

(RESEARCH ARTICLE)



## SPATIO-TEMPORAL OF WATER QUALITY AND NUTRIENTS IN THE TROPICAL EBRIÉ LAGOON, CÔTE D'IVOIRE

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World Journal of Advanced Research and Reviews, 2026, 31(03), 1944–1954

Publication history: Received on 17 August 2026; revised on 24 September 2026; accepted on 26 September 2026

Article DOI: <https://doi.org/10.30574/wjarr.2026.31.3.2476>

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### ABSTRACT

This study assessed the spatial and seasonal variability of physicochemical parameters and nutrient concentrations in sectors IV and V of the Ebrié lagoon, following reports of massive fish mortality. Monthly water sampling was conducted at 11 stations from February 2014 to January 2015. Temperature, pH, salinity, conductivity, dissolved oxygen, transparency, suspended matter, nitrate, nitrite, ammonium and orthophosphate were measured. Seasonal differences were evaluated using analysis of variance, and principal component analysis (PCA) was used to identify station groups and relationships among variables. Water temperature ranged from 28.0 to 31.4 °C, and dissolved oxygen concentrations ranged from 4.4 to 8.7 mg/L. Salinity and conductivity were generally higher during the dry season, whereas ammonium and orthophosphate concentrations tended to increase during the rainy season. Nitrate concentrations were higher during the dry season at several stations, reaching 5.29 mg/L. Nitrite concentrations reached 0.71 mg/L and were generally higher during the rainy season. These elevated nitrite concentrations may pose a risk to aquatic organisms. PCA distinguished three station groups associated with differing nutrient levels and physicochemical conditions. Salinity was strongly correlated with conductivity, while orthophosphate was negatively correlated with water transparency ( $r = -0.96$ ). Overall, the results indicate seasonal variation in water quality, with rainy-season nitrite elevation warranting continued monitoring of the lagoon's aquatic environment.

**Keywords:** Physicochemical Parameters, Fish Mortality, Season, Marine Water, Agnèby River.

### 1 INTRODUCTION

Coastal lagoons are ecosystems of high ecological value, supporting diverse biological communities, economic activities, and scientific research. However, these fragile environments are increasingly threatened by pollution resulting from

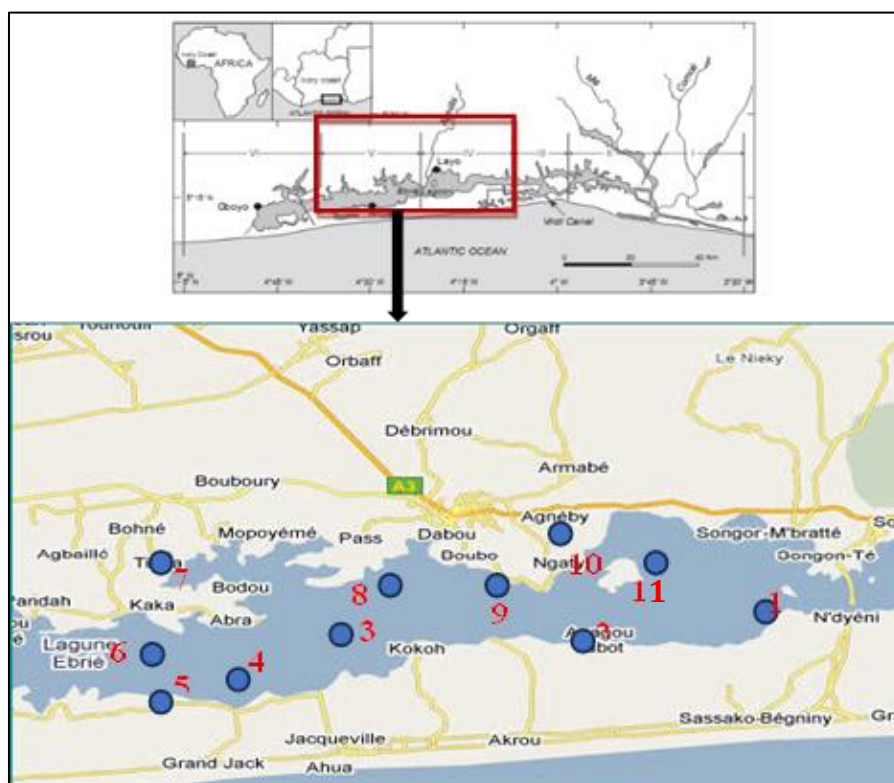
anthropogenic activities [1,2]. Such pressures can degrade water quality, threaten biodiversity and contribute to its decline [3].

In Côte d'Ivoire, the Ebrié lagoon, the country's largest lagoon system is similarly affected. Its water quality is strongly influenced by anthropogenic activities carried out by populations living along its shores [4,5]. The lagoon receives substantial volumes of industrial, hospital, and domestic wastewater discharges from surrounding cities [6]. Consequently, the degradation of its waters has become a complex environmental issue with significant ecological and socioeconomic implication [7]. Recent studies conducted in sectors I, II, and III of the Ebrié lagoon have revealed that these waters are heavily affected by pollutants [8, 9, 4,10]. Earlier investigation by [11] and [12] also characterized the Ebrié lagoon across all its sectors. Nevertheless, sectors IV and V have received little recent scientific attention. Since October 1999, sudden and massive fish mortality has been recorded in these sectors particularly within the Jacquleville and Dabou districts. The recurrent phenomenon intensified in May 2013, resulting in the suspension of fishing activities and the closure of aquaculture farms in the affected lagoon areas. These events highlight the need for an updated environmental characterization on this part of the Ebrié lagoon, with particular emphasis on physicochemical parameters and nutrient salts.

