International Journal of Environment and Climate Change

Volume 13, Issue 11, Page 2509-2521, 2023; Article no.IJECC.108827
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Occurrence, Ecological and Health Risks of Organic Pollution of the Waters from a Tropical Lake System

Konan Kouadio Fabrice Arthur [a,b++]
and Yao Marcel Konan [b#*]

[a] Ecole Doctorale Sciences, Technologie et Agriculture Durable (ED-STAD), 01 BPV 34 Abidjan, Cote d`Ivoire.
[b] Laboratoire de la Réaction et de la Constitution de la Matière (LCRM), UFR SSMT, Université Félix Houphouët-Boigny, 22 BP 582 Abidjan 22, Cote d`Ivoire.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2023/v13i113417

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/108827

Original Research Article

Received: 01/09/2023
Accepted: 04/11/2023
Published: 08/11/2023

ABSTRACT

The monitoring of the organic pollution level and the ecological and health risks of the waters from the Déganobo lake system were the subject of this study. In its implementation, the water samples were collected monthly in this aquatic ecosystem over a year (from August 2021 to July 2022). The organic pollution level of these waters was assessed using their Chemical Oxygen Demand, determined in accordance with NF T 90-101 standard. The ecological and health risks were assessed based on the SEQ-Eau V2 water quality guidelines. Their COD seasonal mean values were between 220,000±51,872 and 361,333±48,273 mg/L O_2. So, their organic pollution was relatively very significant, with the corollary of the zero of its seasonal transparencies and of its

---

[++] *PhD Student (Environmental Chemistry);*
[#] *Research Scientist Senior and Head (Environmental Chemistry);*
**Corresponding author: E-mail: yaomarcelkonan@gmail.com;*

seasonal dissolved oxygen contents. The seasonal dynamics of organic matter in these waters was essentially linked to the hydroclimate (rainfall and ambient temperature) on the watershed of this lake system. The low meteorite waters inputs in dry seasons favoured the increase of their COD by the important punctual wastes inputs of various origins (domestic, agricultural, industrial, hospital, etc.); in opposite of the important meteorite waters inputs in rainy seasons causing their renewal. The consequences of their important COD values are severe ecological and health risks, as highlighted by SEQ-Eau V2 water quality guidelines. So, this lake system is under the strong anthropogenic pressures. This study could serve as complementary information on its pollution level and contribute to decision-making for its rehabilitation, its protection within the framework of its sustainable development.

Keywords: Chemical pollution; Côte d'Ivoire; organic matter; San-Pédro city.

1. INTRODUCTION

Organic matter plays a fundamental role in the aquatic environment by its importance in biogeochemical reactions. However, its high presence in these entities, linked in the majority of cases to anthropogenic activities, is source of ecological scourges [1,2]. Indeed, the degradation of an excessive presence of organic matter in aquatic ecosystems generates an important quantity of nutrients in general, nitrogen and phosphorus nutrients in particular. This process constitutes an important source of their eutrophication [3]. The high presence of non-biodegradable organic matter, such as hydrocarbons and pesticides, are also a direct source of high ecological and health risks [4,5]. So, the knowledge and monitoring of organic matter in these ecosystem, particularly in surface waters, has always been important for the assessment and monitoring of their quality.

The factors impacting the fate of organic matter (degradation and transformation) in surface waters are very numerous. These include light, temperature, transparency, depth, dissolved oxygen content, pH, salinity and, redox potential. Very high transparency of surface water favours the cross of light, particularly UV rays, leading to photosynthesis and other photochemical reactions. These reactions are also favoured by a very good dissolved oxygen content [6,7]. This is more so for shallow environments [7]. The high water temperatures, generally from 25°C, promote good mineralization of organic matter [8]. That is also the case in a basic and reductive environment, at the same time as a very good dissolved oxygen content and a relatively high water temperature. On the other hand, an acidic and oxidizing environment is disadvantageous to the degradation of organic matter [7]. Oscillations of deposition and re-suspension cycles associated with variations in oxic and anoxic conditions can lead to changes in the dissolved organic matter-particulate organic matter balances, therefore modify their composition and degradability [9]. Diffuse and/or punctual exogenous inputs influence all the biogeochemical parameters conditioning the dynamics of organic matter in these aquatic ecosystems. Also, they directly influence their future depending on their organic matter load [7-9].

Located in the urban center of the San-Pédro city, the Déganobo lake system is one of the tourist attractions of this seaside town [10]. It has remarkable biodiversity [11]. It also plays important purifying and socio-economic roles. However, it is currently the receptacle of anthropogenic discharges of all kinds without prior treatment. It is therefore in a very advanced state of disrepair; highlighted by the high presence of aquatic plants in its surface [12]. Given its vital importance to this city, it is necessary to carry out actions for its restoration and protection as part of its sustainable development. So, it is important to assess its current pollution level, particularly that chemical. It is within this framework that this study was carried out. Its main objective is to monitor the seasonal dynamics of its organic pollution through the Chemical Oxygen Demand (COD). The secondary objectives were to monitor the seasonal dynamics of some of its seasonal physical and chemical characteristics; to evaluate their impact on the seasonal dynamics of its COD and; to assess the seasonal ecological and health risks linked to its organic pollution and some of its physical-chemical parameters.

2. MATERIALS AND METHODS

2.1 Geolocation and Characteristics of the Study Area

Commonly referred to as "Lake San-Pédro", the Déganobo lake system is located at the West longitude of 6.63775 and the North latitude of 4.75046 (Fig. 1).

