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Assessment of some physico-chemical parameters of the fish farm water in Abengourou, Côte d'Ivoire

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ABSTRACT

The objective of this study is to assess the physico-chemical quality and the trophic state of the waters of a fish farm in ponds located in Abengourou in the east of the Côte d'Ivoire. The physicochemical parameters were determined in water samples collected on the farm from September to October 2020 according to the NF T90-105 standard of AFNOR (1997). The monthly values of temperature, hydrogen potential, dissolved oxygen, conductivity, total dissolved solids, transparency and suspended matter are respectively between 28.28 - 30.87 ºC; 6.2 - 8.18; 5.28 - 6.92 mg/L; 32 - 101 µS/cm; 21 - 42 mg/L; 25 - 43.6 cm and 101.69 - 149.58 mg/L. Monthly concentrations of nitrite, nitrate, ammonium, phosphate and chlorophyll-a in farm water respectively ranged from 0.009 to 0.028 mg/; from 3.7 to 16.6 mg/L; 1.04 to 2.69 mg/L, 2.2 to 4.3 mg/L and 2.6 to 6.6 µg/L. The values of the measured parameters were compared with the standards recommended for the breeding of tilapia *Oreochromis niloticus*. The comparative analysis revealed that most of the water quality parameters are suitable for the breeding of the fish *Oreochromis niloticus*. However, the transparency, the conductivity and the recorded phosphate results were not compliant with the standard values , which are respectively between 30 - 80 cm, 150-450 µS/cm and 0.5 mg/L. The values of the TDS / EC ratios (0.48 - 0.78) and the pollution indices (2.00 - 2.66) showed a strong mineralization of the water and a high level of organic pollution in all the structures of the farm which indicate a eutrophic state of the water of the dam and the ponds. So this eutrophication phenomenon can lead to long-term stress and mortality of fish if adequate measures are not taken.

INTRODUCTION

Fish is an inexpensive source of protein, and its exploitation is an important commercial activity in many parts of the world (**Dinesh *et al*., 2017**). In fact, fish is not only an important part of men's diets in most countries of the world (**Assiah *et al*., 2004**) but also and above all, it plays an essential role in global food and nutritional security (**FAO, 2013**). However, the fast-growing population and demand for fishery products have led to an alarming decline in capture fisheries. Facing the scarcity of fishery resources and the overexploitation of water bodies, aquaculture has become an essential alternative, which can help populations meet their needs in animal proteins of fishery origin (**FAO, 2014**).

Aquaculture has significantly grown around the world. It is one of the fastest growing food sectors in the world, which almost contributes to 50% of total fish consumption per capita (**Poonkodi, 2014**). In addition, in 2014, most of the fish for human consumption came from aquaculture, and this trend must continue to satisfy future demands for global food production (**FAO, 2016** and **Bachi *et al*., 2020**). Besides, aquaculture is a lucrative activity offering better employment and foreign exchange prospects for a nation (**Ginson *et al*., 2017**).

In Côte d'Ivoire, aquaculture production, which is 4,701 tons per year, is very low compared to the high annual demand which is around 300,000 tons (**FAO, 2018**). It constitutes only 5% of national fishery production (**MIRAH, 2019**). This low production and the quality of aquaculture products are partly linked to environmental conditions (**Sanou, 2018**).

It is known that water quality is the main factor that limits the productivity of aquatic ecosystems. The health of these ecosystems depends on their physicochemical characteristics (**Niyoyitungiye *et al*., 2019**). These physicochemical conditions have a very significant impact on the living environment of fish and therefore on fish farming activity. Indeed, water quality is one of the main factors, which influence the quality of fish, its growth and production (**El-Nemaki *et al*., 2008**). Consequently, the degradation of the water quality can harm aquatic life. The different species of fish as a whole have specific needs in terms of the physico-chemical quality of the water too. Subsequently, the physico-chemical parameters are very important because they have a significant effect both on water quality and breeding performance (**Mohammad *et al*., 2016**).

Farmed fish are found to be much more tolerant of water conditions than wild ones due to their domestication. Nevertheless, extreme limits should not be exceeded; beyond which water could become unsuitable for breeding fish (**Morin, 2012**).

The main objective of this study is to assess the physicochemical quality, the nutrient content and the chlorophyll-a of the water in the rearing structures of a fish farm in ponds. It also evaluates the level of organic pollution and the state of eutrophication of the farm.

MATERIALS AND METHODS

1. Study zone

The fish farm is located in Dramanekro in the Department of Abengourou in the East of the Côte d'Ivoire, between longitude 3°62'53" W and latitude 6°71'66" N (**Fig.1**).

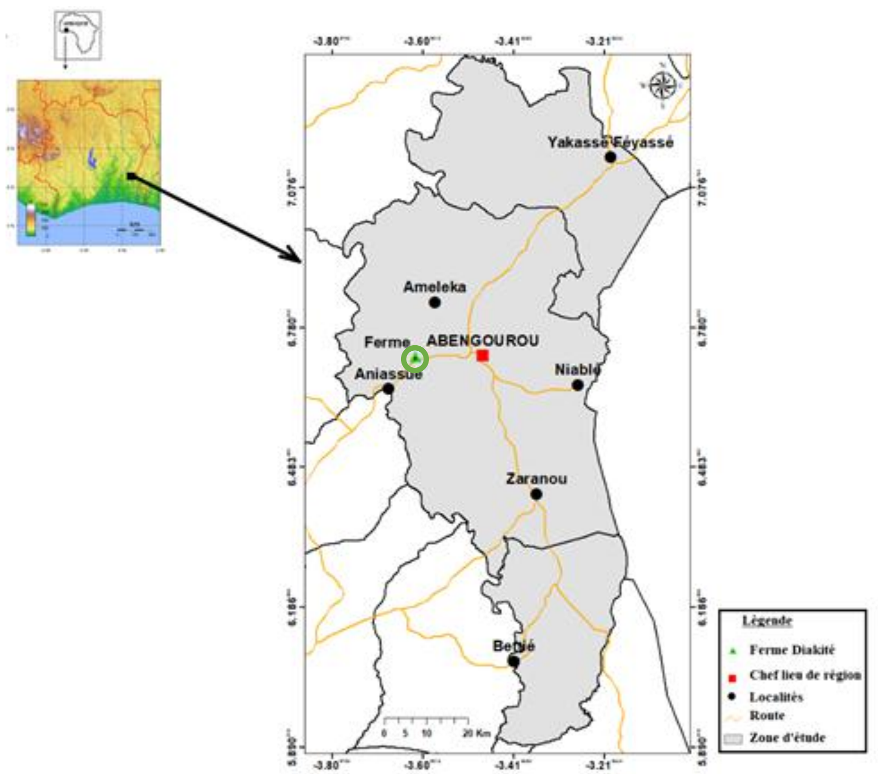

Fig. (1): Location of the fish farm in Dramanekro (Abengourou) (**Guei, 2020**)

