Journal of Materials Science and Chemical Engineering, 2022, 10, 87-99
https://www.scirp.org/journal/msce
ISSN Online: 2327-6053
ISSN Print: 2327-6045

Physico-Chemical Pollution and Trophic State of Biétry Bay (Ebrié Lagoon, Abidjan, Ivory Coast)

Dan Eude Kpannieu[1,2*], Kouakou Norbert Kouadio[2], Ignace Christian M'Bra[3], Coulibaly Nagnonta Hippolyte[2], Lacina Coulibaly[4], S. Ouffouet[5]

[1]Laboratoire de Chimie Physique et Microbiologie pour les Matériaux et l'Environnement, Université de Lorraine, Villers-lès-Nancy, France
[2]UFR Ingénierie Agronomique Forestière et Environnement, Université de Man, Man, Côte d'Ivoire
[3]Laboratoire Thermodynamique et Physico-Chimique du Milieu (LTPCM), Université Nangui Abrogoua Abidjan, Abidjan, Côte d'Ivoire
[4]Laboratoire d'Environnement et Biologie Aquatique, Université Nangui-Abrogoua, Abidjan, Cote d'Ivoire
[5]Centre Ivoirien Anti-Pollution (CIAPOL), Ministère de l'Environnement, De la Salubrité et du Développement Durable (Côte d'Ivoire), Abidjan, Cote d'Ivoire
Email: *kpannieude1@gmail.com

How to cite this paper: Kpannieu, D.E., Kouadio, K.N., M'Bra, I.C., Hippolyte, C.N., Coulibaly, L. and Ouffouet, S. (2022) Physico-Chemical Pollution and Trophic State of Biétry Bay (Ebrié Lagoon, Abidjan, Ivory Coast). *Journal of Materials Science and Chemical Engineering*, **10**, 87-99.
https://doi.org/10.4236/msce.2022.105006

Received: April 14, 2022
Accepted: May 28, 2022
Published: May 31, 2022

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Abstract

The analysis of data from the National Observation Network (RNO) of the water quality of the Ivorian Anti-Pollution Center (CIAPOL) relating to the physico-chemical quality and the trophic state of the lagoon bays of Côte d'Ivoire has allowed apprehending the degree of pollution of the bays of Biétry. This bay is heavily polluted, overall, there is a high salinity at depth between 22.5‰ and 27.5‰, a slightly basic character with a pH oscillating between 7.8 and 8.1 for surface waters and between 7, 6 and 7.8 for bottom waters. This is a very marked surface oxygenation between 100.94% and 114.72%; a slightly elevated temperature oscillating between 28.6˚C and 29˚C for surface waters and between 26.6˚C and 27.1˚C for bottom waters. This is high turbidity due to suspended solids and high nitrogen and phosphorus concentrations as well. As a result, these waters evolve towards a "mesotrophic" character according to the OECD (1982) and they are "eutrophic" according to Carlson (1977). This water is therefore impure according to the WHO concerning water intended for bathing activities.

Keywords

Bietry Bays, Pollution, Ebrié Lagoon, Eutrophic

1. Introduction

Water is of inestimable importance because it is essential not only to the natural balance, but also to the multiple needs of the population. However, water quality is influenced by demographic change and the phenomenon of industrialization. The Ebrié lagoon, located in the economic capital of Côte d'Ivoire (Abidjan), is faced with a pollution problem [1].

Thus, the lagoon ecosystem of Abidjan, the Ebrié lagoon plays an essential role of interface because it is the place of passage and exchanges between fresh water and marine water. This environment is an urban, port and industrial settlement area. It also offers significant tourist opportunities [2] [3].

This pollution comes in organic, microbial and chemical forms.

Organic pollution results from agro-food industries, domestic discharges and fertilizer residues in agriculture. As for microbial pollution, it is most often associated with organic discharges from sewers and involves pathogenic agents. Regarding chemical pollution, it comes from industrial effluents (hydrocarbons, dyes, acids, heavy metals, etc.) and agricultural activities (pesticides).

