±0.08	1.5±0.4	0.009±0.002	0.25±0.06	0.09±0.03	1.72
L13	40±3	23±2	< 0.1	0.43±0.02	< 0.1	0.006±0.001	0.03±0.01	< 0.01	1.74
L14	31±2	18±2	< 0.1	0.37±0.02	< 0.1	< 0.002	0.03±0.01	< 0.01	1.72

Table 5 : Trophic status of different lakes in Yamoussoukro.

Lake	Trophic status index (mg/m ³)			Trophic status
	P _T	Chl _{mean}	Chl _{max}	
L1	840	12.95	14.26	Hypereutrophic
L2	730	10.72	11.98	
L3	890	21.44	23.55	
L4	920	27.38	30.09	
L5	2200	44.34	46.81	
L6	1650	30.98	32.95	
L7	133000	1.75	1.8	
L8	3300	42.98	46.59	
L9	1190	41.69	46	
L10	1390	36.18	36.63	
L11	560	10.86	12.55	
L12	920	8.21	9.56	
L13	430	12.11	13.56	
L14	370	12.11	13.74	

Table 6 : Coverage rate, planktonic biomass and plant cover of the Yamoussoukro lakes.

Lake	Coverage	Biomass (µg/L)	Species encountered	Comments
L1	100%	3237.5	<i>Nelumbo nucifera</i> , shrubs reeds, banana trees	Strong presence of grass, silting and pollution of the lake by waste water, total coverage of the entire lake, completely invaded edge, strong presence of saurians (crocodiles, caimans, etc.)
L2	5%	2680	<i>Nelumbo nucifera</i> , Reeds, grasses of all kinds	Strong presence of saurians (crocodiles, caimans, etc.), damaged slab and lake nozzle, <i>Nelumbo nucifera</i> .
L3	60%	5360	<i>Nelumbo nucifera</i>	Partial coverage of the body of water Strong presence of lizards (crocodiles, caimans...), lake slab and culvert completely damaged, silting and pollution of the lake by wastewater.
L4	75%	6845	<i>Nelumbo nucifera</i> , Herbs of all kinds	Almost total coverage of the body of water by plants, strong presence of saurians (crocodiles, caimans...), silting and pollution of the lake by wastewater.
L5	80%	1105	<i>Nelumbo nucifera</i> , Herbs of all kinds, water hyacinths	Almost total coverage of the water body by plants, silting up and pollution of the lake by wastewater.
L6	90%	7745	<i>Nelumbo nucifera</i> , Herbs of all kinds, water hyacinths	Almost total coverage of the body of water by plants, silting and pollution of the lake by wastewater, strong presence of grasses.
L7	100%	437.5	<i>Nelumbo nucifera</i> , shrubs, reeds, banana tree	Total coverage of the water body by plants, silting and pollution of the lake by wastewater, strong presence of grasses.
L8	70%	10745	<i>Nelumbo nucifera</i> , shrubs, reeds, banana tree	Almost total coverage of the water body by plants, silting up and pollution of the lake by wastewater.
L9	50%	10422.5	<i>Nelumbo nucifera</i> , shrubs, reeds, banana tree	Partial coverage of the water body by plants, silting and pollution of the lake by wastewater
L10	100%	9045	<i>Nelumbo nucifera</i> , shrubs, reeds, banana tree	Heavy presence of grass, silting and pollution of the lake by wastewater, total coverage of the entire lake, completely invaded edge, silting and pollution of the lake by wastewater.
L11	60%	2715	<i>Nelumbo nucifera</i>	Partial coverage of the water body by plants.
L12	60%	2077.5	Reeds	
L13	70%	3027.5	<i>Nelumbo nucifera</i>	Almost total coverage of the water body by plants.
L14	70%	3027.5	Shrubs, reeds, banana tree	