This is a continental farm where the tilapia *Oreochromis niloticus* fish are reared in ponds. Farmed fish are fed with low rice meal mixed with local fish powder. The farm has a gravity dam (12,000 m^2) which supplies five ponds (400 to 500 m^2) **(Fig. 2)**. The ponds have an open pipe system completed by buried polyvinyl chloride (PVC) pipes that ensure the water supply to the livestock structures. The pipes are equipped with a 1 mm mesh protective mosquito net. A minimum water flow is maintained in the ponds. The dam is supplied by a tributary of the Comoe River.

Fig. (2): Livestock structures of the farm (a: Ponds, b: Dam) (**Guei, 2020**)

2. Collection and storage of water samples

The water samples were taken from September to October 2020 in three different ponds and the dam of the fish farm. The water is collected using 300 mL plastic jars previously rinsed with the water to be sampled. The jars are then immersed in the water of the dam and ponds to about 0.5 m deep. Once filled to the brim, the jars are removed from the water and immediately resealed. They are subsequently labeled, numbered indelibly. Samples for the chlorophyll-a assay are wrapped in aluminum foil. All the samples are then kept in a cooler at around 4 °C for the analyzes in the laboratory. The analysis protocol used in this work is based on the NF T90-101 standard of **AFNOR** (**1997**).

3. Determination of parameters

3.1. Parameters determined *in situ*

Temperature (T), hydrogen potential (pH), dissolved oxygen (DO), electrical conductivity (EC) and total dissolved solids (TDS) were measured using a multi-parameter portable type HANNA HI 9829. This device consists of an electrode probe and an electronic box which automatically displays the values according to the chosen parameter. Then, the multi-parameter has been calibrated and the probe has then been immersed in the water to be sampled at 0.5 m deep. Depending on the selected setting, the reading is taken after the value has stabilized on the screen.

Transparency (Trans) was determined using the Secchi disc which consists of a ballasted string graduated in centimeters (cm) and a disc. The Secchi disc is immersed in water until it is completely gone. Then it is slowly risen to the surface. As soon as it reappears, we measure the distance that separates it from the surface of the water. This distance is equal to the transparency.

3.2 Parameters determined in the laboratory

3.2.1. Suspended matters

The suspended matters (SM) were determined according to the method described by **Aminot & Chaussepied** (**1983**). So, Whatman number 1 glass fiber filter membranes (GF/C, millipore 0.5 µm) were first washed and placed in an oven at a temperature of 450 to 500 °C for one hour. The filters are subsequently cooled down in a desiccator and weighed according to the AFNOR T90-105 method to have a mass m_1. Two hundred and fifty (250) mL of each sample were homogenized and gradually filtered under vacuum through previously weighed filter papers in order to retain all particles larger than 0.5 µm. The suspended matters retained on the filters are rinsed with distilled water. The filters are then removed and dried in an oven at 70 °C for two hours to remove all the water. Next, the filter membranes are cooled down in a desiccator and weighed again to have a mass m_2. The difference in masses helps to know the total mass of suspended matter. The mass concentration of SM (mg/L) is given by the following relationship (**Aminot & Chaussepied, 1983**):

$$[SM] = \frac{m_2 - m_1}{V}$$

- m_1: the mass of the filter before filtration (mg);
- m_2: the mass of the filter after filtration (mg);
- V: the volume of filtered water (L).

3.2.2. Determination of nutrient salts and chlorophyll-a

Concentrations of nutrient salts and chlorophyll-a were determined by using a UV 2700 Molecular Absorption Spectrometer (MAS). Nitrates (NO_3^-), nitrites (NO_2^-) and ammonium (NH_4^+) are determined by colorimetric assay according to the method of **Koroleff** (**1976**) described by **Aminot & Chaussepied** (**1983**). Orthophosphate (PO_4^{3-}) is determined according to the method of **Murphy & Riley** (**1962**). Phosphates, nitrites, nitrates and ammonium were respectively measured at wavelengths of 885 nm, 543 nm, 415 nm and 630 nm.

Chlorophyll-a, for its part, was determined by a spectrophotometric assay according to the method of **Lorenzen** (**1967**). The chlorophyll pigments were extracted in 10 ml of 97% ethanol followed by the spectrophotometric reading of each sample at two wavelengths namely 665 and 750 nm.

4. Statistical analysis

STATISTICA software (Version 7.1) was used to perform the correlation test to establish a relationship between physicochemical parameters, nutrient salts and chlorophyll-a. The Bravais-Pearson linear correlation coefficient r varies from -1 to +1. The value -1 indicates a perfect inverse relationship while the value +1 indicates a perfect positive correlation. The value 0 shows an absence of correlation between the parameters. Also, the closer the r value is to -1 or +1, the stronger the linear relationship is.

Nonetheless, the closer the value of the coefficient r is to 0, the weaker the linear relationship is (**Koffi *et al.*, 2014** and **Kouyaté *et al.*, 2021**).

5. Determination of the state of mineralization and organic pollution of water

5.1. TDS/EC ratio

The ratio of total dissolved solids and electrical conductivity (TDS/EC Ratio) helps to assess the level of mineralization of the water. This ratio is generally 0.5 for strong ionic solutions and 0.7 for weak ionic solutions (**Adjiri *et al.*, 2019**).

