# Impact of aquaculture on the physico-chemical quality and chlorophyll biomass of the waters of Ebrié Lagoon at the Jacqueville (Ivory Coast)

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## Abstract

Aquaculture in lagoon enclosures carried out at the Jacqueville aquaculture station is likely to harm the quality of lagoon waters and affect human. This study aims to evaluate the effects of aquaculture on the aquatic environment by studying the quality of the water of the Jacqueville station through physico-chemical parameters and the chlorophyll biomass. Six sampling stations were investigated monthly from January to December 2020. In situ measurements were carried out using electrochemical probe method, with a specific probe multiparameter. Chemical and biological characteristics were analysed in accordance with AFNOR 2005 standards and Lorenzen method respectively. In addition, the organic pollution index (OPI), SEQ-water grid and trophic status were determined to assess the quality of the waters. The results showed that dissolved oxygen, transparency and suspended maters significantly between stations. Temperature (31.44 °C), electrical conductivity (5893 µS/cm), dissolved oxygen (8.59 mg/L) and salinity (3.58 mg/L) are significantly higher in dry season. On the other hand, suspended matters (8.05 mg/L), nitrogen and phosphorus compounds, $BOD_5$ (1.95 $mgO_2/L$) and COD (59.1 $mgO_2/L$) are high in the rainy season. Chlorophyll a content is significantly higher during the main rainy season at all stations. OPI values (3.5) indicate moderate organic pollution. Trophic status values indicate eutrophic waters. The results of this study indicate that despite aquaculture activity, the waters at the aquaculture station remains of relatively good quality. However, setting up a lagoon water monitoring system will enable early detection and management of the potential negative impacts of human activities.

**Keywords :** Ebrié lagoon, aquaculture, physico-chemical, trophic status, chlorophyll biomass.

## Résumé

**Impact de l'aquaculture sur la qualité physico-chimique et la biomasse chlorophyllienne des eaux de la lagune Ebrié à Jacqueville (Côte d'Ivoire)**

L'aquaculture en enclos lagunaire pratiquée à la station aquacole de Jacqueville est susceptible de nuire à la qualité des eaux lagunaires et d'affecter la santé humaine. Cette étude vise à évaluer l'impact de l'aquaculture sur le milieu aquatique en étudiant la qualité des eaux de ladite station au moyen des paramètres physico-chimiques et de la biomasse chlorophyllienne. Six stations ont été prospectées mensuellement de janvier à décembre 2020. Les caractéristiques chimiques et biologiques ont été analysées respectivement selon les normes AFNOR 2005 et la méthode de Lorenzen. En outre, l'indice de pollution organique (IPO), la grille SEQ-Eau et l'état trophique ont été déterminés. Les résultats ont montré que l'oxygène dissous, la transparence et les matières en suspension (MES) fluctuent significativement entre les stations. La température (31,44 °C), la conductivité (5893 µS/cm), l'oxygène dissous (8,59 mg/L) et la salinité (3,58 mg/L) sont significativement plus élevés en saison sèche. En revanche, les MES (8,05 mg/L), les composés azotés et phosphorés, la $DBO_5$ (1,95 $mgO_2/L$) et la DCO (59,1 $mgO_2/L$) sont élevés en saison pluvieuse. La chlorophylle a est significativement plus élevée en grande saison pluvieuse à toutes les stations. Les valeurs de l'IPO indiquent une pollution organique modérée (3,5). Ceux de l'état trophique révèlent des eaux eutrophes. Cette étude indique que malgré la pratique de l'aquaculture, les eaux de la station aquacole de Jacqueville restent relativement de bonne qualité. Toutefois, une mise en place d'un système de surveillance des eaux lagunaires permettra une détection précoce et une gestion des impacts négatifs potentiels des activités humaines.

**Mots clés :** lagune Ébrié, aquaculture, physico-chimique, statut trophique, biomasse chlorophyllienne.

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## 1– Introduction

In recent years, aquaculture production has increased globally (179 million tonnes in 2018), mainly due to the increasing demand for aquaculture produce, and the need for new food supplies (FAO, 2020). These circumstances have contributed significantly to the growth of the Ivorian aquaculture industry, which is undertaking a strategy setting priorities including increasing national aquaculture production from 3394 t in 2011 to 200000 t in 2020 (IPACI, 2014). Indeed, Côte d'Ivoire has immense physical, hydrological (150. 000 ha of lagoons, 350. 000 ha of lakes and numerous lowlands, etc.), climatic and human potential in addition to a rich aquatic fauna containing more than 100 fish families, several species of which have definite aquaculture potential (FAO, 2015). Thus, lagoons are ecosystems rich in biodiversity, widely distributed in the world's coastal zones. They serve as irreplaceable habitats, spawning grounds and nurseries for numerous animal species (Ruiz *et al.,* 2006). Moreover, coastal lagoons are complex socio-ecological systems and among the most biologically productive ecosystems (Newton et al., 2018). Among these is the Ébrié lagoon, which, with a surface area of 566 km$^2$, is one of the most important aquatic ecosystems for its ecological values and aquaculture operations. Since the 1980, lagoon aquaculture has been practiced in both brackish and fresh water. As part of the pilot projects for the development of lagoon aquaculture in Ivory coast, the Ivorian government initiated the creation of the Jacqueville aquaculture station (SAJ). The station is located on the banks of sector V of the Ebrié lagoon. Yet, these habitats play a vital role in the conservation of aquatic biodiversity (Yapo, 2013). However, the practice of aquaculture can have an effect on water quality. In some cases, this can have a major impact on macronutrients and therefore on chlorophyll biomass. The aquaculture ecosystem is indirectly affected by changes in physico-chemical water conditions, which can regulate phytoplankton development (El-Otify, 2015) in such closed pond habitats. In addition, measurements of chlorophyll-a concentration, which is a good predictor of primary productivity and phytoplankton density, are considered an index of fish yield and a criterion of water quality and trophic status (El-Otify, 2015). The importance of aquaculture is clear, but what is the effect of aquaculture activity on water quality? Does aquaculture activity modify environmental parameters and the chlorophyll biomass of waters? These concerns give rise to the hypothesis of whether aquaculture activity would have an impact on water quality at the Jacqueville aquaculture station. To date, only studies by Toulé *et al.* (2017) on certain physico-chemical and bacteriological parameters of the water at the Jacqueville aquaculture station are available. However, this aquaculture activity may have environmental impacts on the balance of aquatic communities. Possible assessments of these impacts can be better studied by including reliable information on the physical, chemical and biological aspects of aquaculture. The general aim of this study is to assess the effects of aquaculture on water quality at the Jacqueville aquaculture station. Specifically, the aim was to determine the trophic status of the water of aquaculture station with a view to maintaining monitoring of these waters. Also, to characterize the waters of the said station using abiotic and biological parameters (in terms of chlorophyll a concentration).

## 2- Material and methods

Eleven sampling campaigns were carried out at each station on a monthly basis. These campaigns were carried out from January to December 2020 (except for the month of March due to the corona virus health crisis).