DISCUSSION

To determine the ecological status of the waters of the Yamoussoukro lakes, several parameters were analyzed. The variation in temperature from one station to another is due to the presence of macrophytes. These constitute a cover on the surface of the lakes which has the direct consequence of a clear decrease in the temperature of the waters they cover. These values are close to those of Ouattara et al. (2012) on the Ziga dam. Regarding pH, high values obtained in places can be linked to the photosynthetic activity of phytoplankton (Tohozin et al., 2018). However, the low values are undoubtedly due to the release of organic acid by the roots of macrophytes; which leads to a drop in pH (Lhote, 2000). The high dissolved oxygen levels obtained in stations L2, L3, L4, L5, L8, L9 and L13 are due to a strong photosynthetic activity of phytoplankton algae and aquatic plants by producing oxygen (Bocodaho et al., 2020).

Indeed, oxygen production by photosynthesis of macrophytes and phytoplankton is the main source of dissolved oxygen during the day, and can lead to supersaturation levels in aquatic ecosystems with high productivity (Wetzel, 2001). The low dissolved oxygen levels in stations L1, L7 and L12 could be explained by the abundant presence of macrophytes which also consume oxygen from the environment to enable the activity of aerobic bacteria in the degradation of organic matter in plants (Parinet et al., 2004). The macrophyte coverage of stations L1 and L7 is total. The low nitrite concentrations ranging from less than 0.002 to 0.035 mg/L would be due to the average oxygenation of the lake waters, promoting the oxidation of ammoniacal nitrogen directly into nitrates (Guildford and Hecky, 2000). Furthermore, the high nitrate values in stations L1, L4, L7, L12 could be explained mainly by the presence of household and commercial waste produced by residents located in the N'zuessy, Habitat and Assabou districts which have a high concentration of people. In the other stations, nitrate exists in trace. This could be explained by a demographic inequality of the population

in the basin of the lakes studied. These values are lower than those reported by Tapsoba et al. (2016) in the waters of dam n°3 in Ouagadougou. The high phosphorus levels in the stations would come from runoff water of anthropogenic origin. These results are consistent with those of Ayah et al. (2015) in the case of the Lomé lagoon system. However, the low orthophosphate levels suggest an endogenous source of nutrients from sediment release. The lack of significant external phosphate input to these lakes may be the cause. These values are close to those determined by Tapsoba et al. (2016). High chlorophyll-a levels reflect a high phytoplankton biomass, which could be explained by the high levels of nutrients (nitrogen and phosphorus) likely to stimulate algal productivity. Studies conducted on the Lokpoho and Morrisson dam lakes in Ivory Coast have shown that the parameters influencing chlorophyll-a production vary according to the seasons. In the dry season, factors such as water transparency, pH and conductivity have a significant influence. However, in the rainy season, it is mainly the concentrations of nitrates, potassium and silicon that play a determining role (Soro et al., 2021). Analysis of total phosphorus concentrations reveals notable differences between the different lakes, with an extremely high concentration of 133000 mg/m³ recorded for station L7. In contrast, the other stations have concentrations ranging from 730 mg/m³ to 2220 mg/m³. This disparity can be largely explained by the size and depth characteristics of the lakes (Parinet et al., 2004). Indeed, lake L7 has modest dimensions compared to the others. In addition, it has a very shallow depth. Due to these characteristics, anthropogenic activities, such as domestic and agricultural activities in the districts of Dioulabougou, Habitat and N'Zuessi, generate a significant amount of phosphorus which has a major impact on this lake. In addition, the low dissolved oxygen content of this lake (1.77 mg/L) promotes the accumulation of phosphorus, thus explaining the high concentration of 133000 mg/m³. In contrast, the other lakes, although subject to the same