5.2. Organic pollution index

The Organic Pollution Index (OPI) was first suggested by **Leclercq & Maquet** (**1987**). This index allows to assess the chemical quality of water impacted by organic pollution from the following parameters: orthophosphate (PO_4^{3-}); ammonium (NH_4^+); nitrites (NO_2^-) and Biological Oxygen Demand over 5 days (BOD_5) (**Table 1**). Nevertheless, the index can only be determined from orthophosphate; ammonium and nitrite. Since BOD_5 was not determined in the present study, OPI was determined from the concentration of orthophosphate (PO_4^{3-}); ammonium (NH_4^+) and nitrite (NO_2^-). The OPI clearly identifies the strongest pollution and the deterioration by phosphates which heralds eutrophication. The value of the OPI ranges from 1 to 5 (5 is the best quality).

To calculate the OPI, we just have to average the classes obtained for the parameters according to **Table (1)**. So the pollution level is determined from the OPI (**Table 2**).

Table 1: Assessment grid for organic water pollution (**Leclercq and Maquet, 1987**)

Classes	**DBO_5** (mg O_2/L)	**NH_4^+** (mg N/L)	**NO_2^-** (mg N/L)	**PO_4^{3-}** (mg P/L)
5	< 2.0	< 0.1	< 0.005	< 0.015
4	2.0 – 5.0	0.1 – 0.9	0.006 – 0.010	0.016 – 0.075
3	5.1 – 10.0	1.0 – 2.4	0.011 – 0.050	0.076 – 0.250
2	10.1 – 15.0	2.5 – 5.0	0.051 – 0.150	0.251 – 0.900
1	> 15.0	> 6.0	> 0.150	> 0.900

Table 2: Level of organic pollution from Organic Pollution Index (**Leclercq & Maquet, 1987**)

Organic pollution index	**Organic pollution level**	**Trophic level**
5.0 – 4.6	Very weak	Not eutrophic
4.5 – 4.0	Weak	Weakly eutrophic
3.9 – 3.0	Moderate	Moderately eutrophic
2.9 – 2.0	Strong	Strongly eutrophic
1.9 – 1.0	Very strong	Hyper eutrophic

RESULTS AND DISCUSSION

1. Physicochemical parameters

The measurement of the physico-chemical parameters of water gives a first estimate of its quality because they have an influence on several physical, chemical and biological processes (**Coulibaly, 2013**). They therefore help to assess the quality of the water and to know whether or not it is suitable for aquatic life (**Dimon *et al*., 2014**; **Noumon *et al*., 2015**) in general and that of fish in particular. Results showed the variation in the physico-chemical parameters of the water in the ponds and the fish farm dam, measured from September to October 2020 **(Fig. 3)**.

1.1. Temperature

Temperature is a key factor that impacts the activities of fish (**Ipungu *et al*., 2015**). It plays an essential role in fish reproduction (**Attingli *et al*., 2016**), in their metabolism and their growth (**Morin, 2012**). The monthly temperature variations measured in the different structures of the farm are presented in **Fig. (3a)**. Analysis of this graph shows that the values oscillate between 28.28 and 30.87 °C during this study.

The temperature remained high in various structures of the fish farm throughout the study period. These high values could be explained on the one hand by the degree of insolation due to direct contact of the sun's rays with the water surface (**Roy & Chavhan, 2017**), and on the other hand, by the low water level (**Raj & Sevarkodiyone, 2018**).

Results in **Table (3)** showed that the water temperature has an inverse relationship with nutrients and these correlations are significant with nitrate (r = - 0.53) and nitrite (r = - 0.53) ions. These results show that the decrease in temperature or even low temperature values lead to an increase in the nutrient salts of the fish farm water, in particular nitrates and nitrites. Furthermore, temperature shows a significant and positive correlation with chlorophyll-a (r = 0.59). This indicates that the chlorophyll-a concentration increases with the rise in temperature accordingly. Our results are the same as those obtained by **Onada *et al*.** (**2015**) in fish farms in Nigeria (27.95 ± 1.88 and 30.21 ± 1.88 °C). But, the temperature values obtained are higher than those recorded by **Makori *et al*.** (**2017**) in Busia County in Kenya (24 to 26 °C). However, the temperatures recorded in the water of the studied farm are favorable to aquatic life (**Noumon *et al*., 2015**) and good productivity. Indeed, according to **Morin** (**2012**), a rise in temperature accelerates the metabolism of fish and stimulates its growth. What is more, our values are consistent with the tolerance range for breeding *Oreochromis niloticus* between 13.5 and 33 °C (**Kestemont *et al*., 1989**).

1.2. Hydrogen potential

The pH is an essential parameter for maintaining life in the aquatic environment and its stability is very important in fish farming (**Morin, 2012**). Usually, a pH between 7 and 8.5 is ideal for biological productivity. Fish can be stressed in waters with a pH ranging from 4 to 6.5 and 9 to 11. Death is almost certain at a pH below 4 or above 11 (**Kane *et al.* 2015**). The pH values of the studied structures are between 6.20 and 8.18

(**Fig. 3b**). The basic nature of the water from the dam (7.13 - 8.07) and from pond 3 (8.04 - 8.18) during the two sampling campaigns and from ponds 1 (7.33) and 2 (7.74) during the month of September could be explained by the formation of nitrogenous organic compounds (**Atta *et al*., 2014**). This basic character can also be due to the quality of the substrate (**Faurie**, **2011**). On the other hand, the acidity of the waters of pond 1 (6.56) and pond 2 (6.20) during the month of October is essentially due to the biological activity of the environment and to the origin of water that supplies the farm (**El Morhit, 2009**). It could also be explained by the mineralization of organic particles and the discharge of runoff containing chemicals from human activities, in particular the rubber plantations near the fish farm (**Atta *et al.*, 2014** and **Boni *et al*., 2016**). The Bravais-Pearson correlation matrix indicates positive and significant correlations between pH and electrical conductivity (r = 0.73), total dissolved solids (r = 0.67) and nitrite (r = 0.55) (**Table 3**). This could be because pH determines the solubility and bioavailability of chemical constituents such as nutrients (**Shetaia *et al*., 2020**). The pH values recorded during the sampling period are within the range recommended for the breeding of *O. niloticus*; values between 5 and 11 (**Kestemont *et al*., 1989**). Our values are close to those reported by **Ouattara *et al*.** (**2005**) in Côte d'Ivoire (6.73 to 8.77) and **Osman and El-Khateeb** (**2016**) in Egypt (6.8 to 8.5). On the other hand, the minimum and maximum values recorded during the present study are lower than the minimum and maximum values obtained by **Ghannam & Aly** (**2018**) which are 7.00 and 8.90.