### 2.1- Description of the study area

Located between 5°14'.24" and 5°16'.48" North latitude and 4°28'.12" and 4°24'.36" West longitude, the Jacqueville aquaculture station (SAJ) is situated in the south of Ivory Coast (Figure 1). The Jacqueville aquaculture station is known locally as SIAL (Ivoirian lagoon aquaculture company) (Toulé *et al.*, 2017). It was created in 1982 as part of the pilot projects for the development of lagoon aquaculture initiated by the Ivorian state. This station is located on the coast of sector V of the Ebrié lagoon, precisely in the village AHUA. Built on two hectares, this station is the only advanced structure for the production of lagoon (*Chrysischthys nigrodigitatus*) still in activity in Ivory coast and in the sub-region. Indeed, this station is specialized in the production of fingerlings for fish farmers. Covering an area of 21.113 m$^2$, with an occupied surface of 16.400 m$^2$, its production capacity is estimated at 1 million of fingerlings. Catfish (*Heterobranchus longifilis*) breeding is also practised there. This station is under the influence of rivers and the sea. These environments are therefore areas of intense human activities, particularly swimming, defecation, washing, fishing, navigation, etc.

In this study, six sampling stations were chosen according to the absence/presence of aquaculture activity and the distance from station S1. Stations S1 and S2 were chosen in lagoon enclosures (presence of aquaculture activity). The characteristics of the sampling points are given in Table I.

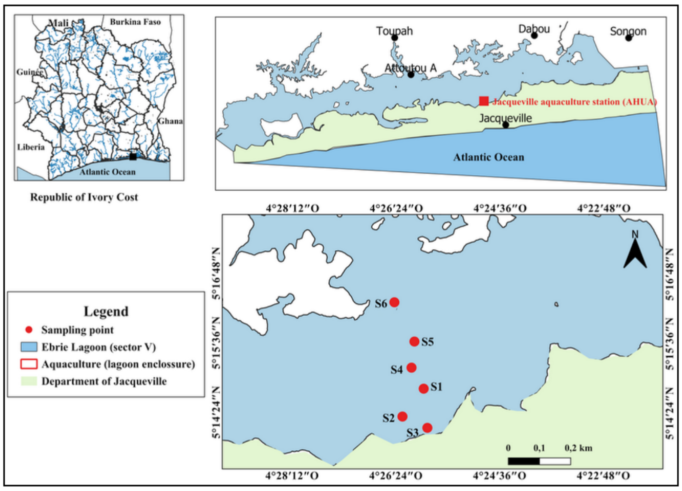


**Figure 1 :** Sampling locations in the Ebrié Lagoon

**Table I :** Location of water point Lagoon and fish enclosure

| Code | Location | Description |
|---|---|---|
| S1 | Aquaculture pond sample point | Fish cage area (*Heterobranchus longifilis* genitor) |
| S2 | Aquaculture pond sample point | Located in the double enclosure (*Heterobranchus longifilis* juvenile). |
| S3 | Ebrié Lagoon | Located at 100 meters from the fish cage |
| S4 | Ebrié Lagoon | 30 meters in upstream from the fish cage |
| S5 | Ebrié Lagoon | 100 meters in upstream from the fish cage |
| S6 | Ebrié Lagoon | 500 meters in upstream from the fish cage |

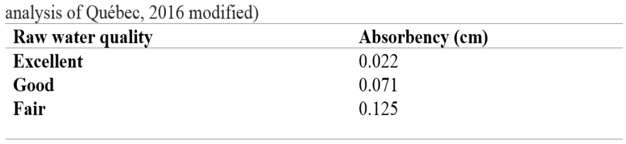
### 2.2- Measurement of physico-chemical parameters

Measurements were carried out between 9 a.m. and 11 a.m. throughout the study. The measurements of temperature, pH, conductivity, dissolved oxygen and salinity were carried out in situ using the electrochemical probe method, with a HACH LANGE portable digital multiparameter (HQ 40d) equipped with specific probes. A Secchi disk with a graduated rope was used to determine the transparency of the water. At each station, a water sample was collected in 1 L polyethylene bottles previously rinsed with water from the station. These water samples were used for the determination of dissolved salts, suspended matter and organic parameters. These were stored in a cooler containing carbohydrate ice at 4°C before being transported to the laboratory within 4 hours.

The nutrients measured were nitrates, nitrites, ammonium, phosphates, total phosphorus and silica. The water samples submitted for these analyses were previously filtered through fiberglass membranes (0.45µm porosity), with the exception of those intended for the analyses of total phosphorus. Nutrients were measured in accordance with the AFNOR standard (2005). Nitrate, nitrite, ammonium and phosphate were determined in the laboratory using spectrophotometric methods as described by Greenberg *et al.* 2012. Total nitrogen was estimated by the sum of $NH_4^+$, $NO_2^-$ and $NO_3^-$. Total phosphorus was determined by LCK 349 tank tests. Regarding the determination suspended matter, it meets AFNOR T90-105, 1994 standard. That consists of filtering 500 mL of waters on filters of 0.45 µm porosity previously dried in an oven (Thermo Scientific) at 105°C for 2 hours and weighed.

Organic matter can be considered as a major parameter influencing water quality. The measurement of organic parameters concerned: absorbency $UV_{254}$, $BOD_5$ and COD. Indeed, these parameters provide information on the state of pollution of the water. The absorbency $UV_{254}$ is used to characterise the dissolved organic matter (Table II).

**Table II :** Water quality based on absorbance values (center of expertise in environmental analysis of Québec, 2016 modified)


analysis of Québec, 2016 modified)

| Raw water quality | Absorbency (cm) |
|---|---|
| **Excellent** | 0.022 |
| **Good** | 0.071 |
| **Fair** | 0.125 |

The chemical oxygen demand (COD) makes it possible to evaluate the organic pollutant load of water through the quantity of oxygen necessary for its chemical oxidation. It was determined using a mineralizer at model HT 200 S type mineralizer. The COD is read with a DR 6000 spectrophotometer at a wavelength of 420 nm according to ISO 15705.

Biochemical oxygen demand (BOD) is the amount of oxygen required by a water sample to oxidise biodegradable organic matter biochemically (bacterial oxidation) (Rodier, 2009). $BOD_5$ was measured using the manometric method based on the WARBURG respirometer principle, by an OxiTop.

## 2.3- Determination of chlorophyll biomass

Chlorophyll a was determined according to the method of Lorenzen (1967). Indeed, 250 mL of water were collected. Filtration at each station was done *in situ* on Whatman GF/C paper (0.7 µm porosity) using a vacuum pump. In the laboratory, it is placed in a glass tube containing 10 mL of 90% acetone and shaken. The absorbency of the supernatant is then measured with a spectrophotometer, at wavelengths of 665 nm and 750 nm, before and after acidification with hydrochloric acid by adding one or two drops. The results are given by the following formula :

$$Chla\ (\mu g/L) = \frac{26.6 * (E1 - E2) * Va}{l * Ve}$$

With Va : volume of acetone (mL); Ve : volume of filtered water (L); l : optical path length of the cell (cm); E1 : absorbency before acidification ($OD_{665}$-$OD_{750}$); E2: absorbency after acidification ($OD_{665}$-$OD_{750}$).

