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RESEARCH ARTICLE

EVALUATION OF THE PHYSICO-CHEMICAL QUALITY OF THE WATERS OF KOSSOU LAKE SUBJECTED TO HEAVY FISHING ACTIVITIES IN FLOATING CAGES (CENTRAL OF CÔTE D'IVOIRE)

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ABSTRACT

Background: In recent years, Lake Kossou has been subject to heavy human activities, including clandestine gold panning and the extensive application of nutrients related to the repetitive fish farming activities of the fish farm in floating cages on the lake. ***Objectives:*** This study thus aims to evaluate the influence of fish farming activities on the ecological quality of the waters of Lake Kossou on the basis of physico-chemical parameters. ***Methodology:*** The physico-chemical parameters of the waters of the floating fish farm on Lake Kossou were studied on a seasonal basis between 12 May 2017 and 26 February 2018. In-situ measurements and chemical analyses were carried out on water samples taken from 0 to 6 m deep in the lake waters. ***Results:*** Analyses show that the waters of Lake Kossou have a low transparency ranging from 0.62 to 1.5 m with high nitrate concentrations ranging from 0.82 to 7.02 mg/l. The two main seasons were characterized by high values of temperature, pH, nitrate and dissolved oxygen content. The stratification of temperature, pH, dissolved oxygen and nitrate content revealed the presence of a metalimnetic layer at a depth of 2 to 3 m in Lake Kossou. ***Conclusion:*** Data obtained from nutrient salts and transparency therefore characterize the advanced trophic status of Lake Kossou.

Key words: Fish farming in floating cages, Lake Kossou, Eutrophication, Thermal stratification.

INTRODUCTION

One of the major environmental challenges facing humanity is the issue of surface water quality (Zalewski, 2002, Fu *et al.*, 2014). The degradation of water resources is mainly due to point and diffuse pollution and changes in physico-chemical characteristics (Malmqvist and Rundle, 2002). Significant inputs of organic matter are a source of disturbance in an aquatic ecosystem with dissolved oxygen consumption during the decomposition of organic matter (Pouriot and Meybeck, 1995). The increase in point inputs of organic matter, especially nitrogen and/or phosphorus, is often blamed for aquatic plant blooms (Smith *et al.*, 1999). These nutrient inputs influence the ecological status of aquatic environments, particularly lake environments. In Côte d'Ivoire, several studies, including those of Ouattara (2000), Mambo et al, (2001), Adon (2006), Aw (2009) and Groga *et al*, (2014), have been carried out on the physico-chemical quality of lake water. However, very few studies on the physico-chemical quality of the waters of Lake Kossou have been carried out on Traoré's work (1977 and 1979) on the first data on environmental factors and on the primary production of Lake Kossou and the limnological characteristics of Lake Kossou respectively. However, in recent years, Lake Kossou has been subjected to heavy human activities, including clandestine gold panning (Konan *et al.*, 2015).

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and the extensive spreading of nutrients linked to the repetitive fish farming activities of the fish farm in floating cages on the lake. The objective of this study is to assess the influence of fish farming activities on the ecological quality of the waters of Lake Kossou on the basis of physico-chemical parameters.

MATERIALS AND METHODS

Geographical location of the area and choice of sampling stations: Lake Kossou is located in the Department of Yamoussoukro. It is 180 km long and 900 km2 in area (FAO, 1996). Lake Kossou, located in the Bandama watershed between 06°57' and 08°08' N latitude and 05°42' and 05°49' W longitude, is mainly drained by the white Bandama. The climate in the study area is characterized by two dry seasons (November to February and July to August) and two rainy seasons (March to June and September to October) (Lévêque *et al.*, 1983). Annual precipitation varies from east to west between 1,100 and 1,600 mm and the annual temperature varies between 19 and 3.4°C. The highest rainfall is recorded in May, June and September. The study was conducted at the Tilapia (O. niloticus) intensive floating fish farm where nutrient application is important and repetitive (Figure 1). Five sampling stations were selected on the farm taking into account the main water flow, depth (Table 1) and layout of the fish cages in which the fish farming activities take place.