1.3. Dissolved oxygen

Dissolved oxygen is an environmental parameter that is not toxic to fish even at very high concentrations. But an insufficient concentration of dissolved oxygen in the water can cause breathing difficulties for fish (**Morin, 2012**) which can lead to their death (**Chouti *et al*., 2010**). Monthly dissolved oxygen concentrations range from 5.28 to 5.85 mg/L during the month of September and from 6.17 to 6.92 mg/L during the month of October (**Fig. 3c**). Our study showed that the waters of the different structures of the farm were oxygenated throughout the sampling period. This is probably the result of the processes of dissolution of atmospheric oxygen by air/water contact (**Martel *et al*., 2013**). The dissolved oxygen values observed in the present study (5.28 and 6.92 mg/L) are higher than those recorded by **Coulibaly *et al*.** (**2018**) which vary from 3.63 ± 0.60 to 4.70 ± 1.23 mg/L in a fish farm in pond in Offoumpo in the department of Agboville (Cote d'Ivoire). The high values of dissolved oxygen in the water of fish farm structures may be due to the abundance of phytoplankton which increases photosynthetic activity resulting in the production of a large amount of dissolved oxygen (**Koffi *et al*., 2014**). This oxygenation of farm water could contribute to the good food intake of the fish as well as their well-being. Actually, according to **Shetaia *et al*.** (**2020**), fish stop feeding when the dissolved oxygen level is between 3 and 4 mg/L and they die when this level drops to 1 mg/L. Our results meet the required standard for rearing *Oreochromis niloticus*. These values, in fact, are all greater than 3 mg/L; value below which tilapia

Oreochromis niloticus exhibits respiratory stress that can bring about death (**Kestemont *et al*., 1989**).

1.4. Electrical conductivity

The conductivity of water has a significant impact on the development of fish. The maturation of fish, of course, is accelerated by the drop in conductivity (**Bénech & Ouattara, 1990**). The electrical conductivity of the water in the farm structures recorded during this study varies between 32 and 101 µS/cm (**Fig. 3d**). The maximum values of conductivity observed in pond 3 (84 - 101 µS/cm) are the result of a massive entry of sestons carried by runoff (**Coulibaly, 2013**). A statistically significant and positive correlation is observed between electrical conductivity and total dissolved solids (r = 0.87) (**Table, 3**). According to **Goher *et al*. (2017**), the increase in electrical conductivity would be induced by an increase in TDS levels. Moreover, the strong positive correlation observed between conductivity and TDS could point out the fact that these two parameters describe the presence of inorganic salts dissolved in solution (**Yaka *et al.*, 2020**). This correlation could also indicate the fact that the increase in conductivity and TDS values is linked to the exogenous supply of food in the breeding structures (**Imorou *et al*., 2010**). The electrical conductivity is positively and significantly correlated with nitrite (r = 0.75). This correlation could imply a strong contribution of nitrite ions in increasing the value of conductivity. In fact, this correlation shows that the electrical conductivity increases with the increase in nitrite concentrations in the water of the fish farm. Our conductivity results are lower than those of **Avit *et al*.** (**2012**), because they recorded values between 222 and 288 µS/cm in pond farms in Cote d'Ivoire. But, in their previous work, **Abubakar *et al*.** (**2015**) recorded values lower than the ones in this study in Nigeria (21 to 62 µS/cm). **Venkatesh** (**2016**) recorded the same low values in Karnataka in India too (164 to 302 µmhos/cm). However, the increase in conductivity does not always have an inhibitory effect on fish reproduction (**Benech & Ouattara, 1990**). Although, the results obtained in the present study are not within the desirable limits (150 - 450 µS/cm) recommended by **Mamadou** (**1998**), they could affect the good productivity of the farm.

1.5. Total dissolved solids

High values of total dissolved solid (TDS) cause increased electrical conductivity (**Goher *et al*., 2017**) and may prevent light penetration and oxygenation of the aquatic environment (**Attingli *et al*., 2016**). They also affect the functions of the gills and kidneys and subsequently the survival and size of fish (**Wright, 2009**). Our study reveals concentrations of total dissolved solids between 21 and 42 mg/L with the highest values in the dam (31 - 39 mg/L) and the pond 3 (39 - 42 mg/L) (**Fig. 3e**). This increase in TDS in these two structures could be due to agricultural practices around the farm with the use of fertilizers and pesticides, and erosion (**Shanur *et al*., 2015**). The Pearson correlation matrix indicates the existence of a positive and significant correlation between total dissolved solids and nitrite (r = 0.84) (**Table, 3**). This shows that the concentration of total dissolved solids in farm water increases significantly with the increase in the nitrite content. The concentrations of total dissolved solids are higher than those of **Agbaire *et al*.** (**2015**) who recorded values between 19.91 and 24.25 mg/L. For these authors, the high values of TDS result in the use of artificial food in the breeding structures. Our results are below the tolerable threshold for the rearing of *Oreochromis niloticus*, which is 200 mg/L (**Mélard, 1999**).