## 2.4- Organic Pollution Index (OPI)

The Organic Pollution Index (OPI) (Leclercq, 2001) indicates the degree of alteration of the water by chemical variables that reveal the organic pollution of the environment. It is calculated from four parameters (ammonium, nitrites, phosphates and $BOD_5$) divided into 5 classes (Table III). The value of the parameter obtained is compared with the values in the table to find out the number of the class to which it belongs. The OPI for a sample is equal to the average of the parameter classes. It is given by the following formula :

$$OPI = \left(\sum_{k \neq 0}^{i} CK, \ldots, Ci\right) / n$$

**Table III :** Class limits for the calculation of Organic Pollution Index (Leclercq, 2001)

| Parameters / Class | Ammonium (mg/L) | Nitrites (µg/L) | Phosphates (µg/L) | $BOD_5$ (mg/L) | Class averages | Organic pollution level |
|---|---|---|---|---|---|---|
| **5** | < 0.1 | ≤ 5 | ≤ 15 | < 2 | 5 – 4.6 | Nil |
| **4** | 0.1 – 0.9 | 6-10 | 16-75 | 2 – 5 | 4.5 – 4 | Low |
| **3** | 1 – 2.4 | 11-50 | 76- 250 | 5.1 - 10 | 3.9 – 3 | Moderate |
| **2** | 2.5 - 6 | 51-150 | 251 - 900 | 10.1 - 15 | 2.9 – 2 | Strong |
| **1** | > 6 | > 150 | > 900 | > 15 | 1.9 – 1 | Very strong |

With Ci: the class number of the parameter; n: the number of parameters analysed

## 2.5- Water Quality Assessment System

The Water Quality Assessment System (WQAS) is a tool for assessing the physical and chemical quality of water and its ability to perform certain functions. Based on the recommendations of the World Health Organisation (WHO), quality classes and indices have been established. By identifying alterations that compromise biological equilibrium or other water uses, the SEQ-Water allows for a precise diagnosis of water quality (Water Agency, 2003). Thus, with the help of 5 aptitude classes, the aptitude of the water for biology and consumption is evaluated for each alteration (Table IV).

**Table IV :** Surface water quality assessment grid (Water Agency, 2003)

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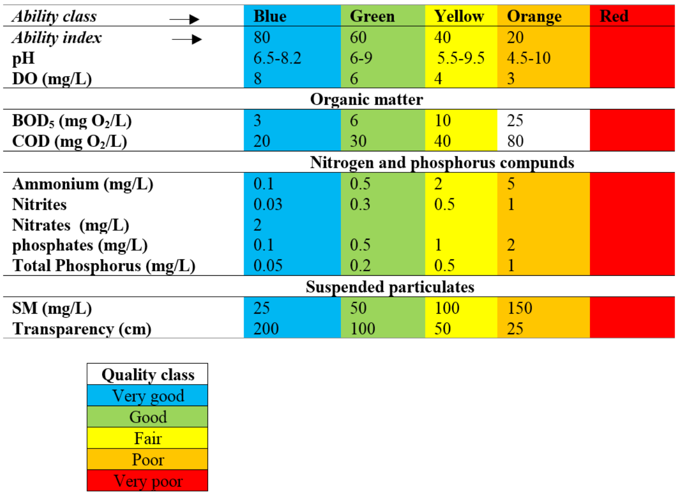

| *Ability class* → | **Blue** | **Green** | **Yellow** | **Orange** | **Red** |
|---|---|---|---|---|---|
| *Ability index* → | 80 | 60 | 40 | 20 | |
| **pH** | 6.5-8.2 | 6-9 | 5.5-9.5 | 4.5-10 | |
| **DO (mg/L)** | 8 | 6 | 4 | 3 | |
| **Organic matter** | | | | | |
| **$BOD_5$ (mg $O_2$/L)** | 3 | 6 | 10 | 25 | |
| **COD (mg $O_2$/L)** | 20 | 30 | 40 | 80 | |
| **Nitrogen and phosphorus compunds** | | | | | |
| **Ammonium (mg/L)** | 0.1 | 0.5 | 2 | 5 | |
| **Nitrites** | 0.03 | 0.3 | 0.5 | 1 | |
| **Nitrates (mg/L)** | 2 | | | | |
| **phosphates (mg/L)** | 0.1 | 0.5 | 1 | 2 | |
| **Total Phosphorus (mg/L)** | 0.05 | 0.2 | 0.5 | 1 | |
| **Suspended particulates** | | | | | |
| **SM (mg/L)** | 25 | 50 | 100 | 150 | |
| **Transparency (cm)** | 200 | 100 | 50 | 25 | |

| **Quality class** |
|---|
| Very good |
| Good |
| Fair |
| Poor |
| Very poor |

## 2.6- Determination of trophic status

To characterise the trophic status of the waters of the Jacqueville aquaculture station the system developed by O.C.D. E (1982) was used (Table V). This system combines information on nutrient status and algal biomass and provides a basis for the assessment of trophic status for the management of aquatic ecosystems. It takes into account the following parameters: total phosphorus (TP), chlorophyll a (Chl-*a*) and transparency (Secchi).

**Table V :** Limit values of the trophic water classification system according to O.C.D.E. (1982). avg: annual average; max: maximum value; min: minimum value

| Trophic status | Trans avg (m) | Trans min (m) | Chl-*a* moy (µg/L) | Chl-*a* max (µg/L) | Tp (mgP/L) |
|---|---|---|---|---|---|
| Oligotrophic | ≥ 6 | ≥ 3 | ≤ 2.5 | ≤ 8 | ≤ 10 |
| Mesotrophic | 6-3 | 3-1.5 | 2.5-8 | 8-25 | 10-35 |
| Eutrophic | 3-1.5 | 1.5-0.7 | 8-25 | 25-75 | 35-100 |
| Hypereutrophic | ≤ 1.5 | ≤ 0.7 | ≥ 25 | ≥ 75 | ≥ 100 |

### 2.7- Statistical analysis

The data were analysed by descriptive statistics (minimum and maximum). Kruskal-Wallis test analysis was used to observe spatial and seasonal variations of physico-chemical and biological parameters (chlorophyll biomass). Differences between values were considered significant when $p < 0.05$. A Principal Component Analysis (PCA) was used to order according to the physico-chemical parameters Subsequently, a hierarchical clustering analysis (HCA) was performed for the grouping of stations and seasons with similar characteristics. The boxplot was used to visualize the distribution of values and all analyses were performed with R software (R Version 3.6.0).

## 3- Results

### 3.1- Spatial variations of physico-chemical parameters

The spatial variations of the physico-chemical parameters measured at the Jacqueville aquaculture station are presented in figures 2 and 3. The dissolved oxygen, transparency, suspended matter and silica showed significant differences from one station to another (Mann-Whitney test, $p < 0.05$). Temperature values varied from 27.5 °C (S2, S4 and S5) to 32.08 °C (S2). The pH values ranged from 6.81 (S5) to 9.31 (S6) and the extreme conductivity values (3629 µS/cm to 6347 µS/cm) were recorded at stations S3 and S5 both. Salinity levels ranged from 2.15 ppt (S3) to 3.80 ppt (S6) and water transparency varied from 58 cm (S3) to 290 cm (S5). Dissolved oxygen values ranged from 5.29 mg/L (S1) to 9.21 mg/L (S3). However, the median of this parameter is significantly higher (8.01 mg/L) in S6 and lower (7.37 mg/L) in S2 (Mann-Withney test, $p < 0.05$). Suspended matter values fluctuated between 2.02 mg/L (S6) and 5.07 mg/L (S1). However, station S1 recorded statically the highest value (7.01 mg/L) while the lowest value is noted at station S6 (Mann-Whitney test, $p < 0.05$).

Among the nutrients, only silica showed a significant difference between sites (Mann-Whitney, $p < 0.05$). Nitrate and nitrite concentrations were fluctuated respectively between 0.4 mg/L (S4), 4.3 mg/L (S2), 0.008 mg/L (S5), and 0.023 mg/L (S5). Values of ammonium ranged from 0.012 mg/L (S6) to 0.29 (S3). Values of total nitrogen ranged from 0.4 mg/L (S4) to 4.7 mg/L (S2). Values of Phosphate ranged from 0.04 mg/L (S1) to 0.82 mg/L (S6). Values of total phosphorus ranged from 0.10 mg/L (S4) to 2.43 mg/L (S5). Values of silica range from 7 mg/L (S1 and S5) to 12 mg/L (S2). However, this parameter is significantly higher in S2 (10 mg/L) and lower (9 mg/L) in S6 (Mann-Withney test, $p < 0.05$).