These different types of pollution lead to disturbances in the lagoon system, in particular the reduction of aquatic organisms, dissolved oxygen; the appearance of invasive aquatic plants [4].

This pollution also has consequences for the population, such as dangers to human health; obstruction of fishing and traffic; the degradation of the quality of water from the point of view of its use; the reduction of possibilities in the field of leisure, and most often the eutrophication of water bodies [5] [6].

On a global scale, the eutrophication of water bodies ranks among the most widespread pollution problems [7].

The main objective of this work is to provide information on the physical and chemical pollution of the bay of Biétry (Ebrié lagoon) and to propose, if possible, appropriate solutions for improving the quality of the water in this bay in particular and the lagoon in general.

More specifically, the aim is to study the influence of physico-chemical pollution; to estimate its degree and to determine the state of eutrophication of Bietry Bay in relation to the quality required for water intended for human activities.

2. Materials and Methods

2.1. Study Area

In Côte d'Ivoire, there are three distinct lagoons which together cover an area of about 1200 km^2. We have from west to east, the lagoon of Grand-Lahou, the Ebrié lagoon and the Aby lagoon [8].

The Ebrié lagoon is located in the south of Côte d'Ivoire, precisely in the district of Abidjan. It is located between 5˚15 and 5˚20 North latitude and between 3˚40 and 4˚50 West longitude. It extends over an area of 566 km^2, with an average depth of 4.8 m, and contains several bays including Bietry Bay which is our study area [6]. Biétry Bay is in the estuary part of the Ebrié lagoon, to the south-east of the Abidjan urban area. Communicating at its extremities with the Ebrié lagoon complex, Biétry bay has the shape of an "S" generally oriented West-East (**Figure 1**) [9].

The main opening to the West consists of a deep pass of 6.3 m maximum and a total section of 450 m^2. It emerges a few hundred meters from the Vridi canal with which it makes an angle of 60˚. At the eastern end, it communicates with the bay of Koumassi by four nozzles with a section of 16 m^2 [9]. The morphological characteristics of Biétry Bay are presented in **Table 1**.