1.6. Suspended matters

Suspended matter mainly come from the supply water of the fish farm and the breeding (**Morin, 2012**). During the present study, SM values ranged from 101.69 mg/L to 149.58 mg/L (**Fig. 3f**). The results presented in our study showed that the levels of suspended matters are higher in the ponds (131.23 - 149.58 mg/L) than in the dam (101.69 - 104.45 mg/L). These high concentrations of suspended matters could be attributed to the huge amounts of organic matter produced from uneaten foods (**Morin, 2012**) and the waste from fish metabolites (**Toule *et al*., 2017**). These high SM levels could adversely affect good fish productivity. The accumulation of solid particles can suffocate the eggs and make the fine structures of the gills of small fish sensitive. What is more, this situation can cause damage to fish by clogging the gills and prevent them from breathing or filtering water for osmoregulation (**Coulibaly *et al*., 2019**). In the present study, SM are inversely and significantly correlated with transparency (r = - 0.98). As a matter of fact, these materials affect the transparency of the water and reduce the penetration of light and as a result photosynthesis (**De Villers *et al.*, 2005**). Besides, SM show negative relationships with all nutrient salts and they are significant with ammonium (r = -0.94), nitrate (r = -0.91) and orthophosphate (r = -0.70) (**Table, 3**). These correlations showed that the concentrations of nutrients in water decrease significantly with increasing levels of suspended solids. But, it should be noted that a positive and significant correlation was found between SM and chlorophyll-a (r = 0.93). This result implies that the concentration of chlorophyll-a increases with the increase in the level of suspended solids content of dam water and fish ponds. The suspended solids contents of the present study are higher than those (3 - 77.6 mg/L) obtained by **Toule *et al***. (**2017**) in the waters of the aquaculture stations of Layo and Jacqueville (Lagune Ebrié, Cote d'Ivoire). On the other hand, the values of our study are included in the range of values obtained by **Ghannam & Aly** (**2018**) which oscillate between 21.00 and 276.00 mg/L. However, the values of the suspended solids obtained are lower than the critical value for the rearing of *Oreochromis niloticus* which is 200 mg/L (**Malcom *et al*., 2000**).

1.7. Transparency

Water transparency affects the penetration of light into the water and influences the productivity of the aquatic system (**Goher *et al*., 2017**). It enables to assess the density of the particles present in the water and it has an effect on the concentration of dissolved oxygen (**Barbe *et al.*, 2000**). The transparency values vary between 25 cm in pond 1 and 43.6 cm in the dam (**Fig. 3g**). Transparency remains low over the entire study period. These low values of transparency confirm the high load of suspended matter in the various livestock structures (**Coulibaly, 2013**). The Bravais-Pearson correlation matrix indicates a reversible relationship between transparency and suspended matters (r = - 0.98); anything that supports the inverse effect of the two variables on each other.

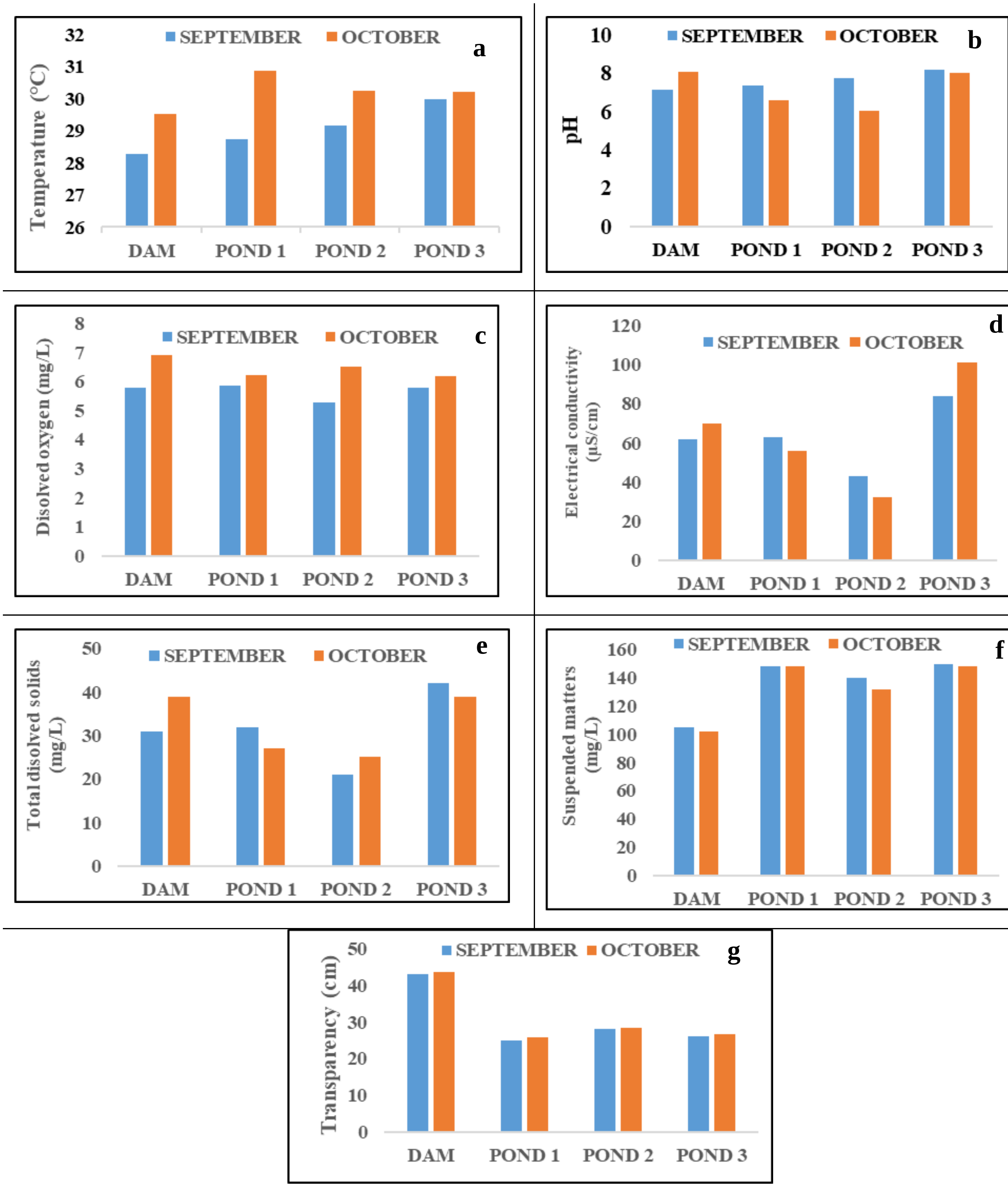

Fig. (3): Monthly variation of the physico-chemical parameters of the fish farm water from September to October 2020

This study revealed that the transparency is low in all the ponds (25 - 28.36 cm) in comparison with the values obtained in the dam (43 - 43.6 cm). The low transparency values recorded in ponds could be explained by the loss of food uneaten by fish and the lack of maintenance of ponds, which greatly contribute to the deterioration of water quality (**Morin, 2012**). Thus, low values of this parameter affected fish life by promoting fungal diseases and decrease the reproduction rate (**Mukasikubwabo, 1990**). Our transparency values are lower than those obtained by **Bamba *et al.*** (**2007**) oscillating between 47.2 ± 0.78 and 50 ± 1.22 cm. Yet, these transparency values are higher than those of **Aboubakar *et al*.** (**2015**) who recorded values ranging from 8 to 11 cm. Only the dam (43 - 43.6 cm) still has a value within the range (30 - 80 cm) recommended for fish farming (**Bhatnagar & Devi, 2013**). The transparency controls the distribution of nutrients in fish farm waters. In fact, it shows positive correlations with all nutrient salts and statistically significant with ammonium (r = 0.98), nitrate (r = 0.95) and phosphate (r = 0.73) (**Table, 3**). The study reveals that transparency is inversely correlated with the value of chlorophyll-a (r = - 0.96) (**Table, 3**). This shows that increasing the transparency of water significantly decreases the chlorophyll-a contents.