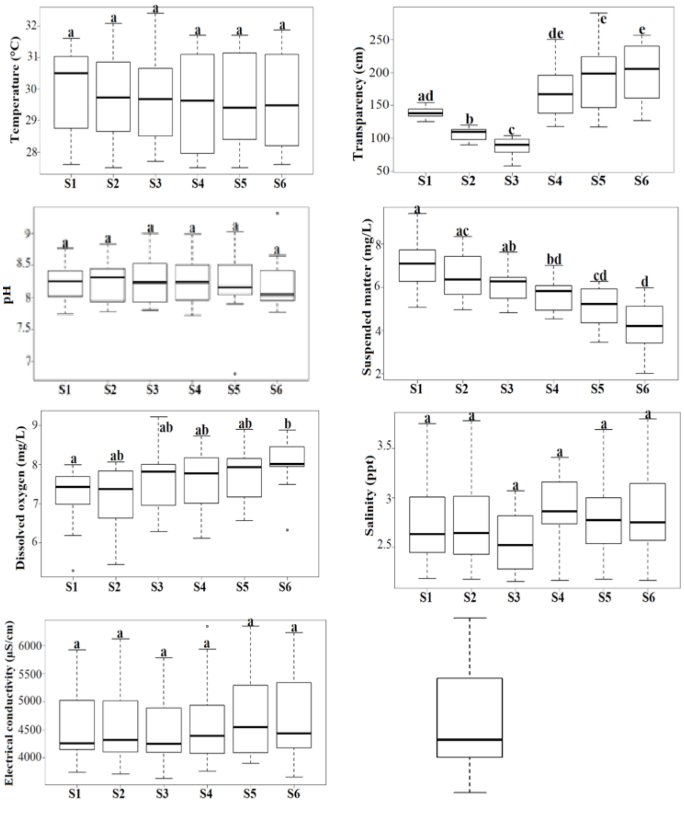

**Figure 2 :** Spatial variations of physico-chemical parameters measured at the Jacqueville aquaculture station: S1 to S6 = Stations; values having a letter in common do not differ significantly (Mann-Withney test; p > 0.05)

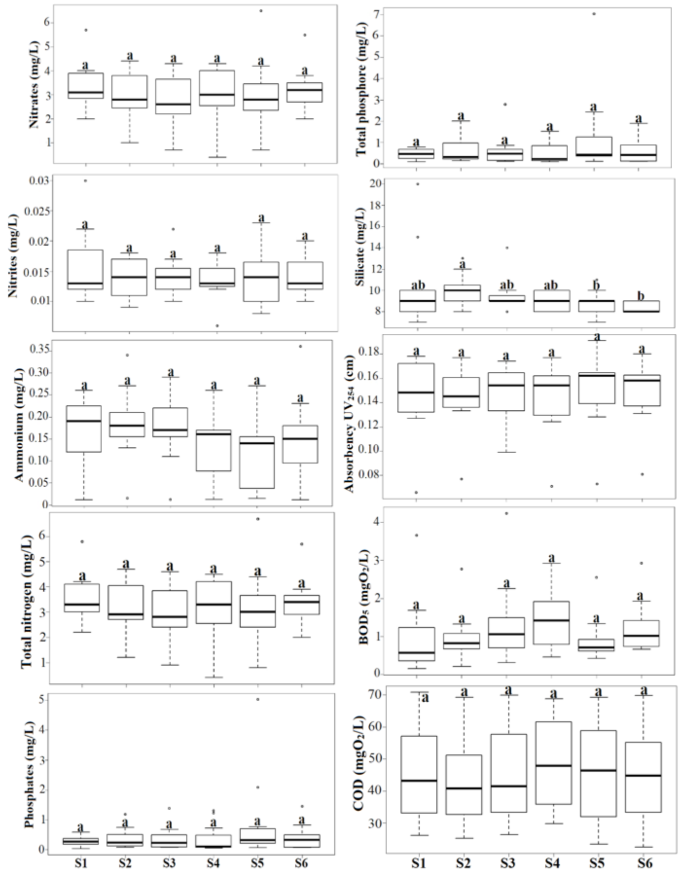

**Figure 3:** Spatial variations of nutrient salts and organic parameters measured at the Jacqueville aquaculture station: S1 to S6 = Stations; $BOD_5$ = Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, values with a letter in common do not differ significantly (Mann-Withney test; p > 0.05)

With regard to the organic parameters, the lowest absorbency $UV_{254}$ value was observed in S1, while the highest was recorded at station S5 with 0.066 cm and 0.191 cm respectively. The $BOD_5$ values vary between 0.15 $mgO_2/L$ (S1) and 2.92 $mgO_2/L$ (S4). As for COD, station S1 recorded the highest value (70.8 $mgO_2/L$) and the lowest value (22.5 $mgO_2/L$) was noted at station S6.

### 3.2- Seasonal variations of physico-chemical parameters

The seasonal evolution of the physico-chemical parameters measured in the waters of the Jacqueville aquaculture station is illustrated in figures 4 and 5. Those parameters vary significantly from one season to another (Mann-Whitney test, $p < 0.05$) except for transparency (Kruskal-Wallis test, $p > 0.05$). The maximum values for temperature (31.44 °C), conductivity (5893 µS/cm), pH (8.76) and salinity (3.58 ppt), were obtained in the long dry season (LDS). The minima for temperature (27.95 °C), conductivity (3970 µS/cm), salinity (2.46 ppt) and pH (7.97) were observed in the short rainy season (SRS). Dissolved oxygen recorded its maximum value (8.59 mg/L) in the short dry season (SDS) and its minimum value (6.38 mg/L) in the short rainy season (SRS). The maximum values of transparency and suspended matter (232 cm and 8.05 mg/L, respectively) were recorded in the rainy season (LRS), while the lowest values (74 cm and 2.55 mg/L) were recorded in the dry season (SDS and LDS respectively).

As for nutrients, the highest nitrate concentrations (4 mg/L) are recorded during the rainy season (SRS) while the lowest values (2.1 mg/L) are observed in the dry season (SDS). The maximum concentrations of nitrite (0.020 mg/L), phosphate (0.74 mg/L) and total phosphorus (1.09 mg/L) are observed during the long rainy season (LRS) and the minimum concentrations (0.08 mg/L and 0.12 mg/L for phosphate and total phosphorus) are noted during the long dry season (LDS), except for nitrite (minimum = 0.010 mg/L observed in short dry season). As for ammonium concentrations, the highest values (0.305 mg/L) are registered in the short rainy season (SRS) while the lowest values (0.064 mg/L) are noted in the long dry season (LDS). The silica content recorded its maximum value (11.67 mg/L) during the long dry season (LDS) and its minimum value (8 mg/L) in the short dry season (SDS).

Regarding the organic parameters, the maximum values of $BOD_5$ (1.95 $mgO_2/L$) and COD (59.1 $mgO_2/L$) were observed during the rainy season (SRS and LDS respectively) and the minimum values (0.56 $mgO_2/L$ and 25.1 $mgO_2/L$) were noted during the rainy season and dry season (LRS and LDS respectively). The highest absorbency $UV_{254}$ value (0.172 $mgO_2/L$) was registered in the dry season (LDS) while the lowest (0.117 $mgO_2/L$) was observed in the rainy season (SRS).