The water seasons of this aquatic ecosystem are those of the terrestrial hydroclimate observed in the San-Pédro Department. Indeed, this department is subject to a subequatorial climate, with a bimodal regime alternating rainy and dry seasons. This climate is characterized by two rainy seasons and two dry seasons of unequal duration, distributed as follows:

- a Great Dry Season (GDS) from December to March;
- a Great Rainy Season (GRS) from April to July;
- a Small Dry Season (SDS) from August to September, marked by the manifestation of the major upwelling season. This is the coldest period on the Ivorian coast;
- a Small Rainy Season (SRS) from October to November [13,14].

The water surface area of the Déganobo lake system have reduced from 160 ha to 75.72 ha under strong anthropogenic pressure [13]. According to the San-Pédro Water Resources Department, this aquatic site lost 45% of its initial surface area between 1986 and 2015 [11].

This aquatic site is made up of two lakes: Lac Est and Lac Ouest, connected by a canal over which the international road “La côtière” crosses. These two lakes are in permanent communication through this canal. Lac Ouest, the larger of these two lakes, has a current open water surface area estimated at 49.05 ha, almost half of its original water surface area of 100 ha. As for Lac Est, its current open water surface area is estimated at 29.87 ha, practically a third of its initial water surface area of 60 ha. This aquatic site is very shallow [13].

This lake system belongs to the watershed of the San-Pédro River [11]. Indeed, the waters of this river, in permanent flood [15], feed this lake system through a lot of swampy areas, especially from Lac Ouest. Also, this system receives waters from Digboué lagoon in rainy seasons, again through the swampy areas [11,15].

This lake system has remarkable biodiversity. According to the San-Pédro Water Resources Department, this site is the habitat of diverse aquatic fauna. It is also an important avian habitat. In January 2022, the San-Pédro Forestry Services estimated a population of 3,150 waterbirds distributed between 14 migratory and sedentary species; making this site the second most important site within the framework of the international waterbird enumeration and identification program [11].

Of natural origin, the Déganobo lake system was intended to serve as an outlet for drainage water and, domestic and industrial wastewater through a collection system for treated

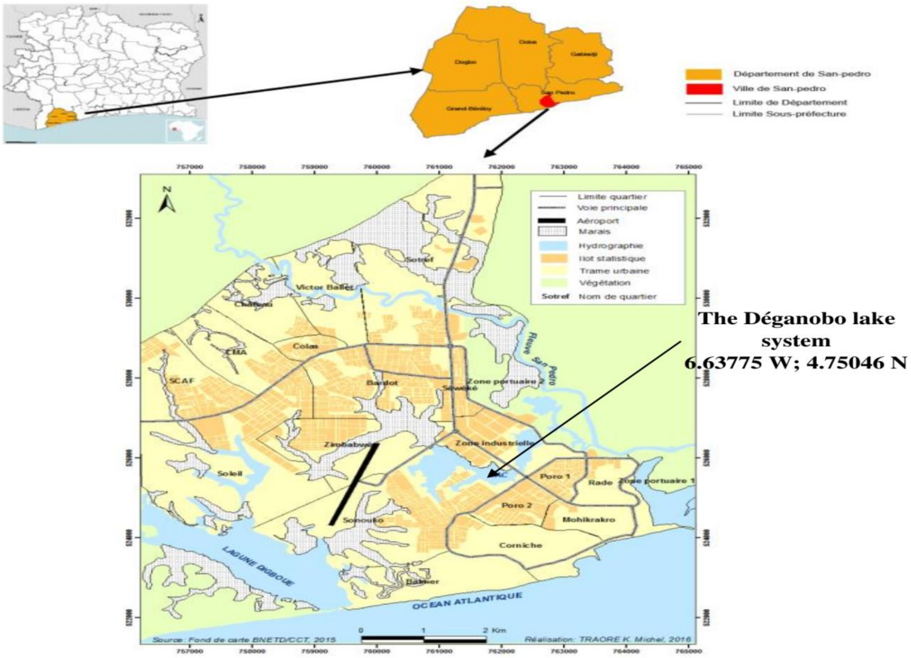

Fig. 1. Geolocation of the Déganobo lake system (Map source: [11])

wastewater upstream as part of the RASW (Regulation Authorities of the South-West) program [10]. The non-existence of a real sanitation system in the San-Pédro city for several years makes this aquatic site the receptacle of anthropogenic discharges of all kinds without prior treatment, especially those from its two great industrial areas and its general hospital located nearby [11,12,16].

2.2. Experimental Techniques

2.2.1 Sample collection, measurements and sample conservation in situ

This study was conducted over the period from August 2021 to July 2022. During this period, water column samples were collected in this lake system using a 1 L capacity Niskin bottle in eight sampling sites. These sampling sites were chosen taking into account the spatial heterogeneity and accessibility of the water body; and this, with the aim of a better estimate of their organic pollution (Fig. 2).

Immediately collected, the water samples intended for the determination of the chemical oxygen demand (COD) were put in very clean and dry 1 L polyethylene bottles. They were subsequently acidified with a 0.1 N H_2SO_4 solution to bring their pH below 2 in order to inhibit the action of microorganisms. These polyethylene bottles were sealed and kept *in situ* in a light-tight cooler containing an important quantity of ice so that the interior temperature was around 4°C. Water sample collection operations were carried out in accordance with ISO 5667 standard [17] and, their conservation was carried out according to NF EN ISO 5667-3 standard [18]. A monthly sample was done during the study period, for a total collection of 96 water samples. Correlatively, the measurements of pH, redox potential (U), salinity, conductivity and dissolved oxygen content of the column waters were carried out *in situ* by using the multi parameter portable meter WTW Multi 3630 IDS (Xylem Analytics Germany Sales GmbH & Co. KG, WTW). The water transparency was assessed using a Secchi disk, while that of the depth of the sample sites was with a graduated metal bar.

Due to the very low draft of this lake system, the different sampling sites were reached using a non-motorized canoe. This fact had the advantage of low disturbance of the waters of this lake system during the samplings.