3.2. Nutrient salts

Nutrient salts are dissolved mineral salts composed of phosphorus and nitrogen (**Charpy, 2008**). The variation in nutrient levels is shown in **Fig. (4)**.

3.2.1. Ammonium ions

The ammonium ion is not toxic to fish (**Morin, 2012**). Yet, it participates in the eutrophication of the aquatic environment (**Yao *et al*., 2009**). In the present study, the ammonium concentrations respectively varied from 1.04 to 2.69 mg/L in the pond 3 and the dam (**Fig. 4a**). These ammonium levels observed in farming structures are thought to result on the one hand from the decomposition of waste and excrement from fish and on the other hand from the rest of the food uneaten by the fish (**Bahri, 2009**). According to **Kestemont *et al.*** (**1989**), an ammonium content below the threshold of 2.3 mg/L is suitable for fish farming. The ammonium concentrations determined in the present study are higher than those reported by **Ntumba *et al.*** (**2016**) in the ponds in Kinshasa which are between 0.1 and 0.4 mg/L. Nonetheless, ammonium contents remained below threshold (2.3 mg/L) for fish farming except in the dam. **Kestemont *et al.*** (**1989**) indicated that a concentration of ammoniacal nitrogen above 0.5 mg/L would result in diseases of fish gills and their mortality if there is a drop in level of dissolved oxygen or frequent handling of fish as observed in fish farms during sexing, sorting, transfer and fishing activities. The Bravais-Pearson correlation matrix **(Table, 3)** revealed a positive and significant correlation between phosphate and ammonium (r = 0.84). Indeed, ammoniacal nitrogen and phosphorus are the main chemical indicators of direct water pollution.

3.2.2. Nitrite ions

Nitrites are extremely toxic to fish (**Najla, 2015**). This toxicity depends on the duration of exposure of the fish and their size (**Morin, 2012**). Nitrites bind to the hemoglobin in red blood cells by oxidizing it to methemoglobin, which cannot carry oxygen in the blood. This causes respiratory problems in the fish leading to death (**Morin, 2012**). The nitrite values obtained in the present study vary from 0.009 to 0.028 mg/L (**Fig. 4b**). Our study reveals low nitrite levels in all livestock structures. These low nitrite values observed can be explained by oxidation of nitrite ions to nitrate under the aerobic conditions that prevail in this medium (**Coulibaly *et al*., 2019**). The recommended limit for freshwater aquaculture is 0.1 mg/L (**Melard, 1999**). The values found in all the structures are therefore compliant with the standard. The obtained contents in this study are higher than those (1.33 ± 0.51 – 5.33 ± 2.99 µg/L) reported by **Avit *et al.*** (**2012**). Yet, our results remain lower than those reported by **Ghannam & Aly** (**2018**) which range between 0.12 and 0.66 mg/L. The nitrite values are positively and significantly correlated with ammonium (r = 0.53) **(Table, 3)**. This correlation showed that ammonium concentration increased with the increase in one of nitrite ions.

3.2.3. Nitrate ions

Nitrate ions are not toxic to fish but they contribute to the eutrophication of the environment (**Yao *et al*., 2009**). The enrichment of fish waters by nitrates could be mainly due to fertilization with various nutrients or the load of organic matter in the waters coming into the rearing structures (**El-Otify, 2015**). Nitrate contents recorded during the present study varied from 3.7 to 16.6 mg/L (**Fig. 4c**). These results showed elevated concentrations of nitrate in all farm settings compared to those of nitrite and ammonium. This high nitrate content could be linked to waste leaching produced by raising chickens on the farm. According to **Coz *et al.*** (**2015**), the nitrate concentration in surface water can reach high levels due to leaching of cultivated land or contamination by wastes of plant or animal origin. The nitrate concentrations in ponds (3.7-6.9 mg/L) are much lower than those recorded in the dam (15.5-16.6 mg/L) (**Fig. 4c**). The low levels of nitrate recorded in the ponds could be explained on one the hand by the significant presence of phytoplankton in aquaculture environment (**Bremond & Perrodon, 1979**) which would have consumed these ions and their reduction by bacterial denitrifying. The high concentrations recorded in the dam could be due to the inflow of runoff and agricultural effluents around the river that supplies the dam (**Yao *et al*., 2009**). Our results are of the same order as those obtained by **Coulibaly *et al.*** (**2019**) (3.24 - 11.21 mg/L). On the other hand, these results are superior to those reported by **Ghannam & Aly** (**2018**) oscillating between 1.10 and 4.40 mg/L. According to **Malcom *et al.*** (**2000**) the critical limit of nitrates for *Oreochromis niloticus* is 5 mg/L. The nitrate levels obtained in this study, at the dam and pond 1, were above the recommended limits. In ponds 2 and 3, these values are below the threshold. The correlation matrix shows a strong positive correlation between nitrate and ammonium (r = 0.98) and also nitrite (r = 0.50) (**Table,**

3). This may point out the fact that in bodies of water, an increase in nitrate can occur through oxidation of nitrite (**Shetaia *et al*., 2020**). Furthermore, a positive and significant correlation is observed between nitrate and phosphate (r = 0.90). This correlation is thought to be due to the fact that the increase in the concentration of phosphate and nitrate in the water would result in an increase in the productivity of phytoplankton (**Abdel-Satar *et al*., 2017**).