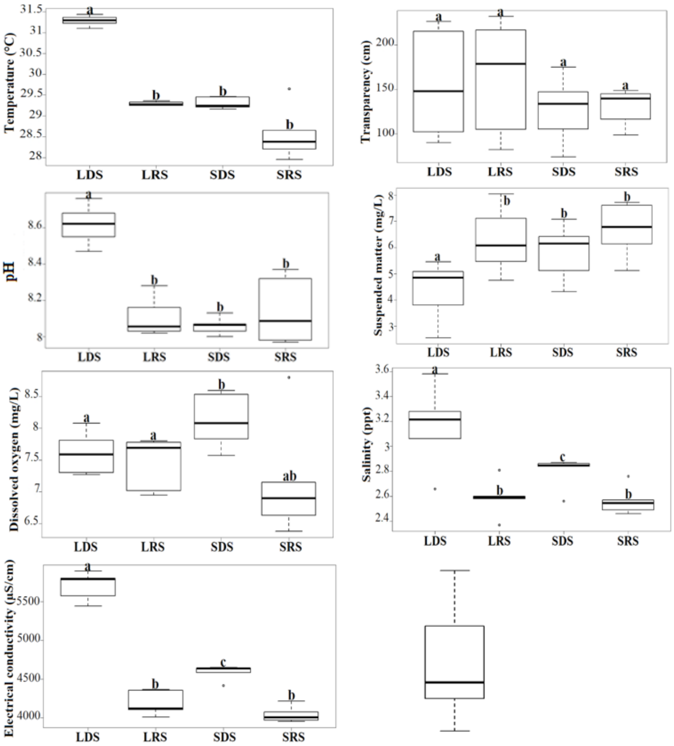

**Figure 4 :** Seasonal variations of physico-chemical parameters measured at the Jacqueville aquaculture station from January to December 2020: LDS = Long Dry season; LRS = Long Rainy season; SDS = Short Dry Season; SRS = **S**hort Rainy **S**eason; values with a common letter do not differ significantly (Mann Whitney test; p > 0.05

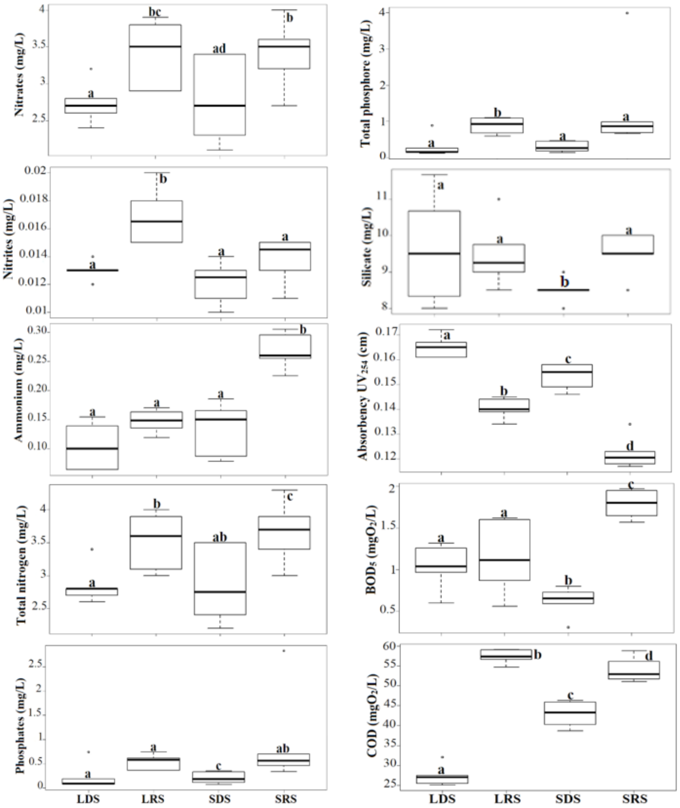

**Figure 5 :** Seasonal variations of nutrients and organics parameters measured in the waters of the Jacqueville aquaculture station from January to December 2020: LDS = Long Dry season; LRS = Long Rainy season; SDS = Short Dry Season; SRS = Short Rainy Season; values with a common letter do not differ significantly (Mann Whitney test; p > 0.05)

### 3.3- Spatial and seasonal variation of Chlorophyll a (Chl-a)

The spatial evolution of the chlorophyll-a content within the six stations of the Jacqueville aquaculture station is illustrated in figure 6. The highest level (15.46 µg/L) was recorded at station S5 and the lowest (0.11 µg/L) at station S2. Chlorophyll a levels did not vary significantly between stations (Kruskal-Wallis test; $p > 0.05$). Seasonally, the highest median values were noted in the long rainy season (LRS) at all stations (figure 7). The lowest median values were obtained in the short dry season (SDS). Chlorophyll a concentration showed a significant difference between the seasons studied (Mann-Whitney test; $p < 0.05$).

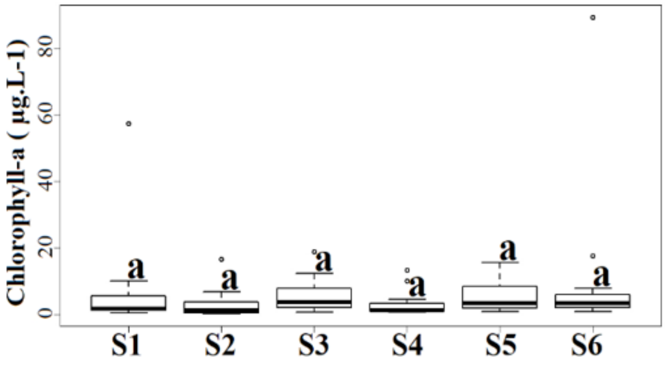

**Figure 6 :** Spatial variation of chlorophyll a concentration of the surveyed stations of the Jacqueville aquaculture station, S1 to S6 = stations; values having a letter in common do not differ significantly (Mann-Withney test; $p > 0.05$)

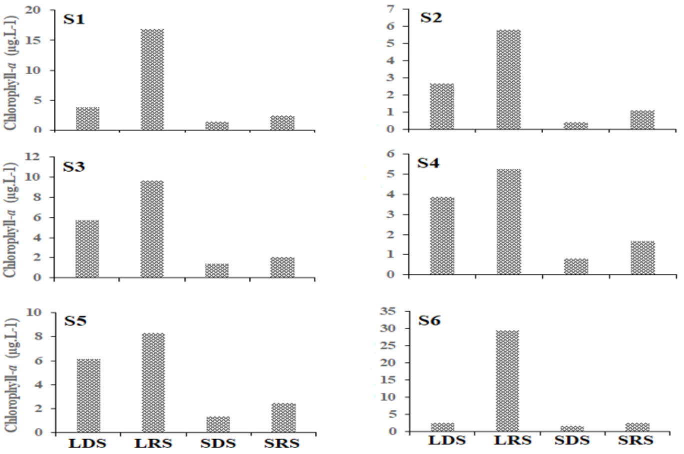

**Figure 7 :** Seasonal variation of median value chlorophyll a concentration in the waters of the Jacqueville aquaculture station, LDS = long dry season; LRS = long rainy season; SDS = short dry season; SRS = short rainy season

### 3.4- Abiotic and biotic typologies of the Jacqueville aquaculture station

### 3.4.1- Spatial clusters

Principal component analysis (PCA) was used to establish the abiotic and biotic typology of the surveyed stations (Figure 8). The first two axes express 50.20 % of the total variance, with 33.51 % for axis 1 and 16.69 % for axis 2 (Figure 7A). The correlation circle (Figure 7B) reveals that suspended matter, ammonium, phosphorus total, Phoshorus and COD are strongly and positively correlated with the axis 1. In contrast, temperature, electrical conductivity, pH, absorbency UV$_{254}$ and salinity are strongly and negatively correlated with this axis. Axis 2 is positively correlated with silicate, nitrate and total nitrogen. This axis is negatively correlated with dissolved oxygen, nitrite and chlorophyll-a. The factorial map (Figure 7C) reveals similar environmental and biological characteristics (chlorophyll biomass) between the stations.