2.2.2 Sample processing in laboratory

2.2.2.1 Sample conservation

Once arrived at the laboratory, the water samples were stored in the freezer at -6°C.

2.2.2.2 COD determination

The COD of the water samples was obtained according to NF T 90-101 standard [19]. The principle of this standard is the return assaying of an excess of the dichromate ions with a Mohr salt solution (iron II and ammonium sulphate solution) after oxidation of the organic matter contained in the water samples by the dichromate ions in the acid environment.

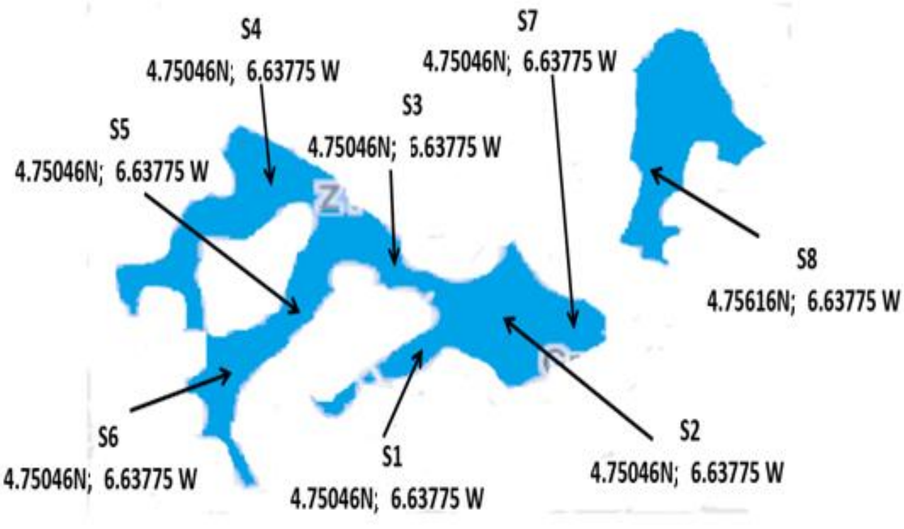

Fig. 2. Geolocation of sample sites used in this study

In practice, 5 mL of a 0.40 mol/L potassium dichromate solution containing 1 mg of the mercury sulphate was added to 10 mL of water sample in a round-necked flask. To this mixture, 15 mL of the sulphuric acid-silver sulphate solution (obtained by dissolving 10 g of silver sulphate in 40 mL of pure water and the whole carefully brought into 960 mL of a pure sulphuric acid (commercial solution with purity between 96 and 98%). After slight stirring, the mixture was brought to reflux at 120°C for 2 hours. The mineralized material obtained was recovered, as well as the rinsing water, in a beaker, then assayed with 0.12 mol/L Mohr salt solution in the presence of ferroin as a coloured indicator. A possible dilution of the water sample was carried out if the COD of the sample is greater than 700 mg O_2/L. A blank, consist of 10 mL of pure water, was treated in the same conditions. All the experiences were done in triplicate.

The COD of the sample, expressed in mg O_2/L, is given by the following relationship:

$$DCO = 8000.C.f.\frac{V_1 - V_2}{V_0}$$

with:

- C, the concentration of Mohr salt solution expressed in mol/L;
- V_0, the volume, in mL, of the test portion before possible dilution;
- V_1, the volume, in ml, of the Mohr salt solution used for the blank test;
- V_2, the volume, in mL, of the Mohr salt solution;
- f, dilution factor.

2.2.3 Assessment of ecological and health risks

The assessment of the seasonal ecological and health risks of these waters during the study period was done using SEQ-Eau V2 water quality guidelines [20] by taking into account their conductivity, COD, transparency and, dissolved oxygen content.

2.2.4 Source of hydroclimate data

The monthly data of the ambient temperature and those of rainfalls in the study period were provided by https://www.historiquemeteo.net/afrique/cote-d-ivoire/san-pedro [21,22].

2.2.5 Statistical analysis

In addition to standard statistical techniques (m (mean), s (standard deviation), VC (variation coefficient), min (minimum mean value) and, max (maximum mean value)), Normalized Principal Component Analysis (NPCA), one-way ANOVA and, the Student test were used.

NPCA was used to assess the seasonal effects of the hydroclimate on the physical and chemical parameters assessed in the water column of this lake system.

The purpose of using one-way ANOVA was to check whether there is a significant difference between the different seasonal mean for the different parameters considered in this study. If this was the case then three post hoc tests were used to determine the seasonal means which differ, but also the homogeneous subgroups which do not differ from each other. These were the Fisher LSD test, the Tukey HSD test and, the Dunnett test. To ensure the significant difference between two seasonal mean and/or homogeneous subgroups of seasonal means not different in a parameter, the Fisher LSD test and the Tukey HSD test were simultaneously carried out. If there was a difference between the results obtained, then the Dunnett test was carried out in the column(s) where the results diverge. Results of one-way ANOVA and post hoc tests were considered statistically significant for $p = .05$.

The student t-test was used in the different limits defines by SEQ-Eau V2 water quality guidelines [20] for a confirmation or none of the ecological and health risks obtained with this standard for the parameters used for this. The result of this test was considered statistically significant for $p = .05$.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Seasonal dynamic of some physic and chemical parameters

The Table 1 presents the seasonal and annual means values of pH, redox potential, conductivity, salinity, transparency, dissolved oxygen and, COD of the waters from the Déganobo lake system obtained on the study period.

This lake system was shallow over the study period, as shown by the annual mean value of their mean depth. Its mean depth was relatively important in GRS and, relatively low in GDS. The very low intra-seasonal variations highlighted the quasi-stability of the seasonal water level of this system in all seasons. This observation was confirmed by one-way ANOVA, which also shows an overall significant difference between its seasonal mean depths (*p* =.05). The post-hoc tests used in this study showed that only their mean depth in GSP is not statistically distinct from other seasonal mean depths (*p* = .05).