This study forms part of a multidisciplinary project led by the Oceanology Research Center (CRO), titled "Study of the impact of environmental changes on the vulnerability of fishery resources in the area between Jacquleville and Dabou (Ebrié lagoon)." Its main objective is to assess the spatiotemporal variability of physicochemical parameters and nutrient salts in the waters of sectors IV and V of the Ebrié lagoon.

## 2 MATERIALS AND METHODS

### 2.1 Study Area



**Figure 1: Sampling stations (1 N'djèm; 2 Taboth; 3 Koko; 4 Bapo; 5 Ahua; 6 Abraco; 7 Mopoyèm; 8 Gboubo; 9 Layo; 10 Papoga; 11 Songon) on the Ebrié lagoon: sector IV and V. [15 modified]**

Sectors IV and V of the Ebrié lagoon are located in the "Grands Ponts" Region, within the Jacquleville and Dabou departments of Côte d'Ivoire (Figure 1). These departments have populations of 52,871 and 65,119, respectively, according to the 1998 General Census of Population and Housing (RGPH-98). The area is bordered by large coconut, banana, palm, pineapple, and rubber plantations and includes several fishing villages. Agrochemicals are frequently used illegally to catch fish. Consequently, several cases of poisoning have been reported following the consumption of contaminated fish [13,14]. It is bordered by large coconut, banana, palm, pineapple, and rubber plantations and is home

to several fishing villages. Agrochemicals are often used illegally to catch fish. As a result of this practice, several cases of poisoning have been reported following the consumption of contaminated fish [13,14].

## 2.2 Measurement of physicochemical parameters

Water sampling and measurements of physicochemical parameters were conducted monthly from February 2014 to January 2015. Temperature (°C), salinity (‰), dissolved oxygen (mg/L), conductivity (mS/cm), and pH were measured *in situ* at a depth of 0.5 m using a YSI 6920 multiparameter probe aboard the vessel. Water transparency (m) was determined using a Secchi disk. The disc was lowered into the water until it completely disappeared from view and was then gradually raised to determine the visibility depth. In the laboratory, suspended matter (SM) was determined according to the method described by [16] and the AFNOR standard NF T90-105 [17]. A 250 ml field-collected water sample was filtered through a membrane filter to retain particles larger than 5 µm. The filter was dried and weighed before and after filtration. The difference in mass allowed for the determination of the total dry mass of the suspended matter. The quantity of dry matter was calculated using the formula:

$$SM = (m_2 - m_1) / V$$

where  $m_1$  is the mass of the filter before filtration;  $m_2$  is the mass of the filter after filtration and drying, and  $V$  is the volume of water analyzed.

## 2.3 Determination of nutrient salt concentrations

Nitrates ( $\text{NO}_3^-$ ), nitrites ( $\text{NO}_2^-$ ), and ammonium ( $\text{NH}_4^+$ ) concentrations are measured calorimetrically following the method of [18], as described by [16]. Orthophosphate ( $\text{PO}_4^{3-}$ ) concentrations were determined using the method of [19]. For nitrate analysis, 0.5 mL of sodium azide and 0.2 mL of glacial acetic acid were added to 10 mL of the water sample. After mixing, 1 mL of sodium salicylate solution was added. The mixture was heated in a water bath (100°C), and after cooling, 1 mL of sulfuric acid is added. The sample is analyzed using a spectrophotometer at a wavelength of 415 nm, and the nitrate concentration (in mg/L) corresponding to the absorbance value is determined using a calibration curve plotted prior to analysis. For nitrite analysis, 1 mL of sulfanilamide reagent (reagent 1) was added to 10 mL of the water sample; the mixture was shaken vigorously and allowed to stand for 2 to 8 minutes, after which 1 mL of N-1-naphthylethylenediamine solution (reagent 2) is added after 15 min, absorbance was measured at 543 nm using a spectrophotometer. Nitrite concentrations (mg/L) were determined from a calibration curve prepared before analysis.

Ammonium was determined by adding 1 mL of reagent 1 to a 20 mL test portion, following by vigorously shaking for a few seconds. Subsequently, 1 mL of reagent 2 was added. Samples were kept protected from light for at least 6 hours before spectrophotometric analysis at 630 nm. Ammonium ion concentrations in the test portions were determined from a calibration curve and expressed in mg/L. A division factor of 0.018 was applied to the results to convert them to mg/L. Orthophosphate was determined calorimetrically using [19] method. A reagent mixture was prepared by combining 10 mL of ammonium molybdate solution, 5 mL of antimony potassium tartrate, 25 mL of sulfuric acid, and 10 mL of ascorbic acid solution. One (1) mL of the reagent mixture was added to a 10 mL test portion and the immediately homogenized by agitation. After 5 min, the absorbance was measured spectrophotometrically at 885 nm. Orthophosphate concentrations, expressed in mg/L, were determined from a calibration curve prepared before analysis.

## 2.4 Statistical analysis

Analysis of variance (ANOVA) was performed to test for significant differences in means by comparing variances across seasons. Principal Component Analysis (PCA) was conducted on a data matrix comprising 132 records. The variables consisted of measured values for seven physicochemical parameters (temperature, pH, dissolved oxygen, salinity, conductivity, transparency, and suspended solids) and four nutrients ( $\text{NO}_3^-$ ,  $\text{NO}_2^-$ ,  $\text{NH}_4^+$ ,  $\text{PO}_4^{3-}$ ). This matrix was constructed using the mean values of environmental variables across all stations, categorized by dry and rainy seasons. It enabled the grouping of stations sharing similar characteristics. All statistical analyses were performed using STATISTICA 7.1 and Microsoft Excel 2007 software.

