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Study of the physicochemical and microbiological quality of the waters of Lake Labion and evaluation of their suitability for drinking water production (Jacqueville, southern Côte d'Ivoire)

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Abstract

Lake Labion located in the Ivorian coastal zone, precisely in the town of Jacqueville is confronted with the consequences of recent developments on its banks. The objective of this study is to diagnose the ecological state of the reservoir and to assess its suitability for drinking water production through the evaluation of the weighted index of global quality (GQWI). To do this, the physico-chemical parameters (T, pH, EC, DO, BOD, COD NO2, NH4, NO3, PO4, SO4 and SS) and microbiological parameters (total coliforms, E.coli and enterococci) were measured on fourteen (14) samples of lake water. The results of the physico-chemical analyses showed waters characterised by neutral to alkaline pH, less oxygenated, poorly mineralised, warm throughout the study period and less rich in nutrient salts. The overall weighted quality index showed that the lake waters are of poor quality and cannot be recommended for drinking water production. The degradation of the water quality of the lake is mainly related to alterations by organic and oxidizable matter in terms of BOD5 and COD and to a lesser degree to alteration by pathogenic micro-organisms. This study highlighted the impact of recent developments on the water quality of Lake Labion and suggests anoxic conditions that limit the self-purification of the ecosystem.

1. Introduction

Water remains one of the most vital resources for human survival. However, its availability is threatened by anthropogenic activities (industrial, domestic, and agricultural) that exert various pressures on the quality, quantity, and access to water resources [1]. The degradation of the quality of surface water resources is accelerated by discharges of effluents from anthropogenic activities coupled with natural processes (soil erosion, precipitation, evaporation, stormwater runoff) [2]. Lakes are confined environments likely to constitute water reserves to produce drinking water. However, these lake environments are subject to pollution problems that could impact on the quality of their water and subsequently influence the health status of both humans and animals [3]. Water quality remains one of the most important criteria for meeting the demand and supply of water to the population [4]. The commune of Jacqueville, located in the south of Côte d'Ivoire, whose aquatic potential is characterised by numerous lakes, is not immune to this situation. Located on its southern periphery, Lake Labion belongs to the lacustrine entity of the vast Ebrié hydrographic complex [5]. It ensures the satisfaction of the drinking water needs of the riparian populations during shortages and contributes to their subsistence through the exploitation of these living resources. Lake Labion, like all the country's coastal water bodies, has seen its banks occupied either for the creation of housing or for the development of crops. As a result, this previously isolated area is now in the middle of a built-up area. This water reservoir is subject to strong pressures from indirect discharges from riparian activities, drained by run-off water. Such threats suggest that the waters of Lake Labion are at risk of deterioration. To contribute to the knowledge of the state of the quality of the water of Lake Labion, this study was carried out, with the aim of making a diagnosis of the ecological state of the reservoir and to appreciate its aptitude to produce drinking water.

2. Study materials and methods

2.1 Presentation of the study environment

Located between longitude 5°13'0" and 5°15'0" North and latitude 4°12'0" and 4°8'0" West, Lake Labion is situated in the south of Côte d'Ivoire between the Atlantic Ocean in the south and the Ebrié Lagoon in the north. Its surface area is about 480.20 hectares (**Figure 1**). It is in a watershed of about 15 km2 **[6]** made up of low plateaus of continental origin dating from the Ante-Holocene period and formed of sandy-clayey sands whose altitude varies from 8 to 12 meters and a plain formed by the coastal strips in the eastern part of its southern half **[5]**. Its tectonic structure is marked by a satellite fault parallel to the major fault (the lagoon fault) of the entire Ivorian sedimentary basin **[7]**. The climate is equatorial with four (4) seasons.

