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Anionic Surfactants Levels in M'Koa Lake Water (Jacqueville, Côte d'Ivoire)

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Abstract

In this study, anionic surfactants concentrations and other physico-chemical parameters of surface water quality were assessed in the water of M'Koa Lake in the city of Jacqueville (Côte d'Ivoire). Three sampling campaigns were conducted at different seasons at six (6) sampling stations, identified in M'koa Lake by taking into account potential sources of pollution. The analyses of physico-chemical parameters were carried out using both the French AFNOR standard and the methods described by Rodier. The anionic surfactants concentrations were performed by using the methylene blue colorimetric method. The average concentrations of anionic surfactants in the water of M'koa Lake ranged from 0.23 ± 0.04 mg·L^{-1} to 1.43 ± 0.68 mg·L^{-1}. They are high compared to both population density and socio-economic activities of Jacqueville's town. These values can be explained by the characteristics of the studied Lake that do not allow enough dilution of the discharged effluent. The results indicate that M'koa Lake is subjected to harmful pollution by anionic surfactants. And among the physicochemical parameters studied, only turbidity and transparency values show water quality deterioration, favoured by wastewater discharge and direct human activities around the Lake.

Keywords

Anionic Surfactants, Physico-Chemical Parameters, Water Quality, Freshwater, Organic Pollutants

1. Introduction

Synthetic surfactants are organic compounds, widely used in many domestic and

industrial applications. They are used as ingredients not only in detergents, cosmetics, and personal care products but also in paints, paper and leather industries, pesticides, etc. The obvious consequences of this widespread application are the very high quantities of these compounds discharged into wastewater treatment facilities or directly in the environment [1] [2] [3]. Most of surfactants are eliminated in wastewater treatment plants [1] [4]. However, without appropriate wastewater treatment, surfactants exhibit deplorable stability, which leads to gradual accumulation in surface waters. The organic molecules present in surfactants are absorbed by aquatic organisms, and cause unbalanced state in aquatic ecosystems [4]-[9]. Subsequently, they can have harmful effects on all steps of the food chain, including land and avian wildlife and as well as humans one. That relationship can be explained by the fact that contaminants are transmitted from one step to another through the consumption of contaminated aquatic organisms. The surfactants are also responsible not only for causing foam in rivers and but also for reduction of water quality [5]. Anionic surfactants are the most commonly used in the formulation of detergents [3] [4] [6] [9]. In Côte d'Ivoire, studies have been made about surface waters and water reservoirs. The results of different studies indicate that aquatic systems, without both adequate wastewater discharge system and treatment plants, undergo heavy physico-chemical and bacteriological pollution [10] [11] [12] [13]. Several studies have been conducted to assess the quality of surface water in Côte d'Ivoire [10] [11] [12]. However, very few studies have been made on detergents in surface water. M'koa Lake is located in the center of Jacqueville's town. Its watershed is made up of three different kinds of areas, namely marshy, agricultural and urban. According to this observation, this study assessed the anionic surfactants levels and the physico-chemical parameters of M'Koa Lake water.

2. Material and Methods

2.1. Study Area

The city of Jacqueville is like an island (a peninsula), delimited by the Ebrié lagoon, the Atlantic Ocean and the city of Abidjan respectively at the north, the south and the west (**Figure 1**). Onsite sanitation is practiced, and there is no wastewater management politics. Jacqueville has 32,288 inhabitants [14], the economic development of the region is based on coconut (cultivation, trade; business). The city of Jacqueville is subject to the subequatorial climate (Attiean type) with four seasons: a long rainy season (from May to July), short dry season (from August to September), short rainy season (from September to November) and long dry season (from December to April). Temperatures range from 21˚C to 34˚C [15]. M'koa Lake is a shallow natural lake, fed by infiltration with a maximum depth of 3.9 m and an area of about 0.180 km^2. M'koa Lake watershed consists of a marshy area, an agricultural area mainly composed of coconut groves and/or fallow crops, an urban area and its wastewater discharges (**Figure 2**).