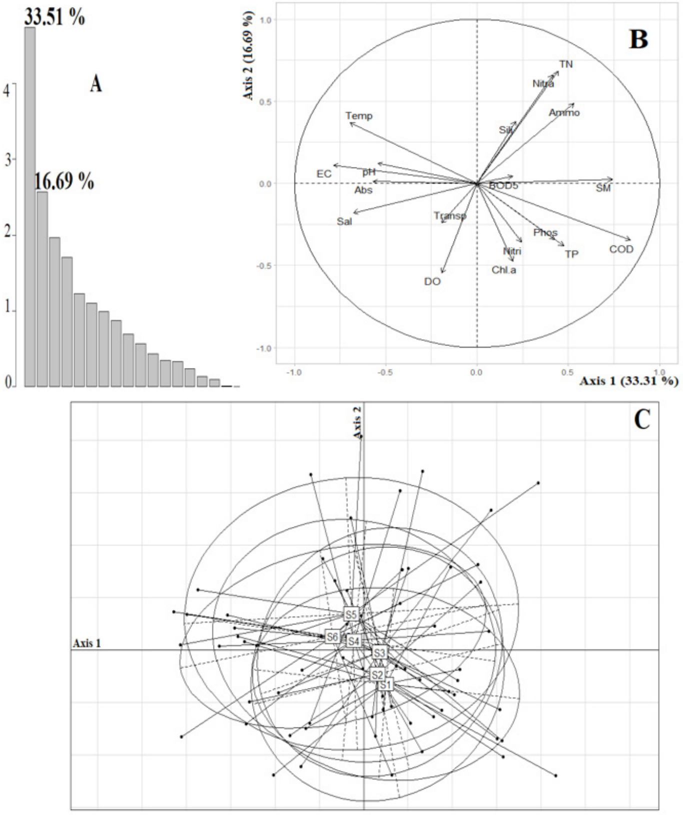

Figure 8 : Spatial ordering according to physico-chemical variables and chlorophyll a of the waters of the Jacqueville aquaculture station studied from a Principal Component Analysis: S1 - S6 = stations; A = histogram of eigenvalues; B = correlation circle; C = factorial map; Temp= temperature; pH= Hydrogen Potential; DO = Dissolved oxygen; EC = Electrical Conductivity; Sal= Salinity; Transp= Transparency; M= Suspended matter; Nitra= Nitrates; Nitri = Nitrites; Ammo= Ammonium ; TN= Total nitrogen ; Phos= Phosphates; TP= Total phosphorus; Sili= silicate ; Abs= absorbency UV$_{254}$ ; BOD$_5$: Biochimical Oxygen Demande. COD: Chemical Oxygen Demand; Chl.a= chlorophyll a

### 3.4.2- Seasonals clusters

The results of the principal component analysis (PCA) performed on the physico-chemical parameters and chlorophyll a showed that 55.97 % of the total inertia of the data is expressed by the first two axes. Axis 1 and 2 expressed 40.62 % and 15.35 % of this variance respectively (Figure 9A). The correlation circle (Figure 9B) shows that axis 1 is strongly and positively correlated with nitrate, ammonium, total nitrogen, phosphate, total phosphorus, suspended matter and COD. In contrast, salinity, electrical conductivity, pH, temperature and absorbency UV$_{254}$ are are strongly and negatively correlated with this axis. Axis 2 is positively correlated with silica and is negatively correlated with dissolved oxygen, nitrite and chlorophyll a. The plane formed by axes 1 and 2 (Figure 9C) and the hierarchical clustering analysis (HCA) defines three groups of seasons (Figure 10). The first is the long dry season (LDS), which is characterised by high pH, salinity, temperature, mineralised water and absorbency. The second is the short dry season (SDS), which is defined by well oxygenated waters, high transparency and chlorophyll a concentration. The third, which includes the rainy seasons (LRS and SRS), is characterised by high levels of Suspended matter, high levels of phosphates, total hosphorus, nitrates, ammonium, $BOD_5$ and COD.

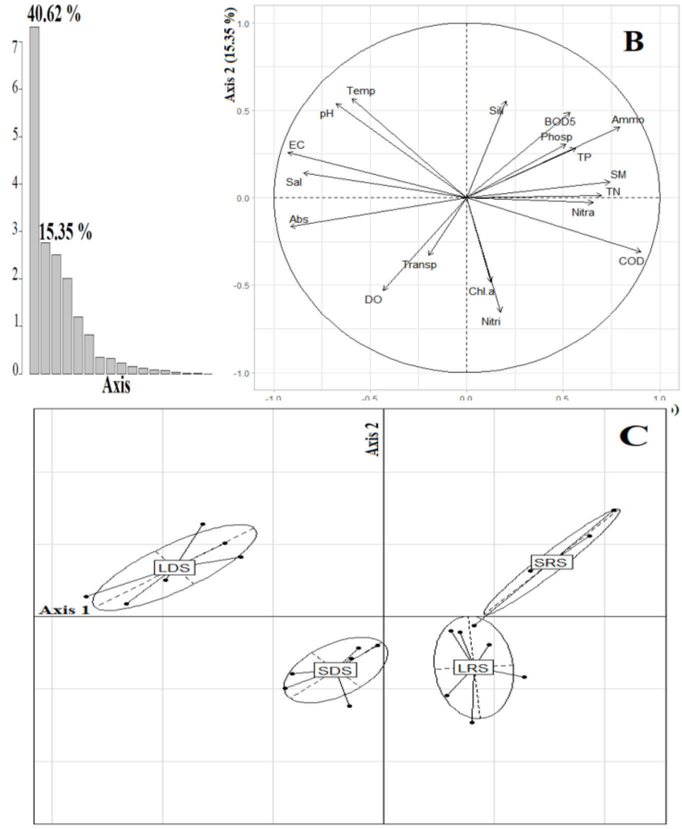

Figure 9 : Sesonal ordering according to physico-chemical and chlorophyll a variables of the waters of the Jacqueville aquaculture station studied from a Principal Component Analysis: S1 - S6 = stations; A = histogram of eigenvalues; B = correlation circle; C = factorial map; Temp= temperature; pH= Hydrogen Potential; DO = Dissolved oxygen; EC = Electrical Conductivity; Sal= Salinity; Transp= Transparency; M= Suspended matter; Nitra= Nitrates; Nitri = Nitrites; Ammo= Ammonium ; TN= Total nitrogen ; Phos= Phosphates; TP= Total phosphorus; Sili= silicate ; Abs= absorbency $UV_{254}$ ; $BOD_5$: Biochimical Oxygen Demande. COD: Chemical Oxygen Demand; Chl.a= chlorophyll a