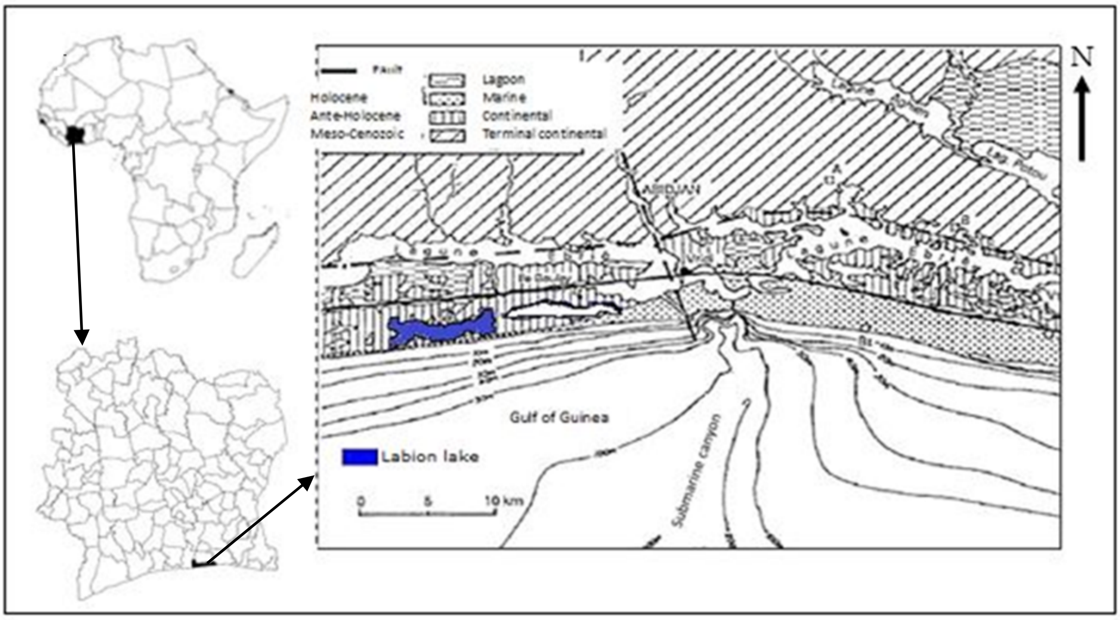

Figure 1. Location of the study area

2.2 Sampling method

The measurement and sampling campaigns were carried out at fourteen stations distributed throughout the lake (**Figure 2**). These points or stations were selected according to three criteria: accessibility of the stations, distribution of the reservoir and location in relation to potential sources of pollution. The water samples were taken at about 20 centimeters below the surface in one-liter polyethylene bottles, rinsed 3 times with the water to be sampled for the physico-chemical parameters. For the microbiological analyses, one (01) liter glass bottles, preferably borosilicate, with emery stopper were used. Before use, these bottles were carefully washed and rinsed to avoid any trace of detergent or antiseptic. They were then dried and capped with carded cotton. The packed stopper and the bottle were wrapped in filter paper and sterilised in an autoclave (120°C) for 15 minutes. All bottles were filled to the brim and sealed, then stored in a cooler to maintain the temperature at 4°C and transported to the laboratory for analysis.