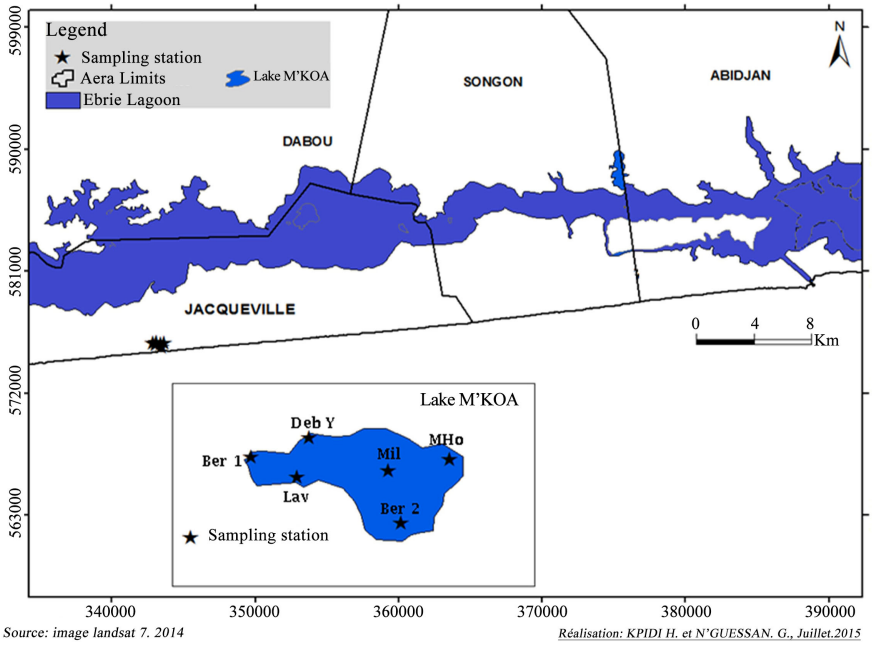

Figure 1. Mapping of the study area [16].

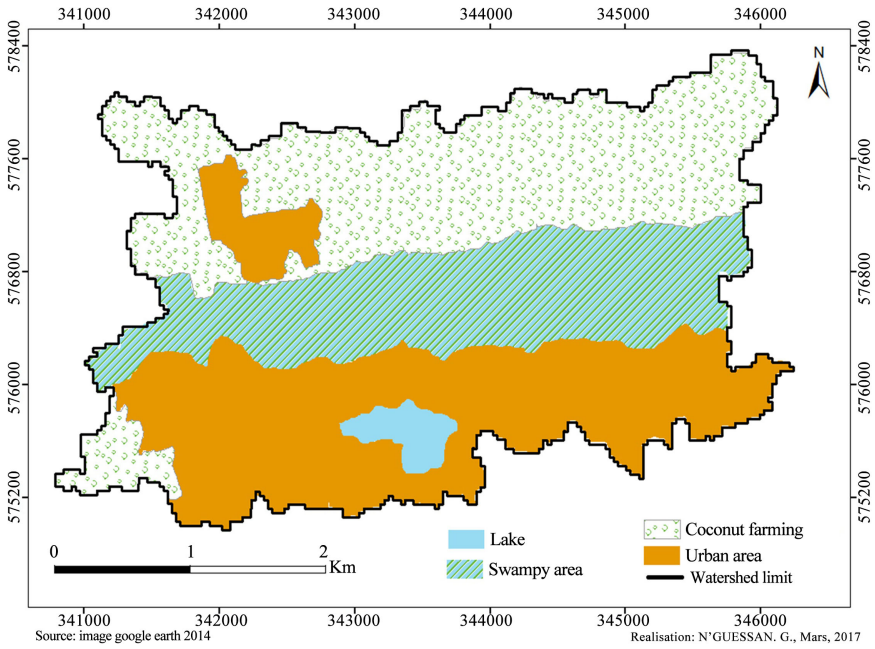

Figure 2. Occupation of the M'koa Lake watershed.

2.2. Physico-Chemical Analyses

Three sampling campaigns of M'koa Lake water were carried out at different climatic seasons, November 2017 (short rainy season), March 2018 (long dry season), and May 2018 (long rainy season). Samples have been collected at six (6) stations taking into account both the potential sources of pollution and accessibility (**Figure 1** and **Table 1**). Samples were analysed for anionic active surfactants and seven other physico-chemical parameters. Temperature, pH, electric

Table 1. Sampling stations and corresponding GPS coordinates.