3.2.4. Phosphate ions

Phosphate is a nutrient that is generally non-toxic to aquatic organisms. However, the excessive supply of phosphates in fish waters causes significant growth of plants which subsequently leads to eutrophication (**Najla, 2015**). Orthophosphate values vary from 2.2 to 4.3 mg/L (**Fig. 4d**). These values are high in the dam (4.28-4.3 mg/L) in comparison with those noted in the ponds (2.2-3.64 mg/L). The high concentrations in the dam could be the consequence of the use of fertilizers in agricultural activities carried out around the farm. In fact, the contamination of surface water by phosphorus can be induced by agro-food and domestic discharges or by the leaching of cultivated land containing phosphate fertilizers and certain pesticides (**Amon *et al*., 2017**). Conversely, the low values of phosphates recorded in ponds would be mainly due to consumption of this nutrient by phytoplankton or to high sorption capacity of various particles for phosphorus which could cause an accumulation of phosphorus in sediments (**El-Otify, 2015**).

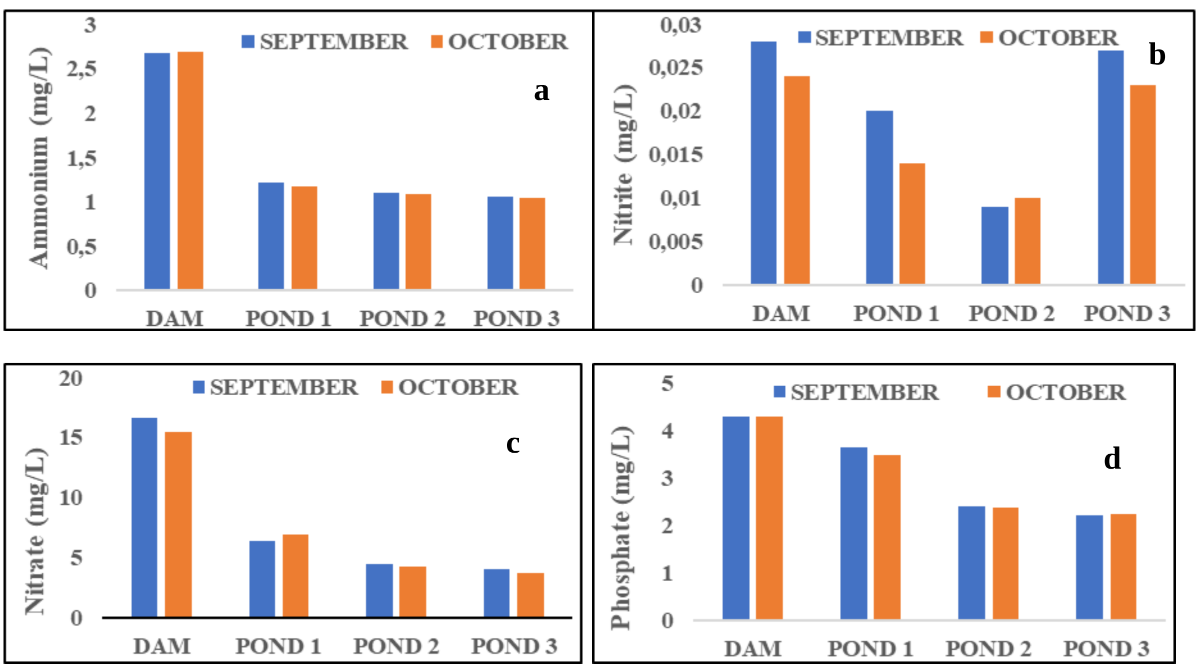

Fig. (4): Monthly variation of nutrient salts in fish farm water from September to October 2020

The presence of phosphate in small amounts in fish farms water is important to the production of phytoplankton which forms food for fish (**Bhavimani & Puttaiah, 2014**). Our study revealed higher orthophosphate concentrations than those obtained by **El-Otify** (**2015**), ranging between 11.87 and 64.33 µg/L. The orthophosphate values in the present study are above the threshold which is 0.5 mg/L (**Barbe *et al*., 2000**).

Mostly, the correlation matrix (**Table 3**) indicates a positive and significant correlation between all nutrients, pointing out on the one hand a common origin of nutrient salts (**Abdel-Satar *et al*., 2017**). According to these authors, agricultural, domestic and industrial waste could actually constitute an important source of nitrogen and phosphorus inputs into the water body. On the other hand, these strong positive correlations observed between nitrogen and phosphorus species could reflect their common influence on the eutrophication of the fish farm. Indeed, it is accepted that the excess of nutrient salts such as nitrates, nitrites, phosphates and ammonium in aquatic ecosystems leads to eutrophication of water (**Menesguen *et al*., 2001**).

3.3. Chlorophyll-a

Chlorophyll-a is one of the three physico-chemical parameters that enable to assess the trophic level of the water in a pond (**Bouzid-Laghas & Djélitat, 2012**). As a matter of fact, it is an important biological indicator for algal biomass and is often considered as the primary endpoint for eutrophication (**Shetaia *et al*., 2020**). In the present study, the lowest values were recorded in the dam (2.6 - 2.78 µg/L) while the highest values were observed in the ponds (5.52 – 6.6 µg/L) (**Fig. 5**). This difference in chlorophyll-a content would probably be due to the exogenous supply of floury foods in the ponds which would increase the nutrient content thus leading to an algae proliferation (**Melard, 2006**). High concentrations of chlorophyll-a in ponds could harm fish.