# 3 RESULTS

## 3.1 Physicochemical parameters

Seasonal variations in physicochemical parameters are presented in Table 1. Water temperature across all stations ranged from  $30.1 \pm 0.2^\circ\text{C}$  to  $31.4 \pm 0.8^\circ\text{C}$  during the dry season and from  $28.0 \pm 2.1^\circ\text{C}$  to  $29.2 \pm 2.3^\circ\text{C}$  during the rainy season. Statistical analysis (ANOVA) revealed a significant difference ( $p < 0.05$ ) between seasons at Papoga and Layo. The highest water temperature was recorded during the dry season ( $31.49 \pm 0.2^\circ\text{C}$ ). Water pH ranged from  $6.7 \pm 0.4$  during the rainy season to  $7.9 \pm 0.4$  during the dry season. Values were alkaline at all stations during the dry season,

whereas rainy-season pH values ranged from slightly acidic to near-neutral. ANOVA analysis revealed a significant difference ( $p < 0.05$ ) between seasons for Abraco, N'djem, Mopoyem, Layo, Papoga, and Songon. Lagoon salinity ranged from  $2.85 \pm 0.77$  to  $9.79 \pm 0.79\text{‰}$  during the dry season and from  $1.58 \pm 2.15$  to  $4.41 \pm 1.03\text{‰}$  during the rainy season.

**Table 1: Seasonal variation of physicochemical parameters measured from February to July 2014 in sectors IV and V of the Ebrié lagoon.**

|                | Saisons | Temp                  | pH                   | Sal                  | Cond     | O <sub>2</sub>       | Transp               | SM                   |
|----------------|---------|-----------------------|----------------------|----------------------|----------|----------------------|----------------------|----------------------|
| <b>Ahua</b>    | DS      | 30.1±0.2              | 7.6±0.2              | 3.3±0.5              | 6.1±0.9  | 5.7±1.4 <sup>a</sup> | 1.3±0.1              | 7.0±0.9              |
|                | RS      | 28.9±1.8              | 7.5±0.6              | 4.3±1.0              | 8.6±2.1  | 8.7±1.9 <sup>b</sup> | 1.6±0.4              | 16.6±5.8             |
| <b>Koko</b>    | DS      | 30.2±0.1              | 7.5±0.1              | 3.3±0.5              | 6.1±0.9  | 4.4±2.0 <sup>a</sup> | 1.5±0.1              | 8.1±4.3 <sup>a</sup> |
|                | RS      | 29.0±1.7              | 7.4±0.6              | 4.4±1.0              | 8.6±2.1  | 8.5±1.9 <sup>b</sup> | 1.3±0.0              | 3.9±1.0 <sup>b</sup> |
| <b>Bapo</b>    | DS      | 30.4±0.1              | 7.9±0.4              | 3.5±0.3              | 6.5±0.7  | 5.8±2.4              | 1.2±0.1              | 6.5±2.8              |
|                | RS      | 28.8±1.8              | 7.5±0.8              | 4.3±1.1              | 8.4±2.2  | 8.5±2.1              | 1.5±0.3              | 7.0±1.4              |
| <b>Taboth</b>  | DS      | 30.6±0.2              | 7.6±0.2              | 5.1±1.3              | 9.3±2.2  | 5.3±2.3              | 1.3±0.2              | 17.2±5.6             |
|                | RS      | 28.7±1.6              | 7.0±0.5              | 4.0±1.5              | 7.9±3.0  | 7.7±3.1              | 1.1±0.0              | 12.0±6.1             |
| <b>N'djem</b>  | DS      | 30.7±0.5              | 7.8±0.2 <sup>a</sup> | 9.7±0.7 <sup>a</sup> | 16.7±0.1 | 5.7±0.8              | 1.3±0.1              | 12.2±3.7             |
|                | RS      | 29.2±2.2              | 6.9±0.6 <sup>b</sup> | 4.1±0.4 <sup>b</sup> | 8.0±8.1  | 5.5±2.8              | 1.1±0.3              | 10.4±3.7             |
| <b>Songon</b>  | DS      | 31.0±0.4              | 7.9±0.3 <sup>a</sup> | 9.4±0.1 <sup>a</sup> | 16.2±2.5 | 5.8±0.9              | 1.0±0.0              | 11.2±2.9             |
|                | RS      | 29.2±2.3              | 6.7±0.5 <sup>b</sup> | 3.6±4.4 <sup>b</sup> | 7.2±8.4  | 6.3±3.4              | 0.9±0.3              | 12.3±2.7             |
| <b>Papoga</b>  | DS      | 31.4±0.8 <sup>a</sup> | 7.8±0.1 <sup>a</sup> | 5.6±0.5              | 9.5±0.2  | 6.7±1.8              | 1.0±0.0              | 13.2±5.4             |
|                | RS      | 28.5±2.1 <sup>b</sup> | 6.9±0.7 <sup>b</sup> | 2.6±3.1              | 5.3±6.0  | 7.0±2.2              | 0.8±0.2              | 18.9±5.3             |
| <b>Layo</b>    | DS      | 31.4±0.5 <sup>a</sup> | 7.8±0.1 <sup>a</sup> | 4.7±0.7              | 6.1±0.9  | 6.5±2.0              | 0.9±0.0              | 15.8±6.1             |
|                | RS      | 28.0±2.1 <sup>b</sup> | 6.8±0.7 <sup>b</sup> | 1.5±2.1              | 3.2±4.2  | 4.9±2.8              | 0.6±0.2              | 18.1±2.3             |
| <b>Mopoyem</b> | DS      | 30.6±0.5              | 7.8±0.3 <sup>a</sup> | 2.8±0.7              | 5.3±1.3  | 5.1±2.1              | 1.1±0.4              | 11.5±5.9             |
|                | RS      | 29.1±1.9              | 6.9±0.6 <sup>b</sup> | 3.6±1.3              | 7.3±2.7  | 5.2±3.3              | 1.0±0.0              | 17.2±6.6             |
| <b>Abraco</b>  | DS      | 30.4±0.0              | 7.7±0.5 <sup>a</sup> | 3.3±0.7              | 6.2±0.9  | 5.7±2.1              | 1.3±0.4              | 8.6±4.1              |
|                | RS      | 28.8±2.1              | 6.7±0.4 <sup>b</sup> | 4.3±1.0              | 8.3±2.1  | 7.0±0.8              | 1.3±0.2              | 6.2±3.5              |
| <b>Gboubo</b>  | DS      | 30.5±0.2              | 7.8±0.1              | 5.1±0.6              | 6.1±0.9  | 6.7±1.8              | 1.0±0.0 <sup>a</sup> | 14.7±5.3             |
|                | RS      | 28.5±2.0              | 7.3±0.7              | 4.1±1.4              | 8.1±2.9  | 7.2±2.4              | 1.3±0.0 <sup>b</sup> | 19.5±5.7             |