Station	Code	GPS coordinats	Station characteristics
Berge 1	Ber 1	5˚12.415'N ; 4˚2.045'W	Hotel residence + septic tank at ±10 m In height
Washing	Lav	5˚12.370'N ; 4˚24.948'W	Washing "fanico", bare and steep terrain + strong erosion
Berge 2	Ber 2	5° 12.267'N ; 4˚24.728'W	Laundry and dishes in the water, swimming and garbage dump nearby
M'koa Hotel	MHo	1° 12.410'N ; 4˚24.627'W	Hotel infrastructure
Y. Landing	Deb	5˚12.457'N ; 4˚24.922'W	Low-traffic pavilion house
M'koa Middle	Mil	5˚12.383'N ; 4˚24.756'W	Deepest area of the lake

conductivity, oxygen saturation and transparency were measured in situ using a multi-parameter probe model HQ 40d (HANNA HI 99301), a HANNA HI 9146 oximeter, and a Secchi disk respectively. Anionic surfactants concentrations were determined by using the methylene blue colorimetric method [17], and turbidity was measured with the HACH Lange 2100Q turbidimeter at the laboratory [18]. Samples were collected, transported and stored according to the procedures defined by AFNOR [19] and Rodier [18]. All chemicals used were of high purity (Merck), and all glassware and laboratory equipments were carefully cleaned before using with HCl to minimize potential contamination. Water samples were collected by means of glass bottles of 1000 mL for surfactants (pH < 2 with H_2SO_4) and 500 mL for turbidity. Samples were stored at +4˚C until analysis.

2.3. Analysis of Anionic Surfactants by Methylene Blue Active Substances (MBAS) Method

Anionic surfactants were determined using UV Spectrometer (HACK-DR6000) at the Laboratory of the Ivoirian Anti-Pollution Center (LCE-CIAPOL). The determination of low levels (typically 0 - 20 $mg{\cdot}L^{-1}$) of anionic surface active materials by MBAS as described by ISO 7875-1 [17] is used in the analysis of a wide range of samples, including surface and potable waters. Higher concentrations can be diluted before analysis. Methylene blue dyes were used to determine anionic surfactants. A volume of 20 mL of sample was put into a 40 mL vial (vial A) equipped with a screw-cap and Teflon liner. Then 2 mL alkaline buffer, 1 mL natural methylene blue solution and 5 mL of chloroform, were added to vial A in that order. The vial was subsequently sealed using a holed screw-cap and Teflon liner, before being vigorously shaken using a vortex mixer for 2 min. After shaking, the content of the vial was allowed to phase separation. The screw-cap was loosened to release the pressure inside. Once the two phases were separated, a Pasteur pipette was used to transfer the chloroform layer into a new vial (vial B) containing 22 mL ultra-pure water and 1 mL acid methylene blue solution. Vial B was then shaken using a vortex mixer for 2 min. The cap was loosened for

a few seconds and then re-tightened. After the chloroform had completely separated from the water (after about 2 min), the chloroform layer was collected using a Pasteur pipette and put into a 10 mm quartz cell. The absorbance of the chloroform phase was measured with ultra-violet spectrophotometer at a wavelength of 650 nm.

2.4. Data Statistical Analyses

The physico-chemical parameters of M'koa Lake water were tested by univariate analyses (mean, standard deviation, minimum and maximum). Analyses of variance (ANOVA with one-factor) were used to test the significance between the averages of the different physico-chemical parameters. The Tukey test was used to determine the significant differences between stations. Principal component analysis (PCA) presents in a limited space, the relationships between the studied parameters. All these analyses were made by using STATISTICA 7.1. Software.

3. Results

3.1. Concentrations of Anionic Surfactants in M'koa Lake Water

Anionic surfactants contents of M'koa Lake's water range from 0.23 ± 0.04 $mg{\cdot}L^{-1}$ to 1.43 ± 0.68 $mg{\cdot}L^{-1}$. It can be seen that concentrations of anionic surfactants are higher in areas near domestic effluent discharge points (Berge 1 and 2 stations, M'koa hotel and washing stations), than those which are far away from them (Middle station) (Table 2). On the other hand, Landing Y. station located near a domestic discharge area is characterized by a low concentration of anionic surfactants. It should be noted that the Y. landing station receives wastewater from a low-traffic pavilion house. In addition, pH, temperature, electrical conductivity, oxygen saturation, turbidity and transparency mean values of these samples are presented in Table 3. Relationship between anionic surfactant concentrations and physico-chemical parameters was determined by "Linear regression analysis". No linear relation between anionic surfactant concentrations and physico-chemical parameters were found ($p > 0.05$). Applying Tukey test showed no significant difference between all the stations.