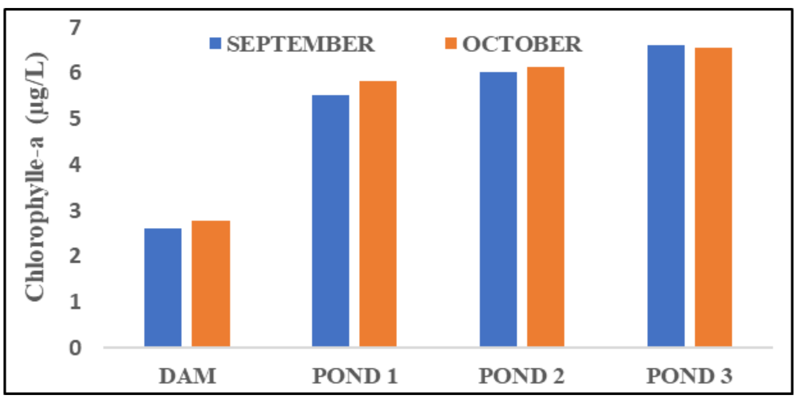

Fig. (5): Monthly variation of cholorophyll-a in fish farm water from September to October 2020

According to **Schlumberger & Girard** (**2013**), in fact, if the chlorophyll is too high, it can consume oxygen at the expense of farmed fish. **Malcom *et al.*** (**2000**) stated that the concentration in water intended for fish breeding should be between 100 and 300 µg/L for optimum production of tilapia. For all the sampled structures, the obtained values were lower than the various standards. The obtained chlorophyll-a values in this study are lower than those (40.56 ± 8.80 to 94.68 ± 12.91 µg/L) of **Agadjihouede *et al.* (2016)** in rice-growing area of Malanville in northeastern Benin. Chlorophyll-a values are negatively correlated with all nutrient salts and are significant with nitrate (r = - 0.99), ammonium (r = - 0.99) and phosphate (r = - 0.89). These coefficients show that the increase in chlorophyll-a significantly decreases the nutrient levels in farm water.

Table (3): Bravais - Pearson linear correlation coefficients r between farm water quality parameters

	T	pH	DO	EC	TDS	Trans	SM	NO_3^-	NO_2^-	NH_4^+	PO_4^{3-}	Chlo-a
T	1											
pH	-0.21	1										
DO	0.41	-0.15	1									
EC	0.09	0.73*	0.07	1								
TDS	0.06	0.67*	0.35	0.87*	1							
Trans	-0.49	0.13	0.36	-0.02	0.18	1						
SM	-0.48	0.00	-0.41	0.18	-0.05	-0.98*	1					
NO_3^-	-0.53*	0.04	0.32	-0.01	0.16	0.95*	-0.91*	1				
NO_2^-	-0.34	0.55*	0.11	0.75*	0.84*	0.46	-0.32	0.50*	1			
NH_4^+	-0.53*	0.13	0.35	0.03	0.22	0.98*	-0.94*	0.98*	0.53*	1		
PO_4^{3-}	-0.49	-0.11	0.30	-0.07	0.06	0.73*	-0.70*	0.90*	0.38	0.84*	1	
Chlo-a	0.59*	-0.04	-0.31	0.07	-0.11	-0.96*	0.93*	-0.99*	-0.45	-0.99*	-0.89*	1

*** Significant correlation at $p < 0.05$**

3.4. Assessment of water mineralization

Table (4) presents the results of the TDS/EC ratios calculated for the waters of the different structures of the fish farm. The values of the TDS / CE ratio are all close to 0.5 except for Pond 2 in September. These results show a strong mineralization of the water from the fish farm (**Adjiri *et al.*, 2019**). Nevertheless, these ratios do not match the obtained conductivity values. These values, in fact, between 32 µS/cm and 101 µS/cm tell that the waters of the fish farm belong to the class of very weakly mineralized waters (0 < EC < 100 µS/cm) and weakly mineralized waters (100 < EC < 200 µS/cm) according to French regulations which established a relationship between the degree of mineralization and conductivity (**Samake, 2002**). This discrepancy between the TDS/EC ratios and the EC classes could result in the existence of unassayed minor ions (**Adjiri *et al.*, 2019**).

Table (4): TDS / EC ratios of the water in the ponds and dam of the fish farm from September to October 2020

		Livestock structures			
		Dam	**Pond 1**	**Pond 2**	**Pond 3**
TDS/EC	**October**	0.50	0.51	0.49	0.50
	September	0.56	0.48	0.78	0.39

3.5. Assessment of organic pollution and the level of eutrophication of water

The values of the pollution index are between 2.00 and 2.66 (**Table 5**) thus indicating a high level of organic pollution and a state of eutrophication of the breeding structures of the farm. This situation could be mainly explained on the one hand by the agricultural activities around the farm, and on the other hand, by the exogenous supply of food in the ponds (**Ouffoue *et al*., 2013**). It can also be linked to excrement from fish and the entry of runoff laden with waste from chickens raised on the farm perimeter (**Coz *et al*., 2015**; **Coulibaly *et al*., 2019)**.

Table (5): Level of eutrophication of the water in the ponds and dam of the fish farm from September to October 2020

Livestock structures	**Organic pollution index**	**Organic pollution level**	**Trophic level**
Dam	2.00	Strong	Strongly Eutrophic
Pond 1	2.33	Strong	Strongly Eutrophic
Pond 2	2.66	Strong	Strongly Eutrophic
Pond 3	2.33	Strong	Strongly Eutrophic

The consequences of eutrophication are numerous. They include fish mortality, ecological imbalance, increased turbidity and degradation of water quality and development of toxic algae (**Bouzid-Lagha & Djelita, 2012**). Fish mortality and toxic algal blooms are the clearest manifestations of eutrophication consequences. In fact, several studies have shown that eutrophication is one of the main causes of mass fish mortality (**MacGarvin, 2000** and **Kane *et al*., 2015**). This situation could therefore affect fish health and the good productivity of fish farm.

CONCLUSION

In the present study, we analyzed the physico-chemical parameters of the waters of a fish farm in order to assess the quality of its waters. A total of 12 physicochemical parameters were determined and compared to the recommended standards for rearing *Oreochromis niloticus*. The results obtained indicated that the fish farm has a high potential. Nine parameters, namely temperature, pH, dissolved oxygen, suspended matter, total dissolved solids, ammonium, nitrite, nitrate and chlorophyll-a are indeed compliant, at the limits recommended for the rearing of *O. niloticus*; while transparency, electrical conductivity and phosphate, do not comply with the values tolerable by *O. niloticus*. The TDS/EC ratio used in this study indicated that fish farm water is classified as very high to highly mineralized water. As for the organic pollution index, it revealed that the livestock structures were in a eutrophic state indicating a phenomenon of eutrophication. Non-conforming values of transparency, electrical conductivity, phosphate and eutrophic state of the medium can affect production causing damage to fish, reduced growth rate and low disease resistance in fish reared in these ponds.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest associated with the publication of this article.

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