Values in the same column bearing superscript letters (a, b) indicate a difference between seasons ( $p < 0.05$ ) for a given station. DS = Dry season; RS = Rainy season. Temp: Temperature (°C); pH : pH level; Sal : Salinity (‰); O<sub>2</sub> : Dissolved oxygen (mg/L) ; Cond : Conductivity (mS/cm) ; Transp: Transparency (m); SM : Suspended matter (mg/L).

Significant seasonal differences in salinity were observed at Songon and N'djem stations ( $p < 0.05$ ), where the highest salinity values occurred during the dry season and the lowest during the rainy season. Seasonal conductivity ranged from  $5.33 \pm 1.30$  to  $16.72 \pm 0.14$  mS/cm during the dry season and from  $3.2 \pm 4.2$  to  $8.6 \pm 2.1$  mS/cm during the rainy season. Dissolved oxygen levels across all stations ranged from  $4.4 \pm 2.0$  mg/L to  $8.7 \pm 1.9$  mg/L. Analysis of variance showed a significant difference ( $p < 0.05$ ) between seasons for Ahua and Koko. Generally, dissolved oxygen levels increase during the rainy season and decrease during the dry season. Water transparency and suspended matter concentrations ranged from  $0.6 \pm 0.2$  m to  $1.6 \pm 0.4$  m and from  $3.9 \pm 1.0$  mg/L to  $19.5 \pm 5.7$  mg/L, respectively. These two parameters showed no significant inter-seasonal variation ( $p > 0.05$ ) at almost all stations, with the exception of Gboubo for transparency and Koko for suspended matter. At these stations, transparency remained relatively stable, whereas the level of suspended matter increases during the hot season.

### 3.2 Nutrient salts

Values for nitrate (NO<sub>3</sub><sup>-</sup>), nitrite (NO<sub>2</sub><sup>-</sup>), ammonium (NH<sub>4</sub><sup>+</sup>), and orthophosphate (PO<sub>4</sub><sup>3-</sup>) in the waters of sectors IV and V of the Ebrié lagoon are presented in Table 2. Nitrate concentrations ranged from  $0.12 \pm 0.1$  mg/L to  $5.29 \pm 2.5$  mg/L, whereas nitrite concentrations ranged from  $0.04 \pm 0.0$  mg/L to  $0.71 \pm 0.1$  mg/L. Nitrate concentrations differed

significantly between the dry and rainy seasons at the Songon and N'djem stations ( $p < 0.05$ ), while a statistical difference regarding nitrite concentrations were observed only at Layo. Nitrate concentrations were generally higher during the dry season, whereas nitrite concentrations were higher during the rainy season. Ammonium and orthophosphate concentrations ranged from  $0.04 \pm 0.0$  mg/L to  $0.23 \pm 0.1$  mg/L and from  $0.02 \pm 0.0$  mg/L to  $0.09 \pm 0.0$  mg/L, respectively. A significant seasonal difference ( $p < 0.05$ ) in ammonium concentrations was observed at Layo, N'djem, Abraco, Papoga, Mopoyem, and Gboubo. Seasonal orthophosphate concentrations also differed statistically ( $p < 0.05$ ) at the Layo, Papoga, Songon, N'djem, and Taboth stations. Overall, Ammonium and orthophosphate concentrations were higher during the rainy season and lower during the dry season.