anthropogenic activities that generate phosphorus, have lower concentrations due to their larger size and considerable depth. These characteristics, combined with the dissolved oxygen levels in these lakes, give them a high purifying capacity, thus reducing phosphorus concentrations. The assessment of the risk of eutrophication of the waters of the fourteen (14) lakes of the district of Yamoussoukro using the OECD diagnostic tool (Mama, 2010), shows that these waters are in a hypereutrophic status over the study period. This observation has been made in other tropical aquatic environments such as Lake Porto-Novo (Mama et al., 2011a), Lake Nokoué (Mama et al., 2011b), the Kogbétouhè reservoir (Noumon et al., 2015) in Benin and Lake Potou in Ivory Coast (Yéo, 2015). These results show that there is availability of nutrients in all the lakes which have generated high primary production expressed by chlorophyll-a and turbidity. This may be due to the wastewater discharges received by certain lakes and the fertilizer used by farmers around the lakes for agriculture.

Following this eutrophication, several ecological impacts are observed, including the invasion of aquatic plants. To this end, in the lakes studied in the district of Yamoussoukro, the species encountered are: *Phragmites australis* (reeds), *Musa paradisiaca* (banana trees), *Nelumbo nucifera* (lotus) and also shrubs. There are also other plant species. These same remarks were made in Lake Obili in Yaoundé where the flowering of *Pistia stratiotes* (water lettuce) and *Eichhornia crassipes* (water hyacinth) was recorded (Ajeegah et al., 2013) and in the Ono lagoon, where strong plant growth was recorded (Gboko et al., 2019). The coverage of invasive aquatic plants expressed by the invasion rate which generally exceeds 50% of the total surface area of these lakes, shows an excessive proliferation of plants illustrated by the total invasion of lakes L1, L7 and L10 (100%). Indeed, in Ivory Coast the waters are warm, the lighting is sufficient, the fertilizers are in relatively large quantities, the phytotoxic products are absent and finally, the predators are absent or present but in insufficient quantity (Djene et al., 2025). Also, the phytoplankton

biomasses estimated by chlorophyll-a are very high in lakes L5, L8 and L9. This is the consequence of the high levels of nutrients likely to stimulate algal production and responsible for phytoplankton growth. This phenomenon is coupled with the low presence of aquatic plants on the surface of these ponds which would have prevented better penetration of light essential for algae. On this subject, Yang et al. (2011) state that high nutrient levels and high temperatures are major factors in the development of high phytoplankton biomass.

Conclusion

This work consisted of assessing the eutrophication status of the natural and artificial lakes of Yamoussoukro using the OECD grid and showing the impact of this phenomenon on their ecology. To achieve this objective, physical, chemical and biological analyses were carried out on water samples from these lakes taken from carefully chosen stations. The trophic status of these waters was then assessed and finally the coverage rate and phytoplankton biomass were determined in order to estimate the ecological impact of these aquatic environments. With the exception of three lakes (L1, L7 and L12) which have slightly acidic waters, the others are clearly alkaline. Mineralization is high and nutrient concentrations are also significant. These waters are poorly oxygenated, with remarkable chlorophyll-a levels. They all present organic pollution in view of the COD/BOD₅ ratio. Based on the total phosphorus and chlorophyll-a results, all fourteen lakes are hypereutrophic according to the OECD scale. Furthermore, the ecological impact of the lakes was determined by the coverage rate, showing significant areas of these lakes colonized by invasive aquatic plants, ranging from 50% to 100%. These include *Phragmites australis* (reeds), *Musa paradisiaca* (banana trees), *Nelumbo nucifera* (lotus), and shrubs. Phytoplankton biomass is very high in lakes L8, L9, and L10, with respective values of 10745, 10722.5, and 9045 µg/L. Lake L7 has the lowest biomass at 437.5 µg/L.

To limit the continued nutrients enrichment of lake environments, it is essential

that people stop dumping their liquid and solid waste into them. The district is responsible for raising awareness and training local residents to adopt good waste management practices.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

The first three authors contributed to the experimental analyses and writing, while the last three authors contributed to improving the manuscript.

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