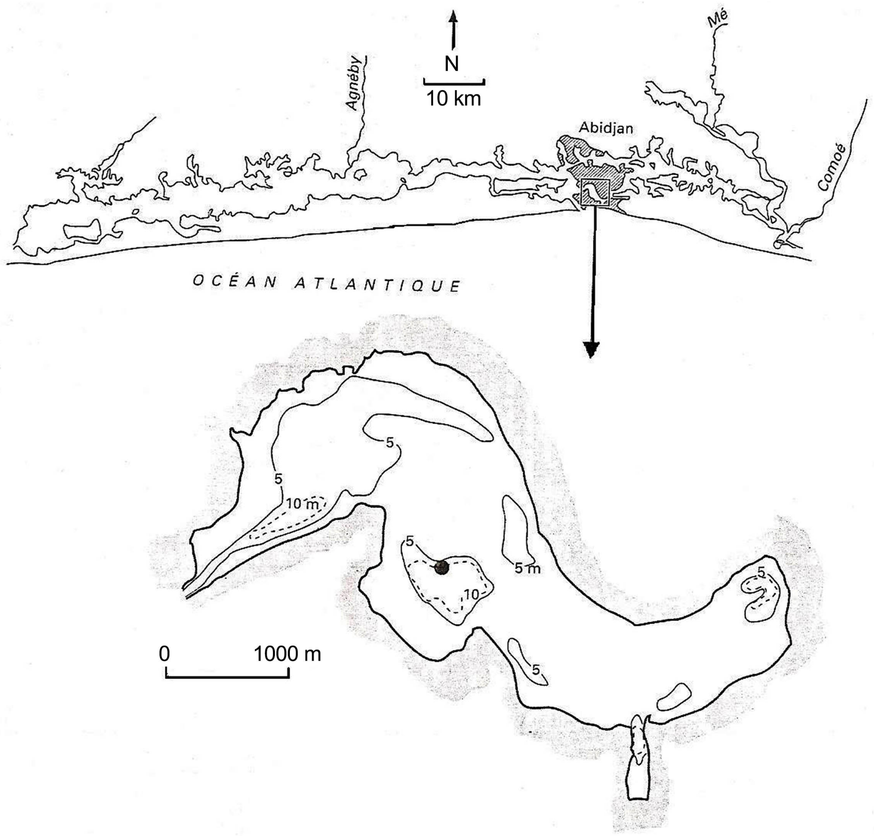

Figure 1. Location and bathymetry of Biétry Bay [9].

Table 1. Morphological characteristics of Biétry Bay [10].

Physical Parameters	Results
Area	6.05×10^6 m^2
Volume	22.91×10^6 m^3
Perimeter	16,360 m
Length	6000 m
Width	500 à 1300 m
Maximum depth	15 m
Average depth	3.8 m

2.2. Study Data

The data used to carry out this work was provided by the Ivorian Anti-Pollution Center (CIAPOL). The data are quantitative and continuous in nature. They were collected monthly over the period 1993-1998 with an average annual size of 10 samples.

2.2.1. Water Quality Monitoring

Temperature, salinity, pH and, dissolved oxygen were measured in situ using a WTW series 196 or YSI 620 M multiparameter probe. Total suspended solids (TSS) are obtained by vacuum filtration on a GF/C glass microfiber filter in accordance with the French standard AFNOR T 90-105. The concentrations ammonium, phosphate ($P\text{-}PO_4^{3-}$) and Total Phosphorus (TP) are determined by colorimetric methods. A spectrophotometer DR/2010 of HACH LANGE was used for Kjeldahl nitrogen (TKN) the titrimetric method in accordance with the French standard AFNOR T 90-11. The other parameters of this study were measured according to the French standard AFNOR T 90-11.

2.2.2. Data Analysis

Data analysis consisted of calculating the means and standard deviations of the physic-chemical parameters made available to us. Except for the temperature, the average values were calculated according to formula (1) during all the periods considered With:

$$M = \frac{\sum_{i=1}^{n} C_i}{N} \tag{1}$$

$$T_m = \frac{T_{\max} - T_{\min}}{2} \tag{2}$$

M: Arithmetic mean; C_i: monthly value of the parameters; *N*: Number of samples taken; Σ: Algebraic sum. Concerning the arithmetic means of the temperatures (T_m), they were obtained from half of the sums of the maximum temperatures (T_{max}) and the minimum temperatures (T_{min}) (Relation 2).

$$C_v = \frac{\sigma}{M} \tag{3}$$

$$\sigma = \sqrt{\frac{\sum (M - C_i)^2}{N - 1}}$$

The Coefficient of Variation (C_v) was calculated according to equation (3). It provides information on the relative dispersion of the data. It is the result of the ratio of the standard deviation to the mean. With C_v: Coefficient of variation and σ (Standard deviation).

For the estimation of the trophic state of Biétry Bay, three (3) methods were used, namely two (2) methods according to the OCDE classification (1982) and one Carlson method (1977). The first method of the [11] namely determined limit value system gave us the summary of the geometric means of the quality parameters of the bay of Biétry from 1993 to 1998. These means allowed by the to classify the trophic state of this berry.The second method [11] is a qualitative prediction of trophic status. It consists in projecting the annual averages of the concentrations of the parameters (total phosphorus, average chlorophyll a) and the peak of chlorophyll a per year on their respective logarithmic curves.The third method, that of [12], is based on empirical formulas considering the transparency of the Secchi disc, total phosphorus and chlorophyll a. [12] carried out this study on bodies of water by classifying them according to their trophic level. The empirical formulas give us indices of the trophic state which allow us to classify the bay of Biétry. According to this author, the trophic state index (TSI) is calculated as follows:

$$TSI\ (SD) = 10\ (6 - \ln SD/\ln 2)$$

$$TSI\ (Chl) = 10\ (6 - (2.04 - 0.68\ \ln Chl)/\ln 2)$$

$$TSI\ (TP) = 10\ (6 - \ln(48/TP)/\ln 2)$$

where

TSI: Trophic Status Index

SD: Secchi disk transparency (m)

Chl: Chlorophyll a (μg/l)

TP: Total phosphorus (μg/l).