Table 2. Average values of anionic surfactants contents at different sampling stations of M'Koa Lake.

Station	Anionic surfactants ($mg{\cdot}L^{-1}$). Mini	Anionic surfactants ($mg{\cdot}L^{-1}$). Moy	Anionic surfactants ($mg{\cdot}L^{-1}$). Maxi
Lav	0.53	1.13 ± 0.74	1.96
Ber 2	0.78	1.43 ± 0.68	2.14
MHo	0.33	1.29 ± 1.01	2.35
Deb	0.20	0.23 ± 0.04	0.28
Mil	0.15	0.24 ± 0.12	0.38
Ber 1	1.10	1.27 ± 0.26	1.57

Table 3. Characteristics of physico-chemical parameters of M'Koa Lake water.

Station		pH	T (˚C)	EC (µs/cm)	Oxyg Sat (%)	Transp (m)	Turb (NTU)
Lav	Aver. ± σ	8.20 ±0.55	30.70 ± 1.08	111.97 ± 21.57	106.00 ± 19.58	0.52 ± 0.05	35.10 ± 4.40
	min - max	7.56 - 8.54	29.80 - 31.90	89.00 - 131.80	83.90 - 12.12	0.46 - 0.55	30.70 - 39.50
Ber 2	Aver. ± σ	7.95 ± 0.51	30.67 ± 0.99	108.25 ± 28.78	98.70 ± 14.78	048 ± 0.06	29.07 ± 2.80
	min - max	7.37 - 8.34	30.00 - 31.80	87.90 - 128.60	81.70 - 108.50	0.44 - 0.55	31.20 - 53.50
MHO	Aver. ± σ	7.57 ± 0.76	30.80 ± 104	108.65 ± 33.45	96.80 ± 15.39	0.47 ± 0.13	42.37 ± 11.15
	min - max	7.12 - 8.45	30.10 - 32.00	85.00 132.30	79.20 107.70	0.35 - 0.60	31.20 - 53.50
Deb	Aver. ± σ	7.69 ± 0.81	30.87 ± 10	109.73 ± 30.17	95.47 ± 18.00	047 ± 0.12	36.20 ± 4.90
	min - max	6.82 - 8.43	30.10 - 32.10	88.40 - 131.06	77.60 113.60	0.40 - 0.60	31.30 - 41.10
Mil	Aver. ± σ	7.67 ± 1.05	30.77 ± 107	110.50 ± 29.98	93.53 ± 17.15	049 ± 0.08	32.47 ± 0.75
	min - max	6.60 - 8.69	30.10 - 32.00	89.30 - 131.70	78.10 - 112.00	0.40 - 0.55	31.70 - 33.20
Ber 1	Aver. ± σ	7.53 ± 1.44	31.00 ± 16	114.05 ± 36.13	6787 ± 4407	039 ± 0.13	30.77 ± 19.65
	min - max	6.15 - 9.03	29.50 - 32.80	88.50 - 139.60	29.70 - 116.10	0.35 - 0.60	11.10 - 50.40

T: temperature; EC: electrical conductivity; Oxyg Sat : oxygen saturation; Transp : transparency; Turb : turbidity.

Figure 3 shows that the concentrations of anionic surfactants in M'Koa Lake water vary according to the period and the place of sample collection. The highest concentrations were recorded in March, i.e., during the long dry season (low-flow period), with values ranging from 0.28 $mg{\cdot}L^{-1}$ to 2.35 $mg{\cdot}L^{-1}$, compared to those in May, varying from 0.15 $mg{\cdot}L^{-1}$ to 0.78 $mg{\cdot}L^{-1}$. The latter period corresponds to the long rainy season (flood's period). At the sampling stations, the highest levels have been observed at ber 1, lav, ber 2 and M'koa stations respectively with concentrations of 1.57 $mg{\cdot}L^{-1}$, 1.96 $mg{\cdot}L^{-1}$, 2.14 $mg{\cdot}L^{-1}$ and 2.35 $mg{\cdot}L^{-1}$.