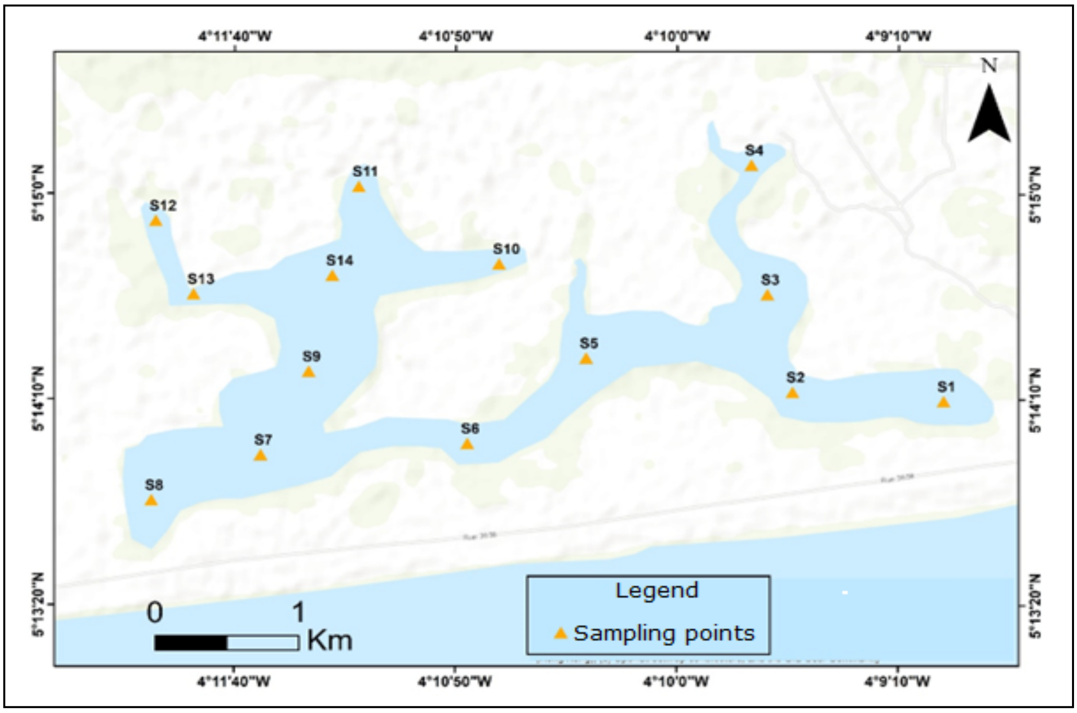

Figure 2. Location of sampling stations

2.3 Methods of analysis

The measurements of certain parameters were carried out in situ using a multi-parameter HANNA HI 9828. These are: hydrogen potential (pH), electrical conductivity (EC) and dissolved oxygen (DO). Other parameters such as BOD5, COD and TSS were measured in the field with a portable multiparameter spectrophotometer Pastel UV - Secomam. In the laboratory, the different parameters were analysed according to the analytical methods recommended by [8] as shown in **Table 1**.

Table 1. Methods of analysis of physicochemical and microbiological parameters used

Parameters	Units	Dosing methods
Ammonium	mg/L	Indophenol blue spectrometric method according to NF T90-015-2.
Nitrite	mg/L	Method by molecular absorption spectrometry (classification index T90-013)
Nitrate	mg/L	Method by molecular absorption spectrometry with sulphosalicylic acid according to NF EN ISO 10304-1.
Phosphate	mg/L	Ammonium molybdate spectrometric method (classification index T 90-023)
Sulphate	mg/L	Nephelometric method according to NF T90-040.
Fecal coliforms	CFU/100ml	Enumeration method by membrane filtration according to NF EN ISO 9308-1
E. coli	CFU/100ml	Enumeration method by membrane filtration according to NF EN ISO 9308-1
Enterococci	CFU/100ml	Enumeration method by membrane filtration according to NF ISO 7899-2.

2.4 Data processing

The evaluation of the physico-chemical and microbiological quality of water allows the characterisation of the disturbances suffered by the water through the search for certain chemical and biological substances present in the water [9]. Within the framework of this study, the system of Global

Quality Weighted Indices (GQWI) developed by the Directorate of Water Resources and Planning (DWRP) in Morocco [10] was used. This approach allows the assessment of water quality and its ability to ensure certain functionalities such as drinking water production [11]. The quality assessment system allows a precise diagnosis of the water quality and contributes to defining the necessary corrective actions for its improvement according to its desired uses. This diagnosis is made by identifying the alterations that compromise the biological balance or the uses of the water [12]. The weighted quality index is calculated for each parameter and for each type of alteration. For this study, each of the six alterations is evaluated by chemical and microbiological parameters (Table 2). The range of values set to assess water quality are transformed into unitless numbers varying from 0 for very poor quality to 100 for excellent quality [10]. The index of a parameter is obtained by weighting and the index of an alteration by the average of the weighted values of the parameters characterising the alteration (PI). The overall quality index is the lowest index obtained for all the alterations considered. The general surface water quality grid sets five classes [13]. The formula for calculating the weighted index is as follows [10].