Several authors agree on this method of classification. According to [13] [14] and [15], the classification of the trophic state of water bodies is done as follows:

- Oligotrophic: TSI ≤ 40
- Mesotrophic: 40 < TSI ≤ 50
- Eutrophic: 50 < TSI.

3. Results and Discussion

3.1. In Situ Analyses (Temperature, Sanility, Conductivity, Dissolved Oxygen, pH)

Spatial variations in temperature are generally characterized by a weak vertical gradient with a slight warming of surface waters. This slight warming would be linked to the temperature of the ambient air. The analysis showed that the temperatures obtained are high at the surface as well as at the bottom, but the waters at depth are slightly colder than those at the surface. These results confirmed the conclusions of several authors (**Figure 2(a)**). This would be linked to the contact of the lagoon with the waters of the sea which have lower temperatures as reported by [16]. According to [17], these high temperature values play a fundamental role in the kinetics of biological and physico-chemical reactions in water. Biétry Bay behaves like a tropical lake because its temperature does not drop below 10˚C [7].

About salinity (**Figure 2(b)**), the low value in surface waters (22.6‰) compared to that of deep waters (27.5‰) could be explained by the circulation of water by a superficial flow of less salty water towards the sea and an underlying flow of salty water in the opposite direction [18]. According to [16], the hydroclimate of the estuary part of the Ebrié lagoon evolves under a double continental oceanic control. Indeed, the fresh waters are desalinated, they penetrate the lagoon while the salty ocean waters penetrate there by the depth. This would explain the high saline concentration at the bottom of the bay compared to the surface. Also, Biétry bay, more isolated and closer to the Vridi Canal, is salty, because it is less influenced by flood waters. These results agree with those of [19].

Like salinity, bottom conductivity is greater than surface conductivity. Indeed, conductivity measures the ability of water to conduct electric current between two electrodes. Most dissolved solids in water are in the form of electrically charged ions. The variations in conductivity (**Figure 2(c)**) observed confirm the quantities of dissolved salts.