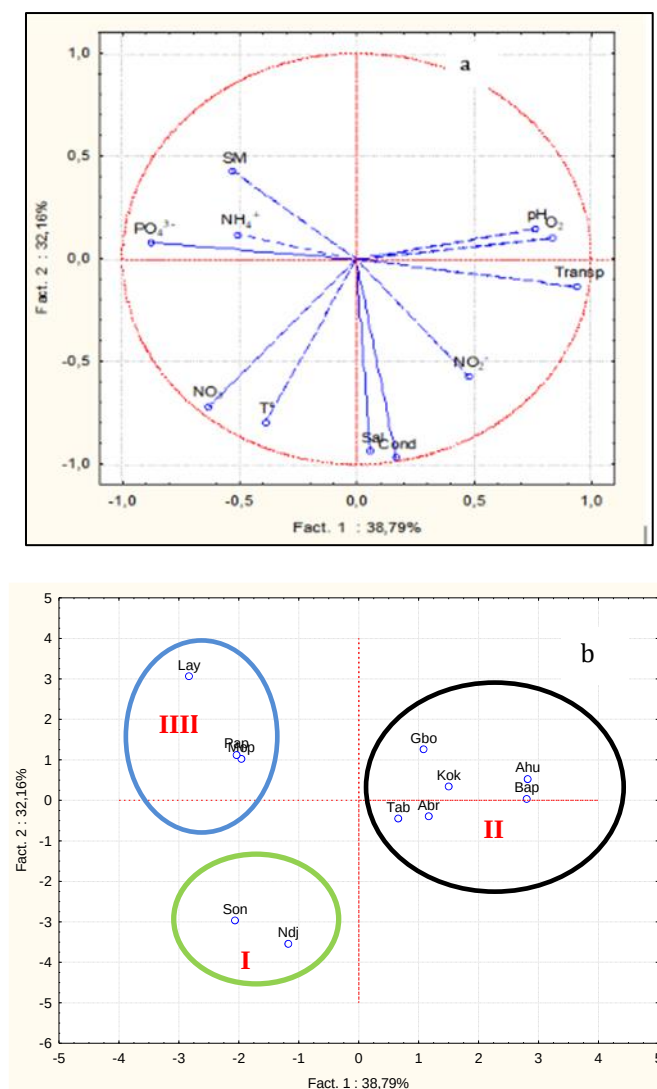
**Table 2: Seasonal variation of nutrient salts concentrations (measured in mg/L) from February to July 2014 in sectors IV and V of the Ebrié lagoon.**

|                | Saisons | Nitrate          | Nitrite          | Ammonium         | Orthophosphate   |
|----------------|---------|------------------|------------------|------------------|------------------|
| <b>Ahua</b>    | DS      | $0.58 \pm 0.6$   | $0.04 \pm 0.0$   | $0.09 \pm 0.0$   | $0.02 \pm 0.0$   |
|                | RS      | $0.29 \pm 0.1$   | $0.49 \pm 0.8$   | $0.09 \pm 0.0$   | $0.03 \pm 0.0$   |
| <b>Koko</b>    | DS      | $0.90 \pm 1.0$   | $0.04 \pm 0.0$   | $0.08 \pm 0.0$   | $0.02 \pm 0.0$   |
|                | RS      | $0.55 \pm 0.2$   | $0.14 \pm 0.2$   | $0.21 \pm 0.2$   | $0.02 \pm 0.0$   |
| <b>Bapo</b>    | DS      | $1.0 \pm 1.0$    | $0.06 \pm 0.0$   | $0.08 \pm 0.0$   | $0.03 \pm 0.0$   |
|                | RS      | $0.35 \pm 0.2$   | $0.55 \pm 0.7$   | $0.13 \pm 0.0$   | $0.03 \pm 0.0$   |
| <b>Taboth</b>  | DS      | $1.37 \pm 1.7$   | $0.05 \pm 0.0$   | $0.06 \pm 0.0$   | $0.03 \pm 0.0^a$ |
|                | RS      | $0.47 \pm 0.2$   | $0.71 \pm 0.1$   | $0.13 \pm 0.0$   | $0.05 \pm 0.0^b$ |
| <b>N'djem</b>  | DS      | $5.31 \pm 1.9^a$ | $0.39 \pm 0.1$   | $0.04 \pm 0.0^a$ | $0.02 \pm 0.0^a$ |
|                | RS      | $0.55 \pm 0.1^b$ | $0.44 \pm 0.1$   | $0.17 \pm 0.0^b$ | $0.06 \pm 0.0^b$ |
| <b>Songon</b>  | DS      | $5.29 \pm 2.5^a$ | $0.27 \pm 0.1$   | $0.04 \pm 0.0$   | $0.03 \pm 0.0^a$ |
|                | RS      | $0.73 \pm 0.3^b$ | $0.29 \pm 0.0$   | $0.17 \pm 0.1$   | $0.07 \pm 0.0^b$ |
| <b>Papoga</b>  | DS      | $1.64 \pm 1.9$   | $0.05 \pm 0.0$   | $0.05 \pm 0.0^a$ | $0.03 \pm 0.0^a$ |
|                | RS      | $0.79 \pm 0.5$   | $0.16 \pm 0.1$   | $0.18 \pm 0.0^b$ | $0.09 \pm 0.0^b$ |
| <b>Layo</b>    | DS      | $1.56 \pm 1.5$   | $0.05 \pm 0.0^a$ | $0.07 \pm 0.0^a$ | $0.04 \pm 0.0^a$ |
|                | RS      | $0.84 \pm 0.4$   | $0.13 \pm 0.0^b$ | $0.16 \pm 0.0^b$ | $0.09 \pm 0.0^b$ |
| <b>Mopoyem</b> | DS      | $1.52 \pm 1.7$   | $0.05 \pm 0.0$   | $0.09 \pm 0.0^a$ | $0.03 \pm 0.0$   |
|                | RS      | $0.40 \pm 0.2$   | $0.19 \pm 0.2$   | $0.23 \pm 0.1^b$ | $0.05 \pm 0.0$   |
| <b>Abraco</b>  | DS      | $1.38 \pm 1.6$   | $0.05 \pm 0.0$   | $0.04 \pm 0.0^a$ | $0.02 \pm 0.0$   |
|                | RS      | $0.40 \pm 0.3$   | $0.68 \pm 1.0$   | $0.15 \pm 0.0^b$ | $0.03 \pm 0.0$   |
| <b>Gboubo</b>  | DS      | $0.12 \pm 0.1$   | $0.05 \pm 0.0$   | $0.05 \pm 0.0^a$ | $0.03 \pm 0.0$   |
|                | RS      | $0.37 \pm 0.3$   | $0.37 \pm 0.4$   | $0.16 \pm 0.0^b$ | $0.05 \pm 0.5$   |