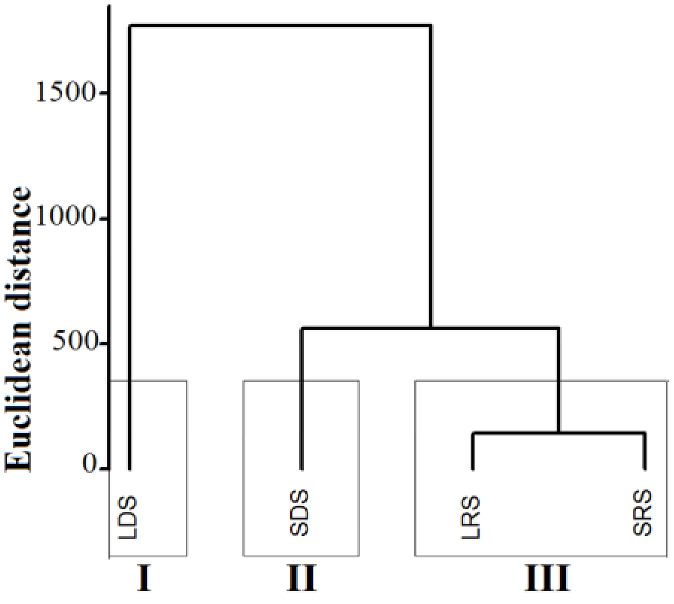

Figure 10 : Hierarchical classification based on the two first axis of the principal component analysis of the physico-chemical parameters and chlorophyll a of the waters of the Jacqueville aquaculture seasonal studied: I, II and III= constituted groups

## 3.5- Evaluation of the water quality of the Jacqueville aquaculture station

### 3.5.1- Absorbency $UV_{254}$ nm

The absorbency $UV_{254}$ values recorded in the waters of the Jacqueville aquaculture station vary from 0.142 cm (S4) to 0.150 cm (S5). At all stations, the absorbency $UV_{254}$ values were greater than 0.125, thus showing a fair level of raw water quality (Table VI).

**Table VI :** Result of the calculation of the absorbency $UV_{254}$ of the waters of the Jacqueville station studied from January to December 2020

| Stations | Value absorbency UV 254 (cm) | Raw water quality |
|---|---|---|
| S1 | 0.147 | Fair |
| S2 | 0.144 | Fair |
| S3 | 0.147 | Fair |
| S4 | 0.142 | Fair |
| S5 | 0.150 | Fair |
| S6 | 0.147 | Fair |

### 3.5.2- Organic Pollution Index (OPI)

The values of the organic pollution index calculated from the average annual levels of $BOD_5$, ammonium, nitrite and phosphate obtained in the waters of the Jacqueville aquaculture station are presented in Table VII. The OPI values are homogeneous at all stations. All the stations (S1, S2, S3, S4, S5 and S6) have a moderate level of organic pollution (OPI = 3.5).

**Table VII :** Result of the calculation of the organic pollution index of the waters of the Jacqueville station studied from January to December 2020

| | Parameters | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Stations | $BOD_5$ | | Ammonium | | Nitrites | | Phosphates | | | |
| | Value (mg/L) | Class | Value (µg/L) | Class | Value (µg/L) | Class | Value (µg/L) | Class | Class averages | Organic pollution levels |
| S1 | 0,99±1,02 | 5 | 0,17 ± 0,07 | 4 | 0,2±0,01 | 3 | 278 ± 0,16 | 2 | 3,5 | moderate |
| S2 | 0,95±0,69 | 5 | 0,18 ± 0,05 | 4 | 0,2 ± 00 | 3 | 386 ± 0,34 | 2 | 3,5 | moderate |
| S3 | 1,35±1,11 | 5 | 0,17 ± 0,07 | 4 | 0,2 ±00 | 3 | 375 ± 0,40 | 2 | 3,5 | moderate |
| S4 | 1,40±0,77 | 5 | 0,15 ± 0,09 | 4 | 0,1 ± 00 | 3 | 408 ± 0,48 | 2 | 3,5 | moderate |
| S5 | 0,9 ± 0,61 | 5 | 0,12 ± 0,09 | 4 | 0,1 ± 00 | 3 | 910 ± 1,48 | 2 | 3,5 | moderate |
| S6 | 1,22 ± 0,7 | 5 | 0,15 ± 0,10 | 4 | 0,1 ± 00 | 3 | 399 ± 0,42 | 2 | 3,5 | moderate |

### 3.5.3- Water classification according to SEQ-Water quality criteria

In accordance with the application of the SEQ-Water surface assessment tool, a water quality classification of the Jacqueville aquaculture station was established. The results are presented in Table VIII. The average values of pH, suspended matter, nitrite, ammonium and $BOD_5$ of all the stations are classified in the "very good" quality class for biology. Dissolved oxygen, nitrates and transparency lead the waters of the aquaculture station to the quality class "good" to "fair". The COD values recorded at all stations indicate a "fair" quality class.

**Table VIII :** Classification of the average concentrations of the various physico-chemical and chemical parameters from January to December 2020 according to the regulatory values of the SEQ-water (2003)

| Parameters | Units | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|---|
| pH | | 8.21 | 8.25 | 8.26 | 8.28 | 8.20 | 8.24 |
| DO | mg/L | 7.18 | 7.15 | 7.62 | 7.64 | 7.78 | 8.04 |
| EC | µS/cm | ndt | ndt | ndt | ndt | ndt | ndt |
| **Suspended particulates** | | | | | | | |
| Transparency | cm | 139.18 | 106.36 | 85.82 | 171.36 | 193 | 201.91 |
| SM | mg/L | 7.11 | 6.52 | 6.08 | 5.69 | 5.07 | 4.13 |
| **Organic matter** | | | | | | | |
| $DBO_5$ | $mgO_2/L$ | 0.99 | 0.95 | 1.35 | 1.41 | 0.90 | 1.22 |
| DCO | $mgO_2/L$ | 45.89 | 43.51 | 45.95 | 48.41 | 46.59 | 45.18 |
| **Nitrogen and phosphorus compounds** | | | | | | | |
| Ammonium | mg/L $NH_4$ | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 |
| Nitrates | mg/L $NH_4$ | 3.4 | 3 | 2.8 | 3 | 3.1 | 3.3 |
| Nitrites | mg/L $NH_4$ | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| phosphates | mg/L | 0.3 | 0.4 | 0.4 | 0.4 | 0.91 | 0.4 |
| Ptot | mg/L | 0.46 | 0.63 | 0.62 | 0.54 | 1.30 | 0.62 |

ndt: not determined

At station S5, in addition to the high temperature (29.69 °C) and phosphate (0.91 mg/L) values, the total phosphorus content places the water at this station in a "very poor" quality class for biology (aquatic life). The average total phosphorus values recorded at stations S2, S3 and S4, respectively, place the water at these stations in a "fair" quality class for biology, while it indicates a good quality class for station S1.

**Table IX :** Trophic status of the waters of the Jacqueville aquaculture station with reference to the O.C.D.E. classification (1982) during the period from January to December 2020

| Indicators | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|
| **PT avg (µg/L)** | 458.18 | 633.64 | 621.82 | 539.09 | 1296.36 | 621.82 |
| **Trans avg (m)** | 1.39 | 1.06 | 0.86 | 1.71 | 1.93 | 2.02 |
| **Trans min (m)** | 1.25 | 0.9 | 0.58 | 1.18 | 1.17 | 1.27 |
| **Chl *a* moy (µg/L)** | 7.88 | 3.12 | 5.71 | 3.41 | 5.39 | 12.24 |
| **Chl a max** | 57.41 | 16.56 | 18.77 | 13.25 | 15.46 | 89.42 |
| **Trophic status** | **Eutrophic** | **Eutrophic** | **Eutrophic** | **Eutrophic** | **Eutrophic** | **Eutrophic** |

### 3.5.4- Determination of the trophic status of the waters of the Jacqueville aquaculture station

The trophic status of the Jacqueville aquaculture station is presented in table IX. The synthesis of the average values of total phosphorus, the average and minimum values of transparency, the average and maximum values of chlorophyll a for all the stations allowed us to qualify their eutrophic state.