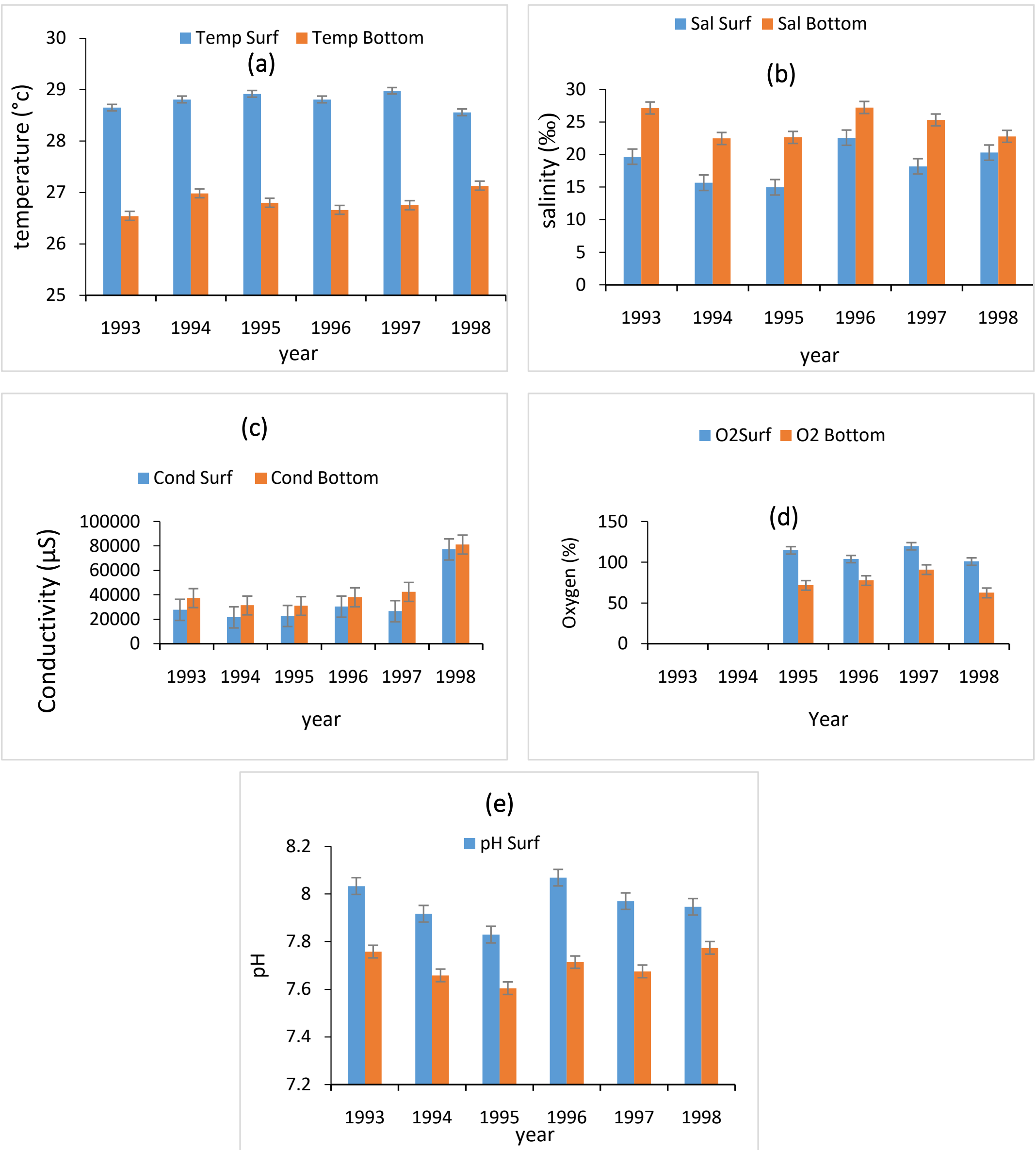

Figure 2. Average annual variation of parameters measured in situ in Bietry bay, Surface and Bottom: temperature (a), salinity (b), conductivity (c), dissolved oxygen (d), pH (e).

Concerning the dissolved oxygen content per year (**Figure 2(d)**), it is generally higher at the surface and slightly lower at the bottom. These concentration fluctuations would come from the phenomena of enrichment (photosynthesis and exchanges with the atmosphere) and consumption (respiration and oxidation); circulation and renewal of water in the bay of Biétry. According to [20], the accumulation of indigenous organic matter causes oxygen consumption in deep waters isolated from the surface. This would explain the difference in concentration between the surface and the bottom. These phenomena would also explain the high pH value of the surface waters of Biétry Bay compared to that of the pH at depth. Indeed, said bay has a slightly basic character. The pH of its surface waters changes on the one hand, according to salinity and on the other hand according to the biological activity of the environment. This pH also depends on dissolved oxygen and the phenomenon of nitrification [21]. Indeed, according to [22], nitrification causes a decrease in the pH and alkalinity of the water. According to [23], in running waters where the pH is between 6.5 and 8.5, most of the ammoniacal nitrogen is in the ionized form (NH_4^+). In the case of Biétry Bay, where the average annual pH is between 7.8 and 8.1 for surface waters and between 7.6 and 7.8 for deep waters, most of the Ammonia nitrogen is also in the form of ammonium ion (NH_4^+)