$$IP_{Pa} = I_i \left[\left(\frac{I_s - I_i}{B_s - B_i} \right) * (B_s - P_a) \right] \quad \textbf{Eqn.1}$$

With:

- **IPpa:** weighted index of the parameter analysed.
- **Ii:** Lower index.
- **Is:** Upper index.
- **bi:** lower bound.
- **bs:** upper bound.
- **pa:** parameter analysed.

Table 2. Grid for the assessment of drinking water quality of surface waters [14]

Quality class		Excellence	Good	Average	Wrong	Very bad
Quality index		100 - 80	80 - 60	60 -40	40 -20	20- 0
Drinking water suitability class		Acceptable	Simple treatment	Conventional treatment	Complex treatment	Unfit
Parameter	**Unit**	**Alteration**				
I- Organic and oxidisable matter						
DO	**mg/L**	> 7	7 - 5	5 - 3	3 - 1	< 1
DOB5	**mgO_2 /L**	< 3	3 - 6	6 - 10	10 - 25	> 25
DOC	**mgO_2 /L**	< 6	6 - 20	20 - 30	30 -40	> 40
Ammonium	**mg/L**	<0,5	0,5 - 1,5	1,5 - 2,8	2,8 - 4	> 4
II- Nitrates						
Nitrates	**mg/L**	< 2	2 - 10	10 - 25	25 - 50	> 50
III- Suspended particulate matter						
TSS	**mg/L**	< 2	2 - 50	50 - 2000	2000 - 5000	> 5000
IV- Mineralization						
EC (20°C)	**µS/cm**	100 -750	750 -1300	1300 -2700	2700 -3000	3000 -7000
Sulphates	**mg/L**	< 60	60 - 120	120 - 190	190 - 250	> 250
V- Acidification						
pH		6.5 - 8	6 - 9	5.5 - 9.5	4.5- 10	
VI- Micro-organisms						
TC	**CFU/100ml**	< 50	50 - 500	500 - 5000	5000-50000	> 50000
E. coli	**CFU/100ml**	< 20	20 - 200	200 - 2000	2000-20000	> 20000
Enterococcus	**CFU/100ml**	< 20	20 - 200	200 - 1000	1000-10000	> 10000

2.5 Principal Component Analysis (PCA)

The physico-chemical parameters were subjected to a simple statistical analysis for a better exploitation of the data. The descriptive statistical analysis using Microsoft Excel software made it possible to calculate the minimum, maximum, average and standard deviation of each parameter studied. Principal Component Analysis (PCA) was used to determine the typology of the lake waters. The analyses concerned 13 physico-chemical parameters and 3 microbiological parameters. The data were processed using XLSTAT Trial software.

3. Results

3.1 Physico-chemical and microbiological characteristics of Lake Labion waters

The results of the descriptive statistics of the physico-chemical and microbiological variables used in this study concerned the minimum, maximum, mean and standard deviation values (**Table 3**). These results of the different parameters analysed were compared to the WHO standards **[15]**.

Table 3. Descriptive statistics of physico-chemical and microbiological variables of Lake Labion