These waters were relatively warm throughout the study period. Their maximum seasonal mean temperature was obtained in GDS and, the lowest was in GRS. The Intra-seasonal variations were very low, demonstrated by one-way ANOVA (*p* = .05); also showing an overall significant difference between their seasonal mean temperatures. The post-hoc tests used highlighted a statistically significant difference between all their seasonal temperatures (*p* = .05).

The waters were slightly basic in all seasons over this period. Their basicity was relatively important in SDS and GDS, and less in SRS. The intra-seasonal variations of their mean pH were also very low, indicating their permanent slight basicity in all seasons over this period. One-way ANOVA showed an overall significant difference between the seasonal mean values of their pH (*p* = .05). The post-hoc tests used in this study highlighted two homogeneous subgroups: SDS and GRS in one hand and, SRS and GDS on other; with statistically significant differences between them (*p* = .05).

The waters of this lake system were slightly reductive in all seasons over the study period. They were more so in GDS and, less so in GRS. The intra-seasonal variations were low in all seasons, as attested by one-way ANOVA. One-way ANOVA also revealed a significant overall difference between their mean redox potentials (*p* = .05). The post-hoc tests used in this study showed that only the differences between their mean potentials obtained in SDS and those determined in SDS and GRS were statistically significant (*p* = .05). The same was true for the differences between the mean redox potentials determined in GDS and those obtained in SRS and GRS (*p* = .05).

These waters had very low salinity over the study period, as illustrated by their mean annual salinity of less than 2 mg/L. Their highest seasonal value was obtained in GDS and, the lowest in GRS. The intra-variations of their seasonal salinity were low. This was shown again by one-way ANOVA, which also highlighted an overall significant difference between their seasonal mean salinities (*p* = .05). the Post-hoc tests used in this study showed that only their salinity mean value obtained in GDS was statistically different from those determined in the other three seasons (*p* = .05).

The mineralization of these waters was relatively very significant, as showed by their annual mean value of their conductivity, very close to 1000 µS/cm. Their mineralization was relatively significant in GDS, and relatively low in GRS. Their intra-seasonal variations were low in all seasons. This is also illustrated by one-way ANOVA, also showing an overall significant difference between their seasonal mean conductivities (*p* = .05). The post-hoc tests implemented in this study revealed that their mean conductivity in SDS is not statistically different from that obtained in SRS (*p* = .05).

The COD seasonal values of these waters was relatively very high over the study period, given their annual mean value very close to 300 mg O_2/L. Their highest COD seasonal mean value was determined in GDS, and the lowest in SDS. Their intra-seasonal variations were low in all seasons. This was highlighted by one-way ANOVA. One-way ANOVA also was highlighted an overall significant difference between their COD seasonal value (*p* = .05). The post-hoc tests used in this study showed that only the difference between their COD mean value obtained in SDS and that determined in SRS is not statistically significant (*p* = .05).

All the seasonal mean values of their dissolved oxygen contents and their transparency were zero over the study period.

3.1.2 Influence of some hydroclimate and physic and chemical parameter on COD seasonal dynamics of these waters

Most of the information due to the 9 variables involved is given by the two first factors at 84.673%. The factor F1, associated with the eigenvalue 4.742, translates it to 52.690%. The second factor, F2, associated with the eigenvalue of 2.878, highlights it at 31.983%. As for the third factor, F3, it is associated with the eigenvalue of 1.379 and gives this information at 15.327%.

The seasonal pH, salinity and, COD of the waters from this lake system, as well as the rainfall in the study area, have high positive correlations with F1, which is the opposite of their seasonal redox potential, temperature and, conductivity (Table 2). SDS presents an

Table 1. Seasonal and annual mean values of some physic and chemical parameters of the waters from the Déganobo lake system from August 2021 to July 2022.

		Seasons				**Annual mean**
		SDS	**SRS**	**GDS**	**GRS**	
Depht (m)	m±s	1.465±0.001	1.600±0.001	1.367±0.002	2.116±0.001	1.637±0.001
	VC(%)	0.07%	0.06%	0.14%	0.05%	0.03%
	min-max	0.78-2.51	0.09-2.22	0.68-2.97	1.43-2.38	0.68-2.97
pH	m±s	7.85±0.01	8.72±0.16	8.73±0.16	7.30±0.05	8.15±0.22
	VC(%)	0.16%	1.78%	1.87%	0.70%	2.72%
	min-max	6.78-8.60	7.26-9.94	7.31-9.29	6.68-7.93	6.68-9.94
Temperature (°C)	m±s	29.77±0.41	31.30±0.14	32.69±0.02	28.21±0.06	30.49±0.23
	VC(%)	1.39%	0.44%	0.05%	0.20%	0.75%
	min-max	28.30-31.30	30.00-32.20	32.10-33,30	26.50-30.00	26.50-33.30
Redox potential (mV)	m±s	-57.46±2.72	-96.00±10.23	-106.21±1.49	-12.40±3.68	-68.02±12.40
	VC(%)	4.74%	10.66%	1.40%	29.73%	18.22%
	min-max	(-129.40) -(-24.00)	(-153.70) -(-10.10)	(-188.90) - (26.30)	(-50.10) -(-12.40)	(-188.90) - (26,30)
Salinity (mg/L)	m±s	1.61±0.05	1.61±0.05	2.90±0.10	1.38±0.40	1.87±0.25
	VC(%)	2.95%	3.38%	3.44%	28.73%	13.45%
	min-max	1,20-2,10	1.40-2.10	2.10-4.60	0.90-3.30	0.90-4.60
Conductivity (mS/cm)	m±s	812.94±23,19	827.19±26.35	1454.75±37.08	683.06±219.45	944.48±129.94
	VC(%)	2,85%	3.19%	2.20%	32.13%	13.76%
	min-max	548-1102	710-1086	1085-2343	451-1705	451-2343
COD (mg O_2/L)	m±s	361.33±58.36	313.33±7.87	220.00±55.78	289.52±70.26	296.05±61.63
	VC(%)	16.15	2.51	25.35	24.27	20.82
	min-max	106.67-533.34	106.67-533.34	106.67-426.67	106.67-853.34	106.67-853.33
Dissolved oxygen content (mg/L)	m±s	0.00±-	0.00±-	0.00±-	0.00±-	0.00±-
	VC(%)					
	min-max	0.00	0.00	0.00	0.00	0.00
Transparency (m)	m±s	0.00±-	0.00±-	0.00±-	0.00±-	0.00±-
	CVC(%)					
	min-max	0.00	0.00	0.00	0.00	0.00