Sampling and laboratory analysis: Data collection campaigns were carried out during the main rainy season (between 12

May 2017 and 30 June 2017) and the main dry season (between 04 December 2017 and 26 February 2018). At each campaign, dissolved oxygen values, farm water temperature, conductivity and pH were measured in situ twice a day (between 7 a.m. and 10 a.m. and between 4 p.m. and 6 p.m.) at each station. These measurements were made using a multi-parameter HQ40d type surface (40 cm), 2, 4 and 6 m deep to obtain a good representation of the variation of these parameters on a vertical profile. Transparency was measured in situ at noon using a Secchi disc. Water samples from 2 to 6 m deep were taken using the Niskin hydrological bottle. For the analysis of nutrient salts (nitrates), 500 ml volumes of water from different depths were collected in scintillation vials. The nitrates were analysed in the laboratory of the Oceanographic Research Centre (CRO) by colorimetric assay (Griess reagent) of the nitrites formed by reduction on Cadmium column.

Statistical analysis of data: Some physico-chemical data were subjected to non-parametric tests (Kruskal-Wallis and Mann-Whitney tests). Those that met the normality tests were subjected to 1-fold ANOVA parametric tests followed by the Tukey test when $p < 0.05$. These analyses were performed using PAST 3.14 software.

RESULTS

Spatial variation of physico-chemical parameters: The water transparency of Lake Kossou fluctuated between 0.62 m (St4) and 1.5 m (St5) (Figure 2A). The transparency values are significantly different between St5 and the others (Tukey test, $p = 0.02$). At the pH level (Figure 2B), the highest value (9.41) was recorded at station St4, while the lowest value (5.7) was measured at station 3 (St3). Statistically, there were no significant differences in pH values between stations (Kruskal-Wallis test, $p = 0.17$). With regard to temperature (Fig. 2C), the values ranged from 26.9 (St2) to 32.8°C (St3). No significant temperature differences were noted between the different stations (Kruskal-Wallis test, $p = 0.18$). For conductivity, the measured values ranged from 58 to 154 µs/cm. The maximum amplitude of the water conductivity was obtained at station 2 (St2), while the minimum amplitude was observed at St5 (Figure 2D). Statistically, there is no significant difference in the conductivity measured at the different stations (Kruskal-Wallis test, $p = 0.30$). Concerning the dissolved oxygen content, the variation was less marked at all study stations. The observed values fluctuated between 5.26 and 9.41 mg/l (Figure 2E). The highest oxygen concentration was obtained in St4 where it varied between 5.75 and 9.41 mg/l, while the lowest was found in St3. At this station, the values ranged from 5.26 to 8.41 mg/l. Dissolved oxygen concentrations at the different stations are statistically identical (Kruskal-Wallis test, $p = 0.53$). As for the nitrate content (Figure 2F), concentrations ranged from 0.82 mg/l (St5) to 7.02 mg/l (St4). High values were observed at St3 and St4 stations, while the lowest values were observed at St1 and St5 stations. The nitrate content of stations St1, St5 is significantlydifferent from that of stations St2, St3 and St4 (Tukey test, $p = 0.0002$).

Temporal variation of physico-chemical parameters: The temporal variations in the physico-chemical parameters presented in Table 2 show the dissolved oxygen (DO) values measured were relatively higher in the high dry season than in the high rainy season. In the dry season, oxygenation varied between 6.66 ± 0.76 mg/l and 8.11 ± 0.86 mg/l. While in the rainy season the values fluctuated between 6.28 ± 0.55 mg/l and 7.49 ± 0.88 mg/l. Concerning the pH, high values were also observed in the high dry season when the pH fluctuated between 7.51 ± 0.24 and 8.74 ± 0.31. In the rainy season, pH values ranged from 6.87 ± 0.34 to 7.41 ± 0.16. With regard to water temperature, the lake waters were less warm during the rainy season. High temperatures were observed in the high dry season with an average of 27.54 ± 2.57°C to 29.46 ± 1.66°C. During the rainy season, the temperature varied between 27.82 ± 0.49°C and 28.18 ± 0.80°C. As for water conductivity and transparency, values were higher in the high rainy season than in the high dry season. In the rainy season, conductivity fluctuated between 120 ± 4.14 µs/cm and 121.75 ± 2.49 µs/cm, while in the high dry season it varied between 78.4 ± 23.30 µs/cm and 118.32 ± 16.54 µs/cm. Transparency values ranged from 0.90 ± 0.10 m to 1.17 ± 0.31 m during the main rainy season, while in the main dry season it fluctuated between 0.76 ± 0.24 m and 0.97 ± 0.01 m. With regard to nitrate content ($NO3^-$), concentrations were higher in the high dry season with an average ranging from 0.9 ± 0.9 mg/l to 3.6 ± 10.13 mg/l. In the main rainy season, the nitrate content varied between 0.46 ± 1.49 mg/l and 2.5 ± 0.81 mg/l. Statistical treatments at the inter-seasonal level found that, with the exception of transparency where $p = 0.26$, dissolved oxygen, nitrates, pH, temperature and conductivity measured between the two major seasons are significantly different (Mann-Whitney test, $p < 0.05$).