Values in the same column bearing superscript letters a, b, or c indicate a difference between seasons ( $p < 0.05$ ) for a given station. DS= Dry season; RS = Rainy season.

### 3.3 Relationship between the various environmental parameters

The factorial map of the sampling stations (Figure 2 & Table 3), together with the variable correlation circle, identified three groups of stations. The first group (I), comprising the Songon and N'djem stations, was characterized by high nitrate concentrations, elevated conductivity, and higher water temperature. The second group (II), comprising the Ahua, Koko, Bapo, Abraco, Taboth, and Gboubo stations, was characterized by low orthophosphate concentrations and salinity, as well as near-neutral pH values. The third group (III), comprising the Layo, Papoga, and Mopoyem stations, was characterized by high concentrations of orthophosphate and ammonium, together with elevated suspended matter. The correlation matrix between physicochemical parameters and nutrients (Table 4) revealed a strong positive correlation between salinity and conductivity, and a strong negative correlation ( $-0.96$ ) between orthophosphate ( $\text{PO}_4^{3-}$ ) and water transparency.



**Figure 2: Principal Component Analysis (PCA ) showing physicochemical parameters and nutrient salts in the water of sectors IV and V of the Ebrié lagoon on axes F1 and F2. (a = variable correlation circle; b = factorial map of stations).**

**Table 3: Correlations of water physicochemical parameters and nutrient salts with the axes.**

| Variables             | Codes                        | F1     | F2     |
|-----------------------|------------------------------|--------|--------|
| Temperature           | T°C                          | -0.38  | -0.79* |
| Potential of hydrogen | Ph                           | 0.75*  | -0.14  |
| Salinity              | Sal                          | 0.83*  | 0.10   |
| Conductivity          | Cond                         | 0.05   | -0.93* |
| Dissolved oxygen      | O <sub>2</sub>               | 0.16   | -0.96* |
| Transparency          | Transp                       | 0.93*  | -0.13  |
| Suspended matter      | MES                          | -0.53  | 0.42   |
| Nitrate               | NO <sub>3</sub> <sup>-</sup> | -0.63  | -0.71* |
| Nitrite               | NO <sub>2</sub> <sup>-</sup> | 0.47   | -0.57  |
| Ammonium              | NH <sub>4</sub> <sup>+</sup> | -0.50  | 0.11   |
| Orthophosphate        | PO <sub>4</sub> <sup>-</sup> | -0.87* | 0.07   |

Values marked with an asterisk (\*) are significant at  $p < 0.05$ .

**Table 4: Correlation matrix between physicochemical parameters and nutrient salts in the water of sectors IV and V of the Ebrié lagoon**

|                              | T°C   | pH    | O <sub>2</sub> | Sal         | Cond  | Transp       | SM    | NO <sub>3</sub> <sup>-</sup> | NO <sub>2</sub> <sup>-</sup> | NH <sub>4</sub> <sup>+</sup> | PO <sub>4</sub> <sup>3-</sup> |
|------------------------------|-------|-------|----------------|-------------|-------|--------------|-------|------------------------------|------------------------------|------------------------------|-------------------------------|
| T°C                          | 1.00  |       |                |             |       |              |       |                              |                              |                              |                               |
| pH                           | -0.29 | 1.00  |                |             |       |              |       |                              |                              |                              |                               |
| O <sub>2</sub>               | -0.36 | 0.72  | 1.00           |             |       |              |       |                              |                              |                              |                               |
| Sal                          | 0.66  | -0.00 | 0.00           | 1.00        |       |              |       |                              |                              |                              |                               |
| Cond                         | 0.71  | 0.04  | 0.07           | <b>0.97</b> | 1.00  |              |       |                              |                              |                              |                               |
| Transp                       | -0.18 | 0.67  | 0.66           | 0.14        | 0.28  | 1.00         |       |                              |                              |                              |                               |
| SM                           | -0.21 | -0.25 | -0.31          | - 0.25      | -0.40 | -0.61        | 1.00  |                              |                              |                              |                               |
| NO <sub>3</sub> <sup>-</sup> | 0.78  | -0.53 | -0.56          | 0.63        | 0.56  | -0.53        | -0.02 | 1.00                         |                              |                              |                               |
| NO <sub>2</sub> <sup>-</sup> | 0.08  | 0.02  | 0.25           | 0.52        | 0.58  | 0.44         | 0.36  | 0.06                         | 1.00                         |                              |                               |
| NH <sub>4</sub> <sup>+</sup> | 0.34  | -0.25 | -0.56          | -0.19       | -0.17 | -0.30        | 0.01  | 0.14                         | -0.65                        | 1.00                         |                               |
| PO <sub>4</sub> <sup>-</sup> | 0.22  | -0.57 | -0.52*         | -0.07       | -0.20 | <b>-0.96</b> | 0.64  | 0.56                         | -0.38                        | 0.14                         | 1.00                          |

Bold values indicate strong correlations.