Table 2. Factorial coordinates of the variables based on the correlations obtained in this case study

Variables	**Factors**		
	F1	**F2**	**F3**
pH	**0.856019**	0.116510	0.503643
Redox potential	**-0.806120**	-0.257788	-0.532650
Salinity	**0.741526**	**0.659479**	-0.123396
Conductivity	**-0.729977**	0.590649	0.343901
Water Temperature	**-0.847084**	0.502532	-0.172945
Depht	0.397013	**-0.856089**	0.330896
Rainfall	**0.883562**	0.281790	-0.374049
Ambient temperature	-0.152546	**-0.974579**	-0.164087
COD	**0.773061**	0.003253	**-0.634324**

In bold significant correlation

Table 3. Factorial coordinates of individuals based on correlations (a) and their contributions to factors (b)

Individus	**Facteurs**			**Facteurs**		
	F1	**F2**	**F3**	**F1**	**F2**	**F3**
PSC	**-2.28818**	1.27768	0.89352	**0.682930**	0.212933	0.104136
PSP	1.26110	**-1.81852**	1.02778	0.267124	0.555453	0.177423
GSC	**2.36727**	1.60264	-0.49265	**0.665940**	0.305218	0.028842
GSP	-1.34019	-1.06181	-1.42864	0.361786	0.227097	0.411117

In bold significant correlation

Table 4. Seasonal qualities of the waters from the Déganobo lake system linked to its some physical and chemical parameters according to SEQ-Eau V2 water quality guidelines [20] over the study period

Chemical and physical parameters	**SEQ-Eau V2 reference values**	**Seasons**				**Annual**
		SDS	**SRS**	**GDS**	**GRS**	
pH	Good quality (6 ≤ pH ≤ 9)	Good quality	Good quality	Good quality	Good quality	Good quality
Conductivity (mS/cm)	Very good quality (120 µS/cm ≤conductivity ≤ 2500 µS/cm)	Very good quality	Very good quality	Very good quality	Very good quality	Very good quality
COD (mg O_2/L))	Very poor quality (COD > 80 mg/L O_2)	Very poor quality	Very poor quality	Very poor quality	Very poor quality	Very poor quality
Dissolved oxygen content (mg/L)	Very poor quality (O_2 < 3 mg/L)	Very poor quality	Very poor quality	Very poor quality	Very poor quality	Very poor quality
Water transparency (m)	Very poor quality (Transparency < 0,1 m)	Very poor quality	Very poor quality	Very poor quality	Very poor quality	Very poor quality

important negative correlation with F1, in contrast to GDS which presents an important positive correlation with this factor. SRS shows an important negative correlation with F2 (Table 3).

So, these results would show that the low rainfall in GDS would have been conducive to a more pronounced basic character, with relatively high salinity and COD of these waters. This would also have been the case of the low rainfall in SDS, less than that in GDS, which with the relatively high temperature of these waters, would have favoured their reductive character.

3.1.3 Ecological and health risks

The results in Table 4 highlight the good quality of these waters for biological activities and uses linked to human health (production of drinking water, leisure and, water sports) as concerned to their pH and conductivity. This is not the case for their transparency, dissolved oxygen content and, COD, which make them of very poor qualities over all the study period according to SEQ-Eau V2 water quality guidelines [20]. These observations are confirmed by the results of the Student t-test carried out for each case ($p = .05$).

4. DISCUSSION

Unlike the Yamoussoukro lake system [23,24], Lake M'koa of Jacquevile [25] and, Lake Guessabo and Lake Dohou [26], the Déganobo lake system has its hydrochemistry indirectly linked to rainfalls. Its hydrochemistry is both linked to meteorite runoff waters inputs during rainfalls, to the permanent waters inputs from the San-Pédro River and, those of the Digboué Lagoon in GRS [15]. The San-Pédro River and the Digboué Lagoon both have their hydrological regimes directly linked to rainfalls in the San-Pédro Department. So, the evolution of the water level of the Déganobo lake system would depend on all these inputs, which are important in the rainy seasons. The paradox observed between the level of these waters in GDS and that in SRS could be explained by the quantity of rainfalls, greater in GDS than in SDS; consequence of climate change observed throughout Côte d'Ivoire in these two recent decades [14]. The significant impact of all these water inputs on the evolution of the water levels of this lake system in GRS would have been highlighted by the post-hoc tests used.

The hypereutrophic state of this aquatic ecosystem was highlighted by the strong presence of macrophytes on its surface in this period. This ecological scourge would have contributed to its total anoxia and total opacity in all seasons over the period [12]. It would be the same for its heavy siltation, consequently its shallow depth over the entire study period [27,28]. This would be contributed by occasional contributions from industrial, hospital and waste discharges [16], in addition to those drained by meteorite waters.