Variable	Units	Min.	Max.	Means.	Standard deviation	WHO [15]
pH	-	7.56	8.18	7.98	0.19	6.5-8.5
T	°C	30.08	32.33	30.74	0.66	≤ 25
EC	µS/cm	54	59	56.50	1.65	≤ 500
DO	mg/L	2.87	2.91	2.90	0.01	≥ 5
DOC	mg/L	10.70	45.10	29.29	12.35	≤ 10
DOB	mg/L	3.40	28.20	13.89	7.36	≤ 6
TSS	mg/L	12.70	92.30	51.89	26.25	≤ 50
NO2	mg/L	0.01	0.05	0.02	0.01	≤ 0.2
NO3	mg/L	1.60	6.10	3.44	1.52	≤ 50
NH4	mg/L	0.01	0.08	0.04	0.02	≤ 0.5
SO4	mg/L	0.27	10.34	4.18	3.01	≤ 250
PO4	mg/L	0.22	0.70	0.35	0.13	≤ 5
TC	CFU/100ml	640	20700	8674.29	7215.92	0/100
E. coli	CFU/100ml	160	8900	3376.43	3033.67	0/100
Enterococcus	CFU/100ml	30	910	437.14	309.38	0/100

The results show that the temperature of the water in Lake Labion is warm and varies between 30.08 and 32.33°C with an average value of 30.74 ± 0.66°C exceeding the WHO standards. The pH is neutral to slightly alkaline and varies between 7.56 and 8.18 with an average of 7.98 ± 0.19 which is within the range of the WHO guidelines. The lake water is less mineralised with an electrical conductivity that varies between 54 and 59 µS/cm with an average of 56.50 ± 1.65 µS/cm. The concentration of dissolved oxygen remained low during the study period, with a minimum value of 2.87 mg/L and a maximum value of 2.91 mg/L for an average of 2.90 ± 0.01 mg/L, well below the WHO recommendations. The COD load of the lake water varies from 10.70 to 45.10 mg/L with an average of 29.29 ± 12.35 mg/L, higher than the WHO standard of 10 mg/L. The BOD5 loads vary from 3.40 to 28.20 mg/L with an average of 13.89 ± 12.35 mg/L. Of the fourteen points sampled, ten (10) or 71.43% had BOD5 loads above the WHO standard (≤ 6 mg/L). Suspended solids in the lake water vary between 12.70 and 92.30 mg/L with an average of 51.89 ± 26.25 mg/L. Of all the sampling sites, nine (09), or 64.29%, have water with suspended solids above the WHO standards (≤ 50 mg/L). Nitrite levels vary from 0.01 to 0.05 mg/L with an average of 0.02 ± 0.01 mg/L. Nitrate concentrations remain low throughout the water body and vary from 1.60 to 6.10 mg/L with an average of 3.44 ± 1.52 mg/L. These levels are within the required standards. Ammonium levels in the lake water fluctuate between 0.01 and 0.08 mg/L with an average of 0.04 ± 0.02 mg/L. The lake water is less concentrated in sulphate ions, with concentrations ranging from 0.27 to 10.34 mg/L with an average of 4.18 ± 3.01 mg/L. Phosphate concentrations in Lake Labion are low in all the points sampled, with levels ranging from 0.22 to 0.70 mg/L and an average of 0.35 ± 0.13 mg/L. The micro-organism loads of the lake water are all above the WHO norms (0/100ml). The bacterial load of total coliforms varies between 640 and 20.7 10^2 UFC/100ml with an average of 86.74 10^2 UFC/100ml. E. coli levels ranged from 160 to 89.10^2 CFU/100ml with an average of 33.76 10^2 CFU/100ml. The concentrations of Enterococci in the lake water increase from 30 to 910 CFU/100ml with an average of 437.14 CFU/100ml.

3.2 Weighted index of overall lake water quality

The results of the average values of the weighted indices of global quality (GQWI) of the water samples taken in Lake Labion are presented in **Figure 3**. The analysis of these values shows that the 14 stations studied have poor water quality and require complex treatment for drinking water use. The degradation of the quality of the water of the lake is mainly related to the alterations of micro-organisms and organic and oxidizable matters in terms of BOD5 and COD.