## 4- Discussion

The results of the physical and chemical parameters of the Jacqueville aquaculture station indicate spatial and seasonal variations. The recorded temperature values (27.5 °C-32.08 °C) are generally observed in tropical areas and correspond to those obtained by Yao (2020) in the Aghien Lagoon (23.10 °C-31.9 °C). In addition, Collins *et al.* (2020) also reported that temperatures around 20°C would favour a significant consumption of food by farmed fish, their metabolism and respiration rate resulting in a slight decrease in the dissolved oxygen content of the water body. This was noted in the results of this study. Indeed, the dissolved oxygen values measured in S1 (enclosure: rearing station) are significantly lower than those recorded at station S6 (lagoon water). The pH (6.81-9.31) obtained at the stations are within the recommended range suitable for aquatic life (Kanangire, 2001). These results are of the same order as measured in Aghien Lagoon (6.61- 8.3) by Koffi *et al.* (2019). The significantly high basic pH values obtained during the long dry season may be related to intense evaporation and the influence of more alkaline oceanic waters loaded with dissolved salts (Tfeil *et al.,* 2018). The influence of oceanic water on the Ebrié Lagoon waters is confirmed in this study by the high values of conductivity (3970-5893 µS/cm) and salinity (2.46 ppt-3.58 ppt). The low values of conductivity and salinity, especially during the short rainy season, would be due to the phenomenon of dilution by rainwater and continental water.

The significantly higher value of suspended solids recorded at station S1 (lagoon enclosure) could be explained by the feeding of fish with artificial feeds, which would result in the production of organic matter from uneaten feeds and fish metabolite waste. Thus, these colloidal particles suspended in the water will make the water less transparent. This observation could be the reason for the low transparency recorded at station S1 (breeding station) compared to station S6. These results corroborate those of Niamien-Ebrottié *et al.* (2017) in the Aghien Lagoon. Seasonally, the high suspended solids values and low transparency values obtained during the rainy season are attributable to the phenomenon of soil leaching during the catchment area and the high river flows (Guillou and Chapalain, 2011).

Nitrogen and phosphorus compounds in mineral form (nitrates, nitrites, ammonium, total nitrogen, phosphates and total phosphorus) are used by algae for their development.

Overall, the average values of these parameters measured comply with the SEQ-Water assessment thresholds for biology (aquatic life). However, the phosphate and total phosphorus values recorded at station S5 (100 m from S1 in open water) indicate that these waters are "fair" and "very poor" respectively. These high total phosphorus values (1.30 mg/L) are higher than those reported by Yéo (2015) (0.18 mg/L) and Koffi *et al.* (2019) (0.25 mgP /L), both in the Aghien lagoon. According to Yéo (2015), these high values are due to the influence of anthropogenic activities. This can be explained by the fact that fish farming is not the only anthropogenic activity practised, and which impacts the other sampling points. Also, Goué'm village and N'dri camp (located upstream from the Jacqueville aquaculture station) are agricultural and anthropised areas.

This would favour the leaching of cultivated land, enriched with fertilizers (chemical and organic) and phytosanitary products or urban effluents. Local people in these villages wash their dishes and clothes directly in these lagoon waters, as well as bathing, using detergents rich in phosphorus and nitrogen compounds. Dèdjiho *et al.* (2013) have also reported this phenomenon of enrichment of the water with nutrient salts in the Porto-Novo lagoon in Benin. Furthermore, according to trophic criteria (O.E.C.D, Pellerin, 2011), high total phosphorus values in the lagoon are indicative of a state of hypertrophy (threshold = 0.1 mg P/L). Which would contribute to the proliferation of phytoplankton algae in waters of the Jacqueville aquaculture station. Indeed, these excessive inputs of nutrients (total phosphorus) from domestic water discharges and agricultural activities would lead to several disruptions of ecosystems and would have consequences on human activities: fishing, swimming, water purification (Durand *et al.,* 2011). The variation in silica content observed at the stations is thought to be due to physical mixing of Atlantic Ocean water and freshwater, interaction between chemicals and minerals, co-precipitation with humic components and biological removal by plankton, especially phytoplankton (Padisa'k and Naselli-Flores, 2021). The increase in silica content seen during the long dry season is thought to be due to intermittent rainfall that may have resulted in runoff on the coast. In addition, the use of silica by phytoplankton (diatoms) may have contributed to its availability (Xu *et al.,* 2022). According to O.E.C.D. classifications, the waters of the Jacqueville aquaculture station are eutrophic. This could be explained by the considerable increase in chlorophyll a concentration observed during the study during the rainy season at the sampling stations.

Concerning the abiotic typology, at the spatial level, the physico-chemical and biological parameters (chlorophyll biomass) have no influence on the stations. This situation could be explained by the proximity of the sampling points. In fact, there is an interconnection between the stations and the environmental parameters measured are more or less the same at each station. At the temporal level, the long dry season (LDS) characterised by high temperatures, basic, saline and mineralised waters could be explained by the high insolation which increases the rates of chemical and biochemical reactions (Groga, 2012). On the other hand, the rainy seasons (LRS and SRS) defined by waters rich in suspended solids and rich in nutrients could be explained by the availability of nutrient salts at this period due to the input of terrigenous waters. Also, this could be explained by the relative richness of the environment due to the high bacterial activity in nutrients favouring algal development (Gboko *et al.,* 2019).

Concerning the spatial evolution of chlorophyll *a* (0.11 µg/L to 15.46 µg/L), the highest value recorded at station S5 could be due to relative richness in total phosphorus recorded at this station. These results obtained are largely higher than those of Seu-Anoï (2012) recorded in the lagoon complexes of Grand-Lahou (0 to 4.3 µg/L) and Ébrié (2.3 to 6.7 µg/L), and relatively lower than those obtained by the same author in the Aby hydrosystem (3.2 to 29.7 µg/L). The significantly high values obtained during the main rainy season are probably the result of a planktonic proliferation fed by the abundance of nutrients coming from the freshwater inflow during this period. Thus, it is confirmed that during the rainy season, nutrient salts have the greatest influence on chlorophyll a production in the lagoon. Indeed, the chloroplast needs light to trigger photosynthesis, but it also necessarily needs an environment rich in nutritive salts (Zongo, 1994). According to Angot and Gerard (1996), nutrient salts have the greatest influence on phytoplankton production and chlorophyll production in an aquatic environment.

OPI values (3.5) indicate moderate organic pollution, which translates into acceptable water quality at the Jacqueville aquaculture station. This result could be explained by the fact that industrial wastewater discharges are not directly discharged into the lagoon. The values of this index are explained by the acceptable levels of nutrient salts (Benbouih *et al.,* 2005). However, planners must take measures to improve the quality of this ecosystem and preserve it in time and space.

## Conclusion

The results of this work provided more data on the physico-chemical parameters and the chlorophyll biomass of the waters of the Jacqueville aquaculture station (SAJ). This long-term monitoring of water quality indicates moderate changes in physico-chemical, organic and biological parameters as a consequence of aquaculture activities. In view of the results, aquaculture has had only a minor impact on the physico-chemical and biological quality of the waters of the Ebrié lagoon. Therefore, it is recommended health education for the populations living along the Ebrié lagoon would be necessary to prevent the risks linked to certain bad hygiene practices in order to avoid possible epidemics.

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