The waters from this lake system are directly related to temperatures. They are 2 to 3°C warmer than the ambient air, just like in lagoon environments [29,30]. This would explain the statistically significant difference between their seasonal temperatures shown by the post-hoc tests used. The higher temperature of these waters in GDS could be explained by their significant insolation in this season. The cloud cover in GRS and the presence of the great marine upwelling of the Atlantic Ocean at the end of this season, would have contributed to the drop in the temperature of these waters. The very shallow depth of this ecosystem would favour an absence of thermal stratification, as also observed by Aw et al. [23] and N'guessan et al. [24] in the Yamoussoukro lake system, Kpidi et al. [25] in Lake M'koa of Jacquevile and, Kouamé [26] in Lake Guessabo and Lake Dohou.

The seasonal basic and reductive characters of these waters, as well as their relatively high seasonal conductivities and relatively low seasonal salinities, would be mainly due to anthropogenic discharges. The low meteorite waters inputs in GDS, with the consequence of the relative strong drop in water level, would have further favoured an interaction of these waters with the sediments on the one hand and, a more pronounced impact of waste of various origins (domestic, agricultural, industrial, hospital, etc.) on their hydrochemistry, on the other. This would contribute to their basic and reductive characters being more pronounced in this season over the study period. The same would have been true for their salinity and conductivity. The effects of low rainfall on basicity and salinity of these waters in this season over this period would have been highlighted by the results of NPCA obtained in this context. On the other hand, the high meteorite waters inputs into this ecosystem, leading to a renewal of these waters and an increase in their volume, would have produced the opposite effects on these physical and chemical characteristics of these waters in GRS. The effects of these significant meteorite inputs in GRS would be felt more in SDS. This would explain the very slight increase in their basic character, salinity and conductivity, but also by the decrease in their reductive character in SDS compared to those determined in GRS. The simultaneous effects of low rainfalls and temperatures on their reductive character would have been illustrated by the results of NPCA obtained. This would also be shown by the non-statistically significant difference between their pH obtained in GRS and that determined in SDS, as highlighted by the post-hoc tests implemented. Meteorite inputs in SRS would contribute to a greater impact of agricultural residues on these physical and chemical characteristics of these waters due to their strong application on the watershed of this aquatic ecosystem in SDS. This would have had low effects on the inter-seasonal variation of their conductivity between these two seasons, highlighted by the post-hoc tests used. The effects of low rainfalls observed in GDS would also be observed in SRS, but with a relatively low amplitude, probably due to the increase in these waters level during this season; which would have explained the statistically significant difference between their basic character obtained in GDS and that determined in SRS. This would not have been the case for their salinity, the concentrations of which in the consecutive seasons GRS, SDS and, SRS are statistically not different according to the post-hoc tests implemented.

The high presence of aquatic plants and the significant anthropogenic discharges would have resulted in the relatively high COD annual mean value of these waters over this period. This fact would be highlighted by their COD seasonal mean values obtained higher than those of Lake M'koa of Jacquevile [25] and, Lake Guessabo and Lake Dohou [26]. Their basic character would have been conducive to the presence of organic matter within them [31,32]. The same would be true of the very shallow depth of this lake system favouring exchanges between the water column and surface sediments [33] and the low salinity of these waters [34,35]. However, the relatively high temperature and the reductive character of these waters would contribute to the partial degradation and mineralization of organic matter within them [36,37]. In GDS, industrial, domestic and, hospital discharges, very loaded with organic matter, would lead to a very high organic load in these waters. This would be even more so with the proliferation of aquatic plants and the strong exchanges between sediments and the water column in this season [33]. The basic character of these waters in this season would also have contributed to a relative importance of organic matter within them by partial inhibition their degradation [31,32]. This would also have been the case for their relatively high salinity in this season [34,35]. However, the more pronounced reductive character and the relatively high temperature of these waters would have partially favoured the degradation of organic matter in these waters in this season [36,37]. The favourable effects of the shallow depth of this lake site, as well as the basic character and the relatively high salinity of these waters, on their relatively high COD mean value in this season would have been highlighted by NPCA. This would also have been the antagonistic effects of their redox potential on this process. The meteorite inputs in GRS and SRS would also favour the organic matter inputs due to leaching from its watershed. However, the renewal of these waters would cause a clear drop in their COD values. This fact would also have been reinforced by the drop in their basicity and salinity [31,32,34,35], as well as by the increase in the water volume of this lake site. On the other hand, the decrease in the reductive character [37] would have contributed to the presence of organic matter in these waters in these two seasons. The effect of renewal of these waters by meteorite waters would be shown more in SDS, where their COD mean value, although significant, is the lowest observed over the study period. In this season, the clear increase in the basicity of these waters [31,32] and salinity [34,35], as well as the drop in their level [33] relative to the previous season, would have contributed to the presence of matter within them. This would have been the opposite of the increase in their reductive character, further favouring their degradation and mineralization [37]. The same phenomena observed on the dynamics in GDS would also be observed in SRS, but with a low amplitude; and this, due to the low rainfalls in this season linked to climate change in the study area. This would have been reflected by the statistically significant difference between their COD mean value obtained in GDS and those determined in GSC and SRS in accordance with the post-hoc tests implemented.

As mentioned above, the Déganobo lake system is the receptacle of anthropogenic discharges of all kinds without prior treatment. So, these strong anthropogenic pressures are responsible for its relatively high organic pollution, the consequence of which would be significant ecological scourges with serious health risks as shown by SEQ-Eau V2 water quality guidelines [20], confirmed by the Student t-test. These strong anthropogenic pressures are also responsible for the accelerated eutrophication of the waters of this lake system through its nutrient enrichment and; the manifestation of which is visibly reflected by the strong presence of macrophytes [12]. Thus, this ecological scourge would contribute to their daily anoxia and their very high turbidity. This situation would contribute to a strong bacterial proliferation in this aquatic ecosystem [38,39]. Thus, this ecological scourge would contribute to the epidemiological risks noted by Koko *et al.* [16] in the San-Pédro city, especially for the local population. This fact would be illustrated by SEQ-

Eau V2 water quality guidelines [20], confirmed again by the Student t-test, relative to their oxygen content and transparency. The degradation of lake systems linked to their high organic load and the consequences of their accelerated eutrophication was also mentioned by Aw *et al.* [23] and by N'guessan *et al*. [24], in the Yamoussoukro lake system.