3.2. Physico-Chemical Characteristics of M'Koa Lake Water

Table 3 presents the results of the physico-chemical analyses of M'Koa Lake water at various stations. For each parameter at a given station, the minimum, maximum, and middle values are indicated. Thus, the high gap between maximum and minimum for most of measurements which have been done reflect significant disturbance in the lake system. Seasonal fluctuations in the water levels are therefore very important and significantly disturb the environment. However, there is relatively low variation between the different stations in terms of temperature, pH, transparency and turbidity. The average pH values of the different stations range from 7.54 ± 1.44 to 8.20 ± 0.55. These values suggest a relatively alkaline nature of the lake, which could be justified by its low mineralization (average electrical conductivities are between 108.25 ± 28.78 µS/Cm and 114.05 ± 36.13 µS/Cm.). The average oxygen saturation values are varying from 67.87% 44.07% to 106.00% ± 19.58% which characterize a satisfactory oxygenation of the Lake's water. Concerning transparency, very low average values of 0.39 ± 0.13 to 0.52 ± 0.05 m are noted. Finally, turbidity, which refers to the content of suspended particles (matters) in water that disturb it, has average values for the different stations ranging from 30.77 ± 19.65 NTU to 42.37 ± 11.15 NTU.

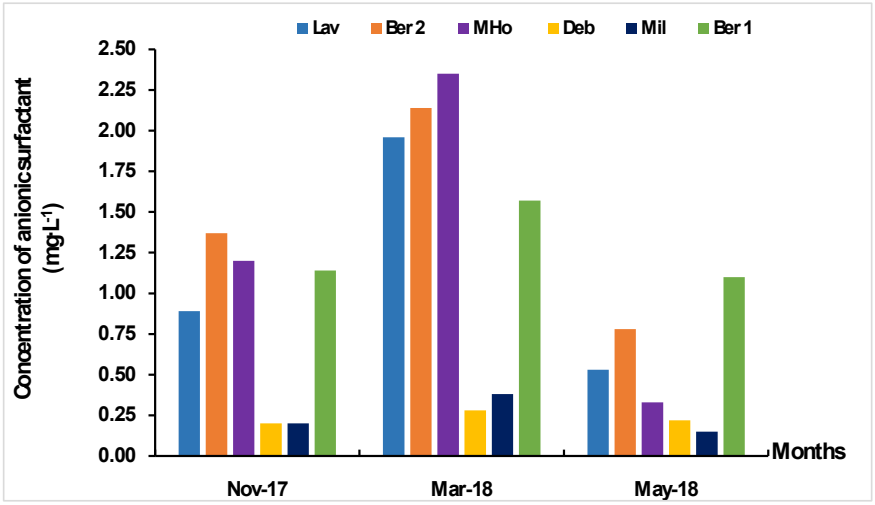

Figure 3. Concentration of anionic surfactants in M'Koa Lake water as a function of sampling periods.

3.3. Correlation between Physico-Chemical Parameters of M'Koa Lake Water

The main component analysis (PCA) was used to assess the physico-chemical parameters that could influence the concentration of anionic surfactants in water. Table 4 presents the eigenvalues of the first three (3) PCA factors. Thus, the recorded which are taken into account are the cumulative variances factors and the factorial weight of the variables. Only the first two factors with 82.53% as the total inertia were considered because they contain the most useful information necessary for interpreting the PCA. The first factor expresses 65.59% of the total variance against 16.94% for the second one. pH, temperature and electrical conductivity are strongly and positively correlated to factor 1, while dissolved oxygen saturation and transparency contribute strongly and negatively to the formation of this same axis. Thus, ordination factor 1 reflects a degradation gradient of organic matter. Turbidity is strongly and positively correlated with factor 2 and reflects an increasing gradient of organic pollution. Anionic surfactants are weakly correlated to factors 1 and 2. Anionic surfactants concentrations do not appear to be influenced by the considered variables. Figure 4 shows the considered physico-chemical variables correlation circle of the water in the Principal component analysis (PCA). Anionic surfactants were no significantly correlated to physico-chemical parameters along Lake M'koa ($p > 0.05$).