Vertical profiles of physico-chemical parameters: The results relating to the vertical profiles of the physico-chemical parameters indicate that, at the level of dissolved oxygen, the water surface of the stations sampled was more oxygenated compared to the bottom layers with a concentration ranging from 7.45 to 8.7 mg/l (Figure 3A). The variation of dissolved oxygen in the stations was homogeneous in the layer from 0 to 2 m deep. Above 3 m depth, dissolved oxygen levels gradually increased at St2, St3 and St4 stations to an average of 7.4 mg/l at 4 m depth before moving down into the deeper layers. The lowest concentrations were obtained at 4 and 6 m depths at St1 and St2 respectively. Concerning pH, its stratification was similar in all the stations studied (Figure 6B). The water column was basic with high surface pH values ranging from 7.73 to 7.88. pH values gradually decreased in the stratum from 0 to 2 m, while they gradually increased in the layer from 3 to 6 m deep. The water layers of the St4 were significantly more basic than those of the other stations. Figure 6C shows that the thermal stratification of the waters of the different stations followed much the same pattern as that of the pH. During this study, the water temperature of Lake Kossou decreased considerably in the layer from 0 to 2 m deep where the lowest value (26.7 °C) was observed at St5. Above 2 m depth, it gradually increased in the basement layers to an average of 27.7°C (6 m). With regard to the vertical conductivity profile (Figure 6D), the values showed that in, the conductivity does not vary significantly from one layer to another except in station 2 (St2) where it varied in the layer from 0 to 4 m deep. The conductivity of St2 water followed a rapid increase with a peak of 163 µs/cm observed at 2 m depth before decreasing in the basal layers. As for the nitrate concentration (NO3-), the water surface of the stations studied was more concentrated in nitrate than at depth (Figure 6E). With the exception of St3, the nitrate content in the layer has decreased from 0 to 2 m deep. Below 3 m depth, nitrate levels evolved differently in the basal layers with low levels ranging from 0.15 mg/l (St4) to 0.66 mg/l (St3) observed at 6 m depth.

Table 1. Coordinates and depth of Sampling stations

Stations	Geographic coordinates		Depth (m)	
	Latitude	Longitude	Min.	Max.
St1	07°01'43.01''N	05°25'01.01''W	6.1	11.9
St2	07°02'09.11''N	05°25'30.52''W	10.5	11.1
St3	07°02'36.38''N	05°26'06.90''W	11.5	15.3
St4	07°01'50.60''N	05°27'12.90''W	11	14.6
St5	07°02'44.47''N	05°26'54.39''W	11.5	18.4

Max: maximal, Mini: minimal.