#### 4 DISCUSSION

In the present study, mean water average temperature ranged from  $28.0 \pm 2.1^{\circ}\text{C}$  to  $31.4 \pm 0.8^{\circ}\text{C}$ , indicating persistently high temperature throughout the study period. According to [20], air temperatures in sub-Saharan Africa generally remain above  $20^{\circ}\text{C}$ . The particularly high temperatures recorded during the dry season at the Papoga and Layo stations may be explained by intense solar heating combined with the shallow water depth at these two stations. In shallow water, solar radiation penetrates the entire column and promotes uniform warming [21]. In sectors IV and V of the Ebrié lagoon, the water was generally alkaline during the dry season and slightly acidic during the rainy season. These alkaline conditions observed in the dry season are likely related to the intrusion of marine waters into the sampling. In contrast, the lower pH recorded during the rainy season may result from freshwater inputs from the Agnéby River. The pH values measured in this study (6.92–7.32) are comparable to those reported by [22] for the same section of the Ebrié lagoon (5.7–7.6).

**Table 5: Comparison of physicochemical parameters in different lagoons**

| Location                               | Temp (°C)      | O <sub>2</sub> (mg/L) | Sal (‰)       | NO <sub>3</sub> <sup>-</sup> (mg/L) | NO <sub>2</sub> <sup>-</sup> (mg/L) | NH <sub>4</sub> <sup>+</sup> (mg/L) | PO <sub>4</sub> <sup>3-</sup> (mg/L) | references    |
|----------------------------------------|----------------|-----------------------|---------------|-------------------------------------|-------------------------------------|-------------------------------------|--------------------------------------|---------------|
| Lembar Bay, Indonesia                  | 28 to 32       | //////                | 30 à 35       | 0.02 to 0.07                        | 0.001 to 0.009                      | //////                              | 0.001 to 0.06                        | [27]          |
| Coastal lagoon, Benin                  | 29.93 to 31.35 | 5.26 to 5.60          | 6.24 to 13.26 | 1.37 to 1.75                        | 0.02                                | 0.22 to 0.26                        | 0.06 to 0.15                         | [26]          |
| Urban area Ebrié lagoon, Côte d'Ivoire | 29.20 to 29.95 | 1.75 to 6.73          | 3.10 to 20.65 | 3.10 to 6.10                        | 0.03 to 0.10                        | //////                              | //////                               | [5]           |
| Ebrié lagoon, Côte d'Ivoire            | 28 to 31.4     | 4.4 to 8.7            | 1.58 to 9.79  | 0.12 to 5.29                        | 0.04 to 0.71                        | 0.04 to 0.23                        | 0.02 to 0.09                         | Present study |

The results of this study showed a strong positive relationship between salinity and conductivity. The elevated salinity and conductivity values recorded at the N'djem and Songon stations during the dry season may be attributed to two factors: increased evaporation and the strong influence of marine water. This marine influence was particularly

pronounced at on these the stations because of their proximity to the Vridi Canal. A significant seasonal variation in dissolved oxygen concentrations was observed at the Ahua and Koko. The higher oxygen concentrations recorded during the rainy season associated with enhanced primary production, runoff during this period could supplied nutrients that stimulate phytoplankton growth, thereby increasing dissolved oxygen through photosynthesis [23,24]. In the present study, dissolved oxygen concentrations remained above levels considered critical for aquatic organisms. For example, concentrations below 3 mg/L may cause asphyxiation in carp [25]. The relatively good oxygenation observed in this sector of the Ebrié lagoon may also reflect the limited discharge of organic matter and chemical pollutants associated with human activities, as development remains relatively low in the surrounding localities. Water transparency was generally high and showed little variation among stations, suggesting relatively stable environmental conditions in the lagoon. Overall, the physicochemical parameters measured in this study fall within the ranges reported by [26] for a coastal lagoon in Benin and by [5] for the urban area of the Ebrié lagoon, Côte d'Ivoire (Table 5).

The distribution of suspended matter depends on riverine inputs, surface runoff, wind-induced resuspension; water currents, and the size and density of suspended particles [7]. In sectors IV and V of the Ebrié lagoon, suspended particulate matter concentrations were low. This result is consistent with the high-water transparency observed in these sectors and suggests a low concentration of suspended solids in the water column. The concentrations recorded in the present study were considerably lower than those reported by [4] for sector III of the Ebrié lagoon (45.23 to 46.84 mg/L). The relatively low concentrations observed in sectors IV and V may be explained by the lower intensity of local anthropogenic activities compared with the highly urbanized area of Abidjan, where domestic, industrial, and urban runoff are more likely to increase suspended particulate matter inputs.