3.2. Phosphorus and Nitrogen: Ammonium Ions (NH_4^+), Nitrite (NO_2^-) and Orthophosphate Ions (PO_4^{3-})

The annual population growth rate is estimated at almost 5% in the Ivorian capitals (Abidjan) [24] [25] [26]. However, these populations generate large volumes of wastewater which is barely treated before being discharged into the natural environment [27] For example, in Abidjan, the daily volume of wastewater collected is approximately 190,000 m^3. In addition, the four activated sludge treatment stations installed in Abidjan no longer work (Yao *et al.,* 2009) [28]. Thus, Abidjan's wastewater does not undergo any treatment before being discharged into the Ebrié lagoon [5] [28]. Consequently, the high degree of pollution of the Ebrié lagoon makes it dangerous both for humans living near the lagoon and for the practice of lucrative activities and fishing [4] [6].

One of the significant environmental impacts of limited wastewater treatment is the introduction of excess phosphorus and nitrogen into the Ebrié lagoon [1], leading to a clearly demonstrated state of eutrophication by the invasion of algae, aquatic plants and bacteria of faecal origin [6] [29]. The presence of the ammonium ion would also come from the transformation of organic nitrogen from wastewater into ammoniacal nitrogen by bacteria. Ammonium is generally more present in surface waters throughout the study period, reflecting the more reducing character of the layers at depth (**Figure 3(a)**).

Nitrates are the most important nitrogen species. The importance of nitrates observed would result from the contribution of agricultural activities, urban discharges, and chemical industries on the edge of the lagoon as well as nitrification [22]. Nitrate concentrations are higher at depth than at the surface (**Figure 3(b)**). Indeed, [23] indicate that part of the nitrate is consumed at the surface by macrophytes; which limits the transfer in the further reducing depth. Nitrites and phosphates come from organic matter. The level of nitrites generally decreases with depth while that of phosphate increases. The presence of nitrites in surface waters is generally due to the bacterial oxidation of ammonia or the reduction of nitrates (used as a preservative).

3.3. Total Suspended Solids (TSS) and Chlophyll a (Chl)

The measurement of chlorophyll a is used as an indicator of phytoplankton biomass in natural waters. It represents the most important pigment in aerobic photosynthetic organisms (excluding cyanobacteria); all algae contain it. Cellular chlorophyll a content is 1% to 2% of dry weight. The chlorophyll pigment levels within the surface layer vary geographically from one end of Biétry Bay to the other, but also seasonally and depending on the year [3].

Chlorophyll a concentrations are very limited at depth than at the surface (**Figure 4(a)**). This could be explained by a difference in dissolved oxygen concentration from the surface (high) to the depth (low). The waters of Biétry Bay are murky. This would be due to the invasion of floating macrophytes which slow down the flow of river water, thus promoting particulate sedimentation of