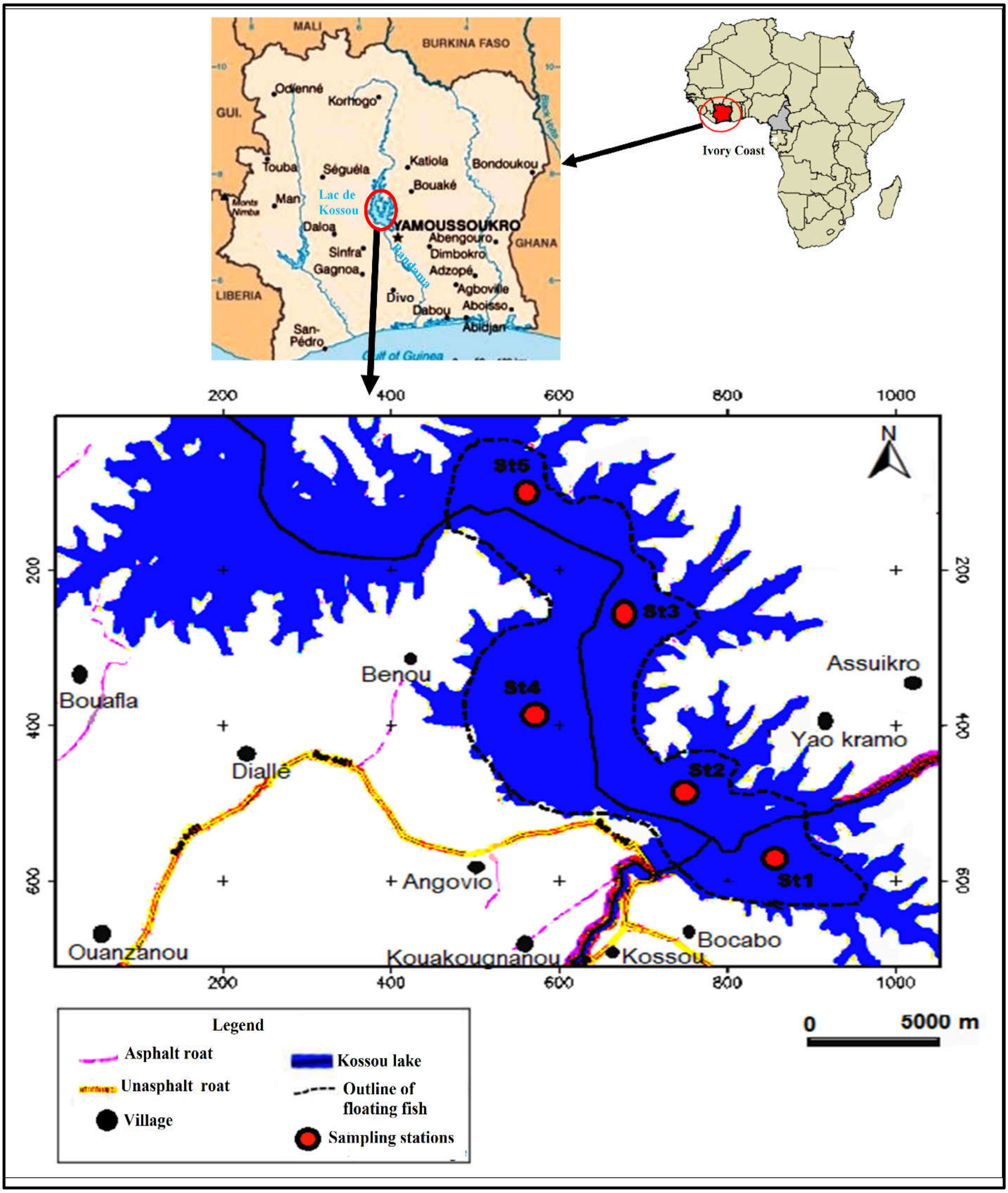

Figure 1. Location of the study area

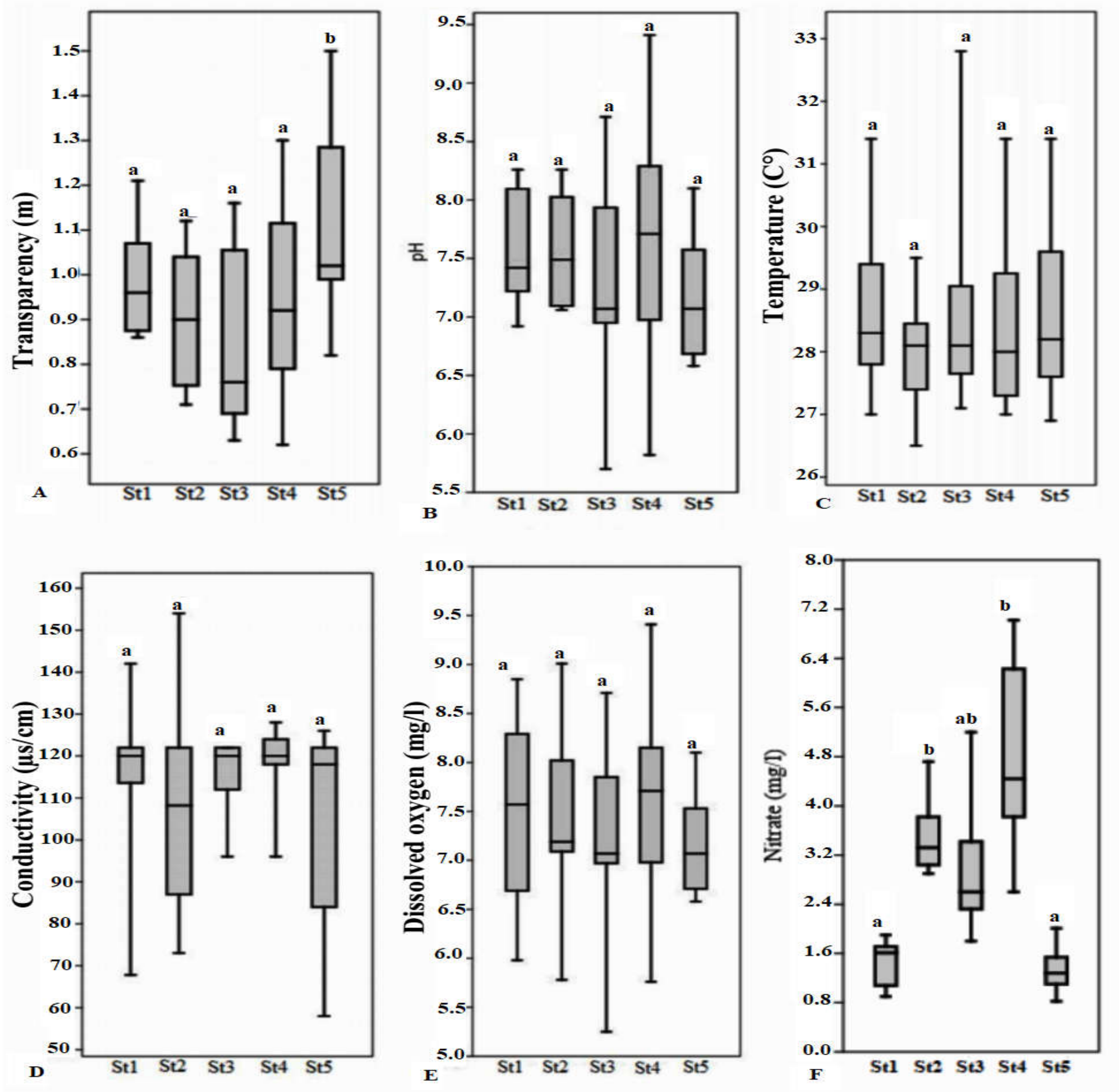

Figure 2. Spatial variations of the physico-chemical parameters of Lake Kossou. The different letters on the moustache boxes indicate a statistically significant difference ($p < 0.05$) between stations. St1, St2, St3, St4, St5: Sampling stations.

Table 2. Seasonal variations in the average of the physico-chemical parameters of the waters of Lake Kossou

Parameter	Season	St1	St2	St3	St4	St5	P-valu inter-season
OD (mg/l)	GSP	6.39 ± 0.69a	6.74 ± 0.61a	7.07 ± 0.80a	**7.49 ± 0.88a**	**6.28 ± 0.55a**	0.011
	GSS	**6.66 ± 0.76a**	7.79 ± 0.88b	7.48 ± 0.74a	**8.11 ± 0.86b**	7.26 ± 0.48a	
pH	GSP	**6.87 ± 0.34ab**	7.22 ± 0.31a	7.26 ± 0.28ab	**7.41 ± 0.16ab**	7.32 ± 0.15b	0.0008