5. CONCLUSION AND RECOMMENDATION

This study was allowed to illustrate the strong anthropogenic pressures subject to this lake system. This fact has a lot of consequences on its waters quality, one of which is their high COD obtained over the study period. The ecological and health risks were severe, confirmed its high degradation. Additional studies should be carried out for the thorough assessment of its chemical pollution, in particular the contamination level of its water and sediments by pesticides and polycyclic hydrocarbons. In additional, competent authorities must implement an emergency actions for the complete restoration of this lake system, by eliminating floating aquatic plants and carrying out continuous dredging in order to reduce its rapid siltation. Also, the wastewater collection and treatment system must be restored and modernized taking into account the rapid population growth in the San-Pédro city.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Anderson E, DeMont I, Dunnington DD, Bjorndahl P, Redden DJ, Brophy MJ, Gagnon GA. A review of long-term change in surface water natural organic matter concentration in the northern hemisphere and the implications for drinking water treatment Lindsay. Science of the Total Environment. 2022;858(1):159699. DOI:https://doi.org/10.1016/j.scitotenv.2022.159699
2. Mallya S, Abdikheibari S, Dumée LF, Muthukumaran S, Lei W, Baskaran K. Removal of natural organic matter from surface water sources by nanofiltration and surface engineering membranes for fouling mitigation–A review Deepak. Chemosphere. 2023 ; 321: 138070. DOI:https://doi.org/10.1016/j.chemosphere.2023.138070
3. Wei Y, Ding D, Gu T, Xu Y, Sun X, Qu K, Sun J, Cui Z. Ocean acidification and warming significantly affect coastal eutrophication and organic pollution: A case study in the Bohai Sea. Marine Pollution Bulletin. 2023; 186: 114380. DOI: 10.1016/j.marpolbul.2022.114380
4. Wolfram J, Bub S, Petschick LL, Schemmer A, Stehle S, Schulz R. Pesticide occurrence in protected surface waters in nature conservation areas of Germany. Science of the Total Environment. 2023 ; 858(3): 160074. DOI:https://doi.org/10.1016/j.scitotenv.2022.160074
5. Zhu Z, Li L, Yu Y, Tan L, Wang Z, Suo S et al. Distribution, source, risk and phytoremediation of polycyclic aromatic hydrocarbons (PAHs) in typical urban landscape waters recharged by eclaimed water. Journal of Environmental Management. 2023;330:117214. DOI:10.1016/j.jenvman.2023.117214
6. Guo Y, Guo Z, Wang J, Ye Z, Zhang L, Ni J. Photodegradation of three antidepressants in natural waters: Important roles of dissolved organic matter and nitrate. Science of the Total Environment. 2022; 802: 149825. DOI:https://doi.org/10.1016/j.scitotenv.2021.149825
7. Mahi AMA, Yao MK, Claon J-S, Trokourey A. Seasonal dynamics of trace metals in the waters from the lagoon area II of Ébrié system. Journal of Global Ecology and Environment. 2022; 14(4): 1-17. DOI:10.56557/jogee/2022/v14i47441.
8. Treilles R, Cayla A, Gaspéri J, Strich B, Ausset P, Tassi B. Impacts of organic matter digestion protocols on synthetic, artificial and natural raw fibers. Science of the Total Environmental. 2020;748: 141230. DOI:https://doi.org/10.1016/j.scitotenv.2020.141230
9. Novotnik B, Chen W, Evan RD. Uranium bearing dissolved organic matter in the porewaters of uranium contaminated lake sediments. Applied Geochemestry. 2018; 91: 36-44. DOI:https://doi.org/10.1016/j.apgeochem.2018.01.009
10. Traoré KM. Analysis of the vulnerabilities of the coastal town of San-Pédro (South-West of Ivory Coast). Thesis from Felix

Houphouët-Boigny University, Abidjan, Ivory Coast. 2016:355. French.