4. Discussion

The analysis results revealed the presence of a no negligible amount of anionic surfactants in M'koa Lake water. This presence is the result of anthropogenic discharges around the lake. The average anionic surfactants concentrations at the different stations ranged from 0.23 ± 0.04 mg·L^{-1} to 1.43 ± 0.68 mg·L^{-1}. These concentrations are above the expected ones according to the socio-economic development and population density of the city of Jacqueville.

Table 4. Eigenvalues, cumulative variances and factor weights of the variables of the 3 first PCA factors.

	Fact 1	Fact 2	Fact 3
Own values	4.59	1.9	0.84
% total variance	**65.59**	**16.94**	**12.06**
Cumulative variance	**65.56**	**82.53**	**94.60**
Settings		**Factor weight of the variables**	
pH	**0.881**	−0.029	−0.367
Temperature	**0.971**	0.033	−0.091
EC	**0.957**	0.161	−0.187
Oxygen Sat	**−0.808**	−0.385	−0.043
Turbidity	−0.026	**0.956**	−0.252
Transparency	**−0.931**	0.096	−0.097
Anionic surfactants	0.483	0.407	**0.758**

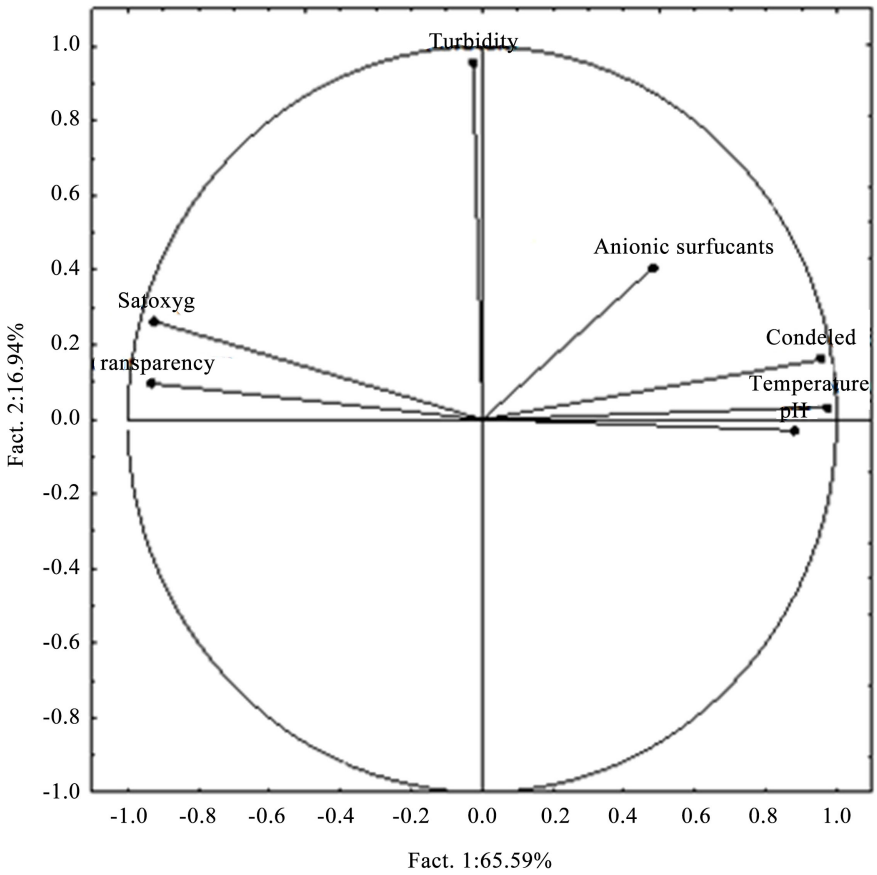

Figure 4. Correlation circle of the physico-chemical variables of the PCA.