	GSS	7.64 ± 0.43a	7.94 ± 0.34a	7.70 ± 0.33a	**8.74 ± 0.31b**	**7.51 ± 0.24a**	
Temp (°C)	GSP	28.00 ± 0.68a	27.94 ± 0.51a	27.84 ± 0.56a	**27.82 ± 0.49a**	**28.18 ± 0.80a**	0.0007
	GSS	29.38 ± 1.61b	**27.54 ± 2.57a**	**29.46 ± 1.66b**	29.31 ± 1.54a	29.37 ± 1.25b	
Cond (µs/cm)	GSP	**121.75 ± 2.49a**	121.50 ± 2.07b	120.50 ± 1.49b	121.50 ± 4.24b	**120 ± 4.14b**	0.00004
	GSS	**118.32 ± 16.54ab**	113.20 ± 10.45a	107.75 ± 7.29a	116 ± 11.40a	**78.4 ± 23.30a**	
NO_3^- (mg/l)	GSP	0.68 ± 0.43a	1.10 ± 1.10b	**0.46 ± 1.49a**	**2.5 ± 0.81ab**	1.08 ± 0.39b	0.0021
	GSS	1.60 ± 0.12ab	2.52 ± 0.09ab	**0.9 ± 0.9b**	**3.6 ± 0.113c**	2.09 ± 0.2ab	
Transp (m)	GSP	**1.60 ± 0.12a**	**0.90 ± 0.10a**	1.02 ± 0.23a	0.97 ± 0.10a	1.17 ± 0.31a	0.26
	GSS	0.97 ± 0.01a	0.81 ± 0.19a	0.86 ± 0.26a	**0.76 ± 0.24a**	**0.95 ± 0.12a**	