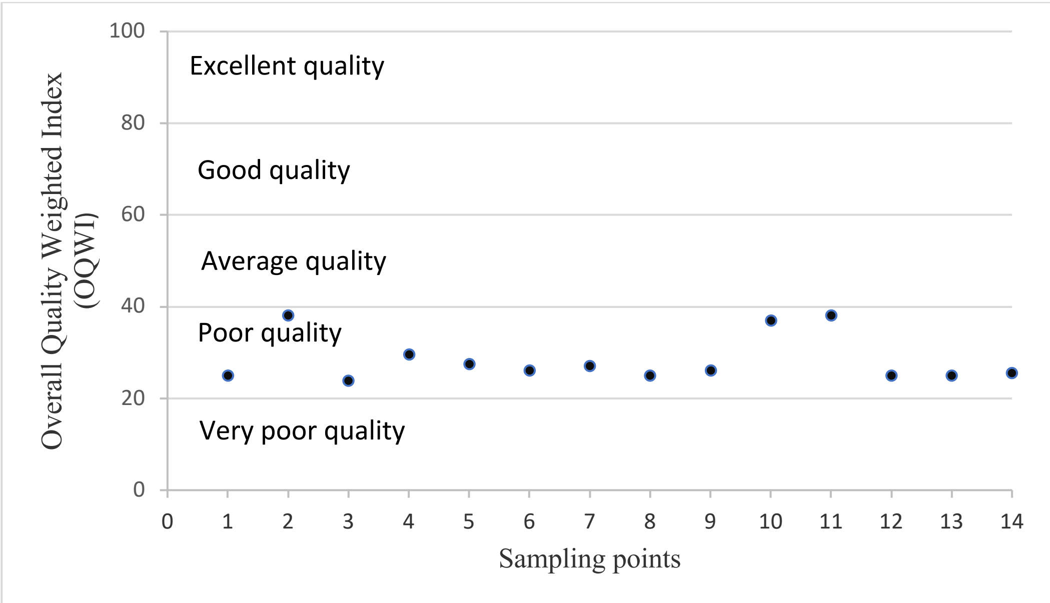

Figure 3. Average values of the overall quality index at the surveyed stations

3.3 Principal Component Analysis (PCA)

Factors F1 and F2 express 59.40 and 15.34 % of the variance respectively. These two factors alone contain 74.74% of the variances expressed and contain the maximum amount of information to allow the interpretation of the results. The representation using the first two factors gives a satisfactory account of the structure of the scatterplots. The examination of the correlations between the axes and the different variables studied makes it possible to explain the significance of each axis in the structured distribution of the scatterplot and the relationship between the typological structure and the environmental variables. The F1 axis is positively correlated with the variables: T, EC, COD, BOD, TSS, NO2, NO3, PO4, SO4, TC and E. coli and negatively correlated with dissolved oxygen. This axis F1 groups together most of the parameters that determine the degree of mineralization and pollution of the lake water. The F2 axis with 15.34 % of the variance is positively correlated with enterococci (**figure 4**)