Nitrogen and phosphorus compounds contribute to the eutrophication of aquatic systems watercourses by stimulating the growth of algae and aquatic plants [28]. Nitrate inputs to the lagoon may originate from plantation runoff and domestic wastewater nearby villages. The lagoon area is bordered by extensive banana, oil palm, pineapple, and rubber plantations and is home to several fishing communities. Indeed, over 350 hectares in the area are devoted to industrial banana cultivation, which relies on substantial inputs of agrochemicals including insecticides, herbicides, and fungicides. Nitrate ( $\text{NO}_3^-$ ) concentrations was high during the dry season, whereas nitrite ( $\text{NO}_2^-$ ) concentrations peak during the rainy season. However, nitrate concentrations in the waters of this lagoon sector do not exceed 12 mg/L [29]. According to these authors, nitrate concentrations above this threshold could indicate significant anthropogenic input and be associated with a presence phytoplankton. Nitrite is toxic to fish, particularly at pH values below 7. The increase in nitrite ( $\text{NO}_2^-$ ) concentrations during the rainy season may be associated with increased discharge from the Agnéby river, which transports organic matter and nitrogen compounds into Ébrié lagoon. The river mouth is located near to the Layo station. Mineralization of organic nitrogen and oxidation of ammonium could contribute to nitrite production [30]. The nitrite concentrations measured in the study could cause stress in fish, leading to respiratory problems, weakness, disease, and increased vulnerability. Nitrite concentrations below 1 mg/L could still lethal, and levels above 0.01 mg/L was problematic for some fish species. Nitrite can rapidly impair the oxygen-carrying capacity of blood by oxidizing hemoglobin, potentially causing asphyxiation [24]. The elevated concentrations observed may also reflect fertilizer use in agricultural activities within the watershed. Nitrate and nitrite concentrations in this study were lower than those reported by [5] for the urban sector of the Ébrié lagoon and [27] for Lembar Bay in Indonesia, (Table 5). Ammonium ( $\text{NH}_4^+$ ) and orthophosphate ( $\text{PO}_4^{3-}$ ) concentrations increased during the rainy season and decreased during the dry season at most stations. This seasonal pattern may be related to increased runoff from plantations. According to [32], ammoniacal nitrogen concentrations of approximately 2 mg/L can severely affect aquatic life at pH 7.4–8.5. Ammonium concentrations in this lagoon sector were below the levels associated with adverse effects on aquatic life, suggesting that they are not likely to pose a threat under the conditions observed. The concentrations measured in this study were similar to those reported for Ouladine lagoon ( $0.07\text{--}0.37\text{ mg L}^{-1}$ ) [31] and Fresco, Côte d'Ivoire, where annual mean concentrations ranged from 0.04 to 0.12 mg/L [33]. Orthophosphate concentrations were low at all stations. This may reflect, in part, phosphate uptake by the abundant algal biomass [7].

Principal component analysis (PCA) was used to examine station groupings and relationships between physicochemical parameters and nutrient concentrations in sectors IV and V of Ébrié lagoon. The factor map, together with the projected water-quality variables, distinguished three station groups. The observed pattern appears to reflect both station location and influence of waters entering the lagoon. Group I, comprising Songon and Ndjem, was associated with higher nitrate concentrations, conductivity, and water temperatures. Its proximity to the Vridi Canal suggests that tidal exchange may influence these stations. Group II included Ahua, Koko, Bapo, Abraco, Taboth, and Gboubo. These stations were characterized by low phosphate concentrations, low salinity, and near-neutral pH. Their distance from both the Agnéby River and the Vridi Canal may account for their comparatively limited exposure to riverine and marine. Group III comprised Layo, Papoga, and Mopoyem, where river inflows and surface runoff may contribute to the relatively high concentrations of phosphate, ammonium, and suspended matter. The correlation matrix showed a strong negative association between transparency and orthophosphate, and a strong positive association between salinity and conductivity. The inverse relationship between transparency and orthophosphate may reflect differences in suspended material and phosphorus distribution across the study area. The salinity-conductivity correlation is consistent with the contribution of dissolved ions to water conductivity.

## 5 CONCLUSION

This study provides an initial assessment of water quality in sectors IV and V of the Ebrié lagoon. The waters were generally characterized by low in salinity, moderate dissolved oxygen, high temperatures, and low transparency. Suspended-solid concentrations were not elevated. Water pH showed seasonal variation, tending to be slightly alkaline during the dry season and acidic during the rainy season. Significant seasonal differences in physicochemical parameters were observed at some stations. Nutrient concentrations also varied seasonally. Nitrite concentrations peaked during the rainy season, potentially reflecting increased river discharge and runoff from the watershed. Given the toxicity of nitrite to fish, these elevated concentrations may pose a risk to aquatic organisms, although their effects would depend on the concentrations and exposure conditions at each station. Ammonium concentrations remained below levels associated with severe effects on aquatic life, while orthophosphate concentrations were low throughout the study area. The PCA distinguished three groups of stations, with patterns associated with their geographical locations and differing exposure to tidal exchange, river inflows, and surface runoff, together, these results identify seasonal nutrient inputs particularly the rainy season increase in nitrite as a water quality concern warranting continued monitoring.

The water in this area was not heavily loaded with suspended solids (TSS) and exhibits slightly basic characteristics during the dry season, shifting to acidic during the rainy season. The study of seasonal variation showed significant differences between seasons at certain sampling stations. Furthermore, the high nitrite concentrations observed during the rainy season could pose a risk of mass mortality for the organisms inhabiting this environment. Principal Component Analysis (PCA) identified three groups of stations characterized by the behavior of physicochemical parameters and nutrient salts. This grouping pattern reflects both the geographical location of the stations and the influence of waters entering the lagoon.

## STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

### *Acknowledgments*

Our thanks go to the Oceanology Research Center and everyone who contributed to the success of this research project.

### *Funding Source*

The Oceanology Research center carried out the monitoring and provided the technical and financial resources.

### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

### *Statement of informed consent*

Informed consent was obtained from all individual participants included in the study.

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