OD: Dissolved oxygen, pH: Hydrogen potential, Temp: Temperature, Cond: Conductivity, NO3- : Nitrates, Transp: Transparency, GSP : High rainfall season ; GSS : High dry season

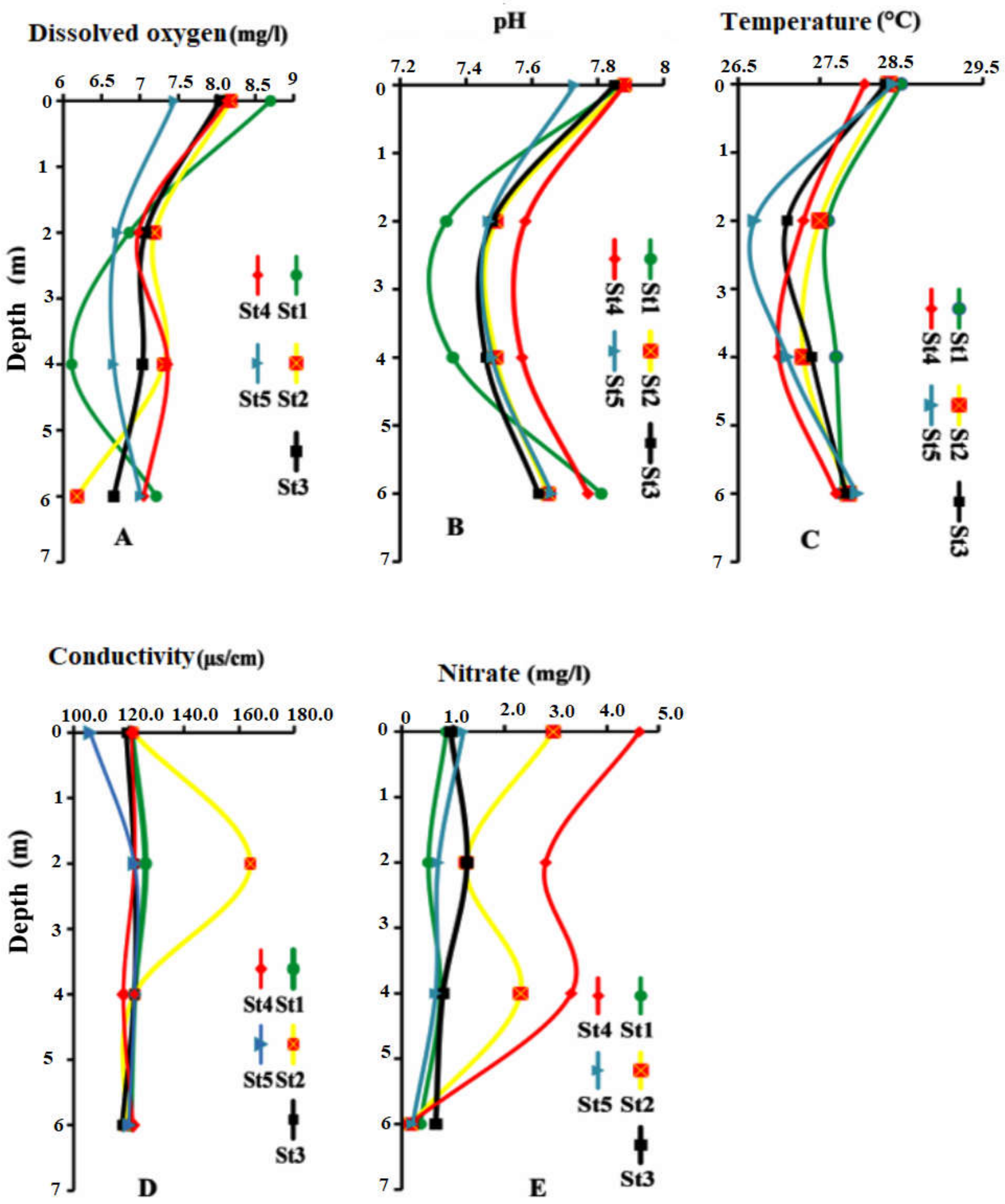

Figure 3. Vertical profiles of the average of the physico-chemical parameters of Lake Kossou. St1, St2, St3, St4, St5: Sampling stations ; A : Dissolved oxygen, B : pH, C : Temperature, D : Conductivity, E : Nitrates.

DISCUSSION

The spatial and temporal variation in the physico-chemical parameters of the water of Lake Kossou shows that the temperature, pH and concentration of dissolved oxygen and nitrates (NO3-) characterized the high dry season. While high values of water conductivity and transparency are characteristic of the high rainy season.

Temporal variation in nitrate appears to be related to atmospheric inputs and leaching from surrounding soils (Mouelhi, 2000). The high nitrate content of water in the dry season could be linked to the high nutrient release during fish feeding. The high pH values during the high dry season could be explained by the increase in photosynthetic activity of algae due to the concentration of dissolved oxygen and nutrients in the water during this dry season.

Spatially, transparency values fluctuating between 0.62 and 1.5 m show that Lake Kossou has a relatively low transparency and is characteristic of eutrophic environments. According to Balvay (1985), the variation in transparency depends on the abundance of suspended particles (clay, silt, etc.) and in particular phytoplankton. In addition, the measured temperature values show that the lake water was not very warm and the temperature was not different from one station to another. These results are in agreement with those of Groga (2012) obtained in Lake Taabo downstream of Lake Kossou.

According to this author, this is related to climatic conditions. In the rainy season, heavy rainfall acted to lower the lake water temperature. The oxygen concentration varying between 5.26 and 9.41 mg/l shows a high oxygenation of the waters of Lake Kossou. This result is in agreement with that of Mambo et al (2001) who observed a decrease in oxygenation in the deep waters of Lake Buyo to 0.8 mg/l. According to Dussart (1992), oxygen concentration is the result of exchanges at the air-water interface, diffusion within the water body and in situ production by photosynthesis. Thus, the high concentrations observed in the dry season are believed to