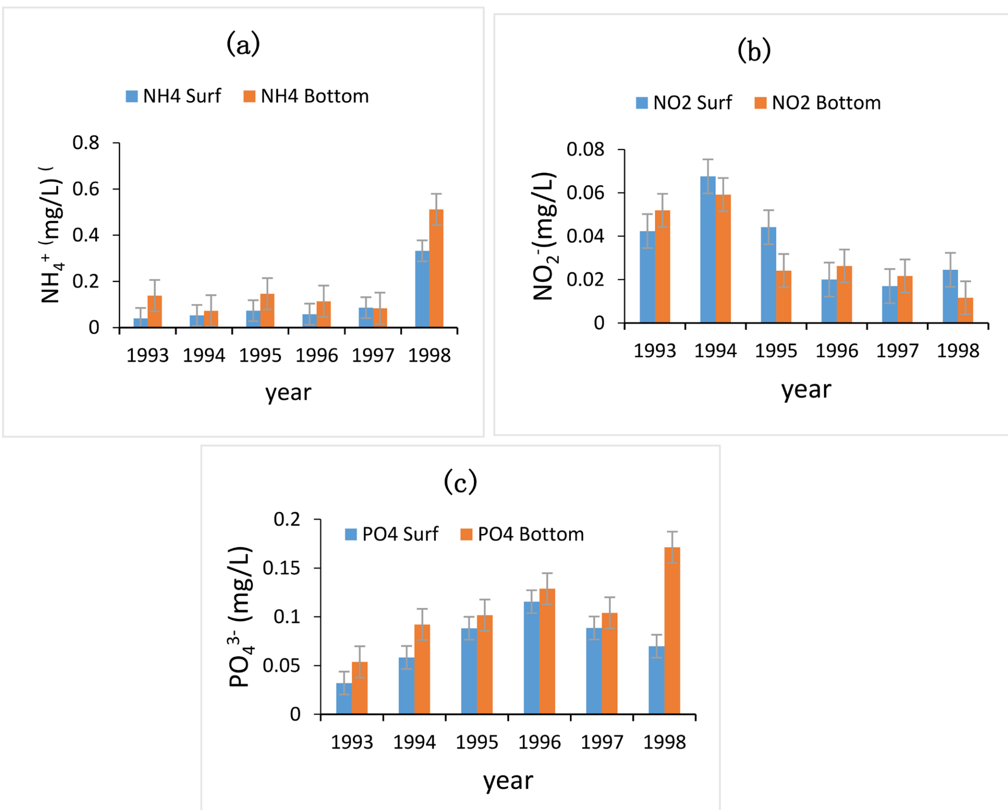

Figure 3. Average annual variation of Phosphorus and nitrogen in Bietry bay, Surface and Bottom: Ammonium ions (a), Nitrite (b) and Orthophosphate ions (c).

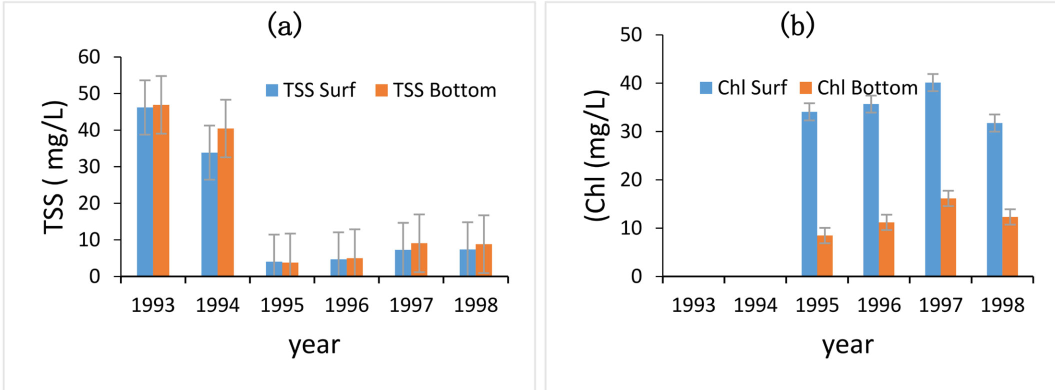

Figure 4. Average annual variation in Bietry bay, Surface and Bottom: Total Suspended Solids (TSS) (a) and Chlophyll a (Chl) (b).

the bay. It would also come from uprooting forces by friction and erosion of the banks; moreover, these particles can reach the aquatic ecosystem through the effect of runoff over the entire catchment area. Finally, discharges from human activities would contribute to these inputs of suspended matter [22]. In the western part, the values are low in the rainy season. On the other hand, the flood period is characterized by very low concentrations linked to the high turbidity of the river waters and their short residence time. Concerning the central part, the variability is less and the contents of the base are higher. As for the eastern part of the bay, it has the highest chlorophyll biomass. There is a succession over time of strong algal blooms (with values greater than 100 mg/m^3); from a base of around 50 mg/m^3. These developments do not appear to be linked to a seasonal event, but stem from the very "eutrophic" character of this part of the bay [3].