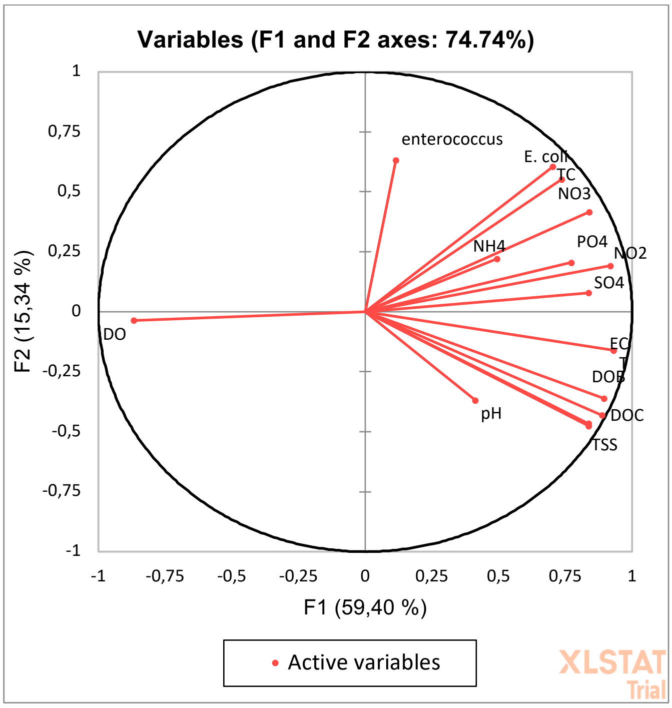

Figure 4. Variable space of the F1-F2 factorial design

The projection of the sampling stations in the F1-F2 factorial plane (**figure 5**) shows the individualisation of two major groupings of stations forming two opposite scatter plots. The first grouping in the positive part of the F1 factorial axis, gathers warm, turbid, less oxygenated waters, with high concentrations of COD, BOD5 and micro-organisms. The second grouping in the negative part of the F1 factorial axis, represents the stations characterised by less warm, clear, oxygenated water, with low loads of BOD, COD, and micro-organisms.