11. AIP, 2022. The Minister of Water and Forests is considering a development plan for Lake San-Pédro. Online article. Available:https://www.aip.ci/cote-divoire-aip-le-ministre-des-eaux-et-forets-reflechit-sur-un-plan-damenagement-du-lac-de-san-pedro/. French.
12. Ogou AWA, Bidi JT. Port, Development and Sustainable Development In San-Pedro (Southwest of Ivory Coast). European Scientific Journal. 2019;15(8): 110-131. DOI:https://doi.org/10.19044/esj.2019.v15n8p110. French.
13. PRICI, 2016. Environmental and social impact study relating to the project to develop the primary collectors of the city of San-Pédro. Final report. Ed. Ministry of Construction, Housing, Sanitation and Urban Planning (MCLAU), Ivory Coast. 2016 :310. French.
14. Yoroba F, Kouassi BK, Diawara A, Yapo LAM, Kouadio K, Tiemoko DT et al. Evaluation of Rainfall and Temperature Conditions for a Perennial Crop in Tropical Wetland: A Case Study of Cocoa in Côte d'Ivoire. Advances in Meteorology. 2019: 1–10. DOI:https://doi.org/10.1155/2019/9405939
15. Doumbia MY, Tchakam MG, Terric Jouaillec M. DINIYO IN SAN-PEDRO From the port city to the coastal metropolis. Context document. AIMU San Pedro. 2021:101. French.
16. Koko ATN, Tuo P, Anoh KP. Environmental management and population health in the town of San Pédro (South-West of Côte d'Ivoire). Regards. 2018;(1). online article. Available:https://regardsuds.org/gestion-de-lenvironnement-et-sante-de-la-population-dans-la-ville-de-san-pedro-sud-ouest-de-la-cote-divoire. French.
17. ISO 5667-6. Water quality -sampling - part 6: guidance on sampling of rivers and streams. 2014:37.
18. NF EN ISO 5667-3. Water quality - Sampling - Part 3: storage and handling of water samples. AFNOR store, France; 2013. French.
19. NF T 90-101. Water testing, determination of Chemical Oxygen Demand (COD). French standards. Water quality, environment ; 1988. French.
20. MEDD and Water Agency. Water Quality Assessment System (SEQ-Eaux), assessment grids, France. 2003;2:40. French. Available:https://www.histoire-meteo.net/afrique/cote-d-ivoire/san-pedro/, 2021. Accessed 02/23/2023. Available:https://www.histoire-meteo.net/afrique/cote-d-ivoire/san-pedro/,2022. Accessed 02/23/2023
21. Aw S, N'goran EBZ, Koffi GAR, Assidjo NE. Study of fluorescent dissolved organic matter (MODF) in the Yamoussoukro lakes (Ivory Coast) using parallel factors analysis (PARAFAC). Larhyss Journal. 2016; 26:31-44. French.
22. N'Guessan KA, Kouassi AM, Gnaboa R, Traoré KS, Houenou PV. Analysis of hydrological phenomena in an urbanized watershed: Case of the town of Yamoussoukro (Centre de la Côte d'Ivoire. Larhyss Journal. 2014;17:135-154. French.
23. Kpidi YH, Yapo OB, Ballet TG, Ohou-Yao M-J. Daily variability of the physicochemical quality of Lake M'koa in Jacqueville (Ivory Coast). International Journal of Biological and Chemical Sciences. 2017; 11(2): 901-910.
24. Kouamé KB. Quality and vulnerability to the population of water resources intended for drinking water: case of Lakes Guessabo and Dohou (Western Ivory Coast). Thesis from Nangui Abrogoua University, Abidjan, Ivory Coast. 2021;253. French.
25. Adolph M-L, Dreßler M, Troelstra V, Wrozyna C, Haberzettl T. Eutrophication and contamination dynamics of Schweriner See, NEGermany, during the past 670 years – A multi-proxy approach on lacustrine surface sediments and sediment cores. Science of the Total Environment. 2023; 877: 162745. DOI:https://doi.org/10.1016/j.scitotenv.2023.162745
26. Qin B, Zhang Y, Zhu G, Gao G., 2023. Eutrophication control of large shallow lakes in China. Science of The Total Environment. 2023; 881: 163494. DOI:https://doi.org/10.1016/j.scitotenv.2023.163494
27. Durand J-R, Guiral D. Hydrochemistry. In "Lagoon environments-Tome", Eds ORSTOM. 1994;59-108. French.
28. Yao MK, Yao KB, Trokourey A, Soro MB. Assessment of the trophic status of the lagoon-bay of Tiagba in Côte d'Ivoire, Australian Journal of Basic and Applied Sciences. 2010; 4:4038–4045.

29. Krachler RF, Krachler R, Stojanovic A, Wielander B, Herzig A. Effects of pH on aquatic biodegradation processes. Biogeosciences Discussions. 2009;6:491–514.
30. Ye Y, Bruning H, Liu W, Rijnaarts H, Yntema D. Effect of dissolved natural organic matter on the photocatalytic micropollutant removal performance of TiO nanotube array. Journal of Photochemistry and Photobiology A: Chemistry. 2019; 371:216-222. https://doi.org/10.1016/j.jphotochem.2018.11.012
31. Kouakou KA, Aw S, Adamou MM, Siaka S, Savane I. Characterization of the sediments of the Yamoussoukro lake system (Ivory Coast) and speciation of their phosphorus. Journal of Materials and Environmental Science. 2014;5(4):1013-1020. French.
32. Chyan JM, Huang SC, Li CJ. Impacts of salinity on degradation of pollutions in hybrid constructed wetlands. International Biodeterioration and Biodegradation. 2017;124: 176-187. DOI:https://doi.org/10.1016/j.ibiod.2017.05.018Get rights and content
33. Liu H, Lennartz B. Short Term Effects of Salinization on Compound Release from Drained and Restored Coastal Wetlands. Water. 2019; 11: 1549. DOI:https://doi.org/10.3390/w11081549
34. Abdelrady A, Sharma S, Sefelnasr A, Abogbal A, Kennedy M., 2019. Investigating the impact of temperature and organic matter on the removal of selected organic micropollutants during bank filtration: A batch study. Journal of Environmental Chemical Engineering. 2019; 7(1):102904. DOI:https://doi.org/10.1016/j.jece.2019.102904
35. Hou Y, Jia R, Ji P, Li B, Zhu J. Organic matter degradation and bacterial communities in surface sediment influenced by Procambarus clarkia. Frontiers Microbiology. 2022;13:985555. DOI:https://doi.org/10.3389/fmicb.2022.985555
36. Akinnawo OS. Eutrophication: Causes, consequences, physical, chemical and biological techniques for mitigation strategies. Environmental Challenges. 2023, 12: 100733. DOI:https://doi.org/10.1016/j.envc.2023.100733.
37. Wang Y, Guo M, Li X, Liu G, Hua Y, Zhao J, Huguet A, Li S. Shifts in microbial communities in shallow lakes depending on trophic states: Feasibility as an evaluations index for eutrophication. Ecological Indicators. 2022;136:108691. DOI:https://doi.org/10.1016/j.ecolind.2022.108691.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/108827