be due to high photosynthetic activity of algae (Hamaidi *et al.,* 2009). The stratification of the physico-chemical parameters of the water showed that the temperature, pH, dissolved oxygen and nitrate content followed a considerable decrease to a depth of 2 m, while beyond 3 m these parameters evolved differently. Thus, a pycnocline, a thermocline and a halocline could be established between 2 and 3 m deep in the waters of the sampled stations. The presence of these hydroclines in the water column of the different stations could be related to the fact that Lake Kossou was stratified during this study. The origin of this stratification observed in Lake Kossou could be mainly due to the presence of pycnocline and thermocline well marked between 2 and 3 m deep characterizing the metalimnetic layer. Indeed, this metalimnetic layer separates the epilimnetic layer (0 to 2 m) from the hypolimnetic layer (more than 3 m deep).

According to Rolland (2009), the thermal stratification of a lake is due to changes in water density at different temperatures. It leads to the separation between a well-lit and oxygenated layer of surface water, but with rapidly decreasing nutrient concentrations, and a deep, less bright and more hypoxic layer. Differences in oxygen and nitrate concentrations in hypolimnion are believed to be largely related to fermentation and bacterial mineralization. These results are similar to those observed in Baie de Biétri by Caumette *et al* (1983). The high values of dissolved oxygen, pH and temperature observed at the surface of the lake waters could be mainly related to the strong photosynthetic activities of microalgae.

Conclusion

This study has provided information on the impact of fish farming activities on the physico-chemical quality of Lake Kossou. Variations in physico-chemical parameters are more marked at the temporal and vertical level than at the spatial level. The thermal stratification of the water column showed the presence of a metalimnetic layer located between 2 and 3 m deep in Lake Kossou. Data obtained from nutrient salts and transparency have shown the share of fish farming activity in the eutrophication of Lake Kossou, suggesting an advanced trophic status of this lake. Taking into account the risks associated with point source pollution, in particular nutrient enrichment due to fish farming activities, requires increased monitoring of Lake Kossou.

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