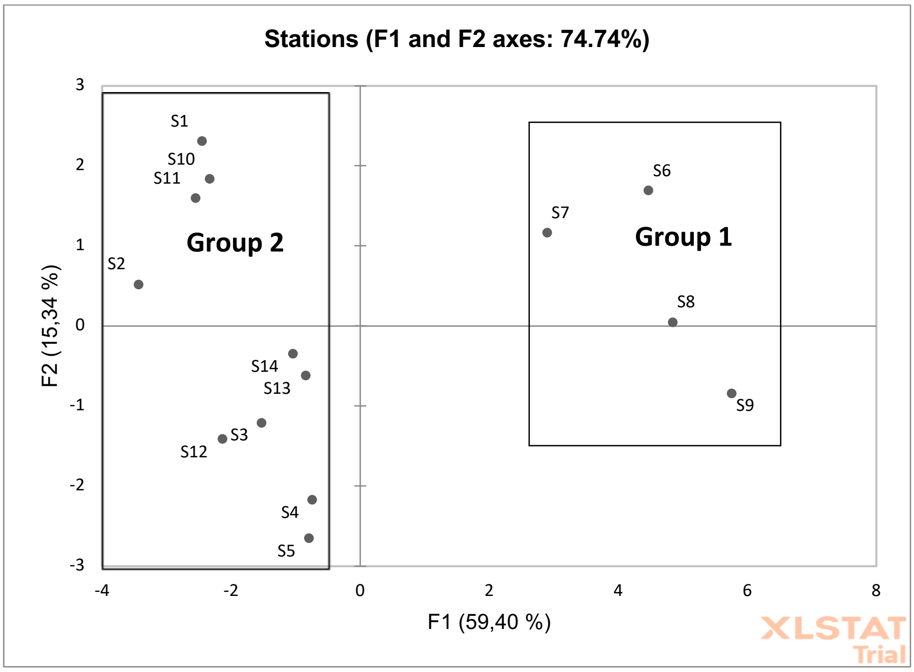

Figure 5. Projection of sampling stations in the F1-F2 factorial plane

4 Discussion

The study of the physicochemical and microbiological quality of the water of Lake Labion and the evaluation of its suitability to produce drinking water showed that the water is of poor quality. The use of this water to produce drinking water requires complex treatment. The degradation of the water quality of the lake is mainly related to the alterations called "micro-organisms" and "organic and oxidizable matter". The "organic and oxidizable matter" alteration in terms of COD and BOD5 accounts for 53% of the degradation of the lake's water quality. This alteration affects 8 stations out of all the study sites. The high COD and BOD levels obtained at these sites are 45.1 and 28.2 mg/L respectively. These COD and BOD levels reveal the presence of an organic load in the lake water. This pollution is believed to be the result of natural processes such as plant decomposition and other contributors that increase nutrient levels in water bodies, namely fertiliser-rich runoff **[16]**. BOD and COD enrichment of the water remains the main cause of poor water quality and dissolved oxygen depletion in the lake water. This lack of dissolved oxygen is a sign of ecological imbalance, which has repercussions on faunal diversity, and only taxa that are tolerant of oxygen deficiency will survive [4]. These observations explain the low dissolved oxygen values obtained in the present study with a maximum of 2.91 mg/L. These low levels of dissolved oxygen would be due to the use of this oxygen during the process of biodegradation of organic matter by the microorganisms present in the water **[17]**. The COD and BOD5 levels observed in the waters of Lake Labion remain in the same range as those determined by **[18]** on the waters of the Aghien lagoon in Côte d'Ivoire, by **[19]** in the waters of Lake Bansagar Shahdol and by **[20]** on the surface waters of the Kan dam. However, they are higher than those determined in Nigeria in the waters of the Ogbe Ijoh and Aladja rivers **[21]**. The micro-organism alteration dominated by total coliforms accounts for 47% of the degradation of the water quality of the lake. The microbiological study revealed significant bacterial contamination of human and/or animal origin, the various concentrations of which measured are higher than the WHO standard **[15]**. The high content of these microorganisms in the lake water highlights bacteriological pollution of faecal origin. The presence of total coliforms and E. coli indicates recent pollution of faecal origin resulting from human activities. However, the presence of streptococci is indicative of old pollution **[22]**. The leaching of soils from the lake's catchment area by run-off water could be the main source of mobilisation of soil biomass. This observation is confirmed by **[23]**, who reported concentrations of microorganisms in water that increased with rainfall in the area. The concentrations of pathogenic microorganisms in the lake are in the same range as those obtained in the lake of Reghaïa in Algeria by **[24]**. However, these concentrations were found to be higher than those measured by **[25]** in the surface waters of the Menoua Basin (West Cameroon).

The principal component analysis (PCA) showed that the mineralization of the waters of Lake Labion is influenced by pollution of anthropic origin. Dissolved oxygen showed a negative correlation with most of the parameters, revealing that its value decreases with increasing levels of other parameters. Our results agree with **[26]** who had similar results on the Lake Hawassa catchment in Ethiopia. The grouping of most of the parameters: T, EC, COD, BOD, TSS, NO2, NO3, PO4, SO4, TC and E. coli, on the F1 axis determines the degree of mineralization and pollution of the lake water. The anthropogenic activities highlighted are the agricultural runoff from the Lake Labion watershed **[27]**. In addition, the PCA showed that the lake water is subdivided into two (02) main classes.

Conclusion

The objective of this study was to diagnose the ecological state of the Lake Labion reservoir and to assess its suitability to produce drinking water. The results of the evaluation of the quality of the lake show that the waters of the lake are threatened by organic and microbiological pollution. This assessment revealed neutral to basic pH values, a very low dissolved oxygen level that rarely reaches the value of 3 mg/L. A temperature between 30.08 and 32.33°C linked to sunshine, which fluctuates during the day and does not exceed 2°C. Similarly, the electrical conductivity, influenced by the geology of the catchment area, is not very variable and varies between 54 and 59µS/cm. The nutrient content of the lake water remains below the WHO standards. However, this does not mean that the lake is not at risk of deterioration. The calculated Global Quality Weighted Index (GQWI) showed that the water of the Lake Labion reservoir is of poor quality and cannot be recommended for drinking water production. The degradation of the water quality of the lake is mainly related to alterations by organic and oxidizable matter in terms of BOD5 and COD and to a lesser degree to alteration by pathogenic micro-organisms. This work is the first of its kind for the study of the physicochemical and microbiological quality of the waters of Lake Labion and also constitutes a complement to the studies carried out at the level of the coastal lakes. The results obtained in this study show the urgency of setting up protection perimeters around the lake to safeguard this ecosystem, which is very much threatened by anthropic activities and especially agricultural practices in its watershed.

Disclosure statement: *Conflict of Interest:* We declare that there are no conflicts of interest.
Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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