Indeed, previous studies on streams, receiving untreated urban effluents in big agglomerations, showed anionic surfactants concentrations far below those obtained in the water of M'koa Lake. For example, water from Besaya and Ason

estuaries, both situated on the Spanish coast, and receiving untreated urban wastewater from several cities, with an estimated population of 162,500 inhabitants exhibited an anionic surfactants concentration of 0.50 $mg{\cdot}L^{-1}$ [20]. Besides, a concentration of less than 0.01 $mg{\cdot}L^{-1}$ was recorded in the waters of the Balfour River in South Africa [21]. The shallow waters of M'koa Lake and the low rate of renewal of the receiving watercourses close to the wastewater discharge outlets reduce the degree of dilution of the effluents. These factors could explain the higher anionic surfactants levels observed in the waters of M'koa Lake compared to those obtained in other highly contaminated surface waters [20] [22] [23]. Studies conducted on household detergents in Burkina Faso, which could be found here in Côte d'Ivoire, give the highest concentration of anionic surfactants at 2.6 $mg{\cdot}L^{-1}$ [24]. The results of anionic surfactants concentrations in Lake M'koa revealed elevated values between 1.57 $mg{\cdot}L^{-1}$ and 2.35 $mg{\cdot}L^{-1}$, and shows well the low dilution of surfactants in lake waters. In fresh waters, anionic surfactants concentrations maximum recommended are 0.1 $mg{\cdot}L^{-1}$, and are of the same order of magnitude as those of the urban effluents treated by a biological treatment [4] [25]. The average concentrations in terms of anionic surfactants in M'koa Lake are well above the recommended threshold. These results indicate that M'koa Lake is subjected to a high level of pollution by anionic surfactants. The temporal and spatial variations of anionic surfactants contents in M'koa Lake's water can be explained by the fact that the concentration of anionic surfactants in rivers and lakes depends on the three following parameters: seasonal variations, distance between residential (living) places and the lake and finally the flow of wastewater during the day [22] [23]. The temporal variations of anionic surfactants show that most anionic surfactants are therefore not drained to the lake by stream water during the rainy season, but originate from anthropogenic activities around the lake. The temperature with a maximum average value of 31.00˚C ± 0.16˚C is the main characteristic of the tropical areas [15]. The pH values, ranging from 7.54 ±1.44 to 8.20 ± 0.55, mean that M'koa Lake water is alkaline. The pH values obtained in this study are higher than those of Buyo Lake, Côte d'Ivoire (7.20 ± 0.50), which was not affected by urban effluent discharges, but by agricultural land runoffs [26]. In general, alkaline agents in detergents could increase the pH of wastewater [4], however, no correlation has been established between pH values and anionic surfactants concentrations in M'Koa Lake water. The average oxygen saturation values ranged 67.87% 44.07% to 106.00% ± 19.58% which characterize a satisfactory oxygenation of the Lake's water [27]. The comparison of the values of transparency (0.39 ± 0.13 m to 0.52 ± 0.05 m) and turbidity (29.07 ± 2.80 NTU to 42.37 ± 11.15 NTU) of the waters of M'koa Lake, with Lake Backré, Côte d'Ivoire (1.91 ± 0.62 m and 2.80 ± 0.42 m and 2.23 NTU to 3.97 NTU [28]) shows a difference in water quality. Analysis of the PCA of physico-chemical variables revealed that ordination factor 1 reflects a degradation gradient of organic matter, turbidity is strongly and positively correlated to factor 2, and reflects an increasing gradient of organic pollution. M'koa Lake is characterized by low mineralization, so low values of transparency

and turbidity may could be due to the presence of organic matter in M'koa Lake. The presence of organic matter would be favored by wastewater discharges and direct human activities around Lake M'koa [10] [16].

5. Conclusion

M'koa Lake is subjected to heavy attacks of pollution by anionic surfactants from urban effluent discharges and direct human activities around the lake. Indeed, the results showed that the average anionic surfactants concentrations in the water of Lake M'koa ranged from 0.23 ± 0.04 mg·L^{-1} to 1.43 ± 0.68 mg·L^{-1}. These values are very high according to the low socio-economic development and population density of the city of Jacqueville. The high concentrations of anionic surfactants would be due to the characteristics of M'koa Lake, which do not allow enough dilution of wastewater effluents in the vicinity of the discharge areas. As a result, observed turbidity and transparency values are showing deterioration in water quality favoured by anthropogenic activities into M'koa Lake. It is urgent to develop appropriate management strategies by the municipal authorities for lake protection.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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