Aphotic deep waters have a very limited chlorophyll biomass, essentially represented by pheopigments, due to their transit in a reducing environment, and the absence of new production [9]. As for Total Suspended Solids (TSS) (**Figure 4(b)**), they are visible indicators of the pollution of aquatic environments. Indeed, water rich in suspended solids raises doubts about its potability character. Suspended solids, in large numbers in an aquatic environment, lead to a reduction in light scattering in the water column. What reduces the photosynthetic activities therefore causes a reduction in the dissolved oxygen content [22].

Trophic analysis of Biétry Bay According to [12]

Table 2 highlights the classification of the trophic state of Biétry Bay according to [12].

According to the approach of the limit values of the [11], we note over the period of study that the classification presents two trophic states for the same body of water. The method without limit value which gives us probabilities of the trophic state of the bay aims to consider the uncertainty affecting the data when classifying a body of water in a particular category [30]. Thus, the probability aspect is now an important element of appreciation when applying this system for forecasting purposes [11]. The limits of these two methods would be due to

Table 2. Trophic state of Biétry Bay according to the Carlson method [12].

Year	Total phosphorus (µg/l)	TSI (TP)	Chlorophyll a (µg/l)	TSI (Chl)	Trophic state
1993	418.4	91.3	(Nil)	(Nil)	Eutrophic
1994	752.9	99.71	(Nil)	(Nil)	Eutrophic
1995	1322.5	107.84	2126.35	105.63	Eutrophic
1996	1217.2	106.64	23442	129.27	Eutrophic
1997	963.3	103	28116.16	131.64	Eutrophic
1998	1667.2	111.18	22016	128.66	Eutrophic

climate change (from temperate to tropical) and to their adaptation to the body of water (Bay of Biétry) which is not a lake.

As for the classification according to [12] based on empirical formulas considering account chlorophyll a, total phosphorus and transparency of the Secchi disc, the analysis of Table II indicates that total phosphorus and average chlorophyll a all have high trophic state indices (TSI), (TSI > 50) over all of their study periods. According to [12], these high values of TSI represent in the classification of the trophic state, the "eutrophic" character. In other words, Biétry Bay presents a single trophic state with Carlson's method (1977). Throughout our study period, Biétry Bay is eutrophic with a very critical increase in the trophic state index (IST). This method would seem more effective than the first two because several authors approve of it.

4. Conclusion

The Ebrié lagoon has several bays which directly receive untreated liquid effluents (domestic and industrial). As part of our study, we limited ourselves to the bay of Biétry. Although relatively isolated from the Ebrié lagoon complex, Biétry Bay remains largely affected by the seasonal hydrological phenomena that affect the lagoon. The physico-chemical parameters of the bay are subject to variations linked to the Comoé floods, rainfall and tides. At the end of our study, we found that the waters of the bay had a eutrophic character with strong physical and chemical pollution. Measures must therefore be taken to avoid possible ecological and human disasters (human health). It is therefore essential that a permanent control of the quality of the waters of the bay of Biétry in particular and of the Ebrié lagoon in general, be encouraged and that strict regulations be applied about the discharge zones. It would even be advisable to prevent any discharge of effluents into the lagoon or to promote the treatment of wastewater before it is discharged into the lagoon. As for the treatment of eutrophication, it depends closely on the control of the main responsible factor, in particular the excessive supply of nutrients favoring the development of aquatic plants. Experience shows that reducing exogenous phosphorus inputs is one of the effective measures to combat eutrophication. We therefore offer self-purification techniques such as lagooning or the treatment of wastewater by Constructed wetlands, which have the advantage of low investment and operating costs, good landscape integration and valuation aquaculture and biomass produced.

Acknowledgements

The authors would like to thank the CIAPOL management and its technicians for the data made available to us.

Conflicts of Interest

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

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